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Red snapper working group for ABC definition

Members: Rob Ahrens, Luiz Barbieri, Scott Crosson, Eric Johnson, Genny Nesslage, Amy Schueller (Chair), Katie Siegfried, Erik Williams

**Note: Can consult outside sources as needed

Task: To collate data, analyses, stock assessments, and any other background information on red snapper in order to determine an Acceptable Biological Catch (ABC). If necessary, work on additional analyses for providing an ABC or tracking an ABC.

ToRs:

1. Collate and evaluate existing information on red snapper
2. Determine if an ABC can be determined from existing information
3. If an ABC cannot be determined from existing information, provide a plan of action for moving forward to determine an ABC
    a. Plan of action should include evaluation of index based methods for tracking ABC, as well as consideration of the index based method can be used to determine an ABC
4. Assess to the extent possible newly developed methods providing strengths and weaknesses of each method
5. Provide a final ABC recommendation and also include any viable alternatives in priority order based on the science and data available

<u>Timeline (approximate):</u>
<u>Council review the ToRs at the November 6 meeting – see John's email</u>

2nd or 3rd week of November – scoping call

2nd week of December – All current information pulled together and vetted; brainstorm ABC determination ideas; brainstorm ideas for tracking the ABC; assign ideas to workgroup members

3-4th week of January – Vet all analyses and ideas assigned to the workgroup members; determine which are sufficient for providing an ABC; prioritize a list of best possible options for providing an ABC

2nd week of February – Continue work from January

2nd week of March – Finalize work from January and prepare materials for distribution to the SSC

April 1 – all materials provided to SSC for sufficient time for review

**Note that additional webinars can be scheduled as needed by the group.

Scope of Work

Analysis Type: Vetting and prioritization of potential methods for determining a Red Snapper Acceptable Biological Catch (ABC)

Justification: Terms of Reference (ToRs):

1. Collate and evaluate existing information on red snapper
2. Determine if an ABC can be determined from existing information
3. If an ABC cannot be determined from existing information, provide a plan of action for moving forward to determine an ABC
    a. Plan of action should include evaluation of index based methods for tracking ABC, as well as consideration of the index based method can be used to determine an ABC
4. Assess to the extent possible newly developed methods providing strengths and weaknesses of each method
5. Provide a final ABC recommendation and also include any viable alternatives in priority order based on the science and data available

Analyst: Work group members include: Rob Ahrens, Luiz Barbieri, Scott Crosson, Eric Johnson, Genny Nesslage, Amy Schueller (chair)

Support has also been provided by both Council staff and SEFSC staff.

Tasks and Timeline: Task: To collate data, analyses, stock assessments, and any other background information on red snapper in order to determine an Acceptable Biological Catch (ABC). If necessary, work on additional analyses for providing an ABC or tracking an ABC.

The work group is currently midway through the work toward achieving the stated terms of reference.

Council reviewed the ToRs – November 6, 2017

Scoping call where methods were reviewed and assignments were made to address each method – November 17, 2017

Second call where the first set of potential methods was reviewed and vetted – December 14, 2017

Third call where the second set of potential methods was reviewed and vetted; action items remaining from the December call were also addressed – January 31, 2018

Fourth call where the action items remaining from the January call will be addressed; will start to create a prioritized list of best possible options for providing an ABC – February 27, 2018

Final call or calls where a prioritized list of best possible options for providing an ABC will be finalized – March of 2018

All draft materials due to chair of working group – April 1, 2018

Final workgroup review – by April 13, 2018

Completion of workgroup report and delivery of report to the SSC – April 16, 2018

Final presentation and review by the SSC – May 1-3, 2018 meeting

Final Report to the Council – June 11-15, 2018

Agenda

Red Snapper ABC work group
Thursday, March 29, 2018
1:00 PM - 3:00 PM EST

1. Welcome and attendance

Genny Nesslage, Eric Johnson, Scott Crosson, Marcel Reichert, Mike Errigo, Erik Williams, Amy Schueller

2. Review of timeline and tasks; review the ToRs

Reviewed timeline and tasks

3. Review and prioritize methods; please review the introduction on the Google Drive - *ALL*
4. Documentation of process; writing due March 30 - *ALL*
5. Writing timeline

Summary of outstanding writing assignments:

1. *Write up summary of projections compared to Amendment 43 including landings versus discards (Katie and Eric)*
2. *Write up of discussion on index based methods (Amy and Genny)*
3. *Validity of indices at low population size (Genny)*
4. *Examples of interpreting data (e.g., catch increases, SSB decreases, but recruitment increases - can lead to an increasing index with high recruitment, but doesn't mean the SSB is increasing) (Genny)*
5. *Write up ACL monitoring information (Scott)*
6. *Add Table 2.1.2 to Amendment 43 summary (Eric)*
7. *Write up DLM discussion regarding applicability to red snapper (Luiz)*

Agenda

Red Snapper ABC work group
Tuesday, March 20, 2018
9:00 AM - 11:00 AM EST

1. Welcome and attendance

Scott Crosson, Mike Errigo, Marcel Reichert, Kyle Shertzer, Erik Williams, Amy Schueller, Rob Ahrens, Genny Nesslage, Eric Johnson (had microphone problems, so didn't contribute verbally)

2. Review of timeline and tasks; review the ToRs
3. Methods that were vetted with remaining action items:
    a. Center Interim Analysis based method (*Kyle and Erik*)
        i. ACTION: Present progress. Write up the methodology for the group's review. Run analysis.

The power point on this topic has been put onto the Google Drive. Kyle Shertzer presented on the Center Interim Analysis, and a discussion followed. The documentation includes a comparison with the status quo projections that were provided via SEDAR 41. The question of how 2017 age compositions compared to the 2017 projections came up, but this hasn't been looked at. This comparison would be useful for planning purposes. Discussed whether the index or the age compositions had a stronger influence on the outcomes, but it seems that both offer some information for recruitment estimation (see scenarios IA1 and IA2). This method isn't as quick as projection analyses, but is quicker than an update assessment; and similarly provides an intermediate level of information on the stock projection. Key assumptions for the stock assessment are maintained in this analysis in order to keep benchmarks the same. The discard ratios are the same as in the stock assessment; the group discussed that the ratios would change over time, but in order for the benchmarks to be consistent, this assumption is reasonable. This method addresses some of the original uncertainties in the stock assessment and projections, which we need to highlight. Additionally, the Interim Analysis is dependent upon the CVID index, so the group should work to highlight the pros and cons of the index. After much discussion, the group agreed that this method provides the best available science for determining an ABC and should be prioritized high.

4. Documentation of process; writing due March 30 - *All*
5. Review and prioritize methods - *ALL*

This will be the task for the second call that we hold in March (March 29 1-3 EST). A strawman prioritization will be put together before the meeting and will be found in the introductory documentation.

6. Assign and review tasks for next meeting
7. Schedule next meeting, if needed. Writing timeline.

Agenda

Red Snapper ABC work group
Tuesday, February 27, 2018
10:00 AM - 12:00 PM EST

1. Welcome and attendance

Amy Schueller, Mike Errigo, Marcel Reichert, Eric Johnson, Genny Nesslage, Scott Crosson, Rob Ahrens, Katie Siegfried, Erik Williams

2. Review of timeline and tasks; review the ToRs; view scope of work

Viewed scope of work document in main directory on the google drive. Note that at this point we have ~month left to finish our work to have time to collate a document and provide it to the SSC.

3. Methods that were vetted with remaining action items:
   a. Red snapper stock assessment and projections (*Katie*)
      i. ACTION: Provide updated projections with 2016 actual landings and discards with current projection methodology (what the Council requested previously plus 2016 data updated)

Documents were provided in the scoping materials folder on the google drive. Projections were run at Frebuild, which was F=0.14. The total ABC in numbers with landings (12,000) and discards (28,000) was 40,000 fish. This ABC option was similar in scale to some of the Amendment 43 ACLs listed in Table 2.1.2; however, these ACLs included landed individuals only and didn't include discards. Discards have been included in the ABC determination for red snapper in the past, as specified by the SSC. Even with no fishing season for red snapper, there are still background discards. There is no information available on how discards change when a season opens. ACTION: Write up summary of these analyses with a comparison to the ACL in Amendment 43. When writing, provide information on landings versus discards.

   b. Center Interim Analysis based method (*Erik and Katie*)
      i. ACTION: Present progress. Write up the methodology for the group's review. Run analysis.

Age comps not ready yet. Marcel will get these to Erik by Friday or early next week. The next call that this group has will be to specifically go over the Center Interim Analysis method. The written documentation will be put on the google drive in advance of the meeting in order to allow sufficient time to read the materials. An email will go out when the materials have been put on the drive.

c. Methods used at other Centers (*Amy and Genny*)

    i. ACTION: Review materials on drive and come to next meeting prepared to discuss whether any index/indices meet the necessary criteria - *ALL need to review*

Indices could be used in one of two ways to set an ABC: 1) if the scale is known, then the index could be related to population size directly or 2) in an ad hoc way where catch is set and then you watch whether the index is increasing, stable, or decreasing and then adjust catch accordingly. Each of these options is currently unavailable for red snapper. For the first option, to know the scale of the index, you would need an absolute index of abundance (for red snapper, we have relative indices of abundance) or you would need to know the catchability of the index (which can not be estimated outside of the stock assessment with the available data). For the second option, management would need to be in place long enough to account for the time lag in management and recruitment of fish to the fishery versus index in order to determine if the management had impacted the population dynamics such that the population size was increasing, stable, or decreasing. The overall consensus of the discussion was that none of the indices for red snapper had a long time series for use and that none of the indices had the auxiliary information available to make then useful in an index based method. The work group did want to note that the indices are useful on a relative scale and have been used for the red snapper stock assessment (and have been used for many other stock assessments in the South Atlantic). Additionally, the increase in the indices for red snapper at the end of the time series may not be actual increases and could be the result of observation error. The work group did recognize that the Headboat index could be useful for comparative evidence in that the ABC should not be set larger than the catch observed during the 1970s. Finally, the work group also wanted to ensure that the following topics were discussed in the report in order to address as many potential questions as possible - usefulness of the fishery-independent data in general *versus the usefulness for red snapper, validity of indices at low population size, fine scale shifts in spatial targeting and the inability to track them, the use of the chevron trap index from 1990 to the present (document why assessments haven't used this index during last two benchmark assessments), and examples of interpreting data (e.g., catch increases, SSB decreases, but recruitment increases - can lead to an increasing index with high recruitment, but doesn't mean the SSB is increasing).*

d. Monitoring of the ACL - current and future - report from SEP (*Scott*)

   i. ACTION: Additional questions to be addressed - What about discards? Any discussion on how to monitor discards without using MRIP? Phone app and logbooks - what data are being collected from this and how are those data intended to be used, has the SSC been consulted on data collection/utility? Any info on rare event workshop?

Scott provided documentation in the scoping materials folder on the google drive. The materials addressed how the ACL is currently tracked given the mini seasons, as well as the new app and what information is being collected. The rare event workshop was canceled. While this isn't part of the ToRs for the work group, we still felt that this information would be useful to the Council when deciding how to move forward with monitoring option for the ACL. Scott agreed to write this up into a section for the report.

4. Documentation of process; writing due February 26 - *All*

Several documents were placed in the folder labeled draft of sections on the google drive. Each of these documents is available for reading and editing by the entire work group. Eric placed a document on the drive summarizing Amendment 43. Eric agreed to add Table 2.1.2 to the document regarding Amendment 43, as well as include information on Amendment 46. Rob placed a document on the drive summarizing the DLMs. Luiz offered in an email to add to the document on DLM a discussion regarding the applicability of DLM to red snapper. Genny and Amy added two documents to the drive, one that is a summary of the available index data for red snapper and the other is documentation of the other methods used at other Science Centers to determine ABC. Finally, an introduction section was added to the drive, which will be the start of the main document resulting from this group's work.

5. Review and prioritize methods - *ALL*

This will be the task for the second call that we hold in March. A strawman prioritization will be put together before the meeting and will be found in the introductory documentation.

6. Assign and review tasks for next meeting

Tasks include:

1. *Write up summary of projections compared to Amendment 43 including landings versus discards (Katie and Eric)*
2. *Finish red snapper ages and provide to SEFSC (Marcel)*
3. *Run Center Interim Analysis and write up (Erik)*
4. *Write up of discussion on index based methods (Amy and Genny)*
5. *Write ups on the following topics to address potential questions from the SSC and Council:*
    a. *Process versus observation error (Rob)*

Interpreting changes in stock abundance from indices of abundance must consider the potential relative impact of both the expected variation in abundance (process error) and variation in sampling (observation error). Previous work has shown that understanding the ratio of process to observation error is a critical for appropriately filtering/smoothing time series data to extract changes in biomass (see Freeman and Kirkwood 1995, Walters and Hilborn 2005). Common approaches are to apply a Kalman filtering (Kalman 1960) and/or Rauch–Tung–Striebel smoothing (Rauch et al. 1965). While most index methods have associated standard error estimates, providing insight into observation error, understanding of process error is limited to the length of the index, as in many instances, process error is estimated as the difference between the apparent total variance in the index and the estimated observation error. In instances where short time series are used the estimation of the process error are poor.

Freeman, S.N., and Kirkwood, G.P. (1995). On a structural time series method for estimating stock biomass and recruitment from catch and effort data. Fish. Res. 22: 77–98.

R. E. Kalman. (1960). A New Approach to Linear Filtering and Prediction Problems. Transaction of the ASME—Journal of Basic Engineering, pp. 35-45

Rauch, H.E., Tung, F., and Striebel, C.T. 1965. Maximum likelihood estimates of linear dynamic systems. AIAA J. 3: 1445–1450.

Walters, C. J., & Hilborn, R. (2005). Exploratory assessment of historical recruitment patterns using relative abundance and catch data. Canadian Journal of Fisheries and Aquatic Sciences, 62: 1985-1990.

b. *Fine scale shifts in spatial targeting and the inability to track them (Rob)*

Changes in the spatial distribution of fisheries and/or research surveys has the potential to obscure changes in stock abundance when catch and effort information are not geospatially referenced at spatial scales at which the assumption of representative sampling can be made. The resulting catch per effort that is commonly used to generate relative abundance trends will tend to not be proportional to stock abundance (hyperstable or hyperdeplete). In general the issue of non-proportionality is greater with fishery dependent data that is documented at broad spatial scales.

c. *Usefulness of the fishery-independent data in general versus the usefulness for red snapper (Amy)*
d. *Use of the chevron trap index from 1990 to the present (last two benchmark assessments) (Amy)*
e. *Validity of indices at low population size (Genny)*
f. *Examples of interpreting data (e.g., catch increases, SSB decreases, but recruitment increases - can lead to an increasing index with high recruitment, but doesn't mean the SSB is increasing) (Genny)*

6. *Write up ACL monitoring information (Scott)*
7. *Add Table 2.1.2 to Amendment 43 summary (Eric)*
8. *Write up DLM discussion regarding applicability to red snapper (Luiz and Rob)*
9. *Create a strawman prioritization for discussion at the second March call (Amy)*
10. *Doodle poll for 2 meetings in March (Amy)*

7. Schedule next meeting

Amy will send 2 doodle polls out for meetings during the weeks of March 19th and 26th. The first meeting date will be to specifically discuss the Center Interim Methods, and the second meeting date will be to prioritize the available methods.

Agenda

Red Snapper ABC work group
Wednesday, January 31, 2018
1:00 - 3:00 PM EST

1. Welcome and attendance

    Mike Errigo, Amy Schueller, Genny Nesslage, Erik Williams, Eric Johnson, Luiz Barbieri, Scott Crosson, Rob Ahrens
2. Review of timeline and tasks
3. Discussion of data, analyses, stock assessments, and any other background information available for red snapper ABC determination and consideration of methods/analyses that could be completed in time
    a. Questions to consider:
        i. Has the method been vetted through the SAFMC SSC?
        ii. What are the pros and cons of each method?
        iii. Are the data for red snapper sufficient for the method?
    b. Methods (Need to finalize review from December):
        i. Amendments 43 and 46 (*Eric and Marcel*)

        Originally one Amendment. Amendment 43 provides an alternative methodology for determining an ACL - based on index increase at end of time series, assumed sustainable, harvest could be set at average harvest or a multiplier (1.88) of that average harvest or at highest level of catch during 2012-2014. Amendment 46 is in scoping.

        SSC did not comment on final Amendment 43.

        Comments on Index based method contained in Amendment 43:

        - *Not been through any peer review.*
        - *Age structure of indices and the age structure of the catch potentially do not match up. Might be a mismatch between increasing indices and what can be caught. Not considering time lags.*
        - *simple, rough estimate that does not consider important demographic factors*

- *Assumes a linear relationship between index and catch, which is unlikely to exist*
- *Assuming 2012-2014 was at a sustainable fishing level*
- *Suffer from some of the same problems the other index based methods suffer from*
- *A change of 1.88 can simple be measurement error. We don't have a good understanding of the relationship between the index and harvest. Concerns about the level of noise contained within the index itself.*
- *Concerns that if the index decreased that there is no accountability to decrease the catch in the current Amendment*
- *Overall, currently data are unavailable to determine if this method is sufficient to provide a sustainable ABC or ACL*
- *ACTION ITEM: summarize Amendment 43 and the methods contained within it, summarize our comments, and provide in the drafts folder on the drive*

ii. Data Limited Approaches (*Luiz and Rob*)

- *Started work on the document. DLM is not best available science and doesn't use best data. These types of methods do not work when you have a recovering stock. DLM method requires similar data to stock assessment, but would go down a Tier in control rule. ACTION: Write up methods, comments from workgroup, and provide in the drafts folder on the drive.*
- *Discussion of memos leading to this working group. Statement that the memos have been unclear. Need to make clear that projections can be provided. Need to include this as a discussion or maybe intro in final document (maybe as background). ACTION: (Amy) add this information to the background/intro for document to go to the SSC.*
- *Note that the PSEs are around ~25%, which is fairly low, given the species that the SE manages.*

iii. Summary of call on Rago's work on Rcrit (*Katie/Amy*)

Summary on drive for inclusion into draft document.

4. Methods that were vetted in December and associated action items:
    a. Red snapper stock assessment and projections (*Katie*)
        i. ACTION: Provide updated projections with 2016 actual landings and discards with current projection methodology (what the Council requested previously plus 2016 data updated)
    b. Center Interim Analysis based method (*Erik and Katie*)
        i. ACTION: *Erik* - Provide documentation from the West Coast and North Pacific regions on this method. *Erik and Katie* - Present progress.

        Talked with Methot, Ianelli, Lynch - West Coast and North Pacific do not do this method, rather they do update assessments. What we are presenting to do is unique. Data sets can be fairly quickly updated - index from MARMAP; ages from MARMAP; and removals. Allowing Rec devs to be estimated to provide a more accurate projection. Status - have code done, have updated removals and index values, waiting on ages (needs about another 10 days). Then, they can run the analysis and write it up. ACTION: Write up the methodology for the group's review. Run analysis.
    c. Methods used at other Centers (*Amy and Genny*)
        i. Need to make sure that OFL and ABC are linked.
        ii. ACTION: *Amy* - Does PIFSC do P* for rebuilding species?

    No, but they only have 1 species in rebuilding and it doesn't have a rebuilding plan...currently a moratorium on catch and part of its range is within a national monument.

        iii. ACTION: Assessment of the appropriateness of the indices available for red snapper; do any indices cross MSY or BMSY, have catch at MSY, or catch that is not impacting MSY; Provide a table - *Genny and Amy*.

    ACTION (ALL): Review materials on drive and come to next meeting prepared to discuss whether any index/indices meet the necessary criteria.
    d. Monitoring of the ACL - current and future (*Scott*)

i. ACTION: Additional questions to be addressed - What about discards? Any discussion on how to monitor discards without using MRIP? Phone app and logbooks - what data are being collected from this and how are those data intended to be used, has the SSC been consulted on data collection/utility? Any info on rare event workshop?

Started working on this. Socio-economic panel (SEP) will be discussing this next week. ACTION: Scott will report back from SEP meeting.

5. IPT development - Who is on Amendment 46 IPT? (*Mike*) - *Scott and Katie are on IPT*
6. Documentation of process - *All*
7. Assign and review tasks for next meeting
8. Schedule next meeting - *Amy send Doodle to schedule for Week of Feb 26*

Deadline for writing assignments - Feb 26

Agenda

Red Snapper ABC work group
Thursday, December 14, 2017
10:00 AM – 12:00 PM

1. Welcome and attendance

   Amy Schueller, Mike Errigo, Erik Williams, Katie Siegfried, Scott Crosson, Genny Nesslage

2. Discussion of data, analyses, stock assessments, and any other background information available for red snapper ABC determination and consideration of methods/analyses that could be completed in time
   a. Questions to consider:
      i. Has the method been vetted through the SAFMC SSC?
      ii. What are the pros and cons of each method?
      iii. Are the data for red snapper sufficient for the method?
   b. Methods:
      i. Red snapper stock assessment and projections (*Katie*)
         1. Reference documents are on the drive in the scoping materials folder.
         2. Yes, vetted through SSC. Pros and Cons available from SSC and reviewers. Largest concern was monitoring of ABC as projected. Assessment was deemed Best Available Science.
         3. On Drive - an overview of assessment results and projections was provided, as well as the updated, corrected assessment. Updated projections need to be requested.
         4. Discussion of MRIP numbers - new numbers will not be available until mid-2018 at the earliest, current MRIP numbers are uncertain but not biased, *setting ABC versus monitoring of the ABC [2 separate issues that we need to take care to separate]*, we have methods to handle uncertain discard data, MRIP data already included in assessment, which was deemed best available science

by reviewers and SSC, uncertainty in terminal year was investigated thoroughly,

5. ACTION: Request for updated projections with 2016 actual landings and discards with current projection methodology (what the Council requested previously plus 2016 data updated) - *Katie*

ii. Amendments 43 and 46 (*Eric and Marcel*) - not in attendance, will come back to this in January

iii. Center Interim Analysis based method (*Erik and Katie*)

1. No, this hasn't been vetted by SAFMC SSC. Data are almost available (waiting on ages, landings and discards are coming in tomorrow). Pros and Cons will be addressed when the method is up and running and we can see how it performs. Some questions include: how well can we update these parameters? Would like to do simulation analyses to test performance. SSC will be first to vet method. West Coast and North Pacific does these types of analyses already. Is documentation available in those regions? This is an ABC determination tool. Can do direct comparison with projections and any differences are expected to be due to index and age data.
2. ACTION: *Erik* - Look into documentation from the West Coast and North Pacific regions. *Katie and Erik* - Present progress at next meeting.
3. As an aside, this could serve as an intermediary assessment in the future; thus this could be useful for all of our stock in the SAtlantic.

iv. Methods used at other Centers (*Amy and Genny*)

1. NEFSC Index based method
2. Other methods?
   a. Reference documents are on the drive in the scoping materials folder in the Methods from other centers folder.

b. Need to take care to make sure that OFL and ABC are linked.
c. Does PIFSC do P* for rebuilding species?
d. ACTION: Need to assess appropriateness of the indices available for red snapper [index working group report from DW and some discussion in AW report]; do we have any indices that cross MSY or BMSY, is catch at MSY or not impacting MSY; a table would be useful - *Amy and Genny*. *Mike* - will find S41 DW working papers on topic.

v. Data Limited Approaches (*Luiz and Rob*) - not in attendance, will come back to this in January

vi. Monitoring of the ACL - current and future (*Scott*)
1. Reference ppt is on the drive in the scoping materials folder.
2. What about discards? Ask if there is any discussion on how to monitor discards without using MRIP? Phone app and logbooks - what data are being collected from this and how are those data intended to be used, has the SSC been consulted on data collection/utility; Any info on rare event workshop?

3. Can anyone attend a webinar Monday, December 18 at 1:30? *Katie*
4. Assign and review tasks for next meeting
5. Schedule next meeting - Doodle poll for Jan meeting (not Jan 17-19 national SSC); Amy will touch base with those not on the call.

NOTE: Need to work on documentation as we move through these discussions. *All*

Amendment 46 is on hold waiting for this group to present to SSC. Who is on the IPT from SEFSC? *Mike* - find out who is on IPT from SEFSC.

Agenda

Red Snapper ABC work group
Friday, November 17, 2017
10:00 AM – 12:00 PM

1. Welcome and attendance

Amy Schueller, Katie Siegfried, Erik Williams, Mike Errigo, Eric Johnson, Luiz Barbieri, Scott Crosson, Marcel Reichert, George Sedberry

2. Review of the tasks and timeline to occur between scoping call and April SSC meeting

3. Discussion of data, analyses, stock assessments, and any other background information available for collation for red snapper and consideration of methods/analyses that could be completed in time (based on timeline above) to determine an ABC for red snapper (including methods used by other Centers or Councils and index based methods)

- *Katie: Red snapper stock assessment (corrected base run is in the appended part of the document) - this includes all projections with the corrected run*
- *Marcel and Eric: Amendment 43 Index based method*
- *Marcel and Eric: Amendment 46 Index based method (determine if the same as Amendment 43)*
- *Erik and Katie: Center Interim Analysis based method - landings, discards, and index will be folded into projections*
- *Amy and Genny: NEFSC Index based method - needs investigation; Contact other Centers to see if they are using any similar methods*
- *Luiz and Rob: Data Limited Approaches (DLM)*
- *Scott: How ABC is currently monitored? How can the ABC be monitored in the future? - Contact Regional Office for current methods; brainstorm additional ideas for monitoring*

Which of these have been vetted through the SSC already?

Expectations: Collate all available information, come to December webinar ready to present the information and discuss options; pros and cons

   a. Assignments for compilation and collation of existing materials
   b. Assignments of new analyses to be completed

4. Review of tasks for next meeting
5. Schedule next meeting

Looking at the week of December 11. Amy will send a Doodle poll. If members are unable to attend, please hand off analysis, info to chair. Amy will contact Rob and Genny.

6. Outline agenda for the next meeting

Interim Analysis and Projections of Red Snapper in the US South Atlantic Region

Sustainable Fisheries Branch, Beaufort Laboratory, SEFSC

22 March 2018

Summary

In the U.S. South Atlantic region, stock assessments are typically several years out of date by the time regulations based on them are implemented. This occurs for numerous reasons, including the length of time to complete an assessment from data provision to SSC review, the length of time for managers to develop new regulations, and the time between assessments themselves (at least 5 years for many species). Consequently, ABC advice is based on uncertain projections several years into the future. These status quo projections include, when available, the latest information on removals (landings, discards), but must make assumptions about annual recruitment. For example, they commonly assume that future recruitment occurs at the long-term, average value.

In this document, we propose an Interim Analysis approach to provide updated ABCs between stock assessments. The application of Interim Analysis is consistent with national guidance from a soon-to-be-released NOAA report, Implementing a Next Generation Stock Assessment Enterprise[1] (eds. Lynch, Methot, and Link). The Interim Analysis approach described here is hybrid between the status quo projection methodology and an update assessment. In short, the approach advances the assessment model beyond the terminal year, fitting to the latest data on removals as well as other key data sources (e.g., index of abundance, age compositions) that might provide information on recent year-class strength. In this way, projections on which ABCs are based utilize more up-to-date information than does the status quo approach, without the need to re-do the full assessment. The approach holds potential for application to numerous stocks in the South Atlantic, increasing throughput of SEDAR in general. Here we focus on red snapper, which was last assessed through SEDAR-41 with a terminal year of 2014. The Interim Analysis updates recruitment estimates through 2016.

Methods

The Interim Analysis (IA) applies the latest assessment model and current projection model, but extends the assessment to include additional, more recent years. In this report, we

[1] A draft version is available from https://www.st.nmfs.noaa.gov/Assets/stock/documents/SAIPCompleteDraft_2-16-17_ExSumm.pdf

describe how the assessment is extended, but rely on previous documentation for more complete descriptions of the assessment and projection models (SEDAR-41 2017[2]).

In the SEDAR-41 red snapper assessment, the terminal year was T1=2014. The IA includes two more years of data, extending the terminal year to T2=2016. However, the IA differs from an Update assessment in two key ways:

- Unlike an Update assessment, not all data sources are updated through the new terminal year T2. Updated data sources include landings by fleet, discards by fleet, an index of abundance, and age compositions associated with that index.
- Unlike an Update assessment, the IA does not attempt to estimate all parameters of the assessment model. Instead, it fixes all parameters at their previously estimated values, with limited exception (described below). Thus, the Interim Analysis does not attempt to modify previous estimates of fishing mortality rate through year T1, selectivity ogives, the spawner-recruit relationship, or catchability applied to indices of abundance. Consequently, estimates of benchmarks remain unaltered from the previous assessment.

Most updated data sources include only the two additional years. The exception is the SERFS fishery independent index of abundance (CVID, combined chevron trap and video survey). Because the index is standardized, it was computed over its full time series (2010–T2) using identical methodology as in SEDAR-41 (2017), but with the two additional years. Specifically, the new data are the following:

- Landings in 2015 and 2016 for each fleet—commercial, headboat, general recreational (Table 1)
- Discards in 2015 and 2016 for each fleet—commercial, headboat, general recreational (Table 1)
- SERFS fishery independent index of abundance for 2010–2016. After standardization, the index was re-scaled such that values in the years 2010–T1 had the same mean as the SEDAR-41 index that spanned those same years. This way, the estimate of catchability from the assessment could be fixed, and the additional two years reflected population trends relative to the previous, SEDAR-41 index.
- Age compositions in 2015 and 2016 collected by SERFS chevron traps.

The intent of including an updated index of abundance and associated age compositions is to better inform recent year-class strength in the projections. Ideally, an index of recruitment would be available for this purpose. Such a focused index is not available for red snapper,

[2] SEDAR-41. 2017. SEDAR 41 – South Atlantic Red Snapper Assessment Report – Revision 1. SEDAR, North Charleston SC. 805 pp. available online at: http://sedarweb.org/sedar-41

however the SERFS did capture young red snapper (age 1+) and is therefore believed to contain information on recent, age-1 recruitment (in addition to older ages).

Only a limited number of parameters are estimated in the IA. These include parameters for each interim year describing fishing mortality associated with landings (3 fleets × 2 years = 6 parameters), fishing mortality associated with discards (3 fleets × 2 years = 6 parameters), and annual recruitment deviations (2 years = 2 parameters). Likelihood formulations for estimating these parameters were the same as for SEDAR-41. The additional years of data also have potential to inform year-class strength prior to the terminal year (T1=2014) of the assessment. We allow for this possibility by estimating an annual multiplier (m_y) on previously estimated recruitment deviations (r_y) in years immediately prior to T1, such that lognormal recruitment deviations in the IA equal $m_y \times r_y$. The MARMAP age compositions included ages 1–13+, and thus we estimated the multipliers starting in year T0=T2–13+1=2004, which is the year age-13 fish in year 2016 would have been age-1. The multipliers were estimated for years T0 through T1 (11 years = 11 parameters). A penalty term to constrain estimates of m_y was added to the total likelihood,

$$\Lambda^m = \sum_{y=T0}^{T1} (m_y - 1)^2$$

Thus, the likelihood was penalized for deviations away from 1, shrinking IA recruitment estimates toward the SEDAR-41 estimates unless informed by the new data.

Uncertainty

Uncertainty in the IA was quantified using MCB analysis. This was done by applying the IA to each MCB run from SEDAR-41. The primary reason for quantifying uncertainty in the IA was to carry that uncertainty forward into projections that may form the basis of ABC advice.

Effect of new data on interim recruitment estimates

To evaluate the effect of new data sources on estimating recruitment deviations and terminal-year (T2) age structure, we incrementally removed sources. For this evaluation, we label the analyses as follows:

- IA1: Interim analysis with all new data sets as described above
- IA2: Interim analysis without age composition data (index and removals only)
- IA3: Interim analysis without age composition or index data (removals only). In this analysis, the data cannot inform recent recruitment, and thus we turned off estimation of recruitment deviations through 2016, by fixing m_y=1 and by using expected, long-term values for 2015–2016 recruitment.

We consider model IA1, with all new data, to be the primary model and use it as the basis for subsequent projections. Model IA2 is a sensitivity analysis to investigate the importance of the new age composition data. Model IA3 is also a sensitivity analysis; it is analogous to the approach used in status quo projections.

Projections

To compute ABCs beyond the new terminal year T2, projections based on Model IA1 were run for 2017–2044. The projection methodology was identical to that from SEDAR-41. The primary difference is that the SEDAR-41 status quo projections started in 2015, and thus had to make assumptions about recruitment in 2015–2016. On the other hand, IA projections start in 2017 with an initial age structure that reflects recent recruitment as estimated from data.

In theory, IA could be performed without any lag between T2 and projections. However, in this application to red snapper, we have a one-year lag between T2=2016 and the earliest possible start of any new management implementation (2018). For the one year in between (2017), we assumed that landings were equal to the average level from 2012–2014, chosen because those years had red snapper season openings similar to 2017. Uncertainty in those landings was carried forward from the bootstrap of landings data performed as part of the SEDAR-41 MCB analysis.

We computed projections for two different levels of fishing mortality, $F=F_{30\%}$ (Scenario 1) and $F=F_{rebuild}$ (Scenario 2), starting in 2018. $F=F_{rebuild}$ was defined to be the fishing mortality rate that provides a 50% chance of rebuilding SSB to SSB_{MSY} by 2044.

Results

The primary model (IA1) fit reasonably well to the new age composition data (Figure 1A,B). It under-fit age-1 fish in 2015, but then fit that same cohort nearly perfectly in 2016. The information content from age composition data must be interpreted in the context of selectivity (Figure 1C).

Model IA1 predicted that the spawning stock continued to increase in 2015 and 2016, and that overfishing continued (Figure 2). These results appear to be robust, based on the MCB uncertainty analysis (Figure 2). The overfishing result comes almost entirely from discard mortalities, especially from the general recreational fleet (Table 1). Although the model estimates that spawning biomass remains below its threshold, it also estimates that total abundance of age-2+ fish is near its highest level since 1970 (Figure 2). The age structure remains truncated relative to that expected at $F_{30\%}$, but this result of relatively high abundance is consistent with reports from anglers and with observations from the SERFS.

Models IA1 and IA2 both captured the recent increasing trend in the SERFS index of abundance, however IA3 did not (Figure 3). Although AI3 was not fit to the index, the model can still generate predictions for comparison to the observed index.

The increasing trend in the index was explained by higher than expected recruitment in recent years (Figure 4A). Compared to IA3, which depicts the SEDAR-41 recruitment estimates through 2014 and the status quo assumption in 2015–2016, the primary model IA1 predicted considerably higher recruitment in 2014–2016, and slightly higher values in years prior. Model IA2 predicted similarly higher values, except for year 2016. That exception underscores the importance of including age composition data for estimating recruitment. However, even with age composition data (as in IA1), the terminal year recruitment estimates are typically very uncertain, especially when selectivity of age-1 fish is low.

Estimated recent recruitment values determine the initial abundance at age in projections (Figure 4B). Estimated initial abundances (in 2017) of ages 2–4 were nearly twice as high for IA1 than for the status quo approach of IA3. These higher values affect projections, including catch levels and the rate of rebuilding, particularly in the short term.

In Scenario 1 projections based on IA1, with fishing rate at the limit reference point of $F=F_{30\%}$, the stock is not projected to recover with a 50% probability by 2044 (Figure 5, Table 2). However, the short-term catch levels are substantially higher than those calculated with status quo projections[3], a consequence of the initial abundance at age. For the same reason, Scenario 2 projections, with $F=F_{rebuild}$, allows for higher short-term catch levels than status quo rebuilding projections (Figure 6, Table 3).

Discussion

On the spectrum of complexity, Interim Analysis falls in between an Update Assessment and a stock projection. IA is less complex than an Update Assessment, because it does not update all of the data sources, nor does it re-estimate all model parameters. IA is more complex than a stock projection because it attempts to estimate year-class strength, in addition to fishing mortality, in years between the terminal year of the assessment and implementation of new management. For some stocks, this gap can span five years or more. If a goal of SEDAR is to provide up-to-date catch advice with more throughput than is currently possible, adopting more frequent IA in place of full assessments could be an efficient approach.

Since the terminal year (2014) of SEDAR-41, the abundance of red snapper has continued to increase, as evidenced by the CVID index of abundance. The IA accounts for this trend by estimating high recruitment in recent years, and these estimates form the basis of the initial age structure projected forward from year 2017. In this way, projections stemming from

[3] Report: SEDAR 41 Red Snapper: Projection Supplement for SSC's ABC Working Group. Available upon request.

the IA are better informed by recent data than are those stemming from the SEDAR-41 Benchmark Assessment. We view this as an improvement, particularly for short-term forecasts. Nonetheless, the IA simply fills the gap of years since the last assessment. Forecasting future dynamics of fish stocks remains a highly uncertain endeavor, with all of the same caveats described in the SEDAR-41 AW report.

Table 1. Estimates of landings and discards for red snapper in the South Atlantic by fleet in 2015 and 2016.

	Commercial		Headboat		General recreational	
	Landings (lb)	Discards (fish)	Landings (fish)	Discards (fish)	Landings (fish)	Discards (fish)
2015	4,762	31,565	750	54,405	1,111	508,196
2016	4,151	34,568	331	66,511	72	788,460

Table 2. Projection results based on IA1 under Scenario 1, with fishing mortality rate fixed at $F = F_{30\%}$ starting in 2018. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), B = biomass (mt), S = spawning stock (1E8 eggs), L = landings expressed in numbers (1000s) or whole weight (1000 lb), and D = dead discards expressed in numbers (1000s) or whole weight (1000 lb), pr.rebuild = proportion of stochastic projection replicates with SSB greater than or equal to $SSB_{F30\%}$. The extension .base indicates expected values (deterministic) from the base run; the extension .med indicates median values from the stochastic projections.

year	R.base(1000)	R.med(1000)	F.base	F.med	B.base(mt)	B.med(mt)	S.base(1E8)	S.med(1E8)	L.base(1000)	L.med(1000)	L.base(1000 lb)	L.med(1000 lb)	D.base(1000)	D.med(1000)	D.base(1000 lb)	D.med(1000 lb)	pr.rebuild
2017	439	316	0.17	0.19	2539	2323	118189	104120	27	27	241	248	59	56	307	303	0.024
2018	442	317	0.15	0.15	2801	2523	155229	133222	28	25	273	250	51	46	302	272	0.057
2019	444	316	0.15	0.15	3012	2705	190469	161787	30	27	322	291	50	45	320	287	0.092
2020	445	315	0.15	0.15	3158	2833	220247	186458	30	28	350	316	49	44	324	290	0.128
2021	445	322	0.15	0.15	3265	2923	244466	205829	30	28	367	331	48	43	324	290	0.169
2022	446	315	0.15	0.15	3346	2996	263728	221523	31	28	380	342	48	43	322	290	0.209
2023	446	320	0.15	0.15	3410	3056	278665	233821	31	28	390	350	48	43	322	290	0.242
2024	446	320	0.15	0.15	3460	3109	290340	243425	31	28	398	357	48	43	324	291	0.272
2025	446	318	0.15	0.15	3499	3146	299082	251261	31	28	404	364	48	43	325	293	0.299
2026	446	320	0.15	0.15	3529	3176	305711	256852	31	28	409	368	48	43	327	296	0.323
2027	446	318	0.15	0.15	3553	3198	310791	261425	31	28	413	372	48	43	329	296	0.342
2028	446	318	0.15	0.15	3571	3224	314599	266410	31	28	416	374	48	43	330	298	0.354
2029	447	321	0.15	0.15	3585	3243	317530	268617	32	29	418	377	48	43	331	299	0.368
2030	447	321	0.15	0.15	3596	3257	319803	271263	32	29	420	379	48	44	332	300	0.382
2031	447	322	0.15	0.15	3605	3265	321558	273056	32	29	422	382	48	43	332	301	0.393
2032	447	317	0.15	0.15	3612	3276	322922	274334	32	29	423	383	48	43	332	301	0.398
2033	447	321	0.15	0.15	3617	3291	323967	275526	32	29	424	384	48	44	333	302	0.404
2034	447	318	0.15	0.15	3621	3303	324751	276633	32	29	424	385	48	44	333	303	0.411
2035	447	318	0.15	0.15	3624	3308	325363	277547	32	29	425	386	48	44	333	304	0.417
2036	447	321	0.15	0.15	3627	3313	325840	279201	32	29	425	386	48	44	333	304	0.42
2037	447	323	0.15	0.15	3629	3311	326221	280149	32	29	426	387	48	44	334	303	0.426
2038	447	320	0.15	0.15	3631	3312	326524	280816	32	29	426	388	48	44	334	303	0.427
2039	447	321	0.15	0.15	3632	3312	326766	280788	32	29	426	388	48	44	334	303	0.431
2040	447	320	0.15	0.15	3633	3308	326959	280823	32	29	426	387	48	44	334	303	0.43
2041	447	325	0.15	0.15	3634	3313	327112	280465	32	29	426	388	48	44	334	304	0.432
2042	447	321	0.15	0.15	3635	3319	327234	281262	32	29	427	389	48	44	334	305	0.435
2043	447	323	0.15	0.15	3635	3323	327331	281149	32	29	427	390	48	44	334	305	0.436
2044	447	323	0.15	0.15	3636	3326	327408	281611	32	29	427	390	48	44	334	304	0.438

Table 3. Projection results based on IA1 under Scenario 2, with fishing mortality rate fixed at F = $F_{rebuild}$ starting in 2018. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), B = biomass (mt), S = spawning stock (1E8 eggs), L = landings expressed in numbers (1000s) or whole weight (1000 lb), and D = dead discards expressed in numbers (1000s) or whole weight (1000 lb), pr.rebuild = proportion of stochastic projection replicates with SSB greater than or equal to $SSB_{F30\%}$. The extension .base indicates expected values (deterministic) from the base run; the extension .med indicates median values from the stochastic projections.

year	R.base(1000)	R.med(1000)	F.base	F.med	B.base(mt)	B.med(mt)	S.base(1E8)	S.med(1E8)	L.base(1000)	L.med(1000)	L.base(1000 lb)	L.med(1000 lb)	D.base(1000)	D.med(1000)	D.base(1000 lb)	D.med(1000 lb)	pr.rebuild
2017	439	316	0.17	0.19	2539	2323	118189	104120	27	27	241	248	59	56	307	303	0.024
2018	442	317	0.14	0.14	2801	2523	155517	133854	27	24	268	239	50	43	296	260	0.06
2019	444	316	0.14	0.14	3018	2717	191334	163695	29	26	316	280	49	43	314	275	0.101
2020	445	316	0.14	0.14	3171	2857	221801	189350	30	27	345	306	48	42	319	280	0.149
2021	445	322	0.14	0.14	3283	2959	246743	210182	30	27	362	322	47	42	319	281	0.2
2022	446	315	0.14	0.14	3369	3037	266706	226573	30	27	376	334	47	42	318	281	0.246
2023	446	320	0.14	0.14	3437	3109	282289	240079	30	27	386	344	47	42	318	282	0.288
2024	446	320	0.14	0.14	3490	3153	294543	250860	31	27	394	351	47	42	319	284	0.326
2025	446	318	0.14	0.14	3532	3201	303787	258943	31	28	401	358	47	42	321	287	0.361
2026	446	320	0.14	0.14	3565	3233	310844	265804	31	28	406	364	47	42	323	288	0.386
2027	446	318	0.14	0.14	3590	3258	316286	270669	31	28	410	367	47	42	325	290	0.405
2028	447	318	0.14	0.14	3610	3285	320395	274758	31	28	413	370	47	42	326	292	0.42
2029	447	321	0.14	0.14	3625	3304	323575	277859	31	28	416	373	47	42	327	293	0.433
2030	447	321	0.14	0.14	3637	3315	326053	280887	31	28	418	376	47	42	328	294	0.446
2031	447	322	0.14	0.14	3647	3326	327976	282835	31	28	419	378	47	42	328	294	0.456
2032	447	317	0.14	0.14	3655	3339	329478	284448	31	28	421	380	47	42	329	295	0.465
2033	447	321	0.14	0.14	3661	3355	330635	285754	31	28	422	380	47	42	329	295	0.469
2034	447	318	0.14	0.14	3665	3362	331507	286417	31	28	422	382	47	42	329	297	0.475
2035	447	318	0.14	0.14	3669	3371	332191	287620	32	29	423	383	47	43	330	297	0.479
2036	447	321	0.14	0.14	3672	3372	332725	288830	32	29	423	383	47	43	330	297	0.486
2037	447	324	0.14	0.14	3674	3372	333153	289327	32	29	424	384	47	42	330	297	0.491
2038	447	320	0.14	0.14	3676	3372	333494	290528	32	29	424	384	47	42	330	297	0.493
2039	447	321	0.14	0.14	3677	3370	333767	290656	32	29	424	383	47	42	330	297	0.496
2040	447	320	0.14	0.14	3679	3375	333985	290827	32	29	424	383	47	42	330	297	0.497
2041	447	325	0.14	0.14	3680	3381	334158	290834	32	29	425	385	47	43	330	298	0.5
2042	447	321	0.14	0.14	3680	3379	334296	291357	32	29	425	385	47	42	330	298	0.499
2043	447	323	0.14	0.14	3681	3390	334406	290894	32	29	425	386	47	43	330	299	0.499
2044	447	323	0.14	0.14	3681	3390	334494	291332	32	29	425	387	47	43	330	299	0.502

Figure 1. Fits of Model IA1 to the interim years of SERFS age compositions (top two panels). Selectivity of the SERFS gear, as estimated by the SEDAR-41 assessment model (bottom panel).

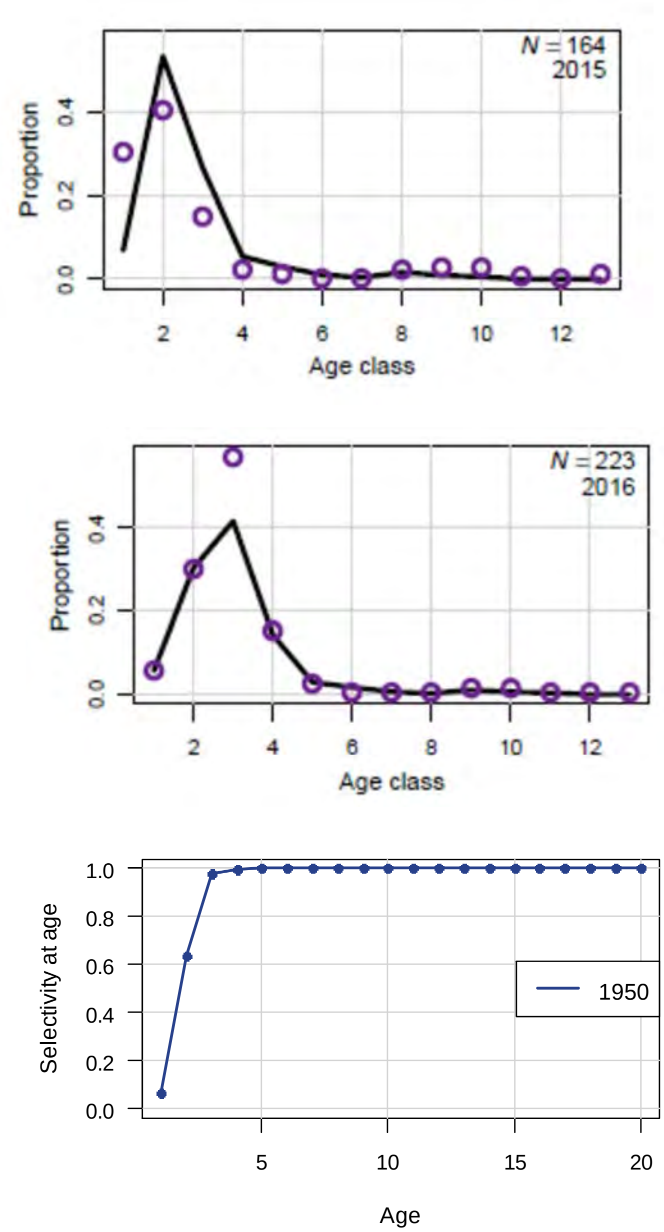


Figure 2. Results from model IA1: spawning biomass relative to that at $F_{30\%}$ (top panel), total abundance of age-2+ fish (middle panel), and F relative to $F_{30\%}$ (bottom panel). In each panel, the solid curve with filled circles represents base-run results, and the dashed line and gray bounds represent median and 95% intervals from the MCB analysis.

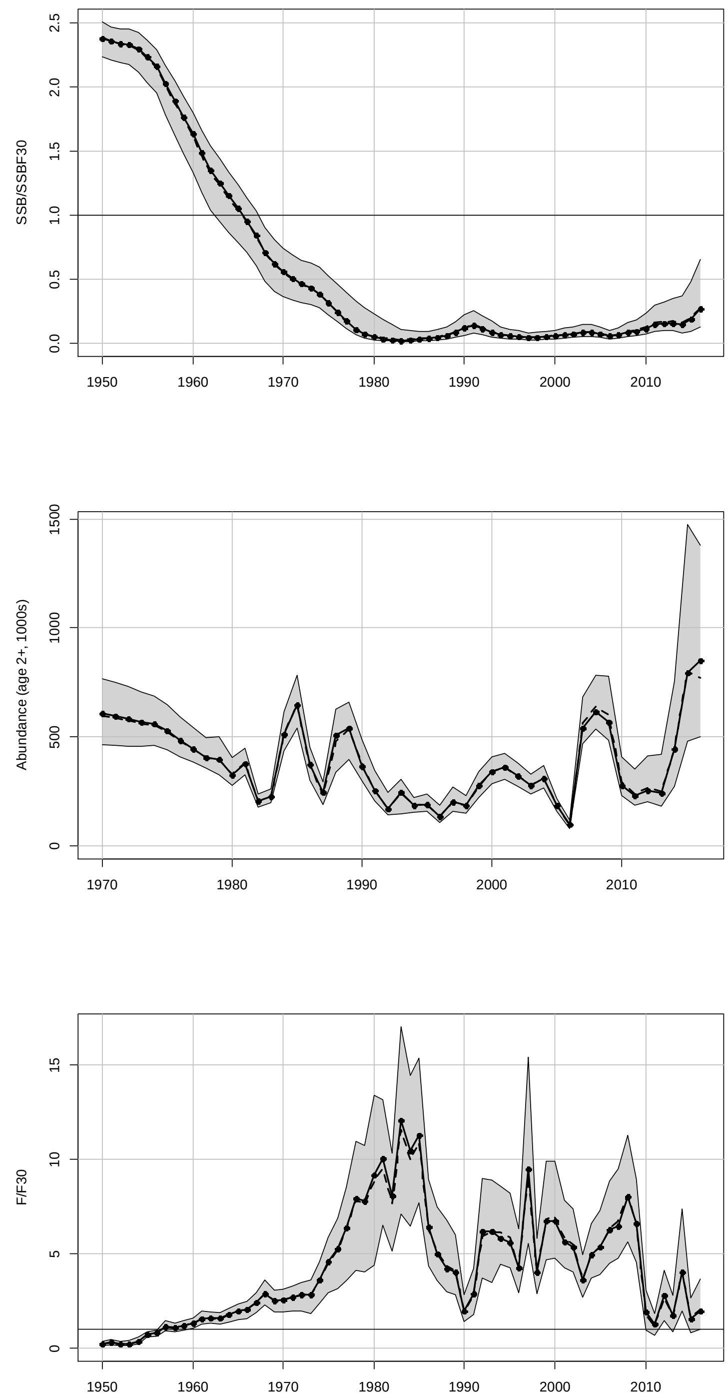


Figure 3. SERFS index of abundance fitted by Models IA1 (top) and IA2 (middle), and generated by Model IA3 (bottom). Model IA3 did not include the index in the objective function.

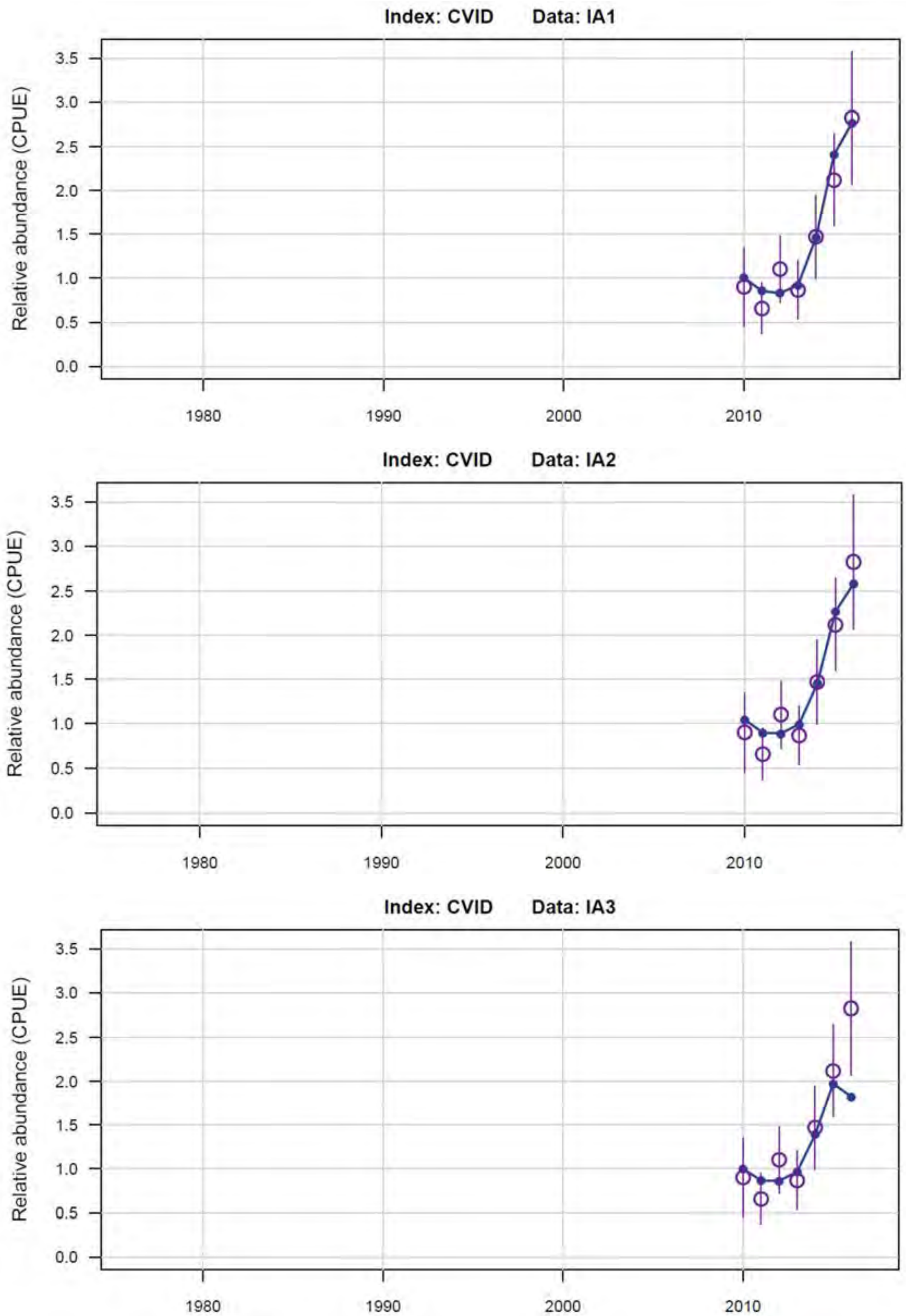


Figure 4. Predicted recruitment since the year 2000 from models IA1, IA2, and IA3 (top panel). Age structure (ages 2–10) in year 2017, as used to initialize population projections (bottom panel).

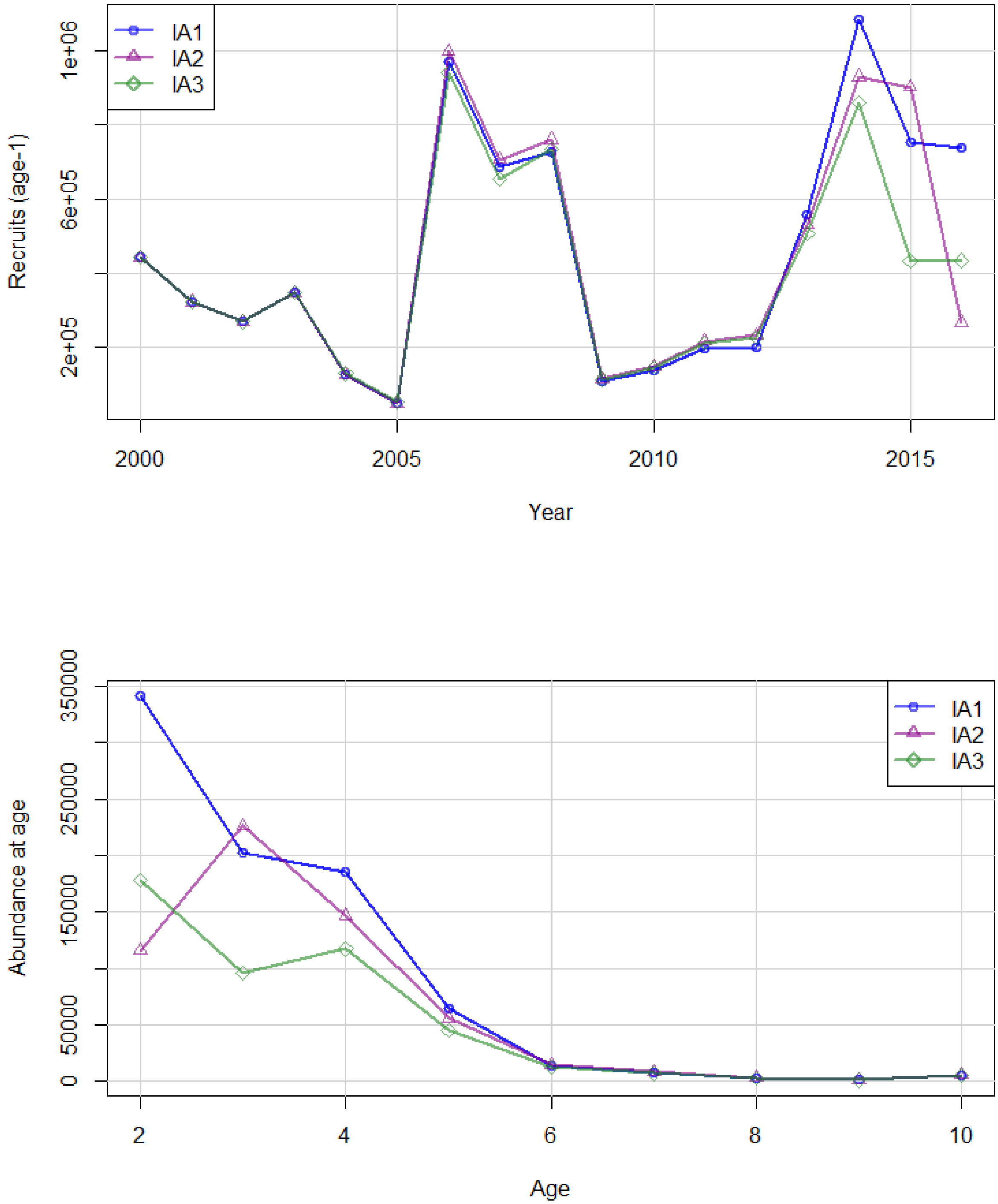


Figure 5. Projection results based on IA1 under Scenario 1, with fishing mortality rate at $F = F_{30\%}$ starting in 2018. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $SSB_{F30\%}$.

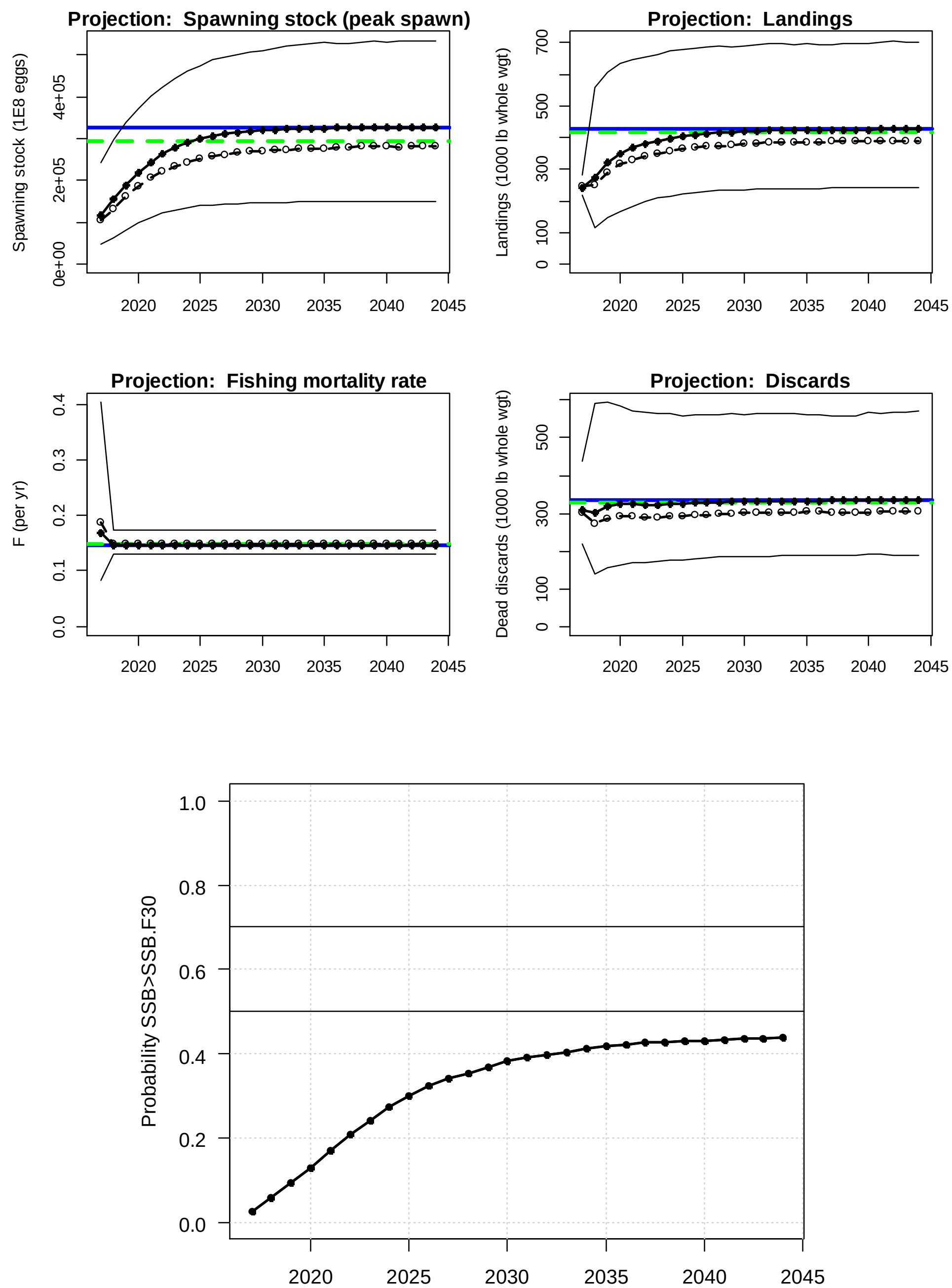
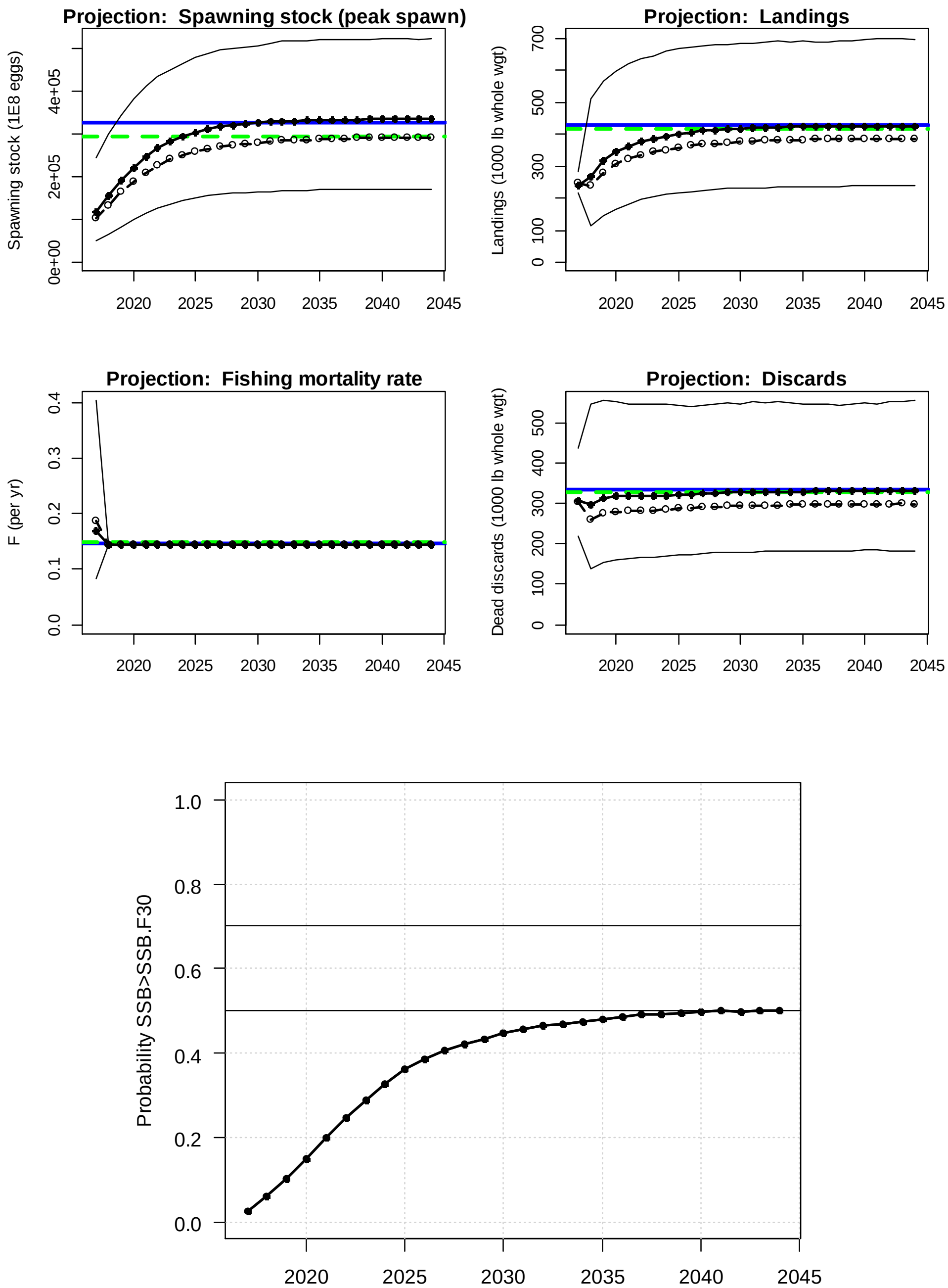


Figure 6. Projection results based on IA1 under Scenario 2, with fishing mortality rate at F = $F_{rebuild}$ starting in 2018. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $SSB_{F30\%}$.



Southeast Data, Assessment, and Review

SEDAR 41

Stock Assessment Report – Revision 1

South Atlantic Red Snapper

April 2017

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

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Southeast Data, Assessment, and Review

SEDAR 41

South Atlantic Red Snapper

SECTION I: Introduction

April 2016

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Executive Summary

SEDAR 41 addressed the stock assessments for South Atlantic gray triggerfish and red snapper. The assessments consisted of four in-person workshops, as well as a series of webinars. Two Data Workshops (DW) were held in Charleston, SC, the first August 4-8, 2014 and the second August 4-6, 2015. The SEDAR 41 Assessment Process was conducted through a combination of an in-person workshop, held December 14-17, 2015 in Morehead City, NC, and a series of webinars held from October 2015 to February 2016. The Review Workshop (RW) took place March 15-18, 2016 in North Charleston, SC.

The Stock Assessment Report is organized into six sections. Section I is the Introduction which contains a brief description of the SEDAR Process, Assessment, and Management Histories for the species of interest, and the management specifications requested by the Cooperator. Section II is the Data Workshop Report. It documents the discussions and data recommendations from the Data Workshop Panel. Section III is the Assessment Report. This section details the assessment model, as well as documents any changes to the data recommendations that may have occurred after the Data Workshop. Consolidated Research Recommendations from all three stages of the process (data, assessment, and review) can be found in Section IV for easy reference. Section V documents the discussions and findings of the Review Workshop. Finally, Section VI is the Addenda and Post-Review Workshop Documentation which consists of any analyses conducted during or after the RW to address reviewer concerns or requests. It may also contain documentation of the final RW-recommended base model, should it differ from the model put forward in the Assessment Report for review.

The final Stock Assessment Report (SAR) for South Atlantic Red Snapper was disseminated to the public in April 2016. The Council's Scientific and Statistical Committee (SSC) will review the SAR for its stock. The SSCs are tasked with recommending whether assessments represent Best Available Science, whether the results presented in the SARs are useful for providing management advice, and developing fishing level recommendations for the Council. An SSC may request additional analyses be conducted or may use the information provided in the SAR as the basis for their fishing level recommendations (e.g. Overfishing Limit and Acceptable Biological Catch). The South Atlantic Fishery Management Council's SSC will review the assessment at its May 2016 meeting, followed by the Council receiving that information at its June 2016 meeting. Documentation on SSC recommendations is not part of the SEDAR process and is handled through each Council.

During the March 2016 RW, the RW Panel evaluated outputs and results from the Beaufort Assessment Model (BAM), the primary assessment model that implements a statistical catch-at-age framework; and a secondary, surplus-production model (ASPIC) which provided a comparison of model results. The RW Panel accepted the new BAM base model with the corrected age compositions for the Southeast Reef Fish Survey (SERFS) combined chevron trap and video (CVID) survey index as the best available model to provide catch or management advice for the South Atlantic red snapper fishery. The RW Panel concluded that the data used in the assessment were generally sound and robust. Likewise, data generally were applied properly, and uncertainty in data inputs was appropriately acknowledged. Numerous sensitivity analyses and exploration of alternative scenarios of the BAM model were also presented during the RW, all of which agreed with the base model run conclusions of stock status. Based on these results, the Review Panel concluded that the stock is overfished and overfishing is occurring. Although the Review Panel concluded that assessment results represent the best available science, there were significant areas of uncertainty identified in both the data and in components to the model. The most significant sources of this uncertainty included: the composition and magnitude of recreational discards, the stock-recruitment relationship, potential changes in CPUE catchability, and the selectivities for the different fishery fleets. The Review Panel recognized that the perception of current selectivity used to derive reference points and projections is conditional on poorly-informed assumptions regarding recent fishing behavior. During the most recent years of the stock assessment series (i.e., the 2010-2014 moratorium), recreational discards were one of the most important and most uncertain sources of information. Also, a retrospective pattern in apical F indicated the base BAM model was very sensitive to the terminal year of data and suggests higher uncertainty in exploitation status.

During the assessment process several data and modeling topics received a lot of discussion. Some of these topics included:

- *Southeast Region Headboat Survey (SRHS) Data Evaluation*: After the 2014 DW, a working paper was submitted questioning the validity of data collected during the early years of the SRHS. The assessment was delayed in order to investigate these potential issues. Prior to the 2015 DW, the SEFSC did a comprehensive evaluation of the SRHS program that indicated no evidence of chronic, widespread misreporting, no evidence of an apparent temporal pattern in potentially misreported data, and minimal spatial patterns in potentially misreported data.
- *Marine Recreational Information Program (MRIP) Access Point Angler Intercept Survey (APAIS) adjustment:* Starting in wave 2 of 2013, the MRIP APAIS implemented a revised sampling design. To address this new survey design change, a Calibration Workshop was held in 2014. The final report recommended an additional calibration for catch estimates and recommended an interim ‘simple ratio’ method using 2013 data. SEDAR 41 was the first time this method was used in a South Atlantic SEDAR assessment.
- *Recreational Red Snapper Charter and Private Mini Season Landings and Discard Estimates*: In 2012 through emergency action and 2013 and 2014 through a process developed in Amendment 28 to the Snapper Grouper Fishery, the red snapper fishery was opened for a very short duration. MRIP was not designed to capture short pulses of fishing. State partners in the South Atlantic supplied data from studies conducted in each state during the mini-seasons as an attempt to supplement the MRIP data. The DW Panel

developed a set of rules in order to determine which dataset (MRIP vs. state partners) was more appropriate for landings and discards by state, mode, and wave.

- *Natural Mortality*: Both the DW and Assessment Workshop (AW) panels had lengthy discussions about natural mortality. The final recommendation was to use the Charnov et al. (2013) age-varying natural mortality curve scaled to the Then et al. (2015) point estimate for those ages fully recruited to the fishery. SEDAR 41 was the first time the Then et al. (2015) estimator has been used in a South Atlantic SEDAR assessment.
- *SERFS Chevron Trap Index Time Series:* The DW Panel recommended using the SERFS trap index from 2010-2014. Chevron trap survey data were available prior to 2010, and the Panel discussed potentially starting the trap index in 2005. However, due to the low incidence of red snapper catches prior to 2010, the Panel recommended using the trap index starting in 2010 and exploring the effect of the longer time series through a sensitivity run.
- *SERFS Chevron Trap and Video Indices – Independence and Selectivity:* The AW Panel recommended combining the trap and video indices into one index (CVID) since the data are collected from the same sampling platform (e.g. cameras are mounted on the traps). Age composition data were not available for the video index, so the selectivity for the combined CVID index was informed by age composition of red snapper caught in chevron traps.
- *Stock Recruitment Curve and Steepness:* Many initial attempts were made to estimate steepness resulting in a value near its upper bound. The AW Panel discussed whether to fix steepness or assume an average annual recruitment while estimating lognormal deviations around that average by setting steepness to 0.99. The AW Panel opted for the latter, acknowledging this would require using spawning potential ratio (SPR) benchmarks to determine stock status rather than MSY-benchmarks.
- *Start Year of Model*: The AW Panel had discussions regarding the start year of the assessment. They weighed the options of starting in 1950 vs. 1978. Only landings data were available for the historic time period (1950 – mid-1970's). No age or length composition data were available. The AW Panel recommended 1950 as the starting year and included a model run with the 1978 start year as a sensitivity run.
- *SERFS Revised Chevron Trap Age Compositions:* An error with the chevron trap survey age composition data was discovered during the RW. The age compositions used at the AW were based on the number of annuli and the corrected data were based on calendar-year age. Revised age compositions along with preliminary assessment results were presented at the RW and accepted for use in the base run of the model.
- *Selectivity for General Recreational Fleet from 2010-2014*: Selectivity of the general recreational fleet was assumed to be flat-topped for the 2010-2014 time block. The RW Panel could not agree on whether the flat-topped assumption was well justified and requested a sensitivity analysis where the selectivity for this time period mirrored the headboat dome-shaped selectivity.
- *Recreational Discard Estimates:* The RW Panel noted that during the most recent years of the assessment (2010-2014 moratorium period), recreational discards were one of the most important sources of information for the assessment. Recreational discards were

also noted as one of the most uncertain sources of information. Despite the uncertainty of recreational catch estimates, the BAM base configuration is conditional on catch estimates. The impact of the uncertainty in discards and landings on stock status was explored through the MCB uncertainty analysis and sensitivity runs.

- *Evaluating Trends of Fishing Mortality (F) Over Time:* The RW Panel noted that evaluating trends in F across time requires a metric that is comparable among years and reflects exploitation across a range of ages. In this assessment, apical F (maximum F at age) is based on a different range of ages among years because of changing fleet contributions and fleet selectivities. The RW Panel discussed other potential F metrics and noted deciding on a more appropriate metric of F was challenging due to the complexity of patterns in estimated F at age. The RW Panel noted the potential large uncertainty in the F estimates including the terminal year of the assessment (2014).

I. Introduction

1. SEDAR Process Description

SouthEast Data, Assessment, and Review (SEDAR) is a cooperative Fishery Management Council process initiated in 2002 to improve the quality and reliability of fishery stock assessments in the South Atlantic, Gulf of Mexico, and US Caribbean. The improved stock assessments from the SEDAR process provide higher quality information to address fishery management issues. SEDAR emphasizes constituent and stakeholder participation in assessment development, transparency in the assessment process, and a rigorous and independent scientific review of completed stock assessments.

SEDAR is managed by the Caribbean, Gulf of Mexico, and South Atlantic Regional Fishery Management Councils in coordination with NOAA Fisheries and the Atlantic and Gulf States Marine Fisheries Commissions. Oversight is provided by a Steering Committee composed of NOAA Fisheries representatives: Southeast Fisheries Science Center Director and the Southeast Regional Administrator; Regional Council representatives: Executive Directors and Chairs of the South Atlantic, Gulf of Mexico, and Caribbean Fishery Management Councils; a representative from the Highly Migratory Species Division of NOAA Fisheries; and Interstate Commission representatives: Executive Directors of the Atlantic States and Gulf States Marine Fisheries Commissions.

SEDAR is typically organized around three stages. First is the Data Stage, where a workshop is held during which fisheries, monitoring, and life history data are reviewed and compiled. Second is the Assessment Stage, which is conducted via a workshop and/or series of webinars, during which assessment models are developed and population parameters are estimated using the information provided from the Data Workshop. The final stage is the Review Workshop, during which independent experts review the input data, assessment methods, and assessment products. The completed assessment, including the reports of all 3 workshops and all supporting documentation, is then forwarded to the Council SSC for certification as 'appropriate for management' and development of specific management recommendations.

SEDAR workshops are public meetings organized by SEDAR staff and the lead Council. Workshop participants are drawn from state and federal agencies, non-government organizations, Council members, Council advisors, and the fishing industry with a goal of including a broad range of disciplines and perspectives. All participants are expected to contribute to the process by preparing working papers, contributing, providing assessment analyses, and completing the workshop report.

SEDAR Review Workshop Panels consist of a chair, three reviewers appointed by the Center for Independent Experts (CIE), and one or more SSC representatives appointed by each council having jurisdiction over the stocks assessed. The Review Workshop Chair is appointed by the council having jurisdiction over the stocks assessed and is a member of that council's SSC. Participating councils may appoint representatives of their SSC, Advisory, and other panels as observers.

2. Management Overview

2.1 Fishery Management Plan and Amendments

The following summary describes only those management actions that likely affect red snapper fisheries and harvest.

Original Snapper Grouper Fishery Management Plan

The Fishery Management Plan (FMP), Regulatory Impact Review, and Final Environmental Impact Statement for the Snapper Grouper Fishery of the South Atlantic Region, approved in 1983 and implemented in August of 1983, establishes a management regime for the fishery for snappers, groupers and related demersal species of the continental shelf of the southeastern United States in the exclusive economic zone (EEZ) under the area of authority of the South Atlantic Fishery Management Council (Council) and the territorial seas of the states, extending from the North Carolina/Virginia border through the Atlantic side of the Florida Keys to 83º W longitude. In the case of the sea basses and scup, the management regime applies only to south of Cape Hatteras, North Carolina. Regulations apply only to federal waters.

SAFMC FMP Amendments affecting red snapper

Description of Action	FMP/Amendment	Effective Date
4" Trawl mesh size and a 12" TL minimum size limit for red snapper.	Snapper Grouper FMP	8/31/1983
Prohibit trawls.	Amendment # 1	1/12/1989
Required permit to fish for, land or sell snapper grouper species.	Amendment # 3	1/31/1991
Prohibited gear: fish traps except bsb traps north of Cape Canaveral, FL; entanglement nets; longline gear inside 50 fathoms; bottom longlines to harvest wreckfish; powerheads and bangsticks in designated SMZs off S. Carolina. Established 20" TL minimum size for red snapper and a 10 snapper/person/day bag limit, excluding vermilion snapper, and allowing no more than 2 red snapper.	Amendment # 4	1/1/1992
Oculina Experimental Closed Area.	Amendment # 6	6/27/1994
Limited entry program; transferable permits and 225 lb non-transferable permits.	Amendment # 8	12/14/1998

Vessels with longline gear aboard may only possess snowy grouper, warsaw grouper, yellowedge grouper, misty grouper, golden tilefish, blueline tilefish, and sand tilefish.	Amendment # 9	2/24/1999
Approved definitions for overfished and overfishing. MSST = [(1-M) or 0.5 whichever is greater]* B_{MSY}. MFMT = F_{MSY}	Amendment # 11	12/2/1999
Extended for an indefinite period the regulation prohibiting fishing for and possessing snapper grouper species within the *Oculina* Experimental Closed Area.	Amendment # 13A	4/26/2004
Established eight deepwater Type II marine protected areas to protect a portion of the population and habitat of long-lived deepwater snapper grouper species. Also protected known spawning areas of many snapper grouper species including red snapper.	Amendment #14 (2007)	2/12/09
Prohibited harvest and possession of red snapper from January 4, 2010 to June 2, 2010. Was extended for 186 days.	Red Snapper Interim Rule	12/4/2009
Specified an ACL=0 for red snapper. Specified a rebuilding plan for red snapper. Specified status determination criteria for red snapper. Specified a monitoring program for red snapper. Required use of non-stainless steel circle hooks when fishing for snapper grouper species with hook-and-line gear north of 28 deg. N latitude in the South Atlantic EEZ. Implemented an area closure for South Atlantic snapper grouper extending from southern Georgia to northern Florida where harvest and possession of all snapper grouper species was prohibited (except when fishing with black sea bass pots or spearfishing gear for species other than red snapper).	Amendment # 17A	12/3/2010 red snapper closure; circle hooks 3/3/2011

Established red snapper seasons for the commercial and recreational sectors in South Atlantic federal waters in 2012. The commercial and recreational annual catch limits for 2012 were 20,818 pounds gutted weight and 9,399 fish, respectively. During the open season, the commercial trip limit was 50 pounds gutted weight, the recreational bag limit was 1 fish per person per day, and there was no minimum size limit for red snapper for either sector. The fishing seasons in 2012 for the commercial and recreational sectors were 14 and 6 days, respectively.	Red Snapper Emergency Rule	8/28/2012
Established regulations to allow limited harvest of red snapper on an annual basis. Also specified the commercial and recreational annual catch limits for red snapper in 2013. The commercial and recreational annual catch limits were 21,447 pounds gutted weight and 9,585 fish, respectively. During the open season, the commercial trip limit was 75 pounds gutted weight, the recreational bag limit was 1 fish per person per day, and there is no minimum size limit for red snapper for either sector. The fishing seasons in 2013 for the commercial and recreational sectors were 43 and 3 days, respectively. The fishing seasons in 2014 for the commercial and recreational sectors were 57 and 8 days, respectively.	Amendment # 28	8/23/2013

SAFMC Regulatory Amendments affecting red snapper

Description of Action	FMP/Amendment	Effective Date
Prohibited fishing in SMZs except with hand-held hook-and-line and spearfishing gear.	Regulatory Amendment # 1	3/27/1987
Established 2 artificial reefs off Ft. Pierce, FL as SMZs.	Regulatory Amendment # 2	3/30/1989
Established artificial reef at Key Biscayne, FL as SMZ.	Regulatory Amendment # 3	11/02/1990
Established 8 SMZs off S. Carolina, where only hand-held, hook-and-line gear and spearfishing (excluding powerheads) was allowed.	Regulatory Amendment # 5	7/31/1993
Established 10 SMZs at artificial reefs off South Carolina,	Regulatory Amendment # 7	1/29/1999
Established 12 SMZs at artificial	Regulatory Amendment # 8	11/15/2000

reefs off Georgia; revised boundaries of 7 existing SMZs off Georgia to meet CG permit specs; restricted fishing in new and revised SMZs.		
Eliminated closed area for snapper grouper species approved in Amendment 17A.	Regulatory Amendment # 10	5/31/2011
Change MSST for 8 snapper grouper species including red snapper from MSST = [(1-M) or 0.5 whichever is greater]*B_{MSY} to 0.75*B_{MSY}	Regulatory Amendment #21	11/6/2014

2.2 Emergency and Interim Rules (if any)

Emergency Rule effective 9/3/1999: Reopened the Amendment 8 permit application process.

Interim Rule effective 12/4/2009: Prohibited harvest and possession of red snapper from January 4, 2010 to June 2, 2010. Was extended for 186 days.

Emergency Rule effective 12/3/2010: Delay the effective date of the area closure for snapper grouper species implemented through Amendment 17A.

Emergency Rule effective 8/28/2012: Established red snapper seasons for the commercial and recreational sectors in South Atlantic federal waters. The commercial and recreational annual catch limits for 2012 were 20,818 pounds gutted weight and 9,399 fish, respectively. During the open season, the commercial trip limit was 50 pounds gutted weight, the recreational bag limit was 1 fish per person per day, and there was no minimum size limit for red snapper for either sector. The fishing seasons in 2012 for the commercial and recreational sectors were 14 and six days, respectively.

2.3 Secretarial Amendments (if any)

None

2.4 Control Date Notices (if any)

Notice of Control Date effective July 30, 1991: Anyone entering federal snapper grouper fishery (other than for wreckfish) in the EEZ off S. Atlantic states after 7/30/91 was not assured of future access if limited entry program developed.

Notice of Control Date effective October 14, 2005: The Council is considering management measures to further limit participation or effort in the commercial fishery for snapper grouper species (excluding Wreckfish).

Notice of Control Date effective March 8, 2007: The Council may consider measures to limit participation in the snapper grouper for-hire fishery.

Notice of Control Date effective January 31, 2011: Anyone entering federal snapper grouper fishery off South Atlantic states after 9/17/10 was not assured of future access if limited entry program is developed.

2.5 Management Program Specifications

Table 2.5.1. General Management Information

South Atlantic

Species	Red Snapper
Management Unit	Southeastern US
Management Unit Definition	All waters within South Atlantic Fishery Management Council Boundaries
Management Entity	South Atlantic Fishery Management Council
Management Contacts SERO / Council	SAFMC: Myra Brouwer/Gregg Waugh SERO: Jack McGovern/Rick DeVictor
Current stock exploitation status	Overfishing
Current stock biomass status	Overfished

Table 2.5.2 Management Parameters

See November 2010 SEFSC report (SEDAR41-RD09) **for updated values from SEDAR 24 based on headboat weight of 0.30.**

Criteria	South Atlantic – Current (SEDAR 24)	
	Definition	Value
MSST[1]	MSST = [(1-M) or 0.5 whichever is greater]*SSB_{MSY}	317,465 lbs ww
	Regulatory Amendment # 21 (effective 11/6/2014) changed definition to MSST = 75%*SSB_{MSY}	258,000 lbs ww
MFMT	$F_{30\%SPR}$ proxy for F_{MSY}	0.204
MSY	Yield at F_{MSY} (1,000 pounds)	1,926
F_{MSY}	$F_{30\%SPR}$	0.204[2]
OY	Yield at F_{OY} (1,000 pounds) Values based on F_{MSY} = 0.206[2]	65%F_{MSY} = 1,794 75%F_{MSY} = 1,863 85%F_{MSY} = 1,905

		98%$F_{30\%SPR}$ adopted as OY but no equilibrium value
R_{MSY}	Recruitment at MSY (1,000 age-1 fish)	608
F Target		
Yield at F_{TARGET} (equilibrium)		
F_{OY}	F_{OY} = 65%,75%, 85%, 98% F_{MSY}	65%F_{MSY} = 0.133 75%F_{MSY} = 0.153 85%F_{MSY} = 0.173 98%$F_{30\%SPR}$ = .200
M	M	0.08
Terminal F	Geometric mean of the fishing mortality rates in 2007-2009 (Fcurrent)	0.569
Terminal Biomass[1]	SSB_{2009} (metric tons)	24
Exploitation Status	$F_{2007\text{-}2009}/F_{30\%SPR}$	2.79
Biomass Status[1]	SSB_{2009}/MSST	0.15
Generation Time		25 years
$T_{REBUILD}$ (if appropriate)		

Criteria	South Atlantic – Proposed (Values from SEDAR 41)		
	Definition	Base Run Values	Median of Base Run MCBs
MSST[1]	MSST* = [(1-M) or 0.5 whichever is greater]*SSB_{MSY} Regulatory Amendment # 21 (effective 11/6/2014) changed definition to MSST = 75%*SSB_{MSY}		
MFMT	$F_{30\%SPR}$ proxy for F_{MSY}		
MSY	Yield at F_{MSY}		
F_{MSY}	F_{MAX}		
OY	Yield at F_{OY} (defined as 98%F30%SPR)		
R_{MSY}	Recruits as MSY		
F Target			
Yield at F_{TARGET} (equilibrium)	Landings and discards, pounds and numbers		
F_{OY}	F_{OY} = 65%,75%, 85% F_{MSY} F_{OY} = 98%$F_{30\%SPR}$		
M	M		
Terminal F	Exploitation		

Terminal Biomass[1]	Biomass		
Exploitation Status	F/MFMT		
Biomass Status[1]	SSB/MSST SSB/SSB_{MSY}		
Generation Time			
$T_{REBUILD}$ (if appropriate)			

1. Biomass values reported for management parameters and status determinations should be based on the biomass metric recommended through the assessment process and Council's Scientific and Statistical Committee (SSC). This may be total, spawning stock or some measure thereof, and should be applied consistently in this table.

2. SAFMC defined $F_{MSY}=F_{30\%SPR}$ (or stated $F_{OY}=98\%F_{30\%SPR}$). SEDAR 24 determined $F_{MSY}=0.178$. SEFSC projections were completed (see Table 1 in SEDAR41-RD09) and determined the following: $F_{30\%SPR}=0.204$, $F_{MSY}=0.206$. (Both of these values use a headboat weight of 0.30). The SAFMC determined that $F_{30\%SPR}$ is used as a proxy for F_{MSY}.

NOTE: "Proposed" columns are for indicating any definitions that may exist in FMPs or amendments that are currently under development and should therefore be evaluated in the current assessment. Please clarify whether landings parameters are 'landings' or 'catch' (Landings + Discard). If 'landings', please indicate how discards are addressed.

Table 2.5.3. Stock Rebuilding Information

Amendment 17A to the FMP specified a 35 year rebuilding schedule with the rebuilding time period ending in 2044. The rebuilding schedule is based on T_{MIN} + one generation Time; SEDAR 15 2008 was the source of the generation time.

Table 2.5.4. General Projection Specifications

South Atlantic

Requested Information	Value
First Year of Management	Assume management begins in 2018. However, if there are no changes to reference points and rebuilding plan, a projection with the revised ABC and OFL should be provided assuming that landings limits are changed in the 2017 fishing year.
Interim basis	ABC, if landings are within 10% of the ABC; average landings since 2012 (implementation of emergency rule and Amendment 28) otherwise.
Current Acceptable Biological (ABC) Value (1,000 fish (landings + dead discards))	2014: 106 2015: 114 2016: 121 2017: 128

	2018: 135 2019: 142
Projection Outputs	
Landings	Pounds and numbers
Discards	Pounds and numbers
Exploitation	F & Probability F>MFMT
Biomass (total or SSB, as appropriate)	B & Probability B>MSST (and Prob. B>B_{MSY} if under rebuilding plan)
Recruits	Number

Table 2.5.5. Base Run Projections Specifications. Long Term and Equilibrium conditions.

Red snapper is currently in a rebuilding plan, implemented in Snapper Grouper Amendment 17A. The rebuilding period is 35 years, ending in 2044. Rebuilding is based on fixed exploitation at F=98% of F30%SPR.

Criteria	Definition	If overfished	If rebuilt
Projection Span	Years	to 2044	10
Projection Values	$F_{CURRENT}$	X	X
	F_{MSY}	X	X
	75% F_{MSY}	X	X
	$F_{REBUILD = 98\%F30\%SPR}$	X	

NOTE: Exploitation rates for projections may be based upon point estimates from the base run (current process) or upon the median of such values from the MCBs evaluation of uncertainty. The critical point is that the projections be based on the same criteria as the management specifications.

Table 2.5.6. Short term projections (P* or exploitation based). Short term specifications for OFL and ABC recommendations. Additional P-star projections may be requested by the SSC once the ABC control rule is applied. Projections based on exploitation rates should provide probabilities of both overfishing and overfished conditions.

Basis	Value	Years to Project	P* applies to
P*	50%	Interim + 5	Probability of overfishing
Exploitation	98% of F30%SPR	Interim + 5	NA

Table 2.5.7. Quota Calculation Details

If the stock is managed by quota, please provide the following information.

Red snapper is managed by catch limits that are established annually, after the results of the prior fishing year are evaluated. Calculation of these catch limits is specified in Snapper Grouper Amendment 28, values are not required to be calculated in this assessment.

2.6 Management and Regulatory Timeline

The following tables provide a timeline of federal management actions by fishery.

Table 2.6.1. Annual Commercial Red Snapper Regulatory Summary (please fill out as appropriate)

Year	Fishing Year	Size Limit	Possession Limit	Open Date	Close Date	Other
1992	Calendar	20”	None	January 1		
1993	Calendar	20”	None	January 1		
1994	Calendar	20”	None	January 1		
1995	Calendar	20”	None	January 1		
1996	Calendar	20”	None	January 1		
1997	Calendar	20”	None	January 1		
1998	Calendar	20”	None	January 1		
1999	Calendar	20”	None	January 1		
2000	Calendar	20”	None	January 1		
2001	Calendar	20”	None	January 1		
2002	Calendar	20”	None	January 1		
2003	Calendar	20”	None	January 1		
2004	Calendar	20”	None	January 1		
2005	Calendar	20”	None	January 1		
2006	Calendar	20”	None	January 1		
2007	Calendar	20”	None	January 1		
2008	Calendar	20”	None	January 1		
2009	Calendar	20”	None	January 1		
2010	Calendar	20”	Zero	January 1	December 3	** see note below
2011	Calendar	No Harvest				
2012	Calendar	No min size limit	50 lb per trip	September 17	September 24	Reopened November 13-21 and December 12-19
2013	Calendar	No min size limit	75 lb per trip	August 26	October 8	
2014	Calendar	No min size limit	75 lb per trip	July 14	September 9	

**Red snapper interim rule prohibited harvest and possession of red snapper from January 4, 2010 to June 2, 2010 and was extended for 186 days. Existing size limits were not changed in the interim rule, but the prohibition of harvest trumped these regulations.

Table 2.6.2. Annual Recreational Red Snapper Regulatory Summary (Please fill out as appropriate)

Year	Fishing Year	Size Limit	Bag Limit	Open Date	Close Date	Other
1992	Calendar	20”	aggregate snapper bag limit – 10/person/day, excluding vermilion snapper and allowing no more than 2 red snappers	January 1		
1993	Calendar	20”	aggregate snapper bag limit – 10/person/day, excluding vermilion snapper and allowing no more than 2 red snappers	January 1		
1994	Calendar	20”	2	January 1		
1995	Calendar	20”	2	January 1		
1996	Calendar	20”	2	January 1		
1997	Calendar	20”	2	January 1		
1998	Calendar	20”	2	January 1		
1999	Calendar	20”	2	January 1		
2000	Calendar	20”	2	January 1		
2001	Calendar	20”	2	January 1		
2002	Calendar	20”	2	January 1		
2003	Calendar	20”	2	January 1		
2004	Calendar	20”	2	January 1		
2005	Calendar	20”	2	January 1		
2006	Calendar	20”	2	January 1		
2007	Calendar	20”	2	January 1		
2008	Calendar	20”	2	January 1		
2009	Calendar	20”	2	January 1		
2010	Calendar	20”	2	January 1	December 3	** see note below
2011	Calendar	No harvest				
2012	Calendar	No min size limit	1	Sept 14-17, and Sept 21-24	Sept 17; Sept 24	Two 3-day weekends
2013	Calendar	No min size limit	1	August 23	August 26	One 3-day weekend
2014	Calendar	No Min size limit	1	Jul 11-14, Jul 18-21, Jul 25-27	Jul 14; Jul 21; Jul 27	Two 3-day weekends and 1 two-day weekend

**Red snapper interim rule prohibited harvest and possession of red snapper from January 4, 2010 to June 2, 2010 and was extended for 186 days. Existing size and bag limits were not changed in the interim rule, but the prohibition of harvest trumped these regulations.

2.6.3 Closures due to Meeting Commercial Quota or Commercial/Recreational ACL

Commercial: See Table 2.6.1

Recreational: See Table 2.6.2

Table 7. State Regulatory History

North Carolina:

There are currently no North Carolina state-specific regulations for red snapper. North Carolina has complemented federal regulations for all snapper grouper species via proclamation authority since 1991. Between 1992 and 2005, species-specific regulations were added to the proclamation authority contained in rule 15A NCAC 03M .0506. In 2002, North Carolina adopted its Inter-Jurisdictional Fishery Management Plan (IJ FMP), which incorporates all Atlantic States Marine Fisheries Commission and Council-managed species by reference, and adopts all federal regulations as minimum standards for management. In completing the 2008 update to the IJ FMP, all species-specific regulations were removed from rule 15A NCAC 03M .0506, and proclamation authority to implement changes in management was moved to rule 15A NCAC 03M .0512. Since this time, all snapper grouper regulations have been contained in a single proclamation, which is updated anytime an opening/closing of a particular species in the complex occurs, as well as any changes in allowable gear, required permits, etc. Beginning in 2015, commercial and recreational regulations are contained in separate proclamations. The most current snapper grouper proclamations (and all previous versions) can be found using this link: http://portal.ncdenr.org/web/mf/proclamations.

15A NCAC 03M .0506 SNAPPER-GROUPER COMPLEX

(a) In the Atlantic Ocean, it is unlawful for an individual fishing under a Recreational Commercial Gear License with seines, shrimp trawls, pots, trotlines or gill nets to take any species of the Snapper-Grouper complex.

(b) The species of the snapper-grouper complex listed in the South Atlantic Fishery Management Council Fishery Management Plan for the Snapper-Grouper Fishery of the South Atlantic Region are hereby incorporated by reference and copies are available via the Federal Register posted on the Internet at www.safmc.net and at the Division of Marine Fisheries, P.O. Box 769, Morehead City, North Carolina 28557 at no cost.

History Note: Authority G.S. 113-134; 113-182; 113-221; 143B-289.52;
Eff. January 1, 1991;
Amended Eff. April 1, 1997; March 1, 1996; September 1, 1991;
Temporary Amendment Eff. December 23, 1996;
Amended Eff. August 1, 1998; April 1, 1997;
Temporary Amendment Eff. January 1, 2002; August 29, 2000; January 1, 2000; May 24, 1999;
Amended Eff. October 1, 2008; May 1, 2004; July 1, 2003; April 1, 2003; August 1, 2002.

15A NCAC 03M .0512 COMPLIANCE WITH FISHERY MANAGEMENT PLANS
(a) In order to comply with management requirements incorporated in Federal Fishery Management Council Management Plans or Atlantic States Marine Fisheries Commission Management Plans or to implement state management measures, the Fisheries Director may, by proclamation, take any or all of the following actions for species listed in the Interjurisdictional Fisheries Management Plan:
(1) Specify size;
(2) Specify seasons;
(3) Specify areas;
(4) Specify quantity;
(5) Specify means and methods; and
(6) Require submission of statistical and biological data.
(b) Proclamations issued under this Rule shall be subject to approval, cancellation, or modification by the Marine Fisheries Commission at its next regularly scheduled meeting or an emergency meeting held pursuant to G.S. 113-221.1.
History Note: Authority G.S. 113-134; 113-182; 113-221; 113-221.1; 143B-289.4;
Eff. March 1, 1996;
Amended Eff. October 1, 2008.

South Carolina:
Sec. 50-5-2730 of the SC Code states:
"Unless otherwise provided by law, any regulations promulgated by the federal government under the Fishery Conservation and Management Act (PL94-265) or the Atlantic Tuna Conservation Act (PL 94-70) which establishes seasons, fishing periods, gear restrictions, sales restrictions, or bag, catch, size, or possession limits on fish are declared to be the law of this State and apply statewide including in state waters."

As such, South Carolina red snapper regulations are (and have been) pulled directly from the federal regulations as promulgated under the Magnuson-Stevens Fishery Conservation and Management Act. There are no know separate red snapper regulations that have been codified in the South Carolina Code.

Georgia:
Georgia state regulations for red snapper are currently:
- 2 fish per person daily creel limit
- 20 inch TL minimum size limit
- Season open year round

The law with these measures was originally enacted on July 1, 1989 with regulations following on September 13, 1989. The Official Code of Georgia Annotated (O.C.G.A.) and regulations sections have changed over time, but management measures have not. The current regulations are found in O.C.G.A 27-4-10 and DNR Rule 391-2-4-.04. Both documents are available upon request.

Florida:

Florida Atlantic Red Snapper Regulatory History

Year	Size Limit	Possession Limit	Other Regulation Changes
1985	12” TL		
1986	12” TL	10 per person per day aggregate snapper bag limit; off-the-water possession limit of 20 per person	Commercial longline gear prohibited; stab or sink nets prohibited off Monroe county; 5% of grouper in possession may be smaller than minimum size; all snappers must be landed in whole condition.
1987	12” TL	“	
1988	12” TL	“	
1989	12” TL	“	
1990	13” TL	2 per person per day within the 10 snapper aggregate; off-the-water possession limit of 4 red snapper	Red snapper designated as a protected species; Hook and line, black sea bass trap, spear, gig, or lance defined as allowable gear; off the water possession limit of 4 red snapper per recreational angler; commercial harvest of any species of snapper is prohibited in state waters if harvest of that species is prohibited in adjacent federal waters.
1991	13” TL	“	
1992	20” TL	“	
1993	20” TL	“	
1994	20” TL	“	Allows a two-day possession limit for reef fish statewide for persons aboard charter and headboats on trips exceeding 24 hours provided the vessel has a permanent berth for each passenger and each passenger has a receipt verifying the length of the trip.

1995	20" TL	"	
1996	20" TL	"	
1997	20" TL	"	
1998	20" TL	"	
1999	20" TL	"	
2000	20" TL	"	
2001	20" TL	"	
2002	20" TL	"	
2003	20" TL	"	Imported reef fish must comply with Florida's minimum size limits; red snapper removed as a protected species.
2004	20" TL	"	
2005	20" TL	"	
2006	20" TL	"	
2007	20" TL	"	Sets commercial trip limits in Florida's Atlantic state waters to be the same as commercial trip limits in adjacent federal waters.
2008	20" TL	"	
2009	20" TL	"	
2010	20" TL	"	Requires use of dehooking tools for all Atlantic reef fish.
2011	20" TL	"	
2012	20" TL	"	
2013	20" TL	"	
2014	20" TL	"	

[1985]

SNAPPER, CH 46-14, F.A.C. (Effective July 29, 1985)

- Implements 12 inch minimum size limits for red snapper, mutton snapper, and yellowtail snapper

[1986]

REEF FISH, CH 46-14, F.A.C. (Effective December 11, 1986)

- Establishes snapper bag limit: 10 per person daily, with an off-the-water possession limit of 20 per person, for any combination of snapper, excluding lane, vermillion, and yelloweye

- Prohibits the use of long line gear in state waters for harvesting snapper, but allowed a 5% bycatch allowance under specific circumstances
- Prohibits use of stab nets (or sink nets) to take snapper in Atlantic waters of Monroe County
- Allows 5% of snapper in possession of harvester to be smaller than the minimum size limit
- Must be landed in whole condition (head and tail intact)

[1990]

REEF FISH, CH 46-14, F.A.C. (Effective February 1, 1990)

- Designates all **snapper** as "restricted species"
- Designates **red snapper** as protected species
- Establishes minimum size limits:
    - Red snapper - 13 inches
- Recreational bag limits: 10 daily per person for any combination of snapper, not including lane and vermillion (no more than 5 may be gray/mangrove snapper and no more than 2 may be red snapper)
- Off-the-water recreational possession limits: 20 per person for any combination of snapper, not including lane and vermillion (no more than 10 may be gray/mangrove snapper and no more than 4 may be red snapper)
- Establishes the following allowable gear: Hook and line, black sea bass trap, spear, gig, or lance (except powerheads, bangsticks, or explosive devices) for snapper
- Prohibits all commercial harvest of any species of snapper in state waters whenever harvest of that species is prohibited in adjacent federal waters
- Requires snapper to be landed in whole condition

[1992]

REEF FISH, CH 46-14, F.A.C. (Effective December 31, 1992)

- Requires the appropriate federal permit in order to exceed **snapper/grouper** bag limits and to purchase or sell snapper/grouper on the state's Gulf coast
- Establishes a minimum size limit of 20 inches for **red snapper** on the state's Atlantic coast

[1994]

REEF FISH, CH 46-14, F.A.C. (Effective March 1, 1994)

- Allows a two-day possession limit for reef fish statewide for persons aboard charter and headboats on trips exceeding 24 hours provided that the vessel is equipped with a permanent berth for each passenger aboard, and each passenger has a receipt verifying the trip length

[2003]

REEF FISH, CH 68B-14, F.A.C. (Effective January 1, 2003)

- Clarifies that imported reef fishes must comply with Florida's legal minimum size limits
- Deletes the rule designation of **red snapper** as protected species

[2007]

REEF FISH, CH 68B-14, F.A.C. (Effective July 1, 2007)

- Sets commercial trip limits in the Atlantic that are the same as trip limits in federal waters

[2010]

REEF FISH, CH 68B-14, F.A.C. (Effective January 19, 2010)

- Requires dehooking tools to be aboard commercial and recreational vessels for anglers to use as needed to remove hooks from Atlantic reef fish

References

None provided.

3. Assessment History and Review

In the early 1990s, a series of reports were prepared by the SAFMC Plan Development Team (in 1990) and by the NOAA-Beaufort Reef Fish Team (in 1991 and 1992), intended for prioritizing stocks for assessment. Those reports described "snapshot" analyses conducted on several snapper-grouper species, including red snapper. The analyses included the estimation of SPR (spawning potential ratio) based on a single year of data.

The first formal assessment of red snapper in the U.S. Atlantic was conducted by Manooch et al. (1998; abstract below). In that assessment, two age-structured models were used: an un-calibrated separable VPA and FADAPT. The results from FADAPT were downplayed because the model was calibrated to an abundance index derived from MARMAP chevron trap data, which had very low sample sizes. Manooch et al. (1998) concluded that "the status is less than desirable, but does appear to be responsive to recent management actions." They found that the fishing mortality rate (F) should be reduced by 33% to 68%, depending on the natural mortality rate and desired SPR. Prior to publication, a report of that assessment was submitted to the SAFMC. After publication, the results were revisited by Potts and Brennan (2001) in a trends report, also prepared for the SAFMC. Potts and Brennan (2001) repeated the findings of Manooch et al. (1998), but suggested a broader range of reduction in F, from 30% to 80%.

This stock of red snapper was first assessed through the SEDAR process in 2007 (SEDAR review held Jan. 28 – Feb. 1, 2008). That assessment applied a statistical catch-age model using data through 2006 (SEDAR 15, 2008). Because the spawner-recruit parameter of steepness was not estimable (hit its upper bound), the SEDAR review panel recommended using proxies for MSY-related benchmarks based on $SPR_{40\%}$. Relative to those benchmarks, the assessment found that since the 1960s, overfishing had been occurring and the stock had been overfished. In the terminal year, the assessment estimated $F_{2006}/F_{40\%}=7.7$ and $SSB_{2006}/SSB_{F40\%}=0.03$. Although quantitative results varied, these qualitative results of overfishing a depleted stock were consistent across all catch-age model configurations examined during and after the assessment process (~40 sensitivity runs), as well as with an alternative model formulation (surplus-production model). SEDAR24–AW–012.

SEDAR 24 (concluded October, 2010) was a benchmark assessment using the Beaufort Assessment Model (BAM) with data through 2009. BAM is a statistical catch-age model developed by the analysts at the Beaufort, NC NMFS laboratory, and is customizable to the data available. A surplus production model called ASPIC (Prager 1994, Prager 2004) was used as a complement for comparison purposes. Based on the assessment provided from the BAM, the Review Panel concluded that the stock was overfished with overfishing occurring. The SSB in the terminal year was estimate to be about 9% of MSST ($SSB_{2009}/MSST = 0.09$) and the fishing level at more than four times F_{MSY} ($F_{2007\text{-}2009}/F_{MSY} = 4.12$). Similar to SEDAR 15, more than 40 sensitivities were run, all of which resulted in the same status determinations.

References

Manooch, C.S., III, J.C. Potts, D.S. Vaughan, and M.L. Burton. 1998. Population assessment of the red snapper from the southeastern United States. Fisheries Research 38:19–32.

Potts, J.C. and K. Brennan. 2001. Trends in catch data and estimated static SPR values for fifteen species of reef fish landed along the southeastern United States. Report prepared for SAFMC.

Prager, M. H. 1994. A suite of extensions to a nonequilibrium surplus–production model. Fishery Bulletin 92: 374–389.

Prager, M. H., 2004. User's Manual for ASPIC: A Stock-Production Model Incorporating Covariates (ver.5) And Auxiliary Programs. National Marine Fisheries Service Beaufort Laboratory Document BL-2004-01, 1-25.

SEDAR. 2008. SEDAR 15 - Stock assessment report (SAR 1) South Atlantic red snapper. SEDAR, North Charleston, SC. 511 p. Available online at http://www.sefsc.noaa.gov/sedar/download/S15%20SAR%201%20Revised%203-09.pdf?id=DOCUMENT

SEDAR. 2010. SEDAR 24 - Stock assessment report South Atlantic Red Snapper. 524 p. Available at http://www.sefsc.noaa.gov/sedar/download/SEDAR%2024_SAR_October%202010_26.pdf?id=DOCUMENT

Abstract from Manooch et al. (1998): Changes in the age structure and population size of red snapper, ***Lutjanus campechanus***, from North Carolina through the Florida Keys were examined using records of landings and size frequencies of fish from commercial, recreational, and headboat fisheries from 1986 to 1995. Population size in numbers at age was estimated for each year by applying separable virtual population analysis (SVPA) to the landings in numbers at age. SVPA was used to estimate annual, age- specific fishing mortality (***F***) for four levels of natural mortality (***M***=0.15, 0.20, 0.25, and 0.30). Although landings of red snapper for the three fisheries have declined, minimum fish size regulations have also resulted in an increase in the mean size of red snapper landed. Age at entry and age at full recruitment were age-1 for 1986-1991, compared with age-2 and age-6, respectively, for 1992-1995. Levels of mortality from fishing (***F***) ranged from 0.31 to 0.69 for the entire period. Spawning potential ratio (SPR) increased from 0.09 to 0.24 (***M***=0.25) from 1986 to 1995. The SPR level could be improved with a decrease in ***F***, or an increase in age at entry to the fisheries. The latter could be enhanced now if fishermen, particularly recreational fishermen, comply with minimum size regulations.

4. Regional Maps

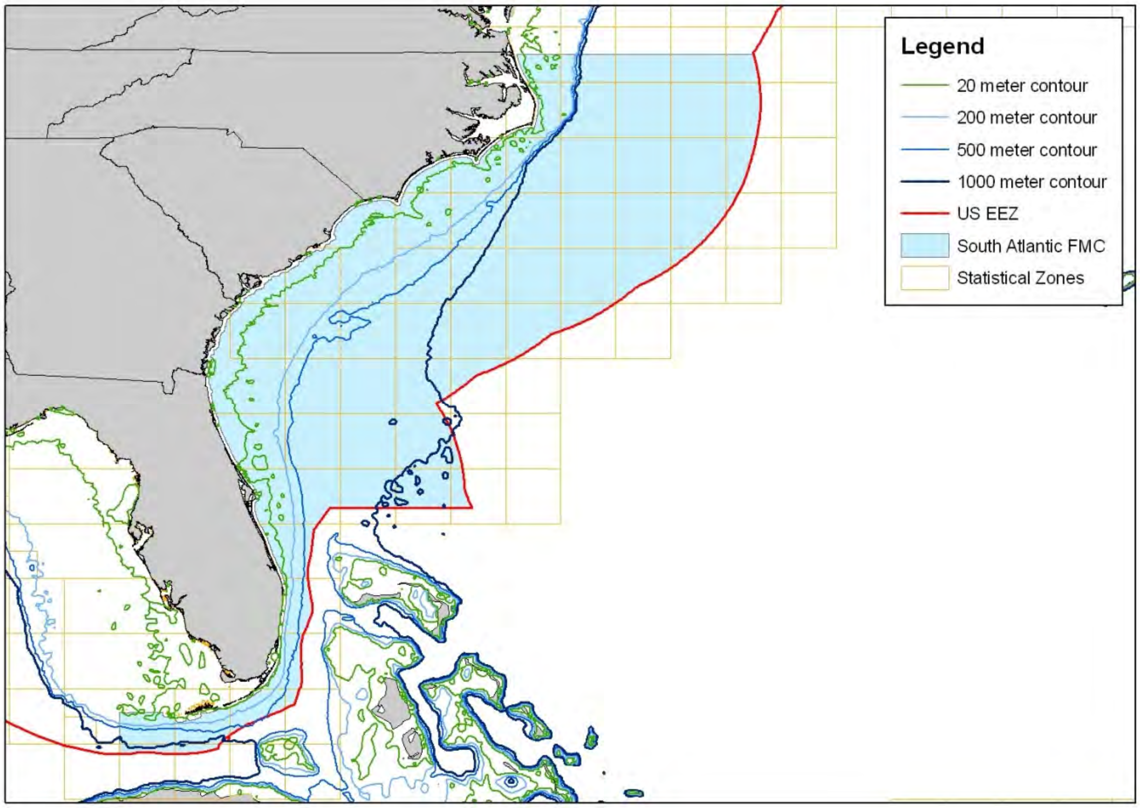

Figure 4.1: South Atlantic Fishery Management Council and EEZ boundaries.

5. SEDAR Abbreviations

APAIS	Access Point Angler Intercept Survey
ABC	Allowable Biological Catch
ACCSP	Atlantic Coastal Cooperative Statistics Program
ADMB	AD Model Builder software program
ALS	Accumulated Landings System; SEFSC fisheries data collection program
AMRD	Alabama Marine Resources Division
ASMFC	Atlantic States Marine Fisheries Commission
B	stock biomass level

BAM	Beaufort Assessment Model
BMSY	value of B capable of producing MSY on a continuing basis
CFMC	Caribbean Fishery Management Council
CIE	Center for Independent Experts
CPUE	catch per unit of effort
EEZ	exclusive economic zone
F	fishing mortality (instantaneous)
FMSY	fishing mortality to produce MSY under equilibrium conditions
FOY	fishing mortality rate to produce Optimum Yield under equilibrium
FXX% SPR	fishing mortality rate that will result in retaining XX% of the maximum spawning production under equilibrium conditions
FMAX	fishing mortality that maximizes the average weight yield per fish recruited to the fishery
F0	a fishing mortality close to, but slightly less than, Fmax
FL FWCC	Florida Fish and Wildlife Conservation Commission
FWRI	(State of) Florida Fish and Wildlife Research Institute
GA DNR	Georgia Department of Natural Resources
GLM	general linear model
GMFMC	Gulf of Mexico Fishery Management Council
GSMFC	Gulf States Marine Fisheries Commission
GULF FIN	GSMFC Fisheries Information Network
HMS	Highly Migratory Species
LDWF	Louisiana Department of Wildlife and Fisheries
M	natural mortality (instantaneous)
MARMAP	Marine Resources Monitoring, Assessment, and Prediction
MDMR	Mississippi Department of Marine Resources
MFMT	maximum fishing mortality threshold, a value of F above which overfishing is deemed to be occurring
MRFSS	Marine Recreational Fisheries Statistics Survey; combines a telephone survey of households to estimate number of trips with creel surveys to estimate catch and effort per trip
MRIP	Marine Recreational Information Program

MSST	minimum stock size threshold, a value of B below which the stock is deemed to be overfished
MSY	maximum sustainable yield
NC DMF	North Carolina Division of Marine Fisheries
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
OY	optimum yield
SAFMC	South Atlantic Fishery Management Council
SAS	Statistical Analysis Software, SAS Corporation
SC DNR	South Carolina Department of Natural Resources
SEAMAP	Southeast Area Monitoring and Assessment Program
SEDAR	Southeast Data, Assessment and Review
SEFIS	Southeast Fishery-Independent Survey
SEFSC	Fisheries Southeast Fisheries Science Center, National Marine Fisheries Service
SERO	Fisheries Southeast Regional Office, National Marine Fisheries Service
SPR	spawning potential ratio, stock biomass relative to an unfished state of the stock
SSB	Spawning Stock Biomass
SSC	Science and Statistics Committee
TIP	Trip Incident Program; biological data collection program of the SEFSC and Southeast States.
TPWD	Texas Parks and Wildlife Department
Z	total mortality, the sum of M and F

SEDAR

Southeast Data, Assessment, and Review

SEDAR 41

South Atlantic Red Snapper

SECTION II: Data Workshop Report

September 12, 2015

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

1. Introduction

1.1 Workshop Time and Place

The initial SEDAR 41 Data Workshop (DW) was held August 4 – 8, 2014 in Charleston, South Carolina. A data scoping call was held May 28, 2014 and webinars were held July 2, 2014, August 15, 2014 September 11, 2014, and September 26, 2014.

A working paper submitted after the DW questioned the validity of data collected during the early years of the Southeast Region Headboat Survey (SRHS). The Data Workshop Panel discussed this issue on a post-DW webinar and recommended stopping the SEDAR 41 assessments for both species to investigate the headboat issues and delaying both assessments until the issues are resolved. The SAFMC and SEDAR Steering Committee were briefed on this recommendation in fall 2014. A new schedule was approved in December 2014 delaying the assessment approximately one year and the terminal year of the assessment was changed to 2014.

The second abbreviated DW was held August 4-6, 2015 in Charleston, SC. This workshop built on the work done at the 2014 DW, revisiting decisions only if new information or analyses were available. Otherwise datasets were updated with 2014 data using decisions from the 2014 DW. Two data webinars were held before the workshop on April 15 and July 1, 2015 and a post-DW webinar was held August 20, 2015.

Between the 2014 and 2015 DW's, the Southeast Fisheries Science Center conducted a headboat data evaluation and submitted a working paper (SEDAR41-DW46) for review at the 2015 DW.

1.2 Terms of Reference

1. Review stock structure and unit stock definitions and consider whether changes are required.
2. Review, discuss, and tabulate available life history information.
    - Evaluate age, growth, natural mortality, and reproductive characteristics.
    - Provide appropriate models to describe growth, maturation, and fecundity by age, sex, or length as applicable.
    - Evaluate the adequacy of available life-history information for conducting stock assessments and recommend life history information for use in population modeling.
    - Evaluate, discuss, and characterize the sources of uncertainty, and data limitations (such as temporal and spatial coverage) for each data source. Provide ranges and/or distributions of uncertainty for data sources used in the stock assessment models[1].

3. Compare and contrast life history traits between the Gulf of Mexico and South Atlantic stocks.
4. Recommend discard mortality rates.
   - Review available research and published literature.
   - Consider research directed at these species as well as similar species from the SE and other areas.
   - Provide estimates of discard mortality rate by fishery, gear type, depth, and other feasible or appropriate strata.
   - Include thorough rationale for recommended discard mortality rates.
   - Provide justification for any recommendations that deviate from the range of discard mortality provided in the last benchmark or other prior assessment.
   - Evaluate, discuss, and characterize the sources of uncertainty, and data limitations (such as temporal and spatial coverage) for each data source. Provide ranges and/or distributions of uncertainty for data sources used in the stock assessment models[1].
5. Provide measures of population abundance that are appropriate for stock assessment.
   - Consider and discuss all available and relevant fishery dependent and independent data sources.
   - Document all programs evaluated; address program objectives, methods, coverage, sampling intensity, and other relevant characteristics.
   - Provide maps of fishery and survey coverage.
   - Develop fishery and survey CPUE indices by appropriate strata (e.g., age, size, area, and fishery) and include measures of precision and accuracy.
   - Discuss the degree to which available indices adequately represent fishery and population conditions.
   - Recommend which data sources adequately and reliably represent population abundance for use in assessment modeling.
   - Evaluate, discuss, and characterize the sources of uncertainty, and data limitations (such as temporal and spatial coverage) for each data source. Provide ranges and/or distributions of uncertainty for data sources used in the stock assessment models[1].
   - Complete the SEDAR index evaluation worksheet for each index considered.
   - Rank the available indices with regard to their reliability and adequacy for use in assessment modeling.
6. Provide commercial catch statistics, including both landings and discards in both pounds and number.

- Evaluate and discuss the adequacy of available data for accurately characterizing harvest and discard by species and fishery sector or gear.
- Evaluate, discuss, and characterize the sources of uncertainty, and data limitations (such as temporal and spatial coverage) for each data source. Provide ranges and/or distributions of uncertainty for data sources used in the stock assessment models[1].
- Provide length and age distributions for both landings and discards if feasible.
- Provide maps of fishery effort and harvest by species and fishery sector or gear.

7. Provide recreational catch statistics, including both landings and discards in both pounds and number.
   - Evaluate and discuss the adequacy of available data for accurately characterizing harvest and discard by species and fishery sector or gear.
   - Evaluate, discuss, and characterize the sources of uncertainty, and data limitations (such as temporal and spatial coverage) for each data source. Provide ranges and/or distributions of uncertainty for data sources used in the stock assessment models[1].
   - Provide length and age distributions for both landings and discards if feasible.
   - Provide maps of fishery effort and harvest by species and fishery sector or gear.
8. Provide recommendations for future research in areas such as sampling, fishery monitoring, and stock assessment. Include specific guidance on sampling intensity (number of samples including age and length structures) and appropriate strata and coverage.
9. Prepare the Data Workshop report providing complete documentation of workshop actions and decisions in accordance with project schedule deadlines (Section II. of the SEDAR assessment report).

[1.] In providing ranges for uncertain or incomplete information, data workshop groups should consider and distinguish between those ranges and bounds that represent probable values (i.e., likely alternative states) to be included in structured uncertainty analyses, and those that represent extreme values to be considered in evaluating model performance through sensitivity analyses.

1.3 List of Participants

2014 Data Workshop Panelists

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* Appointees marked with an * were appointed to the workshop panel but did not attend the workshop. They provided data and reviewed the use of the data, and were available via email or phone for questions as needed.

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1.4 List of Data Workshop Working Papers

South Atlantic red snapper and gray triggerfish data workshop document list. Working papers that were updated from the 2014 DW or were new for the 2015 DW are labeled as such.

Document #	Title	Authors
	Documents Prepared for the Data Workshop (DW)	
SEDAR41-DW01	**UPDATED:** Georgia Headboat Red Snapper Catch and Effort Data, 1983-2013	Amick and Knowlton 2014
SEDAR41-DW02	**UPDATED:** Georgia Red Snapper Catch & Effort Collection during Mini-Seasons, 2012-2014	Knowlton 2015
SEDAR41-DW03	Standardized video counts of Southeast U.S. Atlantic gray triggerfish (*Balistes capriscus*) from the Southeast Reef Fish Survey ****See SEDAR41-DW44 for index updated through 2014**	Purcell et al. 2014
SEDAR41-DW04	Standardized video counts of Southeast U.S. Atlantic red snapper (*Lutjanus campechanus*) from the Southeast Reef Fish Survey ****See SEDAR41-DW45 for index updated through 2014**	Purcell et al. 2014
SEDAR41-DW05	Gray Triggerfish Fishery-Independent Indices of Abundance in US South Atlantic Waters Based on a Chevron Trap Survey	Ballenger et al. 2014

	****See SEDAR41-DW52 for index recommended from 2015 DW**	
SEDAR41-DW06	Red Snapper Fishery-Independent Indices of Abundance in US South Atlantic Waters Based on a Chevron Trap Survey ****See SEDAR41-DW53 and SEDAR41-DW54 for index recommendations from 2015 DW**	Ballenger et al. 2014
SEDAR41-DW07	Age Truncation and Reproductive Resilience of Red Snapper (*Lutjanus campechanus*) Along the East Coast of Florida **(has since been published – see SEDAR41-RD57)**	Lowerre-Barbieri et al. 2014
SEDAR41-DW08	The utility of a hooked gear survey in developing a fisheries-independent index of abundance for red snapper along Florida's Atlantic coast	Guenther et al. 2014
SEDAR41-DW09	Size and age composition of red snapper, *Lutjanus campechanus*, collected in association with fishery-independent and fishery-dependent projects off of Florida's Atlantic coast during 2012 and 2013	Switzer et al. 2014
SEDAR41-DW10	Overview of Florida's Cooperative East Coast Red Snapper Tagging Program, 2011-2013	Brodie et al. 2014
SEDAR41-DW11	Habitat models for Gray Triggerfish collected in fishery-independent trap surveys off the southeastern United States	Muhling et al. 2014
SEDAR41-DW12	**UPDATED:** Preliminary standardized catch rates of Southeast US Atlantic red snapper (*Lutjanus campechanus*) from headboat logbook data	SFB-NMFS 2015
SEDAR41-DW13	**UPDATED:** Preliminary standardized catch rates of Southeast US Atlantic gray triggerfish (*Balistes capriscus*) from headboat logbook data	SFB-NMFS 2015
SEDAR41-DW14	**UPDATED:** Standardized catch rates of red snapper (*Lutjanus campechanus*) from headboat at-sea-observer data	SFB-NMFS 2015
SEDAR41-DW15	Standardized catch rates of gray triggerfish (*Balistes capriscus*) from headboat at-sea-observer data	SFB-NMFS 2014
SEDAR41-DW16	**UPDATED:** Report on Life History of South Atlantic Gray Triggerfish, *Balistes capriscus*, from Fishery-Independent Sources	Kolmos et al. 2015
SEDAR41-DW17	**UPDATED:** Estimates of Historic Recreational	Brennan 2015

	Landings of Red Snapper in the South Atlantic Using the FHWAR Census Method	
SEDAR41-DW18	**UPDATED**: South Carolina Red Snapper Catch and Biological Data Collection during Mini-Seasons, 2012-2014	Dukes & Hiltz 2015
SEDAR41-DW19	**UPDATED**: Standardized catch rates of red snapper (*Lutjanus campechanus*) in the southeast U.S. from commercial logbook data	SFB-NMFS 2015
SEDAR41-DW20	**UPDATED**: Standardized catch rates of gray triggerfish (*Balistes capriscus*) in the southeast U.S. from commercial logbook data	SFB-NMFS 2015
SEDAR41-DW21	North Carolina Division of Marine Fisheries Red Snapper Carcass Collections, 2012-2013	NCDMF 2014
SEDAR41-DW22	SEDAR 41 Red snapper stock assessment must utilize “direct” estimates of gear selectivity	Barile and Nelson 2014
SEDAR41-DW23	Atlantic Red Snapper (*Lutjanus campechanus*) Fishing History Timeline	Hudson 2014
SEDAR41-DW24	Atlantic Red Snapper (*Lutjanus campechanus*) Historical Fishing Pictures	Hudson 2014
SEDAR41-DW25	Historical For-Hire Fishing Vessels: South Atlantic Fishery Management Council, 1930’s to 1985	Hudson 2014
SEDAR41-DW26	SEDAR 41 Atlantic Red Snapper and Gray Triggerfish Data Workshop Historical Photographs of For-Hire Vessels 1930’s to 1985	Hudson 2014
SEDAR41-DW27	Red snapper mini season ad-hoc working group report	Red Snapper Mini Season Ad-hoc Group 2014
SEDAR41-DW28	Red Snapper *Lutjanus campechanus* in Gulf of Mexico versus southeast US Atlantic Ocean waters: gaps in knowledge and implications for management	Rindone et al. 2014
SEDAR41-DW29	Discards of red snapper (*Lutjanus campechanus*) for the headboat fishery in the US South Atlantic ****See SEDAR41-AW01 for updated HB discards WP**	FEB-NMFS 2014
SEDAR41-DW30	Discards of gray triggerfish (*Balistes capriscus*) for the headboat fishery in the US South Atlantic ****See SEDAR41-AW02 for updated HB discards WP**	FEB-NMFS 2014

SEDAR41-DW31	Red Snapper Preliminary Genetic Analysis Temporal Genetic Diversity Trends in the South Atlantic Bight	O'Donnell and Darden 2014
SEDAR41-DW32	SCDNR Charterboat Logbook Program Data, 1993-2013	Hiltz 2014
SEDAR41-DW33	**UPDATED:** Size Distribution, Release Condition, and Estimated Discard Mortality of Red Snapper Observed in For-Hire Recreational Fisheries in the South Atlantic	Sauls et al. 2015
SEDAR41-DW34	**UPDATED:** Size Distribution, Release Condition, and Estimated Discard Mortality of Gray Triggerfish Observed in For-Hire Recreational Fisheries in the South Atlantic	Sauls et al. 2015
SEDAR41-DW35	**UPDATED:** Marine Resources Monitoring, Assessment and Prediction Program: Report on Atlantic Red Snapper, *Lutjanus campechanus*, Life History for the SEDAR 41 Data Workshop	White et al. 2014 Wyanski et al. 2015
SEDAR41-DW36	**UPDATED:** Discards of Red Snapper Calculated for Commercial Vessels with Federal Fishing Permits in the US South Atlantic	McCarthy 2015
SEDAR41-DW37	**UPDATED:** Calculated Discards of Gray Triggerfish from US South Atlantic Commercial Fishing Vessels	McCarthy 2015
SEDAR41-DW38	Historic catch of red snapper by headboats through historic photograph analysis	Gray et al. 2014
SEDAR41-DW39	Index report cards	Index Working Group 2014
SEDAR41-DW40	Problems with Headboat Index of Abundance Confounds Use in SEDAR 41 Red Snapper	Nelson et al. 2014
SEDAR41-DW41	Commercial Fishing Targeting Changes	Fex 2014
SEDAR41-DW42	**NEW:** South Atlantic Red Snapper (*Lutjanus campechanus*) monitoring in Florida: Revised recreational private boat mode estimates for 2012 and 2013 mini-seasons, and new private boat mode estimates for the 2014 mini-season	Sauls 2015
SEDAR41-DW43	**NEW:** Hook Selectivity in gray triggerfish observed in the for-hire fishery off the Atlantic coast of Florida	Gray and Sauls 2015
SEDAR41-DW44	**NEW:** Standardized video counts of Southeast U.S. Atlantic gray triggerfish (*Balistes capriscus*)	Ballew et al. 2015

	from the Southeast Reef Fish Survey	
SEDAR41-DW45	**NEW:** Standardized video counts of Southeast U.S. Atlantic red snapper (*Lutjanus campechanus*) from the Southeast Reef Fish Survey	Ballew et al. 2015
SEDAR41-DW46	**NEW:** Headboat Data Evaluation	NMFS-SEFSC 2015
SEDAR41-DW47	**NEW:** Development of an ageing error matrix for U.S. gray triggerfish *(Balistes capriscus)*	SFB-NMFS 2015
SEDAR41-DW48	**NEW:** Development of an ageing error matrix for U.S. red snapper *(Lutjanus campechanus)*	SFB-NMFS 2015
SEDAR41-DW49	**NEW:** Estimates of reproductive activity in red snapper by size, season, and time of day with nonlinear models	Klibansky 2015
SEDAR41-DW50	**NEW:** Hook Selectivity in red snapper observed in the for-hire fishery off the Atlantic coast of Florida	Gray and Sauls 2015
SEDAR41-DW51	**NEW:** SERFS Chevron Trap Red Snapper Index of Abundance: An Investigation of the Utility of Historical (1990-2009) Chevron Trap Catch Data	Ballenger 2015
SEDAR41-DW52	**NEW:** Gray Triggerfish Fishery-Independent Index of Abundance in US South Atlantic Waters Based on a Chevron Trap Survey (1990-2014)	Ballenger and Smart 2015
SEDAR41-DW53	**NEW:** Red Snapper Fishery-Independent Index of Abundance in US South Atlantic Waters Based on a Chevron Trap Survey (2005-2014)	Ballenger and Smart 2015
SEDAR41-DW54	**NEW:** Red Snapper Fishery-Independent Index of Abundance in US South Atlantic Waters Based on a Chevron Trap Survey (2010-2014)	Ballenger and Smart 2015
Reference Documents		
SEDAR41-RD01	List of documents and working papers for SEDAR 32 (South Atlantic Blueline Tilefish and Gray Triggerfish) – all documents available on the SEDAR website.	SEDAR 32
SEDAR41-RD02	List of documents and working papers for SEDAR 9 (Gulf of Mexico Gray Triggerfish, Greater Amberjack, and Vermilion Snapper) – all documents available on the SEDAR website.	SEDAR 9
SEDAR41-RD03	2011 Gulf of Mexico Gray Triggerfish Update Assessment	SEDAR 2011
SEDAR41-RD04	List of documents and working papers for SEDAR 24 (South Atlantic red snapper) – all documents	SEDAR 24

	available on the SEDAR website.	
SEDAR41-RD05	List of documents and working papers for SEDAR 31 (Gulf of Mexico red snapper) – all documents available on the SEDAR website.	SEDAR 31
SEDAR41-RD06	List of documents and working papers for SEDAR 15 (South Atlantic red snapper and greater amberjack) – all documents available on the SEDAR website.	SEDAR 15
SEDAR41-RD07	2009 Gulf of Mexico red snapper update assessment	SEDAR 2009
SEDAR41-RD08	List of documents and working papers for SEDAR 7 (Gulf of Mexico red snapper) – all documents available on the SEDAR website.	SEDAR 7
SEDAR41-RD09	SEDAR 24 South Atlantic Red Snapper: management quantities and projections requested by the SSC and SERO	NMFS - Sustainable Fisheries Branch 2010
SEDAR41-RD10	Total removals of red snapper (*Lutjanus campechanus*) in 2012 from the US South Atlantic	NMFS - Sustainable Fisheries Branch 2013
SEDAR41-RD11	Amendment 17A to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region	SAFMC 2010
SEDAR41-RD12	Amendment 28 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region	SAFMC 2013
SEDAR41-RD13	Total removals of red snapper (*Lutjanus campechanus*) in 2013 from the U.S. South Atlantic	NMFS - Sustainable Fisheries Branch 2014
SEDAR41-RD14	South Atlantic red snapper (*Lutjanus campechanus*) monitoring in Florida for the 2012 season	Sauls et al. 2013
SEDAR41-RD15	South Atlantic red snapper (*Lutjanus campechanus*) monitoring in Florida for the 2013 season	Sauls et al. 2014
SEDAR41-RD16	A directed study of the recreational red snapper fisheries in the Gulf of Mexico along the West Florida shelf	Sauls et al. 2014
SEDAR41-RD17	Using generalized linear models to estimate selectivity from short-term recoveries of tagged red drum *Sciaenops ocellatus*: Effects of gear,	Bacheler et al. 2009

	fate, and regulation period	
SEDAR41-RD18	Direct estimates of gear selectivity from multiple tagging experiments	Myers and Hoenig 1997
SEDAR41-RD19	Examining the utility of alternative video monitoring metrics for indexing reef fish abundance	Schobernd et al. 2014
SEDAR41-RD20	An evaluation and power analysis of fishery independent reef fish sampling in the Gulf of Mexico and U.S. South Atlantic	Conn 2011
SEDAR41-RD21	Consultant's Report: Summary of the MRFSS/MRIP Calibration Workshop	Boreman 2012
SEDAR41-RD22	2013 South Atlantic Red Snapper Annual Catch Limit and Season Length Projections	SERO 2013
SEDAR41-RD23	Southeast Reef Fish Survey Video Index Development Workshop	Bacheler and Carmichael 2014
SEDAR41-RD24	Observer Coverage of the 2010-2011 Gulf of Mexico Reef Fish Fishery	Scott-Denton and Williams
SEDAR41-RD25	Circle Hook Requirements in the Gulf of Mexico: Application in Recreational Fisheries and Effectiveness for Conservation of Reef Fishes	Sauls and Ayala 2012
SEDAR41-RD26	GADNR Marine Sportfish Carcass Recovery Project	Harrell 2013
SEDAR41-RD27	Catch Characterization and Discards within the Snapper Grouper Vertical Hook-and-Line Fishery of the South Atlantic United States	Gulf and South Atlantic Fisheries Foundation 2008
SEDAR41-RD28	A Continuation of Catch Characterization and Discards within the Snapper Grouper Vertical Hook-and-Line Fishery of the South Atlantic United States	Gulf and South Atlantic Fisheries Foundation 2010
SEDAR41-RD29	Continuation of Catch Characterization and Discards within the Snapper Grouper Vertical Hook-and-Line Fishery of the South Atlantic United States	Gulf and South Atlantic Fisheries Foundation 2013
SEDAR41-RD30	Amendment 1 and Environmental Assessment and Regulatory Impact Review to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region	SAFMC 1988
SEDAR41-RD31	Final Rule for Amendment 1 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region	Federal Register 1989

SEDAR41-RD32	Population Structure and Genetic Diversity of Red Snapper (Lutjanus campechanus) in the U.S. South Atlantic and Connectivity with Red Snapper in the Gulf of Mexico	Gold and Portnoy 2013
SEDAR41-RD33	Oogenesis and fecundity type of Gulf of Mexico gray triggerfish reflects warm water environmental and parental care	Lang and Fitzhugh 2014
SEDAR41-RD34	Depth-related Distribution of Postjuvenile Red Snapper in Southeastern U.S. Atlantic Ocean Waters: Ontogenetic Patterns and Implications for Management	Mitchell et al. 2014
SEDAR41-RD35	Gray Triggerfish Age Workshop	Potts 2013
SEDAR41-RD36	Age, Growth, and Reproduction of Gray Triggerfish *Balistes capriscus* Off the Southeastern U.S. Atlantic Coast	Kelly 2014
SEDAR41-RD37	Assessment of Genetic Stock Structure of Gray Triggerfish (*Balistes capriscus*) in U.S. Waters of the Gulf of Mexico and South Atlantic Regions	Saillant and Antoni 2014
SEDAR41-RD38	Genetic Variation of Gray Triggerfish in U.S. Waters of the Gulf of Mexico and Western Atlantic Ocean as Inferred from Mitochondrial DNA Sequences	Antoni et al. 2011
SEDAR41-RD39	Characterization of the U.S. Gulf of Mexico and South Atlantic Penaeid and Rock Shrimp Fisheries Based on Observer Data	Scott-Denton et al. 2012
SEDAR41-RD40	Does hook type influence the catch rate, size, and injury of grouper in a North Carolina commercial fishery	Bacheler and Buckel 2004
SEDAR41-RD41	Fishes associated with North Carolina shelf-edge hardbottoms and initial assessment of a proposed marine protected area	Quattrini and Ross 2006
SEDAR41-RD42	Growth of grey triggerfish, *Balistes capriscus*, based on growth checks of the dorsal spine	Ofori-Danson 1989
SEDAR41-RD43	Age Validation and Growth of Gray Triggerfish, *Balistes capriscus*, In the Northern Gulf of Mexico	Fioramonti 2012
SEDAR41-RD44	A review of the biology and fishery for Gray Triggerfish, *Balistes capriscus*, in the Gulf of Mexico	Harper and McClellan 1997
SEDAR41-RD45	Stock structure of gray triggerfish, *Balistes capriscus*, on multiple spatial scales in the Gulf of	Ingram 2001

	Mexico	
SEDAR41-RD46	Evaluation of the Efficacy of the Current Minimum Size Regulation for Selected Reef Fish Based on Release Mortality and Fish Physiology	Burns and Brown-Peterson 2008
SEDAR41-RD47	Population Structure of Red Snapper from the Gulf of Mexico as Inferred from Analysis of Mitochondrial DNA	Gold et al. 1997
SEDAR41-RD48	Successful Discrimination Using Otolith Microchemistry Among Samples of Red Snapper *Lutjanus campechanus* from Artificial Reefs and Samples of *L.campechanus* Taken from Nearby Oil and Gas Platforms	Nowling et al. 2011
SEDAR41-RD49	Population Structure and Variation in Red Snapper (Lutjanus campechanus) from the Gulf of Mexico and Atlantic Coast of Florida as Determined from Mitochondrial DNA Control Region Sequence	Garber et al. 2003
SEDAR41-RD50	Population assessment of the red snapper from the southeastern United States	Manooch et al. 1998
SEDAR41-RD51	Otolith Microchemical Fingerprints of Age-0 Red Snapper, *Lutjanus campechanus*, from the Northern Gulf of Mexico	Patterson et al. 1998
SEDAR41-RD52	Implications of reef fish movement from unreported artificial reef sites in the northern Gulf of Mexico	Addis et al. 2013
SEDAR41-RD53	Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species	Then et al. 2014
SEDAR41-RD54	Length selectivity of commercial fish traps assessed from in situ comparisons with stereo-video: Is there evidence of sampling bias?	Langlois et al. 2015
SEDAR41-RD55	MRIP Calibration Workshop II – Final Report	Carmichael and Van Vorhees (eds.) 2015
SEDAR41-RD56	Total Removals of red snapper (*Lutjanus campechanus*) in 2014 from the U.S. South Atlantic	SEFSC 2015
SEDAR41-RD57	Assessing reproductive resilience: an example with South Atlantic red snapper *Lutjanus campechanus*	Lowerre-Barbiere et al. 2015
SEDAR41-RD58	Overview of sampling gears and standard protocols used by the Southeast Reef Fish Survey and its partners	Smart et al. 2014

SEDAR41-RD59	MRIP Transition Plan for the Fishing Effort Survey	Atlantic and Gulf Subgroup of the MRIP Transition Team 2015

2. Life History

2.1 Overview (Group Membership, Leader, Issues)

The life history working group (LHWG) was tasked with reviewing the new data and analysis available (mostly as a result of adding the 2014 data) since the 2014 DW, and combining data from the South East Fisheries Science Center Beaufort Laboratory (SEFSC, NOAA/NMFS-Beaufort), South Carolina Department of Natural Resources (SCDNR), North Carolina Division of Marine Fisheries (NCDMF), Florida Wildlife Research Institute (FWRI), and Georgia Department of Natural Resources (GA-DNR). This combined data set could then be used for analysis of life history parameters for Red Snapper. Note that the collaborative fishery independent snapper grouper monitoring conducted by the Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP), the South East Area Monitoring and Assessment Program-South Atlantic (SEAMAP-SA) (both housed at SC-DNR's Marine Resources Research Institute), and the South East Fishery Independent Survey (SEFIS) (NMFS project housed at SEFSC, Beaufort, NC) are now collectively referred to as the South East Reef Fish Survey (SERFS). Data from all SERFS components were combined for analyses. The SEFSC data predominantly came from various fishery dependent sources. Discussions involved age, growth, reproduction, stock structure, natural mortality, movements, and discard mortality of Atlantic Red Snapper and comparison with Gulf of Mexico (GoM) Red Snapper.
The LHG was tasked with reviewing the data age from the different labs, develop models that describe growth and reproduction most appropriately, determine the biological unit stock based on literature, develop estimates of natural mortality and select a preferred estimate, describe the migration and movements of Red Snapper, and develop a model or point estimate of discard mortality. Additionally the LHWG provided a comparison between estimates/methods proposed for use in SEDAR 41 with estimates/methods used in SEDAR 31for Gulf of Mexico Red Snapper. Note that the development of estimates for discard mortality was discussed by an ad hoc working group formed prior to the 2014 DW.

Life History Work Group (LHWG) Membership for the Data Workshop in August 2014
Panel members
Marcel Reichert - SCDNR/SA-SSC (LH Working Group Leader)
Jennifer Potts - NMFS (Red Snapper Subgroup Leader)
Walter Bubley - SCDNR
Michael Cooper - NMFS
Tanya Darden - SCDNR
Shelly Falk - SCDNR
Cameron Guenther - FWRI
Susan Lowerre - Barbieri - FWRI
Adam Lytton - SCDNR
Todd Kellison - NMFS

Amanda Kelly - SCDNR
Kevin Kolmos - SCDNR*
George Sedberry - NOAA/SSC
Byron White - SCDNR
David Wyanski - SCDNR (Gray Triggerfish Subgroup Leader)
Chip Collier - SAFMC (Bycatch Mortality Subgroup Leader)
Kevin Craig – SEFSC Assessment staff
David Nelson – DW Panel member

* Denotes that Panel Member was not present at the Data Workshop, but participated in data collection, analyses, pre- and post-DW calls and webinars, and report preparation.

Observers
Jessica Lewis - NMFS
Kevin Spanik – SCDNR
Michelle Willis - SCDNR

Note that the Observers played a very active role in assisting with the data compilation and analysis, and their help was much appreciated by the panel members.

LHWG Membership for the Data Workshop in August 2015
Panel members
Marcel Reichert - SCDNR/SA-SSC (LH Working Group Leader)
David Wyanski - SCDNR
Walter Bubley - SCDNR
Jennifer Potts – NMFS (Red Snapper Subgroup Leader)
George Sedberry - NOAA/SSC
Nikolai Klibansky - SEFSC
Kevin Craig - SEFSC Assessment Staff
David Nelson - DW Panel member

Note that Panel members that participated in the 2014 DW, but were not present at the 2015 DW contributed to webinars and assisted with the compiling the data updates and analyses for the 2015 DW.

2.2 Review of Working Papers

SEDAR41-DW02
Georgia Red Snapper Catch & Effort Collection during Mini-Seasons, 2012-2014. Knowlton 2015.

Synopsis
The reviewed paper discusses the methods and results from opportunistic sampling of Red Snapper for biological data and trip survey information via telephone calls and other electronic means during the so-called "mini-seasons" in 2012, 2013 and 2014 in Georgia by GA DNR. Biological sampling included GA DNR staff working dockside as well as donated carcasses deposited into freezers at various locations throughout coastal Georgia . The scope of data collection expanded each year. Initially, dockside sampling targeted one headboat and five charter boats trips, and 24 carcasses were left primarily by private recreational fishers. In 2013, sampling was expanded to intercept commercial fishing trips, for a total of 2 headboat trips, 2 charter boat trips and 6 commercial trips. A total of 42 carcasses were donated, of which 14 came from private recreational fishers. By 2014, GA DNR staff intercepted 6 headboat trips, 10 charter boat trips and 3 commercial trips. An additional 124 carcasses, of which 89 were donated from private recreational fishers.

Critique
The biological data and information are pertinent to SEDAR 41. The details of biological sampling methodology is sufficient to determine which samples with age data are usable in growth modeling and age composition of the recreational and commercial fisheries.

SEDAR41-DW07
Age Truncation and Reproductive Resilience of Red Snapper (*Lutjanus campechanus*) Along the East Coast of Florida. Lowerre-Barbieri, et al. 2014.

Synopsis:
The document describes the assessment of the age structure of red snapper off the east coast of Florida and demographic trends in reproductive traits which might be impacted by age truncation. The population exhibited age truncation, as the maximum sampled age (21 y) was less than half the expected life span (50+ y) and 84% of the sampled fish were < age 7. Virtually all females sampled (99%, n=696) were mature and although two-year-olds were not fully-recruited, 94% (n= 119) were mature. The population spawning season was from April through September, but the probability of being spawning capable within this time differed significantly by size and age, with June being the only month with predicted probabilities > 90% for all fish. Similarly, spawning fraction peaked in June, although older fish had more temporally distributed spawning activity. Red snapper spawned throughout the day and at multiple sites, with relatively few spawning females collected per site (maximum=13 fish). Batch fecundity increased significantly with size and in more northern zones but was highly variable. Egg dry weight did not differ significantly with size or age. Red snapper reproductive physiology suggests they are resilient and highly adaptive. However, age truncation appears to have restricted the time period over which spawning occurs and potentially has caused earlier maturation. Thus, recovery rates

are expected to be affected by environmental conditions in June and if the observed early maturation is due to fisheries-induced evolution.

Critique:
The document contains relevant information and some information, in particular combined with other studies, was included in the LHWG analyses. Note that the report does not identify the length, but the used length was MaxTL (Pers. Comm. by authors).The methodology used to conduct this study was well planned and executed. The analyses were very informative to the reproductive biology of the South Atlantic stock. Two drawbacks to the study include the one year duration of sampling and the range of samples was limited, though did target the center of abundance of the population. For these reasons, some caution should be taken when making inferences to the stock as a whole and to possible changes over time. This study does point out a much needed data inputs to improve the stock assessment and that is to collect routine, annual reproductive tissue samples from red snapper landed in the fishery and in fishery-independent surveys.

SEDAR41-DW09
Size and age composition of Red Snapper, *Lutjanus campechanus*, collected in association with fishery-independent and fishery-dependent projects off of Florida's Atlantic coast during 2012 and 2013. Switzer, et al. 2014.

Synopsis:
The South East Reef Fish Survey, which utilizes chevron traps, has been able to provide some life-history data for Red Snapper during the closure (since 2010). The mini seasons in 2012-13 provided the only fishery-dependent data available since the 2010 Red Snapper closure. Florida's Fish and Wildlife Conservation Commission (FFWCC) collected life history samples from Red Snapper during fishery-independent and fishery-dependent research and monitoring activities along the Atlantic coast of Florida. (A) Most fishery-independent samples were collected in 2012 in association with a one-year pilot study to explore the utility of various fishery-independent, hooked-gear methods. Additional samples were collected in 2012 and 2013 in association with a three-year tagging study to examine movement of Red Snapper. During both studies Red Snapper were culled for life history analyses using random culls with the additional selection of some larger individuals to better characterize the age distribution of larger Red Snapper. (B) Fishery-dependent samples were collected during the limited recreational and commercial harvest seasons in 2012 and 2013. Collections were derived from recreational private boats, charterboats, headboats, and the commercial TIP. During the 2012 and 2013 Red Snapper mini-seasons, parties returning from offshore recreational trips were sampled (random intercept locations). In addition, Red Snapper were targeted for biological sampling at private boat landing sites (not random). Private recreational anglers also donated Red Snapper carcasses at select locations on the east coast of Florida during the 2012 and 2013 season (sample bias unknown),

and Red Snapper were sampled at charter and headboat landing sites (not random). In 2013, FFWCC observers on random charter vessels measured all Red Snapper caught and fish houses were sampled during the commercial season.

Ages of fishery-independent (sampling and tagging) individuals ranged from 1 to 21 years of age, although 90% of individuals were six years old or younger. The age distribution was bimodal, with exceptionally high numbers of age-3 and age-5 Red Snapper, corresponding to the 2009 and 2007 year classes, respectively. Maximum size at age was just over 800 mm TL at approximately 8 – 10 years of age. No notable differences in age distribution or size at age were evident between males and females. An examination of age-specific depths of capture did not identify a significant increase in depth with age. Overall, the results from the fishery-dependent sources mirrored those from the fishery-independent sources.

Critique:
SEDAR41-DW09 was reviewed and deemed pertinent for the SEDAR process. Although each of these data sets contains their own set of biases (as identified by the authors), these are the best available data sources. When sampled in a standardized manner, as has been done over this short period, they can be useful and indicative of changes in the Red Snapper population under management. We recommend the data be incorporated into the SEDAR process as appropriate and the biases considered in their interpretation – the fishery-dependent data are not representative of the population, but the fishery-dependent data are useful for characterizing the size and age of the harvested population.

SEDAR41-DW10
Overview of Florida's Cooperative East Coast Red Snapper Tagging Program, 2011-2013. FWRI, 2014.

Synopsis:
In an effort to better understand red snapper population dynamics off the east coast of Florida, the Florida Fish and Wildlife Conservation Commission (FWC) with federal and industry funding worked cooperatively with various sectors of the recreational, for-hire, and commercial fisheries to initiate a Cooperative East Coast Red Snapper Tagging program in 2011.The program was designed to aid fishery managers in better understanding patterns of distribution, seasonal and spatial dynamics of movement patterns, ontogenetic changes in habitat selectivity, and site fidelity of Red Snapper based on recapture rates throughout the study area. This angler-based tagging program was overseen by FWC personnel who were responsible for coordinating regional training workshops for interested participants, distribution of tagging kits, tagging database management, responding to tag returns, and all aspects of public outreach associated with this project. All Red Snapper released by participating fishermen were tagged externally with a 100-mm Hallprint dart tag. Additional information recorded by the fisher to aid in the

understanding of Red Snapper population dynamics included the coordinates of capture, water depth, and associated catch-specific information (e.g., total length, release condition). A total of 3,441 Red Snapper were tagged by all participating sectors of the Cooperative East Coast Red Snapper Tagging program from 2011 through 2013. There were a total of 211 Red Snapper recaptured from 2011 through 2013, for an overall tag return rate of 6.1%. The time-at-large (days between initial tagging and recapture) of tagged fish ranged from 0 to 887 days. The distance traveled of tagged fish from the initial tag location ranged from 0 to 237 km. Eight fish were recaptured twice and one fish was recaptured three times. The majority of recaptured fish with confirmed location information were caught <1 km from where they were initially tagged, which is indicative of high site fidelity. Analysis of distance traveled in regards to direction of movement (bearing) from initial tag position for fish that moved 3-16 km (n=36) showed no clear ontogenetic movement patterns. Fish were seen to travel in all directions from their initial tag locations. These relatively small movement patterns are most likely a result of fish moving short distances within similar depth strata to nearby available habitat. Generally speaking, water depths and habitat types within the study area, over relatively short distances (3-16 km), change very little. Analysis of fish that moved >16 km from their initial tagging location (n=14), showed a general north-south movement pattern.

Critique:
This document is very relevant and information was considered by the LHWG. The relevance will increase with increasing returns and possible continuation of tagging efforts. Data from this study should be considered in future Red Snapper assessments.

SEDAR41-DW18
South Carolina Red Snapper Catch and Biological Data Collection during Mini-Seasons, 2012-2013. Dukes & Hiltz, 2014.

Synopsis:
This document reviews the collection of biological samples for Red Snapper by the South Carolina DNR during the 2012 and 2013 mini seasons. The SCDNR collected samples from three sources; private recreational vessels, for-hire vessels, and from an online survey. The majority of samples during both years were collected from the private recreational sector (N=43 and 39, respectively), followed by the for-hire sector (N=10 and 14, respectively), and lastly, from the online survey (N=6 and 1 respectively). Private sector samples were obtained through a combination of dockside sampling and carcass donations from participating anglers. For-hire samples were collected through cooperation between SCDNR staff and participating charter/headboats that fish primarily offshore waters. Online survey samples were completed by participating anglers that targeted Red Snapper and included trips where Red Snapper where not caught but were targeted.

Critique:
The document is brief and does not include any information on spatial coverage of the samples from any of the sectors or if there was overlap with other surveys including the SC finfish survey or MRIP sampling. Other concerns include a lack of description on how biological measurements were taken, or by whom they were taken. The samples sizes from the private and for-hire sectors are small. In the absence of more information, is not possible to assess whether or not the length and weight samples were reliably measured, and whether or not the samples are representative of the population. The samples from the online survey are very small and there is concern over the reliability of any reported measurements.

The LHWG reviewers recommend that the biological samples could possibly be included for biological characterization of the population, but due to concerns regarding small sample size, possible overlap between sampling, and non-random nature of the collections, it is not recommended these data are used for catch characterization during the mini-seasons.

SEDAR41-DW21
North Carolina Division of Marine Fisheries Red Snapper Carcass Collections, 2012-2013. NCDMF, 2014.

Synopsis
North Carolina Department of Marine Fisheries attempted to obtain biological sampling of recreational fisherman during the Red Snapper mini-season to supplement existing fishery-dependent sampling which focused on sampling from the commercial sector in 2012 and 2013. Two methods were used to accomplish this: 1. Carcass collection using freezers placed at strategic locations along the coast. 2. Online survey for those fishermen unable or unwilling to donate, but still report their catch. Less than 85 samples were obtained both years and many of the headboat samples were obtained after port samplers had already extracted one of the otoliths and obtained measurements, further decreasing the sample size. The online survey had low levels and none of the submitted data were included in harvest reports.

Critique
There was some concern about the overlap with port samplers due to possibility of duplication of biological samples and measurements. The privately donated fish from the freezers cannot be considered randomly sampled, are likely subject to selectivity biases, and should not be used to characterize the catch. As only otoliths were removed no other biological information such as for reproduction was available.

The data could possibly be used to characterize the biological samples as they may be under-represented size classes at the tails of the distribution, but due to non-random sampling, small sample size, and duplication with other sampling methods, the data should not be considered for catch characterization during the Red Snapper mini-season.

SEDAR41-DW28
Red Snapper *Lutjanus campechanus* in GoM versus southeast US Atlantic Ocean waters: gaps in knowledge and implications for management. Rindone et al., 2014.

Synopsis
This document reviews the relative availability of information supporting Red Snapper assessment and management between the Gulf of Mexico (GoM) and southeastern US Atlantic Ocean (SA). The authors conducted a comprehensive review of available literature and historical records for both mature and juvenile Red Snapper. Of the 110 peer reviewed publications found, 94% were GoM centric. Of the twenty eight available manuscripts focusing on juvenile (<150 mm), none were identified from the SA. Queries of all fisheries independent survey databases from North Carolina through Florida identified only 132 juvenile Red Snapper records out of >75,000 gear deployments and institutional collections. For reference, in a single GoM trawl database, more than 50,000 records of juvenile Red Snapper were found. The results of this review serve to highlight the paucity and need for additional data on Red Snapper (juvenile and mature) in the US south Atlantic.

Critique
While this document does not directly provide any biological information to the life history group, it does serve to highlight and document the severe paucity of data for Red Snapper in the US south Atlantic, especially for juveniles, and provides suggestions for future research directives. The LHWG recommends this working paper for acceptance as it serves as a point of reference for the lack of available data, especially in comparison to Red Snapper in the GoM.

SEDAR41-DW31
Red Snapper Preliminary Genetic Analysis Temporal Genetic Diversity Trends in the South Atlantic Bight. O'Donnell and Darden, 2014.

Synopsis:
There has been only slight fluctuation in genetic diversity of Red Snapper from 1975 to 2012, thus indicating a lack of a population bottleneck or severe reduction in abundance. However, estimates of effective population size from the same samples suggest that Red Snapper experienced a genetic bottleneck that was not detected in genetic diversity estimates due to a lack of samples prior to 1975 (i.e., before the population experienced overfishing). Contemporary estimates of effective population size and inbreeding coefficients provide genetic evidence of population recovery in the Atlantic. Inbreeding coefficient estimates were substantially higher in

the 1970s and 1980s, but have been decreasing (i.e., improving) since 2005, indicating a larger breeding population in recent years.

Critique:
Sample sizes are somewhat small for some years, and do not equally represent all states (however they do reflect state-by-state landings and abundance indices). All samples analyzed were collected after the largest reduction in population abundance (hence relatively stable values within the sample period). There was good agreement in effective population size index in the genetic data and census size (SEDAR), providing support for validity of detected trends. This paper should be used in the assessment.

SEDAR41-DW33
Size Distribution, Release Condition, and Estimated Discard Mortality of Red Snapper Observed in For-Hire Recreational Fisheries in the South Atlantic. Sauls et al., 2014.

Synopsis
The working paper provides a description of the size distribution, release condition, and estimated discard mortality of Red Snapper in for-hire recreational fishery. The paper includes the time series and the geographic coverage of the data collected and methods used to develop the estimates from the at-sea observer program for the south Atlantic.

The At-sea observer program started in 2004 for headboats in the South Atlantic and 2010 for charter boats in Florida. Florida has slightly different methodology than other states and collects more information on the observer trips than other states collect. This allowed for estimates of hook type usage, description of depth for released fish, and an overall estimate of discard mortality for the recreational for-hire fishery in the Red Snapper fishery off Florida.

Critique
The working paper is acceptable for use in the stock assessment. The paper provides needed information on the methods used to estimate the number and lengths of discarded fish and the potential fate of the fish. Additionally this working paper provided the estimate of discard mortality that was recommended for use in the stock assessment for the recreational fishery.

SEDAR41-DW35
Marine Resources Monitoring, Assessment and Prediction Program: Report on Atlantic Red Snapper, *Lutjanus campechanus*, Life History for the SEDAR 41 Data Workshop. White et al., 2014.

Synopsis
This working paper summarizes the data and analyses of Red Snapper as collected by fishery independent monitoring effort in waters off the southeastern US to prepare for the SEDAR 41 Data Workshop. It describes aspects of Red Snapper life history, including depth of capture in fishery-independent and fishery-dependent surveys, length-length and length-weight conversions, length at age, age- and length-at-maturity, sex ratio, spawning seasonality, and spawning frequency.

Critique
SEDAR 41 Reference Document 35 was reviewed and deemed pertinent for the SEDAR process. Data and analyses from this DW were discussed and used during the DW, and are reported in the LHWG DW report. Comments and updated analyses were incorporated I an updated WD.

SEDAR41-DW48
Development of an ageing error matrix for U.S. red snapper (*Lutjanus campechanus*)
Sustainable Fisheries Branch, National Marine Fisheries Service, Eric Fitzpatrick.

Synopsis
The WD describes the age error matrix for use in the SEDAR41 assessment. This analysis was done after the 2014 DW and no update was needed for the 2015 DW.

Critique
The LHWG reviewed the data and analysis and agreed that the presented information should be used to characterize the uncertainty in age estimates based on the variability in age readings between readers and labs. Note that the additional information on the age determination process is provided in section 2.6 of this LHWG report.

SEDAR41-DW49
Estimates of reproductive activity in red snapper by size, season, and time of day with nonlinear models. N. Klibansky

Synopsis
This paper describes a modeling approach to address the spawning season and spawning fraction that may result in more realistic estimates of both.

Critique
The novel modeling approach presented in this WD was considered to be more appropriate than that used in previous assessments. This approach does not assume that all fish start and stop spawning at the same date, and does not assume that fish of all sizes have an equally long spawning season. The presented analysis provides estimates of the proportion spawners by

length (age) during the spawning season. As such, the estimates derived using the approach presented in this paper represent a more realistic evaluation of the reproductive output.

2.3 Stock Definition and Description

Red Snapper are known to utilize both low- and high-relief hard bottom habitats in depths typically ranging from 50-100 m of water. Geographically, Red Snapper distribution ranges from the Yucatan Peninsula throughout the GoM and along the U.S. Atlantic coast north to North Carolina, with occasional occurrences north to Massachusetts (Manooch et al., 1998). Additionally, a disparate portion of the distribution occurs along the north coast of South American (Figure 2.1).

Genetic stock structure of Red Snapper between the GoM and western Atlantic was initially evaluated by Garber et al. (2004) using the mitochondrial control region identified homogeneity in haplotype frequencies among all locations included (four in GoM and one in Atlantic), suggesting Red Snapper in U.S. waters represented a single, panmictic population.

Additional studies limited to GoM collections using both mitochondrial and nuclear markers failed to identify any significant genetic structure (Gold et al., 1997; Pruett et al., 2005; Sallient and Gold, 2006); however, Sallient et al. (2010) evaluating microsatellite genotypes of young of year fish collected from the GoM detected significant spatial autocorrelations indicating small-scale genetic heterogeneity. The authors suggest Red Snapper in the GoM may represent metapopulation population dynamics. Numerous otolith microchemistry studies also provide evidence of regional patterns in the GoM (Patterson et al., 1998; 2001; Nowling et al., 2011; Sluis, 2011).

The most recent genetic evaluation (Gold and Portnoy, 2013 MARFIN Final Report) used both microsatellite and mtND4 data to evaluate gene flow patterns of Red Snapper within and between the U.S. Atlantic and GoM waters. All conventional data analyses failed to identify any level of genetic structuring, but a very weak pattern of isolation by distance was detected only in the mitochondrial data. They conducted an alternative Bayesian analysis which detected significant genetic heterogeneity within the Atlantic (5 locations), within the GoM (3 locations), and between the Atlantic and GoM. However, the new analyses (or at least it is not reported) does not identify locations of gene flow breaks and is in contradiction to all prior results.

During the SEDAR 24 Data Workshop, the Life History Working Group investigated the potential for spatial differences in maturity, growth, and length at age of U.S. Atlantic Red Snapper. They determined that fish in the Florida-Georgia (South) region may mature younger and at smaller sizes than fish in the Carolinas (North) region (See section 2.8 of the SEDAR 24 Data Workshop Report). They detected no difference in mean length-at-age or growth rates between the two regions (SEDAR 24 Data Workshop Report, Figure 2.7.1).

Tagging studies do not provide any additional evidence that suggests movement between GoM and Atlantic stocks, other than one fish tagged off Pensacola, FL was recaptured off St. Augustine, FL (Burns et al. 2008). Fishermen have suggested seasonal migration of fish occurs among regions of the South Atlantic.

During the 2015 DW, no new information was available, therefore, there are no indications from conventional methods that U.S. Red Snapper represent multiple stocks, either between the western Atlantic and GoM or regionally within the western Atlantic. Therefore, the continuation of single stock management of U.S. Atlantic Red Snapper appears to be biologically appropriate based on population genetics and life history trait patterns. However, for the purposes of this assessment, Red Snapper stock definition is from the Florida Keys (Atlantic side) to as for north as landings are recorded.

Recommendation

The Red Snapper stock be defined as the SAFMC jurisdiction of the Florida Keys north to as far as landings are recorded.

2.4 Natural Mortality

2.4.1 Juvenile (YOY)

Juvenile Red Snapper are rarely encountered in a nearshore (<30 ft) fishery-independent trawling program (SEAMAP-SA Coastal Trawl Survey) in the Atlantic. Estimates of juvenile Red Snapper mortality have been developed in the Gulf of Mexico (SEDAR-31), however, little information is available for the US South Atlantic. As with previous Red Snapper assessments from the South Atlantic region off the coast of the United States (SEDAR-32), age 0 fish will not be included as inputs into the stock assessment model and so all calculations regarding natural mortality will involve fish aged 1+.

2.4.2 Adult

Natural mortality (M) of Red Snapper was estimated using several methods. The LHWG also discussed the likelihood that natural mortality rate varies by age and an age-varying approach was advocated (e.g., SEDAR 32). Two methods for estimating age-dependent natural mortality using fitted von Bertalanffy growth models were discussed - Lorenzen (1996), a weight based estimator using length-weight conversions to provide values, and Charnov et al. (2013), using lengths directly from the growth model. Charnov et al. (2013) provides an equation which is an improvement to the empirical equation in Gislason et al. (2010), as well as meta-analyses of other estimators of M, including Lorenzen (1996). They also take into account various aspects of life history traits and habitat of a wide variety of exploited marine and brackish water fishes, leading the LHWG to recommend the Charnov et al. (2013) equation, which utilizes von Bertalanffy growth parameters L_∞ and k, as the best initial estimate of M-at-age:

$$M = ((\text{Length-at-age}/L_\infty)^\wedge(-1.5))*k$$

To apply the Charnov et al. (2013) method, the von Bertalanffy growth model was fit as the population growth model was, but with t_0 fixed at 0. The von Bertalanffy parameters used were:

L_∞ = 883.41 mm
k = 0.279
fixed $t_0 = 0$

The Charnov model provided an age-specific estimate of natural mortality that ranged from 1.395 – 0.279 for fish aged 1 to 51, respectively (Table 2.1). The survivorship to the oldest age using the Charnov et al. (2013) age varying method was unrealistically low ($1.082 * 10^{-6}$), considering the amount of fish caught at older ages. Because the age data, limited as they are at the upper tail, do include fish that are in their 30s, 40s, and 50s, it is more biologically reasonable to assume survivorship to these older ages is greater than zero. Considering the longevity of the species, as well as consistency with past SEDARs, the Charnov M curve was scaled to a point estimate based on the survivorship of the fully recruited ages (4+). Point estimates were generated using empirical models based on maximum observed age (t_{max} = 51 years). The LHWG determined the Then et al. (2015) method ($M = 4.899*t_{max}^{-0.916}$) was the most appropriate means for estimating a point estimate for natural mortality in Red Snapper. It should be noted that the Hoenig (1983) method had been used previously, but Hoenig (a co-author on Then et al. 2015) conceded that Then et al. 2015 is a superior means of obtaining a point estimate of natural mortality. The point estimate is applicable only to those ages that were fully recruited to the fishery. Because the point estimate does not vary with age, it is assumed that the estimate is the average mortality per year from the time at full recruitment. Age at full recruitment was 4+ years, as determined by the mode of the age in the fishery-dependent catch (3 years) and adding 1. The annual instantaneous mortality rate calculated for Red Snapper using the empirical estimator from Then et al. (2015) was 0.134. This resulted in a scaled estimate of natural mortality at age ranging from 0.625 to 0.125 for ages 1-51, respectively (Table 2.1), with the cumulative survival to maximum age at 0.2%.

To incorporate variance around the age-varying natural mortality estimate, the standard deviation (2.89 yr; n = 3) was calculated around the inter-reader variability for the fish with the maximum observed age. Confidence intervals (95%) around the maximum age were calculated from the variance. This, in turn, was used with the Then et al. (2015) method to create natural mortality point estimates based on the upper maximum age (Age = 54.3 yr; M = 0.126) and the lower maximum age (Age = 47.7 yr; M = 0.142). The age-varying natural mortality curve was then scaled to the point estimates calculated from these upper and lower maximum ages, resulting in natural mortality estimates at age for the low end (range = 0.603 - 0.121; cumulative survival = 0.3%) and for the high end (0.678 - 0.136; cumulative survival = 0.1%) for ages 1-51 (Table 2.1).

Recommendations

1. The LHWG recommends using the Charnov age-varying natural mortality curve scaled to the Then et al (2015) point estimate for those ages fully recruited to the fishery (4+).
2. The LHWG recommends that variance about the M age-varying curve be investigated using the inter-reader variation of the oldest aged fish, with 95% confidence intervals being produced to provide an upper and lower maximum age, which in turn is used in the Then et al. (2015) point estimate. The age-varying natural mortality curve was then scaled to these natural mortality point estimates calculated from the upper and lower maximum age estimates.

2.5 Discard Mortality

Note: Discard mortality estimates were developed during the 2014 DW. No new information or analyses were available, so discard mortality estimates were not revisited at the 2015 DW.

Discard Mortality Participants

Zack Bowen	Jimmy Hull
Mark Brown	Robert Johnson
Chip Collier	David Nelson
Chris Conklin	Paul Nelson
Jack Cox	Beverly Sauls
Sonny Davis	Bill Shearin
Kenny Fex	Kate Siegfried
Rusty Hudson	Erik Williams

Discard mortality is an important estimation included in stock assessments and should be considered in evaluating the effectiveness of regulatory actions to reduce harvest. Several studies have been conducted to estimate a discard mortality rate for Red Snapper with values varying from 1 to 93% (see SEDAR 24 and 31 for reviews). Most of these studies have focused on Red Snapper in the GoM where the commercial Red Snapper fishery operates much differently from the snapper grouper fishery off the US South Atlantic both in depths fished and gear used to target Red Snapper (gear differences were displayed at the data workshop). Additionally, other factors that influence discard mortality likely vary between the South Atlantic and GoM including: depths fished by fishing sectors and fishing areas, fishing behavior between sectors and areas, bottom and surface temperature, and usage of circle hooks and dehooking devices.

Therefore, the stock assessments in the South Atlantic have used different discard mortality rates than what has been used in the GoM (Table 2.2).

The estimates of discard mortality used in SEDAR 15 were 90% for the commercial fishery and 40% for the recreational fishery. The SEDAR 15 discard mortality estimates for the recreational (40%) and commercial (90%) fleets were based on the discard mortality estimate for Red Snapper from the GoM for fish caught in waters deeper than 20 meters (SEDAR 7). The values used in SEDAR 24 were 39 to 41% for the recreational sector which was similar to the SEDAR 15 estimate and 48% for the commercial sector. These estimates were based on a depth related discard mortality model developed by Burns et al. (2002). A formal working paper (SEDAR 24 DW-12) was developed for SEDAR 24 and includes a more in depth discussion of discard mortality.

Consideration of Depth Effects

Several studies have focused on depth as an important factor in determining discard mortality due to the visible impact of barotrauma. Studies conducted in depth of less than 35 meters (115 feet) estimated discard mortality rates of 20% or less (Parker 1985, Render and Wilson 1994, Patterson et al. 2002, Burns et al. 2006). Studies conducted in greater than 35 meters generally estimated higher discard mortality rates ranging from 17% to 93% (Gitschlag and Renaud 1994, Burns et al. 2004, Nieland et al. 2007, Burns 2009, Diamond and Campbell 2009, Stephen and Harris 2009). This increase in discard mortality rate with increasing depth is an expected result and has been described for Red Snapper and other snapper grouper species (Patterson et al. 2001, Burns et al. 2002, Patterson et al. 2002, Rudershausen et al. 2007, Stephen and Harris 2009).

To account for increasing discard mortality rate with increasing depth, three models were reviewed in SEDAR 24. Two of the models (Burns et al. 2002, Diamond et al. unpublished data) used a logistic regression function to model the mortality rate (Figure 2.2) and one used a linear trend (Nieland et al. 2007). All three of the models had overlap in the estimation of discard mortality particularly between 50 and 90 meters (see SEDAR 24 DW 12 reference for plots). The linear model had a higher discard mortality rate for Red Snapper caught in depths less than 40 meters than the other two studies (Nieland et al. 2007), likely due to commercial fishing practices observed in the GoM. These fishermen were fishing bandit fishing reels with terminal gear consisting of 20 hooks spread over 4.5 to 6 meters (S. Baker, Jr, personal communication). Typical recreational fishermen in the South Atlantic and GoM as well as commercial fishermen in the South Atlantic fish for snapper/grouper species with terminal gear having less than 5 hooks (Gulf and South Atlantic Fisheries Foundation 2008). The other two models describing discard mortality also included delayed discard mortality in their discard mortality estimate. Koenig (Burns et al. 2002) used a cage study to determine the effects of depth on Red Snapper. Additionally, Red Snapper and gag grouper data were combined in the model since there was no significant difference in the percent mortality at depth. The Diamond et al. (unpublished) combined data from several different studies including the Burns et al. (2002) and Nieland et al. (2007). The discard mortality curves from these two studies were similar with less than 20% discard mortality for fish caught in less than 20 meters increasing to 100% mortality for fish caught in greater than 90 meters.

Consideration of Hook Effects

Hooking related injuries are also important when trying to determine discard mortality (Rummer 2007, Burns et al. 2008). Necropsy results from headboat caught fish showed Red Snapper suffered greatest from acute hook trauma (49.1%), almost equaling all other sources of Red Snapper mortality combined in the headboat fishery in waters less than 42 meters (50.9%, Burns et al. 2008). These hook related injuries caused both immediate and delayed mortality in Red Snapper. The delayed mortality was a result of the hook nicking an internal organ, causing the fish to slowly bleed internally eventually leading to death after a few days (Burns et al. 2004). Circle hooks are generally thought to reduce the discard mortality rate for Red Snapper (SEDAR 7; Rummer 2007); however, Burns et al. (2004) did not observe decreased discard mortality rate when comparing recapture rates of Red Snapper caught on circle and j-hooks. Recent work by Sauls et al. indicated that circle hooks reduced discard mortality for Red Snapper and SEDAR 31 used a discount for regulations that were established in 2008 for the GoM (circle hooks, dehooking devices, and venting). In SEDAR 31, it was stated that the requirement to vent was not quantifiable, but it was included in their model (SEDAR 31).

Consideration of Additional Factors

Additional factors that influence discard mortality rate, such as size of the fish, temperature, and predation, have been considered for Red Snapper but currently data are too limited to include these parameters in a quantifiable estimation of discard mortality. Temperature has been noted in some studies as a significant factor determining discard mortality rate for Red Snapper (Render and Wilson 1994, Rummer 2007, Diamond and Campbell 2009). In these studies, the discard mortality rate increased with increasing temperature. More importantly, both Rummer (2007) and Diamond and Campbell (2009) found the temperature differential between surface and bottom water was more important in determining the discard mortality rate than water temperature alone. A greater differential between the surface and bottom temperature resulted in a higher discard mortality rate.

Red Snapper are preyed upon by several different species including barracuda, sharks, and amberjack (Parker 1985). Dolphins have been listed as a predator in the GoM but this behavior has not been observed in the South Atlantic. In the South Atlantic, the predators of Red Snapper are generally present during months when water temperatures are warmer (personal communication with commercial fishermen).

Descending Devices

Descending devices were mentioned as a potential tool to reduce discard mortality. One fisherman brought in his homemade descending device which he started using in 2014. Currently, the change in discard mortality rate due to descending devices is unknown. There is some research being conducted to determine if descending devices reduce discard mortality. The fishermen pointed out that very few people are using descending devices. Descending devices were not considered for the discard mortality rate.

SEDAR 41 DW Comments and Recommendations

The ad hoc Discard Mortality group's first task was to review the decisions of SEDAR 24. The SEDAR 24 DW recommended using an estimate that included delayed mortality since this would be a better estimate of discard mortality than just surface release information. Immediate mortality is easier to quantify and can be observed at the surface but this value is unlikely to be an accurate estimate of discard mortality for Red Snapper. Delayed mortality is able to incorporate mortality due to hook related injuries, predation, and barotraumas that are not observed at the surface or on board boats. The group felt that delayed mortality rate was more appropriate to describe the fate of discarded Red Snapper.

The SEDAR 24 DW further recommended using a discard mortality model since depth is an important factor in determining discard mortality rate. Some of the participants mentioned that few fish die in the shallow water typically fished for Red Snapper. The plenary decided on using the depth model presented in Burns et al. (2002) to estimate discard mortality (Table 2.3). This model included information on Red Snapper in the South Atlantic and GoM and Gag in the South Atlantic. The model was based on several pieces of information including tag/return data, barotrauma and surface observations. To use the model, depth of discards was developed for each sector. The commercial discard mortality depth estimates came from observer data from the Gulf and South Atlantic Observer study (2008) since this study had depth information combined with catch information. The discard mortality rate estimate of the commercial fishery was 48%. The headboat at sea observer program and logbook data was used to estimate the headboat and charter boat depth distribution. The discard mortality rate estimate for these two sectors was 41%. Private boat depth data was very limited but used depth information from South Carolina DNR tagging study and depths recorded from biological samples from Florida and Georgia fishermen. The private boat discard mortality rate estimate was 39%.

The ad hoc Discard Mortality Working group for this SEDAR agreed with many of the decisions from SEDAR 24. The discard mortality value should include information on delayed mortality and information on depth should be incorporated into the estimate.

Recreational

New methodology using a tag/return model described in Sauls et al. 2014 (SEDAR 41 DW33) was used to condition a model that estimated discard mortality based on release condition and would include information on delayed mortality. The conditions included not impaired/not vented, not impaired/ vented, and impaired for 1,892 Red Snapper. The fish included in this study were post regulation (circle hook requirement and dehooking tool in both areas and venting in the GoM only). The tag/return discard mortality model includes delayed mortality based on the recapture information and a proxy for depth based on condition of the fish. This method was the preferred method to estimate the discard mortality for recreational Red Snapper.

The tag/return condition model estimate was 26.7% for the charter boat fishery and 28.5% for the headboat fishery (Table 2.3). Since the depth profiles were similar among the recreational fisheries (Figure 2.3), a single estimate of discard mortality was recommended. The estimate of discard mortality from the headboat fishery was the preferred estimate (28.5%) because of the higher sample number compared to the charter boat sample number (1,445 headboat, 447 charter boat).

Since this estimate was made based on post-regulation data for circle hooks and dehooking tools in the South Atlantic, an estimate of pre-regulation discard mortality was developed. An estimate of the proportion of discard mortality due to regulation was projected using a regression model from data in SEDAR 31 (data from SEDAR 31 Stock Assessment Report). In general, when discard mortality was low, the proportion of discard mortality due to hooking and releasing was greater than when discard mortality was high, where most of the discard mortality would be associated with barotrauma. This model assumes compliance with the regulations. However, based on observer work and communication with fishermen, compliance with circle hook regulations varied by area (state) and sector. The only compliance data recreational available at the workshop was for the recreational fisheries in Florida. It was estimated that approximately 50% of the trips targeting snapper/grouper were using circle hooks since 2011 (Sauls et al. 2014, SEDAR 41 DW 33). The reduction in discard mortality due to regulations was reduced by 50% based on compliance. The usage of circle hooks prior to 2011 is unknown, but Burns et al. (2002) reported that circle hook usage while snapper/ grouper fishing was minimal in the South Atlantic prior to their study. Using the equation in Figure 2.4 and reducing by 50% for compliance, the pre-regulation discard mortality was 36%.

In an effort to corroborate the method used to calculate discard mortality for the recreational sector, the depth information for the recreational sector was placed into the Burns et al. (2002) model to compare with the results from the tag/return condition model. The Burns et al (2002) model was considered the pre-regulation estimate and the depth related estimate was decreased for a post-regulation estimate due to the limited usage of circle hooks reported in the Burns et al. study. Depth information was obtained from the Florida fishery because this is the only state with depth specific information on discards and is the heart of the Red Snapper fishery. The depth model estimated that post-regulation discard mortality ranged between 23% and 28%. These estimates of post-regulation discard mortality were very similar to the tag/return model estimates and are in the range of sensitivities recommended for use in the assessment.

Commercial

The commercial fishery did not have information on condition of discarded fish; and, therefore the tag/return model based on fish condition could not be used. Instead the depth model (Burns et al. 2002) used in SEDAR 24 was the preferred model. Observer information was used to estimate the depth of discards. Similar to SEDAR 24, the commercial discard mortality was estimate to be 48%. This estimate was developed primarily with information on fish caught with j-hooks which have a significantly higher proportion of potentially lethal hooking interactions (Sauls et al. 2014). To account for the usage of circle hooks, an estimate of post-regulation discard mortality was developed. Observers reported commercial fishermen using circle hooks on approximately 50% of the drops from 2007 to 2011. No other reports were available since 2011 but fishermen at the data workshop indicated the compliance with the circle hook regulation varied by area (state) and sector. They indicated the compliance of 50% was possible but should be investigated before use in other assessments. Using the same method to increase the recreational sector for pre-regulation discard mortality, reduced discard mortality was developed for post 2007 due to the usage of circle hooks. The commercial sector discard mortality rate for 2007 to present was 38%.

The discard mortality for the commercial fishery is much less than the GoM's commercial discard mortality for two main reasons: depth fished and handling time. The modal depth fished for the commercial fishery in the South Atlantic was 31 to 40 meters. The average depth fished in the GoM ranged from 42 to 84 meters. Handling time was noted in SEDAR 31 in the GoM commercial fishery where the commercial fishermen averaged using seven hooks per rig (Scott-Denton et al. 2011). In the South Atlantic, commercial fishermen typically fish one to three hooks and up to five hooks on a rig (Gulf and South Atlantic Fisheries Foundation 2013, commercial fishermen at data workshop). The fewer number of hooks in the South Atlantic leads to less time fighting the fish and also less time dehooking on the deck of the boat.

Discard Mortality Values and Range of Plausible Estimates

Recreational 2011 to present – 28.5% (20% to 36%)
Recreational pre-2011 – 37% (27% to 45%)
Commercial 2007 to present – 38% (28% to 48%)
Commercial pre-2007 – 48% (38% to 58%)

2.6 Age

General introduction

For the 2015 DW, age data were updated and reanalyzed. Juvenile Red Snapper are rarely encountered in the U.S. South Atlantic. SEAMAPs fishery-independent trawling program captured three in 1999, two in 2000, seven in 2013 and four in 2014 in nearshore (<30 ft deep) habitat. One age-0 Red Snapper was landed by a headboat fisherman during the 2012 mini-season. One age-0 fish was landed in the commercial fishery in 1980. Fishermen have reported observing juvenile Red Snapper on artificial reefs in shallow water. Estimates of juvenile Red Snapper mortality have been developed in the Gulf of Mexico; however, little information is available for the US South Atlantic.

The SEFSC, the SCDNR, the GA-DNR, and the FWRI contributed both fishery-dependent and fishery-independent age data for this assessment. The final age data set included samples collected from 1977 – 2014. Most of the age samples were randomly collected by port agents intercepting fishing trips between 1977 and 2014: commercial n = 6,624; charter boat n = 4,025; private boat n = 4,470; headboat n = 6,355; unknown fishery type n = 57. (See Tables 2.4 and 2.5 for randomly collected commercial and recreational fishery age samples and number of trips intercepted.) Some age samples (n = 1,941) were collected from the commercial and recreational fisheries in a non-random way (GADNR and FWRI in 2009 and all states during mini-seasons in 2012 - 2014), and the decision on the treatment of the samples are discussed below. An additional 4,224 samples came from fishery-independent studies. All age data included an increment count, an adjusted calendar age based on timing of annulus formation and an estimate of the amount of translucent edge present, and the determined fractional age using a July 1 birth date.

Issues – 2009 sampling intensity and 2012-2014 mini-seasons

As noted in SEDAR24, sampling intensity for Red Snapper was greatly increased in 2009 for fish landed in Georgia. Also, fishermen donated large Red Snapper landed in Florida and Georgia to FWRI and GADNR during that year. The donated fish were considered non-random and were not used to characterize the landings, but were used in the population growth model. The other samples from GADNR were reviewed and the same conclusions made during SEDAR24 were accepted by the LHWG. The following excerpt from SEDAR24 report is included:

> *GADNR conducted a complete census of Red Snapper landed during May 2009 by three recreational vessels. Concern was raised that the high number of samples (nMay = 284) from one month in the year may bias the overall age structure of the Red Snapper landings for the entire year (nyear = 679). This issue was particularly noted by industry*

representatives who have commented that Red Snapper seem to move through the fishing grounds either latitudinally or longitudinally.
A few of the 2009 samples (n = 68) from the commercial and headboat fisheries were selected by fishermen for the largest fish in the catch.

Recommendations
1. GADNR May census data were plotted against the GADNR random samples for the entire year. No discernible difference was noted in the age frequency or the length distribution between the two sets of data. LHWG recommended keeping the May census data in the dataset used for age composition of the recreational fishery.
2. The fishermen selected samples were identified and will not be used in the age composition data to characterize the fishery, but will be used in the growth model and analysis of fishing by depth of water.

Other directed sampling efforts to obtain biological information on Red Snapper in 2012 - 2014 were undertaken by each state in the U.S. South Atlantic. Following the closure of the Red Snapper fishery in 2010 and 2011, the SAFMC re-opened the recreational fishery in 2012 - 2014 as “mini-seasons” and the commercial fishery as limited harvest. Each state agency provided documentation of methodology to collect Red Snapper samples through carcass collection programs and targeted intercepts of fishing trips by biologist (SEDAR41-DW02, SEDAR41-RD14, SEDAR-RS15, SEDAR41-DW18, and SEDAR41-DW21). These special collections were obtained outside of regular, routine sampling by the Southeast Region Headboat Survey (SRHS), MRIP, and TIP. The length data associated with these age samples would not be included in three fishery surveys, but may be made available to the Commercial and Recreational Work Groups for length composition of the respective fisheries. The LH group reviewed the documents, talked with the state agency representatives, and then assigned random or non-random to the age samples provided. Those samples deemed randomly collected during the directed effort were considered useable for characterizing the catch by fishery, gear, and mode. Those samples deemed non-random were used to model the fish growth at the population level, but were considered not useable for characterizing the catch. Samples considered non-random were those collected from donated fish carcasses into freezers or samples that were collected from tournaments. Tables 2.6 – 2.8 provide the number of samples by state, fishery, and mode, and include the designation of “random” or “not random”.

Recommendations

1. Use age samples from the state collections during the 2012-2014 mini-seasons and considered as randomly sampled to characterize the landings of the fishery and mode from which they came.

2. Age samples collected from a non-random sample or carcass can be used in the overall population growth analysis, but will not be used to characterize the catch.

Review of data collection of the "mini-season" and recommendations for data collection improvements.
Discussion by the LHWG, in particular relative to the relevant WDs reviews, resulted in several recommendations to potentially improve the data collection during possible future Red Snapper mini seasons. The LHWG reviewers recommended that if this program is to continue in the future, an exploration of methods to further incentivize angler participation is warranted, especially with such limited contribution from the private sector in some states. After brief interviews with participants from the recreational fishers group, the following suggestions were provided to increase participation in the private sector*:

- Free fish cleaning at donation site.
- Short questionnaire from a biologist on-site instead of them filling out a form. People are TIRED after being out all day, boat ramps are busy.
- Advertise at local bait & tackle shops.
- NOAA has announcement system on weather radio channel where they also announce season closures, etc. Since fishermen are frequently monitoring this channel for weather updates, it could be an effective communication route to announce the collection information (drop locations, reward information, etc.).
- Dry storage areas are a good place to sample fish as many people store boats there instead of trailering them home.
- Standardization of survey methods across states should be investigated.

*: Suggestions from various recreational fishermen and in particular, David Nelson (SEFA ECS).
The reviewers understand the cost and effort associated with some of these suggestions, making it difficult to implement all of them.

2.6.1 Age Reader Precision and Ageing Error Matrix

To combine age data from various labs, consistency in readings needed to be assessed. The age data were provided from readings by staff at three laboratories – SEFSC, SCDNR, and FWRI. All age readers have been involved in age workshops for Red Snapper from the U.S. South Atlantic. FWRI staff have the added benefit of yearly age workshops with experts from the Gulf of Mexico. Because the South Atlantic stock of Red Snapper were assessed in 2010, the age readers felt that it would be important to read a calibration set of otolith sections to insure consistency had been maintained. A set of 300 samples was created by SEFSC and exchanged between each of the labs.

The results of the calibration readings showed good consistency between labs. One measure of consistency is the Average Percent Error (APE) between paired readers and between all readers. Another consideration is whether one lab shows a bias in readings compared to the other labs.

APEs ranged from 8% between SEFSC and FWRI to 8.5% between FWRI and SCDNR to 11% between SCDNR and SEFSC. The overall APE amongst all readers was 11.4%. These values are higher than the desired level of ≤5%, but most of the variability in the age readings was from those fish aged 8+. Most of the life history parameters have met saturation by that age (maturity, maximum growth, etc.). The bias plots also indicate little bias in aging between the labs (Figure 2.5).

Accounting for error in age estimation is important for age composition data used in stock assessments (Punt et al. 2008). Thus, to account for any error associated with the age estimation process for South Atlantic Red Snapper and to get contemporary precision estimates, an aging error analysis will be completed for the assessment using a program called "agemat" provided by André Punt. Agemat can use age estimation data from multiple readers in order to estimate the coefficient of variation and standard deviation associated with age estimates and to provide an aging error matrix. This program has been used by other SEDAR assessments (ASFMC 2010).

The ageing error matrix was provided after the 2014 DW (SEDAR41-DW48) and reviewed during the 2015 DW (see above).

Recommendation

The age error matrix as provided in the working paper should be used to characterize the uncertainty in the age estimates as a result of the variability in age reading between readers and labs.

Research recommendation:

Continuing the age reading comparisons and calibrations between labs on a reference collection of known age fish would be beneficial for determining a more accurate aging error matrix and would provide accuracy to the age composition data.

2.6.2 Max Age

The 2014 age data did not yield older fish and the maximum observed age for Red Snapper remains 51 years in the combined data set. This fish was a 904 mm maximum TL female, and was caught in 2003 at 67 meters depth off Florida by a charter boat fisher. The maximum age of Red Snapper in SEDAR24 was 54 years. The otolith preparation from this fish was examined by multiple readers at the SEFSC, SCDNR, and FWRI labs. The age was adjusted to 48 years based on consensus by the readers. Note that there were 12 fish with an age of 40 years or more in the data base.

Recommendation

Use 51 years as the maximum age for Red Snapper in the Assessment. This is similar to the 48 years used in the Gulf of Mexico assessment and the 54 years used in SEDAR 24 assessment.

2.7 Growth

Since SEDAR 24, 14,700 additional aged samples were added to the data-set for a total of 27,696 fish for this workshop, thus increasing the temporal and regional coverage of each fishing mode (commercial, recreational, fishery-independent). For all growth models, fractional ages and maximum TL mm (pinched tail) were used, whether it was given with the data or converted using the determined meristics conversions (see Meristics sections). Growth models were constructed using a correction for the truncated normal distribution of size at age due to minimum size limit regulations across time (Diaz correction: Diaz et al. 2004; McGarvey and Fowler 2002).

Growth parameters were estimated on all available data, which represented the population and the fishery-dependent data separately (Table 2.9). Estimated von Bertalanffy growth parameters included L_∞ (the asymptotic fish length, mm maxTL), k (growth coefficient), and t_0 (birth date, yr). The von Bertalanffy population growth model was freely estimated and the Díaz correction was applied to fish restricted by a minimum size limit. The resulting parameter values were L_∞ = 911.36, k = 0.24, and t_0 = -0.33 (Figure 2.6). The model did not require any weighting scheme because sufficient samples at both tails of the data exist and the model was able to fit them well. The fishery-dependent growth model was also freely estimated and did not require inverse weighting of sample size at age, but no Diaz-correction was applied to the data in this model (Figure 2.7). This growth model will be used to estimate size of Red Snapper landed in the fisheries of the U.S. South Atlantic.

The potential of dimorphic growth in this species was investigated by comparing size-at-age analysis for both male and female fish, for fish in which the sex was determined. No discernible difference was found between male (n=4,976) and female (n=5,322) size-at-age (Figure 2.8), therefore spawning biomass should include all data and not discriminate between sex-based growth models.

Recommendation

1. Use combined data, unweighted, freely estimated, Diaz-corrected von Bertalanffy growth model to represent the population.
2. Use the fishery-dependent age data only, unweighted, and freely estimated, von Bertalanffy growth model to estimate the size of fish landed in the fishery.

2.8 Reproduction

2.8.1 Reproductive Strategy and Data Availability

Red Snapper are batch spawners with indeterminate fecundity that do not change sex during their lifetime (gonochorism). The MARMAP study by White and Palmer (2004 - SEDAR24-RD01) and additional samples collected by SERFS since 2001 provide extensive data on the South Atlantic Red Snapper reproductive biology over a large spatial and temporal range. Specimens with reproductive data were collected from 1979 to 2014 and the majority (82% of 3,221) came from fishery-independent sampling, primarily chevron trap catches (Tables 2.21 – 2.28). Many of the commercial fishermen involved in the collection of specimens since 1999 were permitted to land undersized specimens. Data from a published study by FWRI (Lowerre-Barbieri et al. 2015 - SEDAR41-RD57) assessing Red Snapper reproduction off the east coast of Florida, the stock's center of abundance, were also used for SEDAR41. The FWRI data were based on a fishery-independent hooked gear survey (n=1,305), with 696 females that had gonadal development assessed histologically. Although the Lowerre-Barbieri et al. (2015) study collected data from only the 2012 spawning season, it assesses a range of factors affecting reproductive resilience, including the distribution of spawning activity over space and time and if larger, older females exhibit differences in: spawning habitat, reproductive timing, batch fecundity, or egg quality. In SEDAR41, the data from MARMAP/SERFS and FWRI were combined, for a total of 3,917 specimens with reproductive data. All age-related results presented in this section were based on calendar age and maximum (pinched tail) total length. Information below on sexual maturity, sex ratio, spawning seasonality, spawning fraction, and spawning frequency are based on histology, the most accurate technique utilized to assess reproductive condition in fishes.

2.8.2 Spawning Seasonality

Based on the presence of females with spawning indicators (i.e., the occurrence of hydrated oocytes and/or postovulatory follicles) spawning along the Atlantic coast of the southeastern U.S. generally occurs from April through October and peaks during June through August (Figure 2.9). Off the east coast of Florida, spawning indicators occurred from 4 April to 20 September 2012 and the proportion of females with spawning indicators peaked in June (Lowerre-Barbieri et al. 2015). These results are generally similar to those reported in previous assessments (SEDAR24-RD01, Brown-Peterson et al. 2009). During the period April – October, the dataset analyzed for the assessment revealed the occurrence of spawning as early as April 4th (northern Florida) and as late as October (27th) off South Carolina. In addition, specimens with spawning indicators were noted in 2000 (Ft. Pierce, FL: Nov. 13 & 16, n=2; Dec. 15, n=1. Carolinas: Jan. 3, n=1). Spawning females were captured at inner-shelf to shelf-break depths (15-74 m) from St. Lucie Inlet (FL) to the north side of Cape Lookout (NC; Figures 2.10 & 2.11). In the previous assessment, spawning depth was described as mid-shelf to shelf-break (23-72 m) and the latitudinal range was narrower, from Cape Fear, NC, to Melbourne, FL (SEDAR24-RD01).

Recommendation

The LHWG recommends using a spawning season for Red Snapper of April – September.

2.8.3 Sexual Maturity

The LHWG evaluated maturity data to determine if there has been a temporal shift in age at maturity. SERFS data were divided into two periods, the early period (1980-2000) representing SERFS data from a published study of Red Snapper life history (White and Palmer 2004) and the recent period representing data collected by SERFS during 2001-2013 (SEDAR41-DW35) and FWRI data. Note that fishery independent sampling efforts have changed over time with sampling in earlier years (MARMAP) being more concentrated off South Carolina and Georgia, while in more recent years a large number of sampling stations was added off North Carolina, Florida, and Georgia. Probit analysis using the logistic model (proportion mature = 1 - 1/(1 + exp(a+b*age)) showed that female age at 50% maturity (A50) declined from 2.0 yr (95% CI = 1.6-2.2) in the early period to 1.3 yr (95% CI = 1.1-1.5) in the recent period (Table 2.11). However, a plot of the capture location of Ages 1-3 females revealed that specimens were captured primarily off South Carolina and Georgia in the early period versus being caught primarily off Florida in the recent period (Figure 2.12). Given the lack of comparable historic and current samples to confirm changes over time one maturity curve was estimated based on all specimens, including those collected in 2014. The estimate of female A50 was 1.3 yr (95% CI = 1.0-1.4). Mature gonads were present in 38% of females at Age 1, 81% at Age 2, 93% at Age 3, 96% at Age 4, and 100% at Ages > 4 (Table 2.12). The length at 50% maturity (L50) for female Red Snapper from 1979-2000 and 2001-2013 was 381 mm TL (Gompertz, [prop. mature = 1 - exp(-exp(a+b*age))], 95% CI = 366-392) and 328 mm TL (Logistic, 95% CI = 273-356; Table 2.13), respectively. The overall estimate of L50 for females, based on data from 1979-2014, was 325 mm TL (Logistic, 95% CI = 317-331 mm). However, Lowerre-Barbieri et al. (2015) showed Red Snapper are maturing earlier than expected based on Beverton-Holt life history invariants and also earlier than the mean age at maturity for lutjanids (3.5 yr), even though the red snapper potential reproductive lifespan is considerably longer (45 to 49 yr) than the mean for lutjanids (11.7 yr; Martinez-Andrade 2003).

Age at maturity in male Red Snapper was assessed with SERFS data alone. Mature gonads were present in 94% of males at Age 1, 98% at Age 2, 99% at Age 3, and 100% at Ages > 3 (Table 2.14). The logistic model could not be fit to the data to produce a reliable estimate of A50 (i.e., value was negative). Data from 1979-2014 were used to estimate that the L50 for males was 166 mm TL (Logistic, 95% CI = 95-205 mm; Table 2.15).

Recommendation

Given the differing spatial distribution of the specimens between periods, the LHWG recommend use of one maturity curve, based on all specimens, for the assessment. The estimate of female A50 was 1.3 yr (95%CI = 1.0-1.4).

2.8.4 Sex Ratio

Only the SERFS data were used for this and the analyses indicated that there are differences from a 1:1 sex ratio for Red Snapper among certain age and size classes (Table 2.16). In general, males were more common at sizes less than 400 mm TL and Ages < 3 and females were more common at sizes greater than 600 mm TL and Ages >10. The overall sex ratio for all Red Snapper assigned an age, including data from 2014, was not significantly different from the expected 1:1 (n=2,845, Chi-Square=0.84, DF=1, P=36); restricting the analysis to Chevron trap data from 1990-2013 yielded the same result (n=1276, Chi-Square=0.614, DF=1, P=0.43). A length-based (mm TL) analysis of data from 1979-2013 yielded the same 1:1 ratio (n=2196, Chi-Square=0.117, DF=1, P=0.73).

Recommendation

Use a population sex ratio of 1:1 (female : male), since there was no statistical difference in the sex ratio. However, it was noted that the sex ratio varies with calendar age.

2.8.5 Fecundity and Spawning Frequency

Batch Fecundity (BF)

In SEDAR24, a proxy relating gonad weight to whole fish weight was chosen to estimate fecundity because the one estimate of batch fecundity available for Atlantic coast Red Snapper (Brown-Peterson et al. 2009) was based on 12 specimens of a limited size range (560-937 mm TL) captured from a limited geographic area (St. Augustine to Melbourne). An estimate of fecundity at age from the GoM was also considered, but this equation was not as predictive as an estimate of fecundity at length (see Woods 2003; SEDAR7-DW-35) because batch fecundity reached an asymptote at an age of approximately 10-12 yr. In a recent study along the Atlantic coast of Florida by Lowerre-Barbieri et al. (2015), batch fecundity was estimated in 44 specimens ranging in size from 391-846 mm TL. These data were combined with an additional 25 batch fecundities from SERFS, and the combined data set showed larger females produced significantly more eggs per batch than smaller females (Figure 2.13). Batch fecundities ranged from 14 - 4,200 (x 10^3) eggs per female, and significantly increased with TL ($BF=3.012 \times 10^{-8} TL^{4.775}$, 375-862 mm TL, n=69; see SEDAR41-DW49).

Spawning fraction, spawning interval, and spawning frequency

Because the terminology associated with spawning frequency can be confusing, we define them here. Spawning fraction measures the proportion of mature females spawning daily (Hunter and Macewicz 1985; Murua et al. 2003). Spawning interval refers to the time period between spawning events and at the population level is estimated as the reciprocal of the spawning fraction. Spawning frequency refers to the number of spawning events within a spawning season and is traditionally calculated by dividing the number of days within this spawning season by the spawning interval. These definitions follow Lowerre-Barbieri et al. 2011.

To evaluate the level of reproductive activity in the population over the spawning season, an analysis was run using SERFS data to calculate the proportion of spawners among all adult females (active + inactive) in preparation for the SEDAR41 Data Workshop in August 2014. The results showed that the proportion of female Red Snapper with at least one indicator of imminent spawning (migratory nucleus or hydrated oocytes(HO)) or recent spawning (postovulatory complexes, POCs) is consistently around 0.5, as the proportion ranged from 0.41 to 0.54 during June through September, which includes the peak of spawning. These spawning indicators as a group have an estimated duration of 34 hr (SEDAR31-DW07), thus proportionally reducing the range of values to a 24-hr period resulted in a spawning fraction of 0.29 to 0.38. Using traditional methods to assess spawning interval, these proportions correspond to one spawn approximately every 3 days or 70 spawning events in a 210 day (April-October) spawning season. An age-based analysis revealed that there is minimal variation in spawning frequency from Age 2 through Age 38, with no evidence of a clear increasing or decreasing trend (Table 2.10).

Lowerre-Barbieri et al. (2015) using hook-and-line sampling showed slightly higher spawning activity, with an overall spawning fraction of 0.33 for the HO method and 0.18 based on day 1 post-ovulatory follicles (POFs). Using traditional methods to assess spawning interval, these proportions correspond to one spawn approximately every 3 days (HO) or once every 5.7 d (POFs). Based on the proportion of spawning capable females with spawning indicators (i.e., undergoing hydration or with signs of recent spawning), spawning activity was not evenly distributed throughout the spawning season, exhibiting a clear maximum in June. Although the temporal pattern of spawning activity with size was not statistically significant, large fish (≥ 700 mm TL) demonstrated a more even distribution of spawning activity over the months of May (0.64), June (0.75), and July (0.63) than smaller fish .

Spawning frequency by size

Since Red Snapper exhibit indeterminate fecundity, the number of eggs produced per female per year (i.e. annual fecundity) is calculated as the product of batch fecundity (described above) and spawning frequency (the number of batches produced per female per year). Spawning frequency is typically estimated by multiplying the estimated spawning duration by the spawning rate, known as spawning fraction (Murua et al. 2003). This method is analogous to calculating a definite integral (i.e. calculus); essentially, determining the area under a function over an interval. In this case, the function is a horizontal line with a y-intercept equal to the overall spawning fraction, and the interval is the estimated duration of the spawning season, which often increases in batch spawners with size and age (Fitzhugh et al. 2012; Cooper et al. 2013), and was shown to do so in Red Snapper (Lowerre-Barbieri et al. 2015). Since the function is linear, the calculation is simple and it is not usually thought of as a definite integral, though it is. In SEDAR41-DW49, Klibansky fit a more complex, four-parameter plateau-shaped function to the 1979-2014 SERFS (=SCDNR) data. Since the curve is symmetrical and asymptotically approaches the x-axis early and late in the year, the area under this curve can be calculated over the entire year, to estimate spawning frequency. Since spawning fraction has been shown to increase with size or age in multiple species the plateau function was extended by replacing the mean spawning period duration parameter d with a linear function of total length, such that $d = d_0$ -+ d_1TL. Both the basic plateau model and the size-dependent plateau model were separately fit to the data, and the fits of the models compared with Akaike's Information Criterion (AIC). The size-dependent model produced a much stronger fit than the basic model, improving AIC by 42.5 (note that improvements >10 are considered strong; Bolker 2008) and was therefore accepted as the preferred model. The estimate of the slope parameter d_1 was positive (0.42) suggesting an increase in spawning period duration of 4.2 days for every 10 mm of TL. Taking the integral of this model at a particular TL provides an approximation of spawning frequency, which are provided in (SEDAR41-DW49).

Recommendation

The LHWG recommended using the equation, generated from the combined FWRI and SCDNR data, relating total length to batch fecundity, and the relationship between spawning frequency and TL presented in SEDAR41-DW49. Utilizing the total egg production (TEP) method of estimating stock reproductive potential, the equation is:
TEP = proportion female x proportion mature x batch fecundity x spawning frequency. The age-specific estimates of spawning frequency are given in SEDAR41-DW49.

2.9 Movements and Migrations

Since the 2014 DW review of the available literature, no new information became available and the 2014 LHWG recommendations did not change. Red snapper show great site fidelity as adults, which may result in slower replenishment of areas subject to local depletion (Johnson 2013). However, there is increased movement during tropical storms, which may explain reappearance of Red Snapper in formerly depleted areas, in spite of their sedentary nature (Cowan 2011).

Red Snapper undertake short-term movements associated with daily feeding excursions and spawning activities during summer. Adults prefer deeper waters and more complex habitats, so there are apparently ontogenetic movements as well. Red Snapper juveniles are attracted to structure and the dimension and complexity of their habitat increases with fish size (Patterson 2007; Diamond *et al.* 2010). In the South Atlantic, more complex (higher relief; mixture of bottom types) habitats are found in deeper mid-shelf and shelf-edge reefs. This may result in larger fish moving further offshore into more complex reefs as they grow. It should be noted, however, that there was no discernible difference in the distribution of fish by size or age over different depths in the South Atlantic (SEDAR 24).

There have been several tagging studies of Red Snapper, particularly on artificial structures in the GoM, and some recent large efforts in the Atlantic off of Florida. The results confirm long-term site fidelity (months to years), punctuated by very short feeding and spawning excursions.

Addis *et al.* (2013) found that, in spite of previous reports of relative immobility of Red Snapper, they showed the greatest movement among 12 reef fish species tagged on artificial reef sites in the GoM. Mean distance moved among recaptures (173 of 2114 tagged) was 37.1 km (20 nautical miles). During the study, a hurricane passed over the study area, thus adding an unplanned factor to movement analyses. Fish size, reef depth, days at large, and hurricane exposure significantly affected the likelihood of Red Snapper movement, but only fish size significantly affected distance moved (Addis *et al.* 2013).

In another study on artificial reefs in the Gulf, Red Snapper stayed near the artificial reefs (<100 m movement, with 75% of movements within 30 m of the structure), but were significantly farther from the reefs at night (mean = 27.5 m, SD = 7.1) than day (mean = 19.1 m, SD = 8.2). Home range and mean distance from the reef increased with fish size. These fish also showed long-term residence of 332–958 d based on passive acoustic monitoring (Topping and Szedlmayer 2011a).

Tagging data from a number of artificial-reef studies in the GoM demonstrate that, while a substantial percentage of tagged fish were recaptured near their release sites, movement on the scale of hundreds of km also occurs. Because of occasional longer movements, there is sufficient mixing to promote genetic exchange within regions, but overall movement is likely insufficient to affect population demographic differences observed among regions (Patterson 2007).

On natural reefs in the Gulf, Beaumariage (1969) found that 90% of recaptured Red Snapper (of 1,126 tagged) were caught within 5 km of their release site. With very rare exception, there is no reported movement of Red Snapper between the Gulf and South Atlantic (Burns *et al.* 2004). In the Red Snapper largest tagging study, Burns *et al.* (2004) tagged and released 5,272 Red Snapper in the GoM (from Naples, FL, to the eastern border of Texas) and Atlantic (from Cape Canaveral, FL, to Georgia) over a 13-yr period. Approximately 40% of these fish were tagged in the Atlantic. Forty-four percent of the specimens were recaptured within 1.9 km of the tagging site. Less than 10 of the 410 recapture events showed movement >100 miles and movement between the GoM and the Atlantic coast is not mentioned in the report. In a later study, Burns *et al.* (2008) reported 529 Gulf and Atlantic Red Snapper recaptures. Approximately 28.7% were recaptured within 3 km, 15.1% were recaptured within 10 km, and only 3.8% were recaptured more than 50 km of the original tag site. In general, recaptures indicated north/south movement on the Atlantic coast and east and southeast movement (from the Panhandle) in the GoM. A single Red Snapper tagged in the Florida panhandle (during a previous study) was recaptured on the Atlantic coast of Florida.

The results of two smaller studies also indicate minimal movement in Atlantic Red Snapper. The SC Marine Gamefish Tagging Program reported 1,597 Red Snapper tagged with 171 recaptures. Ninety-three percent were recaptured within 2 km of the tagging site. SCDNR (MARMAP) data included 45 tagged Red Snapper with two recaptures, one of which was recaptured in the same vicinity as tagged. The other recapture had no location data.

In a large recent study in the South Atlantic, Brodie *et al.* (2013) tagged 3,441 Red Snapper and reported 211 recaptures (6.1%). Days at large ranged from 0 to 887, and distance traveled ranged from 0 to 237 km (128 nautical miles). Eight fish were recaptured twice and one fish was recaptured three times. The majority of recaptured fish with confirmed location information were caught <1 km from where they were initially tagged, indicating high site fidelity.

Two Red Snapper successfully tagged with acoustic tags at Gray's Reef National Marine Sanctuary (~20 m depth off Sapelo Island GA) were very active on a small spatial scale, appearing on multiple receivers within the 12.6 ha (31 acre) area of the receiver array (Carroll 2010). They exhibited high short-term (several months) site fidelity. One Red Snapper was present 112 d (out of 340 d at large) at the site where it was released and the other was present 580 d (out of 730 d at large) at a site near where it was released. Both individuals were detected on multiple receivers around the array, but returned to a single receiver site on a daily basis. Detections of both Red Snapper were low to absent during the spawning season (May to October), indicating that Red Snapper may move to aggregation sites or into deeper water to spawn, but return to a home territory.

In a larger acoustic tagging study on artificial reefs in the GoM, Topping and Szedlmayer (2011b) found a median residence time of 542 d, ranging from 1 to 1099 d, with 72% of fish staying at least 1 yr at the site. Some fish (n = 12) showed seasonal and directed movements to other sites (up to 8 km away) and returned to original sites up to 7 months later. Diel movements away from the structure tended to occur at night, similar to the pattern seen at Gray's Reef off Georgia. Site fidelity and residence times of Red Snapper found by Topping and Szedlmayer (2011b) were greater than in any previous study, but similar to those found by Carroll (2010).

Recommendation

Available data and the results of studies in the GoM indicate high site fidelity, but that tropical storms may cause greater than normal movement that might help dispersal to depleted areas. This needs to be confirmed in the South Atlantic. More research on Red Snapper movements and migrations in Atlantic waters is needed. Additional acoustic and traditional tagging is needed on known spawning locations to document spawning migrations or aggregations, and return of fish to non-spawning areas.

2.10 Meristic Conversion Factors

Due the large data set, the addition of the 2014 was unlikely to change the conversion factors and the SEDAR41 panel recommended to use the conversions presented at the 2014 DW (Tables 2.17 and 2.18). Data for the length-length, whole weight – gutted weight, and whole weight (g) – length (mm) regressions were pulled from the Southeast Region Headboat Survey (Atlantic portion only), Southeast fishery-independent survey (SCDNR MARMAP and SEFIS), MRIP and Florida FWRI. Maximum total length was agreed upon to be the length type used in the assessment. Linear regressions were run to convert natural total length (TL_{nat}), fork length (FL) and standard length (SL) to maximum total length (TL_{max}, Table 2.17). A no intercept regression was run to convert gutted weight to whole weight. Natural log (Ln) transformed whole weight and length regressions were run for all four length types (Table 2.18). The regression equations were then converted to power equations which included ½ mean squared error (MSE) to account for the transformation bias. Regression parameters are included in Tables 2.17 and 2.18, and Figures 2.14 and 2.15 to illustrate the scatter plot of data points with obvious outliers excluded. Each data source was reviewed before final inclusion in the regression analyses. Outliers were identified and removed from the data set used for meristic conversions. For the whole weight – gutted weight regression, only data from the fishery-independent source were used. Data provided by Florida FWRI was found to not be reliable and removed at the recommendation of the data provider.

2.11 Sample Sizes Available for Analyses

An overview of the available sample sizes and trips by year and state for the various analyses used by the LHWG is provided in Tables 2.19 - 2.26.

2.12 Recommendations for Alternative Parameters Estimates and Comparison of Recommended Parameter Choices between South Atlantic and Gulf of Mexico

Note that alternative parameters estimates and approached recommended by the LHWG are listed under the various chapters discussing the analyses and parameter choices.

An overview of a comparison of parameter choices recommended by the SEDAR 41 LH WG and those used in previous GoM assessments for Red Snapper are given in Table 2.27. As the parameter choice is not always straight forward, the LH WG recommends reviewing the appropriate section of the stock assessment reports for details on the parameter choices.

2.13 Itemized List of Tasks for Completion Following Workshop

- Updating the Life History Working Group report section.
- Completing comparison of parameters and approaches between the South Atlantic and Gulf of Mexico.

2.14 Literature Cited

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2.15 Tables

Table 2.1

Age-varying mortality estimates for Red Snapper. The recommended estimate, Charnov et al. (2013) scaled from the age at full recruitment (4+) to the point estimator obtained using the Then et al. (2015) method, is highlighted. Lower and upper represent 95% confidence intervals of natural mortality calculated from inter-reader variation for age estimates of the oldest observed fish.

Age	Charnov	Scaled Charnov	Lower	Upper
1	1.395	0.638	0.603	0.678
2	0.784	0.359	0.339	0.381
3	0.567	0.259	0.245	0.275
4	0.461	0.211	0.199	0.224
5	0.402	0.184	0.173	0.195
6	0.364	0.167	0.157	0.177
7	0.340	0.155	0.147	0.165
8	0.323	0.148	0.140	0.157
9	0.311	0.142	0.135	0.151
10	0.303	0.139	0.131	0.147
11	0.297	0.136	0.128	0.144
12	0.292	0.134	0.126	0.142
13	0.289	0.132	0.125	0.140
14	0.286	0.131	0.124	0.139
15	0.285	0.130	0.123	0.138
16	0.283	0.130	0.122	0.138
17	0.282	0.129	0.122	0.137
18	0.281	0.129	0.122	0.137
19	0.281	0.128	0.121	0.136
20	0.280	0.128	0.121	0.136
21	0.280	0.128	0.121	0.136
22	0.280	0.128	0.121	0.136
23	0.280	0.128	0.121	0.136
24	0.279	0.128	0.121	0.136
25	0.279	0.128	0.121	0.136
26	0.279	0.128	0.121	0.136
27	0.279	0.128	0.121	0.136
28	0.279	0.128	0.121	0.136
29	0.279	0.128	0.121	0.136
30	0.279	0.128	0.121	0.136
31	0.279	0.128	0.121	0.136
32	0.279	0.128	0.121	0.136
33	0.279	0.128	0.121	0.136
34	0.279	0.128	0.121	0.136
35	0.279	0.128	0.121	0.136

36	0.279	0.128	0.121	0.136
37	0.279	0.128	0.121	0.136
38	0.279	0.128	0.121	0.136
39	0.279	0.128	0.121	0.136
40	0.279	0.128	0.121	0.136
41	0.279	0.128	0.121	0.136
42	0.279	0.128	0.121	0.136
43	0.279	0.128	0.121	0.136
44	0.279	0.128	0.121	0.136
45	0.279	0.128	0.121	0.136
46	0.279	0.128	0.121	0.136
47	0.279	0.128	0.121	0.136
48	0.279	0.128	0.121	0.136
49	0.279	0.128	0.121	0.136
50	0.279	0.128	0.121	0.136
51	0.279	0.128	0.121	0.136
Cumulative survival (Age 4+)	**1.082E-06**	**0.002**	**0.003**	**0.001**

Table 2.2

Discard mortality rates used in SEDARs for Red Snapper.

	GoM			South Atlantic			
	SEDAR 7	SEDAR31		SEDAR 15	SEDAR 24	SEDAR 41	
Sector		Pre-Regulation	Post-Regulation			Pre-Regulation	Post-Regulation
Recreational	15-40%	21-22%	10-11%	40%	39-41%	37%	28.5%
Commercial	71-88%	74-87%	55-74%	90%	48%	48%	38%

Table 2.3

Estimate of discard mortality for South Atlantic Red Snapper using a depth model (Burn et al. 2002) and a tag/return model (Sauls et al. 2014). The estimated regulation reduction was applied to the depth model to compare pre- and post-regulation estimates of discard mortality. The reduction was derived from the SEDAR 31 model and estimated using the function in Figure 2.4.

Fleet	Burns et al. 2002	Estimated Regulation Reduction	Sauls et al. 2014 DW 33
Charter	36%	28%	26.7%
Headboat	31%	23%	28.5%
Recreational	35%	27%	N/A
Commercial	48%	38%	N/A

Table 2.4

Number of commercial trips intercepted and number of individual age samples between brackets of Red Snapper landed in the commercial fishery from North Carolina through the east coast of Florida, including the Keys.

	Handline				Other		
Year	FL	GA	NC	SC	FL	NC	SC
1988				7 (32)			
1989				4 (5)			
1990				11 (29)			
1991				3 (6)			
1992	3 (15)			8 (23)			
1993	1 (7)			8 (12)			
1994	1 (1)			14 (20)			
1995	2 (16)			5 (5)	1 (4)		
1996	16 (118)			32 (86)	1 (11)		
1997	16 (63)			29 (111)			
1998	14 (50)				1 (1)		
1999	5 (13)			10 (151)			
2000	21 (141)	1 (16)		6 (131)	7 (122)		
2001	23 (115)				4 (58)		
2002	5 (30)			2 (3)	1 (1)		
2003	10 (59)						
2004	12 (57)		13 (21)				
2005	6 (38)		35 (64)	12 (33)			
2006	9 (80)		24 (34)	51 (115)			
2007	14 (79)		51 (80)	67 (108)	1 (1)		2 (4)
2008	5 (39)		68 (156)	85 (194)	1 (7)	3 (4)	

2009	106 (2047)		60 (152)	97 (233)	14 (75)		9 (15)
2010	1 (30)						
2011			1 (1)				
2012	22 (106)		4 (9)	13 (33)	4 (17)	2 (4)	
2013	71 (597)	4 (15)	24 (74)	10 (36)	14 (106)	3 (12)	
2014	27 (297)		24 (100)	13 (68)	1 (7)	4 (15)	

Table 2.5

Number of trips intercepted and (number of individual age samples) of Red Snapper landed in the recreational fishery from North Carolina through the east coast of Florida, including the Keys.

	Charter Boat		Headboat				Private	
Year	FL	GA	FL	GA	NC	SC	FL	GA
1977			17 (60)			5 (12)		
1978			76 (270)	4 (5)	1 (1)	2 (2)		
1979			31 (46)			1 (1)		
1980			30 (87)		2 (2)	4 (5)		
1981			141 (405)		3 (3)			
1982			55 (131)		1 (3)			
1983			167 (741)		2 (3)	4 (5)		
1984			147 (553)			19 (28)		
1985			150 (491)			10 (13)		
1986			91 (173)	1 (1)	1 (2)	4 (8)		
1987			60 (86)		1 (1)			
1988			17 (19)		3 (3)			
1989			9 (15)		5 (11)	17 (23)		
1990			13 (20)		6 (8)	4 (5)		
1991			13 (21)		4 (4)	1 (1)		
1992			2 (2)		2 (3)	1 (1)		
1993			6 (9)		2 (2)	5 (7)		
1994	2 (7)		6 (10)		3 (5)	1 (1)		
1995			5 (11)		2 (3)	1 (4)		
1996			11 (16)	1 (1)	2 (2)	13 (31)		

1997			12 (13)					
1998			6 (7)			2 (21)		
2000	4 (7)		2 (2)					
2001	14 (42)		2 (2)				1 (1)	
2002	81 (253)		3 (9)			3 (3)	3 (9)	
2003	91 (352)		6 (10)		1 (1)		2 (2)	
2004	83 (309)		9 (27)		3 (3)		2 (3)	
2005	87 (338)		23 (60)		1 (3)			
2006	43 (169)		61 (150)	5 (5)	1 (1)	7 (7)		
2007	11 (27)		20 (56)	4 (4)	1 (1)	10 (10)	1 (2)	
2008			36 (117)	1 (1)	6 (9)	4 (6)		
2009	51 (271)	26 (169)	193 (839)	56 (381)	7 (8)	8 (11)	7 (18)	1 (5)
2010			1 (2)					
2012	113 (679)	7 (36)	47 (571)	1 (5)	5 (24)	1 (4)	300 (965)	
2013	82 (425)	3 (18)	30 (197)	2 (13)	6 (31)	1 (1)	355 (1049)	
2014	150 (830)	22 (93)	35 (200)	7 (82)	10 (63)	4 (19)	810 (2416)	

Table 2.6

Red Snapper age samples collected by NCDMF during the 2012 - 2014 mini-seasons. All samples were from donated carcasses and considered non-random.

Mode	2012	2013	2014
Charter Boat	5	2	35
Headboat	43		79
Private	2	2	15
Unknown Fishery	2		62

Table 2.7

Red Snapper age samples collected by SCDNR during the 2012 - 2014 mini-seasons. All samples were considered non-randomly collected.

Mode	2012	2013	2014
Charter Boat		2	
Headboat	6	11	40
Private	37	31	33
Unknown Fishery			34

Table 2.8

Red Snapper age samples collected by GADNR and FWRI during the 2012 and 2013 mini-seasons. (Note: data were combined due to confidentiality of data.) Samples were collected by a combination of intercepted trips and carcass donations. “No” indicates donated fish/carcasses that were considered non-randomly collected and not used to characterize age structure of the landings. “Yes” indicates samples collected by state agency personnel who intercepted trips and followed random sample design, but may have collected samples outside of regular MRIP, Headboat, or commercial TIP surveys.

	2012		2013		2014	
Mode	No	Yes	No	Yes	No	Yes
Carcass Program	23		34		94	
Charter Boat	33	714	21	443	402	923
Commercial	7		5	15	13	
Headboat		501	10	91	165	189
Private		965		1049	198	2416
Tournament	234		64			
Unknown Fishery	39		27			

Table 2.9

Summary of von Bertalanffy growth model parameters for the population and fishery-dependent data.

Source	N	Linf	StDev	K	StDev	t_0	StDev
Population	27,696	911.36	2.1189	0.24	0.00187	-0.33	0.0155
Fishery-Dependent	23,472	901.72	2.1531	0.24	0.00205	-0.65	0.0191

Table 2.10

The proportion of Red Snapper spawners (# female spawners/# adult females) by increment group in SERFS histological data from April through September of 1978-2014, including all projects, and gears. A spawner had one or more indicators of spawning, which have a combined duration of approximately 34 h (See SEDAR31-DW07). Spawning season duration represents the # of days between the first and last occurrence of spawners by age class. Cal. Age = calendar age, HO = hydrated oocytes, OM = oocyte maturation, POC = postovulatory complex.

Cal. Age (yr)	N	Prop. Spawners (OM, HO, POC; ~34 h)	Est. Spawning Season Duration (d)	# Batches/ind.fish by Age
1	34	0.12	1	0.1
2	230	0.55	138	53.6
3	295	0.42	152	45.1
4	166	0.34	167	40.1
5	158	0.43	158	48.0
6	99	0.41	164	47.5
7	81	0.46	118	38.3
8	51	0.41	133	38.5
9-11	30	0.37	83	21.7
12-14	19	0.47	72	23.9
15-38	17	0.47	121	39.9
2+	1146	0.42	131	38.7
Total	1180			

batches = (24 hr*Proportion Spawners/34 hr) x Spawning Season Duration

Table 2.11

Results of various regression model analyses for age and length at maturity for male & female Red Snapper, by period. Data from all sources (SERFS and FWRI) and gears were combined, with the exception of male length at maturity (SERFS data used only). Age is expressed in calendar age (Cal.Age) and length is maximum (pinched tail) total length in mm. n=number of fish used in analyses, A_{50}= age at which 50% of population has reached sexual maturity, L_{50}=length at which 50% of the population has reached sexual maturity.

						Parameter Estimate	
Analysis	Period	Model	n	A_{50}/L_{50}	95% CI	**Intercept (Std Err)**	**Cal.Age or MaxTL (Std Err)**
Females Age at Maturity	1980-2000	Logistic	476	2.0	1.6-2.2	-3.204 (0.653)	1.612 (0.224)
Females Age at Maturity	2001-2013	Logistic	1332	1.3	1.1-1.5	-2.651 (0.428)	1.993 (0.201)
Females Age at Maturity	1980-2014	Logistic	2321	1.3	1.0-1.4	-1.556 (0.247)	1.283 (0.102)
Female Length at Maturity	1979-2000	Gompertz	517	381	366-392	-9.538 (1.481)	0.024 (0.004)
Female Length at Maturity	2001-2013	Logistic	1359	314	-	-14.068 (49.099)	0.045 (0.146)
Female Length at Maturity	1979-2014	Logistic	2399	325	317-331	-11.491 (0.829)	0.035 (0.002)
Male Length at Maturity	1979-2014	Logistic	1482	166	95-205	-3.346 (1.040)	0.020 (0.003)

Table 2.12

Percentage of mature specimens by calendar age for female Red Snapper, by period. Specimens in the developing, spawning, regressing, or regenerating states were considered mature. *n*=number of specimens available from all sources (SERFS and FWRI) and gears.

	1980-2014 *n*=2,321	**1980-2000** *n*=476	**2001-2013** *n*=1,332
Age	**% Mature**	**% Mature**	**% Mature**
0	--	--	--
1	38	0	31
2	81	50	79
3	93	85	98
4	96	94	98
5	100	100	100
6	100	100	100
7	100	100	100
8	100	100	100
9	100	100	100
10	100	100	100
11	100	100	100
12	100	100	100

Table 2.13

Percentage of mature specimens by maximum (pinched tail) total length interval (TL, mm) for female Red Snapper, by period. Specimens in the developing, spawning, regressing, or regenerating states were considered mature. *n*=number of specimens available from all sources (SERFS and FWRI) and gears.

	1979-2000		2001-2013	
	n=517		*n*=1,359	
Length (TL mm)	**%**	***n***	**%**	***n***
201-225	0	2	0	7
226-250	0	7	0	17
251-275	0	7	5	22
276-300	25	8	10	20
301-325	29	7	52	23
326-350	20	15	86	43
351-375	17	18	91	75
376-400	57	28	97	70
401-425	87	31	99	83
426-450	85	20	99	72
451-475	100	9	100	64
476-500	100	27	100	55
501-525	100	55	100	37
526-550	100	76	100	36
551-575	100	52	100	41
576-600	100	41	100	53
601-625	100	27	100	71
626-650	100	18	100	66
651-675	100	7	100	62
676-700	100	7	100	79
701-725	100	13	100	94
726-750	100	11	100	64
751-775	100	7	100	71
776-800	100	8	100	62
801-825	100	2	100	30
826-850	100	3	100	14
851-875	100	4	100	13
876-900	100	4	100	9
901-925			100	4
926-950	100	2		
951-975				
976-1000	100	1	100	1

Table 2.14

Percentage of mature specimens by calendar age for male Red Snapper, by period. *n*= number of specimens available from all projects and gears (SERFS data only).

	1980-2014 *n*=1,419	1980-2000 *n*=430	2000-2013 *n*=625
Age	% mat	% mat	% mat
0	0	0	--
1	94	88	94
2	98	90	98
3	99	98	99
4	100	99	100
5	100	100	100
6	100	100	100
7	100	100	100
8	100	100	100
9	100	100	100
10	100		100
11	100		100
12	100		100

Table 2.15

Red Snapper sex ratio by calendar age, 1980-2014, based on data from all sources (SERFS and FWRI) and gears.

Calendar Age (yr)	# Male	# Female	Obs. Prop. Female
1	91	35	0.28
2	359	241	0.40
3	397	403	0.51
4	280	251	0.47
5	112	184	0.62
6	60	108	0.64
7	36	94	0.72
8	23	53	0.70
9	13	26	0.67
10	7	8	0.53
11	1	4	0.80
12	3	6	0.67
13	1	7	0.88
14	2	7	0.78
15	2	4	0.67
16	0	5	1.00
17	2	1	0.33
18	1	0	0.00
19	1	3	0.75
20			
21	3	0	0.00
22	0	1	1.00
23	0	1	1.00
24			
25	1	1	0.50
26	1	0	0.00
27			
28	0	2	1.00
29			
30-46	2	2	0.50
Total	1398	1447	0.51

Table 2.16

Red Snapper sex ratio by maximum Total Length (mm) 1979-2013, based on data from all sources (SERFS and FWRI) and gears.

Total Length	Female: Male	Male n	Female n	Proportion female	Total n
201-225		4	0	0.00	4
226-250		9	0	0.00	9
251-275	0.03	30	1	0.03	31
276-300	0.11	37	4	0.10	41
301-325	0.34	35	12	0.26	47
326-350	0.60	42	25	0.37	67
351-375	0.55	66	36	0.35	102
376-400	0.57	76	43	0.36	119
401-425	0.99	70	69	0.50	139
426-450	0.98	53	52	0.50	105
451-475	1.00	43	43	0.50	86
476-500	1.21	48	58	0.55	106
501-525	1.09	77	84	0.52	161
526-550	1.07	99	106	0.52	205
551-575	0.95	86	82	0.49	168
576-600	1.05	64	67	0.51	131
601-625	1.45	42	61	0.59	103
626-650	1.18	38	45	0.54	83
651-675	1.73	15	26	0.63	41
676-700	1.39	31	43	0.58	74
701-725	1.93	28	54	0.66	82
726-750	1.57	28	44	0.61	72
751-775	2.14	21	45	0.68	66
776-800	2.81	16	45	0.74	61
801-825	1.58	12	19	0.61	31
826-850	1.38	8	11	0.58	19
851-875	1.38	8	11	0.58	19
876-900	3.00	4	12	0.75	16
901-925		0	4	1.00	4
926-950		0	2	1.00	2
951-975					0
976-1000		0	2	1.00	2
Total		**1090**	**1106**		**2196**

Table 2.17

Red Snapper length – length conversion equations and whole weight – gutted weight no intercept equation. TL_{max}: maximum Total Length (with "pinched" caudal fin), TL_{nat}: Natural Total Length (with caudal fin spread) FL: Fork length, SL: Standard length, WW: whole wet weight, GW: gutted wet weight. Range is length or weight range. **Linear regression: y=a*x+b.** Note that the assessment units will be Maximum Total Length (TL_{max}) in mm for length and pound for weight. See also Figures 2.17.

Variables	Units	a (SE)	b (SE)	n	R^2	Range of X
TL_{max} = TL_{nat}	mm	4.62 (1.16)	1.02 (0.00)	1,872	0.99	321 - 943
TL_{max} = FL	mm	2.22 (0.45)	1.07 (0.00)	4,691	0.997	64 - 955
TL_{max} = SL	mm	22.09 (0.83)	1.22 (0.00)	4,622	0.99	54 - 825
TL_{nat} = FL	mm	14.45 (1.32)	1.03 (0.00)	4,108	0.98	240 - 910
TL_{nat} = SL	mm	38.83 (2.06)	1.15 (0.00)	1,832	0.98	242 - 770
TL_{nat} = TL_{max}	mm	-0.54 (1.14)	0.97 (0.00)	1,872	0.99	324 - 970
FL = TL_{nat}	mm	-1.89 (1.29)	0.95 (0.00)	4,108	0.98	262 - 970
FL = SL	mm	19.36 (0.73)	1.14 (0.00)	4,559	0.99	54 - 825
FL = TL_{max}	mm	-0.58 (0.42)	0.93 (0.00)	4,691	0.997	70 - 997
SL = FL	mm	-12.98 (0.66)	0.87 (0.00)	4,559	0.99	64 - 955
SL = TL_{nat}	mm	-21.24 (1.86)	0.85 (0.00)	1,832	0.98	321 - 946
SL = Tl_{max}	mm	-13.44 (0.70)	0.81 (0.00)	4,622	0.99	70 - 997
WW = GW	g	no intercept	1.10 (0.00)	937	0.999	148 - 14,710

Table 2.18

Red Snapper Ln – Ln transformed whole weight (g)– length (mm) and the inverse of that regression converted to the power equation . TL_{max}: maximum Total Length (with "pinched" caudal fin), TL_{nat}: Natural Total Length (with caudal fin spread) FL: Fork length, SL: Standard length, W: whole wet weight. Range is length or weight range. Note that the assessment units will be Maximum Total Length (TL_{max}) in mm for length and pound for weight. See also Figure 2.18.

Variables	Units	a (SE)	b (SE)	MSE	n	R^2	Range of X	Converted Power Equation
W = TL_{max}	g, mm	-11.06 (0.04)	2.99 (0.01)	0.01	2,930	0.99	90 - 997	$W = 1.65*10^{-5} L^{2.99}$
W = TL_{nat}	g, mm	-11.17 (0.03)	3.01 (0.00)	0.02	13,565	0.97	197 - 1024	$W = 1.42*10^{-5} L^{3.01}$
W = FL	g, mm	-11.07 (0.04)	3.03 (0.01)	0.03	7,106	0.97	47 - 955	$W = 1.58*10^{-5} L^{3.03}$
W = SL	g, mm	-9.69 (0.05)	2.88 (0.01)	0.02	2,893	0.98	71 - 813	$W = 6.25*10^{-5} L^{2.88}$
TL_{max} = W	mm, g	3.73 (0.01)	0.33 (0.00)	0	2,936	0.98	12 - 15,850	$L = 41.89 W^{0.33}$
TL_{nat} = W	mm, g	3.78 (0.00)	0.32 (0.00)	0	13,565	0.97	80 - 18,000	$L = 43.82 W^{0.32}$
FL = W	mm, g	3.74 (0.01)	0.32 (0.00)	0	7,106	0.97	12 - 15,850	$L = 42.10 W^{0.32}$

Table 2.19

Number of trips (gear deployments) that collected Red Snapper, by gear type, and year, from Fishery Independent Surveys (MARMAP/SEAMAP-SA, and SEFIS) used by LHWG. Gear codes on the top row are SCDNR Marine Resources Research Institute (MRRI) gear codes: 000=unknown. 014= hook and line; 022=Yankee trawl; 041=mini Antillean s-trap- baited; 043=snapper/bandit reel, electric or manual; 053=blackfish trap; 065=spear gun; 071=flatline otter trawl; 073=experimental trap; 074=Florida Antillean trap; 233=75' Falcon Trawl without TED; 324=chevron trap.

	SCDNR MRRI Gear code														
Year	**000**	**014**	**022**	**041**	**043**	**053**	**061**	**065**	**071**	**073**	**074**	**226**	**233**	**324**	**Totals**
1977	0	0	1	0	2	0	0	0	0	0	0	0	0	0	**3**
1978	0	0	1	1	1	0	0	0	0	0	0	0	0	0	**3**
1979	2	0	0	0	6	0	0	0	2	0	0	0	0	0	**10**
1980	0	0	0	0	5	0	0	0	0	0	0	1	0	0	**6**
1981	0	0	0	0	2	0	0	0	0	0	2	0	0	0	**4**
1982	0	0	0	0	3	0	0	0	0	0	1	0	0	0	**4**
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1984	0	0	0	0	6	0	0	0	0	0	0	0	0	0	**6**
1985	0	0	0	0	0	2	0	0	0	0	1	0	0	0	**3**
1986	1	0	0	0	1	1	0	0	0	0	1	0	1	0	**5**
1987	0	1	0	0	2	1	0	0	0	0	0	0	0	0	**4**
1988	0	1	0	0	4	1	0	0	0	0	1	0	0	7	**14**
1989	0	3	0	0	1	0	0	0	0	0	0	0	0	4	**8**
1990	0	2	0	0	1	0	0	0	0	0	0	0	0	8	**11**
1991	0	2	0	0	0	0	0	0	0	0	0	0	0	9	**11**
1992	0	1	0	0	0	0	0	0	0	0	0	0	0	9	**10**
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	12	**12**
1994	0	2	0	0	2	0	0	0	0	0	0	0	0	19	**23**
1995	0	4	0	0	0	0	0	1	0	0	0	0	0	14	**19**
1996	0	1	0	0	17	0	0	0	0	0	0	0	0	9	**27**
1997	0	0	0	0	41	0	0	0	0	0	0	0	0	7	**48**
1998	0	1	0	0	2	0	0	0	0	0	0	0	0	8	**11**
1999	0	0	0	0	15	0	0	0	0	0	0	0	2	4	**21**
2000	0	0	0	0	25	0	0	7	0	0	0	0	2	8	**42**
2001	0	0	0	0	7	0	0	3	0	0	0	0	0	7	**17**
2002	0	0	0	0	2	0	0	0	0	0	0	0	0	15	**17**
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**1**
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	4	**4**
2005	0	0	0	0	1	0	0	0	0	0	0	0	0	7	**8**
2006	0	0	0	0	0	0	0	0	0	0	0	0	0	5	**5**
2007	0	2	0	0	0	0	1	0	0	0	0	0	0	8	**11**
2008	0	2	0	0	2	0	0	0	0	0	0	0	0	11	**15**
2009	0	3	0	0	7	0	0	1	0	1	0	0	0	9	**21**
2010	0	3	0	0	1	0	0	0	0	0	0	0	1	73	**78**
2011	0	6	0	0	0	0	1	0	0	0	0	0	0	70	**77**
2012	0	29	0	0	10	0	1	3	0	0	0	0	0	155	**198**
2013	0	47	0	0	12	0	0	0	0	0	0	0	4	142	**205**
Total	**3**	**110**	**2**	**1**	**178**	**5**	**3**	**15**	**2**	**1**	**6**	**1**	**10**	**625**	**962**

Table 2.20

Number of Red Snapper specimens with life history data, by gear type, and year, collected by fishery independent Surveys (MARMAP, SEAMAP-SA, and SEFIS) used by LHWG. Gear codes in top row are SCDNR Marine Resources Research Institute (MRRI) gear codes: 000=unknown. 014= hook and line; 022=Yankee trawl; 041=mini Antillean s-trap- baited; 043=snapper/bandit reel, electric or manual; 053=blackfish trap; 065=spear gun; 071=flatline otter trawl; 073=experimental trap; 074=Florida Antillean trap; 233=75' Falcon Trawl without TED; 324=chevron trap.

	SCDNR MRRI Gear Code														
Year	**000**	**014**	**022**	**041**	**043**	**053**	**061**	**065**	**071**	**073**	**074**	**226**	**233**	**324**	**Total**
1977	0	0	1	0	2	0	0	0	0	0	0	0	0	0	**3**
1978	0	0	1	2	1	0	0	0	0	0	0	0	0	0	**4**
1979	6	0	0	0	42	0	0	0	19	0	0	0	0	0	**67**
1980	0	0	0	0	11	0	0	0	0	0	0	5	0	0	**16**
1981	0	0	0	0	3	0	0	0	0	0	8	0	0	0	**11**
1982	0	0	0	0	39	0	0	0	0	0	1	0	0	0	**40**
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1984	0	0	0	0	37	0	0	0	0	0	0	0	0	0	**37**
1985	0	0	0	0	0	2	0	0	0	0	1	0	0	0	**3**
1986	7	0	0	0	1	1	0	0	0	0	1	0	1	0	**11**
1987	0	2	0	0	2	1	0	0	0	0	0	0	0	0	**5**
1988	0	5	0	0	14	1	0	0	0	0	1	0	0	29	**50**
1989	0	4	0	0	2	0	0	0	0	0	0	0	0	5	**11**
1990	0	3	0	0	1	0	0	0	0	0	0	0	0	24	**28**
1991	0	10	0	0	0	0	0	0	0	0	0	0	0	22	**32**
1992	0	11	0	0	0	0	0	0	0	0	0	0	0	21	**32**
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	31	**31**
1994	0	6	0	0	7	0	0	0	0	0	0	0	0	44	**57**
1995	0	7	0	0	0	0	0	4	0	0	0	0	0	29	**40**
1996	0	3	0	0	44	0	0	0	0	0	0	0	0	11	**58**
1997	0	0	0	0	145	0	0	0	0	0	0	0	0	26	**171**
1998	0	2	0	0	23	0	0	0	0	0	0	0	0	25	**50**
1999	0	0	0	0	187	0	0	0	0	0	0	0	3	22	**212**
2000	0	0	0	0	261	0	0	138	0	0	0	0	2	17	**418**
2001	0	0	0	0	11	0	0	51	0	0	0	0	0	9	**71**
2002	0	0	0	0	3	0	0	0	0	0	0	0	0	39	**42**
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	7	**7**
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	5	**5**
2005	0	0	0	0	1	0	0	0	0	0	0	0	0	12	**13**
2006	0	0	0	0	0	0	0	0	0	0	0	0	0	6	**6**
2007	0	5	0	0	0	0	1	0	0	0	0	0	0	29	**35**
2008	0	3	0	0	10	0	0	0	0	0	0	0	0	29	**42**
2009	0	3	0	0	27	0	0	2	0	7	0	0	0	11	**50**
2010	0	3	0	0	1	0	0	0	0	0	0	0	1	168	**173**
2011	0	8	0	0	0	0	1	0	0	0	0	0	0	121	**130**
2012	0	70	0	0	23	0	1	5	0	0	0	0	0	430	**529**
2013	0	132	0	0	15	0	0	0	0	0	0	0	7	375	**529**
Total	**13**	**277**	**2**	**2**	**913**	**5**	**3**	**200**	**19**	**7**	**12**	**5**	**14**	**1547**	**3019**

Table 2.21

Number of Red Snapper specimens with age data, by gear type, and year, collected by fishery independent surveys (MARMAP, SEAMAP-SA, and SEFIS) used by LHWG. Gear codes in top row are SCDNR Marine Resources Research Institute (MRRI) gear codes: 000=unknown. 014= hook and line; 022=Yankee trawl; 041=mini Antillean s-trap- baited; 043=snapper/bandit reel, electric or manual; 053=blackfish trap; 065=spear gun; 071=flatline otter trawl; 073=experimental trap; 074=Florida Antillean trap; 233=75' Falcon Trawl without TED; 324=chevron trap.

	SCDNR MRRI Gear Code													
Year	**000**	**014**	**022**	**041**	**043**	**053**	**061**	**065**	**071**	**073**	**074**	**226**	**233**	**324**	**Totals**
1977	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1978	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1980	0	0	0	0	10	0	0	0	0	0	0	4	0	0	**14**
1981	0	0	0	0	3	0	0	0	0	0	8	0	0	0	**11**
1982	0	0	0	0	36	0	0	0	0	0	0	0	0	0	**36**
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1984	0	0	0	0	2	0	0	0	0	0	0	0	0	0	**2**
1985	0	0	0	0	0	2	0	0	0	0	1	0	0	0	**3**
1986	0	0	0	0	1	1	0	0	0	0	1	0	0	0	**3**
1987	0	1	0	0	1	1	0	0	0	0	0	0	0	0	**3**
1988	0	4	0	0	14	1	0	0	0	0	1	0	0	28	**48**
1989	0	2	0	0	2	0	0	0	0	0	0	0	0	4	**8**
1990	0	3	0	0	1	0	0	0	0	0	0	0	0	24	**28**
1991	0	7	0	0	0	0	0	0	0	0	0	0	0	19	**26**
1992	0	11	0	0	0	0	0	0	0	0	0	0	0	20	**31**
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	29	**29**
1994	0	6	0	0	7	0	0	0	0	0	0	0	0	42	**55**
1995	0	7	0	0	0	0	0	4	0	0	0	0	0	28	**39**
1996	0	2	0	0	37	0	0	0	0	0	0	0	0	10	**49**
1997	0	0	0	0	138	0	0	0	0	0	0	0	0	24	**162**
1998	0	2	0	0	21	0	0	0	0	0	0	0	0	25	**48**
1999	0	0	0	0	180	0	0	0	0	0	0	0	3	19	**202**
2000	0	0	0	0	251	0	0	124	0	0	0	0	2	15	**392**
2001	0	0	0	0	9	0	0	30	0	0	0	0	0	7	**46**
2002	0	0	0	0	3	0	0	0	0	0	0	0	0	38	**41**
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	7	**7**
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	5	**5**
2005	0	0	0	0	1	0	0	0	0	0	0	0	0	12	**13**
2006	0	0	0	0	0	0	0	0	0	0	0	0	0	6	**6**
2007	0	5	0	0	0	0	1	0	0	0	0	0	0	29	**35**
2008	0	3	0	0	10	0	0	0	0	0	0	0	0	29	**42**
2009	0	3	0	0	26	0	0	2	0	7	0	0	0	11	**49**
2010	0	3	0	0	0	0	0	0	0	0	0	0	0	167	**170**
2011	0	8	0	0	0	0	1	0	0	0	0	0	0	120	**129**
2012	0	62	0	0	18	0	1	5	0	0	0	0	0	416	**502**
2013	0	129	0	0	13	0	0	0	0	0	0	0	7	368	**517**
Totals	**0**	**258**	**0**	**0**	**784**	**5**	**3**	**165**	**0**	**7**	**11**	**4**	**12**	**1502**	**2751**

Table 2.22

Number of Red Snapper specimens with reproductive data, by gear type, and year, collected by fishery independent surveys (MARMAP, SEAMAP-SA, and SEFIS) used by LHWG. Gear codes in top row are SCDNR Marine Resources Research Institute (MRRI) gear codes: 000=unknown. 014= hook and line; 022=Yankee trawl; 041=mini Antillean s-trap- baited; 043=snapper/bandit reel, electric or manual; 053=blackfish trap; 065=spear gun; 071=flatline otter trawl; 073=experimental trap; 074=Florida Antillean trap; 233=75’ Falcon Trawl without TED; 324=chevron trap.

	SCDNR MRRI Gear Code														
Year	**000**	**014**	**022**	**041**	**043**	**053**	**061**	**065**	**071**	**073**	**074**	**226**	**233**	**324**	**Total**
1979	0	0	0	0	15	0	0	0	0	0	0	0	0	0	**15**
1980	0	0	0	0	11	0	0	0	0	0	0	5	0	0	**16**
1981	0	0	0	0	2	0	0	0	0	0	8	0	0	0	**10**
1982	0	0	0	0	2	0	0	0	0	0	1	0	0	0	**3**
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1984	0	0	0	0	9	0	0	0	0	0	0	0	0	0	**9**
1985	0	0	0	0	0	1	0	0	0	0	0	0	0	0	**1**
1986	0	0	0	0	1	1	0	0	0	0	1	0	1	0	**4**
1987	0	2	0	0	2	0	0	0	0	0	0	0	0	0	**4**
1988	0	5	0	0	14	1	0	0	0	0	1	0	0	29	**49**
1989	0	3	0	0	2	0	0	0	0	0	0	0	0	4	**9**
1990	0	3	0	0	1	0	0	0	0	0	0	0	0	24	**28**
1991	0	10	0	0	0	0	0	0	0	0	0	0	0	22	**32**
1992	0	11	0	0	0	0	0	0	0	0	0	0	0	21	**32**
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	31	**31**
1994	0	6	0	0	7	0	0	0	0	0	0	0	0	44	**57**
1995	0	2	0	0	0	0	0	0	0	0	0	0	0	12	**14**
1996	0	0	0	0	19	0	0	0	0	0	0	0	0	10	**29**
1997	0	0	0	0	56	0	0	0	0	0	0	0	0	26	**82**
1998	0	2	0	0	21	0	0	0	0	0	0	0	0	25	**48**
1999	0	0	0	0	152	0	0	0	0	0	0	0	0	22	**174**
2000	0	0	0	0	250	0	0	132	0	0	0	0	0	15	**397**
2001	0	0	0	0	3	0	0	40	0	0	0	0	0	9	**52**
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	38	**38**
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	7	**7**
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	5	**5**
2005	0	0	0	0	1	0	0	0	0	0	0	0	0	12	**13**
2006	0	0	0	0	0	0	0	0	0	0	0	0	0	6	**6**
2007	0	5	0	0	0	0	1	0	0	0	0	0	0	27	**33**
2008	0	3	0	0	0	0	0	0	0	0	0	0	0	28	**31**
2009	0	3	0	0	0	0	0	0	0	7	0	0	0	10	**20**
2010	0	3	0	0	1	0	0	0	0	0	0	0	1	164	**169**
2011	0	8	0	0	0	0	1	0	0	0	0	0	0	120	**129**
2012	0	53	0	0	18	0	1	5	0	0	0	0	0	430	**507**
2013	0	76	0	0	14	0	0	0	0	0	0	0	0	374	**464**
Total	**0**	**195**	**0**	**0**	**601**	**3**	**3**	**177**	**0**	**7**	**11**	**5**	**2**	**1515**	**2519**

Table 2.23

Number of Red Snapper specimens with reproductive data, by state, and year, collected by fishery independent surveys (MARMAP, SEAMAP-SA, and SEFIS) used by LHWG.

Year	FL	GA	SC	NC	Total
1979	0	0	0	0	**0**
1980	0	0	0	0	**0**
1981	0	0	0	0	**0**
1982	0	0	0	0	**0**
1983	0	0	0	0	**0**
1984	0	0	0	0	**0**
1985	0	0	0	0	**0**
1986	0	0	0	0	**0**
1987	0	0	0	0	**0**
1988	0	0	24	0	**24**
1989	0	0	4	0	**4**
1990	0	0	24	0	**24**
1991	0	0	22	0	**22**
1992	0	0	20	1	**21**
1993	0	3	28	0	**31**
1994	0	7	37	0	**44**
1995	0	3	9	0	**12**
1996	1	1	8	0	**10**
1997	14	0	12	0	**26**
1998	0	9	16	0	**25**
1999	21	0	1	0	**22**
2000	1	4	10	0	**15**
2001	0	6	3	0	**9**
2002	27	6	5	0	**38**
2003	7	0	0	0	**7**
2004	0	2	3	0	**5**
2005	1	6	5	0	**12**
2006	1	3	2	0	**6**
2007	4	21	2	0	**27**
2008	7	9	12	0	**28**
2009	2	6	2	0	**10**
2010	129	28	6	1	**164**
2011	102	11	7	0	**120**
2012	311	22	16	81	**430**
2013	256	36	24	58	**374**
Total	**884**	**183**	**302**	**141**	**1510**

Table 2.24

Number of positive trap deployments with Red Snapper, by year, and state, collected by fishery independent surveys (MARMAP, SEAMAP-SA, and SEFIS) used by LHWG.

Year	FL	GA	SC	NC	Totals
1979	0	0	0	0	**0**
1980	0	0	0	0	**0**
1981	0	0	0	0	**0**
1982	0	0	0	0	**0**
1983	0	0	0	0	**0**
1984	0	0	0	0	**0**
1985	0	0	0	0	**0**
1986	0	0	0	0	**0**
1987	0	0	0	0	**0**
1988	1	0	6	0	**7**
1989	1	0	3	0	**4**
1990	0	0	8	0	**8**
1991	0	0	9	0	**9**
1992	0	0	8	1	**9**
1993	0	2	10	0	**12**
1994	0	4	15	0	**19**
1995	0	2	12	0	**14**
1996	1	1	7	0	**9**
1997	3	0	4	0	**7**
1998	0	4	4	0	**8**
1999	3	0	1	0	**4**
2000	1	3	4	0	**8**
2001	0	4	3	0	**7**
2002	7	4	4	0	**15**
2003	1	0	0	0	**1**
2004	0	2	2	0	**4**
2005	1	3	3	0	**7**
2006	1	2	2	0	**5**
2007	3	4	1	0	**8**
2008	6	1	4	0	**11**
2009	2	5	2	0	**9**
2010	47	20	5	1	**73**
2011	54	10	6	0	**70**
2012	93	11	10	41	**155**
2013	90	20	11	21	**142**
Totals	**315**	**102**	**144**	**64**	**625**

Table 2.25

Number of Red snapper captured by year, and state, collected by fishery independent surveys (MARMAP, SEAMAP-SA, and SEFIS) used by LHWG.

Year	FL	GA	SC	NC	Total
1979	0	0	0	0	**0**
1980	0	0	0	0	**0**
1981	0	0	0	0	**0**
1982	0	0	0	0	**0**
1983	0	0	0	0	**0**
1984	0	0	0	0	**0**
1985	0	0	0	0	**0**
1986	0	0	0	0	**0**
1987	0	0	0	0	**0**
1988	0	0	24	0	**24**
1989	0	0	4	0	**4**
1990	0	0	24	0	**24**
1991	0	0	22	0	**22**
1992	0	0	20	1	**21**
1993	0	3	28	0	**31**
1994	0	7	37	0	**44**
1995	0	3	26	0	**29**
1996	1	1	9	0	**11**
1997	14	0	12	0	**26**
1998	0	9	16	0	**25**
1999	21	0	1	0	**22**
2000	2	5	10	0	**17**
2001	0	6	3	0	**9**
2002	27	7	5	0	**39**
2003	7	0	0	0	**7**
2004	0	2	3	0	**5**
2005	1	6	5	0	**12**
2006	1	3	2	0	**6**
2007	4	23	2	0	**29**
2008	8	9	12	0	**29**
2009	2	7	2	0	**11**
2010	129	32	6	1	**168**
2011	103	11	7	0	**121**
2012	311	22	16	81	**430**
2013	256	36	24	59	**375**
Total	**887**	**192**	**320**	**142**	**1541**

Table 2.26

Number of Red Snapper specimens with age data, by state, and year, collected by fishery independent surveys (MARMAP, SEAMAP-SA, and SEFIS) used by LHWG.

Year	FL	GA	SC	NC	Total
1979	0	0	0	0	**0**
1980	0	0	0	0	**0**
1981	0	0	0	0	**0**
1982	0	0	0	0	**0**
1983	0	0	0	0	**0**
1984	0	0	0	0	**0**
1985	0	0	0	0	**0**
1986	0	0	0	0	**0**
1987	0	0	0	0	**0**
1988	0	0	24	0	**24**
1989	0	0	4	0	**4**
1990	0	0	24	0	**24**
1991	0	0	19	0	**19**
1992	0	0	19	1	**20**
1993	0	3	26	0	**29**
1994	0	7	35	0	**43**
1995	0	3	25	0	**28**
1996	1	1	8	0	**10**
1997	13	0	11	0	**24**
1998	0	9	16	0	**25**
1999	18	0	1	0	**19**
2000	2	4	9	0	**15**
2001	0	5	2	0	**7**
2002	26	7	5	0	**38**
2003	7	0	0	0	**7**
2004	0	2	3	0	**5**
2005	1	6	5	0	**12**
2006	1	3	2	0	**6**
2007	4	23	2	0	**29**
2008	8	9	12	0	**29**
2009	2	7	2	0	**11**
2010	128	32	6	1	**167**
2011	102	11	7	0	**120**
2012	306	21	15	74	**416**
2013	250	36	23	59	**368**
Total	**869**	**189**	**305**	**135**	**1498**

Table 2.27

Comparison of LH DW parameter recommendations for SEDAR 41 (SA) and those used in the GoM in previous SEDAR assessments.

Parameter	SEDAR 41	GOM value	SEDAR 31 SAR page #	SA value	SEDAR 24 SAR page #	Notes
M	Age varying, scaled (1.395 age 1 - 0.279 age 51)	0.094277 (age-variant)	437	0.08 (age-varying, scaled)	346	
Linf	911.4 mmTL	856.374	438	902	344	
k	0.24	0.191852	438	0.24	344	
t0	-0.33	-0.394525	438	-0.03	344	
Annual fecundity	See section 2.8.5. of LH report	See Table 2.1.4.1	438	Gonad weight and GSI	81 & 347	
Sex ratio	1:1	1 to 1	84	1 to 1	347	
Maximum age	51	57 (see inserted comment)	437	54	15	
age	otoliths - sectioned Calendar age					
Age at maturity	Female A50=1.3 yr; males: 94% age 1, 98% age 2, 99% age 3, 100% age 4+	2	86	See Table 5.2 and Table 5	19 & 344	
length at maturity	Fenale L50=325 mmTL; male L50=166 mm TL					
Maturity schedule		?	84 & 86	See Table 5.2 and Table 5	19 & 344	
Spawning seasonality	April - September	May through September, peak spawning June – August	86		79	
Spawning frequency	See section 2.8.5. of LH report	?	86 #s 8-10		80	
Discard mortality SA Recreational 2011 to present	28.5% (20% to 36%)					
Discard mortality SA Recreational pre-2011	37% (27% to 45%)					
Discard mortality SA Commercial 2007 to present	38% (28% to 48%)					
Discard mortality SA Commercial pre-2007	48% (38% to 58%)					
Discard mortality - for-hire				0.41	347	
Discard mortality - private				0.39	347	
Discard mortality - commercial handline; eastern GOM; closed season; no venting		0.74	443 & 457			For GOM, see Table 2.7.3
Discard mortality - commercial handline; eastern GOM; closed season; venting		0.55	443 & 457			
Discard mortality - commercial handline; eastern GOM; open season; no venting		0.75	443 & 457			
Discard mortality - commercial handline; eastern GOM; open season; venting		0.56	443 & 457			
Discard mortality - commercial handline; western GOM; closed season; no venting		0.87	443 & 457			
Discard mortality - commercial handline; western GOM; closed season; venting		0.74	443 & 457			
Discard mortality - commercial handline; western GOM; open season; no venting		0.78	443 & 457			
Discard mortality - commercial handline; western GOM; open season; venting		0.6	443 & 457			
Discard mortality - commercial longline eastern GOM; closed season; no venting		0.82	443 & 457			
Discard mortality - commercial longline eastern GOM; closed season; venting		0.66	443 & 457			
Discard mortality - commercial longline eastern GOM; open season; no venting		0.81	443 & 457			
Discard mortality - commercial longline eastern GOM; open season; venting		0.64	443 & 457			
Discard mortality - commercial longline western GOM; closed season; no venting		0.95	443 & 457			
Discard mortality - commercial longline western GOM; closed season; venting		0.88	443 & 457			
Discard mortality - commercial longline western GOM; open season; no venting		0.91	443 & 457			
Discard mortality - commercial longline western GOM; open season; venting		0.81	443 & 457			
Discard mortality - recreational; eastern GOM; closed season; no venting		0.21	443 & 457			
Discard mortality - recreational; eastern GOM; closed season; venting		0.1	443 & 457			
Discard mortality - recreational; eastern GOM; open season; no venting		0.21	443 & 457			
Discard mortality - recreational; eastern GOM; open season; venting		0.1	443 & 457			
Discard mortality - recreational; western GOM; closed season; no venting		0.22	443 & 457			
Discard mortality - recreational; western GOM; closed season; venting		0.11	443 & 457			
Discard mortality - recreational; western GOM; open season; no venting		0.22	443 & 457			
Discard mortality - recreational; western GOM; open season; venting		0.1	443 & 457			

2.16 Figures

Figure 2.1

Computer Generated Native Distribution Map for Red Snapper (*Lutjanus campechanus*) in red and modeled future range map based on IPCC A2 emissions scenario in yellow. www.aquamaps.org, version of Aug. 2013. Web. Accessed 5 Aug. 2014.

Figure 2.2

Discard mortality function by depth (m) for Red Snapper derived from Burns et al. (2002) and used in SEDAR 24. This is the preferred function to estimate the pre-regulation discard mortality for the commercial sector in SEDAR 41.

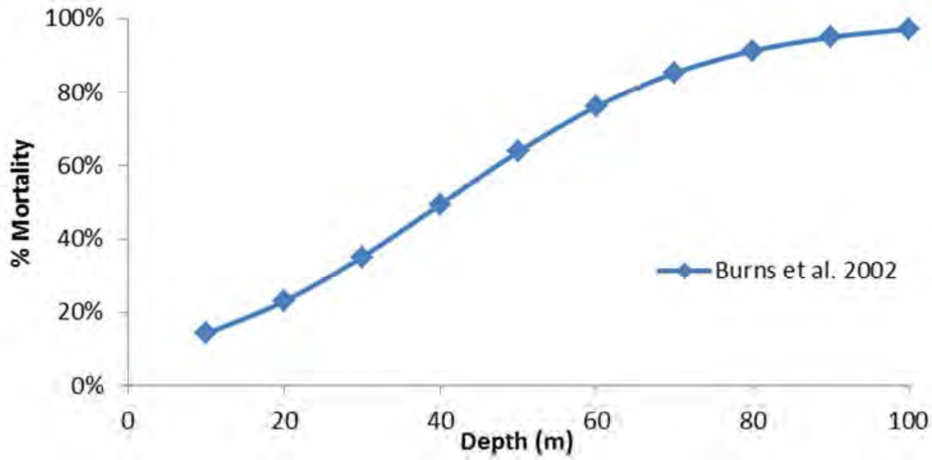

Figure 2.3

Proportion of total discards by depth of observed discards for Red Snapper in the charter boat and headboat fishery off Florida, observed discards for Red Snapper in commercial fishery in the South Atlantic, and reported depths fished during the Red Snapper mini-season off Florida.

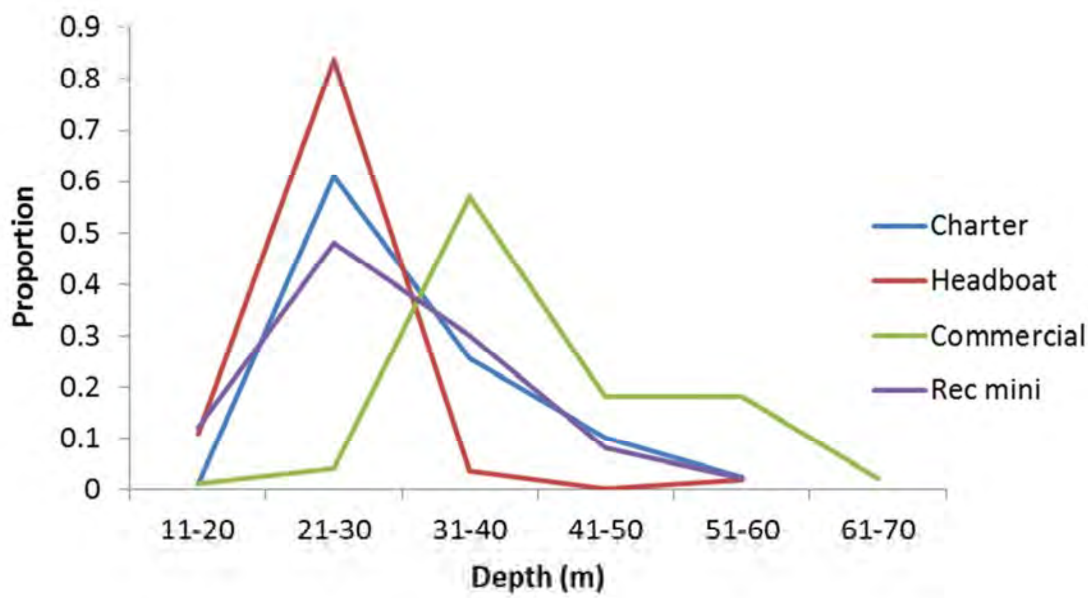

Figure 2.4

The percent of discard mortality associated with regulations plotted with total discard mortality based on data from SEDAR 31 for Red Snapper in the GoM. Linear regression analysis results are given in the legend.

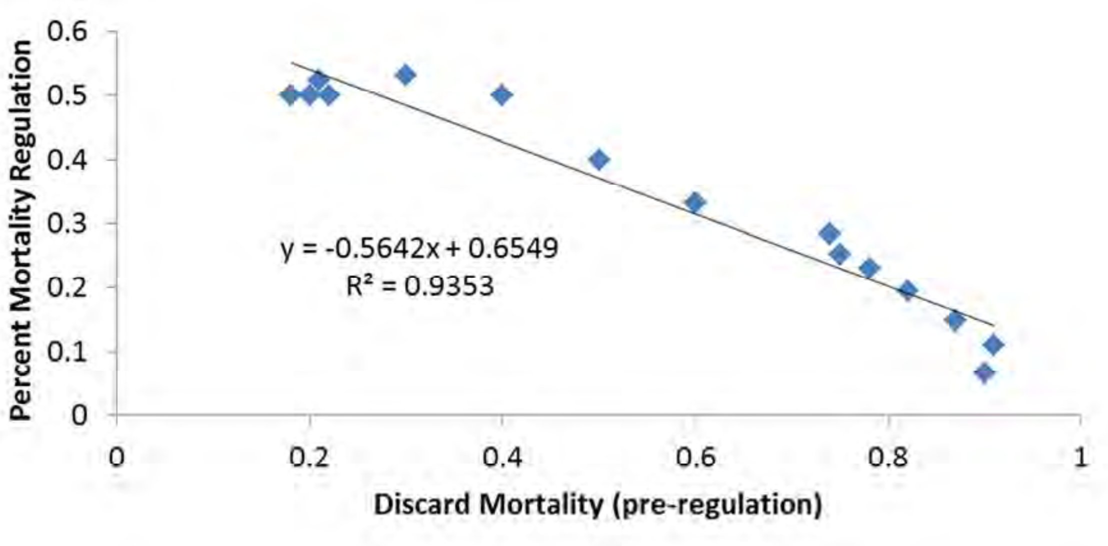

Figure 2.5

Between lab age reading bias plots of Red Snapper calibration set. Error bars represent 95% confidence intervals.

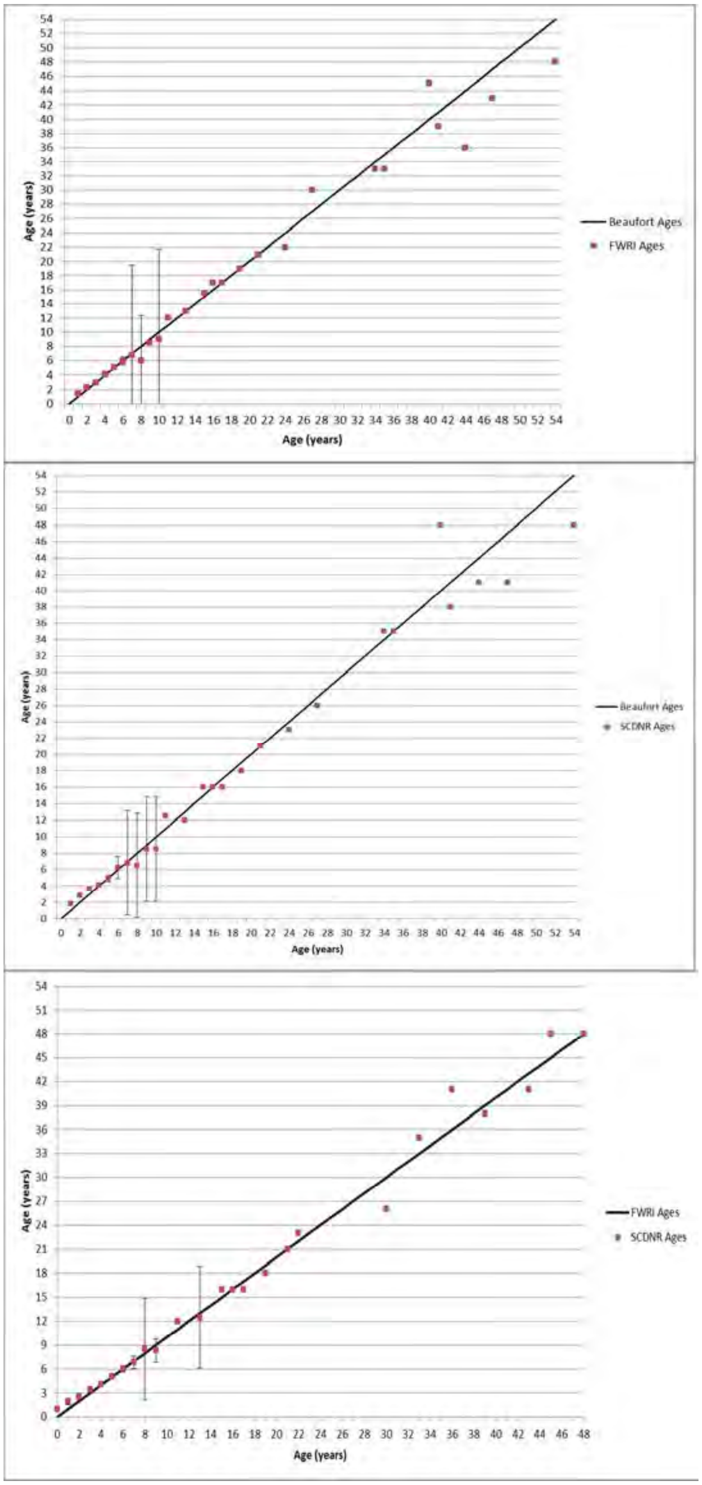

Figure 2.6

Population growth model of U.S. South Atlantic Red Snapper,

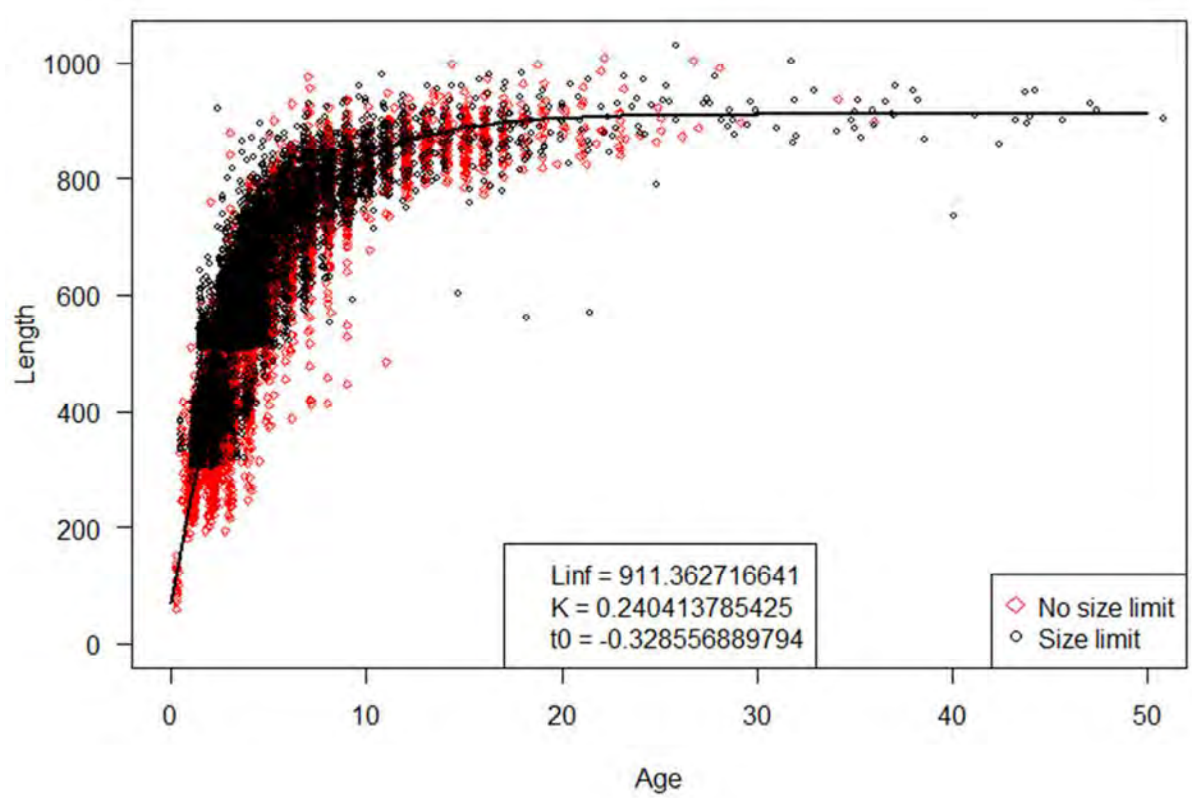

Figure 2.7

Fishery-dependent growth model of U.S. South Atlantic Red Snapper,

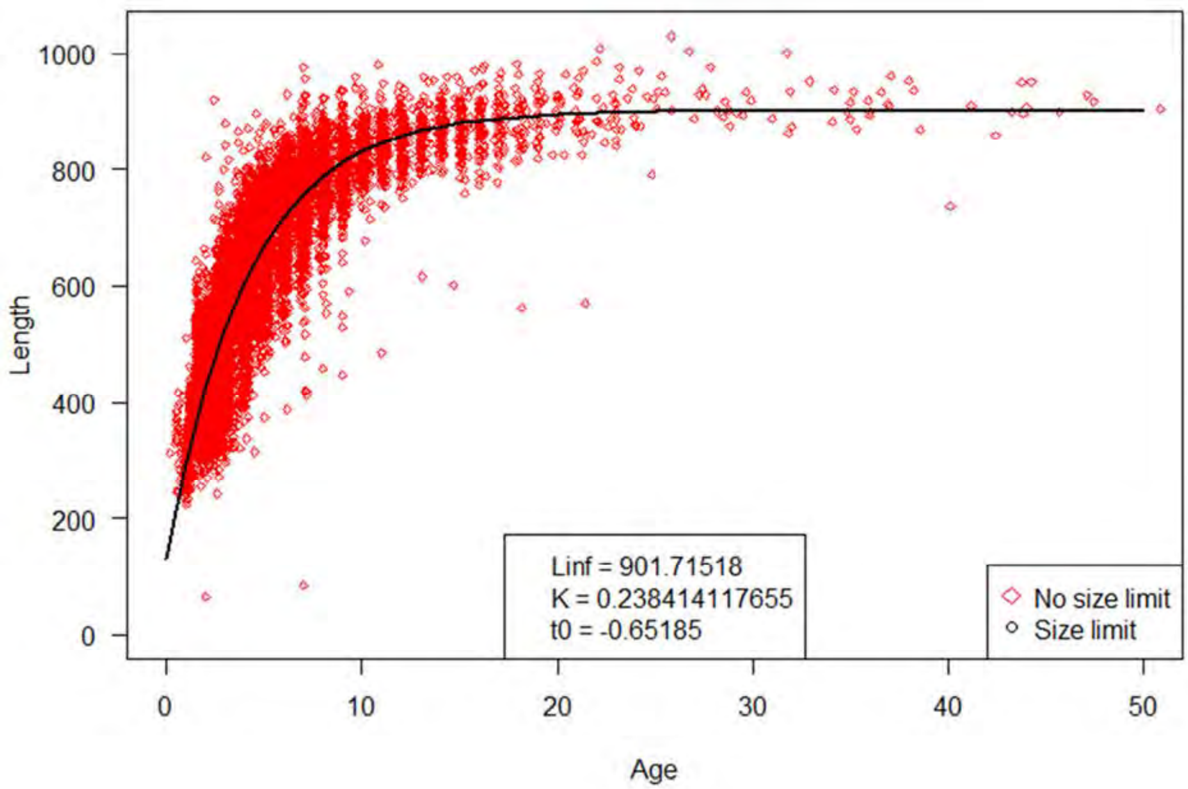

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Figure 2.8

U.S. South Atlantic Red Snapper male and female maximum total length at age. Error bars represent 95% confidence intervals.

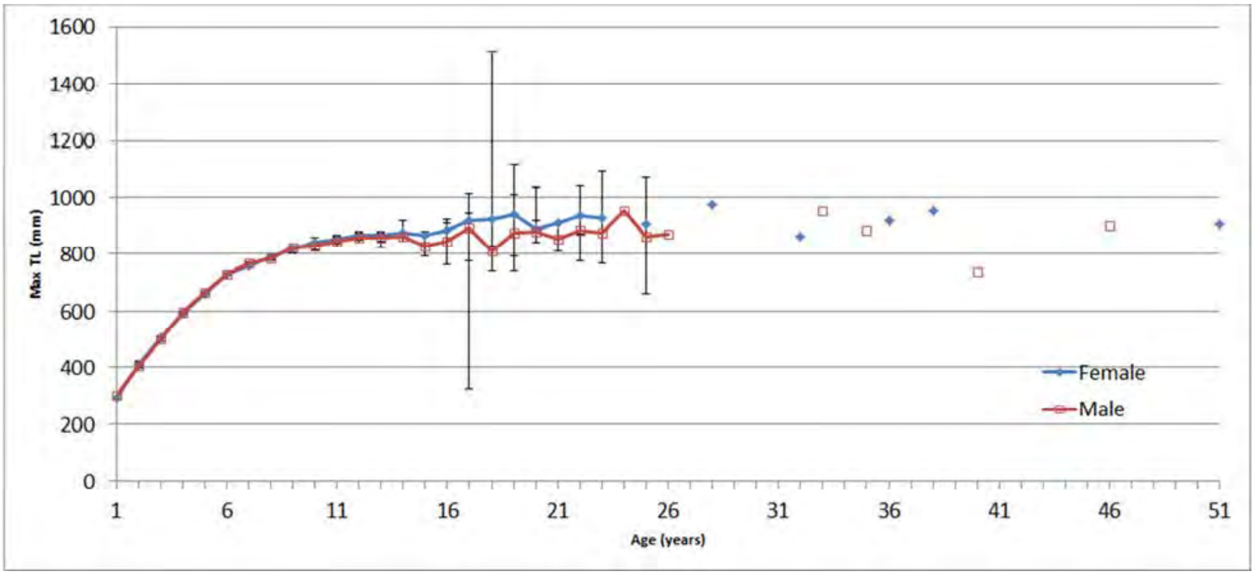


Figure 2.9

Female Red Snapper spawning seasonality, 1979-2013. Developing= Primary growth oocytes and cortical alveoli stage through partially yolked oocytes, Regenerating= Primary growth oocytes only, may have traces of late-stage atresia, Vitellogenic= mid- to late-vitellogenic oocytes present, Immature=Primary growth oocytes only, Regressing=More than 50% of vitellogenic oocytes undergoing alpha or beta atresia, Spawning= Completion of yolk coalescence & hydration and/or presence of POCs.

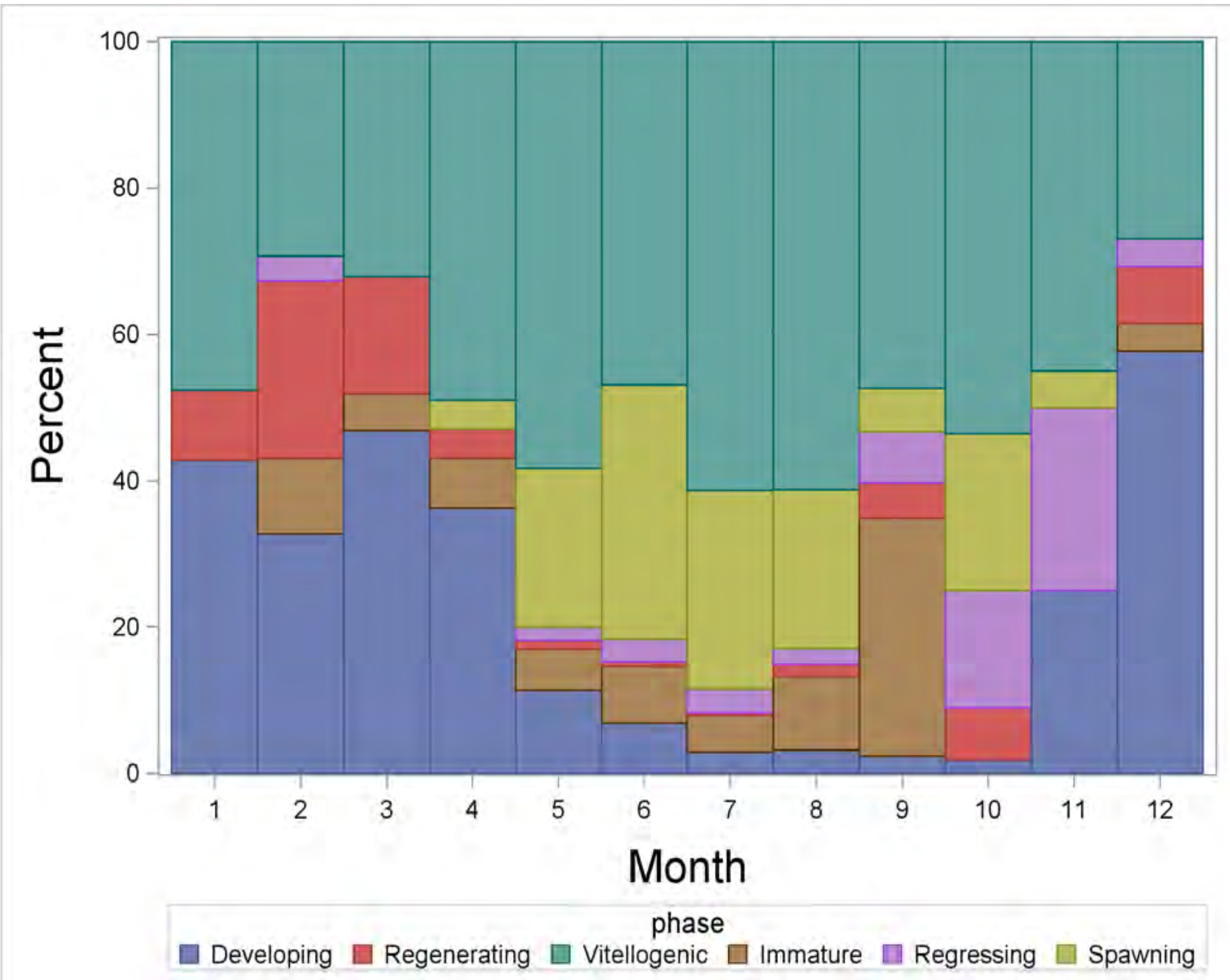


Figure 2.10

Locations where spawning female Red Snapper were collected by fishery-independent sources, 1977-2013.

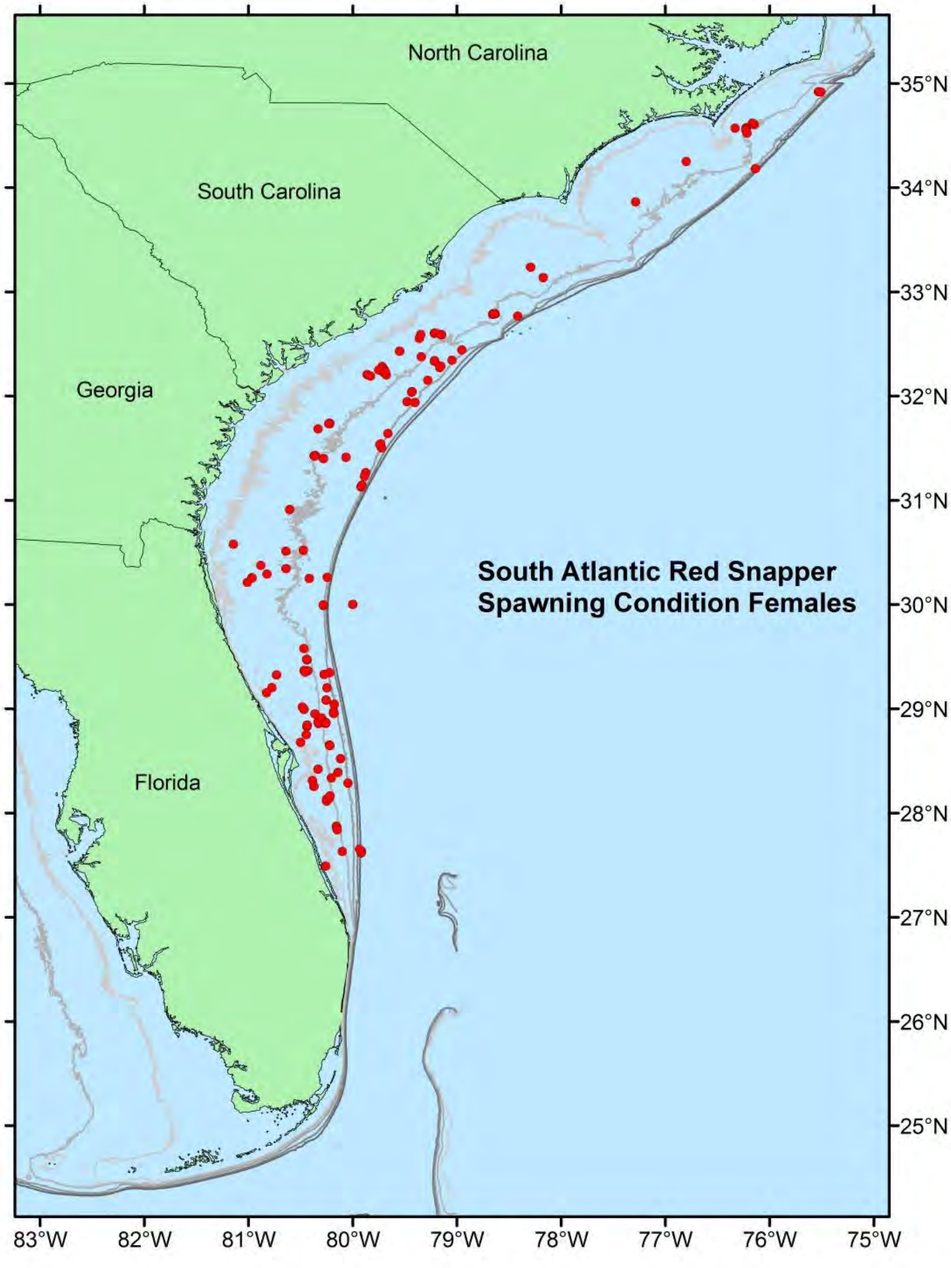


Figure 2.11

Locations where specimens of age 1 female Red Snapper were collected by fishery-independent sources, 1977-2013. Immature females collected 21-42 meters depth. Mature females collected 22-42 meters depth.

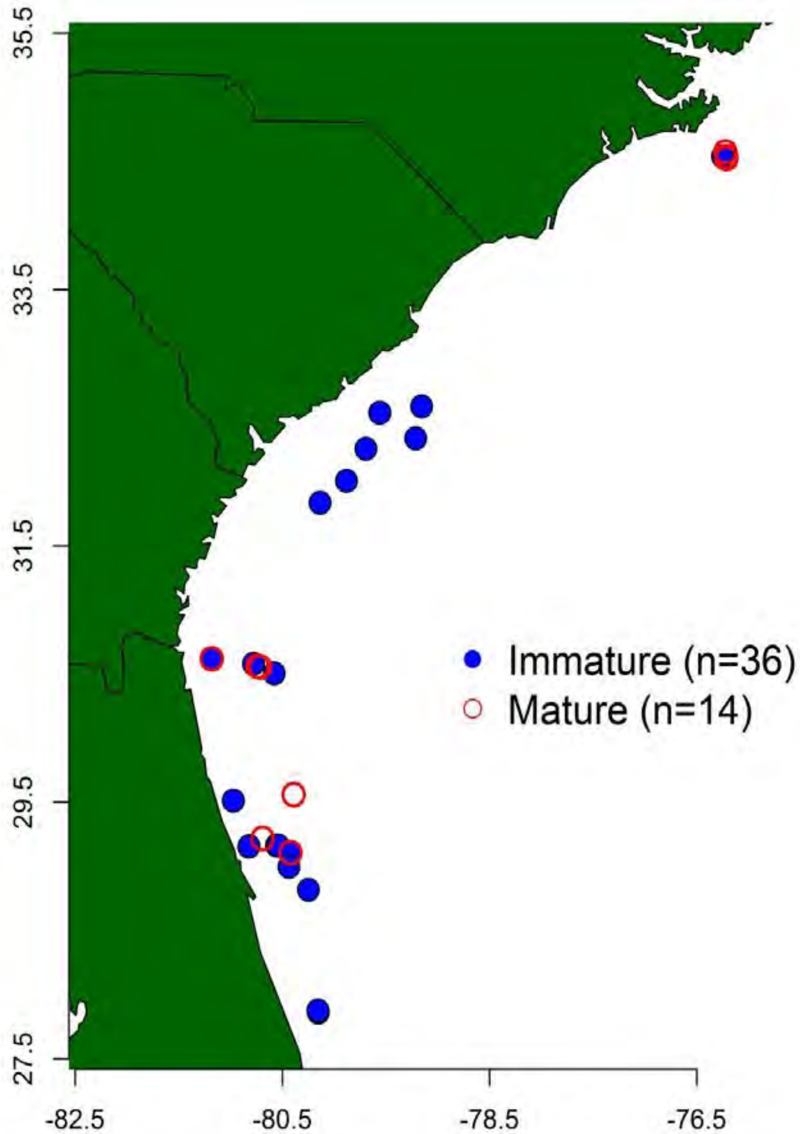


Figure 2.12

Locations where mature female Red Snapper, age 1-3, were collected by fishery-independent sources, by period.

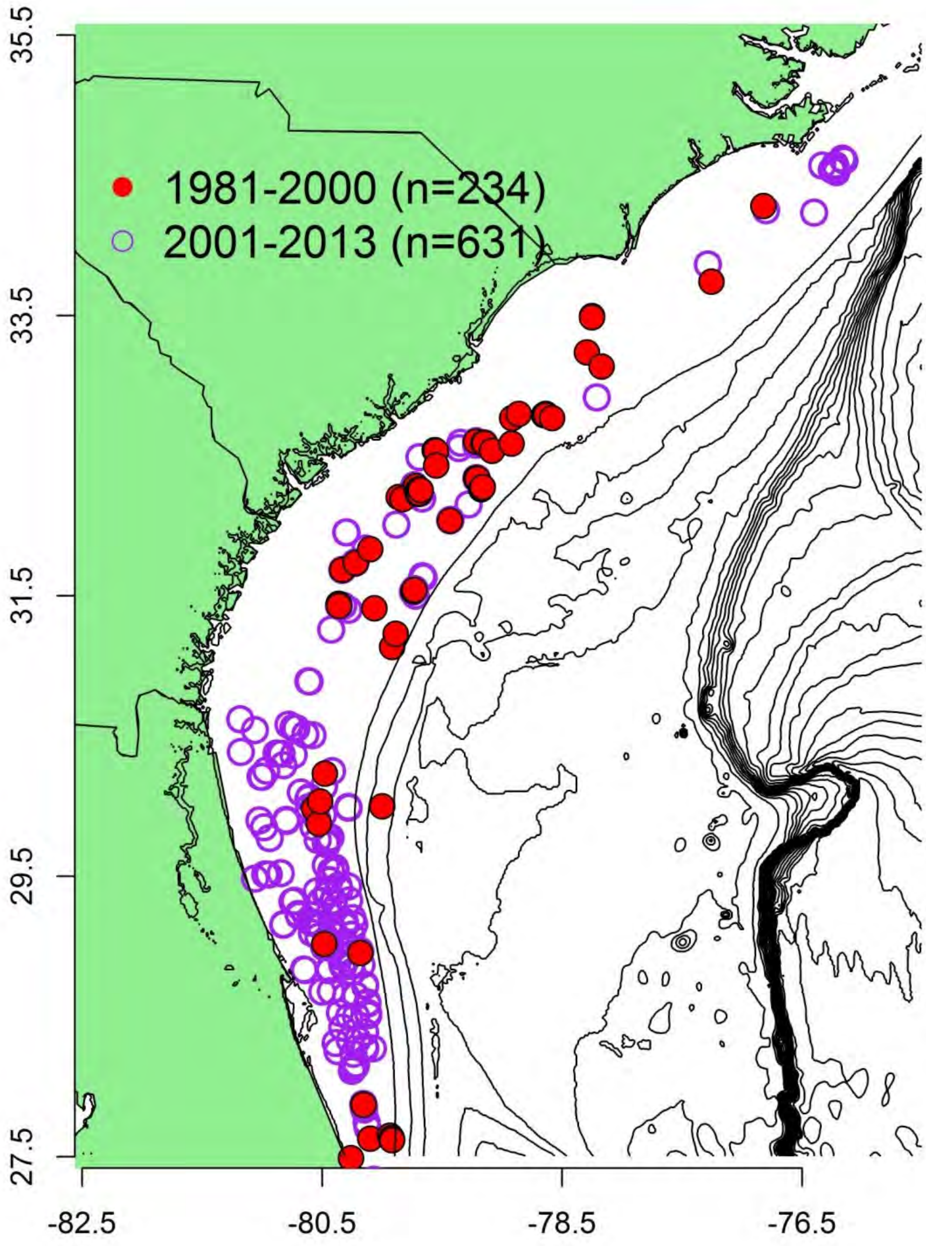


Figure 2.13

Scatterplot of Red Snapper batch fecundity estimates by max total length (TL; mm). Black points represent observed values, while lines indicated models fit by several methods. The solid blue line is a power model fit with negative binomial error (i.e. the recommended method) and the shaded area represents the 95% CI around that line. The dashed line represents a linear fit to log transformed TL and batch fecundity, while the dotted represents this same fit, incorporating a bias correction (Figure from SEDAR41-DW49).

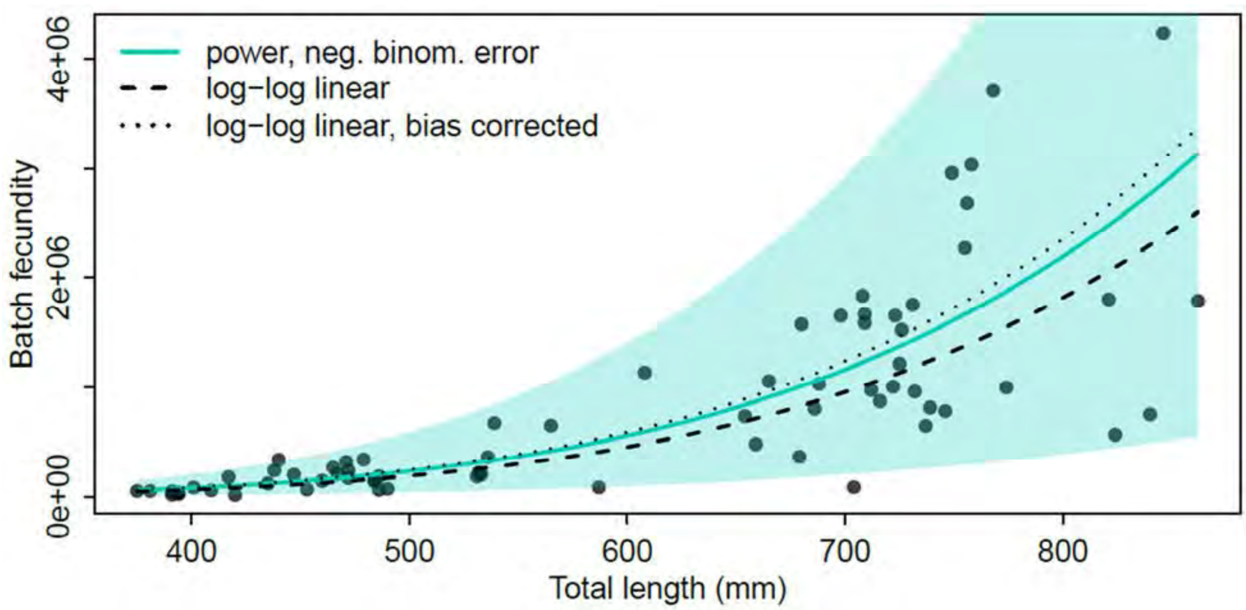


Figure 2.14

Red Snapper scatter plot of raw data used in conversion equations. The various plots represent the various length – length relationships. Data from a variety of fishery dependent and fishery independent sources were used. See Table 2.20 for equations and statistics.

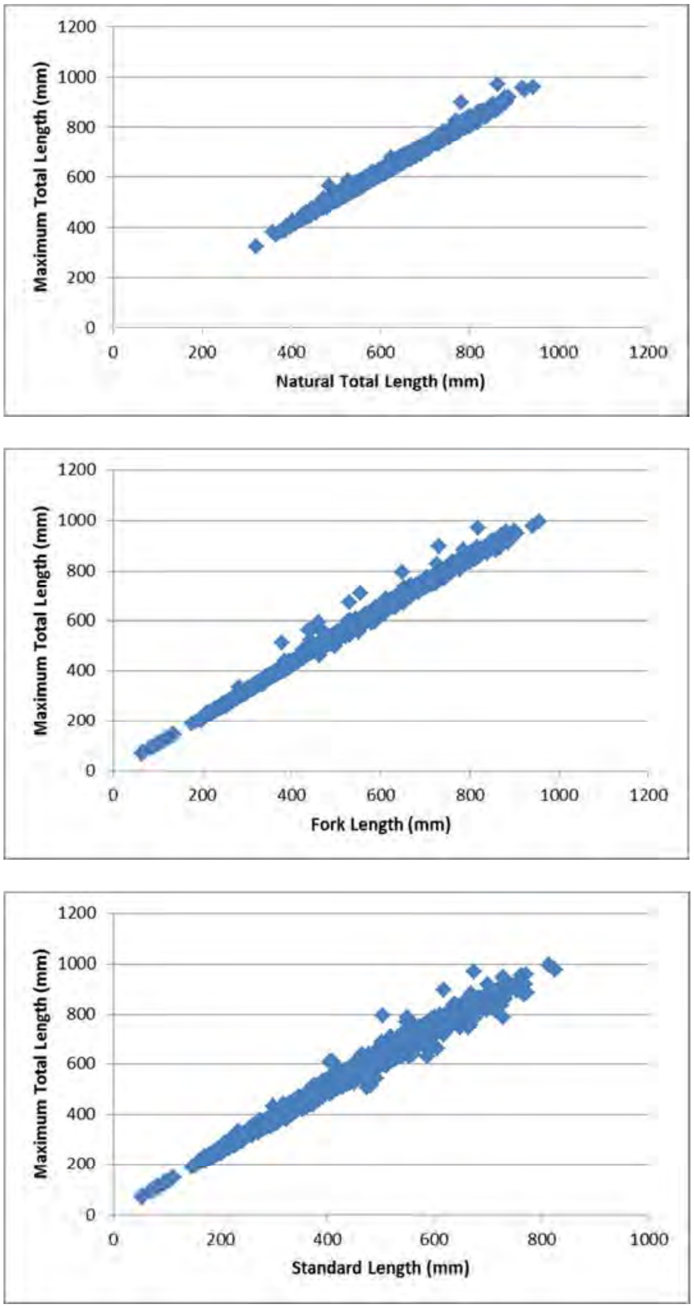
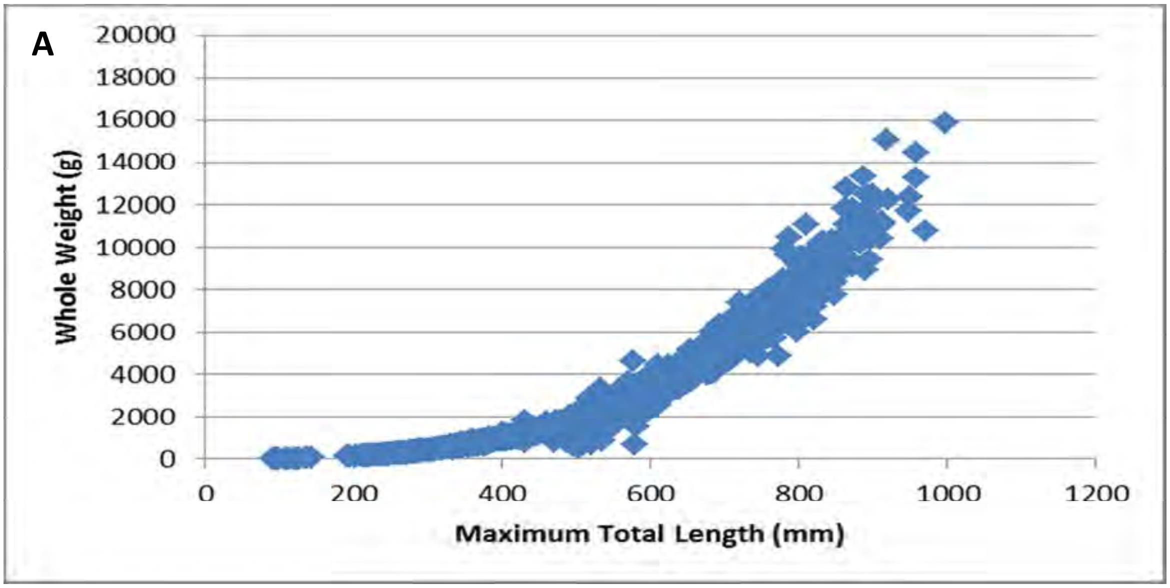
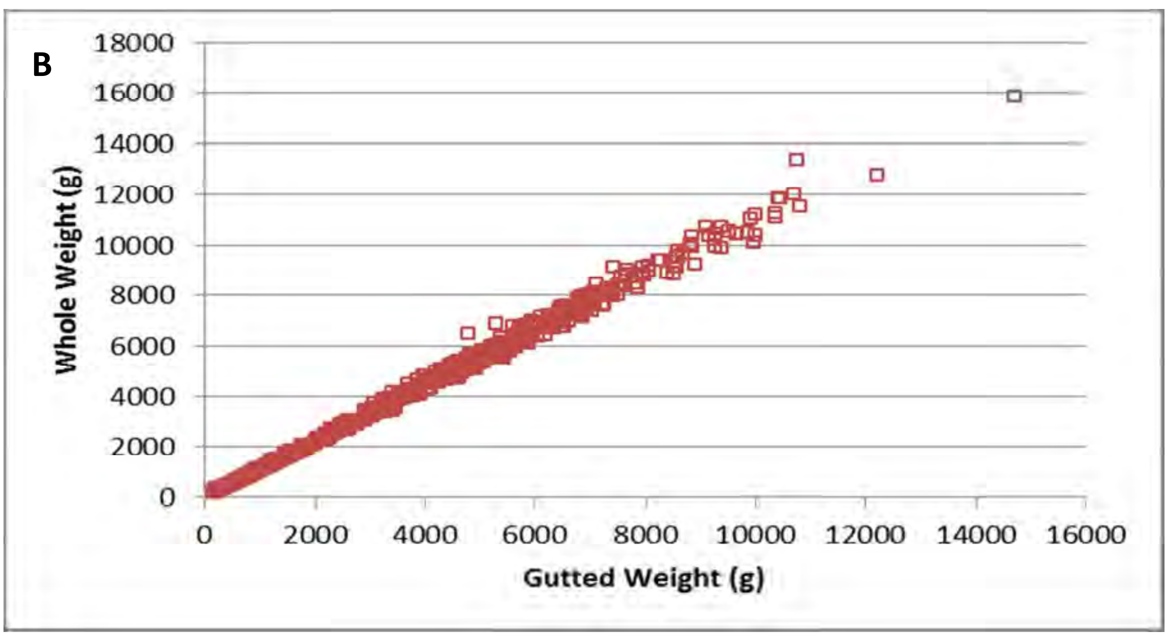


Figure 2.15

Red Snapper scatter plot of raw data used in conversion equations. Whole Weight – Maximum Total Length (A) and Whole Weight – Gutted Weight (B). Data from a variety of fishery dependent and fishery independent sources were used for analysis. See Table 2.21 for equations and statistics.





3. Commercial Fishery Statistics

3.1 Overview

Stock boundaries for red snapper in SEDAR 24 were between the GMFMC/SAFMC jurisdiction line in the Florida Keys to the NC/VA border. For SEDAR 41, the Life History Workgroup recommended using all data north of North Carolina.

Topics discussed by the Commercial Workgroup began with a discussion of stock boundaries, both the southern boundary with the Gulf of Mexico and the northern boundary (north of North Carolina).

To develop annual landings by gear and state, no adjustments were deemed necessary for misidentification of red snapper with other snapper species or inclusion of unclassified snappers that would have been analogous to SEDAR assessments for other snapper-grouper species. Commercial landings for the U.S. South Atlantic red snapper stock were developed by gear (handline, diving/spears, other) in whole weight for the period 1950 through 2014 based on federal and state databases. Intermittent landings estimates from historical reports were also consulted for 1902-1949. Data were more consistent after 1926 so historic data from 1927-1949 will be provided. Interpolated data for years when no red snapper were reported between 1927 and 1949 were calculated based on ratios of reported landings by state during years when at least one state reported. Corresponding landings in numbers were estimated from mean weights estimated from TIP by gear, state, and year for 1950-2014.

Discards, developed from the snapper-grouper logbook, were estimated for recent years (1993-2014) subsequent to the last change in minimum size limit for red snapper along the U.S. South Atlantic coast. Sampling intensity for lengths and age by gear, state and year were considered, and length and age compositions will be developed by gear and year for which sample size was deemed adequate.

Several research recommendations were updated and amended from SEDAR 24.

3.1.1 Commercial Workgroup Participants

Julie DeFilippi	Workgroup co-leader/ Data Provider	ACCSP
Kevin McCarthy	Workgroup co-leader/ Data Provider	SEFSC Miami
Joe Myers	Rapporteur/Data Provider	ACCSP
Steve Brown*	Data provider	FL FWC
Julie Califf	Data provider	GA DNR

Amy Dukes	Data provider	SC DNR
Kenny Fex	Commercial	NC/Snapper-Grouper AP
Stephanie McInerny*	Data provider	NC DMF
David Nelson	Commercial	FL
Larry Beerkircher*	Data provider	SEFSC Miami
2014 Only Workshop		
Neil Baertlein	Workgroup leader	SEFSC Miami
Zach Bowen	Commercial	GA/SAFMC
Chris Conklin	Commercial	SC/SAFMC
Jack Cox	Commercial	NC/SAFMC
Refik Orhun*	Data provider	SEFSC Miami

3.1.2 Issues Discussed at the Data Workshop

Landings issues discussed at the data workshop historic included landings, apportionment of Florida landings, and quantifying uncertainty. Historic reported landings, pre-1950, are largely incomplete and likely inaccurate. Whether or not to interpolate landings was discussed. Landings collected by the Florida Trip Ticket program are often felt to have mis-reported gear and area. NOAA's Coastal Fisheries Logbook data were used to correct for this, however 2010-2014 data could not be used for mean proportions for landings prior to 1993. Since landings data are simply summed, no value of uncertainty could be calculated. It was therefore discussed to use the methodologies used in SEDAR24 to estimate CVs based on method of data collection.

Discard issues discussed primarily involved the inclusion and exclusion of open and closed season discard rates from 2010-2014. Ultimately these years were treated separately.

Methods of extracting and filtering TIP length data were also discussed by the workgroup.

3.2 Review of Working Papers

SEDAR41-DW09: This report discussed fishery-independent and fishery-dependent sampling of red snapper during 2012 and 2013 when there were limited commercial seasons. It was determined that TIP samplers in Florida were actively targeting red snapper while sampling, therefore, estimated trip compositions during these years may have higher red snapper counts compared to years when red snapper sampling was random.

SEDAR41-DW22: This report suggested a re-evaluation of the gear selectivities used in the red snapper stock assessment for South Atlantic hook and line fleets.

SEDAR41-DW23: This report documented the development of the red snapper fishery in the US South Atlantic over time and discusses decadal advances in equipment and gear since the late 1800s.

SEDAR41-RD10: This report presented estimates of red snapper landings and discards from the commercial and recreational fisheries in 2012. Landings and discards were not provided by gear grouping. In the South Atlantic, commercial landings data from recent years are typically provided by the state for stock assessments to ensure edits performed after the data are sent to ACCSP are captured. These estimates were not used by the Commercial Workgroup.

SEDAR41-RD13: This report presented estimates of red snapper landings and discards from the commercial and recreational fisheries in 2013. Landings and discards were not provided by gear grouping. In the South Atlantic, commercial landings data from recent years are typically provided by the state for stock assessments to ensure edits performed after the data are sent to ACCSP are captured. These estimates were not used by the Commercial Workgroup.

SEDAR41-RD39: This report discussed data from 2007-2010 collected by an observer program tasked to characterize the shrimp fisheries in the US Gulf of Mexico and South Atlantic. Data for the South Atlantic penaeid and rock shrimp fisheries are available back to 2008. Red snapper bycatch between 2008 and 2010 was very minimal. The total impact of shrimp trawls on the red snapper fishery was determined by the Commercial Workgroup to be negligible.

Review and final decisions determined during 2014 workshop.

3.3 Commercial Landings

***DW ToR #6**: Provide commercial catch statistics, including both landings and discards in both pounds and number. Evaluate and discuss the adequacy of available data for accurately characterizing harvest and discard by species and fishery sector or gear. Evaluate, discuss, and characterize the sources of uncertainty, and data limitations (such as temporal and spatial coverage) for each data source. Provide ranges and/or distributions of uncertainty for data sources used in the stock assessment models. Provide length and age distributions for both landings and discards if feasible. Provide maps of fishery effort and harvest by species and fishery sector or gear.*

Commercial landings of red snapper were compiled from 1950 through 2014 for the entire US Atlantic Coast. Sources for landings in the US South Atlantic (Florida through North Carolina) included the Florida Trip Ticket program (FTT), South Carolina Department of Natural Resources (SCDNR), North Carolina Division of Marine Fisheries (NCDMF), and the Atlantic Coastal Cooperative Statistics Program (ACCSP). Landings from the Mid- and North Atlantic (north of the NC-VA border) were solely from ACCSP. Further discussion of how landings were compiled from the above sources can be found in section 3.3.5.

3.3.1 Commercial Gears Considered

In preparation for the SEDAR 41 Data Workshop, the commercial working group settled on the following numerical gear codes (ACCSP) for dividing red snapper commercial landings into three categories for consideration by the Workgroup. These gears are detailed in Table 3.1 and included:

Handline (300-303, 320, 700, 701),
Diving (660, 661, 750), and
Other (remaining gear codes including unknown).

Separating handline and diving gears was done because there are differences in the discard mortality and there may be differences in the selectivity and, therefore, length data between the two gears. Diving gear may catch larger red snapper on average.

These were the same gear groupings chosen in SEDAR 24; however, for SEDAR 24, landings with "other" gear type were pooled with handlines, the dominant gear. After further consideration by the Commercial Workgroup, the "other" gear type will be provided separately for SEDAR 41.

Decision 1: The Commercial Workgroup suggested grouping red snapper landings into three gear categories: Handline, Diving/Spears, and Others. The "other" gear category can be lumped into Handline if necessary.

This decision was approved by the plenary.

3.3.2 Stock Boundaries

DW ToR #1*: Review stock structure and unit stock definitions and consider whether changes are required.*

Landings will be provided from the GMFMC/SAFMC boundary in the Florida Keys and extend to north to the most northern extent of reported red snapper landings. The extent of the range can be seen in Figure 3.1 and the GMFMC/SAFMC boundary in Figure 3.2. Landings were obtained from the states north of North Carolina (ACCSP). Prior to 1987, reported red snapper landings were infrequent, occurring only in 1950 (300 lbs whole weight), 1970 (300 lbs), and 1983 (100 lbs). Landings became more frequent beginning in 1987, with positive landings for 1987-1988, 1992-1999, and 2001-2014. If we assume landings were truly 0 in those years none were reported for 1950-2014, then the average annual reported landings of red snapper from north of North Carolina was 98pounds (whole weight). While assuming years with no landings were zero, average landings beginning in 1987 was 234 pounds.

Decision 2: The Life History Workgroup recommended using all available data from the GMFMC/SAFMC jurisdiction line in the Florida Keys to as far north as landings were reported on the Atlantic coast. Because very few red snapper landings were reported north of North Carolina, the addition of these landings should not have an effect on overall landings trends.

This decision was approved by the plenary.

3.3.3 Misidentification and Unclassified Snappers

The next topics of discussion included whether misidentification of red snapper with other snapper species was a concern and whether red snapper landings may be incorporated in significant quantities in the unclassified snapper category. Neither of these issues was considered significant by the SEDAR 15 and SEDAR 24 Commercial Workgroups. The SEDAR 41 Commercial WG discussed and agreed with this decision. There are similar species to red snapper being landed but markets and regulations are different so there should be no misidentifications. Also red snapper have always been kept separate from the unclassified snappers because of their value. If any unclassified snappers were actually red snapper then it was insignificant. Data supporting this is anecdotal.

Decision 3: The Workgroup concurs with prior SEDAR decisions that concerns about mis-identification and unclassified snappers are not significant, and no adjustments are needed.

This decision was approved by the plenary.

3.3.4 Historical Commercial Landings

Historic landings were obtained from NOAA Fisheries' Office of Science and Technology which has available landings from 1880-1949. While reported landings are available back to 1880, consistent landings aren't seen until the 1920s. For this reason, we are providing landings from 1927 through 1949. This is also consistent with what was provided in SEDAR 24. After 1927 there are some gaps in reported landings, including 1933, 1935 and most of the 1940s. For these years when no landings were reported, linear interpolations were made using the first year before and first year after the gap in reporting. Interpolated values were for the years' total landings. Apportionments to state were based on a state's average proportion for years known. For years when at least 1 state reported, null landings were treated as zero. Treating these nulls as missing and inserting a given states' proportion based on 'complete' years, resulted in unrealistically high landings. Landings for the years 1942-1944 were made zero due to the port closures during

World War II. Reported and interpolated landings will be provided with the interpolated landings marked as such for possible exclusion in the assessment (Table 3.2, Figure 3.3).

Decision 4: Provide historic landings for 1927-1949. Interpolated values will be provided and noted.

This decision was approved by the plenary.

3.3.5 Commercial Landings by Gear and State

Statistics on commercial landings (1950 to present) for all species on the Atlantic coast are maintained in the Atlantic Coastal Cooperative Statistics Program (ACCSP) Data Warehouse. The Data Warehouse is an online database of fisheries dependent data provided by the ACCSP state and federal partners. Data sources and collection methods are illustrated by state in Figure 3.4. The Data Warehouse was queried in August 2015 for all red snapper landings (annual summaries by state and gear category) from 1950–2014 from Florida (Atlantic coast plus Monroe County) through Maine (ACCSP 2015). Data are presented using the gear categories as determined at the workshop. The specific ACCSP gears in each category are listed in Table 3.1. Commercial landings in pounds (whole weight) were developed based on classified red snapper by the Workgroup from each state as available by gear for 1950-2014.

<u>Florida</u>

Comparisons were made between Florida's commercial trip ticket data (1986-2014) and the NMFS logbook data (1992-2014). Both datasets were very similar in landings trends and level of landings reported for matching years by gear. The workgroup decided to use the total red snapper landings from the Florida trip ticket data over the logbook data primarily because the logbook data were of a shorter time series and trip ticket data are more complete from year to year. Red snapper have always been reported to species in Florida trip ticket. Final landings are reported as whole weight pounds.

One issue that arose with regard to red snapper landings from Florida South Atlantic waters in the trip ticket data was how to separate South Atlantic from Gulf of Mexico landings in Monroe county (Florida Keys). Red snapper landings in Monroe county have historically been a small portion of the Florida SA landings averaging about 4% annually. However, regulations limiting East coast harvest in recent years caused an increase in the proportion of Monroe South Atlantic red snapper to total Florida South Atlantic red snapper to as much as 10% in 2010 per NMFS logbook. It was decided to use the NMFS logbook data to proportion out South Atlantic red snapper in the trip ticket data since it is believed that fisher reported area fished data were generally more accurate than area fished data reported by dealers. Additionally, it was decided to use NMFS logbook data to apportion landings by gear in the trip ticket data. While both

programs collected gear by trip over the same time series (since 1992), the workgroup decided that gear reported by fisher would generally be more accurate than dealer reported gears.
The total amount of South Atlantic red snapper by year in the Florida was determined by first calculating the proportion of Monroe county South Atlantic red snapper in the logbook data for years 1993-2014. This was done by dividing the amount of SA red snapper into total red snapper landings for Monroe county only, then applying those proportions to the corresponding years for Monroe county total red snapper landings from the trip ticket data. An average proportion for SA Monroe county was calculated from the combined 1993-2014 logbook data and applied to corresponding total Monroe red snapper landings in the trip ticket data from 1986-1992. South Atlantic Monroe county and non-Monroe South Atlantic landings from trip ticket data were then combined into total South Atlantic red snapper landings for Florida. NMFS logbook data were then used to calculate proportions of Florida South Atlantic red snapper harvest by gear. This was done by dividing landings for each gear into total Florida South Atlantic landings, then applying those proportions to the total South Atlantic red snapper landings for Florida by year from 1993-2014. The average proportion of logbook landings over all years by gear was then applied to trip ticket landings from 1986-1992.

Landings from the ACCSP database were selected for 1950-1985.

Decision 5: The Workgroup recommends using 1993-2014 logbook data to apportion Florida landings prior to 1993.

This decision was approved by the plenary.

<u>Georgia</u>

GA DNR staff examined ACCSP landings and compared them to state held versions. It was determined that ACCSP landings were a match and would be used in place of state provided data for the entire time series.

<u>South Carolina</u>

Landings data for red snapper in South Carolina came from two different data sources. The old NMFS Canvass system data, supplied by ACCSP, provided landings data for the state from 1956 to 1971. Data from 1972 to 2014 was provided by SCDNR. This incorporated two different data reporting styles, the first from 1972 to 2003, allowed wholesale seafood dealers to report total monthly landings by species. The second data reporting style, 2004 to 2014, required wholesale seafood dealers to complete individual trip-level. All landings data are provided by year and approved gear type.

Red snapper were landed in gutted pounds. The South Carolina conversion factor used (1.075) to calculate whole pounds was different then the recommended and approved SEDAR 41 conversion factor (1.10). From 1972 to 2003, landings were only available in whole pounds, and since 2004, both gutted and whole pounds were available. To be consistent, all whole pounds were back calculated using the state applied conversion to determine gutted pounds and then the SEDAR 41 conversion factor was applied to determine whole pounds for all years of data. Gear combinations recommended by the Commercial Workgroup for Red Snapper were Handline, Diving/Spears, and Other.

North Carolina

Prior to 1978, the National Marine Fisheries Service collected commercial landings data for North Carolina. Port agents would conduct monthly surveys of the state's major commercial seafood dealers to determine the commercial landings for the state. Starting in 1978, the North Carolina Division of Marine Fisheries entered into a cooperative program with the National Marine Fisheries Service to maintain the monthly surveys of North Carolina's major commercial seafood dealers and to obtain data from more dealers.

The North Carolina Division of Marine Fisheries Trip Ticket Program (NCTTP) began on 1 January 1994. The NCTTP was initiated due to a decrease in cooperation in reporting under the voluntary NMFS/North Carolina Cooperative Statistics Program in place prior to 1994, as well as an increase in demand for complete and accurate trip-level commercial harvest statistics by fisheries managers. The detailed data obtained through the NCTTP allows for the calculation of effort (i.e. trips, licenses, participants, vessels) in a given fishery that was not available prior to 1994 and provides a much more detailed record of North Carolina's seafood harvest.

North Carolina commercial landings of red snapper were provided for 1972-2014 by year and gear type. Landings for North Carolina before 1972 were provided by ACCSP. Gears were grouped into the following categories: Handlines, Diving/Spears, and Others[1]. Most red snapper in North Carolina are reported in gutted condition. From 1972-1993, whole pounds were converted back to gutted using the state conversion code of 1.08 and reconverted to whole pounds using the conversion factor provided by the Life History Workgroup (1.10). From 1994-2014, landings reported as gutted were converted to whole pounds using 1.10. Landings reported as whole were not reconverted.

---

[1] SAS code used to group trip ticket gears into these categories:

```
If Gear1=480 and Gear2=610 and Gear3=. Then Gear1=610;
If Gear1=676 and Gear2=660 and Gear3=. Then Gear1=610;
If Gear1=677 and Gear2=610 and Gear3=. Then Gear1=610;
```

```
Length Geartype $ 15;
If (600 LE Gear LE 616) or Gear in (660,665) Then Geartype='Handlines';
Else if Gear in (760,943) Then Geartype='Spears';
Else Geartype='Others';
```

Combined State Results

Landings are presented in Tables 3.3 and 3.5 and Figures 3.5-3.6. Since 1950, Florida produced over 81% of the commercial harvest, Georgia 4.7%, South Carolina 7.6% and North Carolina 6.1%. Since 1950 handlines have represented about 97% of the catch compared with 2% for diving, and just under 1% other gears.

Decision 6: The Workgroup made the following decisions for reporting commercial landings:

- Landings should be reported as whole weight in pounds and number of fish
- Final landings data would come from the following sources:
    - VA-North: 1950-2014 (ACCSP)
    - NC: 1950-1993 (ACCSP)
      1994-2014 (NCDMF)
    - SC: 1950-1979 (ACCSP)
      1980-2014 (SCDNR)
    - GA: 1950-2014 (ACCSP)
    - FL: 1950-1985 (ACCSP)
      1986-2014 (FL FWC)

This decision was approved by the plenary.

Whole vs. Gutted Weight

Historically, conversions between whole and gutted weight have been based on state specific values. The standard conversion of snappers for Georgia and Florida from gutted weight to whole weight is by multiplying gutted weight by 1.11. South Carolina uses a conversion of about 1.075, obtained by dividing gutted weight by 0.93. North Carolina uses a conversion multiplier of 1.08. For all states North of North Carolina because the conversion factors typically used by each state was not known at the Data Workshop, the federal conversion of 1.08 was assumed. During SEDAR 41, data by state were converted back from whole pounds to gutted weight using the above mentioned conversions and then from gutted weight to whole weight based on data from the Life History Workgroup. The no-intercept regression estimate for slope is 1.10 (the ratio of means for gutted weight to whole weight).

Decision 7: The Commercial Workgroup will provide red snapper landings in pounds whole weight.

This decision was approved by the plenary.

Confidentiality Issues

Landings of red snapper were pooled across states by gear to meet the rule of 3 and ensure confidential landings were not presented in this report. Landings by state and gear will be provided to the data compiler for use in the assessment.

Uncertainty (2015 data workshop)

The commercial workgroup estimated uncertainty in commercial fishery landings, after consultation with assessment biologists, by modifying the methodology used in SEDAR 24. These estimates of uncertainty are not coefficients of variation, but are estimates of possible reporting error; i.e., represent the range in actual commercial landings relative to the reported landings.

In making these uncertainty estimates, two assumptions were made:

1. *Landings may be underreported during all years; however, underreporting was likely highest during early years of the time series and were more accurate in recent years.* This assumption was based upon the following information and data workshop expert testimony: during the period 1950 (beginning of landings time series) to 1961 landings were summarized annually by state and likely did not include landings from small scale dealers. In the years 1962-1977 landings data were collected annually, but under a more all-inclusive program (General Canvass). Monthly landings summaries were collected during the period 1978 to the beginning of trip ticket data collection (starting dates vary among states). The most recent landings data, collected through state trip ticket programs, were assumed to be most reliable and inclusive of all red snapper commercial landings.
2. *Landings may be overestimated during the years 1950-1977 because vermilion snapper may have been reported as red snapper landings.* Market values of similarly sized vermilion snapper and small red snapper were identical and no effort was made to differentiate species specific landings. This practice was phased out during the mid to late 1970's. The workgroup chose 1977 as the final year of misreporting based

upon expert testimony and observed increases in reported vermilion snapper landings. The workgroup recognizes that misreporting of vermilion snapper landings as red snapper landings diminished gradually over time, but lacks sufficient data to accurately characterize that trend.

During workgroup discussions it was recognized that using the levels of landings uncertainty recommended during SEDAR 24 (40-50% uncertainty) would poorly inform the assessment model of landings during the early years of the time series (1950-1977). The group agreed, based upon expert opinion, that an upper bound ½ that recommended during SEDAR 24 be used for the period from 1950-1977 (i.e., 25% landings during 1950-1961, 20% during 1962-1977, 10% during the period 1978 until implementation of state trip ticket programs (varies by state), and 5% during the period of trip ticket reporting (state specific starting years). See Table 3.5, Figure 3.4 for state specific bounds.

The workgroup recommended that a lower bound be set to account for vermilion snapper misreported as red snapper. The workgroup recognized the possibility that such misreporting may have resulted in an underestimate of the true red snapper landings. The lower bound for commercial landings uncertainty was set based upon expert opinion because the workgroup was aware of no available data by which a direct estimate of vermilion snapper misreporting could be estimated. The lower bound of landings uncertainty was set as symmetric with the upper bound for the period from 1950-1977, following the modified SEDAR 24 recommendation (Table 3.4, Figure 3.4).

Decision 8: The Workgroup recommends estimating landings uncertainty following modified (as per discussions with assessment biologists) SEDAR 24 recommendations for landings upper bound and lower bounds.

This decision was approved by the plenary.

3.3.6 Converting Landings in Weight to Landings in Numbers

Commercial landings in weight were converted to commercial landings in numbers based on average weight (in pounds whole weight) from the TIP data for each state, gear, and year. These data were generally available from 1983 to 2014 for handlines. Data for the remaining gear types were sparse, with much more limited data from diving and other gear types available (annual sample sizes by gear, state and year are summarized in Table 3.12). For 1983-2014 annual estimates of mean weight by state and year for handline were applied to the corresponding landings in weight when sample size greater than or equal to 50 (Table 3.6). For years when samples size was less than 50, a mean weight calculated from all years was applied by state. Since no lengths were available for northern states (Virginia through Maine), a mean across all states was applied. The mean weight as calculated from all years was also applied to those years from 1950-1982.

Samples for diving and other gear was limited and sporadic, which would have resulted in a collapsing strata to a single overall mean weight for a gear in order to yield adequate sample sizes. Additionally, large sample sizes in longline and trawl in the 'Other' gear skewed means. More detailed discussion can be found section 3.6.1. The workgroup determined that mean weights as calculated for the handline would be applied to all landings. Calculated numbers of fish can be found in Table 3.5 and Figure 3.6. Mean weights by state and year are provided in Table 3.6.

3.4 Commercial Discards

3.4.1 Directed Fishery Discards

2015 updated analyses
Calculations of the total number of red snapper discarded or kept as bait/eaten from the commercial fishery were updated to include data from 2014. For the 2015 Data Workshop, discards from the trolling fishery were also calculated because some red snapper discards were reported by those vessels. Methods were otherwise unaltered from those recommended during the initial SEDAR41 data workshop in August 2014. Updated calculated discards are provided in Tables 3.7-3.10. Calculated discards for all gears other than vertical line (handline and electric/hydraulic gear) were low. The number of calculated red snapper kept for bait or eaten never exceeded 54 fish in any year for all gears combined and were fewer than 12 fish in all other years. Tables of red snapper kept for bait or eaten have not been provided. Very minor differences in calculated discards between the 2014 data workshop calculations and the 2015 calculations were likely due to updates or edits to the discard logbook and/or coastal logbook data sets.

2014 analyses
Commercial discards were calculated for vertical line (handline and electric/hydraulic reel) vessels in the US South Atlantic using methods described in SEDAR41-DW36. Other gears reported 51 or fewer total trips (per gear) with red snapper discards during the period 2002-2013.

Two methods were used to calculate total discards. A continuity approach followed the methods of SEDAR24 and the 2010 update assessment. Those assessments used delta-lognormal model generated least squares means of year-specific discard rate to calculate total yearly discards for the period 2002-2013 (when discard data were reported). Discard rate for the period 1992-2001 (prior to discard reporting) was assumed to be the mean discard rate over the years 2002-2013, weighted by sample size. An alternative method used yearly nominal discard rates for the years

2002-2013. Separate discard rates were calculated for open and closed red snapper fishing seasons. Calculation of discards for the years 1992-2001 used the mean discard rate for the years 2002-2009 (years with no closed seasons). Both methods used discard rates multiplied by year specific total vertical line effort reported to the coastal logbook program to calculate total discards. Discards were reported in numbers of red snapper.

The working group recommendation and the final recommendation made in plenary session were to calculate total discards using nominal discard rates. To address likely underreporting of discards (reporting "no discards" allows the fisher to remain in compliance for renewing federal fishing permits), data included in that calculation were filtered to remove records from vessels that never reported discards of any species during a year. In addition, data from vertical line vessels that reported more than 17 trips without reporting discards of any species (17=the mean number of reported trips prior to the first trip with reported discard plus two standard deviations of that mean) were excluded. Those data filters were used following the recommendation of the SEDAR32 data workshop. Including data from those fishers that habitually reported no discards would have resulted in discard rates that were erroneously low. Trips targeting mackerel are unlikely to have discards of red snapper, therefore, trips that reported only landings of mackerel species were excluded from this analysis. Additional data filters included the removal of clearly erroneous data (values of gear-specific effort data beyond the 99.9 percentile of the data). Discard logbook data with multiple gears fished on a trip were also excluded because discards could not be unambiguously attributed to a particular gear. That data filtering step was not necessary when summing total effort from the logbook data because reported effort data was gear-specific.

Decision 9: The Workgroup accepts the discard estimates of red snapper for 1992-2014 as developed in working paper S41-DW36.

This decision was approved by the plenary.

The commercial working group accepted the methods described in SEDAR41-DW36 for calculating commercial vertical line vessel red snapper discards for the years 1992-2013. Red snapper discards were reported from 51 or fewer trips with gear other than vertical lines, suggesting that discards from other commercial gears was minimal. The specific method chosen by the working group was the use of year and fishing season (open/closed) specific nominal discard rates. Those discard rates were used with corresponding year and season specific total vertical line effort reported to the coastal logbook program to calculate total discards. The working group also endorsed using the mean discard rate over the years 2002-2009 (years with no red snapper seasonal closures), weighted by sample size, as the discard rate for the period 1992-2001 (prior to discard reporting). During 1992 only 20% of vessels in Florida were required to report to the logbook program; effort reported for Florida was expanded by a factor of five. No effort data were available for calculating discards prior to 1992.

The discard calculations rely on self-reported discard and effort data. Perhaps the most important source of error in the commercial discard calculations was misreporting and non- reporting of discards, both of red snapper and other species. An effort was made to minimize that potential error by removing data from vessels that never reported discards of any species during a year. In addition, data from vertical line vessels that reported more than 17 trips without reporting discards of any species (the mean number of reported trips prior to the first trip with reported discard plus two standard deviations of that mean) were excluded. Although such clear instances of discard non-reporting were identified and excluded, other cases of non-reporting and misreporting have not been quantified. The degree to which continued non or misreporting may have affected the discard calculations is unknown.

The total commercial discards provided in SEDAR41-DW36 may represent a minimum estimate of the number of red snapper discarded from the commercial fishery.

Decision 10: The conclusion of the commercial working group was that given the very limited observer data, fisher reported discard data represent the best available information on commercial red snapper discards.

This decision was approved in plenary.

3.4.2 Shrimp Bycatch

The possibility of constructing red snapper bycatch estimates from the south Atlantic shrimp fishery was investigated. Beginning in 2007, a mandatory observer program was put in place to sample trips in the penaeid and rock shrimp fisheries. During this time only 7 fish, from 872,192 pounds of samples (shrimp and fish), were encountered. These seven red snapper were caught only in rock shrimp trips. Additionally, several fishers present at the data workshop, who have fished in the shrimp fishery, corroborated this extremely low encounter rate. The workgroup felt that total bycatch is negligible in the shrimp fishery and therefore recommended not modelling shrimp bycatch.

Decision 11: Red snapper bycatch from the shrimp fishery will not be constructed as bycatch is negligible.

This decision was approved by the plenary.

Review and final decisions determined during 2014 workshop.

3.5 Commercial Effort

The distribution of directed commercial effort in trips by year was compiled from the Coastal Fisheries Logbook Program (CFLP) for 1993-2013 and supplied here for informational purposes. These data are presented in Figure 3.7. The distribution of harvest by statistical grid, as reported to the CFLP, is a displayed in Figure 3.8. Figure 3.9 shows a distribution of harvest by depth and latitude.

Review and final decisions determined during 2014 workshop. Not updated at 2015 workshop.

3.6 Biological Sampling

Length Samples

Commercial length data were available from the SEFSC Trip Interview Program for all years, 1983 to 2014. TIP data were pulled from the SEFSC TIPONLINE.TIP_MV table, which is a master view table that collapses the one-to many relational tables in the main TIP database tables. The TIP_MV table is audited weekly to insure that the contents agree with the master data tables.

REGIONS other than South Atlantic are filtered out. Data were assigned as South Atlantic samples via a hierarchal procedure. If area fished was in the interview's effort information (e.g. usually derived from captain), this information was used. If the Captain's information was not available, but area fished was provided in the interview's landings information (e.g. derived from the dealer's records/trip tickets), then the landings information was used. If area fished was in neither the effort nor the landings information, then the state and county of landing were used to make a region assignment (e.g., all records not previously resolved that landed in NC, SC, or GA were assumed to be south Atlantic samples, and all records not previously resolved that landed in FL's east coast counties (Dade county northward) were also assumed to be south Atlantic samples).

IS_DISABLED='Y' TRIPS are filtered out. TIP allows errant data to exist in the database until such time as the issue can be resolved. TIP also allows testing trips in the production database. These only make up 0.2 % of all south Atlantic TIP interviews. It is unlikely that BSD would import these records and that agents would send age structures from errant trips. Agents cannot disable trips, only system and database administrators can.

FISHING_MODE<>'COMMERCIAL' are filtered out. TIP is meant to be a commercial representative sampling program, however the TIP database has been used to house recreational, scientific, experimental, etc. data collections. Non-commercial trips make up 14% of south Atlantic TIP interviews.

BIAS_TYPE<>'NO BIAS KNOWN' are filtered out. In the past, samplers where asked to record if they felt the trip was representative, or biased for some particular reason. Trips with a bias indicated make up 1.9% of south Atlantic TIP interviews.

INTERVIEW_TYPE='TRIP_SURVEY' are filtered out. An interview type coded Trip Survey means that the sampling was taken from the aggregated landings of more than one trip (this could involve a single vessel but multiple trips, or multiple vessels). In these cases, if the sampler knew that the gear type and/or area fished varied among the trips included in the trip survey, historical practice was to assign area fished and gear type to what the sampler believed characterized the "majority" of the catch (and therefore in theory the majority of the sampled specimens). Since area fished and gear type cannot be conclusively identified for a trip survey, then if these variables are necessary for the assessment, they should be filtered out. It should be noted that this filter disproportionately affects the lengths available from South Carolina samples in the 1980's and early 1990's. For example, in the south Atlantic data overall trip survey lengths are about 2% of the data, but for South Carolina trip survey lengths account for 41% of the length data. Filtering out these records results in zero lengths for South Carolina in the years 1985, 1986, 1987, 1989, 1990, 1992, and 1995.

GEAR TYPE: Will be determined by the first gear type listed in the trip record. The assumption is that if a trip uses multiple gear types, a single gear type is the primary type used, and is listed by the sampler first. Where a gear type was not obtained via an interview, then the gear information from the dealer was used.

OBSERVATION-SPECIFIC FILTERING:

SAMPLE_RANDOM=NO are filtered out. Samples coded as 'NO" for this variable are assume to have some type of sampling issue; the sample was selected by a non-random or targeted method. These observations may not be representative of the trip's catch and should not be used. For red snapper, samples identified as non-random are 3% of the observations (after above trip filtering is applied as well).

CONDITION_TYPE='GUTTED-HEAD OFF' were removed as length collection should be impossible if the fish was in such condition. Null values for condition type were left in, as it was historically standard practice by many samplers to only record a condition when a weight was taken, also many samplers seemed to operate under the impression that leaving this value as null meant the fish was in standard industry condition (for red snapper, this means the head is left on). Only 4 records were affected by this filter.

LENGTH1_MM= NULL or 0 will be filtered out. A very small number of observations in TIP do not have length data. Some unreasonable lengths were filtered out: for red snapper two lengths of 59 and 70 mm were deleted as unreasonably small, and two lengths of 14541.5 and 5500 mm were deleted as unreasonably large, leaving the length range as 185 mm to 1120 mm.

Age Samples

Most of the age structures were obtained from TIP port agents and ageing analyst coordinated with TIP data collection experts to obtain consistency in filtering data. Ageing analysts contacted state sampling representatives to determine if increased sampling outside the TIP program in recent years were biased in any way. The increased sampling for red snapper since 2009 outside the TIP program accounts for the years with more ages than lengths. Given the complexities of the length and age databases, determining individual lengths not included in the length data may increase the probability of duplicating records and other errors.

3.6.1 Sampling Intensity

Length samples

Gear-specific summaries of the quantity and quality of the length data show that the majority of the length data available for red snapper are from the handline fishery (Table 3.11). All other gears are characterized by relatively poor annual sample sizes, coverage, and variability in the mean length and weight across gears. Annual sample sizes of lengths and number of trips sampled are summarized in Tables 3.12 and 3.13, respectively, by gear and state for red snapper in the U.S. South Atlantic from the TIP database for 1983-2014. The state-specific sample sizes are inadequate to weight samples for any of the gears. Even the most abundant gear, handline, has no length samples for many year/state combinations. A value of zero cannot be weighted and small sample sizes cause spikes in a composition for areas with average or greater landings. A comparison of the relative number of fish sampled across states to the relative landings across states is shown in Figure 3.11. Overall, North Carolina is relatively over-sampled for most of the time period, South Carolina is sporadic with many zero years prior to 1996 where it is then relatively oversampled, Georgia is sporadic through about 1994 with adequate sampling through 2006 and then undersampled, Florida, the state that dominates the landings, is relatively undersampled until about 1992 and then adequately sampled with the exception of a few low years. The workgroup recommends combining North Carolina and South Carolina length samples and weighting by the combined landings for handline gear. The workgroup recommends combining Georgia and Florida length samples and weighting by the combined landings for handline gear. The regional relationship between handline length samples and landings is shown in Figure 3.12. Diving sample sizes are inadequate to develop annual length comps with the exception of a few years. However, a qualitative comparison of the 6 years with 30 or more diving samples shows a general agreement with the handline gear with a shift towards slightly larger fish (Figure 3.10). The “other” gear includes sporadic sampling by states and very different gear types (e.g. longline and trawl).

Age samples
Annual sample sizes for commercial handline and other gears by state are given in Tables 3.14 and 3.15. The age samples are dominated by South Carolina through 1995, then Florida provides the majority if not all of the length samples by trip from 1998-2003. From 2004 to 2008 sampling is greater in the Carolinas.

3.6.2 Length/Age Distribution

Length distributions - Landings
All red snapper lengths were converted to maximum TL in mm using the formula provided by the SEDAR 41 Life History Workgroup and binned into one centimeter groups with a floor of 0.6 cm and a ceiling of 0.5 cm. The length data and landings data were divided into handline, diving/spears, and other gears. Unweighted red snapper handline annual length compositions are provided in the SEDAR 41 data workbook and shown in Figure 3.13.

Age distributions – Landings
Calendar ages were determined by ageing experts and provided to commercial composition analysts for summary. . Unweighted red snapper handline annual age compositions are provided in the SEDAR 41 data workbook and shown in Figure 3.14 (to a maximum of 47 years) and Figure 3.15 (pooled at 15 years).

Length distribution - Discards
Observer reported length frequency data of discarded red snapper were available for use in the SEDAR41 stock assessment. Sampling protocols and collection procedures of those data are reported in GSAFF (2008). Those data were collected from vessels fishing vertical line gear (handline and electric/hydraulic reels) between latitudes 30N and 33N during 2007-2011. A length composition was developed combined across years to represent discard sizes for years with a 20 inch size limit and after the 2010 closure. Data from 2007-2009 with 144 fish and 13 trips was used to develop the 20 inch size limit discard size distribution (provided in the SEDAR 41 data workbook and shown in Figure 3.16).

3.6.3 Adequacy for Characterizing Catch

Length samples
The TIP sample sizes for the development length distributions appear to be adequate for the commercial handline fishery with the exception of 1983 were only 35 fish were collected from 12 trips in North Carolina and 2010 where all fish come from 4 trips. Overall there is more uncertainty in the handline length data prior to 1996 and after 2009. Lack of coverage is the

primary reason for the increased uncertainty in the early and late years with the combined effect of the closure and mini-seasons for 2010-2014.

Lengths samples from the diving and other gear activities were limited. Ultimately the workgroup felt the length distributions for diving could be informed by the handline length distributions (Figure 3.10). Development of any length distributions from other gears would be uninformative due to the lack of spatial and temporal coverage and the disparity in mean length for the different gears. The total landings for all gears other than handline represents only about 6% of the overall landings and assuming they are represented by the handline length compositions would very minimally increase the uncertainty of an assessment.

Age samples

Age samples prior to 1996 when Florida samples are modestly represented may not adequately characterize catch as most if not all samples come from South Carolina. Weighting age compostions by length compostions can correct for bias in sampling age structures from the overall sample as well as region-specific differences.

Decision 12: The Workgroup recommends only development of a handline length distribution which should be weighted regionally (Car and GFL). Years with limited trips or very limited spatial coverage should not be used to characterize catch (including but not limited to 1983 and 2010). The workgroup recommends development of annual handline age compositons weighted by the annual handline length compositions. Years with limited trips or very limited spatial coverage should not be used to characterize catch.

3.7 Comments on Adequacy of Data for Assessment Analyses

Landings

The working group considered the majority of landings data from the U.S. south Atlantic to be adequate for assessment analyses. Data appeared to be most accurate and reliable from the various state data bases in the most recent years. This is likely due to the implementation of state trip ticket programs, beginning with Florida in 1986. Reliable monthly landings data can be found back to 1978. Historic landings prior to 1950 were found to be the least reliable, as there appears to be missing data for various years and states. It was also felt that proper species identification for reporting were made as red snapper is a highly sought fish and therefore handled separately from other snappers.

Discards

Discards estimates may be less adequate for assessment analyses. The only discard data available is from a self-reported data collection program. It is likely that recollections of fish thrown back are not always accurate and will vary from fisher to fisher. There is also an issue of 'no discard' trips reported. The frequency of 'no discard' trips has risen over the past 10 years, from 30% to over 60% of all discard reports submitted. It is unknown which of these are real and which reports were submitted simply to comply with reporting requirements. Observer data were investigated, but data were deemed insufficient for discard estimation.

Length and age samples

Length and age samples from the handline fishery are adequate for assessment analyses. The increased uncertainty for years with limited coverage could be modeled by reducing the weighting factor (typically trip sample size) by the proportion landings represented by missing states. However, length and age samples from diving and other gears are insufficient for analyses.

3.8 Relative Selectivity for Commercial Gears

To potentially address gear selectivity, SEDAR41 assessment scientists requested additional information concerning hook types and sizes used in the red snapper fishery through time. Most fishery dependent data collection programs do not collect this information including the various state trip ticket programs and the Coastal Fisheries Logbook Program. There is however, data available from a south Atlantic observer program that ran from mid-2006 through 2011. There were limited observer data that included hook size recorded from reels with red snapper catch. A total of 38 trips by 17 vessels with red snapper catch were observed from 2006 (1 vessel/1 trip) to 2011 (6 vessels/10 trips). All were vertical line (handline/bandit rig) trips. There were 785 red snapper observed: 456 discards, 320 landed, 6 kept as bait, and 3 with unknown disposition. Manufacturer hook sizes were recorded for 161 caught fish and there were 104 unique trip/set/reel/hook size combinations. Observers directly measured hook size more frequently than they recorded the manufacturer's hook size: 446 discarded red snapper and 317 landed red snapper have measured hooks size. These data along with further analyses will be provided at the SEDAR 41 Assessment workshop.

In addition to observer data, anecdotal data were provided by commercial fishermen. Captain Kenny Fex state that in the mid-1980s, off North Carolina, 5/0 J-hooks were used for small fish, while 10/0 J-hooks and 13/0 circle hooks were used for large grouper and snapper. By the mid-1990s J-hooks were no longer used as circle hooks were found to be more effective. In more recent years 4/0 and 12/0 circle hooks have been used for small and big fish. Two hooks per line has been the gear configurations consistently through this time period. Captain Chris Conklin also added that 10/0 and 12/0 circle hooks have been consistently used.

Lastly, it is worth noting that circle hooks sizes may vary between manufacturers (Serafy 2012). For example, a 10/0 circle hook manufactured by Mustad may be a different size than Eagle Claw's 10/0 circle hook.

Not updated at 2015 workshop.

3.9 Literature Cited

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3.10 Research Recommendations

The Workgroup reviewed recommendations from SEDAR 24 and offers additional recommendations:

Landings

- Improve gear and effort data for each trip.
- Standardize methodology for developing average proportions to parse out unclassified landings.

Discards

- Investigate the validity and magnitude of "no discard" trips. This may include fisher interviews throughout the region.
- Examine potential impacts of "no discard" trips on estimated discards.
- Improve discard logbook data collections via program expansion or more detailed reporting (i.e. electronic logbooks, etc.)
- Establish an observer program that is representative of the fisheries in the South Atlantic.

Biosampling

- Establish an observer program that is representative of the fisheries in the South Atlantic.
- Angler education with regards to recording depths on paper logbooks (i.e. standardized units); validation of additions to the logbook form still needed.
- Standardize TIP sampling protocol to get representative samples at the species level.
- Standardize TIP data extraction.

These recommendations were approved by the plenary.

3.11 Tables

Table 3.1 Specific ACCSP gears in each gear category for red snapper commercial landings.

HANDLINE

GEAR_CODE	*GEAR_NAME*	*TYPE_CODE*	*TYPE_NAME*	*SEDAR 41 CATEGORY*
300	HOOK AND LINE	007	HOOK AND LINE	HANDLINE
301	HOOK AND LINE, MANUAL	007	HOOK AND LINE	HANDLINE
302	HOOK AND LINE, ELECTRIC	007	HOOK AND LINE	HANDLINE
303	ELECTRIC/HYDRAULIC, BANDIT REELS	007	HOOK AND LINE	HANDLINE
320	TROLL LINES	007	HOOK AND LINE	HANDLINE
700	HAND LINE	013	HAND LINE	HANDLINE
701	TROLL AND HAND LINES CMB	013	HAND LINE	HANDLINE

DIVING

GEAR_CODE	*GEAR_NAME*	*TYPE_CODE*	*TYPE_NAME*	*SEDAR 41 CATEGORY*
660	SPEARS	012	SPEARS AND GIGS	DIVING
661	SPEARS, DIVING	012	SPEARS AND GIGS	DIVING
750	BY HAND, DIVING GEAR	014	BY HAND	DIVING

***ALL OTHER GEARS ARE GROUPED AS OTHER**

Table 3.2 Historical red snapper landings, in thousands of whole weight pounds, from 1927-1949. Interpolated values are in the shaded rows. Null pounds for non-interpolated years have been assumed '0'.

Year	FL	GA	NC	SC
1927	59	64	1	0
1928	47	22	2	0
1929	19	33	15	0
1930	34	30	5	0
1931	112	0	2	0
1932	49	0	0	0
1933	90	8	2	0
1934	152	0	0	0
1935	131	12	3	0
1936	140	0	0	0
1937	210	0	0	0
1938	117	0	1	0
1939	96	0	2	0
1940	14	0	0	0
1941	55	5	1	0
1942	0	0	0	0
1943	0	0	0	0
1944	0	0	0	0
1945	246	0	4	0
1946	245	22	5	1
1947	265	24	5	1
1948	286	26	6	1
1949	306	28	6	1

Table 3.3 Red snapper landings (pounds whole weight) by gear (handline, diving, other) from the U.S. Atlantic, 1950-2014. Confidential landings have been replaced with a '*'.

Year	Hand Line	Diving	Other
1950	354,973		13,684
1951	491,135	991	7,639
1952	380,838		5,093
1953	397,883	396	
1954	593,207		
1955	493,315		
1956	483,907		
1957	867,192		99
1958	612,508		
1959	657,736		
1960	670,877		198
1961	791,813		4,561
1962	645,290		694
1963	488,216		573
1964	537,490		99
1965	558,108		
1966	553,386		1,120
1967	724,586		917
1968	865,223		297
1969	523,468		14,723
1970	508,071		4,951
1971	457,393		
1972	383,123		23,518
1973	290,995		5,565
1974	476,366		1,986
1975	600,790		
1976	562,783		8,721
1977	593,664		2,676
1978	547,791	39,988	6,578
1979	392,069	27,184	1,684
1980	352,661	24,856	7,968
1981	342,731	21,645	14,382
1982	285,550	17,115	5,779
1983	294,240	18,378	4,199
1984	234,976	15,719	2,736
1985	231,294	16,904	2,626
1986	203,344	14,568	1,529
1987	173,914	14,113	3,674
1988	159,261	11,946	2,482
1989	250,199	14,316	2,427
1990	209,566	12,227	4,749
1991	128,782	8,183	6,581
1992	96,293	7,459	621
1993	212,970	6,203	980

1994	188,150	4,825	2,344
1995	170,237	6,209	866
1996	126,408	8,933	3,330
1997	100,811	8,913	871
1998	78,893	9,516	1,192
1999	83,235	8,740	1,621
2000	93,365	9,575	1,225
2001	180,055	15,442	1,201
2002	170,427	16,989	550
2003	123,583	14,066	692
2004	154,172	17,543	368
2005	118,882	10,032	785
2006	78,730	7,026	626
2007	101,180	13,452	341
2008	241,956	9,995	196
2009	345,487	16,233	665
2010	4,389	538	1,520
2011	*	*	*
2012	6,107	1,679	357
2013	23,995	6,417	1,187
2014	56,828	7,262	1,353

Table 3.4 Commercial landings uncertainty upper and lower bounds.

Year Range	VA North	NC	GA	SC	FL	
1950-1961	0.25	0.25	0.25	0.25	0.25	**High and Low**
1962-1977	0.2	0.2	0.2	0.2	0.2	
1978-1985	0.2	0.1	0.1	0.1	0.1	**High Only**
1986-1989	0.2	0.1	0.1	0.1	0.05	
1990-1993	0.1	0.1	0.1	0.1	0.05	
1994-2001	0.1	0.05	0.1	0.1	0.05	
2002-2003	0.1	0.05	0.05	0.1	0.05	
2004-present	0.05	0.05	0.05	0.05	0.05	

Table 3.5 Red snapper landings (number of fish) by gear (handline, diving, other) from the U.S. Atlantic, 1950-2014.

Year	Hand Line	Diving	Other
1950	43,433		1,676
1951	60,093	121	907
1952	46,597		605
1953	48,683	49	
1954	72,647		
1955	60,359		
1956	58,687		
1957	105,277		14
1958	74,841		
1959	80,353		
1960	82,241		29
1961	96,498		562
1962	78,932		85
1963	59,763		70
1964	65,739		14
1965	68,240		
1966	67,676		133
1967	89,822		109
1968	105,944		43
1969	64,250		1,834
1970	62,437		636
1971	57,118		
1972	47,670		3,166
1973	35,980		671
1974	59,133		269
1975	74,154		
1976	69,742		1,258
1977	73,851		386
1978	68,659	4,893	891
1979	48,087	3,326	206
1980	42,948	3,041	1,082
1981	41,696	2,648	1,970
1982	34,592	2,094	796
1983	35,595	2,249	574
1984	41,374	1,963	545
1985	46,646	4,056	475
1986	32,249	2,650	245
1987	22,465	1,728	455
1988	22,944	1,479	401
1989	31,501	1,748	373
1990	30,961	2,140	621
1991	19,512	1,014	1,182
1992	9,583	667	60
1993	22,892	557	94

1994	24,924	551	273
1995	19,452	698	97
1996	13,425	958	355
1997	10,359	916	93
1998	9,659	1,190	145
1999	10,366	1,015	198
2000	11,693	1,225	157
2001	25,747	2,026	159
2002	23,078	2,230	73
2003	16,118	1,798	88
2004	18,077	2,115	41
2005	12,119	1,027	77
2006	8,079	742	63
2007	11,084	1,542	37
2008	38,486	1,665	27
2009	43,320	2,022	83
2010	696	88	235
2011	*	*	*
2012	720	185	44
2013	2,832	762	147
2014	6,889	880	164

Table 3.6 Mean whole weight (pounds) of red snapper derived from the length compositions using the U.S. South Atlantic TIP database, 1984-2014. Average weights applied to earlier years, 1950-1983 and years where sample size was less than 50.

Year	FL	GA	SC	NC	VA-North
1950-1982	8.173	6.935	8.422	7.720	7.812
1983	8.173	6.935	8.422	7.720	7.812
1984	8.173	4.162	4.149	4.032	5.129
1985	4.167	5.554	8.422	5.684	5.957
1986	5.484	7.393	8.422	5.745	6.761
1987	8.173	5.103	8.422	5.875	6.893
1988	8.173	5.652	5.608	3.904	5.834
1989	8.173	5.189	8.422	5.637	6.855
1990	5.714	6.935	8.422	5.654	6.681
1991	8.076	5.797	5.414	6.631	6.480
1992	11.501	9.069	8.422	8.934	9.481
1993	11.637	7.757	8.422	6.367	8.545
1994	9.044	7.475	6.705	7.747	7.743
1995	8.866	9.259	8.422	10.079	9.156
1996	9.326	9.225	9.720	8.294	9.141
1997	9.736	6.935	11.290	7.720	8.920
1998	8.000	6.935	9.425	7.720	8.020
1999	8.611	6.935	7.764	6.485	7.449
2000	7.815	8.044	8.389	8.669	8.229
2001	7.627	4.928	7.389	6.842	6.697
2002	7.632	7.182	7.205	7.648	7.417
2003	7.803	6.546	8.166	9.897	8.103
2004	8.250	7.878	9.245	13.373	9.686
2005	9.705	8.614	10.369	12.981	10.417
2006	9.361	6.935	11.819	11.513	9.907
2007	8.674	6.935	11.996	8.883	9.122
2008	5.950	6.935	8.443	6.647	6.994
2009	8.023	6.935	8.493	6.201	7.413
2010	6.114	6.935	8.422	7.720	7.298
2012	8.709	6.935	8.422	7.720	7.946
2013	8.433	6.935	8.422	8.010	7.950
2014	8.237	6.935	8.422	8.993	8.147

Table 3.7 Calculated yearly total discards of red snapper (in numbers of fish) by vertical line vessels including 2014 discards. Vertical line vessels accounted for approximately 97% of calculated discards. Yearly nominal discard rates calculated separately for open and closed red snapper seasons. Effort is in hook hours fished. Discard rate used for the years 1992-2001 was the weighted mean rate for the years 2002-2009. Trips (discards) = trips reporting to the discard logbook program. Trips (total effort) = number of trips reporting to the coastal logbook program.

Year	Season	Trips (discards)	Trips (total effort)	Discard Rate	Discard Rate CV	Total Effort	Calculated Discards
1992*	Open		4,428	0.0124		1,557,323	19,339
1993	Open		11,846	0.0124		1,331,155	16,530
1994	Open		14,446	0.0124		1,680,269	20,865
1995	Open		14,468	0.0124		1,676,441	20,818
1996	Open		15,395	0.0124		1,647,052	20,453
1997	Open		17,642	0.0124		1,778,302	22,083
1998	Open		15,863	0.0124		1,280,778	15,905
1999	Open		14,462	0.0124		1,079,870	13,410
2000	Open		13,298	0.0124		1,155,724	14,352
2001	Open		13,927	0.0124		1,202,087	14,927
2002	Open	1,169	14,575	0.0251	9.97	1,156,630	29,020
2003	Open	1,544	14,062	0.0085	14.57	982,399	8,372
2004	Open	1,032	13,178	0.0025	7.75	874,447	2,192
2005	Open	1,230	11,843	0.0122	14.31	807,361	9,823
2006	Open	880	11,654	0.0054	10.64	880,385	4,739
2007	Open	1,757	12,801	0.0140	21.15	946,780	13,249
2008	Open	3,098	13,036	0.0130	10.28	962,163	12,514
2009	Open	1,715	14,352	0.0144	7.61	1,007,193	14,466
2010	Open	153	757	0.0471	10.96	35,816	1,688
2011	Open**						
2012	Open	232	706	0.0051	5.97	38,923	200
2013	Open	334	1,423	0.0096	9.28	100,868	968
2014	Open	533	2,264	0.0137	5.10	144,207	1,978
2010	Closed	2,800	12,012	0.0167	6.19	783,389	13,121
2011	Closed	3,250	13,093	0.0500	8.16	784,566	39,240
2012	Closed	3,156	11,634	0.0269	8.10	662,827	17,833
2013	Closed	2,516	10,578	0.0258	7.01	650,090	16,798
2014	Closed	2,692	11,822	0.0375	5.06	625,031	23,455

*in 1992 only 20% of vessels in Florida were required to report to the logbook program; effort for areas off Florida were expanded by a factor of five.

**No open season for red snapper during 2011

Table 3.8 Calculated yearly total discards of red snapper (in numbers of fish) by dive vessels including 2014 discards. Dive vessels accounted for approximately 1.4% of calculated discards. Yearly nominal discard rates calculated separately for open and closed red snapper seasons. Effort is in diver hours fished. Discard rate used for the years 1992-2001 was the weighted mean rate for the years 2002-2009. Trips (discards) = trips reporting to the discard logbook program. Trips (total effort) = number of trips reporting to the coastal logbook program.

Year	Season	Trips (discards)	Trips (total effort)	Discard Rate	Discard Rate CV	Total Effort	Calculated Discards
1992*	Open		506	0.0057		22,041	126
1993	Open		976	0.0057		14,084	80
1994	Open		927	0.0057		19,384	111
1995	Open		753	0.0057		17,976	103
1996	Open		978	0.0057		20,472	117
1997	Open		1,243	0.0057		25,297	144
1998	Open		1,196	0.0057		21,984	125
1999	Open		893	0.0057		17,636	101
2000	Open		963	0.0057		17,667	101
2001	Open		1,011	0.0057		17,297	99
2002	Open	10	929	0.0200	3.16	17,330	347
2003	Open	48	894	0.0000		13,609	0
2004	Open	57	772	0.0175	7.55	13,284	233
2005	Open	23	681	0.0290	4.80	12,219	354
2006	Open	20	687	0.0063	4.47	12,369	77
2007	Open	67	856	0.0000		16,941	0
2008	Open	141	745	0.0027	11.87	14,340	38
2009	Open	49	769	0.0000		12,596	0
2010	Open	11	44	0.0000		1,116	0
2011	Open**						
2012	Open	6	83	0.0000		1,105	0
2013	Open	28	199	0.0000		2,779	0
2014	Open	39	280	0.0000		5,094	0
2010	Closed	91	730	0.0680	3.91	14,051	956
2011	Closed	136	926	0.0223	4.13	16,238	362
2012	Closed	120	839	0.0551	3.82	16,263	896
2013	Closed	86	801	0.0518	5.75	13,799	715
2014	Closed	113	744	0.0487	8.23	13,726	668

*in 1992 only 20% of vessels in Florida were required to report to the logbook program; effort for areas off Florida were expanded by a factor of five.

**No open season for red snapper during 2011

Table 3.9 Calculated yearly total discards of red snapper (in numbers of fish) by trap vessels including 2014 discards. Trap vessels accounted for approximately 1.4% of calculated discards. Yearly nominal discard rates calculated separately for open and closed red snapper seasons. Effort is in traps fished. Discard rate used for the years 1992-2001 was the weighted mean rate for the years 2002-2009. Trips (discards) = trips reporting to the discard logbook program. Trips (total effort) = number of trips reporting to the coastal logbook program.

Year	Season	Trips (discards)	Trips (total effort)	Discard Rate	Discard Rate CV	Total Effort	Calculated Discards
1992*	Open		595	0.0026		52,540	139
1993	Open		1,023	0.0026		43,311	114
1994	Open		1,195	0.0026		59,745	158
1995	Open		1,032	0.0026		55,765	147
1996	Open		1,168	0.0026		59,422	157
1997	Open		1,353	0.0026		62,406	165
1998	Open		1,201	0.0026		53,588	142
1999	Open		1,075	0.0026		49,538	131
2000	Open		829	0.0026		37,859	100
2001	Open		1,096	0.0026		43,626	115
2002	Open	51	826	0.0134	6.31	35,942	482
2003	Open	89	783	0.0000		31,505	0
2004	Open	38	820	0.0000		31,221	0
2005	Open	12	596	0.0000		24,787	0
2006	Open	5	786	0.0000		32,018	0
2007	Open	52	616	0.0200	5.15	26,389	529
2008	Open	209	561	0.0000		18,820	0
2009	Open	197	772	0.0000		28,804	0
2010	Open	18	55	0.0000		1,683	0
2011	Open**						
2012	Open	8	17	0.0000		451	0
2013	Open	55	99	0.0044	5.49	2,494	11
2014	Open	24	44	0.0556	4.90	1,131	63
2010	Closed	136	349	0.1104	11.65	13,878	1,533
2011	Closed	51	237	0.0719	7.14	6,986	502
2012	Closed	127	307	0.0099	4.52	8,284	82
2013	Closed	111	268	0.1068	9.35	6,850	732
2014	Closed	108	218	0.0852	3.36	5,313	453

*in 1992 only 20% of vessels in Florida were required to report to the logbook program; effort for areas off Florida were expanded by a factor of five.

**No open season for red snapper during 2011

Table 3.10 Calculated yearly total discards of red snapper (in numbers of fish) by trolling vessels including 2014 discards. Trolling vessels accounted for approximately 0.2% of calculated discards. Yearly nominal discard rates calculated separately for open and closed red snapper seasons. Effort is in hook hours fished. Discard rate used for the years 1992-2001 was the weighted mean rate for the years 2002-2009. Trips (discards) = trips reporting to the discard logbook program. Trips (total effort) = number of trips reporting to the coastal logbook program.

Year	Season	Trips (discards)	Trips (total effort)	Discard Rate	Discard Rate CV	Total Effort	Calculated Discards
1992*	Open		576	0.0000		69,458	0
1993	Open		1,095	0.0000		75,520	0
1994	Open		1,241	0.0000		103,442	0
1995	Open		1,435	0.0000		78,334	0
1996	Open		1,181	0.0000		72,067	0
1997	Open		1,295	0.0000		77,154	0
1998	Open		3,227	0.0000		204,204	0
1999	Open		3,470	0.0000		202,641	0
2000	Open		4,576	0.0000		265,989	0
2001	Open		4,781	0.0000		203,199	0
2002	Open	273	4,349	0.0000		172,868	0
2003	Open	241	3,823	0.0000		134,453	0
2004	Open	224	3,123	0.0000		114,811	0
2005	Open	183	2,855	0.0000		101,320	0
2006	Open	125	2,918	0.0000		104,919	0
2007	Open	482	3,668	0.0000		127,460	0
2008	Open	1,009	3,750	0.0000		114,901	0
2009	Open	634	4,107	0.0000		135,729	0
2010	Open	59	302	0.0000		9,295	0
2011	Open**						
2012	Open	54	160	0.0026	7.35	5,157	14
2013	Open	88	309	0.0000		11,854	0
2014	Open	141	547	0.0003	11.87	17,357	5
2010	Closed	854	3,560	0.0013	27.31	111,864	140
2011	Closed	573	3,392	0.0000	23.94	110,991	3
2012	Closed	798	3,090	0.0018	13.59	103,963	189
2013	Closed	661	2,775	0.0009	9.15	92,440	79
2014	Closed	882	3,074	0.0039	5.58	98,811	387

*in 1992 only 20% of vessels in Florida were required to report to the logbook program; effort for areas off Florida were expanded by a factor of five.

**No open season for red snapper during 2011

Table 3.11 Gear-specific relative percentage of length samples , total number of years with samples (Years), the number of years with 30 or more fish measured (Years>30 (31 Total)), the proportion of years with only one state contributing to the annual length samples (Years1state), mean total length in millimeters (meanTLmm), and mean weight in pounds (meanWt_lb).

Gear	Length Samples	Years	Years>30 (32 Total)	Years 1 state	meanTLmm	meanWt_lb
Lines	92.9%	32	31	0.06	597	7.3
Diving	3.2%	21	6	0.76	639	8.9
Pots	0.9%	11	3	0.63	564	6.1
Longline	1.2%	20	3	0.69	690	11.2
Trawl	0.8%	4	3	1	428	2.7
Other	1.0%	8	0	1	582	6.7

Table 3.12 Number of red snapper fish sampled for lengths by gear (handline, diving, other) and state from the U.S. South Atlantic TIP database, 1983-2014.

	Handline				Diving			Other			
Year	NC	SC	GA	FL	SC	GA	FL	NC	SC	GA	FL
1983	35										
1984	1069	970	50					3	34		
1985	731		203	1228				14		33	36
1986	659		144	130				2			40
1987	394		354					73		47	
1988	200	101	233	5				24	138		
1989	600		191	37				10			
1990	435			173				5			49
1991	197	59	196	75				5	53	1	11
1992	78		110	178			4				13
1993	229	7	128	364			8	1			18
1994	451	58	77	187		1	1	1			37
1995	127		101	872			25				47
1996	58	282	105	427	7		21		6		17
1997	1	177	43	239			10		1		20
1998	17	228	14	208			7				15
1999	187	523	42	274			83	1	3		
2000	59	434	65	387			129				11
2001	270	453	369	802			87		1		29
2002	196	460	124	229			9				
2003	164	667	153	401			222				
2004	90	451	214	125	8						1
2005	94	377	94	50	3			8			
2006	65	143	16	212	15		7				
2007	102	166		320			17	2	1		
2008	170	266	18	219	2		27	2	1		7
2009	162	470		1916	7		63	1	16		143
2010	2			66							
2011											
2012	14	33		92			6				3
2013	79	34		345			110	13			75
2014	98			269			28				

Table 3.13 Number of trips sampled for red snapper lengths by gear (handline, diving, other) and state from the U.S. South Atlantic TIP database, 1983-2014.

	Handline				Diving			Other			
Year	NC	SC	GA	FL	SC	GA	FL	NC	SC	GA	FL
1983	12										
1984	78	43	4					2	2		
1985	94		15	30				5		1	5
1986	70		20	4				2			1
1987	57		32					7		1	
1988	38	22	22	2				10	6		
1989	74		12	2				2			
1990	54			9				2			2
1991	48	10	39	9				3	6	1	4
1992	30		22	30			2				9
1993	49	1	24	42			3	1			8
1994	60	8	16	18		1	1	1			5
1995	49		15	63			5				13
1996	15	73	19	50	2		4		2		6
1997	1	59	10	35			1		1		11
1998	10	66	4	41			2				6
1999	28	83	10	46			13	1	1		
2000	26	67	11	45			9				2
2001	53	80	10	53			6		1		2
2002	43	73	10	18			3				
2003	33	76	11	35			15				
2004	41	70	18	9	1						1
2005	44	75	4	10	1			1			
2006	38	52	4	39	5		5				
2007	58	77		50			7	2	1		
2008	68	86	1	17	1		3	2	1		1
2009	56	110		95	4		16	1	1		9
2010	2			2							
2011	7	13		20							
2012	25	9		58			2				2
2013	23			38			14	3			7
2014	98			269			3				

Table 3.14 Number of fish sampled for red snapper ages by gear (handline, other including diving) and state from the U.S. South Atlantic commercial fishery.

	Handline				Other		
Year	NC	SC	GA	FL	NC	SC	FL
1988		32					
1989		5					
1990		29					
1991		6					
1992		23		15			
1993		12		7			
1994		20		1			
1995		5		16			4
1996		86		118			11
1997		111		63			
1998				50			1
1999		151		13			
2000		131	16	141			122
2001				115			58
2002		3		30			1
2003				59			
2004	21			57			
2005	64	33		38			
2006	34	115		80			
2007	80	108		79		4	1
2008	156	194		39	4		7
2009	152	233		2047		15	75
2010				30			
2011	1						
2012	9	33		106	4		17
2013	74	36	15	597	12		106
2014	100	68		297	15		7

Table 3.15 Number of trips sampled for red snapper ages by gear (handline, other including diving) and state from the U.S. South Atlantic commercial fishery.

	Handline				Other		
Year	NC	SC	GA	FL	NC	SC	FL
1988		7					
1989		4					
1990		11					
1991		3					
1992		8		3			
1993		8		1			
1994		14		1			
1995		5		2			1
1996		32		16			1
1997		29		16			
1998				14			1
1999		10		5			
2000		6	1	21			7
2001				23			4
2002		2		5			1
2003				10			
2004	13			12			
2005	35	12		6			
2006	24	51		9			
2007	51	67		14		2	1
2008	68	85		5	3		1
2009	60	97		106		9	14
2010				1			
2011	1						
2012	4	13		22	2		4
2013	24	10	4	71	3		14
2014	24	13		27	4		1

3.12 Figures

Figure 3.1 Region of red snapper landings.

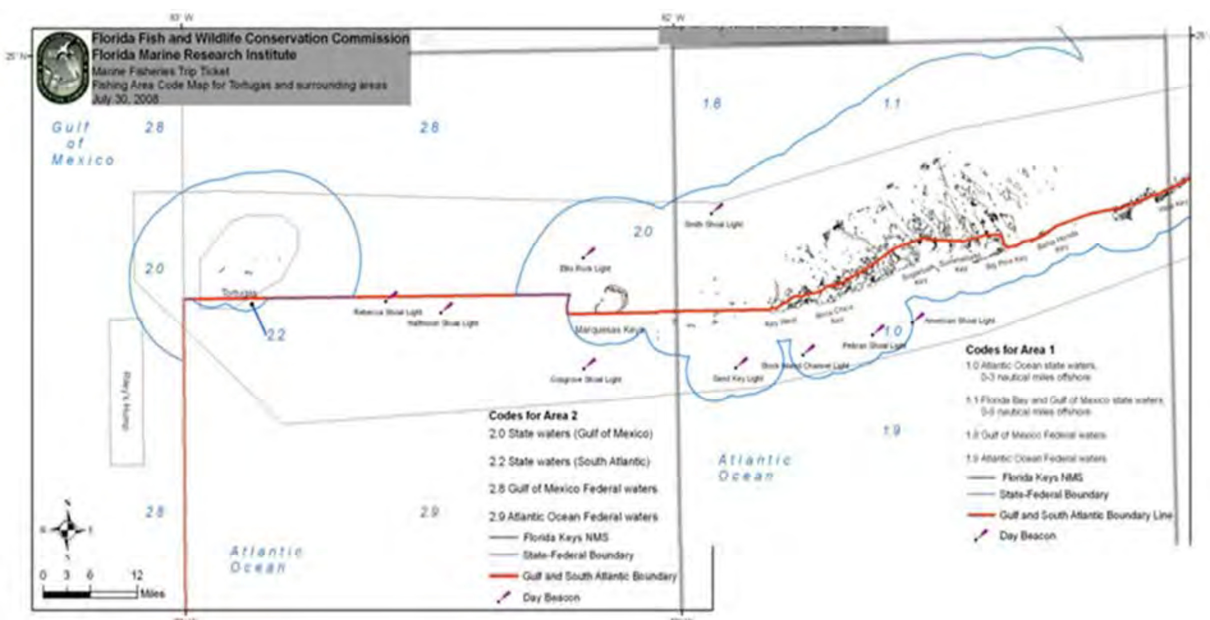

Figure 3.2 Close-up of the southern boundary as defined by the Gulf of Mexico/South Atlantic Council boundary.

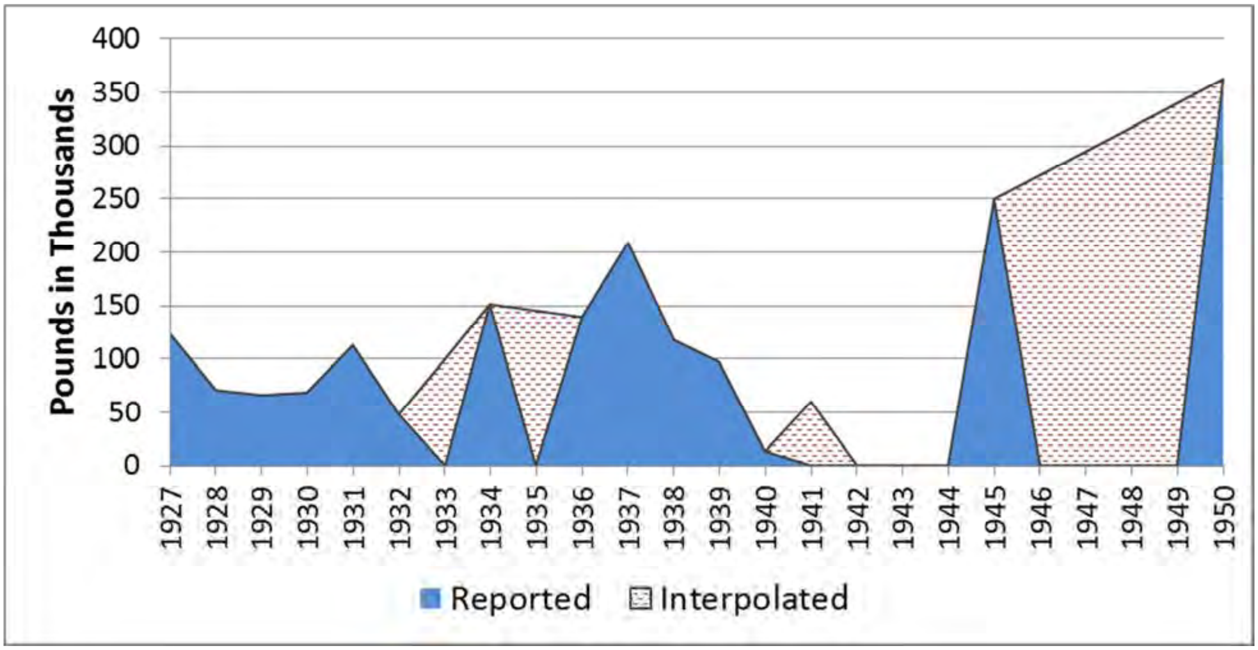

Figure 3.3 Historical red snapper landings, in thousands of whole weight pounds, from 1927-1949.

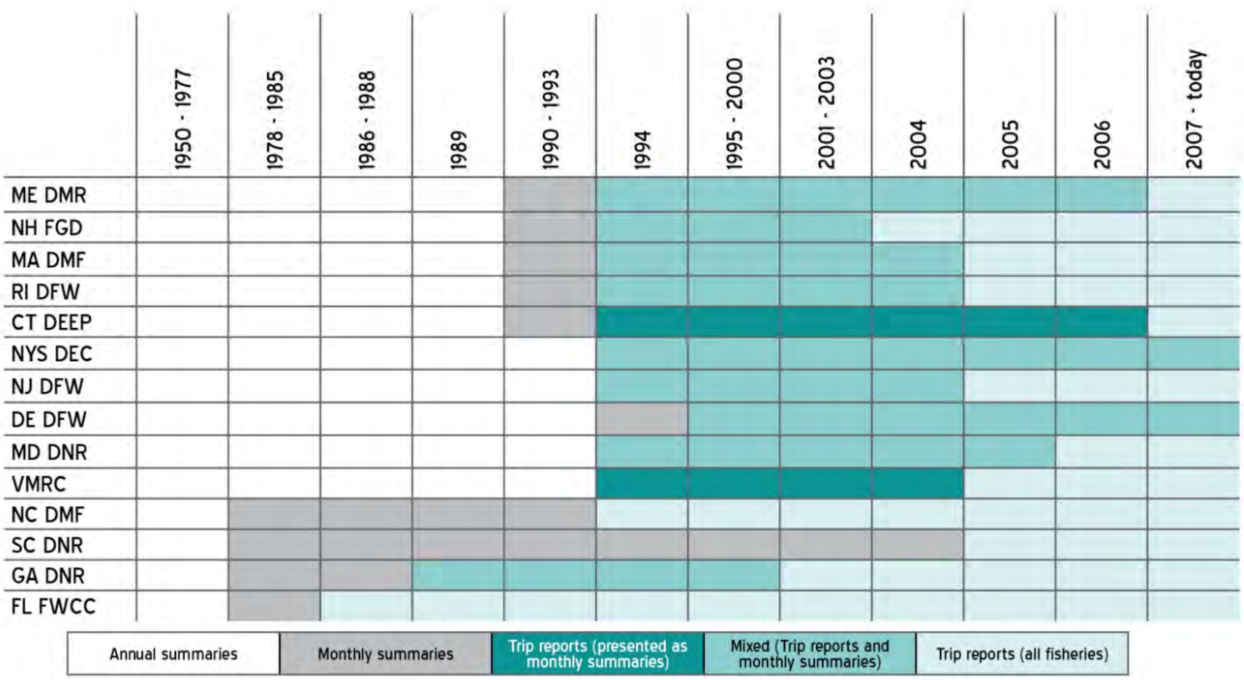

Figure 3.4 Atlantic Coastal Cooperative Statistics Program (ACCSP) Data Warehouse - data sources and collection methods by state.

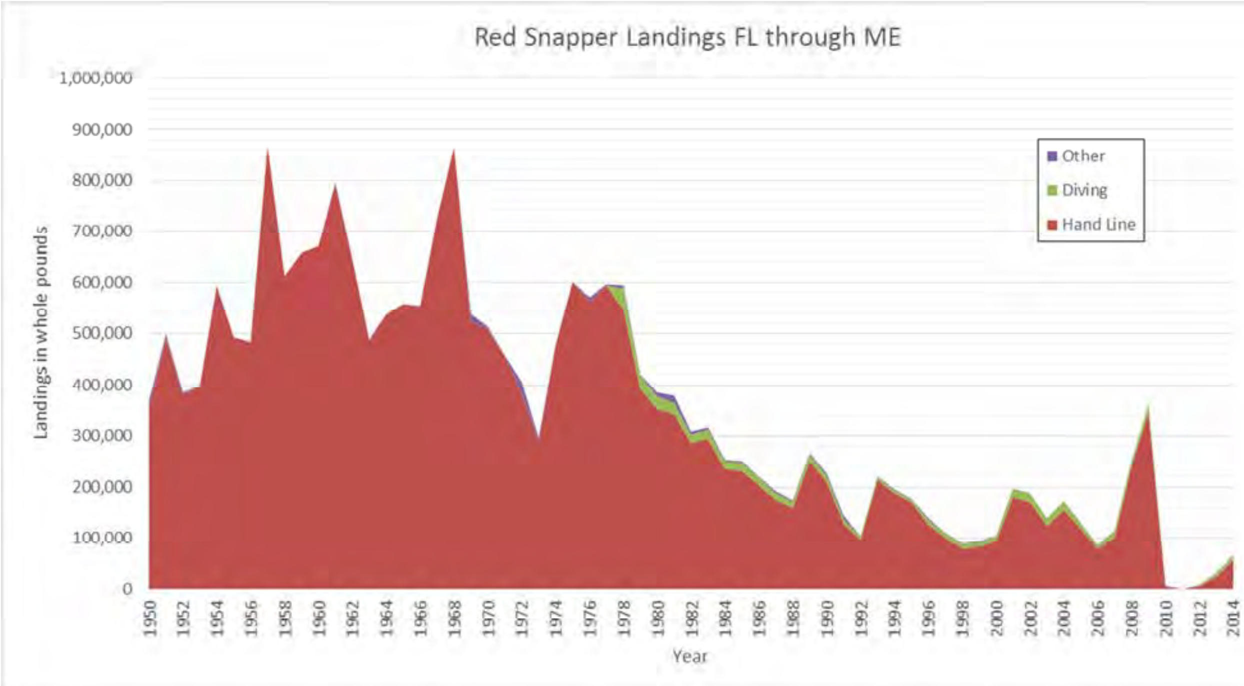

Figure 3.5 Red snapper landings, in pounds (whole weight), for all states (FL-ME) by gear, 1950-2014.

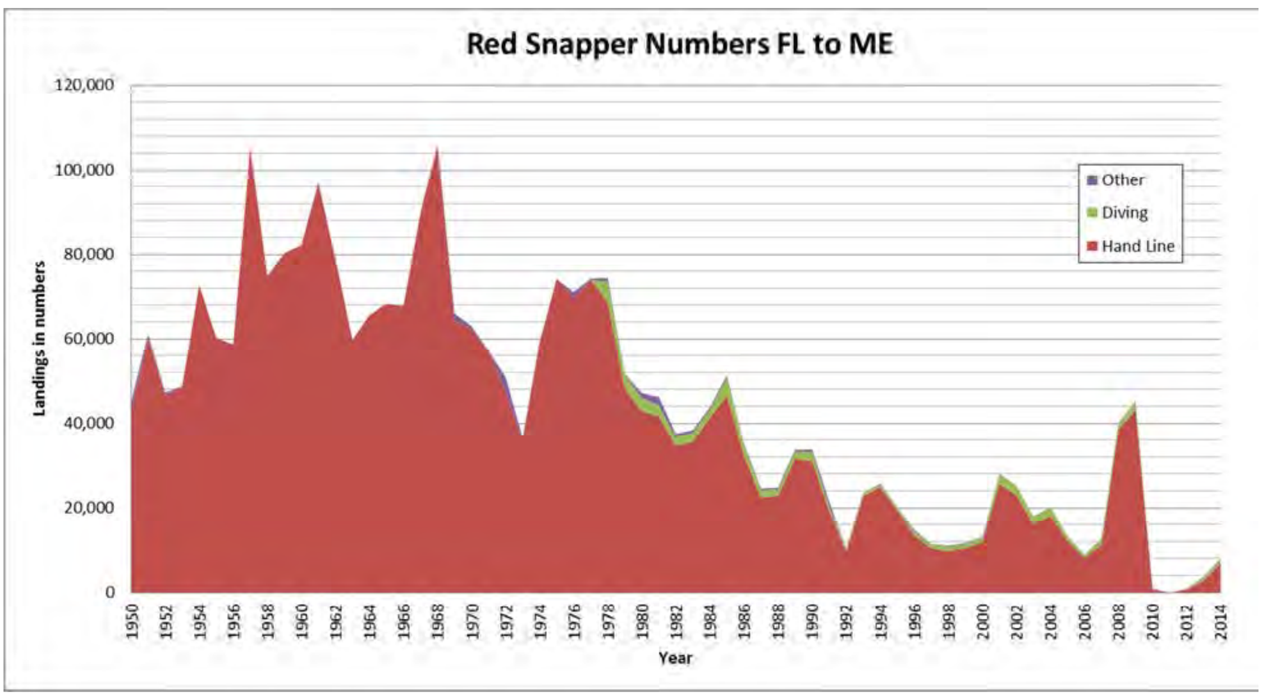

Figure 3.6 Red snapper landings, in numbers of fish, for all states (FL-ME) by gear, 1950-2014.

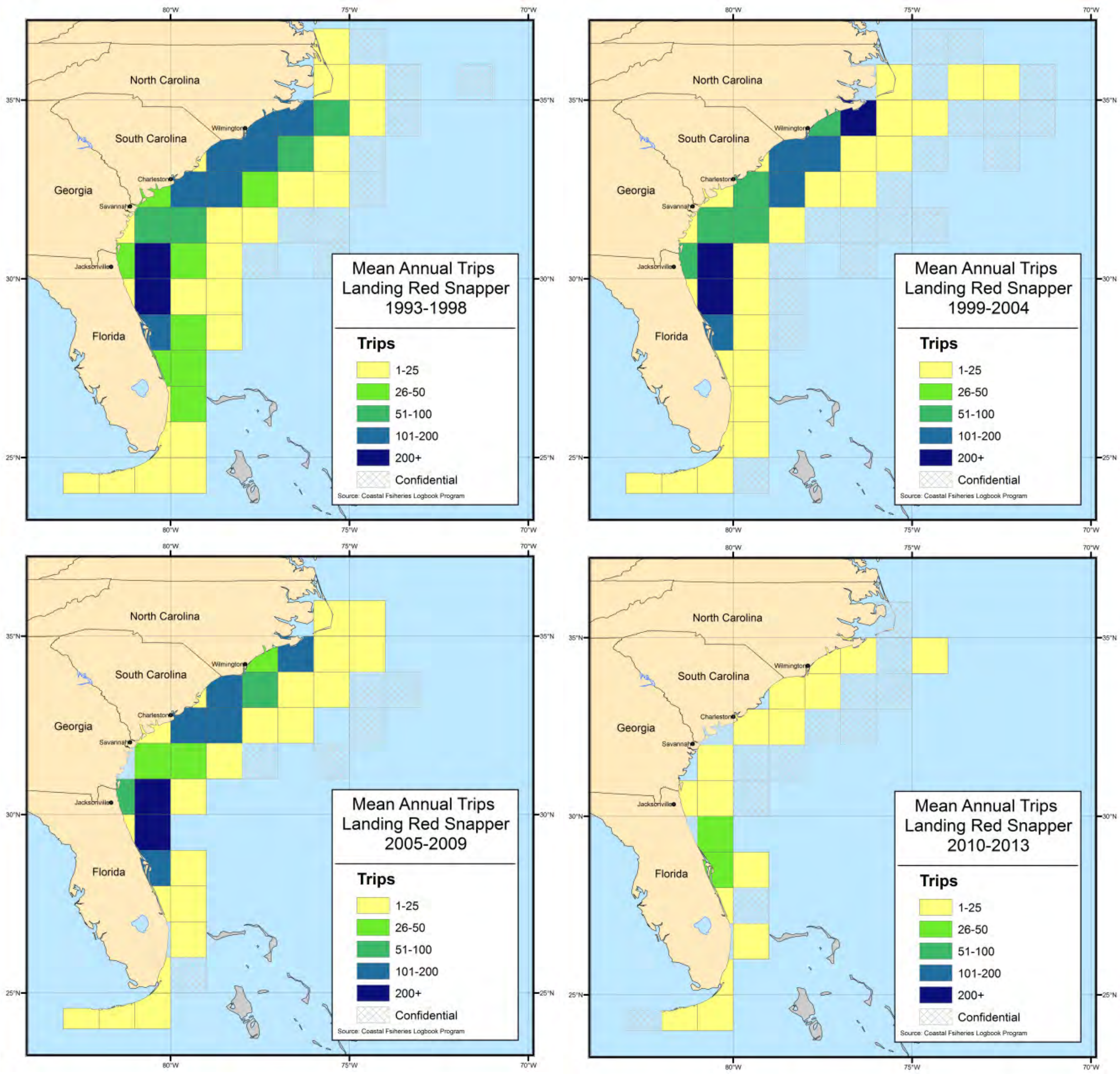

Figure 3.7 Average number of trips landing red snapper, by statistical grid, in the U.S. South Atlantic as reported to the CFLP.

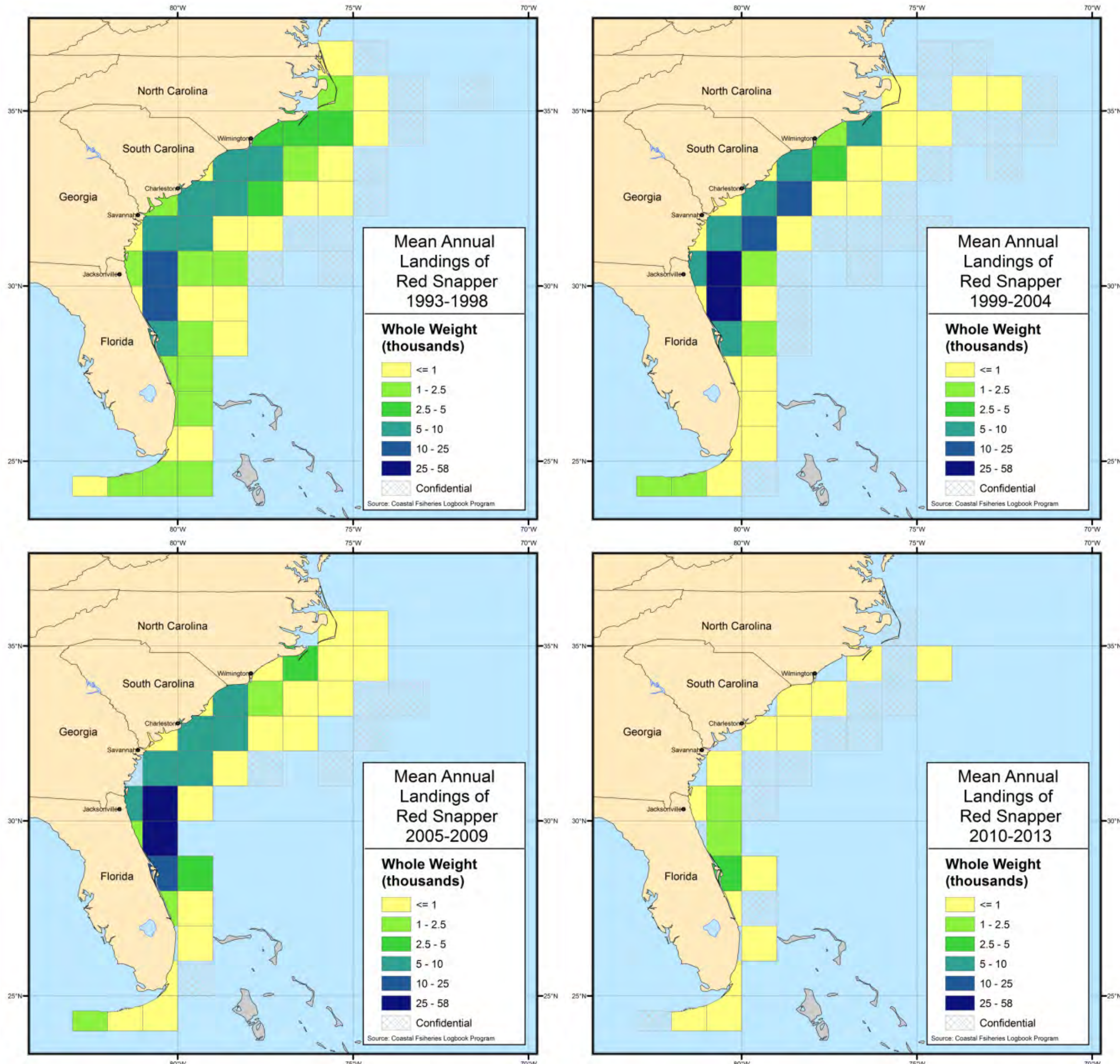

Figure 3.8 Average annual harvest of red snapper, by statistical grid, in the U.S. South Atlantic as reported to the CFLP.

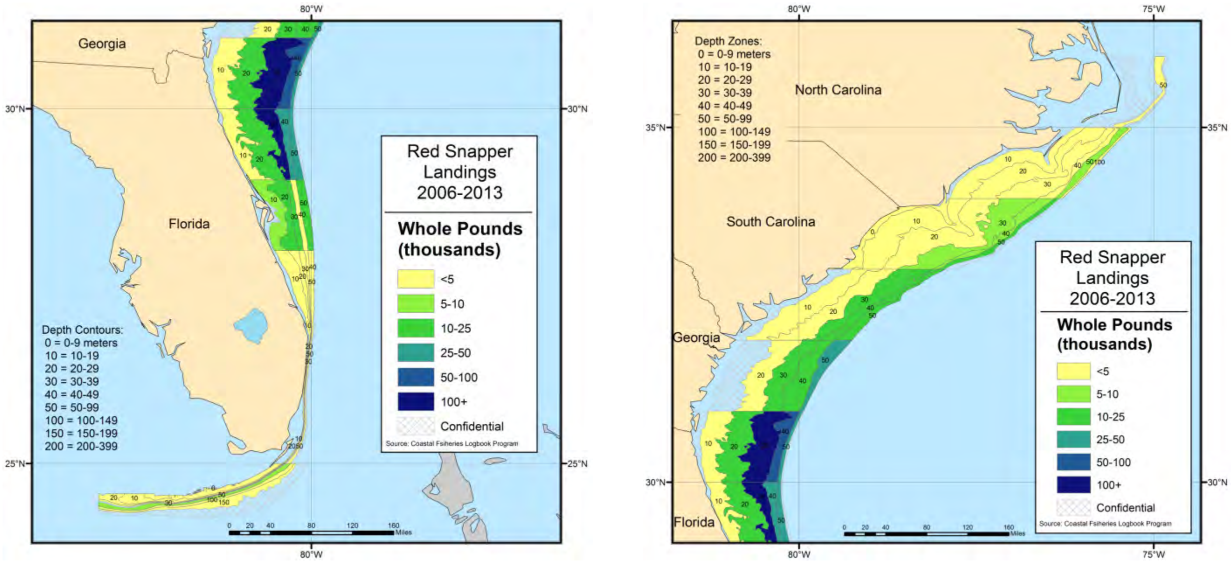

Figure 3.9 Total harvest of red snapper by depth and degrees latitude in the U.S. South Atlantic as reported to the CFLP.

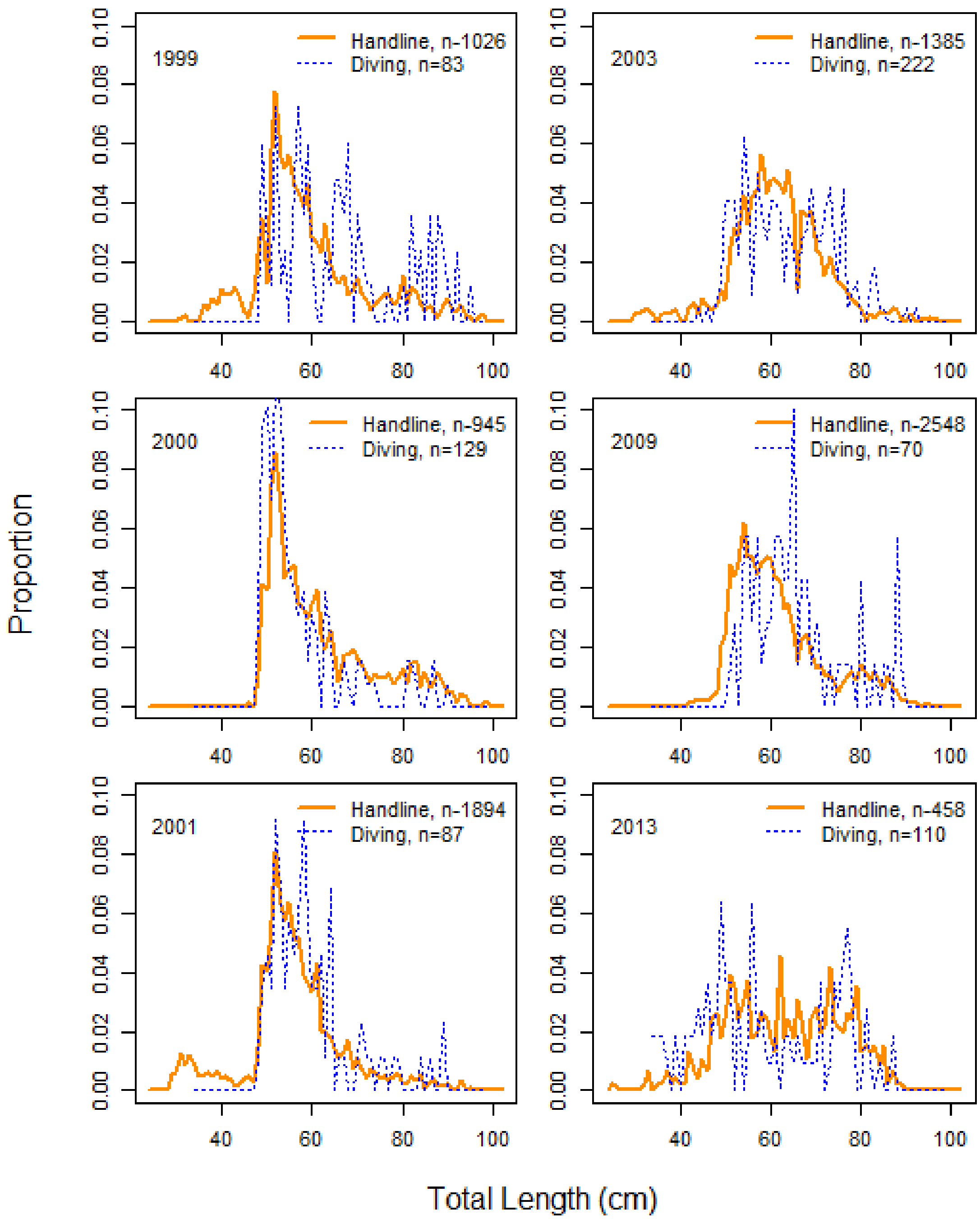

Figure 3.10 Comparison of commercial line and diving length compositions for years with 30 or more diving samples.

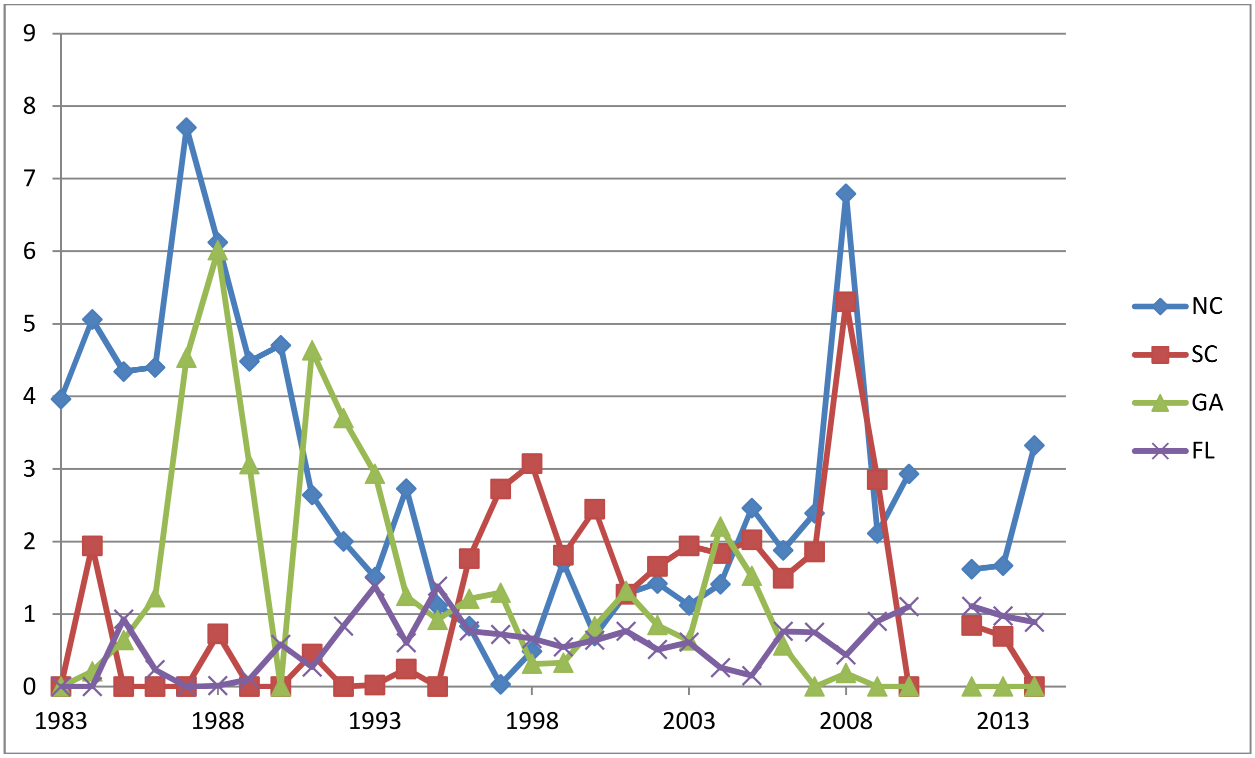

Figure 3.11 Relative comparison of sampled fish to landings in pounds (e.g. if all fish measured are from one state that has 25% of the landings the value would be 4; if 25% of fish sampled are from one state and 25% of the landings are from that state, the value would be 1).

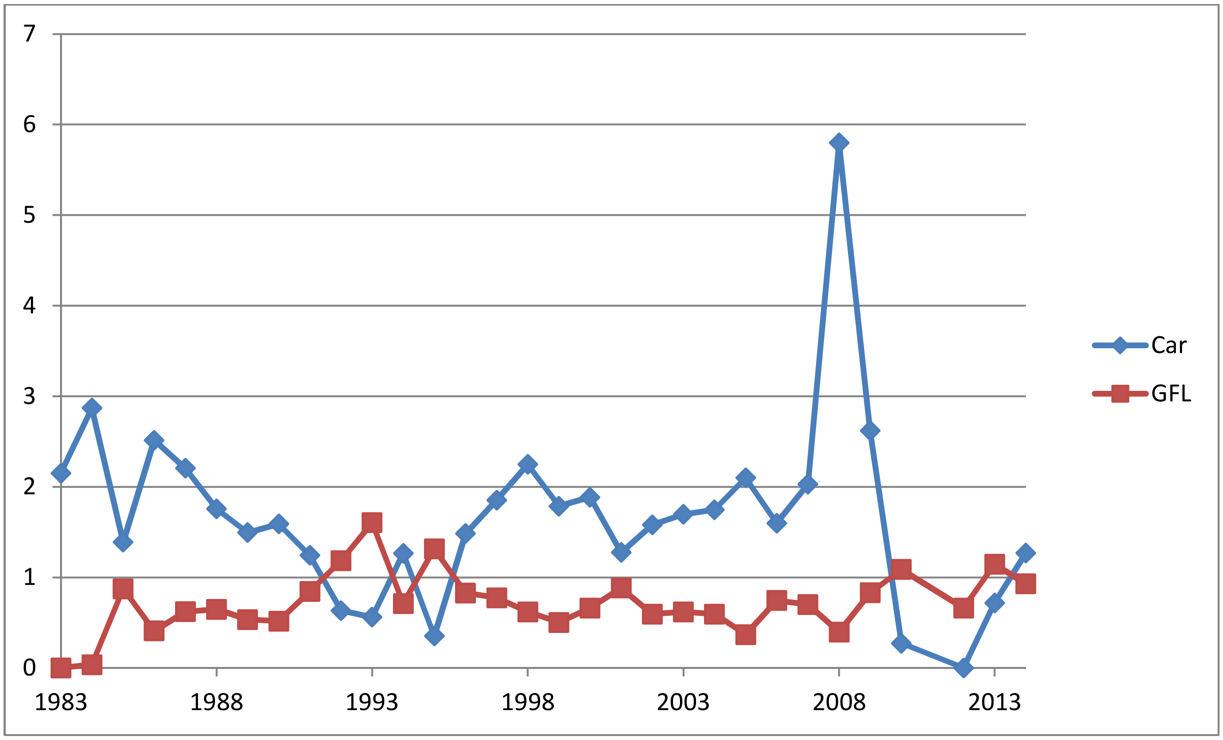

Figure 3.12 Relative comparison of sampled fish to landings in pounds by region (a value of 1 means the fish were sampled proportional to landings).

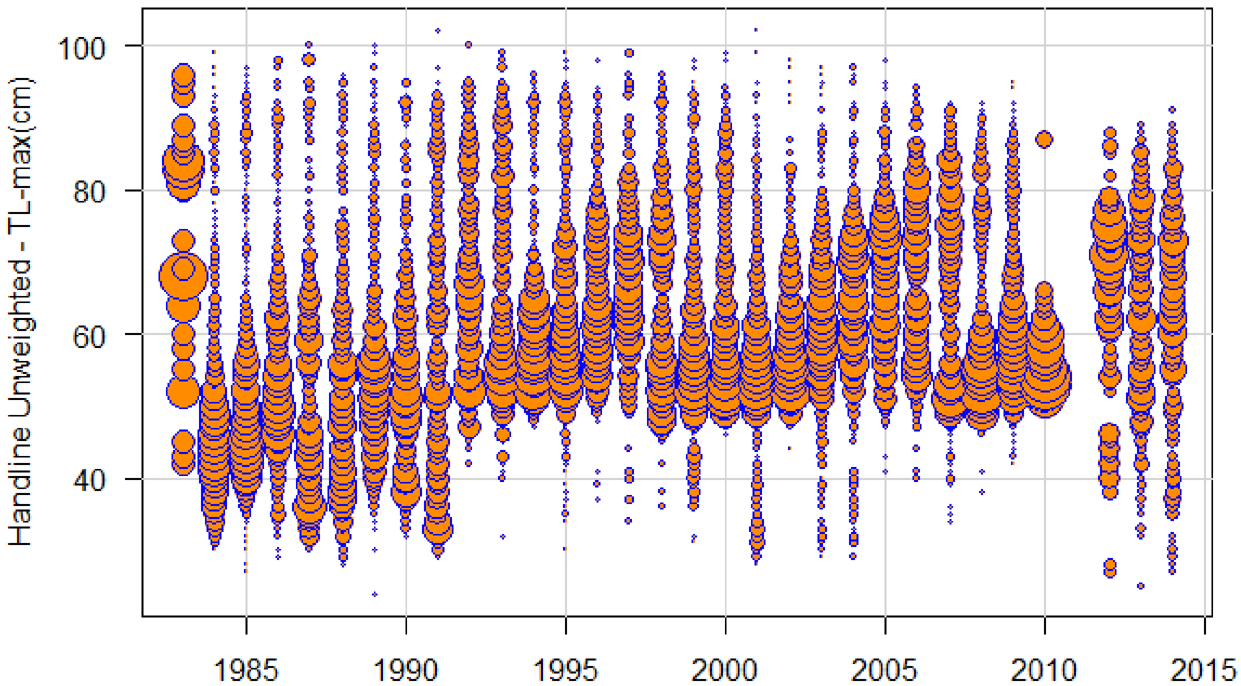

Figure 3.13 Red snapper nominal handline length compositions (area of bubble relative to annual proportion at length in 1 cm bins).

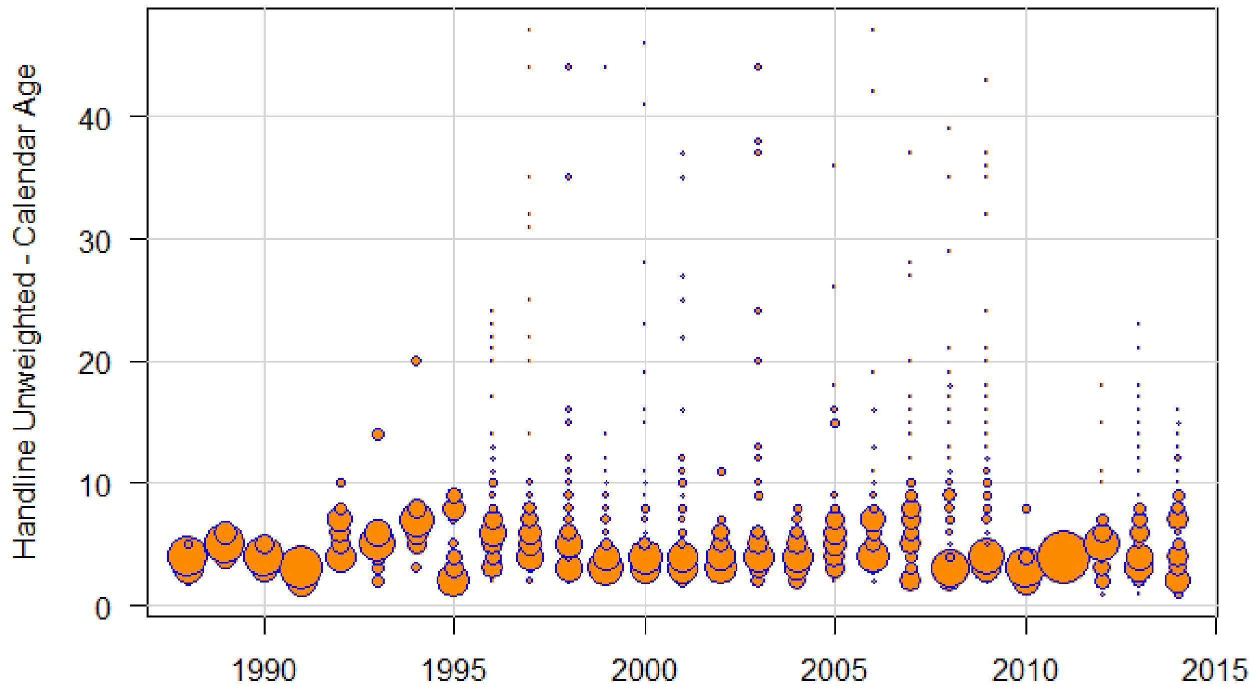

Figure 3.14 Red snapper nominal age composition to a maximum calendar age of 47 years (area of bubble relative to annual proportion at calendar age).

Figure 3.15 Red snapper nominal age composition pooled at 15 years (area of bubble relative to annual proportion at calendar age).

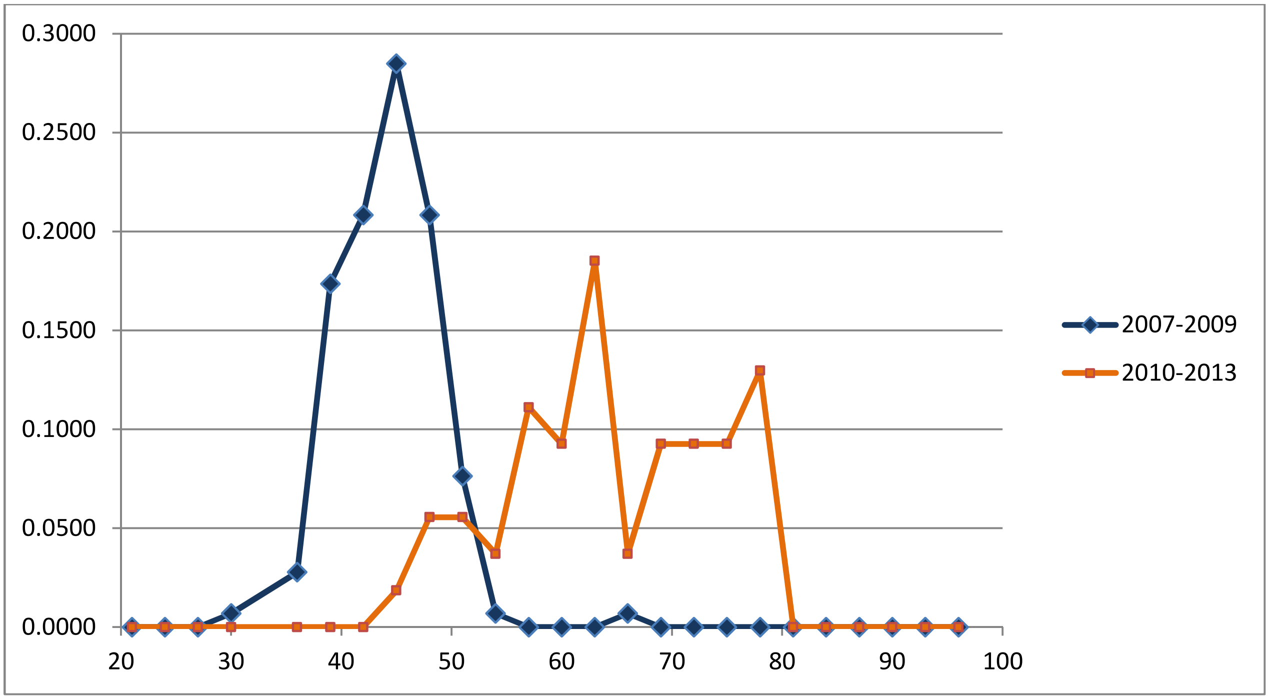

Figure 3.16 Commercial discard length distribution for the period with a 20 inch size limit (2007-2009) and during the closure (2010-2013). These were estimated from limited commercial observer data from 2007-2013.

Appendix A

NMFS SECPR Accumulated Landings System (ALS)
Information on the quantity and value of seafood products caught by fishermen in the U.S. has been collected starting in the late 1800s (inaugural year is species dependent). Fairly serious collection activity began in the 1920s. The data set maintained by the Southeast Fisheries Science Center (SEFSC) in the SECPR database management system is a continuous dataset that begins in 1962.

In addition to the quantity and value, information on the gear used to catch the fish, the area where the fishing occurred and the distance from shore are also recorded. Because the quantity and value data are collected from seafood dealers, the information on gear and fishing location are estimated and added to the data by data collection specialists. In some states, this ancillary data are not available.

Commercial landings statistics have been collected and processed by various organizations during the 1962-to-present period that the SECPR data set covers. During the 16 years from 1962 through 1978, these data were collected by port agents employed by the Federal government and stationed at major fishing ports in the southeast. The program was run from the Headquarters Office of the Bureau of Commercial Fisheries in Washington DC until 1970. After 1970 it was run by the newly created National Marine Fisheries Service, which had replaced the Bureau of Commercial Fisheries. Data collection procedures were established by Headquarters and the data were submitted to Washington for processing and computer storage. In 1978, the responsibility for collection and processing were transferred to the SEFSC.

In the early 1980s, the NMFS and the state fishery agencies within the Southeast began to develop a cooperative program for the collection and processing of commercial fisheries statistics. With the exception of two counties, one in Mississippi and one in Alabama, all of the general canvass statistics are collected by the fishery agency in the respective state and provided to the SEFSC under a comprehensive Cooperative Statistics Program (CSP).

The purpose of this documentation is to describe the current collection and processing procedures that are employed for the commercial fisheries statistics maintained in the SECPR database.

1960 - Late 1980s
=================
Although the data processing and database management responsibility were transferred from the Headquarters in Washington DC to the SEFSC during this period, the data collection procedures remained essentially the same. Trained data collection personnel, referred to as fishery reporting

specialists or port agents, were stationed at major fishing ports throughout the Southeast Region. The data collection procedures for commercial landings included two parts.

The primary task for the port agents was to visit all seafood dealers or fish houses within their assigned areas at least once a month to record the pounds and value for each species or product type that were purchased or handled by the dealer or fish house. The agents summed the landings and value data and submitted these data in monthly reports to their area supervisors. All of the monthly data were submitted in essentially the same form.

The second task was to estimate the quantity of fish that were caught by specific types of gear and the location of the fishing activity. Port agents provided this gear/area information for all of the landings data that they collected. The objective was to have gear and area information assigned to all monthly commercial landings data.

There are two problems with the commercial fishery statistics that were collected from seafood dealers. First, dealers do not always record the specific species that are caught and second, fish or shellfish are not always purchased at the same location where they are unloaded, i.e., landed. Dealers have always recorded fishery products in ways that meet their needs, which sometimes make it ambiguous for scientific uses. Although the port agents can readily identify individual species, they usually were not at the fish house when fish were being unloaded and thus, could not observe and identify the fish.

The second problem is to identify where the fish were landed from the information recorded by the dealers on their sales receipts. The NMFS standard for fisheries statistics is to associate commercial statistics with the location where the product was first unloaded, i.e., landed, at a shore-based facility. Because some products are unloaded at a dock or fish house and purchased and transported to another dealer, the actual 'landing' location may not be apparent from the dealers' sales receipts. Historically, communications between individual port agents and the area supervisors were the primary source of information that was available to identify the actual unloading location.

Cooperative Statistics Program
==============================
In the early 1980s, it became apparent that the collection of commercial fisheries statistics was an activity that was conducted by both the Federal government and individual state fishery agencies. Plans and negotiations were initiated to develop a program that would provide the fisheries statistics that are needed for management by both Federal and state agencies. By the mid-1980s, formal cooperative agreements had been signed between the NMFS/SEFSC and each of the eight coastal states in the southeast, Puerto Rico and the US Virgin Islands.

Initially, the data collection procedures that were used by the states under the cooperative agreements were essentially the same as the historical NMFS procedures. As the states developed their data collection programs, many of them promulgated legislation that authorized their fishery agencies to collect fishery statistics. Many of the state statutes include mandatory data submission by seafood dealers.

Because the data collection procedures (regulations) are different for each state, the type and detail of data varies throughout the Region. The commercial landings database maintained in SECPR contains a standard set of data that is consistent for all states in the Region.

A description of the data collection procedures and associated data submission requirements for each state follows.

Florida
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Prior to 1986, commercial landings statistics were collected by a combination of monthly mail submissions and port agent visits. These procedures provided quantity and value, but did not provide information on gear, area or distance from shore. Because of the large number of dealers, port agents were not able to provide the gear, area and distance information for monthly data. This information, however, is provided for annual summaries of the quantity and value and known as the Florida Annual Canvas data (see below).

Beginning in 1986, mandatory reporting by all seafood dealers was implemented by the State of Florida. The State requires that a report (ticket) be completed and submitted to the State for every trip. Dealers have to report the type of gear as well as the quantity (pounds) purchased for each species. Information on the area of catch can also be provided on the tickets for individual trips. As of 1986 the ALS system relies solely on the Florida trip ticket data to create the ALS landings data for all species other than shrimp.

Georgia
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Prior to 1977, the National Marine Fisheries Service collected commercial landings data Georgia. From 1977 to 2001 state port agents visited dealers and docks to collect the information on a regular basis. Compliance was mandatory for the fishing industry. To collect more timely and accurate data, Georgia initiated a trip ticket program in 1999, but the program was not fully implemented to allow complete coverage until 2001. All sales of seafood products landed in Georgia must be recorded on a trip ticket at the time of the sale. Both the seafood dealer and the seafood harvester are responsible for insuring the ticket is completed in full.

South Carolina
===========
Prior to 1972, commercial landings data were collected by various federal fisheries agents based in South Carolina, either U.S. Fish or Wildlife or National Marine Fisheries Service personnel. In 1972, South Carolina began collecting landings data from coastal dealers in cooperation with federal agents. Mandatory monthly landings reports on forms supplied by the Department are required from all licensed wholesale dealers in South Carolina. Until fall of 2003, those monthly reports were summaries collecting species, pounds landed, disposition (gutted or whole) and market category, gear type, and area fished; since September 2003, landings have been reported by a mandatory trip ticket system collecting landings by species, disposition and market category, pounds landed, ex-vessel prices with associated effort data to include gear type and amount, time fished, area fished, along with vessel and fisherman information.

South Carolina began collecting TIP length frequencies in 1983 as part of the Cooperative Statistics Program. Target species and length quotas were supplied by NMFS and sampling targets were established for monthly commercial trips by gear sampling was set to collect those species with associated length frequencies. In 2005, SCDNR began collecting age structures (otoliths and spines) in addition to length frequencies, using ACCSP funding to supplement CSP funding. Typically for every four fish measured a single age structure was collected. This sampling periodicity was changed in 2010 to collect both a length and age structure from every fish intercepted as a recommendation from the SEFSC.

North Carolina
===========
The National Marine Fisheries Service prior to 1978 collected commercial landings data for North Carolina. Port agents would conduct monthly surveys of the state's major commercial seafood dealers to determine the commercial landings for the state. Starting in 1978, the North Carolina Division of Marine Fisheries entered into a cooperative program with the National Marine Fisheries Service to maintain the monthly surveys of North Carolina's major commercial seafood dealers and to obtain data from more dealers.

The North Carolina Division of Marine Fisheries Trip Ticket Program (NCTTP) began on 1 January 1994. The NCTTP was initiated due to a decrease in cooperation in reporting under the voluntary NMFS/North Carolina Cooperative Statistics Program in place prior to 1994, as well as an increase in demand for complete and accurate trip-level commercial harvest statistics by fisheries managers. The detailed data obtained through the NCTTP allows for the calculation of effort (i.e. trips, licenses, participants, vessels) in a given fishery that was not available prior to 1994 and provides a much more detailed record of North Carolina's seafood harvest.

NMFS SECPR Annual Canvas Data for Florida

The Florida Annual Data files from 1976–1996 represent annual landings by county (from dealer reports) which are broken out on a percentage estimate by species, gear, area of capture, and distance from shore. These estimates are submitted by Port agents, which were assigned responsibility for the particular county, from interviews and discussions from dealers and fishermen collected throughout the year. The estimates are processed against the annual landings totals by county on a percentage basis to create the estimated proportions of catch by the gear, area and distance from shore. The sum of percentages for a given Year, State, County, Species combination will equal 100.

Area of capture considerations: ALS is considered to be a commercial landings database which reports where the marine resource was landed. With the advent of some State trip ticket programs as the data source the definition is more loosely applied. As such one cannot assume reports from the ALS by State or county will accurately inform you of Gulf vs. South Atlantic vs. Foreign catch. To make that determination you must consider the area of capture.

4. Recreational Fishery Statistics

4.1 Overview

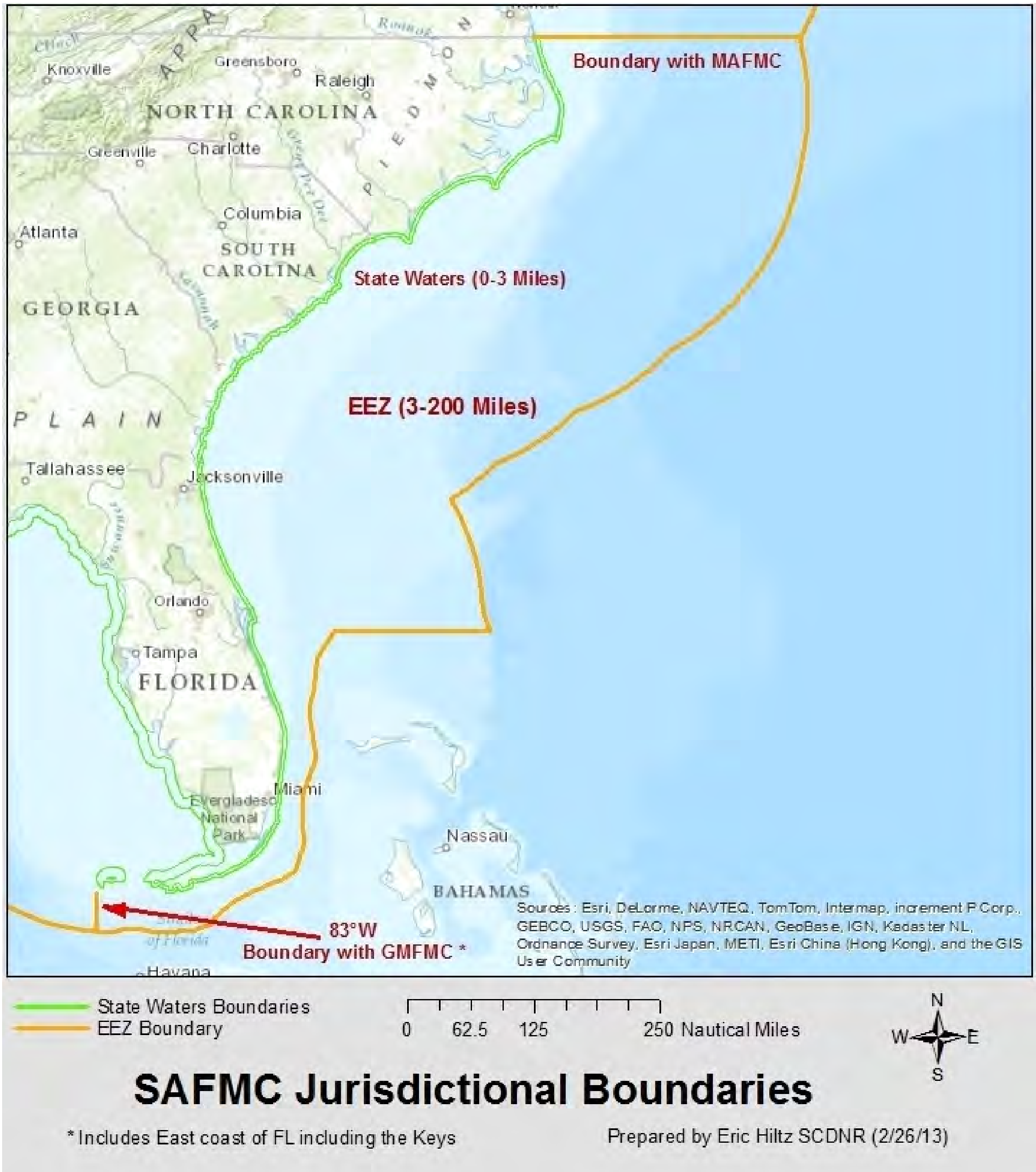
4.1.1 Recreational Working Group (RWG) Membership

Members- Ken Brennan (Leader, NMFS Beaufort, NC), Mark Brown (SAFMC Appointee/Industry rep SC), Sonny Davis (SAFMC Appointee\ Industry rep NC), Kelly Fitzpatrick (NMFS Beaufort, NC), Dawn Franco (GADNR), Eric Hiltz (SCDNR), Rusty Hudson (SAFMC Appointee\ Industry rep FL) Robert Johnson (SAFMC Appointee\ Industry rep FL), Mike Larkin (SERO), Vivian Matter (NMFS SEFSC), Beverly Sauls (FWC, FL), Bill Shearin (SAFMC Appointee\ Industry rep GA), Erik Williams (NMFS Beaufort, NC) and Chris Wilson (NCDNR)

4.1.2 Issues

1) Allocation of Monroe county catches to the Atlantic or the Gulf of Mexico: may vary by data source depending on differing spatial resolutions of the datasets.
2) Headboat estimated landings start in 1972 for NC and SC, 1977 in GA\NEFL and 1981 in SEFL. Estimating red snapper headboat landings from 1972 to1980 (date dependent on region) for periods of partial geographic coverage in the SRHS.
3) Headboat discards. Data are available from the SRHS since 2004. Review whether they are reliable for use, and determine if there are other sources of data prior to 2004 that could be used as a proxy to estimate headboat discards.
4) Calibration of Marine Recreational Fisheries Statistics Survey (MRFSS) to Marine Recreational Information Program (MRIP) 1981-2003.
5) Charter boat landings: MRFSS charter survey methods changed in 2003 in East Florida and in 2004 for Georgia and north.
6) Combined charter boat/headboat landings, 1981-1985: Official headboat landings are available from the SRHS. Therefore, the headboat component of the MRFSS combined charter boat/headboat mode must be parsed out.
7) Usefulness of historical data sources to generate estimates of landings prior to 1981. Review previous methods (SEDAR 24) and other data sources.
8) Review data sources provided for landings and discards in 2012, 2013, and 2014 and decide which will be used for final numbers/estimates.
9) MRIP APAIS adjustment: change in survey protocols starting in 2013.

4.1.3 South Atlantic Fishery Management Council Jurisdictional Boundaries



4.2 Review of Working Papers

SEDAR41-DW-01, *Georgia Headboat Red Snapper Catch & Effort Data, 1983-2014. Capt. Steve Amick and Kathy Knowlton 2015.*
This working paper presents detailed red snapper catch records from a GA headboat. The captain, Steve Amick, recorded his catch records in personal logbooks at the end of every fishing day, including number of released fish (a data element not available for headboats from the NMFS survey until 2004). He offered to provide these data through a cooperative effort with personnel at the Georgia Department of Natural Resources for consideration at SEDAR41. A portion of these data (percent released fish) was used to estimate headboat discards prior to 2007 in SEDAR24. Data elements included vessel, trip type, number red snapper released alive, number red snapper harvested, number of anglers, number of vessel trips and, since 2010, lengths of released fish. Throughout the entire time period (1983 through 2014), Captain Amick typically fished depths of 90-120 feet in the NMFS headboat survey grid 31-80 southeast of Savannah, GA. However, once the moratorium on red snapper harvest began in 2010, Captain Amick's fishing methods changed in an effort to capture and release fewer red snapper. These changes include number of hooks per angler, rigging, bait type, maximum depth fished and angler experience. These changes were significant, and caution should be used when comparing data in the time series from 2010-2014 to those data prior to 2010. Combined, these data represent ~4,400 snapper-grouper fishing trips in which ~45,000 anglers caught ~48,000 and harvested ~22,000 red snapper. They also represent lengths of ~2,000 red snapper released during 2010-2014. The RFWG accepted this working paper and data within for further detailed review.

SEDAR41-DW02, *Georgia Red Snapper Catch and Effort Data Collection during Mini-seasons, 2012-2014. Kathy Knowlton 2015.*
The Georgia red snapper catch and effort data collection during mini-seasons 2012 thru 2014 included phone surveys and biological data collection from for-hire captains, a coast wide carcass collection program, and an electronic survey open to private anglers. Commercial biological sampling was conducted in 2013 and 2014. Biological data collected included centerline length, whole weight (if applicable), sex, and otoliths. General fishing location or depth were also requested for each angler trip. Dockside sampling was mostly from two for-hire captains, at one location, that had previously participated extensively in voluntary red snapper research. A second dockside sampling location was added in 2014. For-hire catch and effort data were collected via telephone interviews with the Georgia for-hire captains who actively fished with and possessed the federal snapper-grouper CH/HB permit. Calls were placed on the Mondays following the fishing weekend, or following the season, and repeated attempts were made throughout the week until the captains were reached. Data elements included whether the trip did or did not target red snapper, number of anglers, and number of fish released and harvested. A voluntary electronic catch survey was available to the public to submit any fishing

trips that targeted red snapper (including trips that targeted but did not catch red snapper). Data elements included trip date and duration, trip departure location, depth fished, number of anglers, number and size of harvested and released fish, and whether the harvested fish were donated to a GADNR carcass freezer. Biological data collected in 2012 included 64 fish via dockside and carcass program sampling (40 whole for-hire fish and 24 carcasses). Effort data collected in 2012 included 16 for-hire trips (2 HB and 14 CH) equaling 100 angler trips (24 HB and 76 CH) and 8 private boat mode vessel trips equaling 31 angler trips. Biological data collected in 2013 included 91 fish via dockside and carcass program sampling (28 whole for-hire fish, 21 gutted commercial fish, and 42 carcasses). Effort data collected in 2013 included 11 for-hire trips (2 HB and 9 CH) equaling 70 angler trips (23 HB and 47 CH) and 13 private boat mode vessel trips equaling 53 angler trips. Biological data collected in 2014 included 283 fish via dockside and carcass program sampling (146 whole for-hire fish, 13 gutted commercial fish, and 124 carcasses). Effort data collected in 2014 included 45 for-hire trips (10 HB and 35 CH) equaling 312 angler trips (132 HB and 180 CH) and 21 private boat mode vessel trips equaling 120 angler trips.

SEDAR41-DW17, *Estimates of Historic Recreational Landings of Red Snapper in the South Atlantic Using the FHWAR Census Method. Brennan, K 2014.*
The National Survey of Fishing, Hunting, and Wildlife-Associated Recreation Survey (FHWAR) has been conducted every 5 years since 1955 and is one of the oldest and most comprehensive recreational surveys. The FHWAR census method utilizes information from these surveys including U.S. angler population estimates and angling effort estimates from 1955–1985 for the South Atlantic region. To obtain historical red snapper landings prior to 1981, estimated saltwater angler trips (1955-1980) are multiplied by average catch rates that are calculated from early years (1981-1985) of the MRFSS/MRIP data. Interpolation is used to complete time series.

SEDAR41-DW18, *South Carolina Red Snapper Catch & Biological Sampling Data Collection during Mini-Seasons, 2012-2013. Duke, A and E. Hiltz 2014.*
Red snapper carcasses were donated to the South Carolina Department of Natural Resources (SCDNR) by private anglers via a freezer collection program and dockside sampling. The mandatory charter logbook information that the SCDNR collects was also used to help access the mini-seasons. Additionally, an online survey was created for anglers to use to tell us about their red snapper catch.

SEDAR41-DW21, *North Carolina Division of Marine Fisheries Red Snapper Carcass Collections, 2012-2013. Duvall, M 2013.*
A pilot carcass collection program was initiated in September 2012 and continued during the 2013 red snapper season to collect biological information for the SEDAR 41 stock assessment. Eight carcass drop-off locations equipped with freezers, informational pamphlets and supplies were strategically chosen at facilities along the coast. Catch cards were used to record trip data

(date, depth, mode of fishing, effort in terms of party size and hours fished, catch information, and contact information) for each donated carcass. Incentives were offered for participation and included fish citation certificates, fish towels, and drink koozies. A total of 82 red snapper carcasses were collected (40 charter boat, 39 headboat, and 3 private boats) during 2012. In 2013, a total of 34 red snapper carcasses were collected (2 charter boat, 29 headboat, and 3 private boats).

SEDAR41-DW23, *Atlantic Red Snapper (Lutjanus campechanus) Fishing History Timeline Hudson, R 2014.*
Southeastern Fisheries Association- East Coast Fisheries Section provides the SEDAR 41 data workshop (DW) working paper to establish a historical timeline of the development of the US Atlantic Red snapper fishery, and follows various events that affected the prosecution of that fishery across time.

SEDAR41-DW24, *Atlantic Red Snapper (Lutjanus campechanus) and Gray triggerfish (Balistes capriscus) Historical Fishing Pictures Summary Hudson, R 2014.*
Southeastern Fisheries Association- East Coast Fisheries Section provides the SEDAR 41 data workshop (DW) a cache of historical deep sea for-hire fishing pictures accurately dated during the 1950's to the 1970's. This collection is from the Ponce de Leon Inlet, Greater Daytona Beach, Volusia County, Florida region. The historically professional photographs are significant as they demonstrate, visually, the for-hire recreational landings of Atlantic Red snapper and Red snapper by day, month and year for this region.

SEDAR41-DW25, *Atlantic Red Snapper (Lutjanus campechanus) and Gray triggerfish (Balistes capriscus) Index of For-Hire Vessels from the SAFMC region Hudson, R 2014.*
Southeastern Fisheries Association- East Coast Fisheries Section provides the SEDAR 41 data workshop (DW) an index of for-hire vessels from the South Atlantic Fishery Management Council (SAFMC) region that mostly participated in the fisheries for Atlantic Red snapper and Red snapper.

SEDAR41-DW26, *Atlantic Red Snapper (Lutjanus campechanus) and Gray triggerfish (Balistes capriscus) Photographic and Other Evidence of For-Hire Vessels in the SAFMC region Hudson, R 2014.*
Southeastern Fisheries Association- East Coast Fisheries Section provides the SEDAR 41 data workshop (DW) photographic and other evidence of for-hire vessels from the South Atlantic Fishery Management Council (SAFMC) region that mostly participated in the fisheries for Atlantic Red snapper and Red snapper.

SEDAR41-DW-27, *Red snapper mini-season ad-hoc working group report. Siegfried, K 2014.*

The main objective of the red snapper mini season ad hoc working group is to inform the decision that the recreational workgroup will make on which landings and discards to report for red snapper during the mini seasons in 2012 and 2013. In 2009, an interim rule was enacted to prohibit harvest of red snapper from January 4, 2010 to June 2, 2010. This rule was extended until December and an emergency rule was used to prohibit harvest through 2011. In 2012 and 2013, emergency rules were used to re-open the fishery for a very short duration. The 2012 mini-season was six days long: 9/14-9/16 & 9/21-9/23. The 2013 mini-season was three days long: 8/23-8/25. The key issue is that MRIP was not designed to capture short pulses of fishing, but rather to capture 2-month intervals (waves) of landings, discards, and effort. When a short opening occurs in a fishery, it is unlikely that MRIP will capture the event during its random sampling. If MRIP does happen to capture the event in terms of catch rate, the event will be scaled up by effort in that wave. State partners from North Carolina, South Carolina, Georgia, and Florida supplied data from studies conducted in each state during the 2012 and 2013 mini-season as an attempt to supplement the MRIP data. A detailed explanation of how MRIP estimates are calculated was included in this document. Full descriptions of methods and data collected are available in the working papers SEDAR41-DW-21 (North Carolina), SEDAR41-DW18 (South Carolina), SEDAR41-DW02 (Georgia), and SEDAR41-RD14 and SEDAR41-RD15 (Florida). Merits and deficiencies of each study were briefly outlined, as well as any potential bias.

SEDAR41-DW32, *SCDNR Charterboat Logbook Program Data, 1993 – 2013. Hiltz, E 2014.*
The South Carolina Department of Natural Resources (SCDNR) charterboat logbook program was used to develop indices of abundance for red snapper from 1993 – 2012. The indices of abundance are standardized catch per unit effort (CPUE; catch per angler hour). For red snapper, a delta GLM was used to produce annual abundance estimates. The indices are meant to describe the population trends of fish caught by V1 (6-pack) charter vessels operating in or off of South Carolina.

SEDAR41-DW33, *Size Distribution, Release Condition, and Estimated Discard Mortality of Red Snapper Observed in For-Hire Recreational Fisheries in the South Atlantic, Sauls, B., C. Wilson and K. Fitzpatrick.*
Since 2004, trained fishery observers have been employed on randomly selected headboat fishing trips to observe angler fishing activity and collect detailed information on discarded fish. In addition, observers were employed on charter vessels on the Atlantic coast of Florida in 2013. This paper summarizes the number of sampled trips by state, generates sample weights, and plots weighted length frequencies for all observed red snapper (both harvested and discarded) from headboats. Additional data collected in Florida on hook type, fishing depth, and release condition of observed discards is also synthesized.

SEDAR41-DW38, *Historic catch rates of Red Snapper by headboats through historic photograph analysis. Gray et al. 2014.*
Photographs that span 1951 through 1974 represent historic evidence of catch rates of common recreational species in the Daytona Beach area during that time, including catch rates for Red Snapper. These photographs precede fisheries dependent monitoring estimates, providing historic catch per unit effort (CPUE) rates for stock assessments. Results presented here are a preliminary analysis for Red Snapper CPUE.

SEDAR41-DW42, *South Atlantic Red Snapper (Lutjanus campechanus) monitoring in Florida: Revised recreational private boat mode estimates for 2012 and 2013 mini-seasons, and new private boat mode estimates for the 2014 mini-season. Sauls, B.*
This report provides revised estimates of Red Snapper recreational harvest during mini-season openings in 2012 and 2013 for the private boat segment off the Atlantic Coast of Florida. Methods and results were previously described in reference documents for the first Data Workshop for SEDAR41 (SEDAR41-RD14, SEDAR41-RD15). New results for the 2014 fishing season are also presented in this paper.

4.3 Recreational Landings

Total recreational landings are summarized below by survey. A map and figures summarizing the total recreational red snapper landings are included in Figure 4.11.1.

4.3.1 Marine Recreational Fisheries Statistics Survey (MRFSS) and Marine Recreational Information Program (MRIP)

Introduction
The Marine Recreational Fisheries Statistics Survey (MRFSS) and the Marine Recreational Information Program (MRIP) provide a long time series of estimated catch per unit effort, total effort, landings, and discards for six two-month periods (waves) each year. MRFSS/MRIP provides estimates for three recreational fishing modes: shore-based fishing (SH), private and rental boat fishing (PR), and for-hire charter and guide fishing (CH). When the survey first began in Wave 2 (Mar/Apr), 1981, headboats were included in the for-hire mode, but were excluded after 1985 in the South Atlantic and Gulf of Mexico to avoid overlap with the Southeast Region Headboat Survey (SRHS) conducted by the NMFS Beaufort, NC lab.

The MRFSS/MRIP survey covers coastal Atlantic coast states from Maine to Florida. The state of Florida is sampled as two sub-regions. The east Florida sub-region includes counties adjacent to the Atlantic coast from Nassau County south through Miami-Dade County, and the west Florida sub-region includes Monroe County (Florida Keys) and counties adjacent to the Gulf of Mexico. Separate estimates are generated for each Florida sub-region, and those estimates may be post-stratified into smaller regions based on proportional sampling. Sampling is not conducted in Wave 1 (Jan/Feb) north of Florida because fishing effort is very low or non-existent, with the exception of NC, where wave 1 has been sampled since 2006.

The MRFSS/MRIP design incorporates three complementary survey methods for estimating catch and effort. Catch data are collected through angler interviews during dockside intercept surveys of recreational fishing trips after they have been completed. Effort data are collected using two telephone surveys. The Coastal Household Telephone Survey (CHTS) uses random digit dialing of coastal households to obtain detailed information about the previous two months of recreational fishing trips from the anglers. The weekly For-Hire Survey was implemented in the South Atlantic in the 2000's and interviews charterboat operators (captains or owners) to obtain the trip information with only one-week recall period. Effort estimates from the two telephone surveys are aggregated to produce total effort estimates by wave. Catch rates from dockside intercept surveys are combined with estimates of effort from telephone interviews to estimate total landings and discards by wave, mode, and area fished (inland, state, and federal waters).

Catch estimates from early years of the survey are highly variable with high proportional standard errors (PSE's), and sample size in the dockside intercept portion have been increased over time to improve precision of catch estimates. Several quality assurance and quality control improvements were implemented for the intercept surveys in 1990. Prior to 1990 the contractor did not have regional representatives hired to supervise the samplers in any given area. All samplers were hired as independent sub-contractors and communicated directly with the contractor's home office staff. It is much more likely that the samplers who worked in the 80's would have varied more in their interpretation of sampling protocols and their ability to identify at least some of the more difficult-to-recognize species. There were a number of other changes made to enhance consistency in sampling protocols and improve error-checking in the Statement of Work for the 1990-1992 contracts. Improvements have continued over the years, but the biggest changes happened at that time (personal communication, NMFS). Full survey documentation and ongoing efforts to review and improve survey methods are available at: http://www.st.nmfs.noaa.gov/recreational-fisheries/MRIP/program-evolutionSurvey methods for the for-hire fishing mode have seen the most improvement over time. Catch rate data have improved through increased sample quotas and additional sampling (requested and funded by the states) to the intercept portion of the survey. It was also recognized that the random household telephone survey was intercepting relatively few anglers in the for-hire fishing mode and the For-Hire Telephone Survey (FHS) was developed to estimate effort in the for-hire mode. The new method draws a random sample of known for-hire charter and guide vessels each week and vessel operators are called and asked directly to report their fishing activity. The FHS was officially adopted in the Gulf coast states (including Monroe County in West Florida) in 2000, in East Florida in 2003, and in Georgia through Maine in 2005. The FHS was pilot tested in the

Gulf of Mexico in 1998 and 1999 and in Georgia through Maine in 2004. The FHS does not consider the estimates during pilot years as official estimates; however, FHS data for these years have been used since 2005(e.g. SEDAR 7 red snapper, SEDAR 16 king mackerel, SEDAR 25 black sea bass, etc.).

A further improvement in the FHS method was the pre-stratification of Florida into smaller sub-regions for estimating effort. Pre-stratification defines the sample unit on a sub-state level to produce separate effort estimates by these finer geographical regions. The FHS sub-regions include three distinct regions bordering the Atlantic coast: Monroe County (sub-region 3), SE Florida from Dade through Indian River counties (sub-region 4), and NE Florida from Martin through Nassau counties (sub-region 5). The coastal household telephone survey method for the for-hire fishing mode continues to run concurrently with the newer FHS method.

Calibration of traditional MRFSS charter boat estimates

Conversion factors have been estimated to calibrate the traditional MRFSS charterboat estimates with the FHS for 1986-2003 in the South Atlantic (SEDAR16-DW-15, Sminkey, 2008) and for 1981-2003 in the mid-Atlantic (SEDAR17-Data Workshop Report, 2008). 1986-2003 South Atlantic calibration factors were updated in 2011 (SEDAR25-Data Workshop Report, 2011). The relationship between the old charterboat method estimates of angler trips and the FHS estimates of angler trips was used to estimate the conversion factors. Since these factors are based on effort, they can be applied to all species' landings. In the Gulf of Mexico and the South Atlantic, the period of 1981-1985 could not be calibrated with the same ratios developed for 1986+ because in the earlier 1981-1985 time period, MRFSS considered charterboat and headboat as a single combined mode. Thus, in order to properly calibrate the estimates from 1981-1985, headboat data from the Southeast Region Head-boat Survey (SRHS) were included in the analysis. To calibrate the MRFSS combined charterboat and headboat mode effort estimates in 1981-1985, conversion factors were estimated using 1986-1990 effort estimates from both modes, in equivalent effort units, an angler trip (SEDAR28-DW-12). These calibration factors were applied to the charterboat estimates and are tabulated in Table 4.10.1. The calibration factors have been updated or developed since SEDAR 24.

Separation of SA combined charter/headboat mode

In the South Atlantic, 1981-1985 charter and headboat modes were combined into one single mode for estimation purposes. Since the NMFS Southeast Region Headboat Survey (SRHS) began in this region in 1981, the MRFSS combined charter/headboat mode must be split in order to not double estimate the headboat mode for these years. MRFSS charter/headboat mode was split in these years by using a ratio of SRHS headboat angler trip estimates to MRFSS charter boat angler trip estimates for 1986-1990. This method has been used in the past (SEDAR 28-Spanish mackerel and cobia). The mean ratio was calculated by state (or state equivalent to match SRHS areas to MRFSS states) and then applied to the 1981-1985 estimates to strip out the headboat component. These headboat estimates were then eliminated from the MRFSS estimates.

MRIP weighted estimates, APAIS changes, and the calibration of MRFSS estimates
The Marine Recreational Information Program (MRIP) was developed to generate more accurate recreational catch rates by re-designing the MRFSS sampling protocol to address potential biases including port activity and time of day. Revised catch and effort estimates from 2004 to 2012, based on MRIP's improved estimation methodology, were released on January 25, 2012. For estimates prior to 2004, an MRIP Calibration Workshop was held in 2012, and the Consultant's Report recommended that MRFSS estimates prior to 2004 be calibrated to the new MRIP estimation method (Boreman, 2012) using a method developed by an MRFSS/MRIP Calibration Ad-hoc Working Group following the Calibration Workshop (Salz et al. 2012).

Starting in 2013, wave 2, the MRIP Access Point Angler Intercept Survey (APAIS) implemented a "revised sampling design that includes an updated sampling frame; eliminates interviewer latitude in selecting interviewing sites; establishes discrete sampling periods of fixed duration, including nighttime sampling; and requires interviewers to collect detailed information about the number of completed boat and angler fishing trips during the sampling period" (MRIP Implementation Plan 2011). To address this new survey design change, a second Calibration Workshop was held in 2014 and the final report from that workshop recommended an additional calibration for catch estimates (Carmichael and Van Vorhees 2015). The recommended interim calibration approach, found in Appendix 2 of the report, uses the ratio of the catch estimated in 2013 using the entire sampling period for the new MRIP APAIS design, versus catch estimated in 2013 using only during peak sampling periods in the old MRFSS survey design. Red snapper catch for all years prior to 2013 was re-estimated using this ratio, based on a single year of data from the new APAIS design (2013), for each sub-region, state, and mode combination with all waves and areas combined. Tables 4.10.2 and 4.10.3 show the differences between the South Atlantic red snapper MRIP APAIS landing and discard estimates and the MRIP estimates for the time period 2004-2012.

As new MRIP APAIS estimates are available for a portion of the recreational time series that the MRFSS covers, conversion factors between the MRFSS estimates and the MRIP APAIS estimates were developed in order to maintain one consistent time series for the recreational catch estimates. Ratio estimators, based on the ratios of the means, were developed for South Atlantic red snapper to hind-cast catch and variance estimates by fishing mode. In order to apply the charter boat ratio estimator back in time to 1981, charter boat landings were isolated from the combined charter boat /headboat mode for 1981-1985. The MRFSS to MRIP APAIS calibration process is the same as the original MRFSS to MRIP adjustment that has been used since 2012, which is detailed in SEDAR31-DW25 and SEDAR32-DW02. Table 4.10.4 shows the ratio estimators used in the calibration. Figure 4.11.2 shows the MRIP versus MRIP APAIS adjusted estimates for South Atlantic red snapper along with the 95% confidence intervals. The RWG expressed concern with basing the MRIP APAIS adjustment on 2013 red snapper MRIP data. The mini season in this year consisted of three fishing days which resulted in low sample sizes in the MRIP database. The group had reservations about using an adjustment based on so little data. The RWG suggested using an additional year of data from 2014 to increase the amount of information used in the adjustment. This was not feasible for this assessment due to limited MRIP staff time. In accordance with the recommendations set forth by the MRIP Calibration Workshop II, MRIP personnel will continue to investigate the remaining two methods described in the report. It is possible that one of them will be determined to be a better method at some future date. In the interim, the simple ratio method is recommended by the MRIP Calibration Workshop II and the RWG.

Monroe County

Monroe County MRFSS landings from 1981 to 2003 can be post-stratified to separate them from the MRFSS West Florida estimates. Post-stratification proportionally distributes the state-wide (FLE and FLW) effort into finer scale sub-regions and then produces effort estimates at this finer geographical scale. This is needed for the private and shore modes (all years) and charter boat mode (prior to FHS). FHS charter boat mode estimates are already pre-stratified, as discussed above. Monroe County MRIP landings starting in 2004 can be estimated separately from the remaining West Florida estimates using domain estimation. The Monroe County domain includes only intercepted trips returning to that county as identified in the intercept survey data. Estimates are then calculated within this domain using standard design-based estimation which incorporates the MRIP design stratification, clustering, and sample weights.

Although Monroe county estimates can be separated using these processes, they cannot be partitioned into those from the Atlantic Ocean and those from the Gulf of Mexico. Red snapper are less common on the extreme south Atlantic coast of Florida. In accordance with SEDAR 24 (SA red snapper) and SEDAR 31 (Gulf red snapper), the recreational workgroup recommends allocating Monroe County estimates from MRIP to the Gulf of Mexico.

Shore Estimates

Red snapper is an offshore species with a strong association with reefs and hard bottom. Several species of nearshore fish are often referred to as “red snapper” by anglers, which may explain the infrequent red snapper shore landings in the MRIP time series. In accordance with SEDAR 24, the recreational workgroup recommends omitting the MRIP shore mode estimates.

Calculating landings estimates in weight

The MRFSS and the MRIP surveys use different methodologies to estimate landings in weight. To apply a consistent methodology over the entire recreational time series, the Southeast Fisheries Science Center (SEFSC) implemented a method for calculating average weights for the

MRIP (and MRIP adjusted) landings. This method is detailed in SEDAR32-DW-02. The length-weight equation developed by the Life History Working Group (W=1.58E-5*(L^3.03)) was used to convert red snapper sample lengths into weights, when no weight was recorded. W is whole weight in grams and L is fork length in millimeters.

1981, wave 1

MRFSS began in 1981, wave 2. In the east coast of Florida, catch for 1981 wave 1 was estimated by determining the proportion of catch in wave 1 to catch in all other waves for 1982-1984 by fishing mode and area. These proportions were then used to estimate wave 1 in 1981 from the estimated catches in other waves of that year. This methodology is consistent with past SEDARs (e.g. SEDAR 28 Spanish mackerel and cobia).

Variances

Variances are provided by MRFSS/MRIP for their recreational catch estimates. Variances are adjusted to take into account the variance of the conversion factor when an adjustment to the estimate has been made (FHS and MRIP conversions). However, the variance estimates of the charter and headboat modes in 1981-1985 are missing. This is due to the MRIP calibration procedure, which requires the combined charter/headboat mode to be split in order to apply the MRIP adjustment to the charter mode back to 1981. In addition, variance estimates are not available for weight estimates generated through the SEFSC method described above.

Results

MRIP landings in numbers of fish and in whole weight in pounds are presented in Table 4.10.5. CVs associated with estimated landings in numbers are also shown. South Atlantic red snapper estimates include North Carolina through East Florida, not including Monroe County, FL. There are no red snapper estimates in MRIP north of North Carolina. MRIP estimates shown are through 2011. Mini season estimates from 2012 to 2014 will be discussed separately.

The RWG examined the high MRIP estimate in 1985 (288,971 fish). The 1984 estimate (212,547 fish) was also quite high, showing an increase in landings these two years. As stated above, the estimates in these early years of the survey are highly variable. The 1985 estimate is made up of a number of cells: FLE, PR, ocean>3mi, wave 1 (81,635 fish); FLE, PR, ocean>3mi, wave 5 (51,675 fish); FLE, CH, ocean>3mi, wave 4 (42,631 fish); NC, CH, ocean>3mi, wave 4 (50,776 fish) among others. Table 4.10.6 shows the estimates for 1984 and 1985 by state, wave, and mode. The RWG investigated two estimates which occurred in waves 1 and 2 that were particularly concerning due to the time of year they occurred. These are highlighted in the table in yellow. The 1984 wave 2 private mode estimate from Florida was based on 3 trips, all with an area greater than 3 miles

1a) Volusia County, March, 2 anglers, 1 fish, size: 330mm; 0.6kg
2a) St. John County, April, 4 anglers, 35 fish, no size information

3a) Duval County, April, 2 anglers, 35 fish, sizes: 232-329mm; 0.2- 0.5kg

The 1985 wave 1 private mode estimate from Florida was based on 4 trips, all occurring in February.

1b) Indian River County, >3 miles, 1 angler, 6 fish, no size information

2b) Indian River County, >3 miles, 4 anglers, 16 fish, sizes: 430-530mm; 1.4- 2.3kg

3b) Dade County, <3 miles, 2 anglers, 1 fish, size: 430mm; 0.9kg

4b) Dade County, <3 miles, 4 anglers, 1 fish, size: 410mm, 1.3kg

The RWG speculated that the red snapper intercepted in trips 1a, 3a, 3b, and 4b were probably vermilion snapper due to their small sizes and in the cases of 3b and 4b, the location of where they were caught. In the case of the 1985 wave 1 private mode estimate from Florida, suspected trips only account for less than 10% of that particular estimate. This was determined using the breakdown of the final estimate by area fished. Less than 10% of that estimate came from area fished less than 3 miles (trips 3b and 4b). It is difficult to make changes to the intercept data many years after the data is collected and the RWG recommends using the resulting estimates "as is" and taking into consideration an appropriate measure of the precision (personal communication, NMFS). Further changes preferred by the assessment panel could include modeling, substitutions, or sensitivity runs. These should be fully documented and approved at the Assessment Workshop.

4.3.2 Southeast Region Headboat Survey

Introduction

The Southeast Region Headboat Survey (SRHS) estimates landings and effort for headboats in the South Atlantic and Gulf of Mexico. The Headboat Survey began in 1972 in North Carolina and South Carolina. In 1976 the survey was expanded to northeast Florida (Nassau-Indian River counties) and Georgia, followed by southeast Florida (St. Lucie-Monroe counties) in 1978. Due to headboat area definitions and confidentiality issues, Georgia and East Florida data must be combined. The SRHS began in the Gulf of Mexico in 1986 and extends from Naples, FL to South Padre Island, TX. The South Atlantic and Gulf of Mexico headboat surveys generally include 70-80 vessels participating in each region annually.

The SRHS incorporates two components for estimating catch and effort. 1) Biological information: size of the fish landed are collected by port samplers during dockside sampling, where fish are measured to the nearest mm and weighed to the nearest 0.01 kg. These data are used to generate mean weights for all species by area and month. Port samplers also collect otoliths and spines for ageing studies during dockside sampling events. 2) Information about total catch and effort are collected via a logbook form that is filled out by vessel personnel for individual trips. These logbooks are summarized by vessel to generate estimated landings by species, area, and time strata. Most recently, the SRHS implemented electronic logbook reporting in the South Atlantic and Gulf of Mexico as of Jan 1, 2013. Headboat personnel now have the ability to report trip information via a website or mobile application.

In the early years of the SRHS, there was only partial geographic coverage in the South Atlantic. Red snapper landings are available in NC and SC beginning in 1972. Landings are not available for GA/NEFL from 1974-1975 or SEFL from 1972-1980. For SEDAR 24, estimates for these areas/time periods were calculated using the ratio of NC and SC landings from 1972-1980 for periods of partial coverage. A three year ratio was used to estimate landings for the areas and time periods without coverage. For GA/NEFL a three year ratio is calculated by dividing the total landings for NEFL (1976-1978) by NC and SC combined total landings (1976-1978). This ratio is then multiplied to the 1974 and1975 combined total landings for NC and SC, resulting in the total landings for NEFL for 1974 and 1975. The same approach was used to calculate landings for SEFL 1972-1980 by using the total landings from 1981- 1983. This same method and landings were accepted for use in SEDAR 41.

Catch Estimates
Final SRHS landings estimates are shown in Table 4.10.7, by year and state in Figure 4.11.3. SRHS areas 1-17 are included in the red snapper stock.

Characterizing sources of uncertainty
Variances estimates are not currently available for the SRHS catch estimates. Further research is required to develop a suitable method to calculate variance. The RWG included this as a research recommendation.

4.3.3 Red Snapper Mini-Season Landings

Introduction
The main objective of the red snapper mini season ad hoc working group was to provide information to the recreational workgroup to aid in decisions that were needed on which landings and discards to report for red snapper during the mini seasons in 2012, 2013 and 2014. In 2009, an interim rule was enacted to prohibit harvest of red snapper from January 4, 2010 to June 2, 2010. This rule was extended until December and an emergency rule was used to prohibit harvest through 2011. In 2012, 2013 and 2014, emergency rules were used to re-open the fishery for a very short duration. The 2012 mini-season was six days long: 9/14-9/16 & 9/21-9/23. The 2013 mini-season was three days long: 8/23-8/25. The 2014 mini-season was 8 days long: 7/11-7/13, 7/18-7/20, and 7/25-7/26. The key issue is that MRIP was not designed to capture short pulses of fishing, but rather to capture 2-month intervals (waves) of landings, discards, and effort. When a short opening occurs in a fishery, it is unlikely that MRIP will capture the event during its random sampling. If MRIP does happen to capture the event in terms of catch rate, that event will be scaled up by effort in that wave.

The sources of mini-season data that were reviewed for potential use are as follows:

- Marine Recreational Information Program (MRIP)
- North Carolina Department of Marine Fishers (NCDMF) state survey
- South Carolina Department of Natural Resources (SCDNR) state survey
- Georgia Department of Natural Resources (GADNR) state survey
- Florida Fish and Wildlife Conservation (FWC) Commission state survey

State partners in the South Atlantic supplied data from studies conducted in each state during the 2012, 2013 and 2014 mini-seasons as an attempt to supplement the MRIP data. Brief synopses of the type of data provided are illustrated in Table 4.10.8. Full descriptions of methods and data collected are available in the working papers SEDAR41-DW27 (MRIP), SEDAR41-DW-21 (NC), SEDAR41-DW18 (SC), SEDAR41-DW02 (GA), SEDAR41-DW-42 (FL).

The recreational workgroup developed a set of rules in order to determine which data set was more appropriate for landings by state (NC, SC, GA, and FLE), mode (charter and private), and wave (1-6):
Either MRIP or state available
• Use state number if no MRIP number exists, making note of any potential bias
• Use MRIP number if no state number exists

Both MRIP and state numbers available
• Landings - Recommend using the estimate/number (MRIP or State) that is more reliable (e.g. larger sample size). In 2014, this option was clarified to include accounting for CV's, and/or biases associated with each survey.

The majority of the waves had either MRIP or State survey data available. When only the state survey data was available, potential sources of bias were considered, and noted in the decisions below. However, using the only available data for the wave was favored over using no data at all. There were several cases of overlap for landings data in 2012 (Table 4.10.9) and 2014 (Table 4.10.11). Florida was the only state that had an overlap of landings data in 2013 (Table 4.10.10).

Issue: *How to characterize the recreational landings during mini-seasons in 2012 for each state, mode, and wave.*

Option 1: Use State number if no MRIP number is available, making note of any potential bias
Option 2: Use MRIP number if no State number is available
Option 3: Use the estimate/number (MRIP or State) that is more reliable (e.g. larger sample size) when both MRIP and State numbers were available.

Decision(s):

Option 1.

- State Charter (CH) - SC (waves 3, 4, and 5) and FLE (wave 5).
- State Private (PR) - NC (wave 5) and SC (Wave 5)

The CH landings from SC and FLE were self-reported through either the logbook program (SC) or telephone survey (FLE) without methods to validate the reported landings. The PR landings from NC were primarily based on number of donated carcasses and are therefore not considered to be a random sample. Some of the PR landings from SC were from donated carcasses but also include intercepts from the SFS.

Option 2.

- MRIP FLE (wave 2).

Option 3.

- MRIP CH - NC (wave 5) - The NC charter MRIP estimate was selected over the state number because the state number was based on donated carcasses and is therefore not considered to be a random sample.
- MRIP PR - GA (wave 5) – The GA private MRIP estimate was selected over the state number because the state number was based on a voluntary self-reported online survey with a very small sample size and was not a random sample.
- State CH – GA (wave5) - The GA state CH numbers were selected over MRIP because the state survey was a census of all active captains that held federally permitted snapper grouper licenses and also had a larger sample size.
- State PR – FLE (wave 5)- The PR landings from FLE did not capture what might have occurred outside of the mini-season, however, the FLE state PR estimate were selected over MRIP due to larger sample sizes along with randomly selected intercept sites, and weighted estimates and was considered a more reliable estimate.

Issue 2: *How to characterize the recreational landings during mini-season in 2013 for each state, mode, and wave.*

Option 1: Use state number if no MRIP number is available, making note of any potential bias
Option 2: Use MRIP number if no state number is available
Option 3: Use the estimate/number (MRIP or State) that is more reliable (e.g. larger sample size) when both MRIP and state numbers were available.

Decision(s):

Option 1.

- State CH and PR – all of 2013 for NC, SC, and GA

The CH landings from NC were based on donated carcasses. The CH landings from SC and GA were self-reported through either the logbook program (SC) or telephone survey (GA) without methods to validate the reported landings but are considered to be a census of all charter captains that would have been fishing during the mini-season. The PR landings from NC and SC were primarily based on number of donated carcasses and are therefore not considered to be a random sample. The PR landings from GA were collected through a voluntary self-reported online survey with a very small sample size.

Option 2.

- MRIP CH - FLE (wave 5)

Option 3.

- State CH and PR - FLE (wave 4).

The state surveys were selected over MRIP due to larger sample sizes for the state survey and that MRIP estimated catch could have potentially been scaled up by effort in the whole 2 month time period.

Issue 3: *How to characterize the recreational landings during mini-season in 2014 for each state, mode, and wave.*

Option 1: Use State number if no MRIP number is available, making note of any potential bias
Option 2: Use MRIP number if no State number is available
Option 3: Use the estimate/number (MRIP or State) that is more reliable (taking into account sample sizes, CV's, and/or biases associated with the survey) when both MRIP and State numbers were available.

Decision(s):
Option1.

- State Charter (CH) – SC (Wave 3 and 4) - The CH landings from SC were self-reported through the logbook program without methods to validate the reported landings.
- State Private (PR) – NC (wave 4) - The PR landings from NC were based on number of donated carcasses and are therefore not considered a random sample.

Option 2.

- MRIP (PR) – FLE (Wave 1,3, and 6)

Estimates for MRIP based on 1 angler trip for each wave with high CV (>1.0) and therefore could be an overestimate of actual landings. These intercepts were verified by looking at the field data sheets.

Option 3.

- MRIP (CH) – NC (Wave 4) - The MRIP estimates were selected for CH in NC (wave 4) due to fact that the state survey number was based on carcass donations and likely to be an underestimate of statewide landings and had a larger associated bias compared with the MRIP survey methodology. The number of angler trips for NC was low (3) but the group felt that there was less potential for bias in the MRIP survey than the NC state survey.
- State (PR) – SC (Wave 4) - The SC state survey also relied solely on carcass donations but the state survey number was determined to be a more accurate representation, in this case, due to the fact that the MRIP estimate was derived from only one angler trip. The number of angler trips was not reported from the SC state survey, only conclusion was the value was greater than 1.
- State (CH) – GA (Wave 4) - The GA state CH number was selected over MRIP because the state survey was a census of all active captains that held federal snapper/grouper permits and also had a larger sample size (180) than MRIP (1).
- MRIP (PR) – GA (Wave 4) - The MRIP PR estimate was chosen over the GA state survey because the state survey information was voluntary angler reported data with no way of validating information or accounting for non-reporting.
- State (CH) – FLE (Wave 4)
- State (PR) – FLE (Wave 4)

The FLE state CH and PR estimates (wave 4) were selected over MRIP due to larger sample sizes and robust survey methodology that included randomly selected intercept sites and weighted estimates. However, it was noted that the FLE state survey could likely be an underestimate of recreational landings since there was no accounting for any fishing that may have occurred outside of the season. There were reported landings in FLE through MRIP on the day following the end of the season, Sunday July 27.

Uncertainty concerning data sources

There was extensive discussion about which data source to choose when both MRIP and state survey data were available for an individual mode and wave. The merits and deficiencies of each data source were discussed at length for the red snapper mini-seasons in 2012, 2013 and 2014. Several RWG members expressed concerns that MRIP is likely to overestimate landings of red snapper because of expansion by effort from the entire wave. Each state survey was unique and there was little similarity in methods used. The SC logbook was a census of all charter captains that would have been targeting Snapper/Grouper species during the mini-season, but it was also noted that these data are self-reported without validation and that there may be some recall bias when logs are handed in one month after the fishing occurred. The GA CH telephone survey was a census of all active CH captains that held federal permits for Snapper/Grouper species, with minimal recall bias because phone calls were made the Monday following each weekend within the mini-season in 2012 and 2013, and the Monday following the end of the mini-season in 2014, but like SC, these are all self-reported data without validation. The FLE CH telephone survey attempted to reach all captains that would have targeted red snapper during the mini-season, data were expanded to account for all captains that were not reached, recall bias was minimal because phone calls were made the week following each weekend opening, but was not a representation of any fishing that might have occurred outside of the mini-season. The SC State Finfish Survey (SFS) was only conducted in 2012 and were solely a record of number of specimens sampled without any effort information. The GA online survey was self-reported information that included number of fish harvested and/or released and number of anglers but could not be used to expand data into an estimate. A consistent comment concerning voluntary angler reported data was that it was likely to produce an underestimate since not all anglers who caught fish will participate. The FLE private boat intercept survey directly targeted the mini-season and should be an accurate estimate of total catch and effort during the mini-season, but as stated above is not a representation of any harvest that might have occurred outside the mini-season. The RWG took all of these points under consideration when deciding which data to use and felt confident in the choices that were made.

4.3.4 Historic Recreational Landings

Introduction
The historic recreational landings time period is defined as pre-1981 for the charter boat, headboat, private boat, and shore fishing modes, which represents the start of the Marine Recreational Fisheries Statistics Survey (MRFSS) and availability of landings estimates for red snapper. The Recreational Working Group was tasked with reviewing all available historical sources of red snapper landings to evaluate potential methods to compile landings prior to the available time series of MRFSS and headboat estimated landings.

The sources of historical landings that were reviewed for potential use are as follows:

- Review and Analysis of Methods to Estimate Historic Recreational Red Snapper Landings in the South Atlantic, SEDAR24-DW11.
- Anderson, 1965.
- The National Survey of Fishing, Hunting, and Wildlife-Associated Recreation Survey (FHWAR) census method, SEDAR41-DW17.
- Review of red snapper historical photos; SEDAR41-DW 24 and SEDAR41-DW 26.
- Preliminary analysis of historical photos: SEDAR41-DW 38.

SEDAR24-DW11
The SEDAR 24 Historic Fisheries Working Group (HFWG) considered several historic data sets for comparison with available recreational data sets as a possible means for regressing recreational statistics back in time. The HFWG recommended the methods that use (1) the ratios

with the commercial red snapper landings and (2) the post-adjusted U.S. Fish and Wildlife Saltwater Angling Survey estimates, be considered by the data workshop for inclusion in the stock assessment. The final decision for SEDAR 24 was to use the ratios with the commercial red snapper landings

Anderson, 1965

The RWG discussed the Anderson study as a possible source of information for historical red snapper landings. The study area designated as the Cape Canaveral area included Brevard and Volusia counties in Florida. The recreational data was obtained from field surveys from February to October, 1963 and was further limited to the southern portion of the study area. The RWG considered this spatially and temporally limiting for possibly expanding estimated landings prior to 1981. However, the RWG did conclude that the data could be used as a reference point for comparison to other methods (i.e. FWHAR method)

Preliminary analysis of historical photos

After reviewing numerous black and white photos from the east coast of Florida charter boat and headboat fishery (courtesy of R. Hudson, see below) back to the early 1950's; it was apparent that red snapper was a common recreational species in the Daytona Beach area during that time. As part of a preliminary analysis of photographs that span 1951 through 1974, 377 photographs with red snapper present were examined for historic catch rates. Red Snapper and anglers were counted and recorded from each picture in order to calculate catch per unit effort (CPUE). The results are reported in SEDAR41-DW38. Although the results were preliminary for this data workshop, the RWG agreed this analysis shows great potential for providing historic CPUE rates for future stock assessments. A proposal is being developed to provide a more complete analysis of the photographs.

FHWAR census method

The FHWAR method (SEDAR41-DW17) was first used in SEDAR 28 to reconstruct landings back to 1950. The two key components from these FHWAR surveys that they used in the census method to produce both estimates of U.S. saltwater anglers and the estimates of U.S. saltwater days. The first objective was to determine the total saltwater anglers and saltwater days for the South Atlantic (SA) by using the summary information of U.S. anglers and U.S. saltwater anglers from the FHWAR surveys. The ratio of U.S saltwater anglers to the total U.S anglers was applied to the total number of anglers for the SA to yield the total saltwater anglers for SA. The same method was used to calculate the total saltwater days for the SA from the FHWAR surveys 1955-1985.

In the FHWAR surveys the South Atlantic included the entire state of Florida, east and west coasts. In order to address the management boundaries for red snapper the saltwater angler days for Florida's west coast (FLW) were separated from the SA saltwater angler days using the ratio of the MRFSS total angler trips for FLW to the MRFSS total angler trips for the South Atlantic (Delaware to FLW). The average ratio from 1984-1986 was applied to the total saltwater days for the SA 1955-1985 to remove FLW effort.

Similar to the SWAS there was a 12 month recall period for respondents, which resulted in greater reporting bias. Research concluded this bias resulted in overestimates of both the catch and effort estimates in the FHWAR surveys from 1955 to 1985. Consequently, as was case in SEDAR 28, an adjustment for recall bias was necessary. The total saltwater days for the SA 1955-1985 were adjusted for recall bias in the FHWAR surveys. The MRFSS total angler trips (private and charter boat modes) for the SA 1984 to1986 was averaged and divided by the total saltwater days for 1985 from the FHWAR survey. This multiplier was then applied to the total SA saltwater days 1955-1985 to adjust for recall bias. In 1984 a 12 inch size limit was instituted in the SA. In order to reflect the discard history prior to 1984 a mean CPUE for red snapper in the SA from the combined estimates from MRFSS and SRHS for 1981 to 1983 was then applied to the adjusted saltwater angler days for the SA 1955-1985 to estimate the historical red snapper landings for those years (Table 4.10.12).

Issue: Available historical red snapper landings prior to 1981.

Option 1: Use the ratio of historic commercial landings as a proxy for recreational catch (SEDAR 24 method)

Option 2: Use FHWAR census method to estimate red snapper landing 1955-1980 in the South Atlantic. Use interpolation to complete time series.

Option 3: Use available recreational time series for the MRFSS\MRIP 1981to 2013and headboat estimates 1972 - 2014.

Decision: *Option 2*.
Option #2: Use FHWAR census method with modifications to estimate red snapper landing back in time.

Historical Catch Estimates
Final historical landings estimates are shown in Table 4.10.13. and Figure 4.11.4.

Uncertainty concerning the FHWAR census method
Standard deviations and variances are provided for the historical recreational catch estimates using the FHWAR census method Table 4.10.12.

4.3.5 Potential Sources for Additional Landings Data

SCDNR Charter boat Logbook Program Data, 1993 – 2014

The Recreational Fisheries Working Group discussed the possibility of replacing the MRIP charter mode estimates for South Carolina from 1993 to 2014 with the SCDNR Charter boat Logbook Program estimates. The SCDNR Charter boat Logbook Program is a mandatory logbook program and is a complete census. However, the data are self-reported and no field validation is done on catch or effort. SCDNR charter boat logbook data were compared with MRIP charter mode estimates (Figure 4.11.5). The Recreational Fisheries Working Group recommended not replacing the MRIP charter boat estimates with the SCDNR Charter boat Logbook Program estimates for 1993 – 2014. The MRIP estimates represent a longer time series and switching from the MRFSS dataset (1981 – 1992) to the SCDNR Charter boat logbook dataset (1993-2014) would artificially reduce the total catch potentially due to the change in methodology that would not necessarily be indicative of a change in the red snapper population which could affect the stock assessment model. Concern was also expressed about replacing the MRIP dataset with the SCDNR Charter boat logbook dataset because the data would only be replaced for one state (SC) and one mode (charter). Additionally since MRFSS/MRIP estimates are currently used to monitor annual catch limits (ACL's), the group thought it would be appropriate to use these estimates for the recreational landings data.

4.4 Recreational Discards

Total recreational discards are summarized below by survey. A map and figures summarizing the total recreational red snapper discards are included in Figure 4.11.6.

4.4.1 MRFSS/MRIP Discards

Discarded live fish are reported by the anglers interviewed by the MRIP/MRFSS. Consequently, neither the identity nor the quantities reported are verified. Lengths and weights of discarded fish are not sampled or estimated by the MRFSS/MRIP.

MRFSS/MRIP estimates of live released fish (B2 fish) were adjusted in the same manner as the landings (i.e. using charterboat calibration factors, MRIP adjustment, substitutions, etc. described above in section 4.3.1).

MRIP discards in numbers of fish and associated CVs are presented in Table 4.10.14. South Atlantic red snapper estimates include North Carolina through East Florida, not including Monroe County, FL. There are no red snapper estimates in MRIP north of North Carolina.

4.4.2 Headboat At-Sea Observer Survey Discards

An observer survey of the recreational headboat fishery was launched in NC and SC in 2004 and in GA and FL in 2005 to collect more detailed information on recreational headboat catch, particularly for discarded fish. Headboat vessels are randomly selected throughout the year in each state, and the east coast of Florida is further stratified into northern and southern sample regions. Biologist's board selected vessels with permission from the captain and observe anglers as they fish on the recreational trip. Data collected include number and species of fish landed and discarded, size of landed and discarded fish, and the release condition of discarded fish (FL only) Data are also collected on the length of the trip, area fished (inland, state, and federal waters) and, in Florida, the minimum and maximum depth fished. In the Florida Keys (sub-region 3) some vessels that run trips that span more than 24 hours are also sampled to collect information on trips that fish farther offshore and for longer durations, primarily in the vicinity of the Dry Tortugas. The red snapper discard data from the MRFSS At-Sea Observer Headboat program and the Southeast Region Headboat Survey (SRHS) logbook were compared (SEDAR 41-DW_29, 2014). Based on the results of these comparisons, it was determined that the SRHS discard rates was validated by the MRFSS/MRIP At-Sea Observer data. Therefore, the SRHS discard estimates would be used and the MRFSS/MRIP At-Sea Observer data was not recommended for use in this assessment.

4.4.3 Headboat Logbook Discards

The Southeast Region Headboat Survey logbook form was modified in 2004 to include a category to collect self-reported discards for each reported trip. This category was described on the form as the number of fish by species released alive and number released dead. Port agents instructed each captain on criteria for determining the condition of discarded fish. A fish was considered "released alive" if it was able to swim away on its own. If the fish floated off or was obviously dead or unable to swim, it was considered "released dead". As of Jan 1, 2013 the SRHS began collecting logbook data electronically. Changes to the trip report were also made at this time, one of which removed the condition category for discards i.e., released alive vs. released dead. The new form now collects only the total number of fish released regardless of condition. These self-reported data are currently not validated within the Headboat Survey. It was determined that the logbook discard data would be used from 2004-2014. This analysis was updated to include the 2014 data, which supported the decision to use the logbook discard data (SEDAR 41-DW_29, 20142015). The RWG concluded that a proxy should be used to estimate the headboat red snapper discards for years prior to 2004. The RWG considered the following three possible data sources to be used as a proxy for estimated headboat discards for 1981-2003 (Figure 4.11.7a & 4.11.7b).

- MRIP CH discard ratio proxy method 1981-2003.
- Captain Steven Amick's discard ratio proxy method 1983-2003. (SEDAR 28-Data Workshop Report, 2010).
- MRIP CH:SRHS discard ratio proxy method 1981-2003 (SEDAR 28-Assessment Workshop Report, 2012).
- SRHS Dockside sample method

Issue: Discard information not available prior to 2004, need a proxy for estimated headboat discards from 1981-2003.

Option 1: MRIP CH: Apply the MRFSS charter boat discard:landings ratio to estimated headboat landings in order to estimate headboat discards from 1981-2003; then apply a 3 year (1981-1983) mean discard:landings ratio to estimated headboat landings in order to estimate headboat discards from 1972-1980.

Option 2: Captain Steve Amick's discard:landings ratio: Apply ratio to estimated headboat landings in order to estimate headboat discards from 1983-2003; then apply a 3 year mean discard:landings ratio to estimated headboat landings in order to estimate headboat discards from 1972-1983.

Option 3: MRIP CH:SRHS: Calculate a ratio of the mean ratio of SRHS discard:landings (2004-2013) and MRIP CH discard:landings (2004-2013). Apply this ratio to the yearly MRIP charter boat discard:landings ratio (1981-2003) in order to determine the yearly SRHS discard:landings ratio (1981-2003). This ratio is then applied to the SRHS landings (1981-2003) in order to estimate headboat discards (1981-2003). Then apply a 3 year (1981-1983) mean discard:landings ratio to estimated headboat landings in order to estimate headboat discards from 1972-1980.

Option 4: SRHS Dockside sample method: From the SRHS dockside samples calculate the mean ratio of fish less than 12in TL (1981-1983) and subtract from that the mean ratio of fish less than 12in TL (1992-2003); apply that to the SRHS landings (1984-2003) to get the number of fish <12in TL discarded (1984-2003). Calculate the mean ratio of fish 12in TL to less than 20in TL (1984-1991) and subtract from that the mean ratio of fish less 12in TL to less than 20in TL (1992-2003); apply that to the SRHS landings (1992-2003) to estimate the number of fish 12in TL to less than 20in TL discarded (1992-2003).

Decision: Option 4. The SRHS dockside sample method uses information collected directly from the SRHS to estimate discards based management measures (i.e. size limits). It was concluded this method would most accurately reflect changes in discards which were due in large part to changes in management. Both the MRIP CH:SRHS discard ratio method and the MRIP CH discard ratio method followed the same pattern, or agreed well with the SRHS discard ratio in 2004-2009. However, these methods produce highly variable discard estimates for this species. Captain Steve Amick's discard ratio was not recommended due to the reduced time series and limited geographical range. While the MRIP PR discard method did follow a similar pattern as the SRHS in 2004-2009, this method would have caused increased variability in the discard estimate and therefore this method was not recommended. Final discard estimates from the SRHS are shown in Table 4.10.15 by year and state and in Figure 4.11.8.

4.4.4 Red Snapper Mini-season Discards

Introduction
The main objective of the red snapper mini season ad hoc working group was to provide information to the recreational workgroup to aid in decisions that were needed on which discards to report for red snapper during the mini seasons in 2012, 2013 and 2014. The 2012 mini-season was six days long: 9/14-9/16 & 9/21-9/23. The 2013 mini-season was three days long: 8/23-8/25. The 2014 mini-season was 8 days long: 7/11-7/13, 7/18-7/20, and 7/25-7/26. The key issue was that MRIP would be more likely to encompass the entire two month time period while some state surveys only captured the short time interval during the mini-season.
The sources of mini-season data that were reviewed for potential use are as follows:

- Marine Recreational Information Program (MRIP)
- North Carolina Department of Marine Fishers (NCDMF) state survey
- South Carolina Department of Natural Resources (SCDNR) state survey
- Georgia Department of Natural Resources (GADNR) state survey
- Florida Fish and Wildlife Conservation (FWC) Commission state survey

State partners in the South Atlantic supplied data from studies conducted in each state during the 2012, 2013 and 2014 mini-season as an attempt to supplement the MRIP data. Brief synopses of the type of data provided are illustrated in Table 4.10.16. Full descriptions of methods and data collected are available in the working papers SEDAR41-DW27(MRIP), SEDAR41-DW-21 (NC), SEDAR41-DW18 (SC), SEDAR41-DW02 (GA), SEDAR41-RD14 and SEDAR41-RD15 (FL).

The recreational workgroup developed a set of rules in order to determine which data set was more appropriate for discards by state (NC, SC, GA, and FLE), mode (charter and private), and wave (1-6):

Either MRIP or state available
• Use state number if no MRIP number exists, making note of any potential bias
• Use MRIP number if no state number exists

Both MRIP and state numbers available
• Discards - Recommend using the estimate/number (MRIP or State)
that is more reliable or encompasses the whole 2 month time period. In 2014, this option was clarified to include accounting for CV's, and/or biases associated with each survey.

The majority of the waves had either MRIP or State survey data available. When only the state survey data was available, potential sources of bias were considered, and noted in the decisions below. However, using the only available data for the wave was favored over using no data at all.

Florida, Georgia and South Carolina had cases of overlap for discard data in 2012 (Table 4.10.16). Florida and Georgia had cases of overlap for discard data in 2013 and 2014 (Table 4.10.17 and 4.10.18).

Issue 1: How to characterize the recreational discards during mini-seasons in 2012 for each state, mode, and wave.

Option 1: Use State number if no MRIP number is available, making note of any potential bias
Option 2: Use MRIP number if no state number is available
Option 3: Use the estimate/number (MRIP or state) that is more reliable (e.g. larger sample size or that encompasses the whole 2 month time period) when both MRIP and State numbers were available.

Decision(s):
Option 1.

- State CH - SC (waves 2, 3, & 6)
- State PR - SC (wave 5)

The CH discards from SC were self-reported data through the logbook without methods for validation but were considered to be a census of all charter captains fishing during the mini-season. The PR discards from SC were reported through the SFS survey were raw numbers (i.e. not an estimate).

Option 2.

- MRIP CH - NC and FLE for all of 2012 and GA (wave 3).
- MRIP PR - NC (wave 5), SC (wave 3), and FLE (waves 2, 3, 4, & 6)

Option 3.

- State CH - SC (waves 4 & 5) - The SC state survey was selected over MRIP due to larger sample size and because it also encompassed the entire 2 month period.
- MRIP CH - GA (wave 5)
- MRIP PR - GA (wave 5) and FLE (wave 5)

MRIP was selected over the state surveys, even though the state surveys had a larger sample size, because MRIP encompassed the entire two month period and not just the mini season.

Issue 2: How to characterize the recreational discards during mini-season in 2013 for each state, mode, and wave.

Option 1: Use State number if no MRIP number is available, making note of any potential bias
Option 2: Use MRIP number if no state number is available

Option 3: Use the estimate/number (MRIP or state) that is more reliable (e.g. larger sample size or that encompasses the whole 2 month time period) when both MRIP and state numbers were available.

Decision:
Option 1.

- State CH - SC (all waves 2013)
- State PR - GA (wave 4)

The CH discards from SC were self-reported data through the logbook without methods for validation. The PR discards from GA were collected through a voluntary self-reported online survey with a very small sample size.

Option 2.

- MRIP CH - NC (all waves 2013), GA (wave 5) and FLE (waves 1, 5 & 6).
- MRIP PR - NC and SC (all waves 2013), GA (wave 5), and FLE (waves 2, 3 & 5)

Option 3.

- MRIP CH - GA and FL (wave 4)
- MRIP PR - FLE (wave 4)

MRIP was selected over the state surveys, even though the state surveys had a larger sample size, because MRIP encompassed the entire two month period and not just the mini season.

Issue 3: *How to characterize the recreational discards during mini-seasons in 2014 for each state, mode, and wave.*

Option 1: Use State number if no MRIP number is available, making note of any potential bias
Option 2: Use MRIP number if no State number is available
Option 3: Use the estimate/number (MRIP or State) that is more reliable (taking into account sample sizes, CV's, and/or biases associated with the survey) when both MRIP and State numbers were available.

Decision(s): Option1.

- State Charter (CH) – SC (Wave 2 through 6) - The CH discards from SC were self-reported data through the logbook and, as stated for previous years, lack validation methods and had a high potential for recall bias.
- State Charter (CH) – GA (Wave 4) - The CH discards for GA were also self-reported through telephone census of charter captains that held a federal snapper/grouper permit with no method of validation but a lower potential recall bias since numbers were submitted immediately after the mini-season. These discards are raw numbers (i.e. not an estimate).

Option 2.

- MRIP (CH) – NC (Wave 3 and 4)
- MRIP (CH) – GA (Wave 2 and 3)
- MRIP (CH) – FLE (Wave 1, 2, 3, 5 and 6)
- MRIP (PR) – NC (Wave 4)
- MRIP (PR) – SC (Wave 3, 4 and 6)
- MRIP (PR) – GA (Wave 2 and 3)
- MRIP (PR) – FLE (Wave 1, 2, 3, 5 and 6)

Some of the estimated discards are based on a fairly low number of angler trips (e.g. 1 or 2 trips) and have high CV's (>1.0).

Option 3.

- MRIP (PR) – GA (Wave 4)
- MRIP (CH) – FLE (Wave 4)
- MRIP (PR) – FLE (Wave 4)

MRIP estimated discards was preferred over state surveys because MRIP encompassed the entire two month period (i.e. complete wave).

Uncertainty concerning data sources

In most cases, only MRIP or state survey information, but not both, were available for each individual wave. The main concern of potential bias with state survey information was that data were self-reported without means of validation. There was also concern that the state surveys were unlikely to represent discards outside of the mini-season while MRIP would represent discards for each wave. The SC logbook was the only exception since the discards were reported for an entire month, not just the mini-season. However, as stated in 4.3.3, the logbook data are self-reported and there is potential for recall bias. The merits and deficiencies of each data source discussed in 4.3.3 were considered when making decisions. The RWG took all of these points under consideration when deciding which data to use and felt confident in the choices that were made.

Total recreational catch from all surveys and all years are presented in Table 4.10.19.

4.5 Biological Sampling

4.5.1 Sampling Intensity Length/Age/Weight

Length samples from recreational landings were obtained from the Marine Recreational Fisheries Statistics Survey and the Southeast Region Headboat Survey.

Any existing natural total length measurements were converted to maximum total length using the following equation derived for the combined South Atlantic stock by the Life History Working Group at the SEDAR 32 data workshop:

$TL_{max} = 4.62 + 1.02TL_{nat}$ ($R^2 = 0.99$)

MRFSS/MRIP Biological Sampling

The MRFSS/MRIP angler intercept survey includes the sampling of fish lengths from the harvested (landed, whole condition) catch. Up to 15 of each species landed per angler interviewed are measured to the nearest mm along a center line (defined as tip of snout to center of tail along a straight line, not curved over body). In those fish with a forked tail, this measure would typically be referred to as a fork length, and in those fish that do not have a forked tail it would typically be referred to as a total length with the exception of some fishes that have a single, or few, caudal fin rays that extend further. Weights are typically collected for the same fish measured although weights are not preferred when time is constrained. Aging structures and other biological samples are not collected during MRFSS/MRIP assignments because of concerns over the introduction of bias to survey data collection.

The number of red snapper measured in the South Atlantic (NC to FLE) from MRFSS/MRIP by year, mode, and state are summarized in Table 4.10.20. The number of angler trips with measured red snapper measured in the South Atlantic (NC to FLE) in the MRFSS/MRIP by year, mode, and state are summarized in Table.4.10.21 There were concerns about low sample sizes for lengths from 1987 to 1998. Caution should be used for these years since the lengths collected may not necessarily be representative of the fishery. Information on the weights collected (number, mean, minimum, and maximum weights) by year and state from the MRFSS/MRIP is tabulated in Table 4.10.22

In 1986 suspect intercepts were found with 155 red snapper weighing 0.1 kg and measuring 197-210mm. Samples came from Volusia County, charter mode, ocean>3mi, wave 1 from multiple days with the same interviewer. In 1988 suspect intercepts were found with 25 red snapper weighing 0.1 kg and measuring 93-212mm. Samples came from Miami-Dade County, private mode, mostly inshore from multiple waves with a different sampler than the 1986 suspect intercepts. Other years, states, FL counties, and samplers show similar low weight red snappers. The RWG speculated that these red snapper were probably vermilion snapper, however, as these intercepts are many and varied it is difficult to make any adjustments as this would introduce additional bias. In general, it is difficult to make changes many years after the data is collected and the RWG recommends using the resulting estimates "as is" and taking into consideration an appropriate measure of the precision, which is most likely nearly twice as high in these early years than the survey data suggests (personal communication, NMFS).

Headboat Survey Biological Sampling

Lengths were collected from 1972 to 2014 by headboat dockside samplers. From 1972 to 1975, only North Carolina and South Carolina were sampled whereas Georgia and northeast Florida were sampled beginning in 1976. The Southeast Region Headboat Survey conducted dockside sampling for the entire range of Atlantic waters along the southeast portion of the US from the NC-VA border through the Florida Keys beginning in 1978. Weights are typically collected for the same fish measured during dockside sampling. Also, biological samples (scales, otoliths, spines, stomachs and gonads) are collected routinely and processed for aging, diet studies, and maturity studies.

Annual numbers of red snapper measured for length in the headboat fleet and the number of trips from which red snapper were measured are summarized in Table 4.10.23. Dockside mean weights for the headboat fishery are tabulated for 1972-2014 in Table 4.10.24

State of Florida Mini-Season Surveys

Red Snapper lengths were collected during random intercept surveys of private recreational boats in Florida during the recreational harvest season openings in 2012, 2013, and 2014. Site selection methods and intercept survey procedures are detailed in SEDAR41-DW42. Length frequency distributions for harvested Red Snapper by year and sample size (numbers of trips) were provided to the SEDAR41 data compiler. Mean weight of harvested Red Snapper during each season is also provided in Table 4.10.25.

SCDNR State Finfish Survey (SFS)

Red Snapper lengths were collected through the SCDNR State Finfish Survey (SFS) from 1988 to 2012. Starting in 2013 SCDNR took over MRIP sampling responsibilities in SC. Because of this the SFS survey was terminated except for January and February sampling. No Red Snapper were sampled during those months in 2013 and 2014. The SFS collects finfish intercept data in South Carolina through a non-random intercept survey at public boat landings along the SC coast. The survey focuses on known productive sample sites, targets primarily private boat mode, and is conducted year-round (January- December) using a questionnaire and interview procedure similar to the intercept portion of the MRIP. From 1988 through March 2009 mid-line lengths were measured and from April 2009 to 2011 total lengths were measured. From 1988 to 2012 85 red snapper lengths were collected by SFS personnel. The Recreational Fisheries Working Group recommended the SCDNR SFS length data for all modes be used to supplement the MRFSS/MRIP length data for length compositions. Mid-line (fork) measurements from 1988-2009 were converted to total length measurements using the following equation from the Life History Working Group at the SEDAR 41 data workshop:

$TL_{MAX} = 2.22 + 1.07*FL$

Summarized length data from 1988 – 2012 can be found in Table 4.10.26.

Headboat At-Sea Sampling (NC-east FL)
Length frequencies and sample sizes for Red Snapper discards observed by state biologists during Headboat At-Sea sampling from North Carolina through the east coast of Florida, and methods used to weight samples by state, are summarized in SEDAR41-DW33. Overall weighted length frequency distributions for observed Red Snapper discards by year were provided to the SEDAR41data compiler. Raw sample sizes for numbers of discarded fish measured and numbers of trips sampled are provided in Table 4.10.27.

Aging data
The number of red snapper aged from the recreational fishery and the number of trips with aged red snapper by year, state, and mode is summarized in Table 4.11.28. The number of trips provided is a combination of angler and vessel trips. It should be noted that for all modes, the number of age samples were low for certain years.

4.6 Recreational Effort

Total recreational effort is summarized below by survey. Effort is summarized for all marine fishing by mode, regardless of what was caught. A map and figures summarizing MRFSS/MRIP effort in angler trips are included in Figure 4.11.9. A map and figures summarizing SRHS effort in angler days are included in Figure 4.11.10.

4.6.1 MRFSS/MRIP Effort

Effort estimates for the recreational fishery survey are produced via telephone surveys of both anglers (private/rental boats and shore fishers) and for-hire boat operators (charterboat anglers, and in early years, party or charter anglers). The methods have changed during the full time series (see section 4.3 for descriptions of survey method changes and adjustments to survey estimates for uniform time-series of catch estimates). An angler-trip is defined as a single day of fishing by a single angler in the specified mode, not to exceed 24 hours. MRFSS effort estimates are presented from 1981 to 2003. MRIP effort estimates are presented starting in 2004. Angler trip estimates are tabulated in Table 4.10. 29 by year and mode and include all South Atlantic states from North Carolina through East Florida.

4.6.2 Headboat Effort

Catch and effort data are reported on logbooks provided to all headboats in the survey. These forms are completed by the captain or designated crew member after each trip and represent the total number and weight of all the species kept, along with the total number of fish discarded for each species. Data on effort are provided as number of anglers on a given trip. Numbers of anglers are standardized, depending on the type of trip (length in hours), by converting number of anglers to “angler days” (e.g., 40 anglers on a half-day trip would yield 40 * 0.5 = 20 angler days). Angler days are summed by month for individual vessels. Each month, port agents collect these logbook trip reports and check for accuracy and completeness. Although reporting via the logbooks is mandatory, compliance is not 100% and is variable by location. To account for non-reporting, a correction factor is developed based on sampler observations, angler numbers from office books and all available information. This information is used to provide estimates of total catch (expanded or corrected for non-reporting) by month and area, along with estimates of effort.

Estimated headboat angler days have decreased in the South Atlantic in recent years (Table 4.10.30). The most obvious factor which impacted the headboat fishery in the Atlantic was the high price of fuel. This coupled with the economic down turn starting in 2008 resulted in a marked decline in angler days in the South Atlantic headboat fishery. Reports from industry staff, captains\owners, and port agents indicated fuel prices, the economy and fishing regulations are the factors that most affected the amount of trips, number of passengers, and overall fishing effort. However, estimated angler days have risen in recent years (2012-2014).

4.8 Itemized List of Tasks for Completion Following Workshop

The length and age distributions will be prepared and discussed in a working paper for the Assessment Workshop.

4.9 Literature Cited

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4.10 Tables

Table 4.10.1 South Atlantic MRFSS charterboat conversion factors and standard errors (in parentheses).

a) Apply to 1981-1985 charterboat/headboat mode in the South Atlantic and Gulf of Mexico.

	WAVE					
STATE	1	2	3	4	5	6
NC	-	2.151 (0.12)	2.294 (0.12)	1.444 (0.12)	1.763 (0.12)	0.857 (0.12)
SC	-	1.035 (0.04)	1.085 (0.04)	1.437 (0.04)	0.891 (0.04)	0.750 (0.04)
GFE	0.845 (0.02)	0.951 (0.02)	0.985 (0.02)	1.016 (0.02)	0.811 (0.02)	0.696 (0.02)
AFW	0.883 (0.03)	0.883 (0.03)	1.104 (0.05)	1.104 (0.05)	0.883 (0.03)	0.883 (0.03)
MS	1.155 (0.11)	1.155 (0.11)	2.245 (0.11)	2.245 (0.11)	1.155 (0.11)	1.155 (0.11)
LA	0.962 (0.09)	0.962 (0.09)	2.260 (0.13)	2.260 (0.13)	0.962 (0.09)	0.962 (0.09)

b) Apply to 1986- 2002 charterboat mode in FLE

	WAVE					
Area	1	2	3	4	5	6
Inshore	1.600 (0.65)	2.786 (0.65)	2.201 (0.65)	2.894 (0.65)	1.630 (0.65)	2.386 (0.65)
Ocean	0.664 (0.10)	0.852 (0.10)	0.828 (0.10)	1.006 (0.10)	0.478 (0.10)	0.549 (0.10)

c) Apply to 1986- 2003 charterboat mode in GA and SC

	WAVE					
Area	1	2	3	4	5	6
Inshore	-	1.635 (0.90)	3.100 (0.90)	2.092 (0.90)	0.931 (0.90)	0.757 (0.90)
Ocean	-	0.939 (0.36)	1.272 (0.33)	2.161 (0.32)	0.835 (0.33)	0.638 (0.36)

d) Apply to 1986- 2003 charterboat mode in NC

	WAVE					
Area	1	2	3	4	5	6
Inshore	-	11.850 (3.48)	10.026 (2.63)	6.616(2.84)	3.766 (2.84)	9.415 (3.11)
Ocean	-	2.188 (0.58)	2.504 (0.58)	1.565 (0.60)	2.102 (0.60)	0.661 (0.60)

Table 4.10.2. Red snapper MRIP vs MRIP APAIS estimates of landings (number of fish) for the South Atlantic (sub-region 6) 2004-2012. See accompanying graph below table which includes the ratio of the MRIP APAIS to MRIP discards (value on right axis).

year	MRIP ab1	MRIP CV_ab1	MRIP APAIS ab1	MRIP APAIS CV_ab1
2004	495,942	0.08	563,576	0.16
2005	217,464	0.09	184,447	0.15
2006	138,513	0.11	150,111	0.24
2007	147,851	0.10	161,419	0.23
2008	137,920	0.10	138,779	0.16
2009	116,190	0.13	149,896	0.23
2010	107,995	0.12	157,981	0.21
2011	112,871	0.10	118,887	0.16
2012	283,304	0.09	341,232	0.18

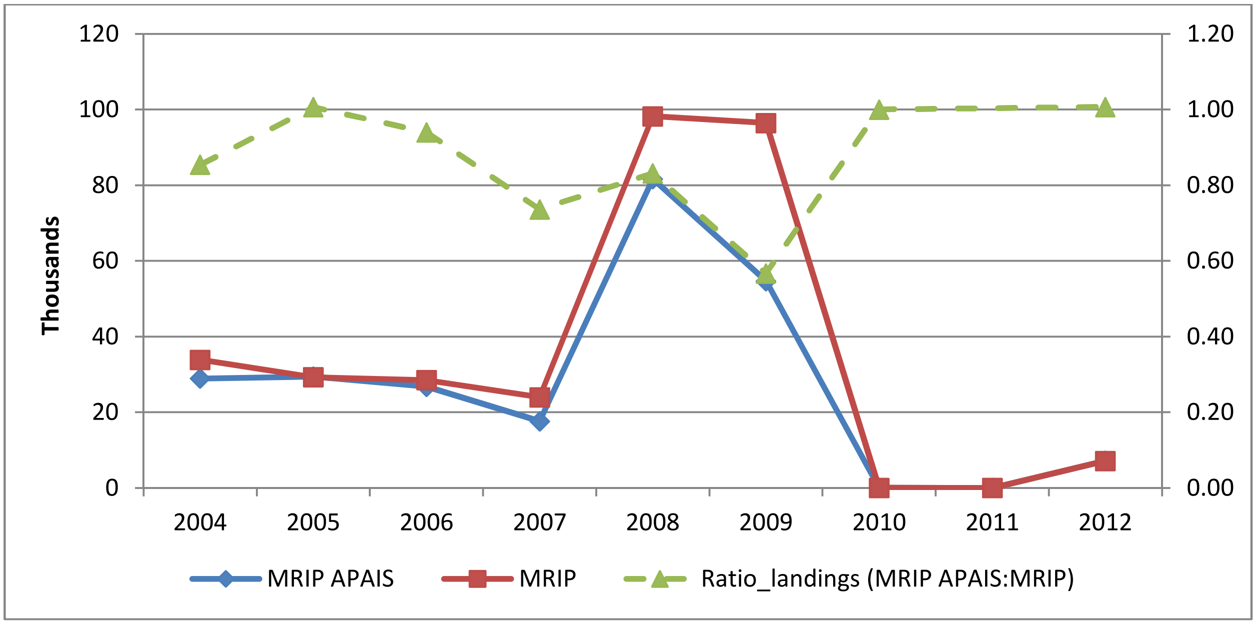


Table 4.10.3. Red snapper MRIP vs MRIP APAIS estimates of discards (number of fish) for the South Atlantic (sub-region 6) 2004-2012. See accompanying graph below table which includes the ratio of the MRIP APAIS to MRIP discards (value on right axis).

year	MRIP b2	MRIP CV_b2	MRIP APAIS b2	MRIP APAIS CV_b2
2004	191,820	0.20	199,638	0.29
2005	62,471	0.20	72,855	0.23
2006	96,517	0.24	119,735	0.31
2007	315,321	0.21	288,276	0.26
2008	394,122	0.22	511,984	0.36
2009	209,211	0.22	240,516	0.38
2010	102,867	0.27	138,478	0.39
2011	56,455	0.36	33,484	0.34
2012	105,477	0.27	142,961	0.39

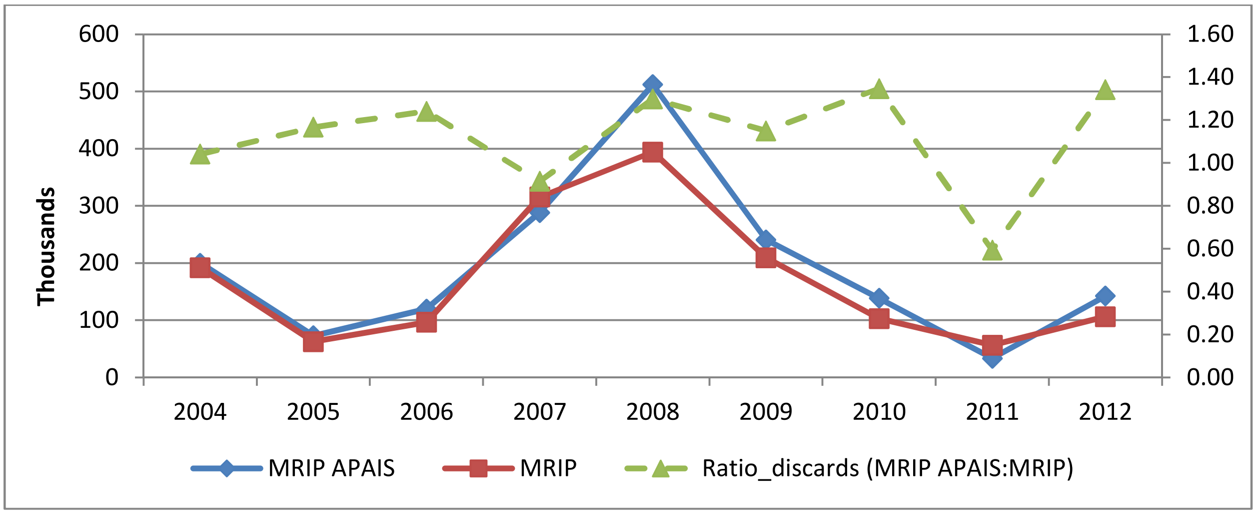


Table 4.10.4. South Atlantic red snapper ratio estimators for adjusting MRFSS numbers and variance estimates (AB1 and B2) to MRIP APAIS numbers and variances for 1981-2003. The variances of the numbers ratio estimators are also shown.

	Numbers Ratio Estimator		Variance Ratio Estimator		Variance of Numbers Ratio Estimator	
MODE	**AB1**	**B2**	**AB1**	**B2**	**AB1**	**B2**
Charterboat	0.699218	0.690369	0.834794	0.090876	0.007867	0.004632992
Private	0.626075	1.039297	1.135478	7.992752	0.011073	0.018337647

Table 4.10.5. South Atlantic (NC-FLE) red snapper landings (numbers of fish and whole weight in pounds) by year and mode (MRFSS, NMFS, 1981-2003; MRIP, NMFS, 2004+). MRFSS estimates adjusted to MRIP estimates prior to 2004. CH mode adjusted for FHS conversion prior to 2004. *CVs for CH mode 1981-1985 are unavailable. 2012-2014 (Mini season years) are presented separately.

	Estimated CH Landings			Estimated PR Landings			ALL MODES Landings			
YEAR	Number	CV*	Pounds	Number	CV	Pounds	Number	CV	Pounds	Avg. Wgt.
1981	19,076		113,181	74,382	0.34	441,339	93,458	0.27*	554,520	5.93
1982	1,958		11,620	34,335	0.36	203,727	36,294	0.34*	215,347	5.93
1983	45,093		267,557	23,375	0.52	138,695	68,469	0.18*	406,253	5.93
1984	72,449		94,618	140,098	0.33	211,013	212,547	0.22*	305,631	1.44
1985	125,843		356,840	163,128	0.36	480,359	288,971	0.20*	837,199	2.90
1986	57,318	0.40	16,274	43,419	0.41	17,754	100,736	0.29	34,029	0.34
1987	15,482	0.34	43,458	31,891	0.25	74,498	47,373	0.20	117,956	2.49
1988	20,885	0.34	34,036	59,936	0.36	42,804	80,821	0.28	76,840	0.95
1989	15,718	0.29	32,352	81,429	0.24	102,203	97,147	0.21	134,555	1.39
1990	5,492	0.33	32,585	6,600	0.45	39,159	12,092	0.29	71,745	5.93
1991	13,382	0.25	79,399	21,335	0.48	126,592	34,717	0.31	205,991	5.93
1992	27,489	0.19	125,522	24,419	0.35	111,504	51,908	0.19	237,026	4.57
1993	4,581	0.27	38,006	6,745	0.32	55,961	11,326	0.22	93,968	8.30
1994	9,618	0.28	67,357	8,695	0.47	60,895	18,313	0.27	128,252	7.00
1995	11,997	0.31	57,623	1,485	0.63	7,130	13,482	0.29	64,754	4.80
1996	2,050	0.36	12,166	7,291	0.53	43,261	9,342	0.42	55,427	5.93
1997	32,030	0.55	94,556	2,208	0.65	6,517	34,238	0.52	101,073	2.95
1998	8,247	0.29	45,841	4,768	0.40	26,500	13,015	0.24	72,341	5.56
1999	25,568	0.33	54,052	14,010	0.28	81,193	39,579	0.23	135,245	3.42
2000	7,606	0.20	42,391	37,741	0.27	223,440	45,347	0.23	265,831	5.86
2001	6,828	0.19	45,947	24,759	0.23	166,069	31,587	0.18	212,016	6.71
2002	13,570	0.19	86,908	21,492	0.25	168,184	35,062	0.17	255,092	7.28
2003	15,961	0.28	120,399	10,016	0.26	76,854	25,977	0.20	197,253	7.59
2004	9,589	0.24	71,809	19,325	0.29	144,300	28,914	0.21	216,109	7.47
2005	11,937	0.33	96,154	17,507	0.35	134,796	29,443	0.24	230,950	7.84
2006	14,156	0.34	143,419	12,613	0.42	119,508	26,769	0.26	262,927	9.82
2007	6,273	0.19	52,298	11,373	0.36	95,065	17,646	0.24	147,363	8.35
2008	11,401	0.35	73,872	70,236	0.31	456,070	81,638	0.27	529,942	6.49
2009	17,061	0.06	111,994	37,605	0.37	268,222	54,666	0.25	380,216	6.96
2010	62	1.00	369	0	0.00	0	62	1.00	369	5.93.
2011	0	0.00	0	0	0.00	0	0	0.00	0	0.00

Table 4.10.6. MRIP landings estimates for 1984 and 1985 by state, mode, and wave. Further information on highlighted estimates can be found in the text.

Sum of ab1			WAVE						
YEAR	mode	state	1	2	3	4	5	6	Grand Total
1984	Cbt	FLE	6,735	9,356	21,488	19,515	384		57,479
		GA			0	1,061			1,061
		NC				8,626			8,626
		SC			500	688	4,096		5,284
	Priv	FLE	12,379	105,256	22,463				140,098
1984 Total			19,114	114,612	44,451	29,890	4,480		212,547
1985	Cbt	FLE	1,344	4,620		42,631	9,039	1,012	58,646
		GA			772	30			802
		NC				50,776			50,776
		SC		3,720	5,064		6,834		15,618
	Priv	FLE	81,635	16,141	3,190	7,421	51,675		160,062
		GA			1,992	59			2,051
		SC			1,015				1,015
1985 Total			82,979	24,481	12,033	100,917	67,549	1,012	288,971

Table 4.10.7. Estimated headboat landings of red snapper in the South Atlantic 1972-2014. Due to headboat area definitions and confidentiality issues, Georgia and East Florida landings must be combined. A 3 year average ratio of NC/SC was used to calculate landings for GA/NEFL 1972-1975 and SEFL 1972-1980.

	Number				Weight (lb)				
Year	NC	SC	GA/FLE	South Atlantic	NC	SC	GA/FLE	South Atlantic	Avg Weight (lb)
1972	1,222	965	35,239	37,426	22,042	18,874	124,134	165,049	4.41
1973	2,367	1,615	64,162	68,144	32,456	27,758	226,017	286,232	4.20
1974	1,885	1,511	54,719	58,115	22,727	14,077	192,756	229,560	3.95
1975	1,351	3,872	84,158	89,381	12,842	26,954	296,456	336,252	3.76
1976	2,212	3,546	60,347	66,105	14,961	39,959	180,022	234,941	3.55
1977	1,049	1,316	42,706	45,071	7,233	11,083	176,882	195,198	4.33
1978	959	1,248	43,635	45,842	12,421	8,962	150,071	171,454	3.74
1979	441	668	31,257	32,366	5,101	9,127	169,291	183,519	5.67
1980	424	2,893	18,281	21,598	2,950	11,649	59,902	74,501	3.45
1981	1,194	1,371	33,466	36,031	7,742	8,762	101,526	118,031	3.28
1982	747	1,612	17,194	19,553	10,487	14,535	98,024	73,002	3.73
1983	416	1,844	28,438	30,698	5,316	10,179	74,004	58,508	1.91
1984	740	1,841	28,565	31,146	4,582	6,875	81,417	69,960	2.25
1985	8,426	2,183	39,727	50,336	31,330	11,768	132,084	88,985	1.77
1986	997	881	14,747	16,625	7,129	4,515	54,381	42,736	2.57
1987	5,346	1,934	17,716	24,996	21,518	6,310	81,840	54,012	2.16
1988	9,555	5,235	21,737	36,527	36,829	15,250	130,070	77,991	2.14
1989	1,134	6,207	16,112	23,453	6,691	26,459	70,796	37,646	1.61
1990	525	3,650	16,744	20,919	2,749	13,341	65,686	49,596	2.37
1991	725	3,290	9,842	13,857	15,991	21,781	72,030	34,258	2.47
1992	2,306	1,275	1,720	5,301	12,049	5,924	28,916	10,943	2.06
1993	1,639	3,623	2,085	7,347	9,043	19,865	42,718	13,809	1.88
1994	567	2,454	5,204	8,225	3,632	6,349	43,017	33,036	4.02
1995	3,791	866	4,169	8,826	23,728	6,340	57,474	27,406	3.11
1996	335	2,374	2,834	5,543	3,130	23,837	46,235	19,267	3.48
1997	1,779	557	3,434	5,770	20,969	6,746	51,205	23,490	4.07
1998	445	696	3,600	4,741	1,082	6,235	26,848	19,530	4.12
1999	973	1,749	4,114	6,836	6,957	11,257	43,559	25,345	3.71
2000	777	984	6,676	8,437	5,946	6,562	49,403	36,894	4.37
2001	1,816	3,878	6,334	12,028	9,605	20,513	68,385	38,267	3.18
2002	2,637	4,345	5,949	12,931	14,194	21,727	70,797	34,877	2.70
2003	399	1,346	3,961	5,706	3,679	12,133	41,353	25,541	4.48
2004	1,274	1,672	7,896	10,842	12,300	16,111	80,349	51,938	4.79
2005	106	1,004	7,797	8,907	1,114	10,399	58,695	47,183	5.30
2006	33	303	5,609	5,945	384	3,540	41,432	37,508	6.31
2007	52	701	6,136	6,889	389	5,016	37,460	32,055	4.65
2008	162	1,551	17,230	18,943	888	8,076	115,309	106,344	5.61
2009	263	373	20,871	21,507	2,368	5,105	141,087	133,615	6.21
2010	4	180	293	477	17	870	2,610	1,723	3.61
2011	9	4	1,346	1,359	39	17	8,660	8,605	6.33
2012	110	11	2,006	2,127	415	82	10,471	9,975	4.69
2013	53	13	1,454	1,520	240	125	12,036	11,671	7.68
2014	862	202	4,840	5,904	3,930	1,939	44,900	39,031	6.61

Table 4.10.8. Summary of different methods used by the Marine Recreational Information Program (MRIP) and states along the southeast Atlantic to collect charter (CH) and private (PR) recreational data for mini-seasons 2012- 2014. A dash (-) indicates that there was no method available. (FHS=For-Hire survey, APAIS=Access Point Atlantic Intercept Survey, CHTS=Coastal Household Telephone Survey, SFS=State Finfish Survey).

	MRIP	NC	SC	GA	FL
Estimate/#	Estimate	#	#	#	Estimate
CH effort	Phone survey (FHS)	-	Logbook	Phone survey	Phone survey
CH harvest (a+b1)	APAIS	-	Logbook	Phone survey	Phone survey
CH discards (b2)	APAIS	-	Logbook	Phone survey	Phone survey
Private effort	Phone survey (CHTS)	-	SFS (2012)	Online survey	Vessel counts
PR harvest (a + b1)	APAIS	-	Carcass	Online survey	Intercept survey
PR discards (b2)	APAIS	-	SFS (2012)	Online survey	Intercept survey
Effort unit	Angler trips	-	Boat trips	Angler trips	Boat trips
Weighted estimates	Y	N	N	N	Y
Random sampling	Y	N	N	N	Y
Carcass freezers	N	Y	Y	Y	Y

Table 4.10.9. Recreational mini-season landings for 2012. Bold text indicates an overlap of MRIP with State surveys within a specific mode and wave. The estimate/number selected by the RWG is highlighted in yellow. After APAIS adjustment, 2012 MRIP estimates are only available by year, not by wave.

		2012 LANDINGS AB1 (N)											
		CHARTER						PRIVATE					
		MRIP			State Surveys			MRIP			State Surveys		
State	Wave	Est	#trips	CV	Est/#	#trips	CV	Est	#trips	CV	Est/#	#trips	CV
NC	1												
	2												
	3												
	4												
	5				40						3		
	6												
NC Total		**2,484**	**7**	**0.54**	**40**						3		
SC	1												
	2												
	3				3	1	NA						
	4				1	1	NA						
	5				21	5	NA				43		NA
	6												
SC Total					25	7	NA				43		NA
GA	1												
	2												
	3												
	4												
	5				52	76	NA				22	31	NA
	6												
GA Total		96	2	0.82	52	76	NA	1,409	1	1.00	22	31	NA
FLE	1												
	2												
	3												
	4												
	5				882	227	0.73				10,729	390	0.15
	6												
FLE Total					882		0.73	3,205	4	1.00	10,729		

Table 4.10.10. Recreational mini-season landings for 2013. Bold text indicates an overlap of MRIP with State surveys within a specific mode and wave. The estimate/number selected by the RWG is highlighted in yellow.

		2013 LANDINGS AB1 (N)											
		CHARTER						PRIVATE					
		MRIP			State Surveys			MRIP			State Surveys		
State	Wave	Est	#trips	CV	Est/#	#trips	CV	Est	#trips	CV	Est/#	#trips	CV
NC	1												
	2												
	3												
	4				2						3		
	5												
	6												
SC	1												
	2												
	3												
	4				17	6	NA				39		NA
	5				1	1	NA						
	6												
GA	1												
	2												
	3												
	4				28	47	NA				41	53	NA
	5												
	6												
FLE	1												
	2												
	3												
	4	**873**	**2**	**0.87**	**971**	**515**		**17,463**	**9**	**0.80**	**6,428**	**549**	**0.16**
	5	58	1	1.01									
	6												

Table 4.10.11. Recreational mini-season landings for 2014. Bold text indicates an overlap of MRIP with State surveys within a specific mode and wave. The estimate/number selected by the RWG is highlighted in yellow.

		2014 LANDINGS AB1 (N)											
		CHARTER						PRIVATE					
		MRIP			State Surveys			MRIP			State Surveys		
State	Wave	Est	#trips	CV	Est/#	#trips	CV	Est	#trips	CV	Est/#	#trips	CV
NC	1												
	2												
	3												
	4	**116**	**3**	**0.76**	**41**		**NA**				14		NA
	5												
	6												
SC	1												
	2												
	3				3		NA						
	4				46		NA	**506**	**1**	**1.01**	**76**	**>1**	**NA**
	5												
	6												
GA	1												
	2												
	3												
	4	**258**	**1**	**0.83**	**150**	**180**	**NA**	**1,014**	**3**	**0.70**	**106**	**120**	**NA**
	5												
	6												
FLE	1							1,151	1	1.01			
	2												
	3							623	1	1.00			
	4	**5,197**	**30**	**0.33**	**2,377**	**136**	**0.39**	**79,618**	**53**	**0.35**	**22,282**	**1,377**	**0.11**
	5												
	6							334	1	0.95			

Table 4.10.12. Estimated red snapper landings using the FHWAR census method, 1955-1985.

Year	Total U.S. Saltwater Days	Adjusted Saltwater Days - South Atlantic	Avg CPUE MRFSS & SRHS 81-83	Historic Catch (number)	CV
1955	4,820,112	2,022,131	0.0181	36,536	0.65
1960	7,038,690	2,952,867	0.0181	53,353	0.65
1965	10,225,693	4,289,877	0.0181	77,510	0.65
1970	10,525,159	4,415,509	0.0181	79,780	0.65
1975	15,726,330	6,597,502	0.0181	119,204	0.65
1980	16,613,593	6,969,725	0.0181	125,929	0.65

Table 4.10.13. Estimated recreational landings of red snapper in the South Atlantic 1955-2014.

Year	Number	Year	Number
1955	36,536	1985	339,307
1956	39,899	1986	117,361
1957	43,263	1987	72,369
1958	46,626	1988	117,348
1959	49,989	1989	120,600
1960	53,353	1990	33,011
1961	58,184	1991	48,574
1962	63,015	1992	57,209
1963	67,847	1993	18,673
1964	72,678	1994	26,538
1965	77,510	1995	22,308
1966	77,964	1996	14,885
1967	78,418	1997	40,008
1968	78,872	1998	17,756
1969	79,326	1999	46,415
1970	79,780	2000	53,784
1971	87,665	2001	43,615
1972	95,549	2002	47,993
1973	103,434	2003	31,683
1974	111,319	2004	39,756
1975	119,204	2005	38,350
1976	120,549	2006	32,714
1977	121,894	2007	24,535
1978	123,239	2008	100,581
1979	124,584	2009	76,173
1980	125,929	2010	539
1981	129,177	2011	1,359
1982	55,847	2012	17,755
1983	99,167	2013	9,108
1984	243,693	2014	34,090

Table 4.10.14. MRIP South Atlantic (NC-FLE) red snapper discards (numbers of fish released alive) by year and mode (MRFSS, NMFS, 1981-2003; MRIP, NMFS, 2004+). MRFSS estimates adjusted to MRIP estimates prior to 2004. CH mode adjusted for FHS conversion prior to 2004. *CVs for CH mode 1981-1985 are unavailable. 2012-2014(Mini season years) are presented separately.

	Estimated CH Discards		Estimated PR Discards		ALL MODES Discards	
YEAR	Number	CV*	Number	CV	Number	CV
1981	709	0.00	0	0.00	709	0.00
1982	0	0.00	0	0.00	0	0.00
1983	12,599	0.00	0	0.00	12,599	0.00
1984	38,082	0.00	23,743	1.45	61,825	0.56
1985	15,426	0.00	65,996	1.65	81,422	1.34
1986	0	0.00	0	0.00	0	0.00
1987	97	0.32	110,748	1.63	110,844	1.62
1988	0	0.00	50,274	1.33	50,274	1.33
1989	0	0.00	20,826	1.18	20,826	1.18
1990	0	0.00	0	0.00	0	0.00
1991	62	0.32	37,262	1.45	37,324	1.45
1992	7,736	0.14	20,258	1.09	27,994	0.79
1993	17,236	0.17	50,913	0.91	68,149	0.68
1994	1,504	0.14	65,036	0.83	66,540	0.81
1995	11,468	0.12	39,422	0.69	50,890	0.53
1996	2,124	0.13	18,321	1.20	20,445	1.07
1997	7,554	0.16	9,020	0.99	16,574	0.54
1998	2,917	0.13	23,872	1.07	26,789	0.96
1999	24,833	0.08	137,877	0.55	162,710	0.47
2000	16,486	0.07	232,111	0.48	248,597	0.45
2001	16,357	0.06	186,309	0.45	202,665	0.42
2002	13,310	0.06	110,052	0.63	123,362	0.56
2003	14,451	0.07	144,879	0.52	159,329	0.47
2004	22,148	0.18	177,490	0.33	199,638	0.29
2005	27,447	0.09	45,408	0.37	72,855	0.23
2006	18,675	0.34	101,060	0.37	119,735	0.31
2007	62,442	0.06	225,834	0.33	288,276	0.26
2008	26,072	0.20	485,912	0.38	511,984	0.36
2009	22,000	0.05	218,516	0.42	240,516	0.38
2010	16,434	0.04	122,044	0.44	138,478	0.39
2011	12,591	0.04	20,892	0.54	33,484	0.34

Table 4.10.15. Estimated South Atlantic red snapper discards for SRHS by year and state. Due to headboat area definitions and confidentiality issues, Georgia and East Florida discards must be combined. 2004-2014 uses the SRHS logbook discards. 1981-2003 HB mode uses SRHS dockside sample discard ratio proxy method. Zero discards are assumed prior to 1983.

Year	NC	SC	GA/FLE	South Atlantic
1972	-	-	-	-
1973	-	-	-	-
1974	-	-	-	-
1975	-	-	-	-
1976	-	-	-	-
1977	-	-	-	-
1978	-	-	-	-
1979	-	-	-	-
1980	-	-	-	-
1981	-	-	-	-
1982	-	-	-	-
1983	-	-	-	-
1984	2	4	63	69
1985	19	5	87	111
1986	2	2	32	37
1987	12	4	39	55
1988	21	12	48	80
1989	2	14	35	52
1990	1	8	37	46
1991	2	7	22	30
1992	1,092	604	814	2,510
1993	776	1,715	987	3,478
1994	268	1,162	2,464	3,894
1995	1,795	410	1,974	4,178
1996	159	1,124	1,342	2,624
1997	842	264	1,626	2,732
1998	211	329	1,704	2,244
1999	461	828	1,948	3,236
2000	368	466	3,160	3,994
2001	860	1,836	2,999	5,694
2002	1,248	2,057	2,816	6,122
2003	189	637	1,875	2,701
2004	26	545	18,219	18,790
2005	12	166	9,698	9,876
2006	1,174	68	15,991	17,233
2007	2,370	1,001	68,515	71,886
2008	1,293	1,062	71,254	73,609
2009	402	390	56,535	57,327
2010	1,245	738	36,460	38,443
2011	170	1,037	40,184	41,391
2012	401	393	45,988	46,782
2013	438	154	46,148	46,740
2014	1,043	358	45,211	46,612

Table 4.10.16. Recreational mini-season discards for 2012. Bold text indicates an overlap of MRIP with State surveys within a specific mode and wave. The estimate/number selected by the RWG is highlighted in yellow.

		2012 DISCARDS B2 (N)											
		CHARTER						PRIVATE					
		MRIP			State Surveys			MRIP			State Surveys		
State	Wave	Est	#trips	CV	Est/#	#trips	CV	Est	#trips	CV	Est/#	#trips	CV
NC	1												
	2												
	3												
	4												
	5												
	6												
NC Total		3,130	23	0.74				323	1	1.00			
SC	1												
	2				24	6	NA						
	3				298	50	NA						
	4				207	42	NA						
	5				114	13	NA				9		NA
	6				13	3	NA						
SC Total		14	5	1.00	656	114	NA	16,130	3	1.00	9		NA
GA	1												
	2												
	3												
	4												
	5				25	76	NA				6	31	NA
	6												
GA Total		287	6	0.71	25	76	NA	787	1	1.00	6	31	NA
FLE	1												
	2												
	3												
	4												
	5										**8,065**	**390**	**0.3**
	6												
FLE Total		11,670	32	0.00				109,969	41	0.48	8,065		

Table 4.10.17. Recreational mini-season discards for 2013. Bold text indicates an overlap of MRIP with State surveys within a specific mode and wave. The estimate/number selected by the RWG is highlighted in yellow.

		2013 DISCARDS B2 (N)											
		CHARTER						PRIVATE					
		MRIP			State Surveys			MRIP			State Surveys		
State	Wave	Est	#trips	CV	Est/#	#trips	CV	Est	#trips	CV	Est/#	#trips	CV
NC	1												
	2												
	3	137	5	0.55				243	1	1.06			
	4	276	2	1.01									
	5	16	2	1.04									
	6												
SC	1												
	2				21	5	NA						
	3				165	33	NA						
	4				173	44	NA	1,025	1	0.65			
	5				104	27	NA						
	6				9	2	NA						
GA	1												
	2												
	3												
	4	**210**	**1**	**0.85**	**5**	**47**	**NA**				13	53	NA
	5	214	2	0.45				4,668	5	0.87			
	6												
FLE	1	379	4	0.54									
	2							11,796	4	0.96			
	3							6,919	15	0.63			
	4	**323**	**8**	**0.19**	**1,494**	**515**		**21,750**	**16**	**0.69**	**3,144**	**549**	**0.24**
	5	5,161	42	0.53				30,244	8	0.55			
	6	147	3	0.69									

Table 4.10.18. Recreational mini-season discards for 2014. Bold text indicates an overlap of MRIP with State surveys within a specific mode and wave. The estimate/number selected by the RWG is highlighted in yellow.

		2014 DISCARDS B2 (N)											
		CHARTER						PRIVATE					
		MRIP			State Surveys			MRIP			State Surveys		
State	Wave	Est	#trips	CV	Est/#	#trips	CV	Est	#trips	CV	Est/#	#trips	CV
NC	1												
	2												
	3	325	2	0.99									
	4	524	6	0.68				4,400	4	0.85			
	5												
	6												
SC	1												
	2				29		NA						
	3				242		NA	1,357	4	0.83			
	4				184		NA	1,453	2	1.03			
	5				73		NA						
	6				53		NA	290	1	1.04			
GA	1												
	2	55	1	1.05				388	2	1.14			
	3	207	2	0.39				9,859	2	0.97			
	4				75	180	NA	**1,689**	**5**	**0.88**	**265**	**120**	**NA**
	5												
	6												
FLE	1	27	4	1.06				16,014	7	0.79			
	2	1,422	2	0.78				1,592	1	1.00			
	3	4,883	20	0.42				41,637	43	0.32			
	4	**13,347**	**61**	**0.40**	**2,871**	**136**	**0.28**	**136,175**	**73**	**0.37**	**9,960**	**1,377**	**0.17**
	5	3,190	45	0.51				1,281	3	0.64			
	6	11,428	17	0.65				33,762	9	0.74			

Table 4.10.19. Total recreational catch (landings and discards) from all sources and years from 1955-2014.

	Number of fish		
Year	Landings	Discards	Total Catch
1955	36,536		36,536
1956	39,899		39,899
1957	43,263		43,263
1958	46,626		46,626
1959	49,989		49,989
1960	53,353		53,353
1961	58,184		58,184
1962	63,015		63,015
1963	67,847		67,847
1964	72,678		72,678
1965	77,510		77,510
1966	77,964		77,964
1967	78,418		78,418
1968	78,872		78,872
1969	79,326		79,326
1970	79,780		79,780
1971	87,665		87,665
1972	95,549		95,549
1973	103,434		103,434
1974	111,319		111,319
1975	119,204		119,204
1976	120,549		120,549
1977	121,894		121,894
1978	123,239		123,239
1979	124,584		124,584
1980	125,929		125,929
1981	129,489	709	130,198
1982	55,847		55,847
1983	99,167	12,599	111,765
1984	243,693	61,893	305,587

	Number of fish		
Year	Landings	Discards	Total Catch
1985	339,307	81,533	420,840
1986	117,361	37	117,398
1987	72,369	110,899	183,268
1988	117,348	50,354	167,702
1989	120,600	20,877	141,477
1990	33,011	46	33,057
1991	48,574	37,354	85,928
1992	57,209	30,503	87,713
1993	18,673	71,627	90,301
1994	26,538	70,434	96,972
1995	22,308	55,068	77,376
1996	14,885	23,069	37,954
1997	40,008	19,305	59,313
1998	17,756	29,033	46,789
1999	46,415	165,946	212,361
2000	53,784	252,591	306,375
2001	43,615	208,359	251,974
2002	47,993	129,483	177,476
2003	31,683	162,031	193,714
2004	39,756	218,428	258,183
2005	38,350	82,731	121,081
2006	32,714	136,968	169,682
2007	24,535	360,162	384,697
2008	100,581	585,593	686,174
2009	76,173	297,843	374,016
2010	539	176,921	177,460
2011	1,359	74,875	76,234
2012	17,755	189,743	207,497
2013	9,108	130,732	139,840
2014	34,090	332,574	366,664

Table 4.10.20. Number of red snapper measured in the South Atlantic (NC-FLE) in the MRFSS/MRIP by year, mode, and state from 1981-2014.

	CH					PR				
YEAR	FLE	GA	SC	NC	All	FLE	GA	SC	NC	All
1981						25				25
1982						28				28
1983	3		5		8	11	2			13
1984	16	10	1	7	34	41				41
1985		4			4	32	4			36
1986	205		1		206	19	1			20
1987		1		24	25	17	9		12	38
1988	8			13	21	38			14	52
1989	5	4	4	8	21	32	5	1		38
1990				14	14	2			2	4
1991		3		10	13	1			2	3
1992	4	1		3	8	6	1		2	9
1993		11		4	15	8				8
1994	3	18		14	35	2				2
1995	4	9		11	24	2				2
1996		3	2	4	9	4			2	6
1997	2	2	16		20					
1998	4	11	11		26	6		1		7
1999	14	17	68	8	107	25				25
2000	51	4	20	1	76	14		2		16
2001	70	3	10	7	90	32				32
2002	181	2	4	12	199	33				33
2003	126	9	1	21	157	7		2		9
2004	83	37	6	1	127	25	3		1	29
2005	50	11		2	63	11			2	13
2006	38	10	3	12	63	9	4		1	14
2007	26	18	1		45	15	1	2		18
2008	34	49	2	10	95	91	8			99
2009	39	60		5	104	108	1		4	113
2010			1		1					
2011										
2012		9		35	44	3	4			7
2013	4				4	12				12
2014	100	2			102	89	8	4		101

Table 4.10.21. Number of angler trips with measured red snapper in the South Atlantic (NC-FLE) in the MRFSS/MRIP by year, mode, and state from 1981-2014.

	CH					PR				
YEAR	FLE	GA	SC	NC	All	FLE	GA	SC	NC	All
1981						10				10
1982						10				10
1983	2		2		4	2	1			3
1984	2	1	1	2	6	9				9
1985		1			1	11	3			14
1986	73		1		74	8	1			9
1987		1		5	6	5	2		3	10
1988	4			7	11	12			4	16
1989	2	1	3	6	12	11	1	1		13
1990				3	3	2			2	4
1991		2		5	7	1			1	2
1992	2	1		3	6	3	1		1	5
1993		8		3	11	6				6
1994	2	10		11	23	2				2
1995	1	4		5	10	2				2
1996		3	2	1	6	4			1	5
1997	1	2	2		5					
1998	2	5	3		10	6		1		7
1999	8	5	11	3	27	12				12
2000	19	2	4	1	26	12		1		13
2001	27	3	2	6	38	17				17
2002	34	1	2	8	45	11				11
2003	35	5	1	7	48	5		1		6
2004	25	13	6	1	45	14	3		1	18
2005	18	6		1	25	6			2	8
2006	13	4	3	3	23	6	1		1	8
2007	9	7	1		17	7	1	1		9
2008	9	12	1	5	27	33	4			37
2009	10	14		3	27	25	1		3	29
2010			1		1					
2011										
2012		2		7	9	3	1			4
2013	3				3	9				9
2014	21	1			22	32	2	1		35

Table 4.10.22. Number, mean, minimum, and maximum weights of red snapper in the South Atlantic (NC-FLE) in the MRFSS/MRIP by year and state from 1981-2014.

	FLE				GA				SC				NC			
YEAR	N	Mean (lbs)	Min (lbs)	Max (lbs)	N	Mean (lbs)	Min (lbs)	Max (lbs)	N	Mean (lbs)	Min (lbs)	Max (lbs)	N	Mean (lbs)	Min (lbs)	Max (lbs)
1981	27	2.39	0.44	8.82												
1982	20	4.10	0.22	21.83												
1983	15	2.09	0.22	7.94	3	9.33	1.32	25.35	4	9.76	8.38	11.46				
1984	48	1.24	0.22	2.65	10	1.19	0.66	2.65	1	24.25	24.25	24.25	7	2.11	0.88	3.31
1985	32	2.95	0.66	5.73	8	2.07	0.66	2.65	1	1.32	1.32	1.32				
1986	224	0.41	0.22	2.65	1	3.31	3.31	3.31	1	2.65	2.65	2.65	1	2.20	2.20	2.20
1987	20	1.17	0.44	4.63	4	1.38	1.10	2.20	1	2.20	2.20	2.20	38	2.81	0.44	9.70
1988	52	1.34	0.22	7.94					2	5.62	1.10	10.14	22	3.93	0.88	10.14
1989	41	1.77	0.22	9.70	9	1.20	0.44	3.09	7	3.56	1.76	4.85	8	4.05	0.66	7.72
1990	2	10.58	3.53	17.64									8	6.61	0.44	22.93
1991	5	4.50	1.54	7.72	3	10.88	9.04	14.55	1	3.09	3.09	3.09	7	2.20	0.66	4.85
1992	15	4.81	1.10	18.52	10	4.81	1.98	7.72					6	4.01	1.98	5.95
1993	9	6.86	0.44	14.55	16	10.06	1.10	27.56					4	5.18	3.31	6.83
1994	9	3.86	0.66	14.99	21	9.28	2.20	27.12					14	5.97	0.66	14.99
1995	6	5.73	3.53	10.58	15	6.63	3.53	12.90					11	2.32	0.44	5.73
1996	6	7.68	5.51	12.57	5	10.85	5.07	18.96	2	1.05	0.88	1.21	4	3.22	1.32	4.85
1997	3	11.57	9.92	13.23	3	8.52	6.83	11.46	26	1.31	0.44	9.92				
1998	10	9.57	1.17	25.13	9	6.41	0.66	16.53	12	1.75	0.55	12.35				
1999	43	5.57	0.99	17.64	17	2.94	0.44	11.24	71	1.33	0.44	8.82	8	2.26	1.10	6.17
2000	62	6.10	3.09	18.81	4	6.20	1.21	14.77	22	2.93	0.77	12.13	1	14.33	14.33	14.33
2001	102	6.69	1.06	25.35	2	20.17	19.40	20.94	10	6.92	1.21	8.82	7	5.32	4.41	6.61
2002	210	6.43	2.49	23.59	2	8.27	6.17	10.36	4	3.64	2.09	4.85	12	7.49	4.12	12.30
2003	128	7.64	0.93	25.13	10	13.37	4.41	31.97	3	7.72	6.61	8.82	15	3.18	1.54	10.19
2004	105	7.21	2.07	21.14	41	9.18	3.75	25.13	6	8.97	5.29	11.02	2	10.35	10.23	10.47
2005	59	7.64	0.93	22.18	5	13.01	5.51	16.98					4	9.65	3.92	19.49
2006	41	9.94	3.64	27.20	11	6.15	3.97	12.79	5	6.22	1.10	16.53	13	3.67	0.22	14.37
2007	41	8.37	1.32	23.15	19	6.17	2.98	11.90	1	17.64	17.64	17.64				
2008	124	6.48	3.44	24.80	55	6.27	1.76	17.64	2	5.51	4.85	6.17	9	5.54	4.74	8.60
2009	148	6.95	3.53	24.80	61	7.01	3.31	13.67					8	8.65	4.41	22.05
2010									1	2.31	2.31	2.31				
2011																
2012	3	5.43	1.34	13.23	12	8.78	2.09	16.31					35	10.60	2.76	25.90
2013	16	10.04	1.41	15.08												
2014	188	12.98	1.32	21.96	9	7.35	1.54	20.28	4	14.00	8.60	18.96				

Table 4.10.23. Number of red snapper measured and number of trips with measured red snapper in the SRHS by year and state 1972-2014.

	Fish(N)				Trips(N)			
Year	NC	SC	GA/FLE	South Atlantic	NC	SC	GA/FLE	South Atlantic
1972	18	30		48	11	19		30
1973	12	20		32	8	18		26
1974	29	66		95	19	33		52
1975	69	86		155	38	36		74
1976	143	51	303	497	44	28	45	117
1977	59	82	577	718	29	43	125	197
1978	49	45	646	740	22	25	161	208
1979	7	8	230	245	5	6	80	91
1980	10	14	234	258	9	10	73	92
1981	17	3	652	672	13	3	183	199
1982	30	6	421	457	16	5	133	154
1983	53	24	929	1,006	32	18	203	253
1984	48	103	1,170	1,321	26	59	229	314
1985	170	51	970	1,191	59	22	217	298
1986	51	30	354	435	35	16	139	190
1987	50	53	203	306	30	28	100	158
1988	63	43	98	204	36	29	51	116
1989	38	53	274	365	22	33	102	157
1990	31	43	293	367	17	19	101	137
1991	7	29	116	152	7	14	43	64
1992	20	25	28	73	16	16	17	49
1993	22	128	53	203	15	52	29	96
1994	14	46	60	120	11	17	29	57
1995	13	41	93	147	9	22	43	74
1996	7	16	55	78	6	11	29	46
1997	4	6	57	67	3	6	33	42
1998	11	25	113	149	7	15	56	78
1999	7	15	140	162	6	12	73	91
2000	7	9	107	123	6	5	59	70
2001	17		239	256	15		103	118
2002	8	12	341	361	7	8	142	157
2003	9	21	299	329	8	16	121	145
2004	3	10	290	303	3	7	102	112
2005	3	3	189	195	1	2	92	95
2006	4	9	159	172	4	7	91	102
2007	2	15	153	170	2	12	55	69
2008	10	12	435	457	6	4	81	91
2009	16	12	738	766	12	8	166	186
2010			4	4			1	1
2011			1	1			1	1
2012	28	4	100	132	5	1	10	16
2013	32	2	143	177	6	1	24	31
2014	66	22	203	291	10	4	28	42

Table 4.10.24. Mean weight (kg) of red snapper measured in the SRHS by year and state, 1972-2014.

	NC				SC				GA/FLE			
Year	N	Mean (kg)	Min (kg)	Max (kg)	N	Mean (kg)	Min (kg)	Max (kg)	N	Mean (kg)	Min (kg)	Max (kg)
1972	18	7.57	1.77	11.80	30	8.37	0.73	15.89				
1973	12	9.63	6.63	11.71	20	7.78	2.00	10.62				
1974	29	5.49	0.45	11.35	66	4.04	0.86	14.21				
1975	69	4.27	0.45	16.12	86	2.84	0.59	11.85				
1976	143	3.93	0.36	14.07	51	4.63	1.59	11.58	303	1.30	0.09	12.03
1977	59	4.64	0.91	11.58	82	3.91	1.09	11.35	577	1.51	0.14	12.49
1978	49	6.57	1.73	16.34	45	3.43	0.15	12.35	646	1.61	0.15	25.50
1979	7	7.07	4.00	11.75	8	3.58	1.20	10.50	230	2.44	0.16	16.00
1980	10	6.20	1.30	20.88	14	1.76	0.93	2.45	234	1.83	0.22	12.26
1981	17	3.07	1.37	10.22	3	1.92	0.87	3.65	652	1.52	0.14	18.00
1982	30	6.17	0.33	13.62	6	4.91	0.62	10.65	421	1.81	0.16	10.70
1983	53	5.57	0.43	12.94	24	2.47	0.63	7.90	929	0.94	0.18	10.70
1984	48	2.74	0.28	13.28	103	1.75	0.38	15.48	1,170	1.18	0.10	12.00
1985	170	1.68	0.18	16.53	51	2.14	0.20	13.70	970	1.02	0.14	13.80
1986	51	2.83	0.93	14.54	30	2.38	0.90	4.30	354	1.44	0.11	12.25
1987	50	1.93	0.44	5.42	53	1.45	0.35	4.70	203	1.24	0.12	8.89
1988	63	1.48	0.11	11.02	43	1.67	0.39	6.33	98	1.70	0.10	12.54
1989	38	1.80	0.59	2.98	53	1.83	0.65	6.40	274	1.12	0.08	11.66
1990	31	2.51	0.79	8.86	43	1.70	0.68	3.72	293	1.36	0.36	10.29
1991	7	2.11	0.49	6.17	29	2.75	0.10	11.21	116	1.61	0.41	11.33
1992	20	2.49	0.88	5.02	25	2.06	0.00	4.39	28	3.40	1.64	11.22
1993	22	2.43	1.08	5.16	128	2.55	1.20	10.48	53	2.82	1.18	12.27
1994	14	3.30	1.99	5.07	46	2.87	1.32	10.55	60	2.93	1.52	11.98
1995	13	2.55	1.76	4.38	41	3.29	0.91	6.92	93	3.07	1.47	12.28
1996	7	4.37	1.80	10.64	16	4.91	2.08	10.11	55	2.89	1.64	10.53
1997	4	4.72	1.16	7.12	6	4.92	2.71	6.05	57	3.32	0.36	11.22
1998	11	0.89	0.22	2.82	25	3.71	0.62	10.35	113	2.47	1.18	6.57
1999	7	3.77	0.63	8.15	15	2.91	1.59	8.14	140	2.76	0.90	12.95
2000	7	4.34	1.13	9.90	9	3.24	2.13	5.52	107	2.47	1.59	5.13
2001	17	2.46	1.84	3.57					239	2.93	1.34	12.34
2002	8	3.52	2.12	5.03	12	2.33	1.20	3.63	341	2.63	0.22	10.44
2003	9	4.31	2.94	6.41	21	4.09	1.30	12.07	299	2.75	0.81	12.19
2004	3	4.99	2.62	6.40	10	4.73	2.03	6.83	290	2.94	0.97	12.73
2005	3	5.69	5.25	6.12	3	7.51	4.04	10.93	189	2.92	1.35	9.21
2006	4	4.61	1.02	8.20	9	5.77	1.93	10.05	159	3.07	1.61	11.52
2007	2	2.05	2.05	2.05	15	4.53	1.74	8.80	153	2.63	1.37	11.58
2008	10	2.19	1.66	2.83	12	3.99	2.10	8.54	435	2.60	1.40	12.93
2009	16	2.91	1.72	5.46	12	3.19	1.93	8.48	738	2.87	0.11	13.18
2010									4	2.79	2.57	3.01
2011									1	3.52	3.52	3.52
2012	28	1.66	0.46	5.25	4	4.42	3.43	5.03	100	2.51	0.54	7.11
2013	32	2.09	0.41	6.54	2	5.69	5.48	5.89	143	3.36	0.28	12.55
2014	66	1.67	0.27	9.11	22	3.35	0.86	8.18	203	2.27	0.18	8.90

Table 4.10.25. State of Florida Red Snapper Mini-Season Surveys. Number of harvested Red Snapper measured, number of trips with measured Red Snapper, and mean weight of Red Snapper sampled by year for private boat mode.

Year	Fish (n)	Trips (n)	Mean weight (kg)
2012	440	167	4.09
2013	631	244	5.03
2014	1,718	583	5.02

Table 4.10.26. SCDNR State Finfish Survey number of red snapper measured (total and by mode), mean length, standard deviation of length, and minimum and maximum size range (all modes combined). No length measurements were recorded during1988, 1990, 1991, 1994-1998, 2004, 2006, 2007, 2010, and 2011.

Year	Total number measured	Total number measured by mode		Mean TLmax(mm)	StDev TLmax(mm)	Minimum TLmax(mm)	Maximum TLmax(mm)
		Charter	Private				
1988							
1989	1	0	1	437.18		437.18	437.18
1990							
1991							
1992	7	0	7	365.45	78.16	309.23	489.87
1993	2	0	2	341.48	56.26	301.70	381.27
1994							
1995							
1996							
1997							
1998							
1999	22	18	4	589.72	31.18	493.10	639.33
2000	17	15	2	739.84	124.11	471.59	847.94
2001	4	0	4	629.39	76.32	555.46	710.30
2002	15	0	15	607.22	112.48	441.48	774.82
2003	6	0	6	634.49	129.30	398.47	768.37
2004							
2005	2	0	2	806.00	153.59	697.40	914.60
2006							
2007							
2008	2	0	2	633.96	41.06	604.92	662.99
2009	4	0	4	582.76	47.89	540.00	650.00
2010							
2011							
2012	3	0	3	750.666667	85.33	670.00	840.00

Table 4.10.27. Headboat At-Sea Sampling. Number of discarded Red Snapper measured and number of trips sampled by observers by state and year.

	Number Fish (n)					Number Trips (n)				
Year	NC	SC	GA-NEFL	SEFL	Sum	NC	SC	GA-NEFL	SEFL	Sum
2005	0	0	366	48	414	97	57	49	93	296
2006	0	0	672	0	672	88	45	45	71	249
2007	13	2	1450	34	1499	91	52	57	69	269
2008	23	1	1626	28	1678	78	39	55	74	246
2009	3	0	425	8	436	69	34	61	76	240
2010	7	0	325	14	346	83	26	51	72	232
2011	8	0	307	0	315	79	22	51	68	220
2012	18	1	635	3	657	78	36	62	64	240
2013	28	0	472	1	501	55	41	61	79	236
2014	7	0	606	0	613	70	41	68	79	258

Table 4.10.28. Number of red snapper aged and number of trips with aged red snapper in the recreational fishery by year, state, and mode. Trips (N) are a combination of angler and vessel trips.

	Fish(N)							Trips(N)*						
	Charter		Headboat			Private		Charter		Headboat			Private	
Year	FL	GA	FLE/GA	NC	SC	FL	GA	FL	GA	FLE/GA	NC	SC	FL	GA
1977	-	-	60	-	12	-	-	-	-	17	-	5	-	-
1978	-	-	275	1	2	-	-	-	-	80	1	2	-	-
1979	-	-	46	-	1	-	-	-	-	31	-	1	-	-
1980	-	-	87	2	5	-	-	-	-	30	2	4	-	-
1981	-	-	405	3	-	-	-	-	-	141	3	-	-	-
1982	-	-	131	3	-	-	-	-	-	55	1	-	-	-
1983	-	-	741	3	5	-	-	-	-	167	2	4	-	-
1984	-	-	553	-	28	-	-	-	-	147	-	19	-	-
1985	-	-	491	-	13	-	-	-	-	150	-	10	-	-
1986	-	-	174	2	8	-	-	-	-	92	1	4	-	-
1987	-	-	86	1	-	-	-	-	-	60	1	-	-	-
1988	-	-	19	3	-	-	-	-	-	17	3	-	-	-
1989	-	-	15	11	23	-	-	-	-	9	5	17	-	-
1990	-	-	20	8	5	-	-	-	-	13	6	4	-	-
1991	-	-	21	4	1	-	-	-	-	13	4	1	-	-
1992	-	-	2	3	1	-	-	-	-	2	2	1	-	-
1993	-	-	9	2	7	-	-	-	-	6	2	5	-	-
1994	7	-	10	5	1	-	-	2	-	6	3	1	-	-
1995	-	-	11	3	4	-	-	-	-	5	2	1	-	-
1996	-	-	17	2	31	-	-	-	-	12	2	13	-	-
1997	-	-	13	-	-	-	-	-	-	12	-	-	-	-
1998	-	-	7	-	21	-	-	-	-	6	-	2	-	-
2000	7	-	2	-	-	-	-	4	-	2	-	-	-	-
2001	42	-	2	-	-	1	-	14	-	2	-	-	1	-
2002	253	-	9	-	3	9	-	81	-	3	-	3	3	-
2003	352	-	10	1	-	2	-	91	-	6	1	-	2	-
2004	309	-	27	3	-	3	-	83	-	9	3	-	2	-
2005	338	-	60	3	-	-	-	87	-	23	1	-	-	-
2006	169	-	155	1	7	-	-	43	-	66	1	7	-	-
2007	27	-	60	1	10	2	-	11	-	24	1	10	1	-
2008	-	-	118	9	6	-	-	-	-	37	6	4	-	-
2009	271	169	1,220	8	11	18	5	51	26	249	7	8	7	1
2010	-	-	2	-	-	-	-	-	-	1	-	-	-	-
2012	679	36	576	24	4	965	-	113	7	48	5	1	300	-
2013	425	18	210	31	1	1,049	-	82	3	32	6	1	355	-
2014	830	93	282	63	19	2,416	-	150	22	42	10	4	810	-

Table 4.10.29. South Atlantic (NC-FLE) estimated number of angler trips for charter boat mode, mode (MRFSS, NMFS, 1981-2003; MRIP, NMFS, 2004+). CH mode adjusted for FHS conversion prior to 2004. MRFSS headboat effort from the South Atlantic has been separated from the combined Cbt/Hbt mode and removed. *CVs for CH mode 1981-1985 are unavailable.

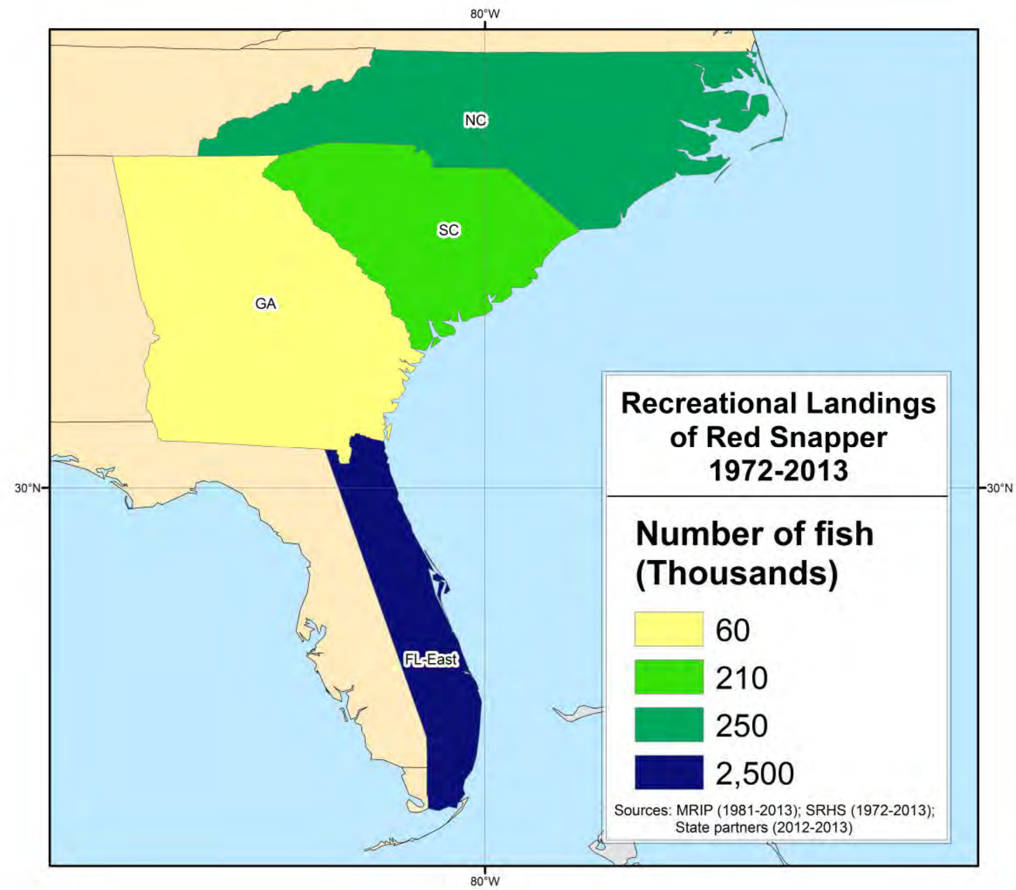
	Estimated CH Angler Trips		Estimated PR Angler Trips		ALL MODES Angler Trips	
YEAR	Trips	CV*	Trips	CV	Trips	CV
1981	686,826		3,042,475	0.06	3,729,301	0.05
1982	692,725		4,940,950	0.06	5,633,675	0.05
1983	1,269,339		5,723,506	0.06	6,992,845	0.05
1984	793,750		6,406,104	0.05	7,199,854	0.05
1985	964,607		6,287,166	0.06	7,251,772	0.05
1986	1,046,581	0.17	6,484,617	0.05	7,531,198	0.05
1987	744,484	0.15	7,753,996	0.04	8,498,480	0.03
1988	1,019,369	0.12	7,973,600	0.03	8,992,969	0.03
1989	795,017	0.13	7,072,914	0.04	7,867,931	0.04
1990	505,373	0.12	6,381,615	0.03	6,886,988	0.03
1991	528,549	0.10	7,222,081	0.03	7,750,630	0.03
1992	600,009	0.10	7,168,313	0.02	7,768,322	0.02
1993	784,034	0.08	6,846,164	0.02	7,630,198	0.02
1994	1,028,348	0.07	8,266,083	0.02	9,294,431	0.02
1995	1,178,551	0.07	7,666,576	0.02	8,845,128	0.02
1996	1,306,227	0.07	7,392,545	0.02	8,698,771	0.02
1997	1,279,959	0.08	8,276,257	0.02	9,556,217	0.02
1998	1,073,517	0.07	7,534,670	0.02	8,608,188	0.02
1999	874,133	0.08	6,935,225	0.02	7,809,358	0.02
2000	680,796	0.09	9,119,183	0.02	9,799,979	0.02
2001	685,504	0.09	9,565,115	0.02	10,250,619	0.02
2002	635,191	0.09	8,265,877	0.02	8,901,068	0.02
2003	619,013	0.10	9,962,637	0.02	10,581,649	0.02
2004	491,941	0.05	9,900,722	0.03	10,392,663	0.03
2005	502,579	0.06	9,896,001	0.03	10,398,580	0.03
2006	455,949	0.04	9,822,545	0.03	10,278,495	0.03
2007	503,429	0.04	11,536,245	0.03	12,039,673	0.03
2008	414,845	0.04	10,909,888	0.03	11,324,733	0.03
2009	390,551	0.04	8,922,867	0.03	9,313,417	0.03
2010	367,854	0.04	9,513,792	0.03	9,881,646	0.03
2011	372,379	0.05	8,663,086	0.03	9,035,465	0.03
2012	348,342	0.06	8,774,870	0.03	9,123,212	0.03
2013	336,441	0.04	7,877,791	0.03	8,214,232	0.03
2014	414,272	0.05	7,836,314	0.03	8,250,585	0.03

Table 4.10.30. South Atlantic headboat estimated angler days by year and state, 1981-2014.

Year	NC	SC	GA/FLE	South Atlantic
1981	19,374	59,030	298,883	377,287
1982	26,939	67,539	293,133	387,611
1983	23,830	65,733	277,863	367,426
1984	28,865	67,314	288,994	385,173
1985	31,384	66,001	280,845	378,230
1986	31,187	67,227	317,058	415,472
1987	35,261	78,806	333,041	447,108
1988	42,421	76,468	301,775	420,664
1989	38,678	62,708	316,864	418,250
1990	43,240	57,151	322,895	423,286
1991	40,936	67,982	280,022	388,940
1992	41,176	61,790	264,523	367,489
1993	42,786	64,457	236,973	344,216
1994	36,691	63,231	242,781	342,703
1995	40,295	61,739	210,714	312,748
1996	35,142	54,929	199,857	289,928
1997	37,189	60,150	173,273	270,612
1998	37,399	61,342	155,341	254,082
1999	31,596	55,499	164,052	251,147
2000	31,351	40,291	182,249	253,891
2001	31,779	49,265	163,389	244,433
2002	27,601	42,467	151,546	221,614
2003	22,998	36,556	145,011	204,565
2004	27,255	48,763	175,400	251,418
2005	31,573	34,036	172,839	238,448
2006	25,736	56,074	175,522	257,332
2007	29,002	60,729	157,150	246,881
2008	17,158	47,287	123,943	188,388
2009	19,468	40,919	136,420	196,807
2010	21,071	44,951	123,662	189,684
2011	18,457	44,645	132,492	195,594
2012	20,766	41,003	147,699	209,468
2013	20,547	40,963	165,679	227,189
2014	22,691	42,025	195,890	260,606

4.11 Figures

a) Red Snapper Landings by State 1972-2013



b) Red Snapper Landings by State and Year 1972-2014

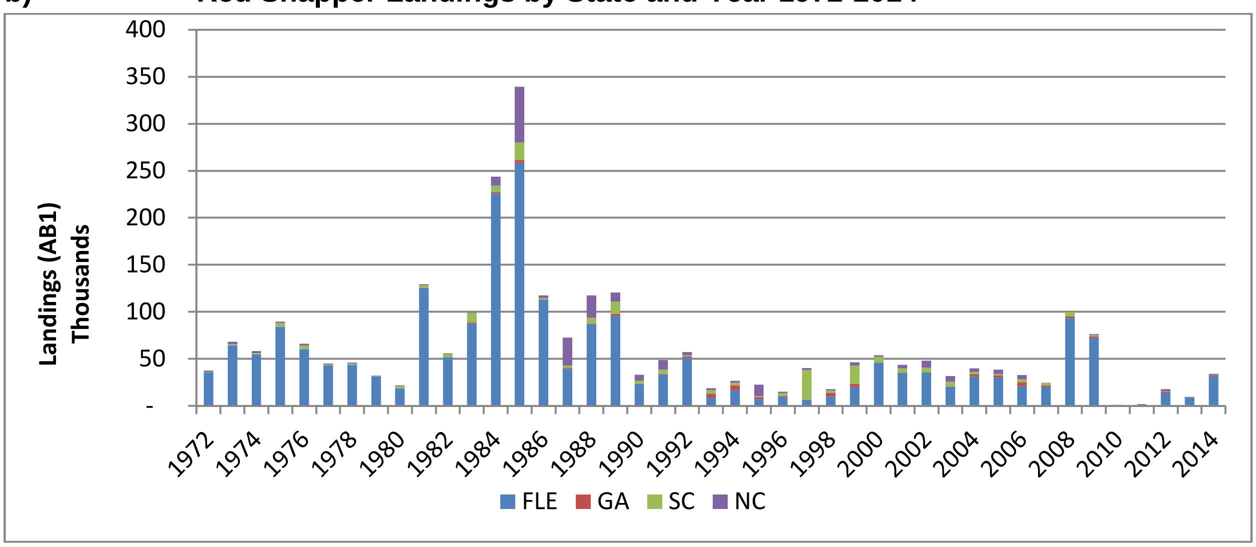
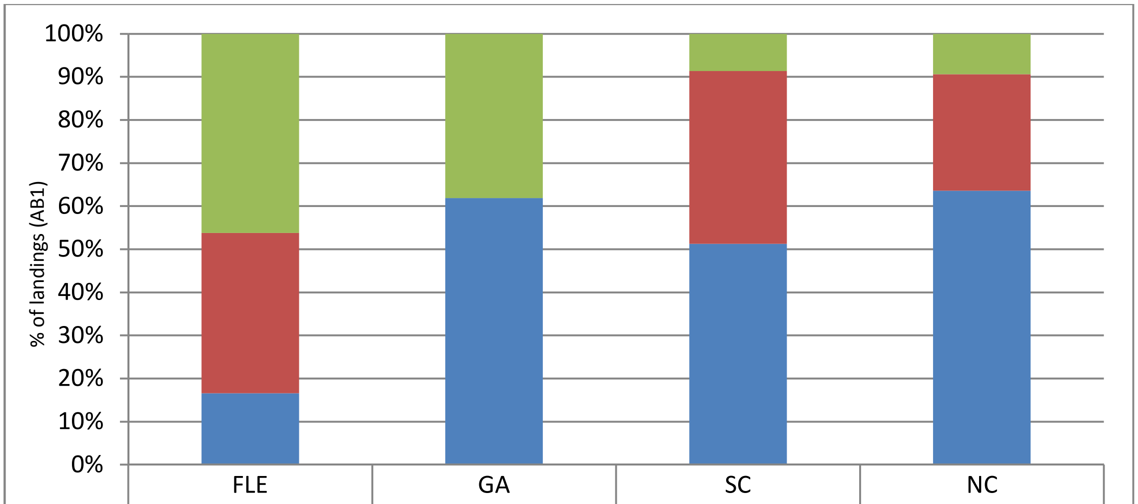


Figure 4.11.1. Estimated number of South Atlantic red snapper landings from MRIP (1981-2014), SRHS (1972-2014), and state partners (2012-2014) by state (a), by state and year (b), and by state and mode (c). SRHS landings for GA and FLE are grouped and shown in FLE due to vessel confidentiality issues.

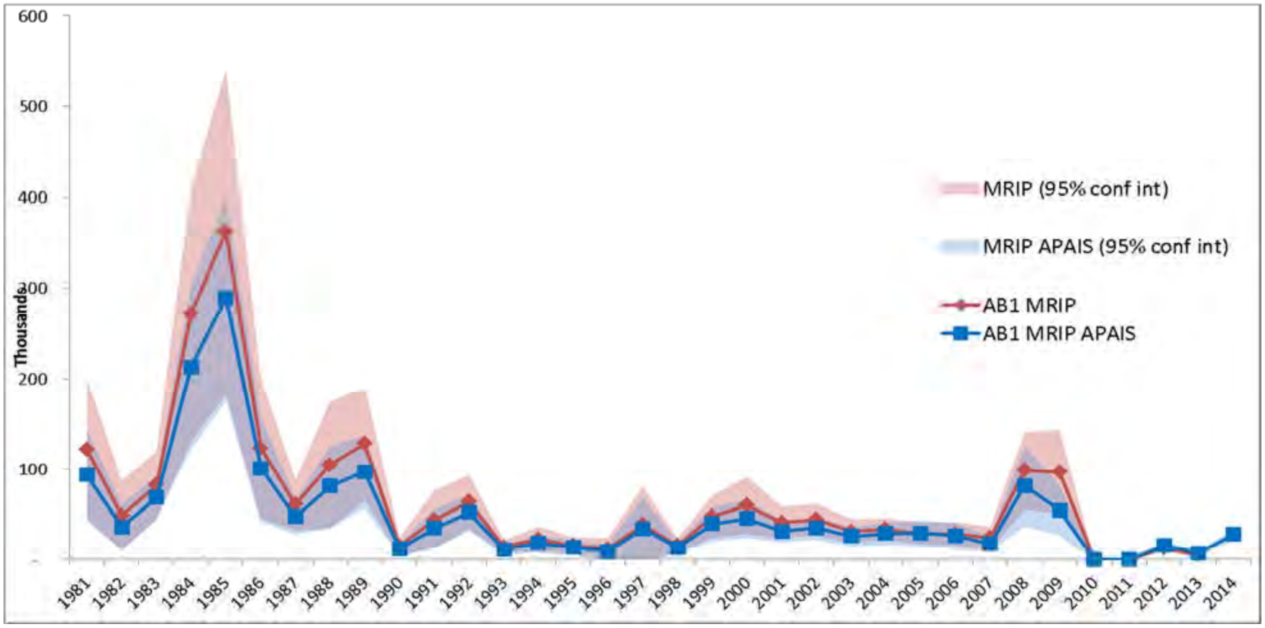
c) **Red Snapper Landings by State and Mode 1972-2014**



Landings	FLE	GA	SC	NC
Priv	998,996	18,854	16,883	21,672
Hbt	804,349		77,843	62,107
Cbt	359,483	30,640	99,695	146,116

Figure 4.11.1 (continued). Estimated number of South Atlantic red snapper landings from MRIP (1981-2014), SRHS (1972-2014), and state partners (2012-2014) by state (a), by state and year (b), and by state and mode (c). SRHS landings for GA and FLE are grouped and shown in FLE due to vessel confidentiality issues.

a) AB1 (number of fish) landed



b) B2 (number of fish) discarded alive

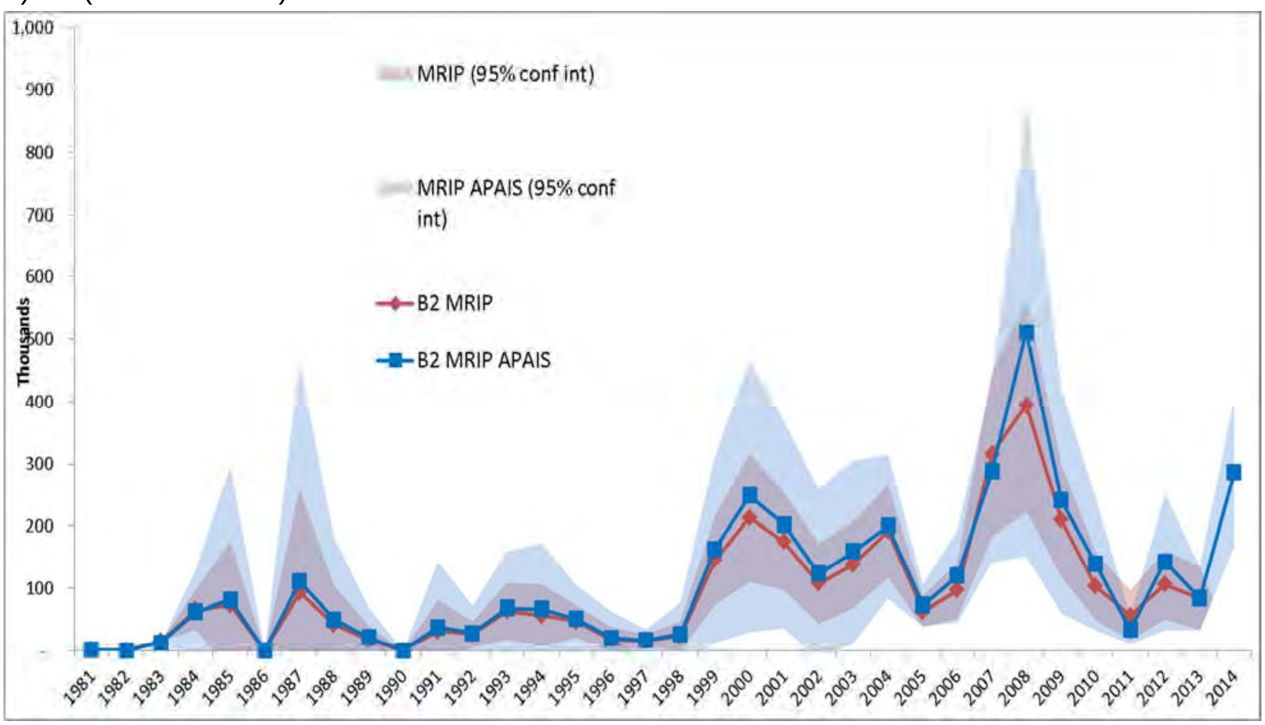


Figure 4.11.2. MRIP estimates versus MRIP adjusted estimates for South Atlantic red snapper 1981-2014. 95% confidence intervals are included.

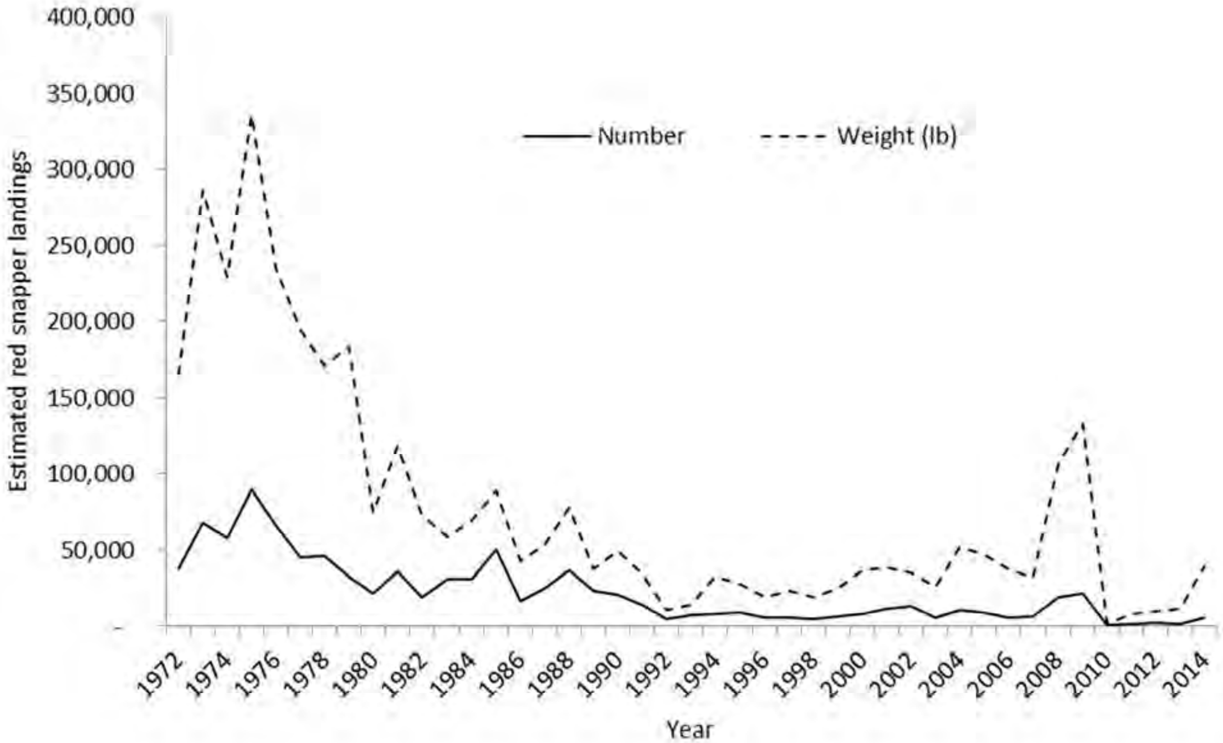


Figure 4.11.3. South Atlantic estimated red snapper landings (number and pounds) for the headboat fishery, 1972-2014.

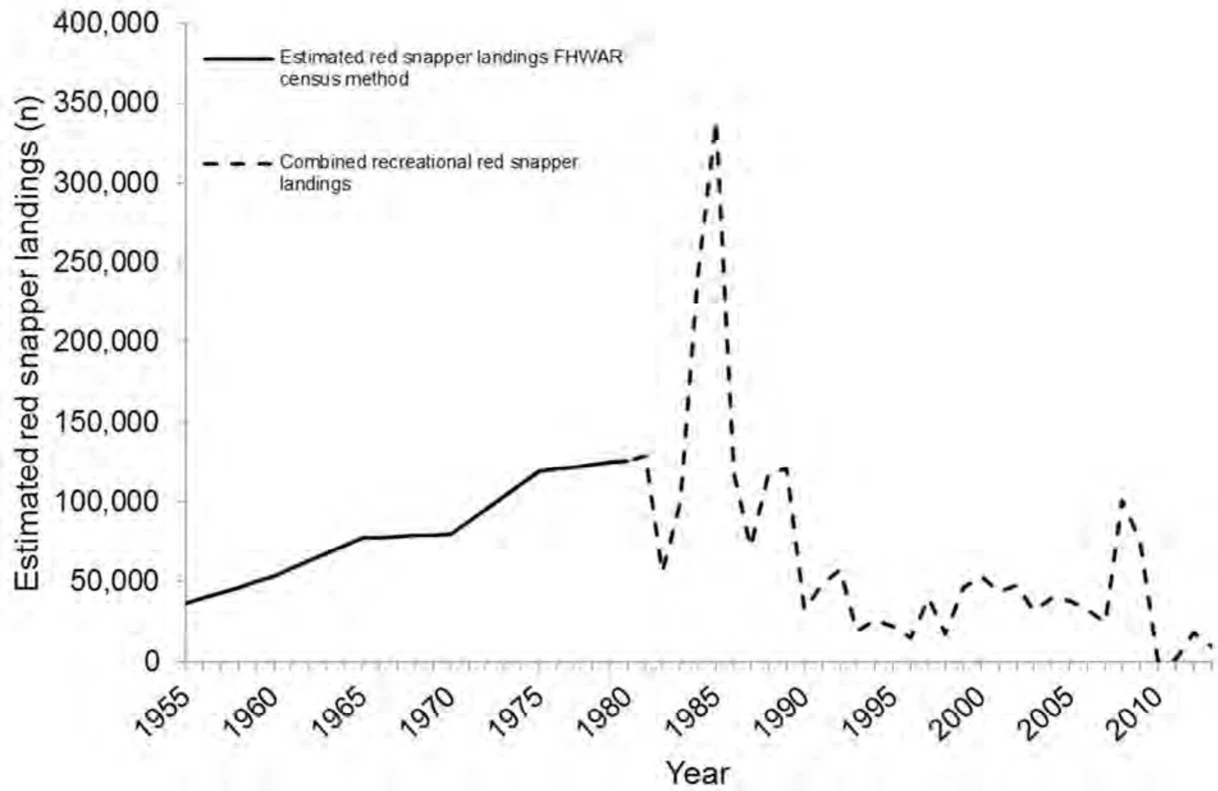


Figure 4.11.4. Estimated red snapper landings using the FHWAR census method, 1955 – 1980.

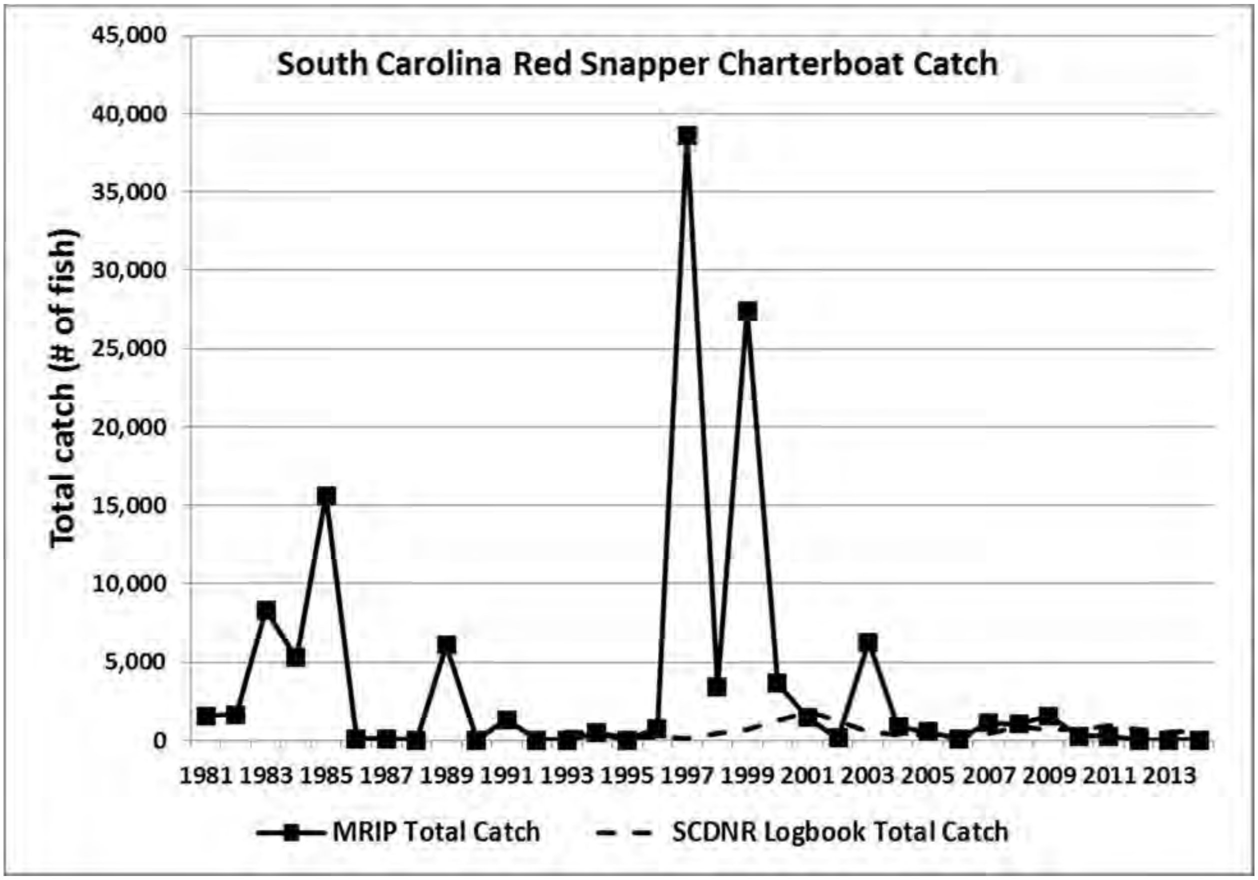
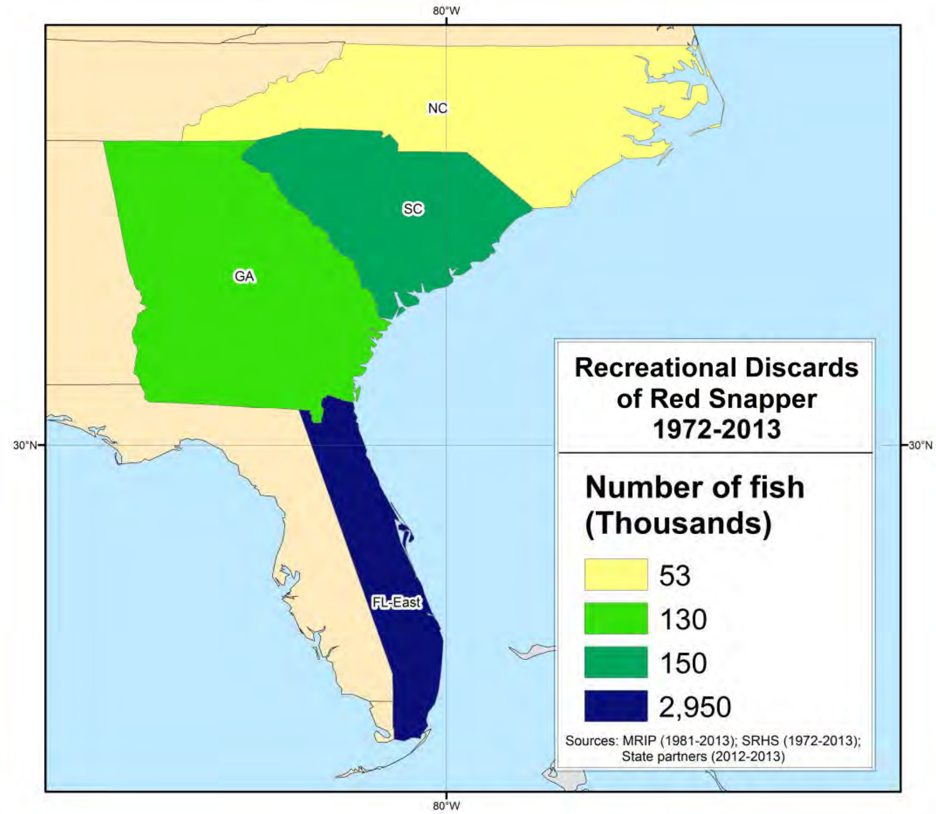


Figure 4.11.5. Comparison of SC total red snapper catch (a+b1+b2) from MRIP charter mode and SCDNR charter boat logbook program, 1993-2014.

a) Red Snapper Discards by State 1972-2013



b) Red Snapper Discards by State and Year 1972-2014

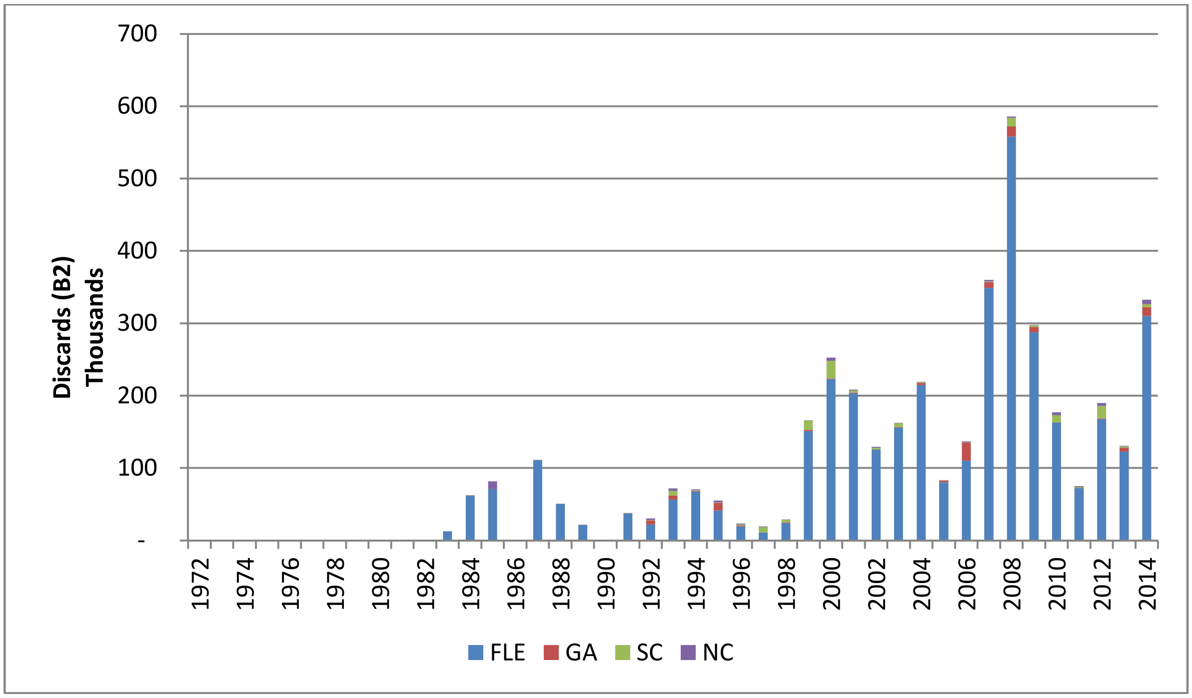


Figure 4.11.6. Estimated number of South Atlantic red snapper discards from MRIP (1981-2014), SRHS (1972-2014), and state partners (2012-2014) by state (a), by state and year (b), and by state and mode (c). SRHS discards for GA and FLE are grouped and shown in FLE due to vessel confidentiality issues.

c) **Red Snapper Discards by State and Mode 1972-2014**

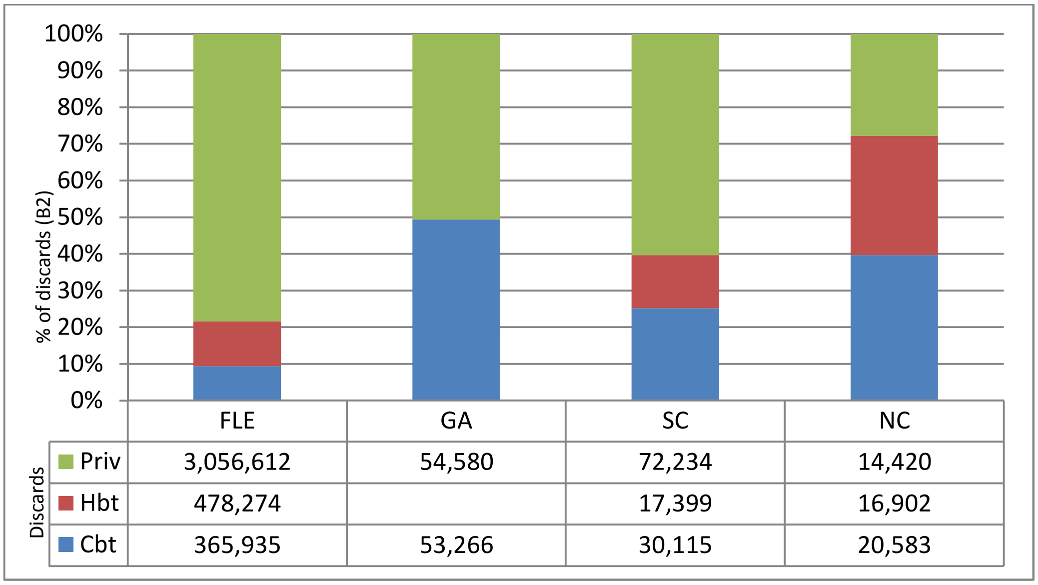


Figure 4.11.6 (continued). Estimated number of South Atlantic red snapper discards from MRIP (1981-2014), SRHS (1972-2014), and state partners (2012-2014) by state (a), by state and year (b), and by state and mode (c). SRHS discards for GA and FLE are grouped and shown in FLE due to vessel confidentiality issues.

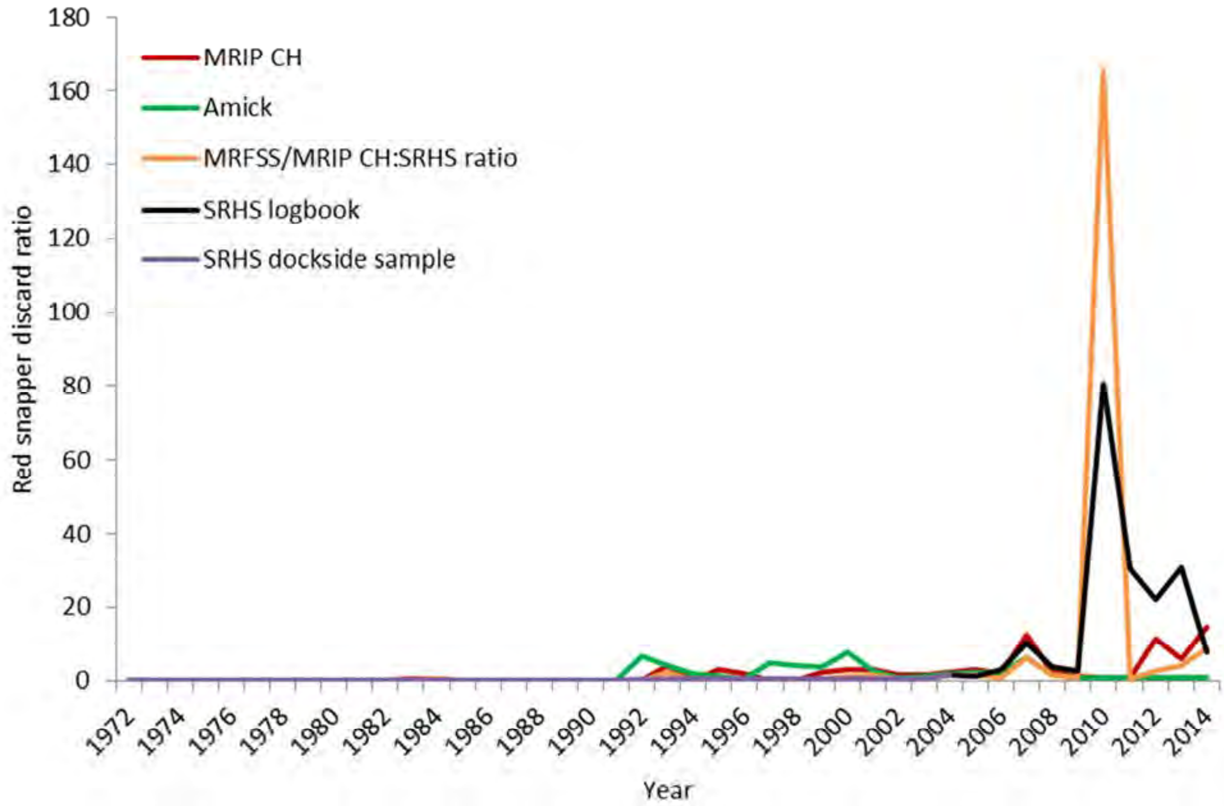


Figure 4.11.7a. MRIP CH (1981-2014), Amick (1983-2014), MRIP CH:SRHS discard ratio methods (1981-2014), SRHS dockside sample (1984-2003),and SRHS discard ratios (2004-2014).

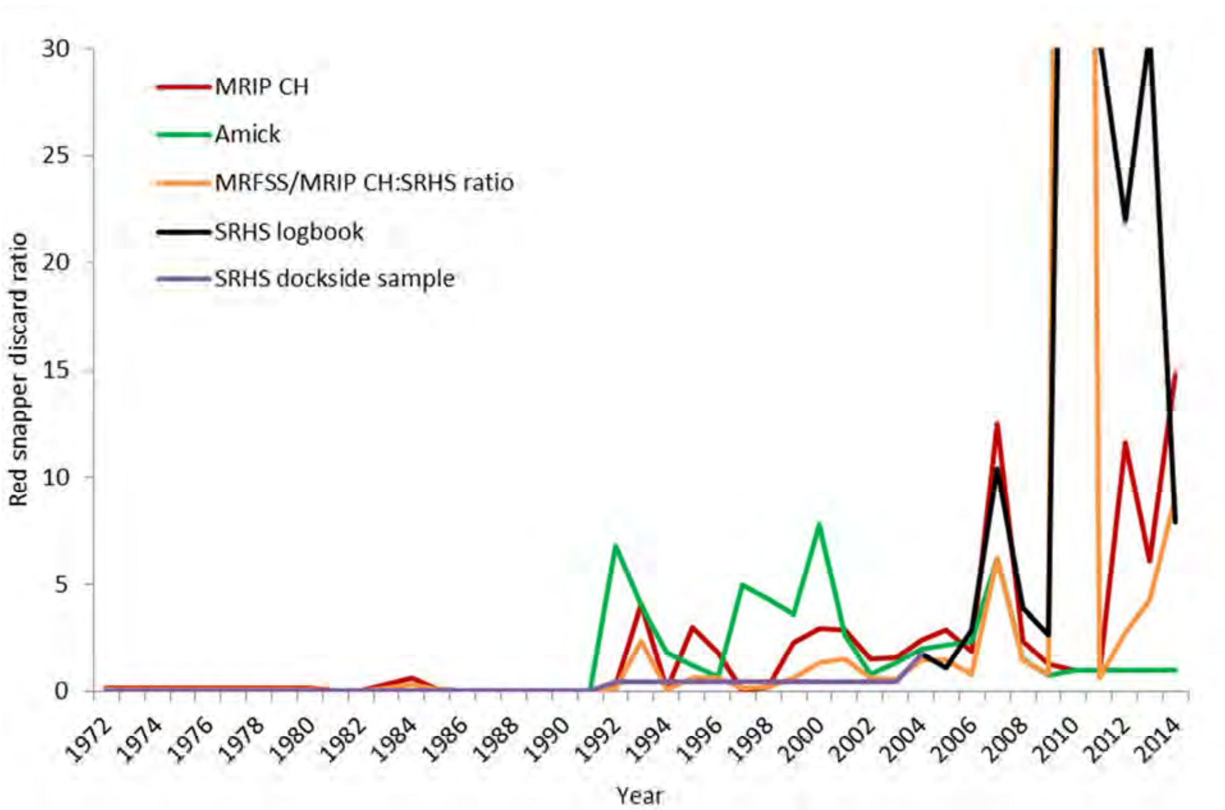


Figure 4.11.7b. MRIP CH (1981-2014), Amick (1983-2014), MRIP CH:SRHS discard ratio methods (1981-2014), SRHS dockside sample (1984-2003),and SRHS discard ratios (2004-2014) at reduced scale.

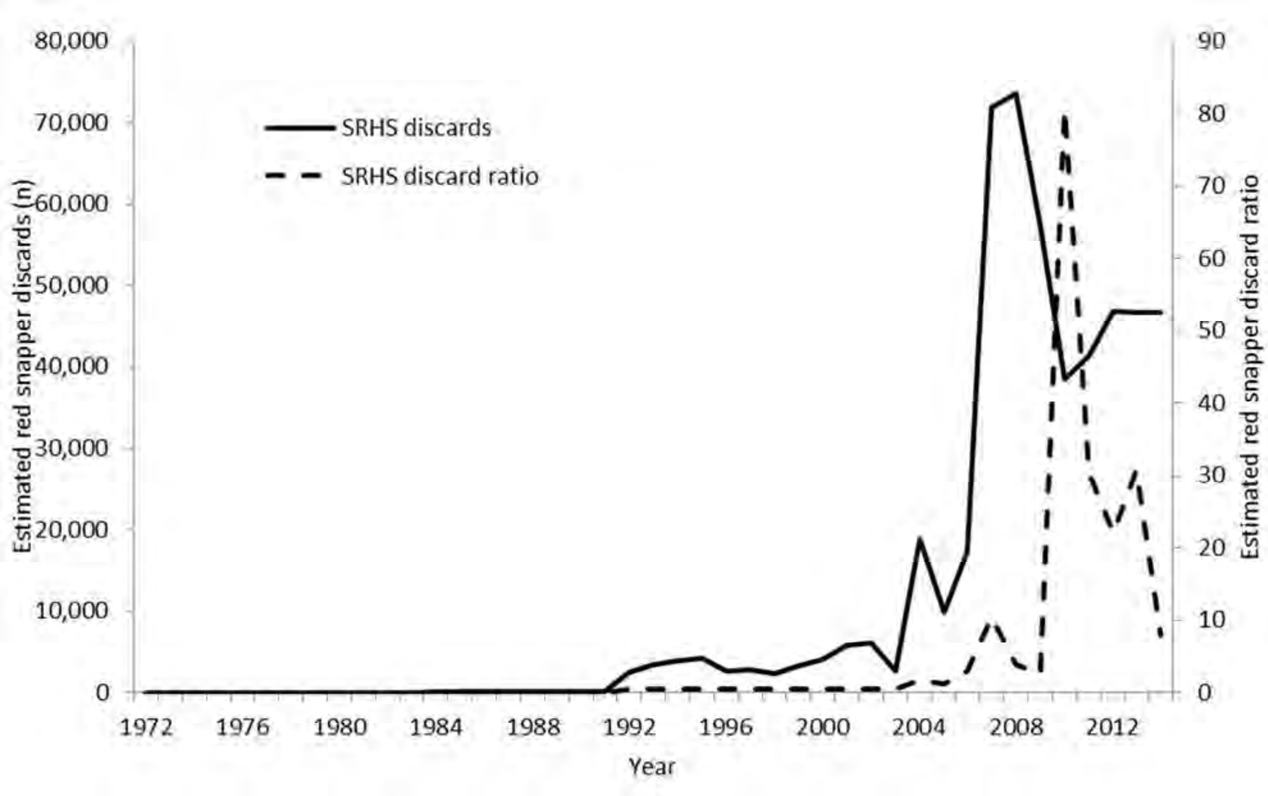
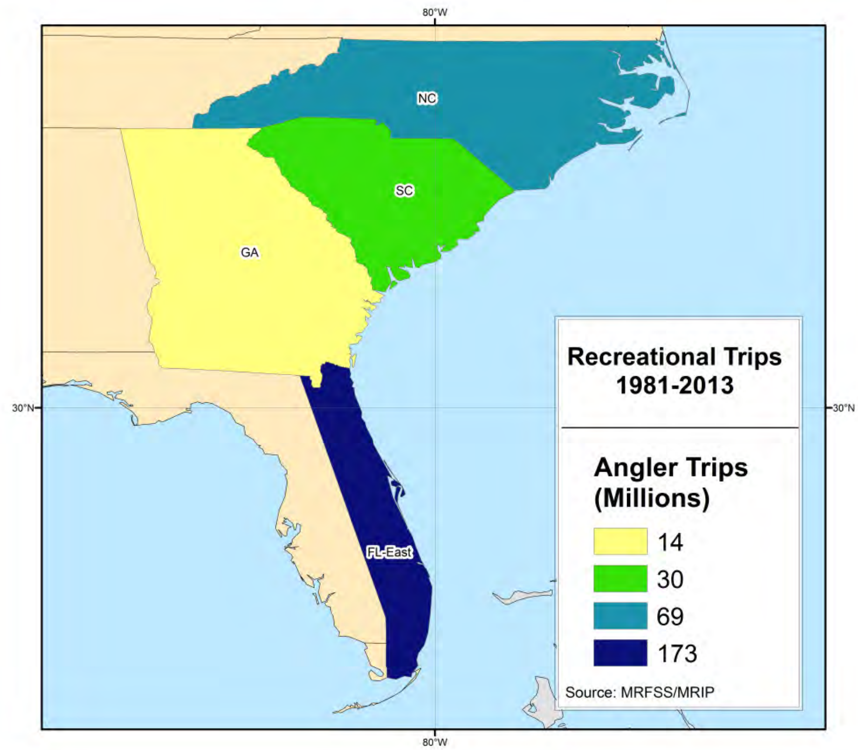


Figure 4.11.8. South Atlantic estimated red snapper discards and discard ratio for headboats assume zero discards 1972-1983; SRHS dockside sample proxy method 1984-2003; SRHS 2004-2014).

a) Angler Trips by State 1981-2013



b) Angler Trips by State and Year 1981-2014

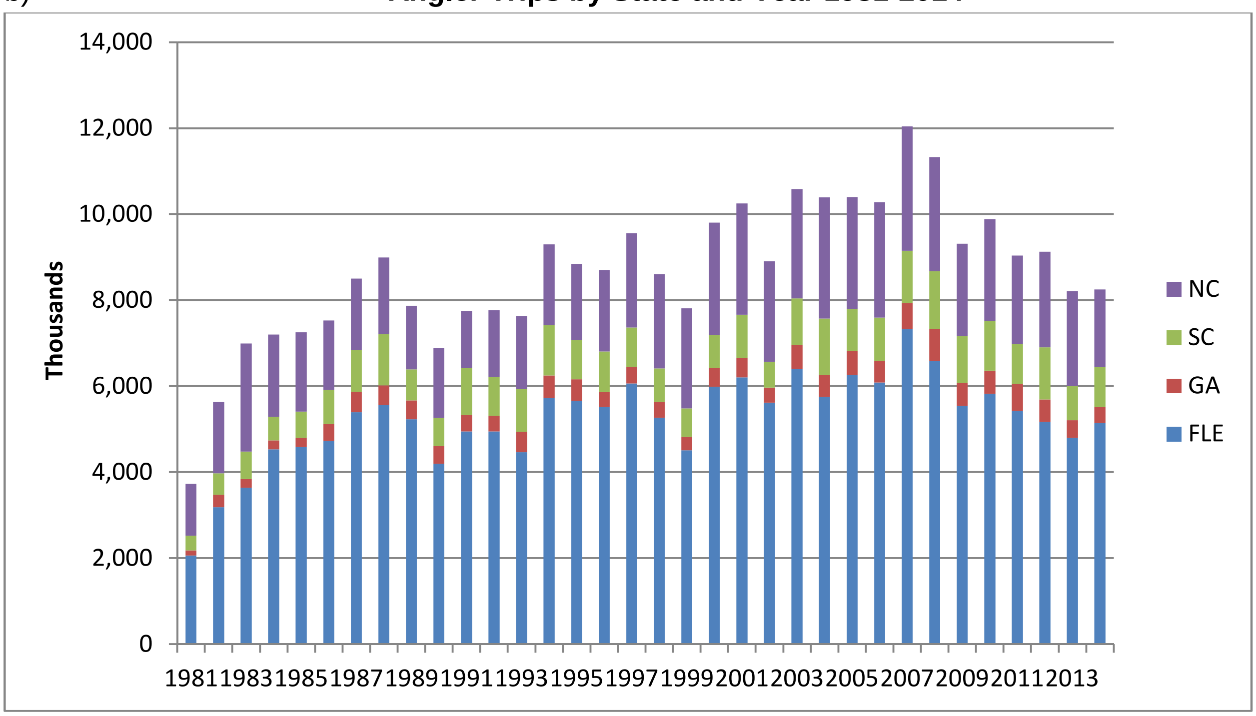
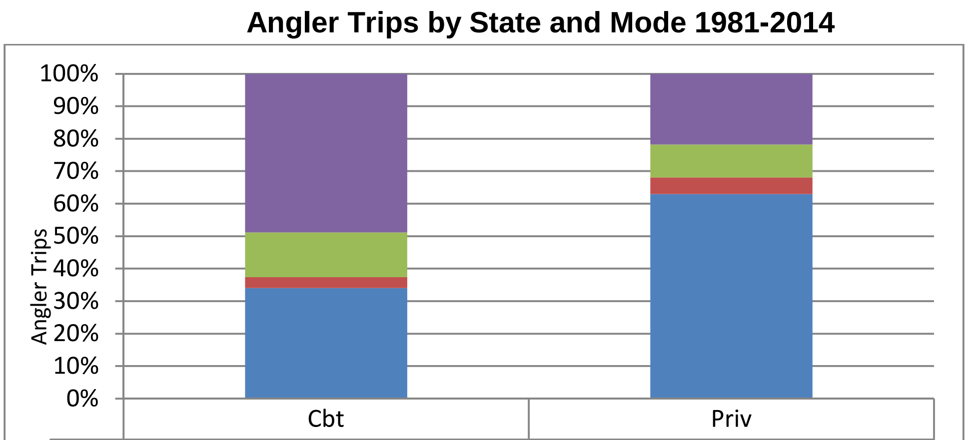


Figure 4.11.9. South Atlantic estimated number of angler trips from MRFSS/MRIP (1981-2014) by state (a), by state and year (b), and by state and mode (c). MRFSS/MRIP data from NC to FLE. MRFSS headboat effort has been removed from the South Atlantic.

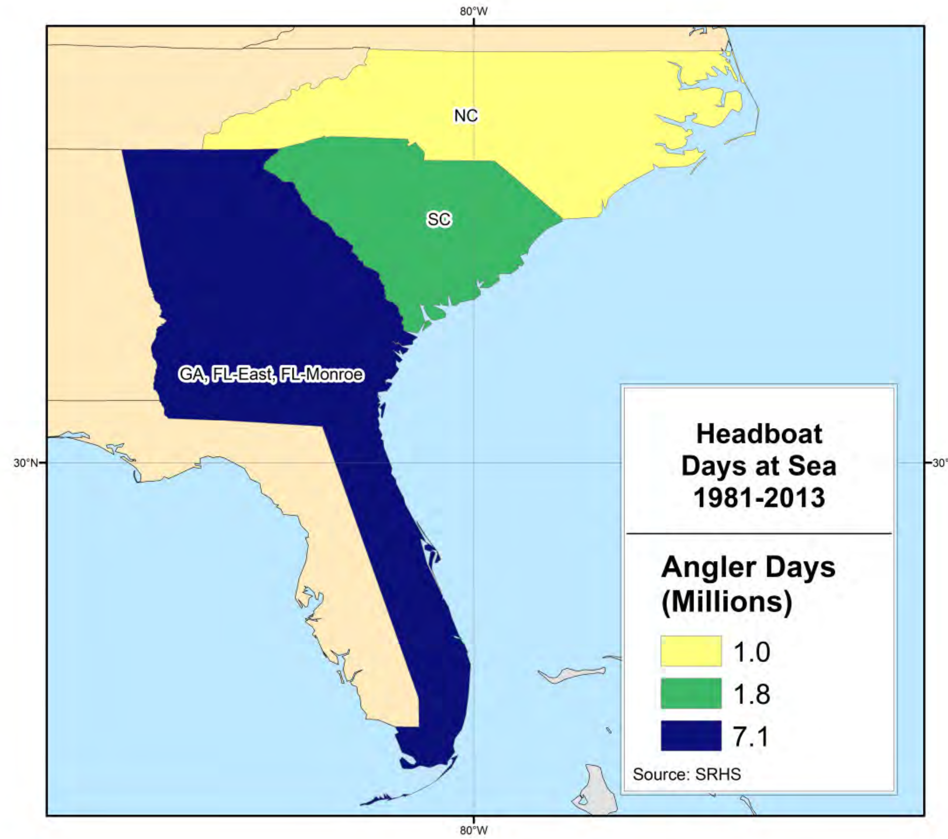
c)



	Cbt	Priv
NC	11,927,165	58,748,896
SC	3,342,427	27,366,768
GA	817,688	13,829,525
FLE	8,303,204	169,996,598

Figure 4.11.9. (continued). South Atlantic estimated number of angler trips from MRFSS/MRIP (1981-2014) by state (a), by state and year (b), and by state and mode (c). MRFSS/MRIP data from NC to FLE. MRFSS headboat effort has been removed from the South Atlantic.

a) **Angler Days by State 1981-2013**



b) **Angler Days by State and Year 1981-2014**

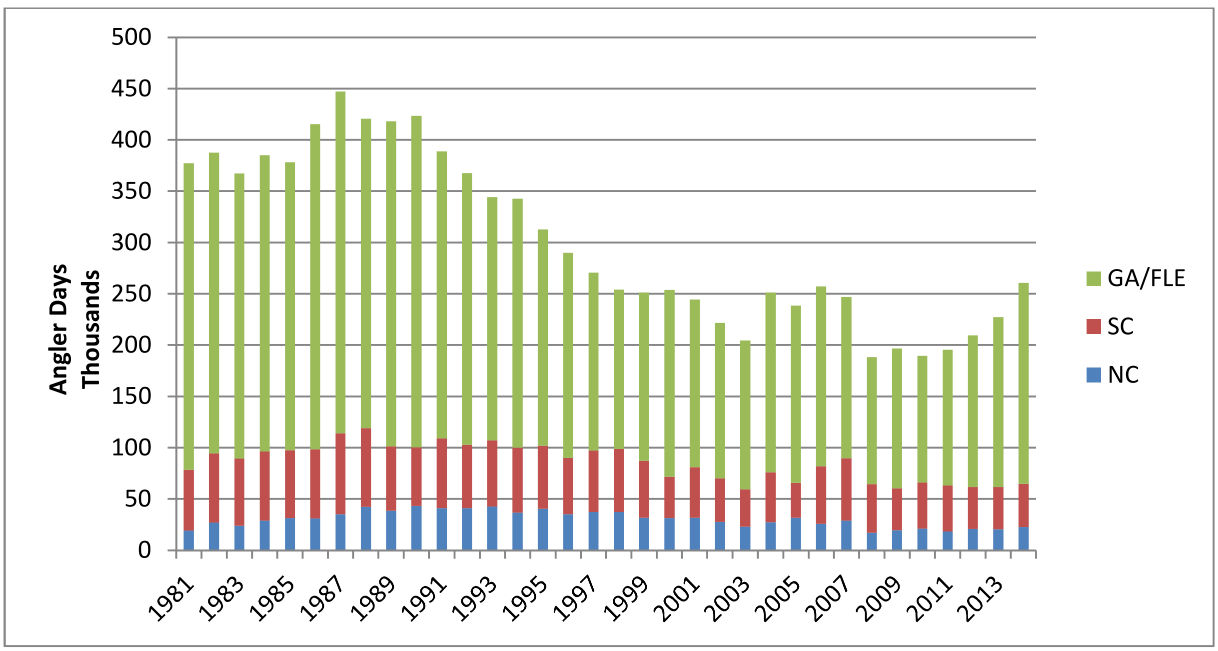


Figure 4.11.10. South Atlantic estimated number of headboat angler days from SRHS (1981-2014) by state (a) and by state and year (b). Due to confidentiality concerns, effort from Georgia has been grouped together with East Florida. SRHS data from NC to FLE, including Atlantic side of the Florida Keys.

5. Measures of Population Abundance

5.1 Overview

Seven fishery independent data sets were considered for use as an index of abundance (Table 5.1). During the data webinar prior to the DW, five of these datasets were discarded because of small sample sizes or limited geographic extent. Two fishery independent data sets were retained for further consideration at the DW: SERFS chevron traps and SERFS video survey.

Six fishery dependent data sets were considered for use as an index of abundance (Table 5.1). During the data webinars, five were recommended for further consideration at the DW. Ultimately, the DW recommended indices from three of these fishery dependent data sets for potential use in the assessment model: recreational headboat, headboat at-sea-observer data, and commercial handline.

In total, the DW recommended two fishery independent indices (SERFS chevron traps and video survey) and three fishery dependent indices (recreational headboat index, headboat at-sea observer index, and a commercial handline index) for potential use in the red snapper stock assessment. These indices are listed in Table 5.1, with pros and cons of each in Table 5.2.

Group Membership

Membership of this DW Index Working Group (IWG) included Nate Bacheler, Joey Ballenger, Nicholas Ballew, Peter Barile, Russ Brodie, Rob Cheshire, Kevin Craig, Eric Fitzpatrick, Kevin Purcell, Christina Schobernd, Kyle Shertzer (chair), Katie Siegfried, Tracy Smart, Ted Switzer, and Erik Williams. Several other DW panelists and observers contributed to the IWG discussions throughout the DW1 and DW2 workshops.

5.2 Review of Working Papers

The relevant working papers describing index construction were presented to the IWG. In most cases, the IWG recommended modifications to the initial modeling attempts, such that data treatments and/or model specifications were updated during the DW. Final working papers reflect decisions made during the DW, using addenda if necessary. In addition to working papers on index construction, the IWG also discussed any working papers available at the DW that were relevant to indices of abundance, namely SEDAR41-DW08, SEDAR41-DW11, and SEDAR41-DW46. SEDAR41-DW08 describes a pilot program for data collection using hook gear, SEDAR41-DW11 describes habitat models for gray triggerfish, and SEDAR41-DW46 describes evaluation of the headboat data set.

The index working papers provide information on sample sizes, diagnostics of model fits, and in some cases, maps of catch and effort. A summary of each index is provided below.

5.3 Fishery Independent Indices

Until 2009, virtually all fishery independent sampling of reef fishes in southeast U.S. Atlantic waters was conducted by the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program. In 2009, the Southeast Area Monitoring and Assessment Program – South Atlantic (SEAMAP-SA) program joined the chevron trap survey through their Reef Fish Complement. In 2010, the Southeast Fisheries Independent Survey (SEFIS) was created and joined the chevron trap survey. The partner-led survey is now referred to as the Southeast Reef Fish Survey (SERFS). With the advent of the partner programs, sampling coverage in the region has expanded, primarily in Florida. SERFS now samples between Cape Hatteras, North Carolina and St. Lucie Inlet, Florida, and it targets a sampling universe of approximately 3,000 sites of hard-bottom habitats between approximately 15 and 100 meters deep.

5.3.1 Chevron Trap

5.3.1.1 Methods, Gears, and Coverage

Chevron traps were baited with whole and cut Clupeids and deployed at stations randomly selected by computer from a database of live bottom stations on the continental shelf and shelf edge and soaked for approximately 90 minutes.

An index of abundance was developed by standardizing catch (number of Red Snapper caught) using a zero-inflated negative binomial model (SEDAR41-DW54; Zuur et al. 2009). Effort (trap soak minutes) was included as an offset in the regression. Analyses were computed using the *pscl* library in R (Jackman 2008; Zeileis et al 2008; R Development Core Team 2014). Model covariates included sampling characteristics and environmental data.

5.3.1.2 Sampling Intensity and Time Series

Chevron traps were deployed from 1990 through 2014, ranging from 219 to 1465 traps per year meeting the depth criteria for this analysis. Prior to 2010, red snapper were caught in chevron traps infrequently (SEDAR41-DW51). In 2010 with the advent of SERFS, sampling coverage in the region has expanded, primarily in Florida. Consequently, the spatial coverage of the survey after 2010 adequately covered the center of the distribution of red snapper and percent positives increased to levels high enough to develop an index. The time series was truncated for index development to 2010-2014 based on recommendations of the IWG. The annual number of traps (collections) used to compute the index is shown in Table 5.3.

5.3.1.3 Size/Age Data

The ages of red snapper collected by chevron traps (1990-2014) ranged from 0 to 26 (median = 2, mean = 3.3, n= 2085), and sizes ranged from 19 to 99 cm maximum (pinched tail) total length.

For the truncated time series (2010-2014), ages ranged from 0 to 26 (median = 2, mean = 3.4, n= 1686). Age composition data are available for estimating the selectivity of this gear.

5.3.1.4 Catch Rates

Standardized catch rates are shown in Table 5.3 and in Figure 5.1 (top panel). The units on catch rates are in numbers of fish. Effort was modeled as an offset, rather than as the denominator in the response variable.

5.3.1.5 Uncertainty and Measures of Precision

Measures of precision were computed using a bootstrap procedure (Efron and Tibshirani 1994), in which sampling events were drawn at random (by year) with replacement. The CVs are shown in Table 5.3.

5.3.1.6 Comments on Adequacy for Assessment

This index was considered to be adequate for the assessment. Recent years of the survey show that traps can and do catch red snapper, and sample sizes in the truncated time series were sufficiently large to create a meaningful index. Because the chevron trap index is fishery independent and has accompanying selectivity information (lengths and ages), it was considered by the IWG to be the highest ranking source of information on trends in population abundance.

Several issues were addressed or discussed. During DW1, models included covariates as categorical variables. For DW2, models applied the zero-inflated negative binomial but included covariates as continuous variables using polynomials and backward selection by Bayesian Information Criterion. The polynomial approach was ultimately adopted. In addition, the group discussed a modeling approach to project the index back in time when data were sparse (SEDAR41-DW51; SEDAR41-DW53). That longer time series (Figure 5.1, bottom panel) was not recommended as a primary index, but might reasonably be considered for a sensitivity analysis of the assessment model. One topic discussed by the group, but not explicitly addressed, was the non-independence between chevron traps and the video survey; this topic was identified for future research.

5.3.2 Video Survey

5.3.2.1 Methods, Gears, and Coverage

In 2010 the SERFS program began attaching video cameras to a limited number of chevron traps (Georgia and Florida only), with cameras being attached to all traps beginning in 2011 as a standard component of the sampling program. An index of abundance for red snapper was developed based on these videos using a zero-inflated negative binomial modeling approach

(SEDAR41-DW45, Zuur *et al*. 2009). All data manipulation and analyses were conducted using R (R Development Core Team 2014). Modeling was executed using the ***zeroinfl*** function in the ***pscl*** package (Jackman 2008; Zeileis et al. 2008).

5.3.2.2 Sampling Intensity and Time Series

The video index time series consists of only 5 years (2010-2014). Additionally, the first year of sampling was regionally limited to the coastal shelf of Georgia and Florida, representing approximately 20-33% of the sampling intensity in later years (SEDAR41-DW45). The IWG recognized differences in sampling in 2010 (more limited spatial coverage, different camera), but ultimately thought that 2010 should be included in the red snapper index for two reasons. First, the initial year of sampling was located in the core of red snapper's spatial distribution, and second, SERFS data provide the only information on relative abundance with fishery closures starting in 2010. Furthermore, a camera calibration study made it possible to adjust 2010 values for consistency with those from subsequent years. This decision was supported by the recommendations of the Video Index Development Panel, a special working group convened in the spring of 2014 to guide and recommend a set of best practices for the development of a video indices based on SERFS data in the south Atlantic (SEDAR41-RD23).

A total of 4923 videos were considered for development of the red snapper index. Of those, 514 were removed based on modeling considerations (SEDAR41-DW45), leaving a total of 4409 videos for index construction. These data span a wide latitudinal and depth range, covering a substantial region of the south Atlantic coastal shelf (SEDAR41-DW45, Figure 2). Detailed information on the depth, latitudinal, and seasonal distribution of sampling can be found in the index working paper (SEDAR41-DW45, Table 2).

5.3.2.3 Size/Age Data

As currently implemented, the size and age composition of populations sampled with the SERFS video survey gear are unknown, and therefore selectivity of the gear cannot be estimated from data. However, in a different system, Langlois et al. (2015) compared length compositions of snappers and groupers caught in traps to those observed on video cameras, and found those length compositions to be quite similar. Based on that, the IWG recommended applying selectivity of chevron traps to the video gear, in one of two ways: 1) if chevron trap selectivity is flat-topped, the video gear selectivity should mirror that of the chevron traps, or 2) if chevron trap selectivity is dome-shaped, the video gear selectivity should mirror only the ascending portion and then assume flat-topped selectivity. This recommendation was based on the expectation that the video gear should be flat-topped, because older, larger fish are present throughout the depths sampled and because there is no known reason why larger (older) individuals would be less observable on video than smaller (younger) individuals. The IWG recognized the need for age/size compositions of the video survey, and recommended future research to remedy this limitation.

5.3.2.4 Catch Rates

Annual standardized index values for red snapper, including CVs, are presented in Table 5.4 and in Figure 5.2.

5.3.2.5 Uncertainty and Measures of Precision

Using a bootstrap procedure with 1000 replicates, confidence intervals of 2.5% and 97.5% were calculated for each year of the survey (Figure 5.2), as were CVs (Table 5.4). Due to the changes in sampling distribution and equipment (SEDAR41-RD23), the nominal value for 2010 (2.61) was considerably higher than the standardized index value for 2010 (1.21), which was expected because of a camera calibration to the standardized index (SEDAR41-RD23, SEDAR41-DW45).

5.3.2.6 Comments on Adequacy for Assessment

The red snapper video index (2010-2014) was recommended for use in the assessment. The resulting index was ranked second of the two fishery independent sources based on the absence of information concerning the age composition of the video sampling gear. Non-independence between the video survey and chevron traps was discussed and identified as a topic for future research.

5.4 Fishery Dependent Indices

In general, indices from fishery independent data are believed to represent abundance more accurately than those from fishery dependent data. This is because fishery dependent indices can be strongly affected by factors other than abundance, such as management regulations on the focal or other species, shifts in targeting, changes in fishing efficiency (technology creep), and density dependent catchabililty (hyperdepletion or hyperstability). The standardization procedures attempt to account for some of these issues to the extent possible.

5.4.1 Recreational Headboat Index

The headboat fishery in the south Atlantic includes for-hire vessels that typically accommodate 11-70 passengers and charge a fee per angler. The fishery uses hook and line gear, generally targets hard bottom reefs as the fishing grounds, and generally targets species in the snapper-grouper complex. This fishery is sampled separately from other fisheries, and the available data were used to generate a fishery dependent index.

Headboats in the south Atlantic are sampled from North Carolina to the Florida Keys (Figure 5.3). Data have been collected since 1972, but logbook reporting did not start until 1973. In addition, only North Carolina and South Carolina were included in the earlier years of the data set. In 1976, data were collected from North Carolina, South Carolina, Georgia, and northern Florida, and starting in 1978, data were collected from southern Florida.

Variables reported in the data set include year, month, day, area, location, trip type, number of anglers, species, catch, and vessel identification. Biological data and discard data were recorded for some trips in some years.
The IWG, along with headboat captains, discussed several key issues related to this index:

- Beginning in 1992, a 20" TL minimum size regulation was implemented. In some cases, the size limit may have influenced the fishing behavior of headboats that relied heavily on red snapper catch. Thus, the IWG recommended modeling the change in selectivity that likely resulted from the size limit, and further acknowledged that the assessment model could be configured to allow for time-varying catchability.
- The red snapper closure starting in 2010 led to a shift in fishing behavior (avoidance). Because of that, and because this index is based on landings only (i.e., no discards included), the IWG decided to end the index in 2009.

5.4.1.1 Methods of Estimation

Data Filtering

The headboat data and programmatic evaluation (SEDAR41-46) found a small percentage of logbook reports to be extreme outliers. Those values were likely erroneous and were removed from the data set prior to deriving the index.

Trips to be included in the computation of the index need to be determined based on effective effort for red snapper. This may not be straightforward, because some trips caught red snapper only incidentally, and some trips likely directed effort at red snapper unsuccessfully. Given that direct information on species targeted is not available, effective effort must be inferred.

To determine which trips should be used to compute the index, the method of Stephens and MacCall (2004) was applied. The Stephens and MacCall method uses multiple logistic regression to estimate a probability for each trip that the focal species was caught, given other species caught on that trip. Species compositions differ across the south Atlantic; thus, the method was applied separately for two different regions: north (areas 2-10) and south (areas 11, 12, and 17) (Shertzer *et al.* 2009). To avoid rare species, the number of species in each analysis was limited to those species that occurred in 1% or more of trips. The most general model therefore included all species in the snapper-grouper complex which occurred in 1% or more of trips as main effects, excluding red porgy. Red porgy was removed because of regulations (closure followed by strict bag limits), which could erroneously remove trips likely to have caught red snapper in recent years. A backward stepwise AIC procedure (Venables and Ripley 1997) was then used to perform further selection among possible species as predictor variables. In this procedure, a generalized linear model with Bernoulli response was used to relate presence/absence of red snapper in headboat trips to presence/absence of other species.

Model Description

Response and explanatory variables

The response variable, catch per unit effort (CPUE), has units of fish/angler and was calculated as the number of red snapper caught divided by the number of anglers. All explanatory (predictor) variables were modeled as categorical, rather than as continuous.

Years – 1976-2009

Area – Areas were pooled into regions of North Carolina (NC=2,3,9,10), South Carolina (SC=4,5), Georgia and North Florida (GNFL=6,7,8), and south Florida (sFL=11,12,17).

Season – The seasons were defined as winter (January, February, March), spring (April, May, June), summer (July, August, September) and fall (October, November, December).

Party – Five categories for the number of anglers on a boat were considered in the standardization process. The categories included: ≤20 anglers, 21-40 anglers, 41-60 anglers, 61-80 anglers, and >80 anglers. The minimum number of anglers per vessel was set at 6, which excluded the lower 0.5% of trips. These trips were excluded because they were possibly misreported and likely don't reflect the behavior of headboats in general.

Trip Type – Trip types of half and full day trips were included in the analysis. Three-quarter day trips were pooled with half-day trips (<10%). Multi-day trips were removed because most were in Florida and likely targeting deepwater species for some portion of the trip.

Standardization

CPUE was modeled using the delta-glm approach (Lo *et al.* 1992; Dick 2004; Maunder and Punt 2004). In particular, fits of lognormal and gamma models were compared for positive CPUE. Also, the combination of predictor variables was examined to best explain CPUE patterns (both for positive CPUE and the Bernoulli submodels). All analyses were performed in the R programming language (R Development Core Team 2014), with much of the code adapted from Dick (2004).

Bernoulli submodel. One component of the delta-GLM is a logistic regression model that attempts to explain the probability of either catching or not catching red snapper on a particular trip. First, a model was fit with all main effects to determine which effects should remain in the binomial component of the delta-GLM. Stepwise AIC (Venables and Ripley1997) with a backward selection algorithm was then used to eliminate those that did not improve model fit. In this case, the stepwise AIC procedure did not remove any predictor variables. No concerning patterns were apparent in the quantile residuals (Dunn and Smyth 1996).

Positive CPUE submodel. To determine predictor variables important for describing positive CPUE, the positive portion of the model was fitted with all main effects using both the lognormal and gamma distributions. Stepwise AIC (Venables and Ripley1997) with a backward selection algorithm was then used to eliminate those that did not improve model fit. In this case, no predictor variables were removed for either error term.

Both submodels (Bernoulli and either lognormal or gamma) were then combined, and the models were compared using AIC. In this case, the delta-lognormal distribution performed best and used in the final analysis. No concerning patterns were apparent in standard diagnostic plots of residuals.

5.4.1.2 Sampling Intensity

The resulting data set contained more than 51,000 trips across years with approximately 30–80% positive for red snapper. Annual numbers of trips used to compute the index are shown in Table 5.5.

5.4.1.3 Size/Age Data

The sizes/ages represented in this index should be the same as those of landings from the corresponding fleet (See section 4 of the DW report).

5.4.1.4 Catch Rates

Standardized catch rates and associated error bars are shown in Figure 5.4, and tabulated in Table 5.5. The units on catch rates were number of fish landed per angler.

5.4.1.5 Uncertainty and Measures of Precision

Measures of precision were computed using the bootstrap procedure. Annual CVs of catch rates are tabulated in Table 5.5.

5.4.1.6 Comments on Adequacy for Assessment

The index of abundance created from the headboat data was considered by the IWG to be adequate for use in the assessment. The data cover a wide geographic range relative to most of the stock, and logbooks are intended to represent a census of the headboats. The data set has an adequately large sample size and has a long enough time series to provide potentially meaningful information for the assessment. For the duration of the index, sampling was consistent over time, and some of the data were verified by port samplers and observers.

After DW1, industry representatives questioned the headboat data set, in particular the "veracity of data reported by the fishery" prior to 1992 (SEDAR41-DW40). The DW panel recognized the importance of those concerns, and recommended that the assessment be paused until the headboat data set could be thoroughly evaluated. That evaluation (SEDAR41-DW46) was conducted and available to inform DW2. It found "no evidence of chronic misreporting by vessels, no evidence of apparent temporal trends in potentially misreported data, and minimal spatial trends in potentially misreported data." The evaluation did identify a small percentage of obviously erroneous data that were corrected or removed from the data base, and it recommended that standard data filtering techniques be applied when developing indices of abundance. Such techniques were applied for SEDAR41, and the DW2 index working group thought there was sufficient justification to recommend the headboat index for use in the assessment.

The primary caveat concerning this index was that it was derived from fishery dependent data. Headboat effort generally targets snapper-grouper species and not necessarily the focal species, which should minimize changes in catchability relative to fishery dependent indices that target more effectively. The closure of the red snapper was addressed by terminating the index in 2010, and changes in selectivity and possibly catchability (e.g, in 1992) could be addressed by the assessment model.

5.4.2 Headboat At-sea Observer Program

The data used for this index were all trips in the headboat at-sea observer database which discarded red snapper from 2005 to 2014. The at-sea-observer program occurred during 2004-2014 in North and South Carolina, but started in Florida and Georgia in 2005. In addition, coverage in the Florida Keys was not consistent across years and therefore not included. Observer coverage occurred on approximately 2% of headboat trips.

Trip-level information included state, county, Florida region, year, month, day, dock to dock hours (total trip hours), the number of hours fished (to the nearest half hour), the total number of anglers on the boat, the number of anglers observed on a trip, the number of red snapper discarded, minimum depth of the fishing trip, and maximum depth of the fishing trip. Depth information was not collected for South Carolina, North Carolina, and Georgia; therefore, it was not used in this analysis. Refer to working paper SEDAR41-DW33 for more details regarding this program.

5.4.2.1 Methods of Estimation

Data Treatment

Data from 2004 were dropped from the analysis because Georgia and Florida were not sampled. Trips that fished at night targeting sharks or trips that were designated drift fishing were removed from the analysis. All other trips were thought to be fishing for snapper-grouper species. Observer trips by year and area relative to all headboat trips, as well as total red snapper observed, are presented in SEDAR41-DW14.

A 20" TL minimum size regulation has been in place since 1992. In SEDAR 24, headboat at-sea observer data were used to index discards below 20" TL minimum. A 2010 closure has created a scenario where all fish observed are discarded (mini-seasons in 2012 and 2013 were removed). During this closure period, discards greater than 20" TL were removed.

Although the closure went into effect in 2010, the IWG recommended treating this index as a single time series, 2005-2014. This was because the index only included fish less than 20" TL, and it was believed that any attempts at avoiding these smaller fish began in 1992 with implementation of the minimum size limit and continued with the closure in 2010. That is, with respect to fish less than 20" TL, fishing behavior remained relatively consistent throughout the time series. This notion was corroborated by testimony of an industry representative who contributed to the group's discussions. Although the IWG recommended a single time series, the group acknowledged that the assessment model could account for time-varying catchability, if necessary.

Response and explanatory variables

The response variable, catch (≤20 inches) per unit effort (CPUE), is defined as units of fish/angler interviewed and was calculated as the number red snapper discarded divided by the number of anglers interviewed. All explanatory (predictor) variables were modeled as categorical, rather than as continuous.

Years – 2005-2014

Area –Area was defined as North Carolina, South Carolina and Georgia, north Florida (nFL), south Florida, (excluding the keys, flreg=3)

Season – The seasons were defined as winter (January, February, March), spring (April, May, June), summer (July, August, September) and fall (October, November, December).

Party – Four categories for the number of anglers on a vessel were considered in the standardization process.

Hrsf– Four categories for the number of hours fished were considered in the standardization process.

Standardization

CPUE was modeled using the delta-glm approach (Lo *et al.* 1992; Dick 2004; Maunder and Punt 2004). In particular, fits of lognormal and gamma models were compared for positive CPUE. Also, the combination of predictor variables was examined to best explain CPUE patterns (both for positive CPUE and the Bernoulli submodels). All analyses were performed in the R programming language (R Development Core Team 2014), with much of the code adapted from Dick (2004).

Bernoulli submodel. One component of the delta-GLM is a logistic regression model that attempts to explain the probability of either catching or not catching red snapper on a particular trip. First, a model was fit with all main effects to determine which effects should remain in the binomial component of the delta-GLM. Stepwise AIC (Venables and Ripley1997) with a backward selection algorithm was then used to eliminate those that did not improve model fit. In this case, the stepwise AIC procedure did not remove any predictor variables. No concerning patterns were apparent in the quantile residuals (Dunn and Smyth 1996).

Positive CPUE submodel. To determine predictor variables important for describing positive CPUE, the positive portion of the model was fitted with all main effects using both the lognormal and gamma distributions. Stepwise AIC (Venables and Ripley1997) with a backward selection algorithm was then used to eliminate those that did not improve model fit. In this case, no predictor variables were removed for either error distribution.

Both submodels (Bernoulli and either lognormal or gamma) were then combined, and the models were compared using AIC. Based on the selection criterion, the delta-lognormal model with all factors was used. No concerning patterns were apparent in standard diagnostic plots of residuals.

5.4.2.2 Sampling Intensity

The resulting data set contained 1700 trips across all years with approximately 15-30% of those trips having positive catches of red snapper. Annual numbers of trips used to compute the index are shown in Table 5.6.

5.4.2.3 Size/Age Data

The sizes/ages represented in this index should be the same as those of discards (≤20 inches) from the corresponding fleet (See section 4 of the DW report).

5.4.2.4 Catch Rates

Standardized catch rates and associated error bars are shown in Figure 5.5, and tabulated in Table 5.6. The units on catch rates were number of fish (≤20 inches) caught per angler.

5.4.2.5 Uncertainty and Measures of Precision

Measures of precision were computed using a jackknife procedure. Annual CVs of catch rates are tabulated in Table 5.6.

5.4.2.6 Comments on Adequacy for Assessment

The indices of abundance created from the headboat at-sea data were considered by the IWG to be adequate for use in the assessment. Because these data excluded fish greater than 20 inches, the index may provide information on recruitment prior to other indices. Lagged correlations with other indices suggested recruits would enter this index one year prior to indices from other fishery dependent data sources (Table 5.8).

5.4.3 Commercial Handline Index

Landings and fishing effort of commercial vessels operating in the southeast U.S. Atlantic have been monitored by the NMFS Southeast Fisheries Science Center through the Coastal Fisheries Logbook Program (CFLP). The program collects information about each fishing trip from all vessels holding federal permits to fish in waters managed by the Gulf of Mexico and South Atlantic Fishery Management Councils. Initiated in the Gulf in 1990, the CFLP began collecting logbooks from Atlantic commercial fishers in 1992, when 20% of Florida vessels were targeted. Beginning in 1993, sampling in Florida was increased to require reports from all vessels permitted in coastal fisheries, and since then has maintained the objective of a complete census of federally permitted vessels in the southeast U.S.

Catch per unit effort (CPUE) from the logbooks was used to develop an index of abundance for red snapper landed with vertical lines (manual handline and electric reel), the dominant gear for this red snapper stock. The time series used for construction of the index spanned 1993–2009, when all vessels with federal snapper-grouper permits were required to submit logbooks on each fishing trip. The January 2010 closure of the red snapper fishery prevented extending the series. The 2012-2014 red snapper mini-seasons had targeting issues as well as a 75 pound trip limit which confounds the catch rate from those trips.

5.4.3.1 Methods of Estimation

Data Treatment

For each fishing trip, the CFLP database included a unique trip identifier, the landing date, fishing gear deployed, areas fished, number of days at sea, number of crew, gear-specific fishing effort, species caught, and weight of the landings. Fishing effort data available for vertical line gear included number of lines fished, hours fished, and number of hooks per line. For this southeast U.S. Atlantic stock, areas used in analysis were those between 24 and 37 degrees latitude, inclusive of the boundaries (Figure 5.6).

Data were restricted to include only those trips with landings and effort data reported within 45 days of the completion of the trip. Reporting delays beyond 45 days likely resulted in less reliable effort data (landings data may be reliable even with lengthy reporting delays if trip ticket reports were referenced by the reporting fisher). Also excluded were records reporting multiple gears fished, which prevents designating catch and effort to specific gears. Therefore, only those trips that reported one gear fished were included in the analyses. Where trips reported multiple areas, the first area reported was used in the analysis. Only the latitude from the area designated was used in the analysis assuming most trips with multiple areas fished were moving across the shelf rather than north and south.

Clear outliers (>99.5 percentile) in the data were also excluded from the analyses. These outliers were identified for all snapper/grouper trip manual handlines as records reporting more than 6 lines fished, 8 hooks per line fished, 10 days at sea, 5 crew members or 105 hours fished; outliers were identified for electric reels as records reporting more than 6 lines fished, 10 hooks per line fished, 12 days at sea, 5 crew members or 143 hours fished. Trips reporting fewer than 4 hours fished for both gears were removed. Positive red snapper trips reporting greater than 24 pounds/hook-hr were excluded for both gears.

To determine which trips should be used to compute the index, the method of Stephens and MacCall (2004) was applied. The Stephens and MacCall method uses multiple logistic regression to estimate a probability for each trip that the focal species was caught, given other species caught on that trip. Species compositions differ across the south Atlantic; thus, the method was applied separately for areas north and south of Cape Canaveral, which has been identified as a zoogeographical boundary (Shertzer et al. 2009). Cape Canaveral falls in the middle of the one degree commercial sampling grid and was assigned to the south with the split at 29 degrees. To avoid rare species, the number of species in each analysis was limited to those species that occurred in 1% or more of trips. The most general model therefore included all species in the snapper-grouper complex which occurred in 1% or more of trips as main effects, excluding red porgy. Red porgy was removed because of regulations (closure followed by strict bag limits), which could erroneously remove trips likely to have caught red snapper in recent years. A backward stepwise AIC procedure (Venables and Ripley 1997) was then used to perform further selection among possible species as predictor variables. In this procedure, a generalized linear model with Bernoulli response was used to relate presence/absence of red snapper in commercial trips to presence/absence of other species. An alternative generalized linear model with Bernoulli response related the catch in pounds of other species to the presence/absence of red snapper. Although the alternative method theoretically may be more efficient at identifying species associations, the IWG rejected the method due to concerns that the increase in trip limits in recent years may bias the results.

Model Description

Response and explanatory variables

The response variable, CPUE, was calculated for each trip as,

CPUE = pounds of red snapper/hook-hour

where hook-hours is the product of number of lines fished, number of hooks per line, and total hours fished. Explanatory variables, all categorical, are described below.

The explanatory variables were year, season, latitude, crew size, and days at sea, each described below:

Years – Year was necessarily included, as standardized catch rates by year are the desired outcome. Years modeled were 1993–2009.

Season – The seasons were defined as winter (January, February, March), spring (April, May, June), summer (July, August, September) and fall (October, November, December).

Lat – Location is reported as latitude and longitude in one degree increments centered at the middle (e.g., CFLP lat=28 is centered at 28.5 degrees). The few trips with latitude reported north of 34 degrees and south of 24 degrees were pooled into the 34 and 24 degree bins, respectively (Figure 5.6).

Crew size – Crew size (crew) was pooled into three levels: one, two, and three or more.

Days at sea – Days at sea (sea days) was pooled into three levels: one or two days, three or four days, and five or more days.

Standardization

CPUE was modeled using the delta-glm approach (Lo et al. 1992; Dick 2004; Maunder and Punt 2004). In particular, fits of lognormal and gamma models were compared for positive CPUE. Also, the combination of predictor variables was examined to best explain CPUE patterns (both for positive CPUE and the Bernoulli submodels). All analyses were performed in the R programming language (R Development Core Team 2014), with much of the code adapted from Dick (2004).

Bernoulli submodel. One component of the delta-GLM is a logistic regression model that attempts to explain the probability of either catching or not catching red snapper on a particular trip. First, a model was fit with all main effects to determine which effects should remain in the binomial component of the delta-GLM. Stepwise AIC (Venables and Ripley1997) with a backward selection algorithm was then used to eliminate those that did not improve model fit. In this case, the stepwise AIC procedure did not remove any predictor variables. No concerning patterns were apparent in the quantile residuals (Dunn and Smyth 1996).

Positive CPUE submodel. To determine predictor variables important for describing positive CPUE, the positive portion of the model was fitted with all main effects using both the lognormal and gamma distributions. Stepwise AIC (Venables and Ripley1997) with a backward selection algorithm was then used to eliminate those that did not improve model fit. In this application, the lognormal distribution outperformed the gamma distribution, and was therefore used to compute the index.

Both submodels (Bernoulli and lognormal) were then combined into a single delta-lognormal model (1993-2009), with all predictor variables used for both submodels. No concerning patterns were apparent in standard diagnostic plots of residuals.

5.4.3.2 Sampling Intensity
Annual numbers of trips used to compute the index is typically greater than 1000, as shown in Table 5.7.

5.4.3.3 Size/Age Data
The sizes/ages represented in this index should be the same as those of landings from the corresponding fleet (See section 3 of the DW report).

5.4.3.4 Catch Rates
Standardized catch rates and associated error bars are shown in Figure 5.7 and are tabulated in Table 5.7. The units on catch rates were pounds of fish landed per hook-hour.

5.4.3.5 Uncertainty and Measures of Precision
Estimates of variance were based on 1000 bootstrap runs where trips were chosen randomly with replacement (Efron and Tibshirani 1994). Annual CVs of catch rates are tabulated in Table 5.7.

5.4.3.6 Comments on Adequacy for Assessment

The index of abundance created from the commercial logbook data was considered by the IWG to be adequate for use in the assessment. The data cover a wide geographic range relative to that of the stock, and logbooks represent a census of the fleet. The data set has an adequately large sample size and has a long enough time series to provide potentially meaningful information for the assessment.

Several concerns were discussed by the IWG, all related to this index coming from fishery dependent data. First, commercial fishermen may target different species through time. If changes in targeting have occurred, effective effort can be difficult to estimate. However, the DW recognized that the method of Stephens and MacCall (2004), used here to identify trips for the analysis, can accommodate changes in targeting, as long as species assemblages are consistent. Second, the data are self-reported and largely unverified. Some attempts at verification have found the data to be reliable. Third and probably foremost, the data are obtained from a directed fishery and therefore the index could contain problems associated with any fishery dependent index. Fishing efficiency of the fleet has likely improved over time due to improved electronics. In addition, overall efficiency may have changed throughout the time series if fishermen of marginal skill have left the fishery at a greater rate than more successful fishermen. Also of concern is whether catch rates in a directed fishery are density-dependent. As fish abundance decreases, fishermen may maintain relatively high catch rates, and as fish abundance increases, catch rates may saturate.

5.4.4 Other Fishery Dependent Data Sources Considered During the DW

Several data sources were discussed during the pre-DW webinar for the potential to support indices of abundance, and some of these were discarded based on initial summaries of data. Two data sources were recommended during the webinar for further consideration, but were subsequently not recommended by the DW for use in the assessment: SCDNR charterboat logbooks and the MRFSS/MRIP data (Table 5.1). Reasons for their exclusion are provided in Table 5.2.

5.5 Consensus Recommendations and Survey Evaluations

The DW recommended two fishery independent (chevron traps and videos) and three fishery dependent indices (headboat logbooks, headboat at-sea observer data, commercial handline logbooks) for potential use in the red snapper stock assessment. Pearson correlations and significance values (p-values) between indices are presented in Table 5.8. All recommended indices and their CVs are in Table 5.9, and the indices are compared graphically in Figure 5.8.

The IWG discussed relative ranking of the ability of each index to represent true population abundance. Based on these discussions, the indices recommended for the assessment were ranked as follows, with pros and cons of each listed in Table 5.2.

1. Chevron traps
2. Video
3. Headboat index
4. Headboat at-sea observer index
5. Commercial handline index

Note that these rankings were made during the DW and are based solely on *a priori* information about each index. Therefore, the rankings should be considered preliminary, as they do not benefit from viewing indices for consistency with other data sets (e.g., age comp data). The assessment panel, with all data in hand, will be in a better position to judge the indices for use in the assessment.

5.6 Literature Cited

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5.7 Tables

Table 5.1. Table of the data sources considered for indices of abundance.

Fishery Type	Data Source	Area	Yrs	Units	Standardization Method	Issues	Use?
Recreational	Headboat	NC-FL	1976-2009	N kept/ angler	Delta-GLM	Fishery dependent, self reported	Yes
Recreational	MRFSS/ MRIP	NC-FL	1995-2013	N caught/ angler-hr	Nominal	Fishery dependent. Potential bias in intercepts. Not standardized	No
Recreational	Headboat-at-sea-observer	NC-FL	2005-2014	N caught ≤20"/ angler	Delta-GLM	Fishery dependent.	Yes
Recreational	SCDNR charterboat logbook	SC	1993-2013	N caught/ angler-hr	Delta-GLM	Limited geographic coverage; outside core red snapper habitat	No
Commercial	Commercial logbook handline	NC-FL	1993-2009	lb kept/ hook-hour	Delta-GLM	Fishery dependent, self reported	Yes
Commercial	Commercial logbook diving	NC-FL	1993-2009	lb kept/ hook-hour		Fishery dependent, self reported; small sample sizes, almost all from FL	No
Independent	SERFS: chevron trap	NC-FL	1990-2014	N caught	Zero inflated negative binomial	Expanded spatial coverage through time	Yes
Independent	SERFS: video survey	NC-FL	2010-2014	N observed	Zero inflated negative binomial	Ages/sizes unknown	Yes
Independent	SEAMAP trawl survey	SC				Few samples (~1 fish/yr)	No

Independent	MARMAP: blackfish trap	Mostly SC	1981-1987			Few samples	No
Independent	MARMAP: Florida trap	Mostly SC	1981-1987			Few samples	No
Independent	MARMAP: Short-bottom longline					Few samples	No
Independent	MARMAP: Kali pole					Few samples	No

Table 5.2. Table of the pros and cons for each data set considered at the data workshop. Note that several data sources were considered (Table 5.1), but discarded, prior to the DW.

Fishery independent indices

SERFS Chevron Trap Index (*Recommended for use*)
Pros:
- Fishery independent random hard bottom survey
- Adequate regional coverage
- Standardized sampling techniques
- All fish caught are aged and measured

Cons:
- Short time series

SERFS Video Index (*Recommended for use*)
Pros:
- Fishery independent random hard bottom survey
- Adequate regional coverage
- Standardized sampling techniques
- Relatively high detection probabilities
- Likely to be less selective than capture gears

Cons:
- Short time series, with sampling differences in the first year
- Ages/sizes observed are unknown

Fishery dependent indices

Recreational Headboat (*Recommended for use*)
Pros:
- Complete census
- Covers the entire management area
- Some data are verified by port samplers and observers
- Large sample size
- Strongly correlated with headboat at-sea-observer index
- Generally non-targeted for focal species, which should minimize changes in catchability relative to fishery dependent indices that target specific species

Cons:
- Fishery dependent (i.e., potentially affected by regulations, targeting, hyperdepletion, hyperstability)
- Little information on discard rates, particularly before mid-2000s
- Catchability may vary over time or with abundance

- Effective effort is difficult to identify

General recreational (MRFSS) (*Not recommended for use*)
Pros:
- Intercept data by port samplers
- Spans the management area
- Includes estimates of discards

Cons:
- Nominal index only, not standardized
- Fishery dependent (i.e., potentially affected by regulations, targeting, hyperdepletion, hyperstability)
- Catchability may vary over time or with abundance
- Potential bias in trips intercepted
- High variability
- Effective effort is difficult to identify

Commercial Logbook – Handline (*Recommended for use*)
Pros:
- Complete census
- Covers the entire management area
- Large sample size

Cons:
- Fishery dependent (i.e., potentially affected by regulations, targeting, hyperdepletion, hyperstability)
- Data are self-reported and largely unverified
- Catchability may vary over time or with abundance
- Landings could be cross-referenced with other data sources, but effective effort difficult to identify
- No information on discard rates
- Potential shifts in species targeted; commercial fishermen more skillful than general recreational fishermen at targeting focal species

Headboat at-sea observer index (*Recommended for use*)
Pros:
- Observer program
- Good discard data (provides amount of discards and length frequency)
- Random sampling design
- Broad spatial coverage

Cons:

- Fishery dependent (i.e., potentially affected by regulations, targeting, hyperdepletion, hyperstability)
- Relatively short time series
- Information overlaps with headboat index, but this was mitigated by using fish <20inches
- Coverage of fleet is ~2%, but varies across states

SCDNR Charterboat ***(Not recommended for use)***

Pros:

- Census

Cons:

- Fishery dependent (i.e., potentially affected by regulations, targeting, hyperdepletion, hyperstability)
- South Carolina only, limited geographic coverage relative to south Atlantic
- Outside core habitat of red snapper
- No field validation

Table 5.3 The number of trapping events (N), standardized index, and CV for the red snapper index computed from SERFS chevron traps.

Year	N	Standardized index	CV
2010	695	0.66	0.18
2011	674	0.69	0.16
2012	1114	1.14	0.11
2013	1331	0.91	0.12
2014	1429	1.61	0.11

Table 5.4 The nominal index (*SumCount*), number of trapping events (N), proportion positive, standardized index, and CV for the red snapper index computed from the SERFS video survey.

Year	Relative nominal *SumCount*	N	Proportion positive	Standardized index	CV
2010	2.61	166	0.355	1.21	0.22
2011	0.43	575	0.233	0.59	0.17
2012	0.57	1075	0.241	1.06	0.14
2013	0.64	1219	0.267	0.80	0.12
2014	0.75	1374	0.218	1.35	0.14

Table 5.5 The number of trips (N), nominal CPUE, relative nominal CPUE, standardized index, and CV for red snapper from headboat logbook data, 1976-2009.

Year	N	Nominal CPUE	Relative nominal	Standardized CPUE	CV
1976	876	0.55	2.62	2.37	0.05
1977	900	0.47	2.21	2.16	0.08
1978	1576	0.48	2.26	2.13	0.03
1979	1293	0.46	2.20	2.23	0.05
1980	1409	0.31	1.45	1.45	0.05
1981	1092	0.51	2.40	2.95	0.04
1982	1347	0.20	0.97	1.20	0.05
1983	1579	0.31	1.47	1.64	0.05
1984	1477	0.34	1.60	1.42	0.03
1985	1741	0.35	1.67	2.07	0.05
1986	2185	0.11	0.54	0.48	0.07
1987	2199	0.14	0.65	0.58	0.05
1988	2061	0.16	0.73	0.56	0.06
1989	1438	0.20	0.94	0.90	0.05
1990	1468	0.16	0.78	0.87	0.06
1991	1463	0.14	0.65	0.69	0.04
1992	2156	0.03	0.15	0.08	0.10
1993	1981	0.06	0.27	0.16	0.08
1994	1633	0.09	0.42	0.26	0.05
1995	1523	0.08	0.36	0.28	0.06
1996	1130	0.07	0.31	0.25	0.06
1997	790	0.06	0.30	0.27	0.09
1998	1647	0.06	0.30	0.24	0.08
1999	1706	0.08	0.37	0.29	0.05
2000	1442	0.10	0.49	0.41	0.05
2001	1553	0.17	0.81	0.76	0.07
2002	1466	0.23	1.08	0.88	0.05
2003	1150	0.12	0.59	0.52	0.05
2004	1606	0.16	0.77	0.76	0.04
2005	1290	0.14	0.69	0.76	0.04
2006	1406	0.11	0.53	0.43	0.05
2007	1505	0.11	0.52	0.44	0.08
2008	1551	0.32	1.52	1.71	0.05
2009	1917	0.30	1.40	1.81	0.03

Table 5.6. The number of trips(N), nominal CPUE, relative nominal CPUE, standardized index, and CV for red snapper (≤20" TL) from the headboat at-sea observer data, 2005-2014.

Year	N	Nominal CPUE	Relative nominal	Standardized CPUE	CV
2005	204	0.10	0.50	0.33	0.34
2006	178	0.18	0.91	0.40	0.40
2007	200	0.37	1.89	2.49	0.19
2008	172	0.50	2.59	1.99	0.29
2009	164	0.17	0.86	0.95	0.26
2010	160	0.06	0.31	0.44	0.29
2011	151	0.11	0.56	0.46	0.34
2012	165	0.17	0.85	1.17	0.25
2013	154	0.13	0.68	0.95	0.27
2014	168	0.17	0.85	0.82	0.28

Table 5.7. The number of trips (N), proportion positive, relative nominal CPUE, standardized index, and CV for red snapper from commercial logbook data (handlines).

Year	N	Proportion Positive	Relative nominal	Standardized CPUE	CV
1993	772	0.72	0.571	1.086	0.063
1994	1210	0.70	0.521	0.891	0.051
1995	1400	0.66	0.716	0.891	0.046
1996	1101	0.57	0.525	0.612	0.055
1997	1390	0.53	0.662	0.589	0.054
1998	1222	0.53	0.694	0.659	0.055
1999	1068	0.56	0.507	0.798	0.060
2000	1067	0.55	0.746	0.737	0.056
2001	1282	0.70	0.940	1.274	0.049
2002	1386	0.73	0.903	1.383	0.046
2003	1117	0.66	0.699	1.042	0.053
2004	1030	0.65	0.840	1.423	0.054
2005	1067	0.61	0.786	1.188	0.058
2006	893	0.49	0.440	0.597	0.071
2007	1108	0.48	0.599	0.665	0.064
2008	955	0.56	1.933	1.223	0.066
2009	911	0.63	4.918	1.942	0.073

Table 5.8. Pearson correlation values for indices recommended for use. P-values (in parentheses) represent the probability of obtaining the Pearson value under the null hypothesis of correlation=0. The HB at-sea index was lagged by one year when compared with other fishery dependent indices, because it only included fish ≤20 inches and would therefore track recruits prior to the other indices. CVT=chevron traps, HB=headboats, and Comm=commercial handline.

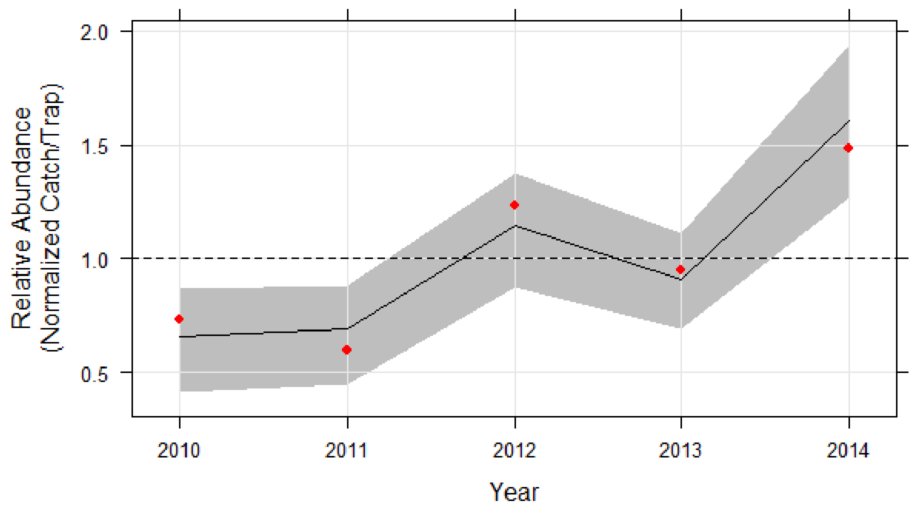
	Headboat	HB at-sea	CVT	Video	Comm
Headboat	1.000				
HB at-sea	0.971 (0.006)	1.000			
CVT	-	0.569 (0.316)	1.000		
Video	-	0.166 (0.790)	0.613 (0.272)	1.000	
Comm	0.788 (0.000)	0.780 (0.120)	-	-	1.000

Table 5.9. Red snapper standardized indices of abundance and annual CVs recommended for potential use in the stock assessment. CVT=chevron traps, HB=headboats, and Comm=commercial handline. Each index is scaled to its mean.

	Standardized indices					**CVs**				
Year	HB	HB at-sea	CVT	Video	Comm	HB	HB at-sea	CVT	Video	Comm
1976	2.37					0.05				
1977	2.16					0.08				
1978	2.13					0.03				
1979	2.23					0.05				
1980	1.45					0.05				
1981	2.95					0.04				
1982	1.20					0.05				
1983	1.64					0.05				
1984	1.42					0.03				
1985	2.07					0.05				
1986	0.48					0.07				
1987	0.58					0.05				
1988	0.56					0.06				
1989	0.90					0.05				
1990	0.87					0.06				
1991	0.69					0.04				
1992	0.08					0.10				
1993	0.16				1.09	0.08				0.06
1994	0.26				0.89	0.05				0.05
1995	0.28				0.89	0.06				0.05
1996	0.25				0.61	0.06				0.06
1997	0.27				0.59	0.09				0.05
1998	0.24				0.66	0.08				0.06
1999	0.29				0.80	0.05				0.06
2000	0.41				0.74	0.05				0.06
2001	0.76				1.27	0.07				0.05
2002	0.88				1.38	0.05				0.05
2003	0.52				1.04	0.05				0.05
2004	0.76				1.42	0.04				0.05
2005	0.76	0.33			1.19	0.04	0.34			0.06
2006	0.43	0.40			0.60	0.05	0.40			0.07
2007	0.44	2.49			0.67	0.08	0.19			0.06
2008	1.71	1.99			1.22	0.05	0.29			0.07
2009	1.81	0.95			1.94	0.03	0.26			0.07
2010		0.44	0.66	1.21			0.29	0.18	0.22	
2011		0.46	0.69	0.59			0.34	0.16	0.17	
2012		1.16	1.14	1.06			0.25	0.11	0.14	
2013		0.96	0.91	0.80			0.27	0.12	0.12	
2014		0.82	1.61	1.35			0.28	0.11	0.14	

5.8 Figures

Figure 5.1. The nominal (red dots) and standardized index (solid black line) for red snapper computed from SERFS chevron traps. Gray shaded area represents 95% confidence interval as estimated from 10,000 bootstraps. (Top panel): the index recommended for use in the assessment. (Bottom panel): longer index developed for consideration as a sensitivity run.



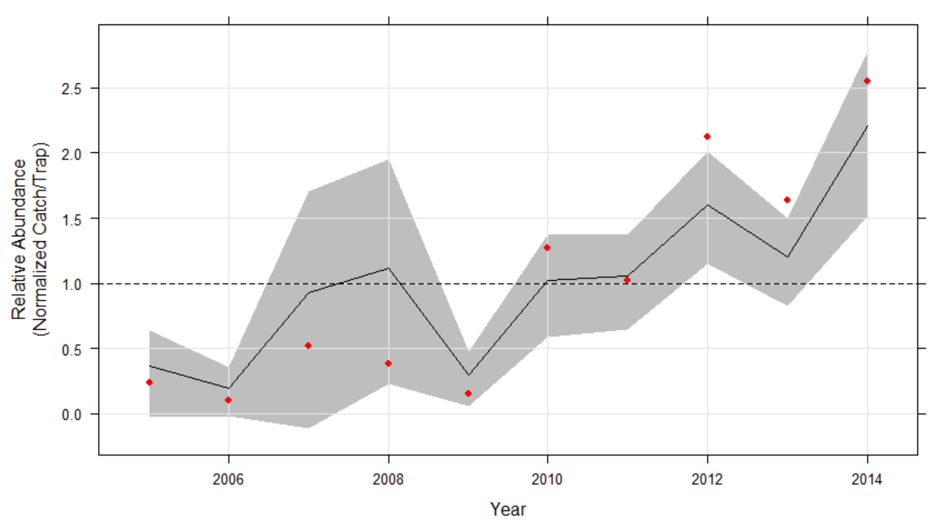


Figure 5.2. The nominal and standardized index for red snapper computed from the SERFS video survey.

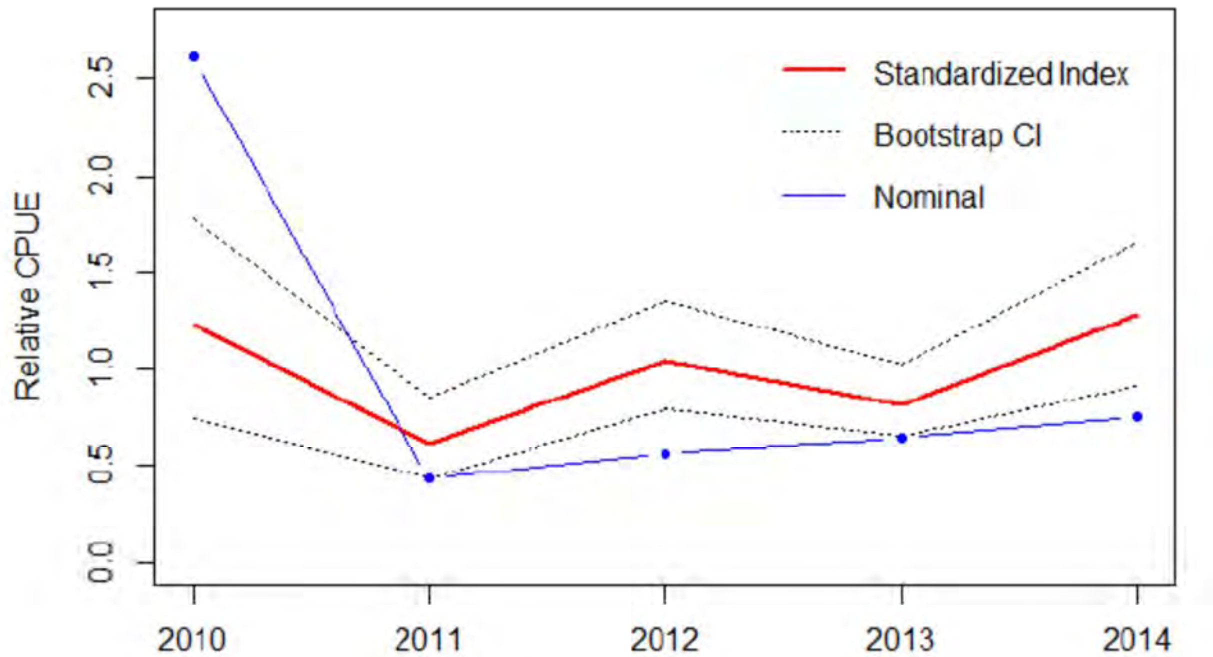


Figure 5.3. Map of headboat sampling area definitions. For analysis, areas were pooled as described in the text.

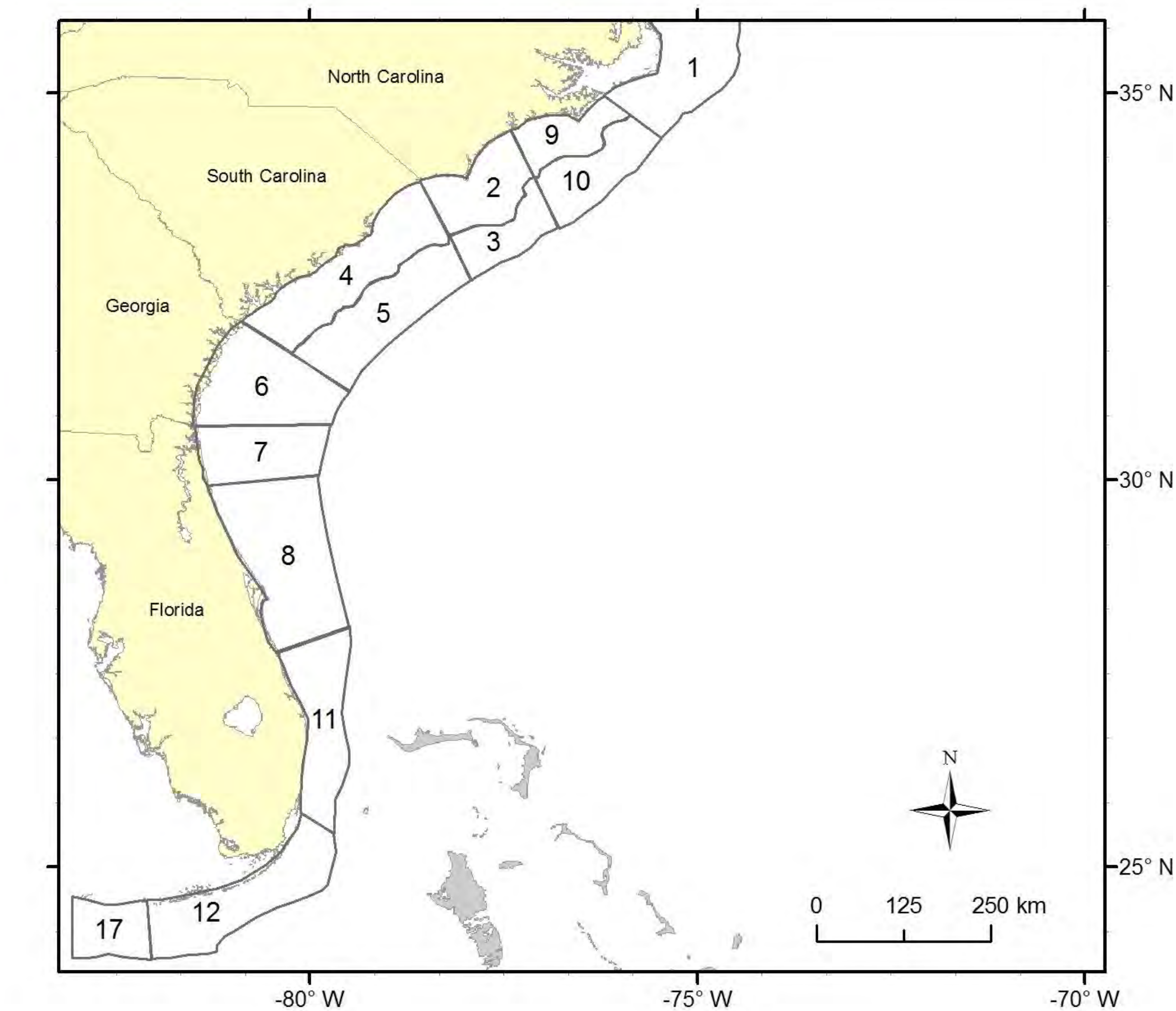


Figure 5.4. The nominal and standardized index for red snapper computed from headboat data, 1976-2009. Error bars represent approximate 95% confidence intervals.

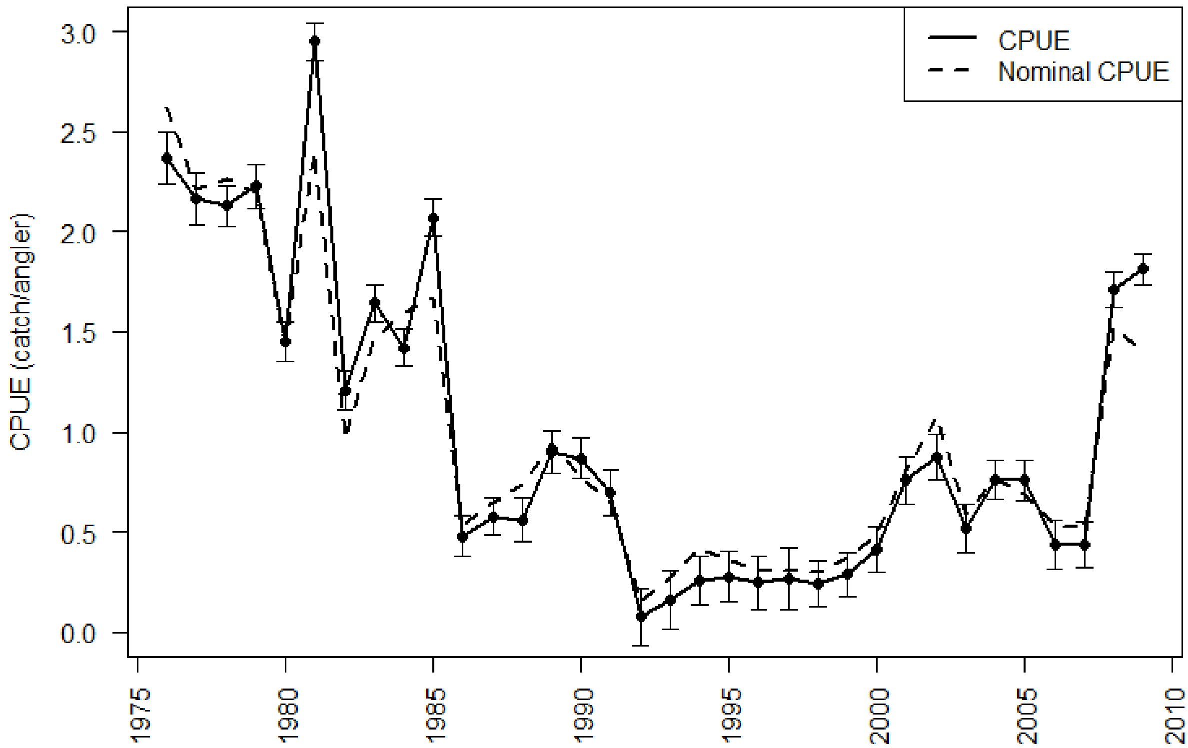


Figure 5.5. The standardized and nominal index with error bars at (+/-) 2 standard deviations computed for red snapper (≤20" TL) using the headboat at-sea observer data, 2005-2014.

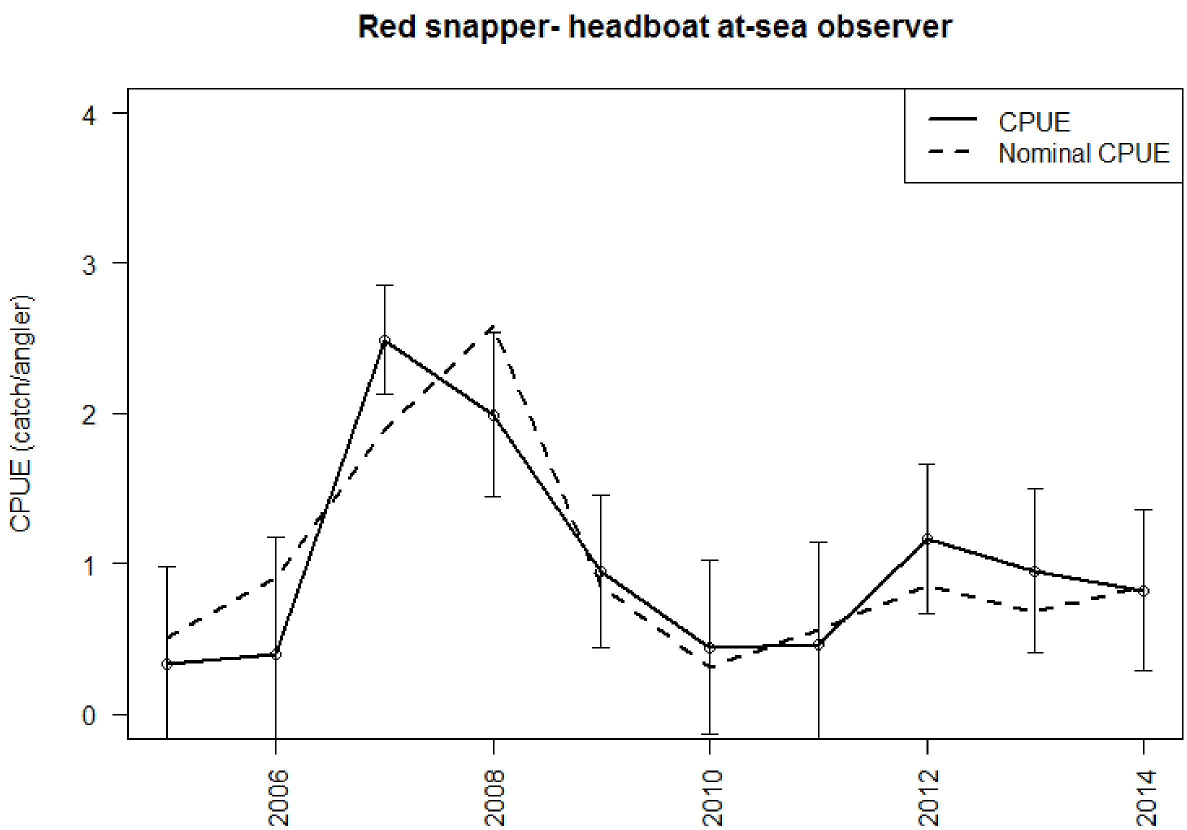


Figure 5.6. Latitude reported in the Coastal Fisheries Logbook Program (CFLP, commercial logbooks). Area is recorded in degrees where the first two digits signify degrees latitude, second two degrees longitude.   Only latitude was used in this analysis.

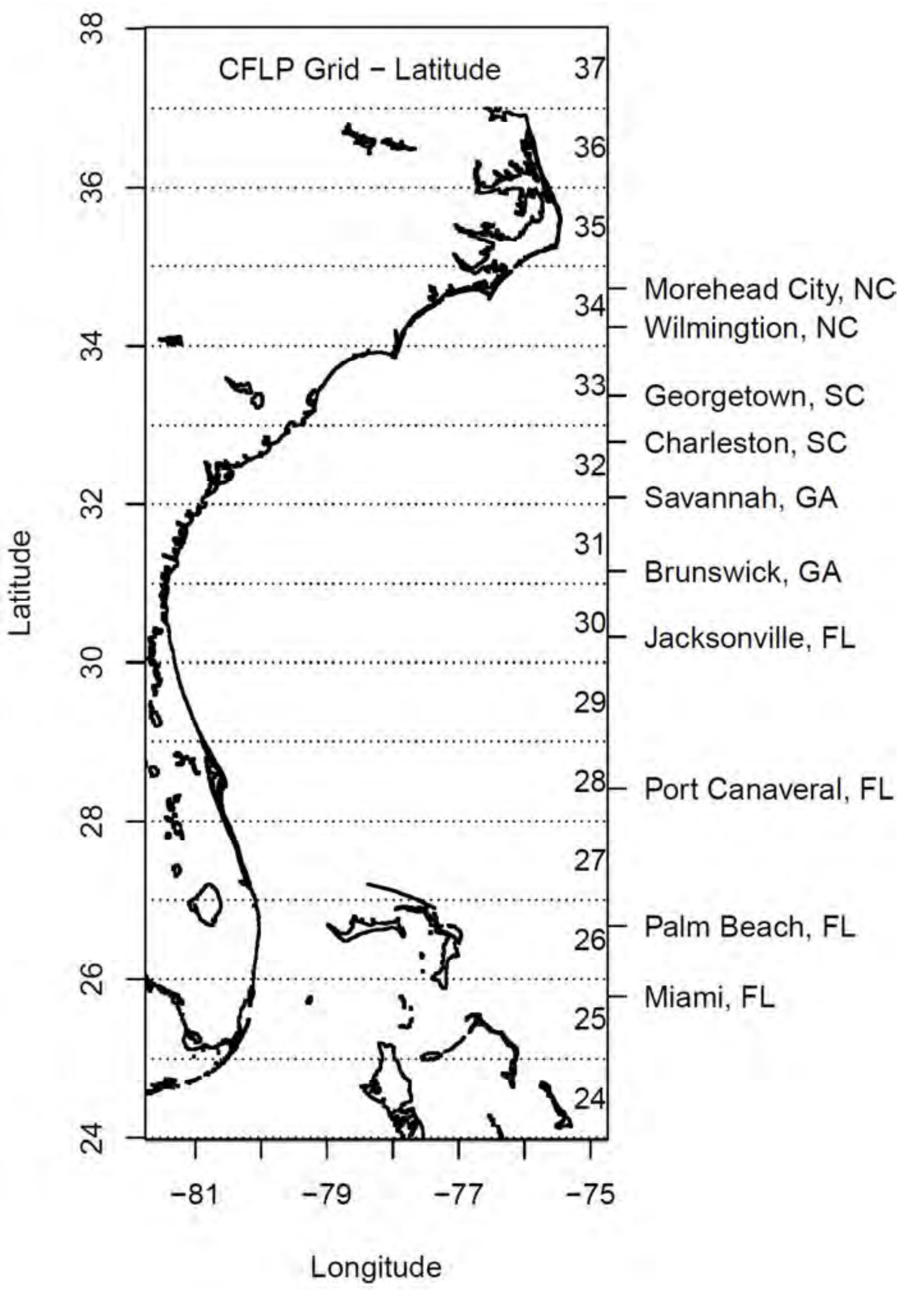


Figure 5.7. The nominal and standardized index for red snapper computed from commercial logbook handline data, 1993–2009. Error bars represent approximate 95% confidence intervals. The nominal (Nominal CPUE), Standardized Stephens and MacCall approach approved for use in SEDAR 41 (SandM.CPUE), and positive-only (SEDAR 41 Pos CPUE) runs are shown.

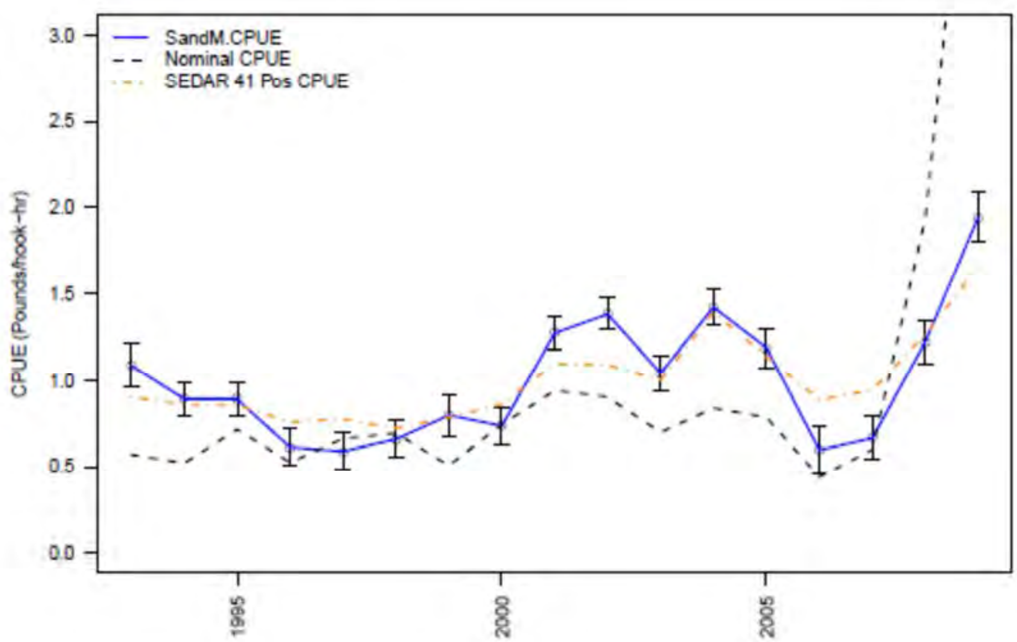
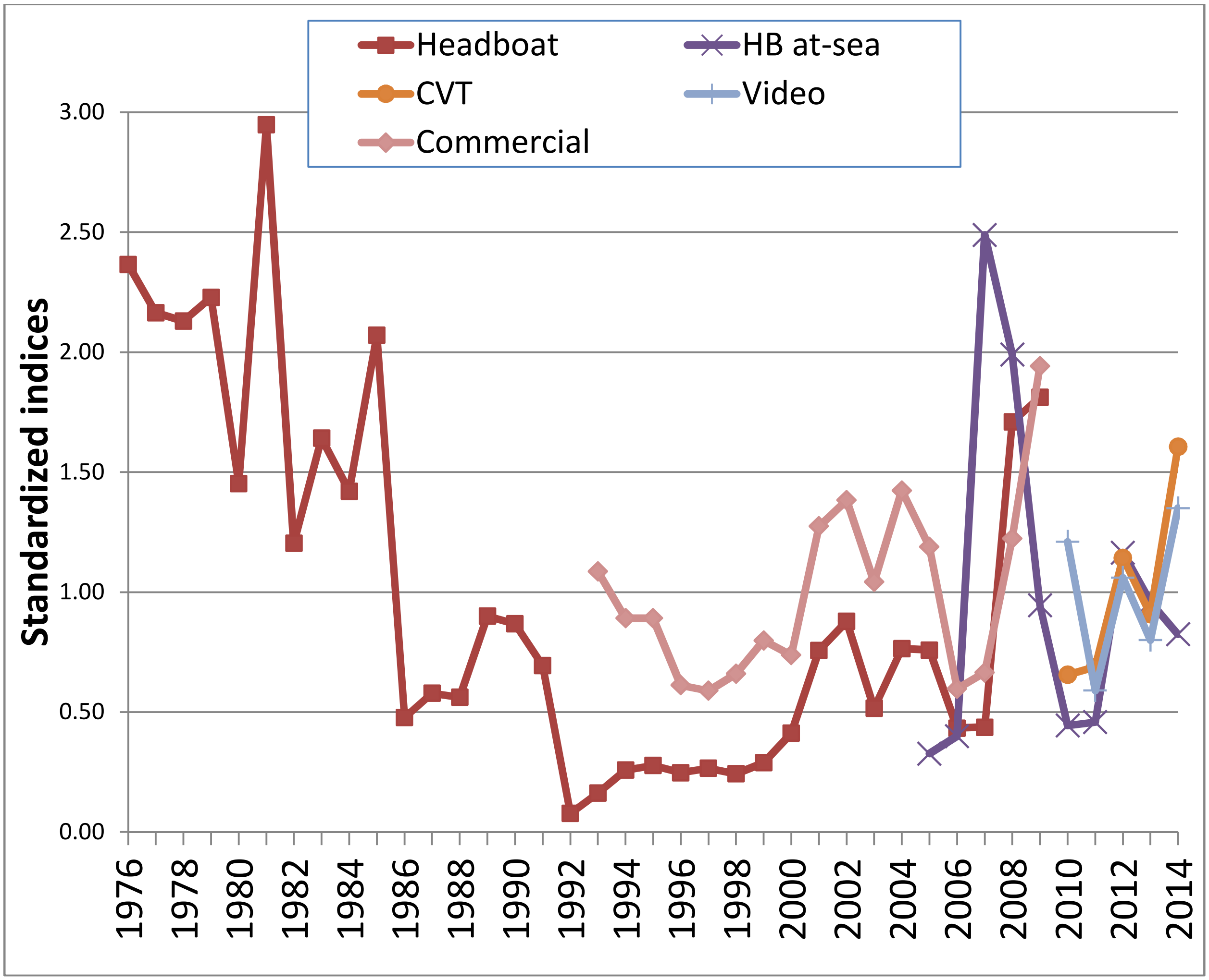


Figure 5.8. All indices (scaled to their respective means) recommended for potential use in the red snapper stock assessment. CVT=Chevron traps, and HB=Headboat.



6. Analytical Approach

Based on the reports received from the data workshops and the webinars held to date (8/20/2015), the data are sufficient to attempt to fit the BAM model with the ASPIC as a simpler complementary model. The data provided will include catches, discards, indices, length and age compositions, and life history information. This is consistent with the modeling approach and data available for SEDAR 24.

7. Research Recommendations

7.1 Life History

Red Snapper Mini Season

If this program, along with continued closure of the fishery, is to extend into future seasons, an exploration of methods to further incentivize angler participation would be useful. After brief interviews with participants from the recreational fishers group at SEDAR 41, the following suggestions were provided to increase angler participation:

- Free fish cleaning at donation site.
- As people may be tired after being out on the water all day and with busy boat ramps, short questionnaire from a biologist on-site could be used instead of the anglers filling the forms out or requiring fishermen to fill out a survey online after they return home.
- Advertise data collection at local bait & tackle shops.
- Use NOAA's announcement system on weather radio channel where they also announce season closures, etc. Since fishermen are frequently monitoring this channel for weather updates, it could be an effective communication route to announce the collection information (drop locations, reward information, etc.).
- Dry storage areas are a good place to sample; many people store boats there instead of trailering home.

Life History Research

- More research on red snapper movements and migrations in Atlantic waters is needed. Available data and the results of studies in the Gulf of Mexico indicate high site fidelity, but that tropical storms may cause greater than normal movement that might help dispersal to depleted areas. This needs to be confirmed in the South Atlantic. Additional acoustic and traditional tagging is needed on known spawning locations to document spawning migrations or aggregations, and return of fish to non-spawning areas.
- Evaluate more thoroughly the data/sample collection during the mini-season to improve utility for assessments. This should include what samples should be collected (e.g. reproductive information).

- Possible changes in life history parameters, in particular relative to reproduction, need to be further investigated.
- Much is unknown about the early life history of Red Snapper, in particular relative to spawning areas, larval and juvenile stages, including habitat and dispersal.
- Alternative methods of reproductive output. The methods described in Klibansky's SEDAR41-DW49 may provide a more accurate estimate of reproductive output than previously used. Further investigation into this modeling effort and use for future assessments should be investigated.
- Duration of spawning indicators. The definition of spawning indicators has received significant discussion recently. As this has significant implications for the estimates of reproductive output, further research is needed to define consistent criteria for spawning indicators in finfish.
- Continuing the age reading comparisons and calibrations between labs on a reference collection of known age fish would be beneficial for determining a more accurate aging error matrix and would provide accuracy to the age composition data.

7.2 Commercial

Landings

- Improve gear and effort data for each trip.
- Standardize methodology for developing average proportions to parse out unclassified landings.

Discards

- Investigate the validity and magnitude of "no discard" trips. This may include fisher interviews throughout the region.
- Examine potential impacts of "no discard" trips on estimated discards.
- Improve discard logbook data collections via program expansion or more detailed reporting (i.e. electronic logbooks, etc.)
- Establish an observer program that is representative of the fisheries in the South Atlantic

Biosampling

- Establish an observer program that is representative of the fisheries in the South Atlantic.
- Angler education with regards to recording depths on paper logbooks (i.e. standardized units); validation of additions to the logbook form still needed.
- Standardize TIP sampling protocol to get representative samples at the species level.
- Standardize TIP data extraction.

7.3 Recreational

- Complete analysis of available historic photos for trends in CPUE and mean size of landed Red Snapper and Gray Triggerfish for pre-1981 time period. (Ultimately all species).
- Formally archive data and photos for all other SEDAR target species.
- For Hire Survey (FHS) should collect additional variables (e.g. depth fished).
- Increasing sample sizes for at-sea headboat observers (i.e. number of trips sampled).
- Compute variance estimate for headboat landings.
- Mandatory logbooks for all federally permitted for-hire vessels.

7.4 Indices

- Compare existing methods and/or develop new methods to define effective effort in fishery dependent data.
- Estimate selectivity of video gear in the SERFS.
    - Tagging, stereo cameras
- For video reading, evaluate methods to score water clarity and habitat.
- Evaluate effect of (non) independence between chevron traps and videos, including methods to combine the indices.
- Continue exploring the use of continuous predictor variables (e.g., splines or polynomials) for ZIP and ZINB standardization models.
- Headboat at-sea observer program needs depth data from all states (not just FL) and increased coverage overall.
- SCDNR charterboat logbook program should be replicated by other states.
- Develop fishery independent hook-gear index (S41-DW08).

SEDAR

Southeast Data, Assessment, and Review

SEDAR 41

South Atlantic Red Snapper

SECTION III: Assessment Workshop Report

February 2016

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

NOTE: Modifications to the model results reported in this report were made during the Review Workshop held March 15-18, 2016. For complete results reflecting those changes, please see Addenda 1 of the Stock Assessment Report (Section VI). In April 2017, the SEFSC discovered an error in the assessment and provided an updated Assessment Workshop Report. The corrected report can be found in Addenda 2 of the Stock Assessment Report (Section VII).

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1. Introduction

1.1 Workshop Time and Place

The SEDAR 41 Assessment Process was conducted through a combination of an in-person workshop and series of webinars held from October 2015 to February 2016. The in-person workshop was held December 14-17, 2015 in Morehead City, NC. The workshop was originally scheduled for November 2015, but was delayed approximately one month to ensure a preliminary base run would be available at the beginning of the workshop. Six assessment webinars were held, three pre-workshop and three post-workshop, on the following dates: November 2, November 17 and December 1, 2015 and January 11, January 27, and February 17, 2016.

1.2 Terms of Reference

1. Review any changes in data following the Data Workshop and any analyses suggested by the Data Workshop. Summarize data as used in each assessment model. Provide justification for any deviations from Data Workshop recommendations.

2. Develop population assessment models that are compatible and appropriate with available data. Document input data, model assumptions and configuration, and equations for each model considered.

3. Provide estimates of stock population parameters, including:
   - Fishing mortality, abundance, biomass, selectivity, stock-recruitment relationship, and other parameters as necessary to describe the population.
   - Appropriate measures of precision for parameter estimates.

4. Characterize uncertainty in the assessment and estimated values.
   - Consider uncertainty in input data, modeling approach, and model configuration.
   - Provide a continuity model consistent with the prior assessment configuration, if one exists, updated to include the most recent observations. Alternative approaches to a strict continuity run that distinguish between model, population, and input data influences on findings, may be considered.
   - Consider and include other sources of uncertainty as appropriate for this assessment.
   - Provide appropriate statistical measures of model performance, reliability, and ‘goodness of fit’.
   - Provide measures of uncertainty for estimated parameters.

5. Provide estimates of yield and productivity.
   - Include yield-per-recruit, spawner-per-recruit, and stock-recruitment models.

6. Provide estimates of population benchmarks or management criteria consistent with the available data, applicable FMPs, proposed FMPs and Amendments, other ongoing or proposed management programs, and National Standards.
   - Evaluate existing or proposed management criteria as specified in the management summary.
   - Recommend proxy values when necessary.

7. Provide declarations of stock status relative to management benchmarks, or alternative data poor approaches if necessary.

8. Provide uncertainty distributions of proposed reference points and stock status metrics that provides the values indicated in the management specifications. Include probability density functions for biological reference point estimates and population metrics (e.g. biomass and exploitation) used to evaluate stock status.

9. Project future stock conditions (biomass, abundance, and exploitation; including probability density functions) and develop rebuilding schedules if warranted; include estimated generation time. Develop stock projections for the following circumstances, in accordance with the guidance on management needs provided in the management history:
   A) If stock is overfished:
      F=0, F=current, F=Fmsy, Ftarget
      F=Frebuild (max exploitation that rebuilds in the greatest allowed time)
      Fixed landings equal to the ABC
   B) If stock is overfishing
      F=Fcurrent, F=Fmsy, F=Ftarget, Fixed landings equal to the ABC
   C) If stock is neither overfished nor overfishing
      F=Fcurrent, F=Fmsy, F=Ftarget, Fixed landings equal to the ABC
   D) If data-limitations preclude classic projections (i.e. A, B, C above), explore alternate models to provide management advice.
   E) Gray triggerfish projections should account for changes in selectivity that may result from actions in Snapper Grouper Amendment 29.

10. Compare and contrast productivity measures and assessment assumptions between the Gulf of Mexico and South Atlantic stocks.

11. Provide recommendations for future research, data collection, and assessments.
    - Be as specific as practicable in describing sampling design and sampling intensity.
    - Emphasize items which will improve future assessment capabilities and reliability, and reduce uncertainty.
    - Consider data, monitoring, and assessment needs.

12. Complete the Assessment Workshop Report in accordance with project schedule deadlines (Section III of the SEDAR Stock Assessment Report).

1.3 List of Participants

ASSESSMENT PANELISTS
Kevin Craig - Lead Analyst Gray Triggerfish, SEFSC Beaufort
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Alexei Sharov, MD DNR / SSC

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Robert Johnson, FL
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Chris Conklin, SAFMC

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Kelly Fitzpatrick, SEFSC Beaufort
Jared Flowers, NCDMF
Laura Lee, NCDMF
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Amy Schueller, SEFSC Beaufort / SSC
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Roy Crabtree, SERO
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Dawn Franco, GADNR
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Deidra Jeffcoat, GA fisherman
Kathy Knowlton, GADNR
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Jean-Jacques Maguire, Science Center for Marine Fisheries – Quebec
Anne Markwith, NCDMF
Mike Nelson, FL fisherman
Paul Nelson, FL fisherman
George Sedberry, NOAA / SSC
Tom Sminkey, NOAA
Karolyn Stillman, SEFSC Beaufort
Yuying Zhang, FL International University

1.4 Document List

SEDAR 41 assessment working paper and reference document list.

Document #	Title	Authors
	Documents Prepared for the Assessment Workshop	
SEDAR41-AW01	Addendum to SEDAR41-DW29: Discards of red snapper (***Lutjanus campechanus***) for the headboat fishery in the US South Atlantic	FEB-NMFS 2015
SEDAR41-AW02	Addendum to SEDAR41-DW30: Discards of gray triggerfish (***Balistes capriscus***) for the headboat fishery in the US South Atlantic	FEB-NMFS 2015
SEDAR41-AW03	South Atlantic U.S. red snapper (***Lutjanus campechanus***) age and length composition from the recreational fisheries	FEB-NMFS 2015
SEDAR41-AW04	South Atlantic U.S. gray triggerfish (***Balistes capriscus***) age and length composition from the recreational fisheries	FEB-NMFS 2015
SEDAR41-AW05	Commercial age and length composition weightings for Atlantic Red Snapper (***Lutjanus campechanus***)	SFB-NMFS 2015
SEDAR41-AW06	Commercial age and length composition weightings for Atlantic Gray Triggerfish (***Balistes capriscus***)	SFB-NMFS 2015
SEDAR41-AW07	Addendum to SEDAR41-DW17: Estimates of Historic Recreational Landings of Red Snapper in the South Atlantic Using the FHWAR Census Method	Brennan 2015
SEDAR41-AW08	South Atlantic U.S. red snapper (***Lutjanus campechanus***) catch curve analysis	SFB-NMFS 2015
	Reference Documents	
SEDAR41-RD01	List of documents and working papers for SEDAR 32 (South Atlantic Blueline Tilefish and Gray Triggerfish) – all documents available on the SEDAR website.	SEDAR 32
SEDAR41-RD02	List of documents and working papers for SEDAR 9 (Gulf of Mexico Gray Triggerfish, Greater Amberjack, and Vermilion Snapper) – all documents available on the SEDAR website.	SEDAR 9
SEDAR41-RD03	2011 Gulf of Mexico Gray Triggerfish Update Assessment	SEDAR 2011

SEDAR41-RD04	List of documents and working papers for SEDAR 24 (South Atlantic red snapper) – all documents available on the SEDAR website.	SEDAR 24
SEDAR41-RD05	List of documents and working papers for SEDAR 31 (Gulf of Mexico red snapper) – all documents available on the SEDAR website.	SEDAR 31
SEDAR41-RD06	List of documents and working papers for SEDAR 15 (South Atlantic red snapper and greater amberjack) – all documents available on the SEDAR website.	SEDAR 15
SEDAR41-RD07	2009 Gulf of Mexico red snapper update assessment	SEDAR 2009
SEDAR41-RD08	List of documents and working papers for SEDAR 7 (Gulf of Mexico red snapper) – all documents available on the SEDAR website.	SEDAR 7
SEDAR41-RD09	SEDAR 24 South Atlantic Red Snapper: management quantities and projections requested by the SSC and SERO	NMFS - Sustainable Fisheries Branch 2010
SEDAR41-RD10	Total removals of red snapper (***Lutjanus campechanus***) in 2012 from the US South Atlantic	NMFS - Sustainable Fisheries Branch 2013
SEDAR41-RD11	Amendment 17A to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region	SAFMC 2010
SEDAR41-RD12	Amendment 28 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region	SAFMC 2013
SEDAR41-RD13	Total removals of red snapper (***Lutjanus campechanus***) in 2013 from the U.S. South Atlantic	NMFS - Sustainable Fisheries Branch 2014
SEDAR41-RD14	South Atlantic red snapper (***Lutjanus campechanus***) monitoring in Florida for the 2012 season	Sauls et al. 2013
SEDAR41-RD15	South Atlantic red snapper (***Lutjanus campechanus***) monitoring in Florida for the 2013 season	Sauls et al. 2014
SEDAR41-RD16	A directed study of the recreational red snapper fisheries in the Gulf of Mexico along the West Florida shelf	Sauls et al. 2014
SEDAR41-RD17	Using generalized linear models to estimate	Bacheler et al. 2009

	selectivity from short-term recoveries of tagged red drum ***Sciaenops ocellatus***: Effects of gear, fate, and regulation period	
SEDAR41-RD18	Direct estimates of gear selectivity from multiple tagging experiments	Myers and Hoenig 1997
SEDAR41-RD19	Examining the utility of alternative video monitoring metrics for indexing reef fish abundance	Schobernd et al. 2014
SEDAR41-RD20	An evaluation and power analysis of fishery independent reef fish sampling in the Gulf of Mexico and U.S. South Atlantic	Conn 2011
SEDAR41-RD21	Consultant's Report: Summary of the MRFSS/MRIP Calibration Workshop	Boreman 2012
SEDAR41-RD22	2013 South Atlantic Red Snapper Annual Catch Limit and Season Length Projections	SERO 2013
SEDAR41-RD23	Southeast Reef Fish Survey Video Index Development Workshop	Bacheler and Carmichael 2014
SEDAR41-RD24	Observer Coverage of the 2010-2011 Gulf of Mexico Reef Fish Fishery	Scott-Denton and Williams
SEDAR41-RD25	Circle Hook Requirements in the Gulf of Mexico: Application in Recreational Fisheries and Effectiveness for Conservation of Reef Fishes	Sauls and Ayala 2012
SEDAR41-RD26	GADNR Marine Sportfish Carcass Recovery Project	Harrell 2013
SEDAR41-RD27	Catch Characterization and Discards within the Snapper Grouper Vertical Hook-and-Line Fishery of the South Atlantic United States	Gulf and South Atlantic Fisheries Foundation 2008
SEDAR41-RD28	A Continuation of Catch Characterization and Discards within the Snapper Grouper Vertical Hook-and-Line Fishery of the South Atlantic United States	Gulf and South Atlantic Fisheries Foundation 2010
SEDAR41-RD29	Continuation of Catch Characterization and Discards within the Snapper Grouper Vertical Hook-and-Line Fishery of the South Atlantic United States	Gulf and South Atlantic Fisheries Foundation 2013
SEDAR41-RD30	Amendment 1 and Environmental Assessment and Regulatory Impact Review to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region	SAFMC 1988
SEDAR41-RD31	Final Rule for Amendment 1 to the Fishery	Federal Register

	Management Plan for the Snapper Grouper Fishery of the South Atlantic Region	1989
SEDAR41-RD32	Population Structure and Genetic Diversity of Red Snapper (Lutjanus campechanus) in the U.S. South Atlantic and Connectivity with Red Snapper in the Gulf of Mexico	Gold and Portnoy 2013
SEDAR41-RD33	Oogenesis and fecundity type of Gulf of Mexico gray triggerfish reflects warm water environmental and parental care	Lang and Fitzhugh 2014
SEDAR41-RD34	Depth-related Distribution of Postjuvenile Red Snapper in Southeastern U.S. Atlantic Ocean Waters: Ontogenetic Patterns and Implications for Management	Mitchell et al. 2014
SEDAR41-RD35	Gray Triggerfish Age Workshop	Potts 2013
SEDAR41-RD36	Age, Growth, and Reproduction of Gray Triggerfish ***Balistes capriscus*** Off the Southeastern U.S. Atlantic Coast	Kelly 2014
SEDAR41-RD37	Assessment of Genetic Stock Structure of Gray Triggerfish (***Balistes capriscus***) in U.S. Waters of the Gulf of Mexico and South Atlantic Regions	Saillant and Antoni 2014
SEDAR41-RD38	Genetic Variation of Gray Triggerfish in U.S. Waters of the Gulf of Mexico and Western Atlantic Ocean as Inferred from Mitochondrial DNA Sequences	Antoni et al. 2011
SEDAR41-RD39	Characterization of the U.S. Gulf of Mexico and South Atlantic Penaeid and Rock Shrimp Fisheries Based on Observer Data	Scott-Denton et al. 2012
SEDAR41-RD40	Does hook type influence the catch rate, size, and injury of grouper in a North Carolina commercial fishery	Bacheler and Buckel 2004
SEDAR41-RD41	Fishes associated with North Carolina shelf-edge hardbottoms and initial assessment of a proposed marine protected area	Quattrini and Ross 2006
SEDAR41-RD42	Growth of grey triggerfish, ***Balistes capriscus***, based on growth checks of the dorsal spine	Ofori-Danson 1989
SEDAR41-RD43	Age Validation and Growth of Gray Triggerfish, ***Balistes capriscus***, In the Northern Gulf of Mexico	Fioramonti 2012
SEDAR41-RD44	A review of the biology and fishery for Gray Triggerfish, ***Balistes capriscus***, in the Gulf of Mexico	Harper and McClellan 1997

SEDAR41-RD45	Stock structure of gray triggerfish, ***Balistes capriscus***, on multiple spatial scales in the Gulf of Mexico	Ingram 2001
SEDAR41-RD46	Evaluation of the Efficacy of the Current Minimum Size Regulation for Selected Reef Fish Based on Release Mortality and Fish Physiology	Burns and Brown-Peterson 2008
SEDAR41-RD47	Population Structure of Red Snapper from the Gulf of Mexico as Inferred from Analysis of Mitochondrial DNA	Gold et al. 1997
SEDAR41-RD48	Successful Discrimination Using Otolith Microchemistry Among Samples of Red Snapper ***Lutjanus campechanus*** from Artificial Reefs and Samples of ***L.campechanus*** Taken from Nearby Oil and Gas Platforms	Nowling et al. 2011
SEDAR41-RD49	Population Structure and Variation in Red Snapper (Lutjanus campechanus) from the Gulf of Mexico and Atlantic Coast of Florida as Determined from Mitochondrial DNA Control Region Sequence	Garber et al. 2003
SEDAR41-RD50	Population assessment of the red snapper from the southeastern United States	Manooch et al. 1998
SEDAR41-RD51	Otolith Microchemical Fingerprints of Age-0 Red Snapper, ***Lutjanus campechanus***, from the Northern Gulf of Mexico	Patterson et al. 1998
SEDAR41-RD52	Implications of reef fish movement from unreported artificial reef sites in the northern Gulf of Mexico	Addis et al. 2013
SEDAR41-RD53	Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species	Then et al. 2014
SEDAR41-RD54	Length selectivity of commercial fish traps assessed from in situ comparisons with stereo-video: Is there evidence of sampling bias?	Langlois et al. 2015
SEDAR41-RD55	MRIP Calibration Workshop II – Final Report	Carmichael and Van Vorhees (eds.) 2015
SEDAR41-RD56	Total Removals of red snapper (***Lutjanus campechanus***) in 2014 from the U.S. South Atlantic	SEFSC 2015
SEDAR41-RD57	Assessing reproductive resilience: an example with South Atlantic red snapper ***Lutjanus campechanus***	Lowerre-Barbiere et al. 2015

SEDAR41-RD58	Overview of sampling gears and standard protocols used by the Southeast Reef Fish Survey and its partners	Smart et al. 2014
SEDAR41-RD59	MRIP Transition Plan for the Fishing Effort Survey	Atlantic and Gulf Subgroup of the MRIP Transition Team 2015
SEDAR41-RD60	Technical documentation of the Beaufort Assessment Model (BAM)	Williams and Shertzer 2015
SEDAR41-RD61	Stock Assessment of Red Snapper in the Gulf of Mexico 1872-2013, with Provisional 2014 Landings: SEDAR Update Assessment	Cass-Calay et al. 2015
SEDAR41-RD62	Excerpt from the December 2013 SAFMC SEDAR Committee Minutes (pages 11-21 where SEDAR 41 ToR were discussed)	SAFMC SEDAR Committee
SEDAR41-RD63	Population structure of red snapper (***Lutjanus campechanus)*** in U.S. waters of the western Atlantic Ocean and the northeastern Gulf of Mexico	Hollenbeck et al. 2015
SEDAR41-RD64	SEDAR31-AW04: The Effect of Hook Type on Red Snapper Catch	Saul and Walter 2013
SEDAR41-RD65	SEDAR31-AW12: Estimation of hook selectivity on red snapper (***Lutjanus campechanus***) during a fishery independent survey of natural reefs in the Gulf of Mexico	Pollack et al. 2013
SEDAR41-RD66	Effect of Circle Hook Size on Reef Fish Catch Rates, Species Composition, and Selectivity in the Northern Gulf of Mexico Recreational Fishery	Patterson et al. 2012
SEDAR41-RD67	Effect of trawling on juvenile red snapper (***Lutjanus campechanus***) habitat selection and life history parameters	Wells et al. 2008
SEDAR41-RD68	SEDAR24-AW05: Selectivity of red snapper in the southeast U.S. Atlantic: dome-shaped or flat topped?	SFB-SEFSC 2010
SEDAR41-RD69	Hierarchical analysis of multiple noisy abundance indices	Conn 2010
SEDAR41-RD70	Data weighting in statistical fisheries stock assessment models	Francis 2011
SEDAR41-RD71	Corrigendum to Francis 2011 paper	Francis
SEDAR41-RD72	Quantifying annual variation in catchability for	Francis et al. 2003

	commercial and research fishing	
SEDAR41-RD73	Evolutionary assembly rules for fish life histories	Charnov et al. 2012
SEDAR41-RD74	User's Guide for ASPIC Suite, version 7: A Stock-Production Model Incorporating Covariates and auxiliary programs	Prager 2015
SEDAR41-RD75	Standing and Special Reef Fish SSC, September 2015 Meeting Summary (see pages 4-7 for SEDAR 43 review)	Gulf of Mexico Standing and Special Reef Fish SSC
SEDAR41-RD76	Standing and Special Reef Fish SSC, January 2016 Meeting Summary (see pages 2-7 for SEDAR 43 review)	Gulf of Mexico Standing and Special Reef Fish SSC
SEDAR41-RD77	SEDAR 43 Gulf of Mexico Gray Triggerfish Stock Assessment Report	SEDAR 43

1.5 Statements Addressing Each Term of Reference

The following are the terms of reference with a statement explaining how each was addressed in the assessment report:

Assessment Workshop Terms of Reference

1. Review any changes in data following the data workshop and any analyses suggested by the data workshop. Summarize data as used in each assessment model. Provide justification for any deviations from Data Workshop recommendations.

- ***The data review and data updates are provided in Sections 2.1 and 2.2. Tables, figures and written justification are provided for each data change.***

2. Develop population assessment models that are compatible and appropriate with available data. Document input data, model assumptions and configuration, and equations for each model considered.

- ***The stock assessment model configuration is described in Sections 3.1 through 3.16. The equations are provided in a technical memorandum referenced in Section 3.1.***

3. Provide estimates of stock population parameters, including: fishing mortality, abundance, biomass, selectivity, stock-recruitment relationship, and other parameters as necessary to describe the population. Provide appropriate measures of precision for parameter estimates.

- ***Estimated parameters are listed in Section 4.2. Specific estimate sections are as follows: fishing mortality – Section 4.6, abundance – Section 4.3, biomass – Section 4.4, selectivities – Section 4.5, and stock-recruitment relationship – Section 4.7. Measures of precision are provided by the Monte Carlo Bootstrap uncertainty analysis and are described and displayed alongside the point estimates.***

4. Characterize uncertainty in the assessment and estimated values. Consider uncertainty in input data, modeling approach, and model configuration. Provide a continuity model consistent with the prior assessment configuration, if one exists, updated to include the most recent observations. Alternative approaches to a strict continuity run that distinguish between model, population, and input data influences on findings, may be considered. Consider and include other sources of uncertainty as appropriate for this assessment. Provide appropriate statistical measures of model performance, reliability, and 'goodness of fit'. Provide measures of uncertainty for estimated parameters.

- ***Uncertainty in the assessment is captured by the analyses described in Section 3.24. The MCB analysis considered uncertainty in the data through the bootstrap step (described in Section 3.24.1), and used a probabilistic framework to capture uncertainty in key parameter estimates (Sections 3.25-3.28). A continuity run was done through sensitivity analysis where the key assumptions made for the previous benchmark assessment were adopted, but current data were used (Sections 3.20 and 4.11, sensitivity 24). Measures of goodness of fit are described in Section 3.18, and multiple supplementary plots are provided in SEDAR41-RW04. Measures of uncertainty for estimated parameters are provided by the MCB analysis.***

5. Provide estimates of yield and productivity. Include yield-per-recruit, spawner-per-recruit, and stock-recruitment models.

- ***Per recruit and equilibrium analyses are provided in Section 4.8.***

6. Provide estimates of population benchmarks or management criteria consistent with the available data, applicable FMPs, proposed FMPs and Amendments, other ongoing or proposed management programs, and National Standards. Evaluate existing or proposed management criteria as specified in the management summary. Recommend proxy values when necessary.

- ***The current proxy used in the rebuilding plan for Red Snapper is $F_{30\%}$, and that was used as a reference point for stock status determination. Those estimates are provided in Section 4.9.***

7. Provide declarations of stock status relative to management benchmarks, or alternative data poor approaches if necessary.

- ***The measures of stock status are in Section 4.10 along with measures of their uncertainty.***

8. Provide uncertainty distributions of proposed reference points and stock status metrics that provides the values indicated in the management specifications. Include probability density functions for biological reference point estimates and population metrics (e.g., biomass and exploitation) used to evaluate stock status.

- ***The distributions of the stock status are described in Section 4.10, and the corresponding plots are Figures 36, 38 and 39.***

9. Project future stock conditions (biomass, abundance, and exploitation; including probability density functions) and develop rebuilding schedules if warranted; include estimated generation time. Develop stock projections for the following circumstances, in accordance with the guidance on management needs provided in the management history:
A) If stock is overfished: F=0, F=current, F=Fmsy, Ftarget, F=Frebuild (max exploitation that rebuilds in greatest allowed time), Fixed landings equal to the ABC
B) If stock is overfishing: F=Fcurrent, F=Fmsy, F= Ftarget, Fixed landings equal to the ABC

- ***The stock is estimated to be overfished with overfishing occurring, therefore five standard projections were performed: $F=0$, $F=F_{current}$, $F=_{Fmsy\ proxy}$, F_{target}, $F=F_{rebuild}$ (max exploitation that rebuilds in greatest allowed time). Section 3.29 contains the descriptions of the runs, and Section 4.12 contains the results. The fixed landings projection will be performed when the SSC provides suggested ABCs.***

10. Compare and contrast productivity measures and assessment assumptions between the Gulf of Mexico and South Atlantic stocks.

- ***The table addressing this ToR is found in Section 9.***

11. Provide recommendations for future research, data collection and assessments. Be as specific as practicable in describing sampling design and sampling intensity. Emphasize items which will improve future assessment capabilities and reliability, and reduce uncertainty. Consider data, monitoring, and assessment needs.

- ***Research recommendations are in Section 5.3.***

12. Complete the Assessment Workshop Report in accordance with project schedule deadlines (Section III of the SEDAR Stock Assessment Report) – ***Report submitted on time.***

2 Data Review and Update

The input data for this assessment are described below, with focus on modifications from the SEDAR41 DW.

2.1 Data Review

In this benchmark assessment, the Beaufort assessment model (BAM) was fitted to data sources developed during the SEDAR 41 DW with some modifications and additions.

Model input compiled during the DW

- Life history: Life history meristics, population growth, female maturity, proportion female, number of batches at age, size-dependent batch fecundity, and discard mortality
- Landings and discards: Commercial handline landings and discards, Headboat landings and discards, Recreational landings and discards
- Indices of abundance: Commercial handline, Headboat, Headboat discards, SERFS chevron trap, SERFS video

Model input modified or developed after the DW

- Life history: Fishery-dependent growth estimates, Growth estimates during the 20 inch size regulation, Age–specific natural mortality
- Landings and discards: changes to the recreational discards
- Indices of abundance: Fishery–independent indices combined (Chevron trap and Video)
- Length compositions: Commercial handline, Headboat, Recreational
- Age compositions: Commercial handline, Headboat, Recreational, Chevron trap

2.2 Data Update

2.2.1 Life History

Estimates of the von Bertalanffy growth parameters were provided by the DW for the population as a whole: (911mm, 0yr^{-1}, and 0yr). Two alternative von Bertalanffy curves were generated: one for all fisheries when no size limit was in place, and another to represent the fish captured by all fisheries under a 20 inch size limit regulation. Age-specific mortality was updated due to an error in the original calculation which forced the t_0 value to 0. Life-history information is summarized in Tables 1 and 2.

2.2.2 Landings and Discards

The fleet structure to be modeled was decided after the DW. The general recreational fleet comprises the charterboat and private boat fleets, while the headboat fleet stands alone. The decision was made to separate headboat from all other recreational fishing modes because length compositions diverge later in the time series. The general recreational fleet discards contained some zeros (years 1982, 1986, and 1990) that the panel considered unlikely to be accurate due to the magnitude of the surrounding years' values. The decision was made by the panel to fill in the zeros with the lowest observed discards in the regulatory time block of the zero value. Total removals as used in the assessment are in Table 3.

2.2.3 Indices of Abundance

The DW provided a SERFS chevron trap and video index separately. However, because the data are collected from the same sampling platforms (i.e. cameras mounted on the chevron traps), the two indices are not independent measures of abundance. Therefore, the panel decided to combine the two using the Conn (2010) method for combining indices. All indices and their corresponding CVs are shown in Table 4, and Figure 1 shows the indices as recommended by the data workshop plotted with the new CVID index for comparison. Fishery dependent indices of abundance were assumed to have CVs of 0.2, which is consistent with Francis (2003).

2.2.4 Length Compositions

Length compositions for all data sources were developed in 3-cm bins over the range 21–99 cm (labeled at bin center). All lengths below and above the minimum and maximum bins were pooled. The commercial handline, general recreational and headboat lengths were weighted by the region and landings (SEDAR41-AW05 2015). For inclusion, length compositions in any given year had to meet the sample size criteria of $nfish > 30$ and $ntrips \geq 10$ (Table 5). Furthermore, the AW panel decided to eliminate length comps where age comps were available. There were conflicts between the length compositions and age compositions, and the panel thought, given the relative ease of ageing this species and the fact the model is age-structured, the age compositions would provide more informative signals of year-class strength and better represent the catch in each fleet or survey.

2.2.5 Age Compositions

For age composition data, the upper range was pooled at 13 years old because a very small proportion of the data exist past age 13. The age compositions were weighted by the length compositions in attempt to address bias in selection of fish to be aged. For inclusion, age compositions in any given year had to meet the sample size criteria of $nfish > 10$ and $ntrips \geq 10$ (Table 5). Age composition was preferred over length composition when both were available from a given fleet in a given year.

2.2.6 Additional Data Considerations

Size limits were in place beginning in 1983 (12 inch minimum size limit TL), and changed in 1992 (20 inch minimum size limit TL). A moratorium was put in place for Red Snapper in 2010, and three subsequent mini-seasons were allowed (2011-2014) with no size limit. The panel examined size composition data and determined that three time blocks should be used to account for size limits, or the lack thereof: 1950-1991, 1992-2009, and 2010-2014. Data available for this assessment are summarized in Tables 1–5.

3 Stock Assessment Methods

3.1 Overview

The primary model discussed during the Assessment Workshop (AW) was a statistical catch-age model implemented using the Beaufort Assessment Model (BAM) software (Williams and Shertzer 2015). BAM applies a statistical catch-age formulation, coded using AD Model Builder (Fournier et al. 2012). BAM is referred to as an integrated analysis because it uses all population dynamics-relevant data (e.g. removals, length and age compositions, and indices of abundance) in a single modeling framework. In contrast, production models (e.g. ASPIC or ASPM) or catch curve analyses only use subsets of the available data and often require simplifying assumptions. In essence, the catch-age model simulates a population forward in time while including fishing processes (Quinn and Deriso 1999; Shertzer et al. 2008). Quantities to be estimated are systematically varied until characteristics of the simulated population matches available data on the real population. The model is similar in structure to Stock Synthesis (Methot 1989; 2009). Versions of BAM have been used in previous SEDAR assessments of reef fishes in the U.S. South Atlantic, such as Red Porgy, Black Sea Bass, Tilefish, Blueline Tilefish, Gag, Greater Amberjack, Red Grouper, Snowy Grouper, and Vermilion Snapper, as well as in the previous SEDAR assessments of Red Snapper (SEDAR24 2010). In addition, a surplus production model implemented using ASPIC and a catch curve analysis (SEDAR41-AW08 2015) were used to provide supplementary information.

3.2 Data Sources

The catch-age model included data from three fleets that caught Red Snapper in southeastern U.S. waters: general recreational (charter and private boat), commercial handlines (hook-and-line), and recreational headboats. The model was fitted to data on annual landings (in numbers for the recreational fleets, in whole weight for commercial fleet); annual discards (in numbers for all fleets), annual length compositions of removals; annual age compositions of landings and surveys; three fishery dependent indices of abundance (commercial handlines, headboat, and headboat discards); and one fishery independent index of abundance (combined SERFS chevron trap and SERFS video index). Removals included landings and dead discards, assuming the mortality rates provided by the Data Workshop. Data used in the model are tabulated in §2 of this report.

3.3 Model Configuration

The assessment time period was 1950–2014. A general description of the assessment model follows.

3.4 Stock dynamics

In the assessment model, new biomass was acquired through growth and recruitment, while abundance of existing cohorts experienced exponential decay from fishing and natural mortality. The population was assumed closed to immigration and emigration. The model included age classes $1 - 20^+$, where the oldest age class 20^+ allowed for the accumulation of fish (i.e., plus group).

3.5 Initialization

Initial (1950) numbers at age assumed the stable age structure computed from expected recruitment and the initial, age-specific total mortality rate. That initial mortality was the sum of natural mortality and fishing mortality, where fishing mortality was the product of an initial fishing rate (F_{init}) and F-weighted average selectivity. The initial fishing rate was estimated using a prior centered around $F_{\text{init}} = 0.03$. The assumption matches what was used for SEDAR24 with the justification that the value should be small given the relatively low volume of landings prior to the assessment period. The initial recruitment in 1950 was assumed to be the expected value from the spawner-recruit curve. For the remainder of the initialization period (1950–1977), recruitment was assumed equal to expected values. Without sufficient age/length composition data prior to 1978, there is little information to estimate those historic recruitment deviations with accuracy.

3.6 Natural mortality rate

The natural mortality rate (M) was assumed constant over time, but decreasing with age. The form of M as a function of age was based on Charnov et al. (2013), a change from SEDAR24 which based natural mortality on the findings of Lorenzen (1996). The Charnov et al. (2013) approach inversely relates the natural mortality at age to somatic growth. As in previous SEDAR assessments, the age-dependent estimates of M_a were rescaled to provide the same fraction of fish surviving from age 4 through the oldest observed age (51 yr) as would occur with constant $M = 0.134$. This approach using cumulative mortality allows that fraction at the oldest age to be consistent with the findings of Then et al. (2014).

3.7 Growth

Mean size at age of the population, fishery removals under no size limit, and fishery removals under a 20 inch size limit (total length, TL) were modeled with the von Bertalanffy equation, and weight at age (whole weight, WW) was modeled as a function of total length (Figure 2, Table 2). Parameters of growth and conversions (TL-WW) were treated as input to the assessment model. For fitting length composition data, the distribution of size at age was assumed normal with a CV estimated by the assessment model for each growth curve.

3.8 Female maturity and sex ratio

Female maturity was modeled with a logistic function; parameters for this model and a vector of maturity at age were provided by the DW and treated as input to the assessment model (Table 2). The sex ratio was assumed to be 50:50, as recommended by the DW.

3.9 Spawning stock

Spawning biomass was modeled as population fecundity (number of eggs). For Red Snapper, peak spawning was considered to occur at the end of June. This included information on batch size as a function of age, as well as information on the number of annual batches as a function of age (SEDAR41-DW49 (2015) and Fitzhugh et al. (2012)).

3.10 Recruitment

Expected recruitment of age-1 fish was predicted from spawning biomass using the Beverton–Holt spawner-recruit model. Steepness, h, is a key parameter of this model, and unfortunately it is often difficult to estimate reliably (Conn et al. 2010). In this assessment, many initial attempts to estimate steepness resulted in a value near its upper bound of 1.0, indicating that the data were insufficient for estimation. Likelihood profiling showed that the value was likely above 0.92, and was unreliably estimated between 0.92 and 0.98. The AW Panel decided to assume an average annual recruitment while estimating lognormal deviations around that average. This was achieved by fixing steepness at $h = 0.99$.

3.11 Landings

Time series of landings from three fleets were modeled: commercial handline (1950–2014), general recreational (1955–2014), and headboat (1955–2014). Landings were modeled with the Baranov catch equation (Baranov 1918) and were fitted in either weight or numbers, depending on how the data were collected (1000 lb whole weight for commercial fleets, and 1000 fish for recreational). The DW provided observed landings back to the first assessment year (1950) for the commercial fleet and back to 1955 for the recreational fleets. However, sampling of headboats began in 1972 and other recreational sectors in 1981. Thus, historic landings of the recreational fleets were estimated indirectly by the DW using the FHWAR ratio method (SEDAR41 41dw17). Historic landings were considered (and treated) in this assessment as a primary source of uncertainty.

3.12 Discards

As with landings, discard mortalities (in units of 1000 fish) were modeled with the Baranov catch equation (Baranov 1918), which required estimates of discard selectivities and release mortality probabilities. Discards were assumed to have fleet-specific, year-specific mortality probabilities, as suggested by the DW. Until 2007, the rate for commercial handlines was 0.48, and 0.38 thereafter. Until 2011, the general recreational and headboat rate was 0.37, with 0.285 thereafter. Annual discard mortalities, as fit by the model, were computed by multiplying total discards (tabulated in the DW report) by the fleet-specific and year-specific discard mortality rate. For general recreational and headboat fleets, discard time series were assumed to begin in 1981; for the commercial handlines fleet, discards were modeled starting in 1992 corresponding to the implementation of the 20-inch size limit.

3.13 Fishing

For each time series of removals (landings and discards), the assessment model estimated a separate full fishing mortality rate (F). Age-specific rates were then computed as the product of full F and selectivity at age. The across-fleet annual F was represented by apical F, computed as the maximum of F at age summed across fleets.

3.14 Selectivities

Selectivity curves applied to landings were estimated using a parametric approach. This approach applies plausible structure on the shape of the curves, and achieves greater parsimony than occurs with unique parameters for each age. Flat-topped selectivities were modeled as a two-parameter logistic function. Dome-shaped selectivities were modeled by combining two logistic functions: a two-parameter logistic function to describe the ascending limb of the curve, and a two-parameter logistic function to describe the descending limb. To model landings, the AW Panel recommended flat-topped selectivity for commercial handlines and dome-shaped selectivity for headboat and the general recreational fleets.

The assessment panel devoted substantial discussion and exploration to the pattern (flat-topped or dome-shaped) of selectivity at age. Several working papers and scientific literature (SEDAR24-AW05, SEDAR24-AW09, SEDAR24-AW12, SEDAR31-AW04, SEDAR31-AW12, SEDAR41-DW50, SEDAR41-DW08, Patterson et al. (2012), Wells et al. (2008), and Mitchell et al. (2014)) helped guide the panel's decisions by providing insight into selectivity based on length and age compositions, depth distributions of fishing effort, skill levels of fishermen, and how circumstances contrasted between the Atlantic and Gulf of Mexico. The choice of flat-topped selectivity for commercial handlines landings and dome-shaped for all others was based on several criteria. Two related considerations were the fleet-specific depths of fishing effort and the distribution of age at depth. In general, the commercial handlines fleet fish

in deeper water than other fleets, and although there was only weak correlation between depth and age of older fish (5^+), younger fish (1–5) were more readily caught in shallower depths (SEDAR24-AW05, and Mitchell et al. (2014)). It was also suggested that commercial gear and fishermen can better handle larger fish (SEDAR24-AW12). Catch curve data were consistent with the hypothesis that older fish are more vulnerable to the commercial handlines fleet than to recreational fleets (SEDAR41-AW08 2015).

Selectivity of each fleet was fixed within each block of size-limit regulations, but was permitted to vary among blocks where possible or reasonable. Fisheries experienced four blocks of size-limit regulations (no limit prior to 1983, 12-inch limit during 1983–1991, 20-inch limit during 1992–2009, and no size limit during the moratorium/miniseasons 2010–2014). However, the panel combined blocks one and two after seeing that the 12-inch size limit had a negligible effect on the selectivity pattern. Age and length composition data are critical for estimating selectivity parameters, and ideally, a model would have sufficient composition data from each fleet over time to estimate distinct selectivities in each period of regulations. That was not the case here, and thus additional assumptions were applied to define selectivities, as follows. Because the general recreational fleet had little age or length composition data prior to 1998, this fleet mirrored the headboat fleet until the final time block. All domed-shaped selectivities meant to characterize landings were configured so as not to allow a selectivity of 0 at older ages, which was considered implausible. Size and age composition data show larger, older fish are caught by all fleets. However, the selectivity functions would reach zero before the plus group age of 20. Therefore, the panel examined the age composition data and used the information they contained to create a plus group for the selectivities. Headboat selectivities were fixed as constant after age 10 at the value estimated for age 10. For the general recreational fleet, the constant age at which we fixed selectivity was 13. These plus groups were consistent with how the age composition data were fitted.

Selectivities of discards were estimated in a similar fashion to the landings in that the general recreational fleet discards mirrored the headboat fleet discards. Both the commercial handline discards and the headboat discards had sufficient length composition to estimate selectivities.

Selectivities of fishery dependent indices were the same as those of the relevant fleet. The fishery independent CVID index selectivity was assumed logistic and informed by the SERFS chevron trap age compositions.

3.15 Indices of abundance

The model was fit to three fishery dependent indices of relative abundance (headboat 1976–2009; headboat discards 2005–2014; and commercial handlines 1993–2009), and one fishery independent index of abundance (SERFS combined video and trap, CVID). Predicted indices were conditional on selectivity of the corresponding fleet or survey, and were computed from abundance at the midpoint of the year or, in the case of commercial handlines, biomass. The headboat discard index tracks small fish (less than 20 inches) and was included as a measure of recruitment strength.

3.16 Catchability

In the BAM, catchability scales indices of relative abundance to the estimated population at large. For the base model, the AW Panel recommended a time-invariant catchability.

A sensitivity run adopted a time-varying catchability for the headboat index. In this formulation, catchability was estimated in two stanzas, pre- and post-1992. Choice of the year 1992 was based on the implementation of a fishery management plan that may have changed fishing behavior.

3.17 Biological reference points

Biological reference points (benchmarks) were calculated based on the fishing rate that would allow a stock to attain 30% of the maximum spawning potential which would have been obtained in the absence of fishing mortality. Computed benchmarks included the MSY proxy, fishing mortality rate at $F_{30\%}$, total biomass at $F_{30\%}$, and spawning stock at $F_{30\%}$ (Gabriel and Mace 1999). In this assessment, spawning stock measures total eggs of the mature stock. These benchmarks are conditional on the estimated selectivity functions and the relative contributions of each fleet's fishing mortality. The selectivity pattern used here was the effort-weighted selectivities at age, with effort from each fleet estimated as the full F averaged over the last three years of the assessment.

3.18 Fitting criterion

The fitting criterion was a penalized likelihood approach in which observed removals (landings and discards) were fit closely, and observed composition data and abundance indices were fit to the degree that they were compatible. Removals and index data were fit using lognormal likelihoods. Length and age composition data were fit using robust multinomial likelihoods (Francis 2011), and only from years that met minimum sample size criteria ($nfish > 30$ and $ntrips \geq 10$) for length compositions and ($nfish > 10$ and $ntrips \geq 10$) for age compositions. Commercial and headboat discard length composition minimum sample size threshold was set lower ($nfish > 10$) due to the fact that the discard composition data were the only information available to estimate selectivity.

The model includes the capability for each component of the likelihood to be weighted by user-supplied values. For data components, these weights were applied by either adjusting CVs (lognormal components) or adjusting effective sample sizes (multinomial components). In this application to Red Snapper, CVs of landings and discards (in arithmetic space) were assumed equal to 0.05, to achieve a close fit to these time series yet allowing some imprecision. In practice, the small CVs are a matter of computational convenience, as they help achieve the desired result of close fits to the landings, while avoiding having to solve the Baranov equation iteratively (which is complex when there are multiple fisheries). Weights on other data components (indices, age/length compositions) were adjusted iteratively, starting from initial weights as follows. The CVs of indices were set equal to the values estimated by the GLMs used for standardization or at the fixed value of 0.2 for the headboat and commercial handline indices. Effective sample sizes of the multinomial components were assumed equal to the number of trips sampled annually, rather than the number of fish measured, reflecting the belief that the basic sampling unit occurs at the level of trip. These initial weights were then adjusted until standard deviations of normalized residuals were near 1.0 (Francis 2011). In sensitivity runs, weights on the fishery dependent indices were adjusted upward to explore their effects (not because up-weighted runs were considered equally plausible).

For parameters defining selectivities, CV of size at age, and σ_R, normal priors were applied to maintain parameter estimates near reasonable values, and to prevent the optimization routine from drifting into parameter space with negligible gradient in the likelihood. For σ_R, the prior mean (0.6) and standard deviation (0.25) were based on Beddington and Cooke (1983) and Mertz and Myers (1996).

3.19 Configuration of a base run

The base run was configured as described above. This configuration does not necessarily represent reality better than all other possible configurations, and thus this assessment attempted to portray uncertainty in point estimates through sensitivity analyses and through a Monte-Carlo/bootstrap approach (described below).

3.20 Sensitivity analyses

Sensitivity runs were chosen to investigate issues that arose specifically with this benchmark assessment. They were intended to demonstrate directionality of results with changes in inputs or simply to explore model behavior, and not all were considered equally plausible. These model runs vary from the base run as follows:

- S1: Remove the 2008 and 2009 years from the handline and headboat indices
- S2: Upweight fishery independent index further than was explored in the Assessment Workshop (10X likelihood weight after the iterative reweighting)
- S3: Upweight handline and headboat indices (3X likelihood weight after iterative reweighting)
- S4: Fishery dependent indices only
- S5: High value of M
- S6: Low value of M
- S7: Low discard mortality probabilities (commercial handlines rate set to 0.38 or 0.28, all recreational set to 0.27 or 0.20)
- S8: High discard mortality probabilities (commercial handlines rate set to 0.58 or 0.48, all recreational set 0.45 or 0.36)
- S9: Longer combined chevron trap and video (CVID) index (2005-2014)
- S10: Reduced general recreational landings in 1984 and 1985 by taking the geometric mean of surrounding years
- S11: Steepness $h = 0.84$
- S12: Headboat discard index excluded after 2009
- S13: Ageing error matrix included
- S14: Low value for age-specific number of batches
- S15: High value for age-specific number of batches
- S16: Headboat discard index dropped
- S17: High landings
- S18: Low landings
- S19: High discards
- S20: Low discards
- S21: Dome-shaped selectivity for commercial handline fleet
- S22: Separate video and trap index rather than a single CVID index
- S23: Fishery independent index only
- S24: Continuity run: changes include SEDAR24 values such as M, steepness, maturity, and SSB
- S25: Two time blocks for Headboat logbook index catchability (pre- and post-1992)
- S26: Retrospective - 1 year of data
- S27: Retrospective - 2 years of data
- S28: Retrospective - 3 years of data
- S29: Retrospective - 4 years of data

- S30: Use 1978 as the starting year, applied a loose prior to the estimation of F_{init} that corresponds to the geometric mean of the fishing mortality for 1950-1977
- S31: Estimate selectivities without fixing a plus group (for the selectivity estimation)

Sensitivities 5, 6, 14, 15, and 17-20 used the 10th and 90th quantiles (as the low and the high respectively) from the bootstraps of the observed data described in the uncertainty analysis methods (Section 3.24).

3.21 Parameters Estimated

The model estimated annual fishing mortality rates of each fleet, selectivity parameters, catchability coefficients associated with indices, parameters of the spawner-recruit model (except steepness), annual recruitment deviations, and CV of size at age for each age and growth relationship.

3.22 Per Recruit and Equilibrium Analyses

Yield per recruit and spawning potential ratio were computed as functions of F, as were equilibrium landings and spawning biomass. Equilibrium landings and discards were also computed as functions of biomass B, which itself is a function of F. As in the computation of benchmarks (described in §3.23), per recruit and equilibrium analyses applied the most recent selectivity patterns averaged across fleets, weighted by each fleet's F from the last three years of the assessment (2012–2014).

3.23 Benchmark/Reference Point Methods

In this assessment of Red Snapper, the quantities $F_{30\%}$, $\text{SSB}_{\text{F}30\%}$, $B_{\text{F}30\%}$, and $L_{\text{F}30\%}$ were estimated as proxies for MSY-based reference points. Steepness was not reliably estimable, so the stock-recruit relationship was not used to identify a maximum yield. Instead, steepness was fixed at 0.99 in order to assume an average level of recruitment while estimating deviations around the mean. $F_{30\%}$ was used in the rebuilding plan for Red Snapper, therefore, it was used here to generate fishing benchmarks. However, because the stock-recruitment relationship was not estimated, assumptions about recruitment are required to generate biomass benchmarks. Here, equilibrium recruitment was assumed equal to expected recruitment (arithmetic average). On average, expected recruitment is higher than that estimated directly from the spawner-recruit curve, because of lognormal deviation in recruitment. Thus, in this assessment, the method of benchmark estimation accounted for lognormal deviation by including a bias correction in equilibrium recruitment. The bias correction (ς) was computed from the variance (σ_R^2) of recruitment deviation in log space: $\varsigma = \exp(\sigma_R^2/2)$. Then, equilibrium recruitment (R_{eq}) associated with any F is,

$$R_{eq} = \frac{R_0 \left[\varsigma 0.8 h \Phi_F - 0.2(1-h)\right]}{(h-0.2)\Phi_F} \tag{1}$$

where R_0 is virgin recruitment, h is steepness which is fixed in this assessment, and $\Phi_F = \phi_F/\phi_0$ is spawning potential ratio given growth, maturity, and total mortality at age (including natural and fishing mortality rates). Because steepness is fixed at 0.99, R_{eq} as a function of F is approximately a straight line. The R_{eq} and mortality schedule imply an equilibrium age structure and an average sustainable yield (ASY). The estimate of $F_{30\%}$ is the F giving 30% of the SPR, and the estimate of $L_{\text{F}30\%}$ is that ASY. The estimate of $\text{SSB}_{\text{F}30\%}$ follows from the corresponding equilibrium age structure, as does the estimate of discard mortalities $D_{F30\%\}}$, here separated from ASY (and consequently, $L_{\text{F}30\%}$).

Estimates of $L_{\mathrm{F30\%}}$ and related benchmarks are conditional on selectivity pattern. The selectivity pattern used here was an average of terminal-year selectivities from each fleet, where each fleet-specific selectivity was weighted in proportion to its corresponding estimate of F averaged over the last three years (2012–2014). If the selectivities or relative fishing mortalities among fleets were to change, so would the estimates of $L_{\mathrm{F30\%}}$ and related benchmarks.

The maximum fishing mortality threshold (MFMT) is defined by the SAFMC as $F_{30\%}$, and the minimum stock size threshold (MSST) as $75\%\mathrm{SSB}_{\mathrm{F30\%}}$. Overfishing is defined as $F >$ MFMT and overfished as SSB $<$ MSST. However, because this stock is currently under a rebuilding plan, increased emphasis is given to SSB relative to $\mathrm{SSB}_{\mathrm{F30\%}}$ (rather than MSST), as $\mathrm{SSB}_{\mathrm{F30\%}}$ is the rebuilding target. Current status of the stock is represented by SSB in the latest assessment year (2014), and current status of the fishery is represented by the geometric mean of F from the latest three years (2012–2014). Recent SEDAR assessments have considered the mean over the terminal three years to be a more robust metric.

3.24 Uncertainty and Measures of Precision

As in SEDAR24, this assessment used a mixed Monte Carlo and bootstrap (MCB) approach to characterize uncertainty in results of the base run. Monte Carlo and bootstrap methods (Efron and Tibshirani 1993; Manly 1997) are often used to characterize uncertainty in ecological studies, and the mixed approach has been applied successfully in stock assessment, including Restrepo et al. (1992), Legault et al. (2001), SEDAR4 (2004), and many South Atlantic SEDAR assessments since SEDAR19 (2009). The approach is among those recommended for use in SEDAR assessments (SEDAR Procedural Guidance 2010).

The approach translates uncertainty in model input into uncertainty in model output, by fitting the model many times with different values of "observed" data and key input parameters. A chief advantage of the approach is that the results describe a range of possible outcomes, so that uncertainty is characterized more thoroughly than it could be by any single fit or handful of sensitivity runs. A minor disadvantage of the approach is that computational demands are relatively high.

In this assessment, the BAM was successively re-fit in $n = 4000$ trials that differed from the original inputs by bootstrapping on data sources, and by Monte Carlo sampling of several key input parameters. The value of $n = 4000$ was chosen because a minimum of 3000 runs were desired, and it was anticipated that not all runs would converge or otherwise be valid. Of the 4000 trials, approximately 0.88% were discarded, because the model did not properly converge (in most cases, an estimated quantity was at its upper bound). This left $n = 3965$ MCB trials used to characterize uncertainty, which was sufficient for convergence of standard errors in management quantities.

The MCB analysis should be interpreted as providing an approximation to the uncertainty associated with each output. The results are approximate for two related reasons. First, not all combinations of Monte Carlo parameter inputs are equally likely, as biological parameters might be correlated. Second, all runs are given equal weight in the results, yet some might provide better fits to data than others.

3.24.1 Bootstrap of observed data

To include uncertainty in the indices of abundance, multiplicative lognormal errors were applied through a parametric bootstrap. To implement this approach in the MCB trials, random variables ($x_{s,y}$) were drawn for each year y of time series s from a normal distribution with mean 0 and variance $\sigma^2_{s,y}$ [that is, $x_{s,y} \sim N(0, \sigma^2_{s,y})$]. Annual observations were then perturbed from their original values ($\hat{O}_{s,y}$),

$$O_{s,y} = \hat{O}_{s,y}[\exp(x_{s,y} - \sigma^2_{s,y}/2)] \tag{2}$$

The term $\sigma^2_{s,y}/2$ is a bias correction that centers the multiplicative error on the value of 1.0. Standard deviations in log space were computed from CVs in arithmetic space, $\sigma_{s,y} = \sqrt{\log(1.0 + CV^2_{s,y})}$. As used for fitting the base run, CVs of indices of abundance were those provided by, or modified from, the data providers (tabulated in Table 4 of this assessment report).

Uncertainty was modeled for historical commercial landings similarly to the indices, and by the CVs provided by the commercial working group at the DW. No commercial discard CVs, headboat landings CVs, or headboat discard CVs by year were provided, therefore the panel had to make some assumptions. We assumed a value of $CV = 0.20$ for commercial discards and headboat discards. For headboat landings, we used information from the headboat program to assume a decreasing CV by time blocks (i.e. $CV = 0.15$ 1981-1995, $CV = 0.1$ for 1996-2007, and $CV = 0.05$ thereafter). General recreational landings and discards had complementary CVs, and those were used as provided except in a few instances. A CV greater than 1 was capped at 1, which was sufficiently large to represent high uncertainty but not so high that bootstrapped values caused implausible time series. The panel thought the resulting draws sufficiently represented uncertainty in spite of the dampening of a few years' CVs (Table 6).

Uncertainty in age and length compositions were included by drawing new distributions for each year of each data source, following a multinomial sampling process. Ages (or lengths) of individual fish were drawn at random with replacement using the cell probabilities of the original data. For each year of each data source, the number of fish sampled was the same as in the original data.

3.24.2 Monte Carlo sampling

In each successive fit of the model, several parameters were fixed (i.e., not estimated) at values drawn at random from distributions described below.

3.25 Natural mortality

A vector of age-specific natural mortality was provided by the Life History Working Group. They used the Charnov et al. (2013) estimator scaled to the Then et al. (2014) max age asymptotic M, and then used the uncertainty around the determination of maximum age to provide an upper and lower bound to the M vector. The Assessment Panel thought the upper ($M = 0.14$) and lower ($M = 0.12$) bound were too similar to the base vector to represent the true uncertainty around M. Instead, the AW Panel wanted to carry the uncertainty forward in both maximum age and the parameters of the Then et al. (2014) estimator of asymptotic M:

$$M = aT^b_{max} \tag{3}$$

To estimate uncertainty in a and b, we acquired the data of Then et al. (2014) and conducted a bootstrap of $n = 10,000$ iterations, drawing from the original data set with replacement. For each MCB iterations, one of the 10,000 fits was drawn at random, thus maintaining any correlation structure between a and b. We then drew T_{max} from a uniform distribution and calculated asymptotic M. For the age-dependent vector, we started with the Charnov age-dependent curve, and scaled it to the M estimate we calculated in the previous steps. A new M value was drawn and a new age-dependent vector was calculated for each MCB trial.

3.26 Discard mortality

The discard mortality working group provided an upper and lower bound for each time block (pre- and post-regulation) and fishery (commercial and recreational). Commercial rates before 2007 ranged from 38% to 58%, and 2007 to present ranged from 28% to 48%. Recreational rates before 2011 ranged from 27% to 45%, and 2011 on ranged from 20% to 36%. The rates decreased in response to the implementation of circle hooks, which are meant to cause fewer fatal bycatch events. We drew the rate for the earlier time period for each fleet from a truncated normal distribution with mean equal to the point estimate and a standard deviation devised to provide a 95% confidence interval similar to what the working group provided above. For the later time period for each fleet we also drew from a truncated normal distribution created similarly as in the previous step but with the upper bound fixed at the random draw from the earlier time period. The last step is meant to ensure that the second value is not larger than the first, so as to maintain the feature that discard mortality has decreased due to the circle hook regulation.

3.27 Batch Fecundity

Prior to the MCB analysis, a bootstrap procedure was run on the data set used to estimate batch fecundity at age for the base run. For each of 10000 bootstrap runs, the 69 paired observations of batch fecundity and fish length were sampled 69 times with replacement, the regression model refit, and the bootstrap parameters estimates saved to a data matrix. Once all bootstraps were run, the parameter matrix was trimmed by removing runs where either parameter value was outside of its 95% confidence interval. The parameters were found to be highly correlated, so during the MCB analysis, pairs of parameters were randomly drawn, with replacement, from the trimmed bootstrap parameter matrix. For each MCB run, predicted batch fecundity at age was calculated using a set of bootstrap parameters and a vector of length at age.

3.28 Batch number

Prior to the MCB analysis, a similar but separate bootstrap procedure was run on the data set used to estimate batch number at age for the base run. For each of 10000 bootstrap runs, the 1472 paired observations of spawning indicator presence, fish length, and day of the year were sampled 1472 times with replacement and the regression model refit. Predicted batch number at age was then calculated from the bootstrap parameter estimates and a vector of length at age, and the vectors saved to a data matrix. Once all bootstraps were run, the batch number at age matrix was trimmed by first summing batch number at age for each run, yielding lifetime batch number; runs where lifetime batch number was outside of the 95% confidence interval were trimmed. During the MCB analysis, a vector of batch number at age was randomly drawn, with replacement, from the trimmed bootstrap batch number at age matrix for each MCB run.

3.29 Projections

Projections were run to predict stock status in years after the assessment, 2015–2044. The year 2044 is the last year of the current rebuilding plan.

The structure of the projection model was the same as that of the assessment model, and parameter estimates were those from the assessment. Any time-varying quantities, such as recreational selectivity, were fixed to the most recent values of the assessment period. A single selectivity curve was applied to calculate removals, averaged across fleets using geometric mean Fs from the last three years of the assessment period, similar to computation of $L_{\mathrm{F30\%}}$ benchmarks (§3.23).

Expected values of SSB (time of peak spawning), F, recruits, and removals were represented by deterministic projections using parameter estimates from the base run. These projections were built on the spawner-recruit relationship with steepness fixed ($h = 0.99$) and with bias correction, and were thus consistent with estimated benchmarks in the sense that long-term fishing at $F_{30\%}$ would yield $L_{\mathrm{F30\%}}$ from a stock size at $\mathrm{SSB}_{\mathrm{F30\%}}$. Uncertainty in future time series was quantified through stochastic projections that extended the Monte Carlo/Bootstrap (MCB) fits of the stock assessment model.

3.29.1 Initialization of projections

Initial age structure at the start of 2015 was computed by the assessment model.

Fishing rates that define the projections were assumed to start in 2017. Because the assessment period ended in 2014, the projections required an initialization period (2015–2016). For 2015, a moratorium year, the landings selectivity was set to 0 and the discard selectivity was rescaled to peak at 1. Then, an optimization routine solved for the F that matched the current dead discards (mean of 2012-2014) in numbers. In 2016, a similar routine soved for the F that matched current landings (mean of 2012-2014), assuming a mini-season would occur.

3.29.2 Uncertainty of projections

To characterize uncertainty in future stock dynamics, stochasticity was included in replicate projections, each an extension of a single MCB assessment model fit. Thus, projections carried forward uncertainties in natural mortality, reproduction, landings, discards, and discard mortalities, as well as in estimated quantities such as selectivity curves, and in initial (start of 2015) abundance at age.

Initial and subsequent recruitment values were generated with stochasticity using a Monte Carlo procedure, in which the estimated Beverton–Holt model (i.e. R_0, σ_R estimated, and $h = 0.99$) of each MCB fit was used to compute mean annual recruitment values ($\bar{R}_y$). Variability was added to the mean values by choosing multiplicative deviations at random from a lognormal distribution,

$$R_y = \bar{R}_y \exp(\epsilon_y). \tag{4}$$

Here ϵ_y was drawn from a normal distribution with mean 0 and standard deviation σ_R, where σ_R is the standard deviation from the relevant MCB fit.

The procedure generated 20,000 replicate projections of MCB model fits drawn at random (with replacement) from the MCB runs. In cases where the same MCB run was drawn, projections would still differ as a result of stochasticity in projected recruitment streams. Central tendencies were represented by the deterministic projections of the base run, as well as by medians of the stochastic projections. Precision of projections was represented graphically by the 10^{th} and 90^{th} percentiles of the replicate projections.

3.30 Rebuilding time frame

Based on results from the previous SEDAR24 benchmark assessment, Red Snapper is currently under a rebuilding plan. In this plan, the terminal year is 2044, and rebuilding is defined by the criterion that projection replicates achieve stock recovery (i.e., $\mathrm{SSB}_{2044} \geq \mathrm{SSB}_{\mathrm{F30\%}}$) with probability of at least 50%. Here, the probability of stock recovery in each year of the rebuilding plan was computed as the proportion of stochastic projections where $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F30\%}}$, with $\mathrm{SSB}_{\mathrm{F30\%}}$ taken to be iteration-specific (i.e., from that particular MCB run).

Projection scenarios Five projection scenarios were considered.

- Scenario 1: $F = 0$
- Scenario 2: $F = F_{\text{current}}$
- Scenario 3: $F = F_{30\%}$
- Scenario 4: $F_{target} = 98\% F_{30\%}$
- Scenario 5: $F = F_{\text{rebuild}}$, with rebuilding probability of 0.5 in 2044
- Scenario 6: Discards only

The F_{current} is represented by the geometric mean of fishing mortalities from 2012-2014. The F_{rebuild} is defined as the maximum F that achieves rebuilding in the allowable time frame. The discards only scenario treated the initialization year 2016 the same as 2015 (discards only), and then applied the mean F (from 2015-2016) forward starting in 2017.

3.31 Surplus Production Model

3.31.1 Overview

A logistic surplus production model, implemented in ASPIC (Version 7.03; Prager 2005), was used to estimate stock status of Red Snapper off the southeastern U.S. While primary assessment of the stock was performed using the age-structured BAM, the surplus production approach was intended as a complement, for additional comparison with the age-structured model's results. More specifically, this model focuses on the dynamics of the removals as they relate to the indices of abundance, while ignoring any age data or age-structure in the population.

3.31.2 Data Sources

Data sources supplied to a production model include a time series of removals (i.e. landings plus dead discards) and one or more indices of abundance (i.e. catch per unit of effort). These inputs should be in units of biomass (i.e. weight), therefore some of the data developed at the SEDAR41 DW required additional formatting. These changes are detailed below.

Removals

The available removals time series comprised commercial landings (1950-2014), recreational landings (1955-2014), commercial dead discards (1992-2014), and recreational dead discards (1981-2014), in pounds, summed by year.

Commercial Landings

The SEDAR41 DW reported commercial landings in pounds, thus these data did not need to be modified for the production model.

Recreational landings

During the SEDAR41 DW, recreational landings for the historical period (1955-1980) were estimated in numbers of individuals using the The National Survey of Fishing, Hunting, and Wildlife-Associated Recreation Survey (FHWAR) census method (see SEDAR41-DW17). For the contemporary period (1981-2014), the SEDAR-41 DW reported Southeast Region Headboat Survey (SRHS) and Marine Recreational Information Program (MRIP) recreational landings in numbers and weights. Recreational landings from this period did not need to be modified, but were used to convert historical landings to weight.

Following a similar approach used in SEDAR24, recreational landings in weight and numbers for all fleets were combined by year for the first three years of the contemporary period; dividing annual landings in weight by landings in numbers produced annual mean weight estimates. The average of these three mean weights (3.4 lb) was then multiplied by the historical landings in numbers to convert them to weight. The historical and combined contemporary recreational landings series were then joined to produce a single time series of recreational landings, in pounds.

Dead Discards

Discard estimates were generated in numbers at the SEDAR-41 DW. Since many discarded fish survive after release, discard mortality rates were applied to discards in numbers to calculate dead discards. For commercial discards, a discard mortality rate of 0.48 was applied prior to regulations in 2007, and a rate of 0.38 was applied from 2007 onward. For recreational discards, a discard mortality rate of 0.37 was applied prior to regulations in 2011, and a rate of 0.285 was applied from 2011 onward.

Mean weight of commercial discards was estimated by converting lengths of commercial discards to weights using data and a conversion equation supplied by the SEDAR-41 DW, and then calculating the average weight of these individuals. The data on lengths of commercial discards were divided into two time periods before (2007-2009) and after (2010-2013) the fishery was closed. The average estimated weights of commercial discards from each time period (before = 2.93 lb; after = 8.84 lb) were multiplied by discards in numbers, for years before and after the closure, respectively.

Mean weight of recreational discards was estimated by converting lengths of recreational headboat-at-sea observer discards to weights using data and a conversion equation supplied by the SEDAR-41 DW, and then calculating the average weight of these individuals. Year-specific mean weight estimates were multiplied by recreational discards in numbers for corresponding years when available (2005-2014). For years prior to 2005 where year-specific mean weights were not available, discards in numbers were multiplied by the average mean weight across the available years before the 2010 closure (1.96 lb).

Indices of Abundance

Five indices of abundance were produced by the SEDAR-41 DW for Red Snapper: commercial logbook handline index (hereafter commercial handline; units = lb kept per hook-hour), headboat (number of fish kept per angler), headboat-at-sea-observer (number of fish caught $<20''$ per angler), Southeast Reef Fish Survey (SERFS) chevron trap (number of fish caught per trap), and the SERFS video (number of fish observed per video). The commercial handline index was already in weight and did not need to be converted. The headboat index was converted to pounds by multiplying by year-specific mean weights, generated by dividing headboat landings in pounds by landings in numbers for each year. The headboat-at-sea-observer index was converted to pounds by multiplying by the same mean weights used to convert recreational discards to weight. The SERFS chevron trap and video indices were converted to weights by multiplying by year-specific mean weights calculated from combined recreational (headboat and MRIP) landings in weight divided by landings in numbers.

3.31.3 Model Configuration and Equations

Production modeling used the model formulation and ASPIC software (version 7.03) of Prager (1994; 2005). This is an observation-error estimator of the continuous-time form of the Schaefer (logistic) production model (Schaefer 1954; 1957). Estimation was conditioned on catch. The logistic model for population growth is the simplest form of a differential equation which satisfies a number of ecologically realistic constraints, such as a carrying capacity (a consequence of limited resources). When written in terms of stock biomass, this model specifies that

$$\frac{dB_t}{dt} = rB_t - \frac{r}{K}B_t^2 \qquad (5)$$

where B_t is biomass in year t, r is the intrinsic rate of increase in absence of density dependence, and K is carrying capacity (Schaefer 1954; 1957). This equation may be rewritten to account for the effects of fishing by introducing an instantaneous fishing mortality term, F_t :

$$\frac{dB_t}{dt} = (r - F_t)B_t - \frac{r}{K}B_t^2 \qquad (6)$$

By writing the term F_t as a function of catchability coefficients and effort expended by fishermen in different fisheries, Prager (1994) showed how to estimate model parameters from time series of yield and effort.

For Red Snapper, the model proved difficult to fit. It was configured using various combinations of removals, indices, starting dates, prior distributions and starting values, resulting in approximately 324 configurations. Many of these runs were completed during early model development but many others incorporated small changes to data inputs or model specifications suggested by AW panel members during the Assessment Workshop. As the BAM developed, most of these runs became obsolete and are not presented here. The run configured according to recommendations by the SEDAR41 AW panel is presented here. This model configuration (run 320) contained removals from 1950 to 2014 and the four indices used in the BAM (Comm, HB, HB-at-sea, CVID) from 1976 to 2014. Following the recommendations of the AW panel, the CVID index was upweighted by a factor of three (i.e. CVs divided by three), and the headboat-at-sea index was shifted forward by one year, since it indexes younger fish than the other indices.

Three other runs (318, 319, and 323) are also presented to relate the main run (320) to ASPIC results from the previous Red Snapper assessment (SEDAR 24). All three runs contain only the commercial and headboat indices, starting in 1993 and 1976 respectively, and removals starting in 1950. But in run 318 (the continuity run), the final year of removals and indices is 2009, as in SEDAR 24, while in run 319 (the updated continuity run) the final year of removals and indices is 2014, as in the BAM for the current assessment. Since both the commercial and headboat indices ended in 2009 the only difference between the continuity run and updated continuity run is the removals estimates from 2010-2014. Finally a run was completed (run 323; best configuration $\frac{B_1}{K}$ fixed) that is identical to the best configuration run, but with $\frac{B_1}{K}$ fixed at the estimate for the continuity run, for reasons described below.

To evaluate the uncertainty in the model fit and parameter estimates of the best configuration run, 1000 bootstrap runs were conducted. Percentile confidence intervals were also calculated for parameters.

4 Stock Assessment Results

4.1 Measures of Overall Model Fit

In general, the Beaufort assessment model (BAM) fit well to the available data. Predicted length compositions from the commercial handline and discards from the commercial and headboat fleets were reasonably close to observed data in most years, as were predicted age compositions (Figure 3). The model was configured to fit observed commercial and recreational removals closely (Figures 4–9). Fits to indices of abundance generally captured the observed trends but not all annual fluctuations (Figures 10–13).

4.2 Parameter Estimates

Estimates of all parameters from the catch-age model are shown in Appendix B. Estimates of management quantities and some key parameters are reported in sections below.

4.3 Stock Abundance and Recruitment

In general, estimated abundance at age showed truncation of the older ages through most of the assessment period, but with some signs of increase during the last decade (Figure 14; Table 7). Total estimated abundance was at its lowest value in the early 1990s, but near its highest levels at the end of the time series, comparable to those in the early 1970s, but with a more truncated age structure. The MCB results reflect the same patterns with their associated uncertainties for total abundance and abundance of age 2+ (Figure 18). Annual number of recruits is shown in Table 7 (age-1 column) and in Figure 15. The highest recruitment values were predicted to have occurred in the mid-1980s, 2006, and the terminal year of the model (2014).

4.4 Total and Spawning Biomass

Estimated biomass at age followed a similar pattern as abundance at age (Figure 16; Table 9). Total biomass and spawning biomass showed similar trends—general decline through to the early-1990s, and relatively stable or slowly increasing patterns since the mid-1990s (Figure 17; Table 10). Terminal year estimates are at levels not seen since the 1970s.

4.5 Selectivity

Selectivity of the SERFS index is shown in Figure 19, and selectivities of landings from commercial and recreational fleets are shown in Figures 20, 21, and 22. Selectivities of discards from commercial and recreational fleets are shown in Figures 23, 24, and 25. In the most recent years, full selection occurred near ages 2–4, depending on the fleet and time block.

Average selectivities of landings, dead discards, and the total weighted average of all selectivities were computed from F-weighted selectivities in the most recent three assessment years (Figure 26). This average selectivity was used in computation of point estimates of benchmarks, as well as in projections. All selectivities from each time block, including average selectivities, are tabulated in Tables 11, 12, and 13.

4.6 Fishing Mortality and Removals

Estimates of total F at age are shown in Table 15. In any given year, the maximum F at age (i.e., apical F) may be less than that year's sum of fully selected Fs across fleets. This inequality is due to the combination of two features of estimated selectivities: full selection occurs at different ages among gears and several sources of mortality have dome-shaped selectivity.

Estimated time series of landings and discards are shown in Tables 18, 19, 20, 21. Table 16 shows total landings at age in numbers, and Table 17 in weight. Landings have been dominated by the general recreational and commercial handline fleet until recent years when the general recreational fleet became the dominant source of removals (Tables 18 and 19). Also since 2010, total landings remained below the level at $L_{\mathrm{F30\%}}$ (Figure 29).

Estimated discard mortalities occurred on a smaller scale than landings until the implementation of regulations and the use of mini-seasons, and have been above the $D_{F_{30\%}}$ level for most of the moratorium years (Tables 20 and 21, and Figure 30).

4.7 Spawner-Recruitment Parameters

The Beverton–Holt spawner-recruit curve is shown in Figure 31, along with the effect of density dependence on recruitment, depicted graphically by recruits per spawner as a function of spawning stock (1E8 Eggs). Values of recruitment-related parameters were as follows: steepness $h = 0.99$ (fixed), unfished age-1 recruitment $\widehat{R_0} = 330503$, and standard deviation of recruitment residuals in log space $\widehat{\sigma}_R = 0.79$ (which resulted in bias correction of $\varsigma = 1.37$). Uncertainty in these quantities was estimated through the MCB analysis (Figure 32).

4.8 Per Recruit and Equilibrium Analyses

Yield per recruit and spawning potential ratio were computed as functions of F. These computations applied the most recent selectivity patterns averaged across fleets, weighted by F from the last three years (2012–2014) (Figures 33 and 34).

As in per recruit analyses, equilibrium landings and spawning biomass were computed as functions of F (Figure 35). $F_{30\%}$ is used as a proxy for MSY, and the corresponding landings and spawning biomass are $L_{\mathrm{F30\%}}$ and $\mathrm{SSB}_{\mathrm{F30\%}}$.

4.9 Benchmarks / Reference Points

As described in §3.23, biological reference points (benchmarks) were derived analytically assuming equilibrium dynamics, corresponding to the spawner-recruit curve with fixed steepness $h = 0.99$ (Figure 31). Reference points estimated were $F_{30\%}$, $L_{\mathrm{F30\%}}$, $B_{\mathrm{F30\%}}$ and $\mathrm{SSB}_{\mathrm{F30\%}}$. Based on $F_{30\%}$, three possible values of F at optimum yield (OY) were considered—$F_{\mathrm{OY}} = 65\% F_{30\%}$, $F_{\mathrm{OY}} = 75\% F_{30\%}$, and $F_{\mathrm{OY}} = 85\% F_{30\%}$—and for each, the corresponding yield was computed. Standard errors of benchmarks were approximated as those from MCB analysis (§3.24).

Maximum likelihood estimates (base run) of benchmarks, as well as median values from MCB analysis, are summarized in Table 22. Point estimates of $L_{\mathrm{F30\%}}$-related quantities were $F_{30\%} = 0$ (y^{-1}), $L_{\mathrm{F30\%}} = 459$ (1000 lb), $B_{\mathrm{F30\%}} = 3693$ (mt), and $\mathrm{SSB}_{\mathrm{F30\%}} = 329948$ (1E8 Eggs). Median estimates were $F_{30\%} = 0$ (y^{-1}), $L_{\mathrm{F30\%}} = 450$ (1000 lb), $B_{\mathrm{F30\%}} = 3628$ (mt), and $\mathrm{SSB}_{\mathrm{F30\%}} = 299651$ (1E8 Eggs). Distributions of these benchmarks from the MCB analysis are shown in Figure 36.

4.10 Status of the Stock and Fishery

Estimated time series of stock status $\mathrm{SSB}/\mathrm{SSB}_{\mathrm{F30\%}}$ showed general decline throughout the beginning of the assessment period, a leveling off, and then a modest increase since 2010 (Figure 37, Table 10). Base-run estimates of spawning biomass have remained below the threshold (MSST) since the early-1970s. Current stock status was estimated in the base run to be $\mathrm{SSB}/\mathrm{SSB}_{\mathrm{F30\%}} = 0$ (Table 22), indicating that the stock has not yet recovered to $\mathrm{SSB}_{\mathrm{F30\%}}$. Median values from the MCB analysis indicated similar results $\mathrm{SSB}/\mathrm{SSB}_{\mathrm{F30\%}}$ =0. The uncertainty analysis suggested that the terminal estimate of stock status is robust (Figures 38, 39). Of the MCB runs, 100% indicated that the stock was below $\mathrm{SSB}_{\mathrm{F30\%}}$ in 2012. Age structure estimated by the base run generally showed fewer older fish than the (equilibrium) age structure expected at $L_{\mathrm{F30\%}}$, but it also showed increases since 2006.

The estimated time series of $F/F_{30\%}$ suggests that overfishing has occurred throughout most of the assessment period (Table 10, Figure 37). Current fishery status in the terminal year, with current F represented by the geometric mean from 2012–2014, was estimated by the base run to be $F/F_{30\%} = 3$ (Table 22). The fishery status was also robust (Figures 38, 39). Of the MCB runs, approximately 99.5% agreed with the base run that the stock is currently experiencing overfishing.

4.11 Sensitivity and Retrospective Analyses

Sensitivity runs, described in §3.3, were used for exploring data or model issues that arose during the assessment process, for evaluating implications of assumptions in the base assessment model, and for interpreting MCB results in terms of expected effects of input parameters. In some cases, sensitivity runs are simply a tool for better understanding model behavior, and therefore all runs are not considered equally plausible in the sense of alternative states of nature. Time series of $F/F_{30\%}$ and $\mathrm{SSB}/\mathrm{SSB}_{\mathrm{F30\%}}$ are plotted to demonstrate sensitivity to the changing conditions in each run. The sensitivity of the base run to changes in natural mortality, steepness, dome-shaped selectivity for the commercial handline fleet, various index adjusts for both the fishery dependent indices and fishery independent index, the use of an ageing error matrix and high and low levels of landings and discards was explored (Figures 40–52). Sensitivity 24 is a version of a continuity run in that various assumptions made about parameters for SEDAR 24 were adopted for this sensitivity (e.g. higher discard mortalities, lower M, using gonad weight as a proxy for SSB, different female maturity and fecundity information, higher max age, lower steepness, different time of year for peak spawning, and fixed recruitment standard deviation). Time series of stock and fishery status estimated by this assessment are similar to those from the previous, SEDAR24 assessment (Figure 53). Trends in $F/F_{30\%}$ from the two assessments generally track each other, though the magnitude of the variations differ. Trends in $\mathrm{SSB}/\mathrm{SSB}_{\mathrm{F30\%}}$ track each other, though there is divergence at the end of the time series where the current model estimates a more optimistic stock status.

None of the sensitivities show a recovered stock in 2014. A couple sensitivities suggest the stock is undergoing less overfishing than is estimated in the base. However, those runs eliminate the fishery independent index entirely, or upweight the fishery dependent indices to the point of swamping out any signal from the survey data. The vast majority of runs agree with the status indicated by the base run (Figure 54, Table 23). Results appeared to be most sensitive to natural mortality and steepness.

Retrospective analyses suggest a pattern of overestimating fishing mortality in the terminal year, however, the trend is less apparent for SSB (Figure 55).

4.12 Projections

Projections based on $F = 0$ allowed the spawning stock to grow such that the majority of replicate projections recovered to $\mathrm{SSB}_{\mathrm{F30\%}}$ by 2025 (Figure 56, Table 24), however the stock is already in a rebuilding plan so other projections were also requested in the TORs. This was not the case for projections based on $F = F_{\mathrm{current}}$ (Figure 57, Table 25), or if the fishing rate were reduced to $F_{30\%}$ (Figure 58, Table 26) or F_{target} (Figure 59, Table 27). By design, projections based on $F = F_{\mathrm{rebuild}}$ showed recovery with the desired probability in 2044 (Figure 60, Table 28). The projection with discard mortality only showed similar trajectories to the run assuming no other fishing mortality(Table 29 and Figure 61).

4.13 Surplus Production Model

4.13.1 Model Fit

For the best configuration run, model predictions underestimated observed values for the headboat index for the first ten years of the time series (1976-1985; Figure 62). They also underestimated the commercial index during the first five years of that series (1993-1997), while overestimating the headboat index for those same years. The model provided a very poor fit to the headboat-at-sea discard index (2006-2014) but produced a much better fit to the upweighted CVID index (2005-2014). The model did not fit high index values in 2008 and 2009 very closely, but predicted a slight decline from 2007-2009 followed by an increasing trend from 2010 to 2014.

4.13.2 Parameter Estimates and Uncertainty

The ASPIC model fits three main parameters ($\frac{B_1}{K}$, MSY, and F_{MSY}) as well as catchability coefficients (q_i) for each index i. Several other parameters can then be derived from these estimates: $r = 2F_{MSY}$, $K = \frac{2MSY}{F_{MSY}}$ and $B_{MSY} = \frac{K}{2}$. Recent status indicators $\frac{F}{F_{MSY}}$ and $\frac{B}{B_{MSY}}$ are calculated with the most recent estimates of F (2014) and B (2015). Estimates of the main parameters and recent status indicators for all four runs are presented in Table 30. Prior distributions and model estimates of the main parameters for the best configuration run are presented in Figure 63.

Across all runs, most of the main parameters varied very little (e.g. CV $MSY = 0.0027$; CV $F_{MSY} = 0.014$). By contrast $\frac{B_1}{K}$ varied widely (CV $\frac{B_1}{K} = 0.74$), due to variation in B_1 (CV $B_1 = 0.74$) rather than K (CV $K = 0.013$; Table 30). Among bootstrap runs based on the best configuration, distributions of $\frac{B_1}{K}$, MSY, and F_{MSY} were unimodal and relatively symmetrical (Figure 64).

4.13.3 Status of the Stock and Fishery

In the current best configuration run of the surplus production model, $\frac{B}{B_{MSY}}$ is greater than one, suggesting that the South Atlantic stock of Red Snapper is not overfished. The 95% bootstrap percentile confidence intervals for $\frac{B}{B_{MSY}}$ do not contain one (Figure 64). Since the surplus production model estimates that $\frac{F}{F_{MSY}}$ is less than one, the stock is considered to not be undergoing overfishing (Table 30; Figure 65). The 95% bootstrap percentile confidence intervals for $\frac{F}{F_{MSY}}$ do not contain one (Figure 64).

4.13.4 Interpretation

Status indicators in the continuity run (318), agree with the surplus production model from SEDAR 24 that South Atlantic Red Snapper were overfished and undergoing overfishing in 2009 (Table 30). However, in the updated continuity run (319), which is identical to the continuity run except for the 2010-2014 addition of landings data from 2010-2014, the surplus production model suggests that the stock is no longer overfished or undergoing overfishing. Despite several differences between the updated continuity run and the best configuration run (320), described above, most of the parameter estimates and status indicators are similar (Table 30). However the model estimate of $\frac{B_1}{K}$ is much lower in the best configuration run, driven by a lower estimate of B_1. After observing this difference, run 323 was configured by taking the best configuration run and fixing $\frac{B_1}{K}$ at the estimate from the continuity run to investigate potential influence. Fixing $\frac{B_1}{K}$ at this much lower value had little effect on status or most parameters, but caused the estimate of B_1 to go much lower.

As described above, the only data that go into a surplus production model are biomass of removals and abundance indices. Therefore such a model does not make use of many other sources of information such as sex, maturity, growth, fecundity, or population age and size structure. Because such data are available for Red Snapper, a model that uses them would be preferred for a detailed assessment on which to base management.

5 Discussion

5.1 Comments on the Assessment

Estimated benchmarks played a central role in this assessment. Values of $\text{SSB}_{\text{F30\%}}$ and $F_{30\%}$ were used to gauge the status of the stock and fishery to be consistent with established definitions of $MFMT$ and the existing rebuilding plan. The computation of the benchmarks was conditional on selectivity. If selectivity patterns change in the future, for example as a result of new size limits or different relative catch allocations among sectors, estimates of benchmarks would likely change as well.

The base run of the BAM indicated that the stock remains overfished $\mathrm{SSB}/\mathrm{SSB}_{\mathrm{F30\%}}$ =0, and that overfishing is occurring $F/F_{30\%}$ =3, though at a lower rate than in 2009 (F/F_{MSY} =4.12 for SEDAR 24). Median values from the MCB analyses were in qualitative agreement with those results. This assessment estimates that, since 2010, the stock has been increasing at a modest rate and is now at levels not seen since the 1970s.

In addition to including the more recent years of data, this benchmark assessment contained several modifications to the previous data of SEDAR24, such as the use of APAIS-adjusted MRIP estimates instead of MRFSS, a new method for the reconstruction of historic recreational catch, the inclusion of a new fishery-independent survey, and the corresponding age composition data. Furthermore, life-history information was updated, including female maturity, sex ratio, growth, natural mortality, fecundity, and meristics. The assessment model itself was also modernized to the current version of BAM. The sum of these improvements should result in a more robust assessment.

In general, fishery dependent indices of abundance may not track actual abundance well, because of factors such as hyperdepletion or hyperstability. Furthermore, this issue can be exacerbated by management measures. In this assessment, the commercial handline and headboat indices generated from logbook data, were not extended beyond 2009 because of the moratorium on Red Snapper. In general, management measures in the southeast U.S. have made the continued utility of fishery dependent indices will be questionable. This situation amplifies the importance of fishery independent sampling and sampling programs conducted by the states.

Many assessed stocks in the southeast U.S. have shown histories of heavy exploitation. High rates of fishing mortality can lead to adaptive responses in life-history characteristics, such as growth and maturity schedules. Such adaptations can affect expected yield and stock recovery, and thus resource managers might wish to consider possible evolutionary effects of fishing in their management plans (Dunlop et al. 2009; Enberg et al. 2009). Indeed, Red Snapper have a very young age at maturity relative to their maximum lifespan, and some have hypothesized that this may be an adaptive response to exploitation.

Because steepness could not be estimated reliably in this assessment, its value in the base run was fixed at 0.99. Fixing steepness at its upper bound was not meant to imply that the stock has perfect compensation at any exploitation or stock level. Rather, it was a computational convenience to use the stock recruitment curve with $h = 0.99$ in order to treat recruitment as an average through time while estimating deviations around that average. Thus MSY-based management quantities are not appropriate, and the AW Panel provided the proxy of $F_{30\%}$ as was used for management subsequent to the last assessment.

The assessment start year was 1950, so as to include the period of largest landings. To initialize the model in 1950, the initial age structure was assumed to be in equilibrium, based on natural mortality at age and F_{init}. Average recruitment was assumed until the recruitment deviations could be estimated at the onset of the composition data (1978). These assumptions are common in assessment models, and they were tested with sensitivity runs where the start was 1978 and with different values of F_{init}. The end results were qualitatively similar, which indicates that the base run is not sensitive to these assumptions.

A complementary analysis was conducted using a surplus production model (ASPIC). ASPIC treats the stock as a pooled biomass and ignores the age structure in the population and the landings. It is unable to take into account that different ages are differentially vulnerable to fishing and therefore was not able to incorporate the (time-varying) selectivities used in the BAM. ASPIC is also not able to take into account that the reproductive contribution of this species increases with age or that there is variability in recruitment through time. ASPIC is useful in examining the relationship between removals and the indices. However, for a long-lived species with age-based data available, the catch-age model (BAM) provides the best illustration of the stock and is a better indicator of stock status, because it can account for the age structure of the population and landings and for year-class strength.

5.2 Comments on the Projections

Projections should be interpreted in light of the model assumptions and key aspects of the data. Some major considerations are the following:

- In general, projections of fish stocks are highly uncertain, particularly in the long term (e.g., beyond 5–10 years).
- Although projections included many major sources of uncertainty, they did not include structural (model) uncertainty. That is, projection results are conditional on one set of functional forms used to describe population dynamics, selectivity, recruitment, etc.
- Fisheries were assumed to continue fishing at their estimated current proportions of total effort, using the estimated current selectivity patterns. New management regulations that alter those proportions or selectivities would likely affect projection results.
- The first five scenarios of projections assumed no change in the selectivity applied to discards. As stock increase generally begins with the smallest size classes, management action may be needed to meet that assumption.
- The projections assumed that the assumed spawner-recruit relationship applies in the future and that past deviations represent future uncertainty in recruitment. If future recruitment is characterized by runs of large or small year classes, possibly due to environmental or ecological conditions, stock projections may be affected.
- Projections apply the Baranov catch equation to relate F and landings using a one-year time step, as in the assessment. The catch equation implicitly assumes that mortality occurs throughout the year. This assumption is violated when seasonal closures or small intensive fishing seasons are in effect, introducing additional and unquantified uncertainty into the projection results.

5.3 Research Recommendations

- Increased fishery independent information, particularly maintaining reliable indices of abundance and composition data streams
- Red Snapper were modeled in this assessment as a unit stock off the southeastern U.S. For any stock, variation in exploitation and life-history characteristics might be expected at finer geographic scales. Modeling such sub-stock structure would require more data, such as information on the movements and migrations of adults and juveniles, as well as spatial patterns of larval dispersal and recruitment. In addition, it is unclear whether a spatial model would improve the assessment.
- More research to describe the juvenile life history of Red Snapper is needed, including more work to identify the location of juveniles before they recruit to the fishery.
- The effects of environmental variation on the changes in recruitment or survivorship.
- The Florida sampling program, during the miniseason in particular, provided invaluable data to this assessment. Programs such as these would be useful in all South Atlantic states, particularly if the management regulations continue to make established methods of index development or composition sampling from fleets less regular or possible.

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7 Tables

Table 1. Life-history characteristics at age, including average body total length (TL) and weight (mid-year), proportion female, annual proportion females mature, and natural mortality at age. The CV of length was estimated by the assessment model; other values were treated as input.

Age	Avg. TL (mm)	Avg. TL (in)	CV length	Avg. Whole weight (kg)	Avg. Whole weight (lb)	Fem. maturity	Proportion Female	Nat. mortality
1	323.9	12.8	0.11	0.53	1.17	0.43	0.5	0.595
2	449.3	17.7	0.11	1.41	3.10	0.73	0.5	0.364
3	547.9	21.6	0.11	2.55	5.62	0.91	0.5	0.271
4	625.4	24.6	0.11	3.78	8.34	0.97	0.5	0.222
5	686.4	27.0	0.11	5.00	11.02	0.99	0.5	0.193
6	734.4	28.9	0.11	6.12	13.49	1.00	0.5	0.174
7	772.2	30.4	0.11	7.11	15.67	1.00	0.5	0.162
8	801.9	31.6	0.11	7.96	17.54	1.00	0.5	0.153
9	825.2	32.5	0.11	8.67	19.12	1.00	0.5	0.146
10	843.6	33.2	0.11	9.26	20.42	1.00	0.5	0.142
11	858.1	33.8	0.11	9.74	21.48	1.00	0.5	0.138
12	869.4	34.2	0.11	10.13	22.34	1.00	0.5	0.135
13	878.4	34.6	0.11	10.45	23.04	1.00	0.5	0.133
14	885.4	34.9	0.11	10.70	23.59	1.00	0.5	0.132
15	891.0	35.1	0.11	10.90	24.04	1.00	0.5	0.130
16	895.3	35.2	0.11	11.06	24.39	1.00	0.5	0.129
17	898.7	35.4	0.11	11.19	24.67	1.00	0.5	0.129
18	901.4	35.5	0.11	11.29	24.89	1.00	0.5	0.128
19	903.5	35.6	0.11	11.37	25.07	1.00	0.5	0.128
20	905.2	35.6	0.11	11.43	25.21	1.00	0.5	0.127

Table 2. Size (TL) in inches and weight in pounds (lb) at age as applied to the population (Pop), fishery–dependent portion of the population (FD), and fishery–dependent portion of the population during the 20 mm size limit (FD20). The CV of length was estimated by the assessment model; other values were treated as input through the von Bertalanffy growth parameters.

Age	Pop.TL	CV.Pop.TL	Pop.lb	FD.TL	CV.FD.TL	FD.lb	FD20.TL	CV.FD20.TL	FD20.lb
1	12.8	0.11	1.2	11.2	0.14	0.8	16.2	0.1	2.4
2	17.7	0.11	3.1	16.2	0.14	2.4	19.5	0.1	4.1
3	21.6	0.11	5.6	20.2	0.14	4.6	22.2	0.1	6.1
4	24.6	0.11	8.3	23.4	0.14	7.2	24.5	0.1	8.2
5	27.0	0.11	11.0	26.0	0.14	9.8	26.5	0.1	10.3
6	28.9	0.11	13.5	28.1	0.14	12.3	28.1	0.1	12.4
7	30.4	0.11	15.7	29.7	0.14	14.7	29.5	0.1	14.3
8	31.6	0.11	17.5	31.1	0.14	16.7	30.6	0.1	16.0
9	32.5	0.11	19.1	32.1	0.14	18.5	31.6	0.1	17.6
10	33.2	0.11	20.4	33.0	0.14	20.0	32.5	0.1	19.0
11	33.8	0.11	21.5	33.7	0.14	21.3	33.2	0.1	20.3
12	34.2	0.11	22.3	34.2	0.14	22.4	33.7	0.1	21.4
13	34.6	0.11	23.0	34.7	0.14	23.3	34.2	0.1	22.4
14	34.9	0.11	23.6	35.0	0.14	24.0	34.7	0.1	23.2
15	35.1	0.11	24.0	35.3	0.14	24.6	35.0	0.1	23.9
16	35.2	0.11	24.4	35.6	0.14	25.0	35.3	0.1	24.5
17	35.4	0.11	24.7	35.7	0.14	25.4	35.6	0.1	25.1
18	35.5	0.11	24.9	35.9	0.14	25.8	35.8	0.1	25.5
19	35.6	0.11	25.1	36.0	0.14	26.0	36.0	0.1	25.9
20	35.6	0.11	25.2	36.1	0.14	26.2	36.1	0.1	26.2

Table 3. Observed time series of landings(L) and discards(D) for commercial lines (cH), headboat (HB), and general recreational (GR). Commercial landings are in units of 1000 lb whole weight. Recreational landings and discards and commercial discards are in units of 1000 fish. Confidential data have been redacted.

Year	cH.L	HB.L	GR.L	cH.D	HB.D	GR.D
1950	368.657	.	.	.	.	.
1951	499.765	.	.	.	.	.
1952	385.930	.	.	.	.	.
1953	398.279	.	.	.	.	.
1954	593.207	.	.	.	.	.
1955	493.315	12.501	24.035	.	.	.
1956	483.907	13.652	26.248	.	.	.
1957	867.291	14.803	28.460	.	.	.
1958	612.508	15.953	30.673	.	.	.
1959	657.736	17.104	32.885	.	.	.
1960	671.075	18.255	35.098	.	.	.
1961	796.374	19.908	38.276	.	.	.
1962	645.983	21.561	41.454	.	.	.
1963	488.789	23.214	44.633	.	.	.
1964	537.589	24.867	47.811	.	.	.
1965	558.108	26.520	50.989	.	.	.
1966	554.506	26.676	51.288	.	.	.
1967	725.503	26.831	51.587	.	.	.
1968	865.520	26.986	51.885	.	.	.
1969	538.190	27.142	52.184	.	.	.
1970	513.023	27.297	52.483	.	.	.
1971	457.393	29.995	57.670	.	.	.
1972	406.641	32.693	62.857	.	.	.
1973	296.560	35.391	68.044	.	.	.
1974	478.352	38.088	73.231	.	.	.
1975	600.790	40.786	78.418	.	.	.
1976	571.504	41.246	79.303	.	.	.
1977	596.339	41.707	80.187	.	.	.
1978	594.356	42.167	81.072	.	.	.
1979	420.936	42.627	81.957	.	.	.
1980	385.485	43.087	82.842	.	.	.
1981	378.759	36.031	93.458	.	.	1.641
1982	308.445	19.553	36.294	.	.	1.641
1983	316.818	30.698	68.469	.	.	1.641
1984	253.431	31.146	212.547	.	0.026	22.875
1985	250.824	50.336	288.971	.	0.041	23.713
1986	219.440	16.625	100.736	.	0.014	23.713
1987	191.701	24.996	47.373	.	0.020	23.713
1988	173.689	36.527	80.821	.	0.030	18.601
1989	266.942	23.453	97.147	.	0.019	7.172
1990	226.542	20.919	12.092	.	0.017	7.172
1991	143.546	13.857	34.717	.	0.011	7.172
1992	104.374	5.301	51.908	9.409	0.929	10.358
1993	220.153	7.347	11.326	8.028	1.287	25.215
1994	195.319	8.225	18.313	10.144	1.441	24.620
1995	177.312	8.826	13.482	10.113	1.546	18.829
1996	138.671	5.543	9.342	9.949	0.971	7.565
1997	110.595	5.770	34.238	10.748	1.011	6.132
1998	89.602	4.741	13.015	7.762	0.830	9.912
1999	93.595	6.836	39.579	6.548	1.197	60.203
2000	104.165	8.437	45.347	6.985	1.478	91.981
2001	196.697	12.028	31.587	7.268	2.107	74.986
2002	187.967	12.931	35.062	14.327	2.265	45.644
2003	138.342	5.706	25.977	4.019	0.999	58.952
2004	172.083	10.842	28.914	1.164	6.952	73.866
2005	129.700	8.907	29.443	4.885	3.654	26.956
2006	86.382	5.945	26.769	2.312	6.376	44.302
2007	114.973	6.889	17.646	5.236	26.598	106.662
2008	252.146	18.943	81.638	4.770	27.235	189.434
2009	362.386	21.507	54.666	5.497	21.211	88.991
2010	6.448	0.477	0.062	6.626	14.224	51.237
2011	− − −	− − −	0.062	15.241	11.796	9.543
2012	8.142	2.127	15.628	7.301	13.333	40.744
2013	31.600	1.520	7.588	7.335	13.321	23.938
2014	65.443	5.904	28.186	10.263	13.284	81.499

Table 4. Observed indices of abundance and CVs from commercial line (cH), headboat (HB), combined chevon trap and video (CVID), and headboat discard (HB.D).

Year	cH	cH CV	HB	HB CV	CVID	CVID CV	HB.D	HB.D CV
1976	.	.	2.37	0.2	.	.	.	.
1977	.	.	2.16	0.2	.	.	.	.
1978	.	.	2.13	0.2	.	.	.	.
1979	.	.	2.23	0.2	.	.	.	.
1980	.	.	1.45	0.2	.	.	.	.
1981	.	.	2.95	0.2	.	.	.	.
1982	.	.	1.20	0.2	.	.	.	.
1983	.	.	1.64	0.2	.	.	.	.
1984	.	.	1.42	0.2	.	.	.	.
1985	.	.	2.07	0.2	.	.	.	.
1986	.	.	0.48	0.2	.	.	.	.
1987	.	.	0.58	0.2	.	.	.	.
1988	.	.	0.56	0.2	.	.	.	.
1989	.	.	0.90	0.2	.	.	.	.
1990	.	.	0.87	0.2	.	.	.	.
1991	.	.	0.69	0.2	.	.	.	.
1992	.	.	0.08	0.2	.	.	.	.
1993	1.09	0.2	0.16	0.2	.	.	.	.
1994	0.89	0.2	0.26	0.2	.	.	.	.
1995	0.89	0.2	0.28	0.2	.	.	.	.
1996	0.61	0.2	0.25	0.2	.	.	.	.
1997	0.59	0.2	0.27	0.2	.	.	.	.
1998	0.66	0.2	0.24	0.2	.	.	.	.
1999	0.80	0.2	0.29	0.2	.	.	.	.
2000	0.74	0.2	0.41	0.2	.	.	.	.
2001	1.27	0.2	0.76	0.2	.	.	.	.
2002	1.38	0.2	0.88	0.2	.	.	.	.
2003	1.04	0.2	0.52	0.2	.	.	.	.
2004	1.42	0.2	0.76	0.2	.	.	.	.
2005	1.19	0.2	0.76	0.2	.	.	0.56	0.30
2006	0.60	0.2	0.43	0.2	.	.	0.41	0.37
2007	0.67	0.2	0.44	0.2	.	.	2.02	0.17
2008	1.22	0.2	1.71	0.2	.	.	1.39	0.21
2009	1.94	0.2	1.81	0.2	.	.	0.63	0.27
2010	.	.	.	.	0.90	0.26	0.56	0.30
2011	.	.	.	.	0.66	0.23	0.41	0.37
2012	.	.	.	.	1.10	0.18	2.02	0.17
2013	.	.	.	.	0.87	0.20	1.39	0.21
2014	.	.	.	.	1.47	0.17	0.63	0.27

Table 5. Sample sizes (number of trips) of length compositions (len) or age compositions (age) by survey or fleet. Data sources are commercial lines (cH), headboat (HB), headboat discard (HB.D), general recreational (GR),and MARMAP chevron trap (CVT).

Year	len.cH	len.cH.D	len.HB.D	age.cH	age.HB	age.GR	age.CVT
1978	.	.	.	.	80	.	.
1979	.	.	.	.	31	.	.
1980	.	.	.	.	30	.	.
1981	.	.	.	.	141	.	.
1982	.	.	.	.	55	.	.
1983	.	.	.	.	167	.	.
1984	125	.	.	.	166	.	.
1985	139	.	.	.	160	.	.
1986	94	.	.	.	97	.	.
1987	89	.	.	.	60	.	.
1988	84	.	.	.	.	.	.
1989	88	.	.	.	.	.	.
1990	63	.	.	11	23	.	.
1991	106	.	.	.	13	.	.
1992	82	.	.	11	.	.	.
1993	.	.	.	.	.	.	.
1994	.	.	.	14	.	.	.
1995	.	.	.	.	.	.	.
1996	.	.	.	48	.	.	.
1997	.	.	.	45	.	.	.
1998	.	.	.	14	.	.	.
1999	.	.	.	15	.	.	.
2000	.	.	.	28	.	.	.
2001	.	.	.	23	.	15	.
2002	.	.	.	.	.	84	.
2003	.	.	.	10	.	91	.
2004	.	.	.	25	.	83	.
2005	.	.	37	53	22	78	.
2006	.	.	29	84	49	26	.
2007	.	.	64	132	34	.	.
2008	.	.	61	158	47	.	.
2009	.	13	56	263	241	58	.
2010	.	.	50	.	.	.	73
2011	.	.	48	.	.	.	70
2012	.	.	56	39	40	121	148
2013	.	13	60	109	35	139	139
2014	.	.	56	64	49	315	150

Table 6. Coefficients of variation used for the MCB bootstraps of landings and discards. Commercial handline landings (cv.L.cH), headboat landings (cv.L.HB), general recreational landings (cv.L.GR), commercial handline discards (cv.D.cH), headboat discards (cv.D.HB), and general recreational discards (cv.D.GR).

Year	CV.L.cH	CV.L.HB	CV.L.GR	CV.D.cH	CV.D.HB	CV.D.GR
1950	0.25	–	–	–	–	–
1951	0.25	–	–	–	–	–
1952	0.25	–	–	–	–	–
1953	0.25	–	–	–	–	–
1954	0.25	–	–	–	–	–
1955	0.25	0.59	0.59	–	–	–
1956	0.25	0.59	0.59	–	–	–
1957	0.25	0.59	0.59	–	–	–
1958	0.25	0.59	0.59	–	–	–
1959	0.25	0.59	0.59	–	–	–
1960	0.25	0.59	0.59	–	–	–
1961	0.25	0.59	0.59	–	–	–
1962	0.20	0.59	0.59	–	–	–
1963	0.20	0.59	0.59	–	–	–
1964	0.20	0.59	0.59	–	–	–
1965	0.20	0.59	0.59	–	–	–
1966	0.20	0.59	0.59	–	–	–
1967	0.20	0.59	0.59	–	–	–
1968	0.20	0.59	0.59	–	–	–
1969	0.20	0.59	0.59	–	–	–
1970	0.20	0.59	0.59	–	–	–
1971	0.20	0.59	0.59	–	–	–
1972	0.20	0.59	0.59	–	–	–
1973	0.20	0.59	0.59	–	–	–
1974	0.20	0.59	0.59	–	–	–
1975	0.20	0.59	0.59	–	–	–
1976	0.20	0.59	0.59	–	–	–
1977	0.20	0.59	0.59	–	–	–
1978	0.10	0.59	0.59	–	–	–
1979	0.10	0.59	0.59	–	–	–
1980	0.10	0.59	0.59	–	–	–
1981	0.10	0.15	0.27	–	–	1.00
1982	0.10	0.15	0.34	–	–	1.00
1983	0.10	0.15	0.18	–	–	1.00
1984	0.10	0.15	0.22	–	0.20	0.56
1985	0.10	0.15	0.20	–	0.20	1.34
1986	0.05	0.15	0.29	–	0.20	1.00
1987	0.05	0.15	0.20	–	0.20	1.00
1988	0.05	0.15	0.28	–	0.20	1.33
1989	0.05	0.15	0.21	–	0.20	1.18
1990	0.05	0.15	0.29	–	0.20	1.00
1991	0.05	0.15	0.31	–	0.20	1.00
1992	0.05	0.15	0.19	0.20	0.20	0.79
1993	0.05	0.15	0.22	0.20	0.20	0.68
1994	0.05	0.15	0.27	0.20	0.20	0.81
1995	0.05	0.15	0.29	0.20	0.20	0.53
1996	0.05	0.10	0.42	0.20	0.20	1.00
1997	0.05	0.10	0.52	0.20	0.20	0.54
1998	0.05	0.10	0.24	0.20	0.20	0.96
1999	0.05	0.10	0.23	0.20	0.20	0.47
2000	0.05	0.10	0.23	0.20	0.20	0.45
2001	0.05	0.10	0.18	0.20	0.20	0.42
2002	0.05	0.10	0.17	0.20	0.20	0.56
2003	0.05	0.10	0.20	0.20	0.20	0.47
2004	0.05	0.10	0.21	0.20	0.20	0.29
2005	0.05	0.10	0.24	0.20	0.20	0.23
2006	0.05	0.10	0.26	0.20	0.20	0.31
2007	0.05	0.10	0.24	0.20	0.20	0.26
2008	0.05	0.05	0.27	0.20	0.20	0.36
2009	0.05	0.05	0.25	0.20	0.20	0.38
2010	0.05	0.05	1.00	0.20	0.20	0.39
2011	0.05	0.05	1.00	0.20	0.20	0.34
2012	0.05	0.05	0.17	0.20	0.20	0.39
2013	0.05	0.05	0.18	0.20	0.20	0.31
2014	0.05	0.05	0.11	0.20	0.20	0.21

Table 7. Estimated total abundance at age (1000 fish) at start of year.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
1950	451.38	248.86	170.37	126.19	98.12	78.54	64.07	52.90	44.07	36.97	31.14	26.34	22.34	18.99	16.15	13.77	11.75	10.03	8.57	50.48	1581.01
1951	451.38	248.85	170.29	126.08	98.03	78.47	64.01	52.85	44.03	36.94	31.11	26.31	22.32	18.97	16.14	13.76	11.74	10.02	8.56	50.43	1580.29
1952	451.37	248.81	169.34	124.65	96.86	77.53	63.25	52.22	43.51	36.50	30.74	26.00	22.05	18.74	15.95	13.59	11.60	9.90	8.46	49.83	1570.91
1953	451.36	248.84	170.10	125.09	96.66	77.32	63.08	52.08	43.39	36.40	30.66	25.93	21.99	18.69	15.90	13.56	11.57	9.87	8.43	49.69	1570.62
1954	451.36	248.83	170.03	125.52	96.89	77.07	62.84	51.88	43.22	36.26	30.54	25.83	21.91	18.62	15.84	13.51	11.52	9.83	8.40	49.50	1569.40
1955	451.34	248.77	168.58	123.39	95.59	75.96	61.58	50.82	42.33	35.52	29.92	25.30	21.46	18.24	15.52	13.23	11.29	9.63	8.23	48.49	1555.19
1956	451.31	248.00	162.02	115.41	89.26	71.88	58.84	48.78	40.97	34.60	29.28	24.76	21.00	17.85	15.19	12.95	11.05	9.43	8.05	47.46	1518.10
1957	451.27	247.88	160.50	109.83	82.74	66.61	55.34	46.39	39.19	33.40	28.47	24.19	20.52	17.44	14.84	12.65	10.79	9.21	7.87	46.36	1485.47
1958	451.18	247.59	156.19	103.58	75.00	58.90	49.00	41.76	35.72	30.65	26.38	22.58	19.24	16.36	13.91	11.86	10.12	8.64	7.38	43.48	1429.52
1959	451.08	247.49	156.52	101.76	71.50	54.06	43.95	37.56	32.71	28.45	24.68	21.33	18.31	15.63	13.30	11.34	9.68	8.26	7.05	41.56	1396.20
1960	450.98	247.29	154.75	100.09	69.01	50.70	39.74	33.25	29.07	25.77	22.67	19.75	17.12	14.72	12.58	10.73	9.15	7.81	6.67	39.32	1361.18
1961	450.85	247.08	153.06	97.31	66.81	48.24	36.81	29.74	25.49	22.71	20.38	18.00	15.72	13.66	11.76	10.07	8.59	7.33	6.26	36.91	1326.78
1962	450.68	246.75	149.73	92.74	62.66	45.15	33.94	26.76	22.20	19.41	17.53	15.79	13.99	12.25	10.65	9.19	7.88	6.72	5.74	33.83	1283.57
1963	450.50	246.52	148.88	90.35	59.58	42.35	31.86	24.80	20.12	17.06	15.14	13.72	12.40	11.01	9.64	8.40	7.26	6.22	5.31	31.31	1252.43
1964	450.33	246.31	148.60	90.05	58.29	40.52	30.14	23.53	18.89	15.68	13.50	12.03	10.94	9.90	8.80	7.73	6.74	5.82	4.99	29.42	1232.21
1965	450.14	245.99	146.09	87.47	56.61	38.72	28.24	21.85	17.62	14.50	12.24	10.58	9.46	8.61	7.81	6.95	6.11	5.33	4.61	27.26	1206.20
1966	449.92	245.65	143.53	83.70	53.61	36.76	26.45	20.12	16.12	13.35	11.18	9.48	8.22	7.36	6.71	6.09	5.43	4.77	4.17	24.95	1177.57
1967	449.65	245.41	142.16	81.09	50.62	34.38	24.83	18.66	14.71	12.12	10.22	8.59	7.30	6.35	5.69	5.20	4.73	4.21	3.70	22.62	1152.24
1968	449.27	245.00	138.04	76.19	46.53	30.85	22.11	16.70	13.02	10.56	8.86	7.51	6.33	5.39	4.69	4.21	3.85	3.50	3.13	19.55	1115.30
1969	448.68	244.44	132.99	69.30	40.98	26.64	18.68	14.03	11.02	8.85	7.33	6.17	5.24	4.43	3.78	3.29	2.96	2.71	2.46	15.96	1069.96
1970	448.12	244.22	135.93	70.17	39.25	24.74	17.03	12.53	9.80	7.94	6.51	5.41	4.57	3.89	3.29	2.81	2.45	2.20	2.02	13.75	1056.64
1971	447.62	243.87	135.37	71.31	39.52	23.57	15.74	11.38	8.72	7.04	5.82	4.79	3.99	3.38	2.88	2.44	2.09	1.82	1.64	11.73	1044.73
1972	447.12	243.32	133.31	69.65	39.51	23.44	14.87	10.48	7.92	6.27	5.18	4.30	3.55	2.96	2.51	2.14	1.82	1.56	1.36	9.98	1031.24
1973	446.63	242.73	130.94	67.09	37.85	23.09	14.64	9.85	7.28	5.70	4.63	3.84	3.20	2.65	2.21	1.88	1.60	1.36	1.17	8.50	1016.83
1974	446.21	242.22	129.99	65.83	36.55	22.28	14.60	9.86	6.98	5.37	4.32	3.52	2.93	2.44	2.02	1.70	1.44	1.23	1.05	7.44	1007.96
1975	445.47	241.26	121.77	58.45	32.19	19.42	12.80	8.99	6.43	4.76	3.77	3.05	2.49	2.08	1.73	1.44	1.21	1.03	0.88	6.05	975.25
1976	443.94	239.81	111.58	47.42	24.89	15.04	9.93	7.09	5.32	4.00	3.06	2.44	1.98	1.62	1.35	1.13	0.94	0.79	0.67	4.53	927.52
1977	441.43	238.18	104.58	39.38	18.40	10.69	7.13	5.14	3.95	3.14	2.45	1.89	1.51	1.22	1.00	0.84	0.70	0.58	0.49	3.23	885.94
1978	493.85	235.75	94.74	31.43	13.08	6.83	4.43	3.26	2.56	2.09	1.74	1.36	1.05	0.84	0.68	0.56	0.47	0.39	0.33	2.09	897.55
1979	367.80	262.12	82.82	22.90	8.46	3.99	2.36	1.71	1.39	1.17	1.00	0.84	0.66	0.51	0.41	0.33	0.27	0.23	0.19	1.18	760.33
1980	543.28	195.04	92.54	20.43	6.32	2.66	1.43	0.95	0.76	0.67	0.59	0.51	0.43	0.34	0.26	0.21	0.17	0.14	0.12	0.70	867.52
1981	194.01	285.97	60.81	18.59	4.65	1.67	0.82	0.50	0.38	0.33	0.31	0.27	0.24	0.20	0.16	0.12	0.10	0.08	0.07	0.38	569.64
1982	320.72	101.34	84.85	11.22	3.89	1.13	0.47	0.27	0.19	0.15	0.14	0.13	0.12	0.10	0.09	0.07	0.05	0.04	0.03	0.20	525.21
1983	886.15	169.97	36.12	20.54	2.99	1.15	0.37	0.17	0.10	0.08	0.07	0.06	0.06	0.05	0.05	0.04	0.03	0.02	0.02	0.10	1118.14
1984	1003.78	463.16	45.51	5.43	3.49	0.59	0.27	0.10	0.05	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.04	1522.60
1985	458.35	510.98	130.80	8.28	1.15	0.89	0.18	0.10	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	1110.93
1986	246.99	226.63	126.32	20.20	1.54	0.27	0.26	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.02	622.42
1987	758.45	122.13	86.53	38.92	7.05	0.61	0.12	0.13	0.04	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	1014.07
1988	579.89	393.25	54.45	32.82	16.29	3.25	0.31	0.07	0.08	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	1080.48
1989	192.10	303.67	184.92	22.67	15.06	8.23	1.80	0.18	0.04	0.05	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	728.78
1990	82.71	101.52	145.34	78.22	10.51	7.65	4.55	1.07	0.12	0.03	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	431.80
1991	70.98	43.25	57.72	82.11	47.48	6.73	5.11	3.15	0.76	0.09	0.02	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	317.46
1992	343.72	35.71	21.89	28.32	44.40	27.85	4.24	3.43	2.22	0.56	0.06	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	512.45
1993	124.40	175.94	22.16	9.80	8.54	15.02	11.41	2.09	1.98	1.43	0.39	0.05	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.01	373.25
1994	210.08	57.86	102.98	9.79	2.99	2.86	5.76	4.92	0.99	1.00	0.76	0.21	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	400.25
1995	99.53	97.79	33.82	47.09	3.15	1.05	1.14	2.57	2.41	0.52	0.55	0.42	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	290.19
1996	248.48	44.51	55.44	15.59	16.12	1.19	0.45	0.54	1.32	1.32	0.29	0.32	0.25	0.07	0.01	0.00	0.00	0.00	0.00	0.00	385.89
1997	180.06	126.71	28.20	29.60	6.50	7.18	0.58	0.24	0.30	0.78	0.79	0.18	0.19	0.15	0.04	0.01	0.00	0.00	0.00	0.00	381.53
1998	318.30	91.64	76.68	9.91	5.55	1.40	1.98	0.20	0.10	0.15	0.42	0.46	0.11	0.12	0.09	0.03	0.00	0.00	0.00	0.00	507.15
1999	423.89	165.69	59.12	41.70	4.22	2.53	0.70	1.09	0.12	0.06	0.10	0.28	0.30	0.07	0.08	0.06	0.02	0.00	0.00	0.00	700.03
2000	459.88	197.76	96.30	25.18	11.81	1.34	0.97	0.32	0.58	0.07	0.04	0.06	0.19	0.21	0.05	0.05	0.04	0.01	0.00	0.00	794.86
2001	324.84	202.68	110.01	39.81	6.94	3.67	0.50	0.44	0.17	0.34	0.04	0.03	0.04	0.13	0.14	0.03	0.04	0.03	0.01	0.00	689.88
2002	276.32	142.42	113.75	49.70	12.91	2.47	1.50	0.23	0.22	0.09	0.19	0.03	0.02	0.03	0.08	0.09	0.02	0.02	0.02	0.01	600.12
2003	346.33	125.01	81.57	53.14	17.26	4.94	1.08	0.74	0.13	0.13	0.06	0.12	0.02	0.01	0.02	0.05	0.06	0.01	0.01	0.02	630.71
2004	129.02	158.12	73.39	44.72	24.60	8.59	2.70	0.64	0.47	0.09	0.09	0.04	0.09	0.01	0.01	0.01	0.04	0.04	0.01	0.02	442.69
2005	57.11	45.66	76.10	33.76	17.01	10.41	4.12	1.45	0.38	0.30	0.06	0.06	0.03	0.06	0.01	0.00	0.01	0.02	0.03	0.02	246.59
2006	894.27	20.51	21.94	33.63	12.05	6.84	4.84	2.18	0.85	0.24	0.20	0.04	0.04	0.02	0.04	0.01	0.00	0.01	0.02	0.03	997.76
2007	636.29	454.43	12.82	10.10	10.65	4.25	2.86	2.38	1.23	0.53	0.16	0.14	0.03	0.03	0.01	0.03	0.00	0.00	0.00	0.04	1135.98
2008	656.59	288.19	261.18	5.52	2.97	3.49	1.63	1.26	1.18	0.66	0.30	0.09	0.08	0.02	0.02	0.01	0.02	0.00	0.00	0.03	1223.24
2009	204.65	254.88	144.37	90.41	1.13	0.70	1.02	0.58	0.54	0.57	0.35	0.16	0.05	0.05	0.01	0.01	0.00	0.01	0.00	0.02	699.49
2010	83.19	77.39	126.65	54.62	22.28	0.31	0.23	0.39	0.25	0.25	0.29	0.18	0.09	0.03	0.02	0.00	0.01	0.00	0.01	0.01	366.20
2011	268.39	37.95	42.07	71.43	31.60	13.50	0.20	0.16	0.28	0.19	0.20	0.22	0.14	0.07	0.02	0.02	0.00	0.00	0.00	0.01	466.47
2012	256.30	139.96	24.04	27.35	47.08	21.43	9.44	0.14	0.11	0.21	0.14	0.15	0.17	0.11	0.05	0.02	0.01	0.00	0.00	0.01	526.74
2013	457.91	124.67	81.45	14.00	14.90	25.17	11.88	5.47	0.09	0.07	0.13	0.09	0.10	0.11	0.07	0.03	0.01	0.01	0.00	0.01	736.17
2014	1146.50	237.07	78.73	52.68	8.76	9.31	16.14	7.83	3.69	0.06	0.05	0.09	0.06	0.07	0.08	0.05	0.02	0.01	0.01	0.01	1561.22
2015	432.79	582.88	144.14	45.74	25.89	3.98	4.31	7.72	3.86	1.87	0.03	0.03	0.05	0.03	0.04	0.04	0.03	0.01	0.00	0.01	1253.44

Table 8. Estimated biomass at age (mt) at start of year

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
1950	239.0	350.3	434.0	477.6	490.5	480.6	455.4	420.9	382.1	342.4	303.4	266.9	233.4	203.2	176.1	152.4	131.5	113.2	97.4	577.1	6327.6
1951	239.0	350.3	433.8	477.2	490.1	480.1	455.0	420.6	381.8	342.1	303.2	266.7	233.2	203.0	176.0	152.2	131.4	113.1	97.3	576.6	6322.7
1952	239.0	350.3	431.4	471.8	484.3	474.4	449.6	415.5	377.2	338.0	299.6	263.5	230.5	200.6	173.9	150.4	129.8	111.8	96.1	569.7	6257.3
1953	238.9	350.3	433.4	473.5	483.2	473.1	448.4	414.4	376.2	337.1	298.7	262.8	229.8	200.1	173.4	150.0	129.5	111.5	95.9	568.2	6248.3
1954	238.9	350.3	433.2	475.1	484.4	471.6	446.7	412.8	374.8	335.8	297.6	261.8	228.9	199.3	172.7	149.4	129.0	111.0	95.5	566.0	6234.8
1955	238.9	350.2	429.5	467.0	477.9	464.8	437.8	404.4	367.1	328.9	291.5	256.4	224.3	195.2	169.2	146.4	126.3	108.8	93.6	554.4	6132.4
1956	238.9	349.1	412.8	436.8	446.2	439.8	418.3	388.2	355.2	320.4	285.3	251.0	219.5	191.0	165.6	143.2	123.6	106.5	91.6	542.6	5925.7
1957	238.9	348.9	408.9	415.7	413.7	407.6	393.4	369.1	339.8	309.3	277.4	245.1	214.4	186.6	161.8	139.9	120.8	104.0	89.5	530.0	5714.9
1958	238.9	348.5	397.9	392.0	375.0	360.4	348.3	332.3	309.7	283.9	257.1	228.8	201.1	175.0	151.7	131.2	113.3	97.5	83.9	497.1	5323.7
1959	238.8	348.4	398.8	385.2	357.5	330.8	312.4	298.9	283.6	263.5	240.4	216.1	191.3	167.3	145.0	125.4	108.3	93.2	80.2	475.1	5060.2
1960	238.7	348.1	394.3	378.9	345.0	310.2	282.5	264.6	252.1	238.7	220.9	200.1	178.9	157.6	137.2	118.7	102.4	88.2	75.9	449.6	4782.4
1961	238.7	347.8	390.0	368.3	334.0	295.2	261.6	236.6	221.0	210.3	198.6	182.4	164.3	146.2	128.2	111.4	96.2	82.8	71.2	422.0	4506.8
1962	238.6	347.4	381.5	351.0	313.2	276.3	241.3	212.9	192.5	179.8	170.8	160.0	146.2	131.1	116.1	101.6	88.1	75.9	65.3	386.7	4176.2
1963	238.5	347.0	379.3	342.0	297.9	259.2	226.5	197.4	174.4	158.0	147.5	139.1	129.6	117.8	105.1	92.9	81.2	70.2	60.4	358.0	3921.9
1964	238.4	346.7	378.6	340.8	291.4	248.0	214.3	187.3	163.8	145.2	131.6	121.9	114.3	106.0	96.0	85.5	75.4	65.7	56.8	336.4	3743.9
1965	238.3	346.3	372.2	331.1	283.0	236.9	200.7	173.9	152.8	134.3	119.3	107.2	98.8	92.2	85.1	76.9	68.4	60.2	52.4	311.7	3541.7
1966	238.2	345.8	365.7	316.8	268.0	224.9	188.0	160.1	139.8	123.7	109.0	96.1	85.9	78.7	73.2	67.4	60.8	53.9	47.4	285.2	3328.5
1967	238.0	345.5	362.2	306.9	253.1	210.4	176.5	148.5	127.6	112.2	99.6	87.1	76.3	67.9	62.0	57.5	52.9	47.6	42.1	258.6	3132.4
1968	237.8	344.9	351.7	288.4	232.6	188.8	157.1	132.9	112.9	97.8	86.4	76.1	66.2	57.7	51.1	46.6	43.1	39.5	35.5	223.5	2870.7
1969	237.5	344.1	338.8	262.3	204.9	163.0	132.8	111.7	95.6	82.0	71.4	62.6	54.8	47.4	41.2	36.4	33.1	30.6	28.0	182.5	2560.6
1970	237.2	343.8	346.3	265.6	196.2	151.4	121.1	99.7	85.0	73.5	63.4	54.8	47.8	41.6	35.9	31.1	27.4	24.9	23.0	157.2	2427.0
1971	237.0	343.3	344.9	269.9	197.6	144.2	111.9	90.6	75.6	65.2	56.7	48.6	41.7	36.2	31.4	27.0	23.4	20.6	18.6	134.1	2318.4
1972	236.7	342.5	339.6	263.6	197.5	143.4	105.7	83.4	68.6	58.1	50.4	43.6	37.1	31.7	27.4	23.7	20.4	17.6	15.4	114.2	2220.7
1973	236.4	341.7	333.6	253.9	189.3	141.3	104.1	78.4	63.1	52.8	45.1	38.9	33.4	28.3	24.1	20.8	18.0	15.4	13.3	97.2	2129.0
1974	236.2	341.0	331.2	249.2	182.7	136.3	103.7	78.4	60.5	49.7	42.1	35.7	30.6	26.2	22.1	18.8	16.1	13.9	11.9	85.0	2071.3
1975	235.8	339.6	310.2	221.2	160.9	118.8	91.0	71.5	55.7	44.1	36.7	30.9	26.0	22.2	18.9	15.9	13.5	11.6	10.0	69.1	1903.8
1976	235.0	337.6	284.3	179.5	124.5	92.1	70.6	56.4	46.1	37.0	29.9	24.7	20.7	17.3	14.7	12.5	10.5	8.9	7.6	51.7	1661.5
1977	233.7	335.3	266.4	149.0	92.0	65.4	50.7	40.9	34.3	29.1	23.9	19.1	15.7	13.1	10.9	9.3	7.9	6.6	5.6	37.0	1445.8
1978	261.4	331.9	241.4	119.0	65.4	41.8	31.5	26.0	22.2	19.4	16.9	13.8	11.0	9.0	7.5	6.2	5.3	4.4	3.7	23.9	1261.7
1979	194.7	369.0	211.0	86.7	42.3	24.4	16.8	13.6	12.0	10.8	9.8	8.5	6.9	5.4	4.4	3.7	3.1	2.6	2.2	13.5	1041.3
1980	287.6	274.6	235.7	77.3	31.6	16.3	10.1	7.6	6.6	6.2	5.8	5.2	4.4	3.6	2.8	2.3	1.9	1.6	1.3	8.0	990.5
1981	102.7	402.6	154.9	70.4	23.2	10.2	5.8	4.0	3.3	3.1	3.0	2.8	2.5	2.1	1.7	1.3	1.1	0.9	0.7	4.4	800.7
1982	169.8	142.7	216.2	42.5	19.5	6.9	3.4	2.1	1.6	1.4	1.4	1.3	1.2	1.1	0.9	0.8	0.6	0.5	0.4	2.2	616.5
1983	469.1	239.3	92.0	77.7	14.9	7.1	2.6	1.4	0.9	0.7	0.6	0.6	0.6	0.6	0.5	0.4	0.3	0.3	0.2	1.2	911.1
1984	531.4	652.0	115.9	20.5	17.4	3.6	1.9	0.8	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.5	1346.5
1985	242.6	719.3	333.2	31.4	5.8	5.5	1.3	0.8	0.4	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	1341.8
1986	130.8	319.0	321.8	76.4	7.7	1.6	1.9	0.5	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.2	861.3
1987	401.5	171.9	220.5	147.3	35.3	3.7	0.9	1.0	0.3	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.2	983.3
1988	307.0	553.6	138.7	124.2	81.4	19.9	2.2	0.5	0.7	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1229.0
1989	101.7	427.5	471.1	85.8	75.3	50.3	12.8	1.5	0.4	0.5	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1227.4
1990	43.8	142.9	370.3	296.1	52.6	46.8	32.3	8.5	1.0	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	995.3
1991	37.6	60.9	147.1	310.8	237.4	41.2	36.3	25.0	6.6	0.8	0.2	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	904.4
1992	182.0	50.3	55.8	107.2	222.0	170.4	30.2	27.3	19.3	5.2	0.6	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	870.7
1993	65.9	247.7	56.5	37.1	42.7	91.9	81.1	16.7	17.1	13.3	3.8	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.1	674.6
1994	111.2	81.4	262.4	37.0	14.9	17.5	40.9	39.2	8.6	9.3	7.4	2.1	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	632.6
1995	52.7	137.7	86.2	178.2	15.8	6.4	8.1	20.5	20.9	4.8	5.3	4.3	1.2	0.2	0.0	0.1	0.0	0.0	0.0	0.0	542.4
1996	131.5	62.7	141.2	59.0	80.6	7.3	3.2	4.3	11.5	12.2	2.9	3.2	2.6	0.7	0.1	0.0	0.0	0.0	0.0	0.0	523.0
1997	95.3	178.4	71.8	112.0	32.5	43.9	4.1	1.9	2.6	7.2	7.7	1.8	2.0	1.6	0.5	0.1	0.0	0.0	0.0	0.0	563.7
1998	168.5	129.0	195.4	37.5	27.7	8.6	14.1	1.6	0.9	1.4	4.1	4.6	1.1	1.3	1.0	0.3	0.0	0.0	0.0	0.0	597.1
1999	224.4	233.2	150.6	157.8	21.1	15.5	5.0	8.6	1.0	0.6	0.9	2.8	3.2	0.8	0.9	0.7	0.2	0.0	0.0	0.0	827.4
2000	243.5	278.4	245.3	95.3	59.0	8.2	6.9	2.6	5.0	0.7	0.4	0.6	2.0	2.2	0.5	0.6	0.5	0.1	0.0	0.0	951.8
2001	172.0	285.3	280.3	150.7	34.7	22.5	3.6	3.5	1.5	3.1	0.4	0.3	0.4	1.4	1.5	0.4	0.4	0.3	0.1	0.0	962.3
2002	146.3	200.5	289.8	188.1	64.6	15.1	10.6	1.9	1.9	0.9	1.9	0.3	0.2	0.3	0.8	1.0	0.2	0.3	0.2	0.1	924.8
2003	183.3	176.0	207.8	201.1	86.3	30.2	7.7	5.9	1.1	1.2	0.6	1.2	0.2	0.1	0.2	0.6	0.6	0.1	0.2	0.2	904.7
2004	68.3	222.6	187.0	169.3	123.0	52.5	19.2	5.1	4.1	0.8	0.9	0.4	0.9	0.1	0.1	0.1	0.4	0.5	0.1	0.3	855.6
2005	30.2	64.3	193.9	127.8	85.1	63.7	29.3	11.5	3.3	2.7	0.5	0.6	0.3	0.6	0.1	0.1	0.1	0.3	0.3	0.2	614.9
2006	473.4	28.9	55.9	127.3	60.3	41.9	34.4	17.3	7.4	2.2	1.9	0.4	0.4	0.2	0.5	0.1	0.0	0.1	0.2	0.4	853.1
2007	336.8	639.7	32.7	38.2	53.2	26.0	20.3	19.0	10.6	4.9	1.5	1.4	0.3	0.3	0.1	0.3	0.0	0.0	0.0	0.4	1186.1
2008	347.6	405.7	665.4	20.9	14.9	21.4	11.6	10.1	10.2	6.1	2.9	0.9	0.8	0.2	0.2	0.1	0.2	0.0	0.0	0.3	1519.5
2009	108.3	358.8	367.8	342.2	5.6	4.3	7.2	4.6	4.7	5.3	3.4	1.7	0.5	0.5	0.1	0.1	0.1	0.1	0.0	0.2	1215.4
2010	44.0	108.9	322.7	206.7	111.4	1.9	1.6	3.1	2.2	2.4	2.8	1.8	0.9	0.3	0.3	0.1	0.1	0.0	0.1	0.1	811.3
2011	142.1	53.4	107.2	270.4	158.0	82.6	1.4	1.2	2.4	1.8	1.9	2.3	1.5	0.7	0.2	0.2	0.0	0.0	0.0	0.1	827.6
2012	135.7	197.0	61.3	103.5	235.4	131.1	67.1	1.1	1.0	1.9	1.4	1.5	1.8	1.1	0.6	0.2	0.2	0.0	0.0	0.1	942.1
2013	242.4	175.5	207.5	53.0	74.5	154.0	84.4	43.5	0.8	0.7	1.3	0.9	1.0	1.2	0.8	0.4	0.1	0.1	0.0	0.1	1042.2
2014	606.9	333.7	200.6	199.4	43.8	56.9	114.7	62.3	32.0	0.6	0.5	0.9	0.7	0.7	0.8	0.5	0.3	0.1	0.1	0.1	1655.7
2015	229.1	820.5	367.2	173.1	129.4	24.4	30.6	61.4	33.5	17.3	0.3	0.3	0.5	0.4	0.4	0.4	0.3	0.1	0.0	0.1	1889.4

Table 9. Estimated biomass at age (1000 lb) at start of year

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
1950	526.9	772.3	956.8	1052.9	1081.4	1059.5	1004.0	927.9	842.4	754.9	668.9	588.4	514.6	448.0	388.2	336.0	289.9	249.6	214.7	1272.3	13950.0
1951	526.9	772.3	956.4	1052.0	1080.5	1058.4	1003.1	927.3	841.7	754.2	668.4	588.0	514.1	447.5	388.0	335.5	289.7	249.3	214.5	1271.2	13939.2
1952	526.9	772.3	951.1	1040.1	1067.7	1045.9	991.2	916.0	831.6	745.2	660.5	580.9	508.2	442.2	383.4	331.6	286.2	246.5	211.9	1256.0	13795.0
1953	526.7	772.3	955.5	1043.9	1065.3	1043.0	988.6	913.6	829.4	743.2	658.5	579.4	506.6	441.1	382.3	330.7	285.5	245.8	211.4	1252.7	13775.1
1954	526.7	772.3	955.0	1047.4	1067.9	1039.7	984.8	910.1	826.3	740.3	656.1	577.2	504.6	439.4	380.7	329.4	284.4	244.7	210.5	1247.8	13745.4
1955	526.7	772.1	946.9	1029.6	1053.6	1024.7	965.2	891.5	809.3	725.1	642.6	565.3	494.5	430.3	373.0	322.8	278.4	239.9	206.4	1222.2	13519.6
1956	526.7	769.6	910.1	963.0	983.7	969.6	922.2	855.8	783.1	706.4	629.0	553.4	483.9	421.1	365.1	315.7	272.5	234.8	201.9	1196.2	13063.9
1957	526.7	769.2	901.5	916.5	912.1	898.6	867.3	813.7	749.1	681.9	611.6	540.4	472.7	411.4	356.7	308.4	266.3	229.3	197.3	1168.4	12599.2
1958	526.7	768.3	877.2	864.2	826.7	794.5	767.9	732.6	682.8	625.9	566.8	504.4	443.3	385.8	334.4	289.2	249.8	215.0	185.0	1095.9	11736.7
1959	526.5	768.1	879.2	849.2	788.2	729.3	688.7	659.0	625.2	580.9	530.0	476.4	421.7	368.8	319.7	276.5	238.8	205.5	176.8	1047.4	11155.8
1960	526.2	767.4	869.3	835.3	760.6	683.9	622.8	583.3	555.8	526.2	487.0	441.1	394.4	347.4	302.5	261.7	225.8	194.4	167.3	991.2	10543.4
1961	526.2	766.8	859.8	812.0	736.3	650.8	576.7	521.6	487.2	463.6	437.8	402.1	362.2	322.3	282.6	245.6	212.1	182.5	157.0	930.3	9935.8
1962	526.0	765.9	841.1	773.8	690.5	609.1	532.0	469.4	424.4	396.4	376.5	352.7	322.3	289.0	256.0	224.0	194.2	167.3	144.0	852.5	9206.9
1963	525.8	765.0	836.2	754.0	656.8	571.4	499.3	435.2	384.5	348.3	325.2	306.7	285.7	259.7	231.7	204.8	179.0	154.8	133.2	789.3	8646.3
1964	525.6	764.3	834.7	751.3	642.4	546.7	472.5	412.9	361.1	320.1	290.1	268.7	252.0	233.7	211.6	188.5	166.2	144.8	125.2	741.6	8253.9
1965	525.4	763.5	820.6	729.9	623.9	522.3	442.5	383.4	336.9	296.1	263.0	236.3	217.8	203.3	187.6	169.5	150.8	132.7	115.5	687.2	7808.1
1966	525.1	762.4	806.2	698.4	590.8	495.8	414.5	353.0	308.2	272.7	240.3	211.9	189.4	173.5	161.4	148.6	134.0	118.8	104.5	628.8	7338.1
1967	524.7	761.7	798.5	676.6	558.0	463.9	389.1	327.4	281.3	247.4	219.6	192.0	168.2	149.7	136.7	126.8	116.6	104.9	92.8	570.1	6905.8
1968	524.3	760.4	775.4	635.8	512.8	416.2	346.3	293.0	248.9	215.6	190.5	167.8	145.9	127.2	112.7	102.7	95.0	87.1	78.3	492.7	6328.8
1969	523.6	758.6	746.9	578.3	451.7	359.4	292.8	246.3	210.8	180.8	157.4	138.0	120.8	104.5	90.8	80.2	73.0	67.5	61.7	402.3	5645.1
1970	522.9	757.9	763.5	585.5	432.5	333.8	267.0	219.8	187.4	162.0	139.8	120.8	105.4	91.7	79.1	68.6	60.4	54.9	50.7	346.6	5350.6
1971	522.5	756.8	760.4	595.0	435.6	317.9	246.7	199.7	166.7	143.7	125.0	107.1	91.9	79.8	69.2	59.5	51.6	45.4	41.0	295.6	5111.2
1972	521.8	755.1	748.7	581.1	435.4	316.1	233.0	183.9	151.2	128.1	111.1	96.1	81.8	69.9	60.4	52.2	45.0	38.8	34.0	251.8	4895.8
1973	521.2	753.3	735.5	559.8	417.3	311.5	229.5	172.8	139.1	116.4	99.4	85.8	73.6	62.4	53.1	45.9	39.7	34.0	29.3	214.3	4693.6
1974	520.7	751.8	730.2	549.4	402.8	300.5	228.6	172.8	133.4	109.6	92.8	78.7	67.5	57.8	48.7	41.4	35.5	30.6	26.2	187.4	4566.4
1975	519.8	748.7	683.9	487.7	354.7	261.9	200.6	157.6	122.8	97.2	80.9	68.1	57.3	48.9	41.7	35.1	29.8	25.6	22.0	152.3	4197.2
1976	518.1	744.3	626.8	395.7	274.5	203.0	155.6	124.3	101.6	81.6	65.9	54.5	45.6	38.1	32.4	27.6	23.1	19.6	16.8	114.0	3663.0
1977	515.2	739.2	587.3	328.5	202.8	144.2	111.8	90.2	75.6	64.2	52.7	42.1	34.6	28.9	24.0	20.5	17.4	14.6	12.3	81.6	3187.4
1978	576.3	731.7	532.2	262.3	144.2	92.2	69.4	57.3	48.9	42.8	37.3	30.4	24.3	19.8	16.5	13.7	11.7	9.7	8.2	52.7	2781.6
1979	429.2	813.5	465.2	191.1	93.3	53.8	37.0	30.0	26.5	23.8	21.6	18.7	15.2	11.9	9.7	8.2	6.8	5.7	4.9	29.8	2295.7
1980	634.0	605.4	519.6	170.4	69.7	35.9	22.3	16.8	14.6	13.7	12.8	11.5	9.7	7.9	6.2	5.1	4.2	3.5	2.9	17.6	2183.7
1981	226.4	887.6	341.5	155.2	51.1	22.5	12.8	8.8	7.3	6.8	6.6	6.2	5.5	4.6	3.7	2.9	2.4	2.0	1.5	9.7	1765.2
1982	374.3	314.6	476.6	93.7	43.0	15.2	7.5	4.6	3.5	3.1	3.1	2.9	2.6	2.4	2.0	1.8	1.3	1.1	0.9	4.9	1359.1
1983	1034.2	527.6	202.8	171.3	32.8	15.7	5.7	3.1	2.0	1.5	1.3	1.3	1.3	1.3	1.1	0.9	0.7	0.7	0.4	2.6	2008.6
1984	1171.5	1437.4	255.5	45.2	38.4	7.9	4.2	1.8	0.9	0.7	0.7	0.4	0.4	0.4	0.4	0.4	0.2	0.2	0.2	1.1	2968.5
1985	534.8	1585.8	734.6	69.2	12.8	12.1	2.9	1.8	0.9	0.4	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.7	2958.2
1986	288.4	703.3	709.4	168.4	17.0	3.5	4.2	1.1	0.9	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.4	1898.8
1987	885.2	379.0	486.1	324.7	77.8	8.2	2.0	2.2	0.7	0.4	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.4	2167.8
1988	676.8	1220.5	305.8	273.8	179.5	43.9	4.9	1.1	1.5	0.4	0.4	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2709.5
1989	224.2	942.5	1038.6	189.2	166.0	110.9	28.2	3.3	0.9	1.1	0.4	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2706.0
1990	96.6	315.0	816.4	652.8	116.0	103.2	71.2	18.7	2.2	0.7	0.7	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2194.3
1991	82.9	134.3	324.3	685.2	523.4	90.8	80.0	55.1	14.6	1.8	0.4	0.7	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	1993.9
1992	401.2	110.9	123.0	236.3	489.4	375.7	66.6	60.2	42.5	11.5	1.3	0.4	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.2	1919.6
1993	145.3	546.1	124.6	81.8	94.1	202.6	178.8	36.8	37.7	29.3	8.4	1.1	0.2	0.4	0.2	0.0	0.0	0.0	0.0	0.2	1487.2
1994	245.2	179.5	578.5	81.6	32.8	38.6	90.2	86.4	19.0	20.5	16.3	4.6	0.7	0.2	0.2	0.0	0.0	0.0	0.0	0.0	1394.6
1995	116.2	303.6	190.0	392.9	34.8	14.1	17.9	45.2	46.1	10.6	11.7	9.5	2.6	0.4	0.0	0.2	0.0	0.0	0.0	0.0	1195.8
1996	289.9	138.2	311.3	130.1	177.7	16.1	7.1	9.5	25.4	26.9	6.4	7.1	5.7	1.5	0.2	0.0	0.0	0.0	0.0	0.0	1153.0
1997	210.1	393.3	158.3	246.9	71.7	96.8	9.0	4.2	5.7	15.9	17.0	4.0	4.4	3.5	1.1	0.2	0.0	0.0	0.0	0.0	1242.7
1998	371.5	284.4	430.8	82.7	61.1	19.0	31.1	3.5	2.0	3.1	9.0	10.1	2.4	2.9	2.2	0.7	0.0	0.0	0.0	0.0	1316.4
1999	494.7	514.1	332.0	347.9	46.5	34.2	11.0	19.0	2.2	1.3	2.0	6.2	7.1	1.8	2.0	1.5	0.4	0.0	0.0	0.0	1824.1
2000	536.8	613.8	540.8	210.1	130.1	18.1	15.2	5.7	11.0	1.5	0.9	1.3	4.4	4.9	1.1	1.3	1.1	0.2	0.0	0.0	2098.4
2001	379.2	629.0	618.0	332.2	76.5	49.6	7.9	7.7	3.3	6.8	0.9	0.7	0.9	3.1	3.3	0.9	0.9	0.7	0.2	0.0	2121.5
2002	322.5	442.0	638.9	414.7	142.4	33.3	23.4	4.2	4.2	2.0	4.2	0.7	0.4	0.7	1.8	2.2	0.4	0.7	0.4	0.2	2038.8
2003	404.1	388.0	458.1	443.3	190.3	66.6	17.0	13.0	2.4	2.6	1.3	2.6	0.4	0.2	0.4	1.3	1.3	0.2	0.4	0.4	1994.5
2004	150.6	490.7	412.3	373.2	271.2	115.7	42.3	11.2	9.0	1.8	2.0	0.9	2.0	0.2	0.2	0.2	0.9	1.1	0.2	0.7	1886.3
2005	66.6	141.8	427.5	281.8	187.6	140.4	64.6	25.4	7.3	6.0	1.1	1.3	0.7	1.3	0.2	0.2	0.2	0.7	0.7	0.4	1355.6
2006	1043.7	63.7	123.2	280.6	132.9	92.4	75.8	38.1	16.3	4.9	4.2	0.9	0.9	0.4	1.1	0.2	0.0	0.2	0.4	0.9	1880.8
2007	742.5	1410.3	72.1	84.2	117.3	57.3	44.8	41.9	23.4	10.8	3.3	3.1	0.7	0.7	0.2	0.7	0.0	0.0	0.0	0.9	2614.9
2008	766.3	894.4	1467.0	46.1	32.8	47.2	25.6	22.3	22.5	13.4	6.4	2.0	1.8	0.4	0.4	0.2	0.4	0.0	0.0	0.7	3349.9
2009	238.8	791.0	810.9	754.4	12.3	9.5	15.9	10.1	10.4	11.7	7.5	3.7	1.1	1.1	0.2	0.2	0.2	0.2	0.0	0.4	2679.5
2010	97.0	240.1	711.4	455.7	245.6	4.2	3.5	6.8	4.9	5.3	6.2	4.0	2.0	0.7	0.7	0.2	0.2	0.0	0.2	0.2	1788.6
2011	313.3	117.7	236.3	596.1	348.3	182.1	3.1	2.6	5.3	4.0	4.2	5.1	3.3	1.5	0.4	0.4	0.0	0.0	0.0	0.2	1824.5
2012	299.2	434.3	135.1	228.2	519.0	289.0	147.9	2.4	2.2	4.2	3.1	3.3	4.0	2.4	1.3	0.4	0.4	0.0	0.0	0.2	2077.0
2013	534.4	386.9	457.5	116.8	164.2	339.5	186.1	95.9	1.8	1.5	2.9	2.0	2.2	2.6	1.8	0.9	0.2	0.2	0.0	0.2	2297.7
2014	1338.0	735.7	442.2	439.6	96.6	125.4	252.9	137.3	70.5	1.3	1.1	2.0	1.5	1.5	1.8	1.1	0.7	0.2	0.2	0.2	3650.2
2015	505.1	1808.9	809.5	381.6	285.3	53.8	67.5	135.4	73.9	38.1	0.7	0.7	1.1	0.9	0.9	0.9	0.7	0.2	0.0	0.2	4165.4

Table 10. Estimated time series of status indicators, fishing mortality, and biomass. Fishing mortality rate is apical F. Total biomass (B, mt) is at the start of the year, and spawning biomass (SSB, 1E8 Eggs) at the time of peak spawning (mid-year). The $MSST_{F30}$ is defined as $75\% SSB_{F30}$, with constant $M = 0.134$.

Year	F	F/F_{30}	B	$B/B_{unfished}$	SSB	$SSB/SSBB_{F30}$	$SSB/MSST_{F30}$
1950	0.030	0.208	6328	0.786	780250	2.365	3.153
1951	0.042	0.284	6323	0.785	773414	2.344	3.125
1952	0.032	0.221	6257	0.777	769048	2.331	3.108
1953	0.033	0.228	6248	0.776	766696	2.324	3.098
1954	0.050	0.343	6235	0.774	755812	2.291	3.054
1955	0.108	0.736	6132	0.762	736224	2.231	2.975
1956	0.118	0.803	5926	0.736	711697	2.157	2.876
1957	0.167	1.139	5715	0.710	667321	2.023	2.697
1958	0.157	1.074	5324	0.661	623844	1.891	2.521
1959	0.176	1.201	5060	0.628	582561	1.766	2.354
1960	0.193	1.316	4782	0.594	539537	1.635	2.180
1961	0.230	1.570	4507	0.560	490901	1.488	1.984
1962	0.234	1.597	4176	0.519	446658	1.354	1.805
1963	0.232	1.581	3922	0.487	412811	1.251	1.668
1964	0.259	1.766	3744	0.465	380886	1.154	1.539
1965	0.286	1.951	3542	0.440	347909	1.054	1.406
1966	0.300	2.046	3328	0.413	316118	0.958	1.277
1967	0.353	2.406	3132	0.389	279545	0.847	1.130
1968	0.418	2.852	2871	0.357	236584	0.717	0.956
1969	0.368	2.513	2561	0.318	206348	0.625	0.834
1970	0.374	2.552	2427	0.301	185290	0.562	0.749
1971	0.394	2.684	2318	0.288	168164	0.510	0.680
1972	0.416	2.836	2221	0.276	153947	0.467	0.622
1973	0.417	2.842	2129	0.264	143809	0.436	0.581
1974	0.528	3.603	2071	0.257	128607	0.390	0.520
1975	0.672	4.584	1904	0.236	105348	0.319	0.426
1976	0.771	5.256	1662	0.206	81166	0.246	0.328
1977	0.931	6.351	1446	0.180	58018	0.176	0.234
1978	1.149	7.837	1262	0.157	37336	0.113	0.151
1979	1.129	7.700	1041	0.129	25314	0.077	0.102
1980	1.334	9.099	990	0.123	17080	0.052	0.069
1981	1.419	9.681	801	0.099	11929	0.036	0.048
1982	1.148	7.829	616	0.077	9209	0.028	0.037
1983	1.625	11.081	911	0.113	6799	0.021	0.027
1984	1.432	9.771	1347	0.167	8907	0.027	0.036
1985	1.597	10.895	1342	0.167	10528	0.032	0.043
1986	0.906	6.182	861	0.107	12382	0.038	0.050
1987	0.699	4.765	983	0.122	15116	0.046	0.061
1988	0.605	4.130	1229	0.153	20881	0.063	0.084
1989	0.589	4.020	1227	0.152	28619	0.087	0.116
1990	0.300	2.046	995	0.124	38649	0.117	0.156
1991	0.441	3.010	904	0.112	45004	0.136	0.182
1992	0.977	6.664	871	0.108	35087	0.106	0.142
1993	0.966	6.587	675	0.084	24738	0.075	0.100
1994	0.910	6.207	633	0.079	20691	0.063	0.084
1995	0.850	5.798	542	0.067	17843	0.054	0.072
1996	0.652	4.450	523	0.065	16811	0.051	0.068
1997	1.452	9.904	564	0.070	12872	0.039	0.052
1998	0.631	4.307	597	0.074	14323	0.043	0.058
1999	1.040	7.092	827	0.103	15832	0.048	0.064
2000	1.067	7.279	952	0.118	17266	0.052	0.070
2001	0.904	6.166	962	0.120	19909	0.060	0.080
2002	0.835	5.699	925	0.115	22166	0.067	0.090
2003	0.548	3.738	905	0.112	25713	0.078	0.104
2004	0.744	5.078	856	0.106	26400	0.080	0.107
2005	0.808	5.511	615	0.076	23391	0.071	0.095
2006	0.928	6.330	853	0.106	18520	0.056	0.075
2007	1.001	6.827	1186	0.147	19394	0.059	0.078
2008	1.365	9.310	1520	0.189	24276	0.074	0.098
2009	1.179	8.039	1215	0.151	23965	0.073	0.097
2010	0.325	2.218	811	0.101	29584	0.090	0.120
2011	0.195	1.334	828	0.103	38688	0.117	0.156
2012	0.433	2.954	942	0.117	41236	0.125	0.167
2013	0.278	1.896	1042	0.129	44587	0.135	0.180
2014	0.597	4.069	1656	0.206	44799	0.136	0.181
2015	.	.	1889	0.235	.	.	.

Table 11. Selectivity at age for SERFS combined trap and video index (CVID), commercial handlines (cH), headboat (HB), and general recreational (GR) landings (L) and discards (D). For time-varying selectivities, values shown are from selectivity block 1 (1950–1991).

Age	CVID	cH.L	HB.L	GR.L	cH.D	HB.D	GR.D
1	0.044	0.014	0.048	0.048	0.989	1.000	1.000
2	0.581	0.475	0.658	0.658	1.000	0.765	0.765
3	0.977	0.983	1.000	1.000	0.769	0.333	0.333
4	0.999	1.000	0.899	0.899	0.435	0.098	0.098
5	1.000	1.000	0.751	0.751	0.196	0.025	0.025
6	1.000	1.000	0.588	0.588	0.077	0.006	0.006
7	1.000	1.000	0.431	0.431	0.029	0.001	0.001
8	1.000	1.000	0.298	0.298	0.010	0.000	0.000
9	1.000	1.000	0.197	0.197	0.004	0.000	0.000
10	1.000	1.000	0.125	0.125	0.001	0.000	0.000
11	1.000	1.000	0.125	0.125	0.000	0.000	0.000
12	1.000	1.000	0.125	0.125	0.000	0.000	0.000
13	1.000	1.000	0.125	0.125	0.000	0.000	0.000
14	1.000	1.000	0.125	0.125	0.000	0.000	0.000
15	1.000	1.000	0.125	0.125	0.000	0.000	0.000
16	1.000	1.000	0.125	0.125	0.000	0.000	0.000
17	1.000	1.000	0.125	0.125	0.000	0.000	0.000
18	1.000	1.000	0.125	0.125	0.000	0.000	0.000
19	1.000	1.000	0.125	0.125	0.000	0.000	0.000
20	1.000	1.000	0.125	0.125	0.000	0.000	0.000

Table 12. Selectivity at age for SERFS combined trap and video index (CVID), commercial handlines (cH), headboat (HB), and general recreational (GR) landings (L) and discards (D). For time-varying selectivities, values shown are from selectivity block 2 (1992–2009).

Age	CVID	cH.L	HB.L	GR.L	cH.D	HB.D	GR.D
1	0.044	0.001	0.001	0.004	0.989	1.000	1.000
2	0.581	0.026	0.031	0.062	1.000	0.765	0.765
3	0.977	0.426	0.670	0.525	0.769	0.333	0.333
4	0.999	0.954	1.000	1.000	0.435	0.098	0.098
5	1.000	0.998	0.769	0.904	0.196	0.025	0.025
6	1.000	1.000	0.525	0.699	0.077	0.006	0.006
7	1.000	1.000	0.326	0.492	0.029	0.001	0.001
8	1.000	1.000	0.189	0.319	0.010	0.000	0.000
9	1.000	1.000	0.105	0.194	0.004	0.000	0.000
10	1.000	1.000	0.056	0.113	0.001	0.000	0.000
11	1.000	1.000	0.056	0.064	0.000	0.000	0.000
12	1.000	1.000	0.056	0.036	0.000	0.000	0.000
13	1.000	1.000	0.056	0.020	0.000	0.000	0.000
14	1.000	1.000	0.056	0.020	0.000	0.000	0.000
15	1.000	1.000	0.056	0.020	0.000	0.000	0.000
16	1.000	1.000	0.056	0.020	0.000	0.000	0.000
17	1.000	1.000	0.056	0.020	0.000	0.000	0.000
18	1.000	1.000	0.056	0.020	0.000	0.000	0.000
19	1.000	1.000	0.056	0.020	0.000	0.000	0.000
20	1.000	1.000	0.056	0.020	0.000	0.000	0.000

Table 13. Selectivity at age for SERFS combined trap and video index (CVID), commercial handlines (cH), headboat (HB), and general recreational (GR) landings (L) and discards (D). For time-varying selectivities, values shown are from selectivity block 3 (2010–2014).

Age	CVID	cH.L	HB.L	GR.L	cH.D	HB.D	GR.D
1	0.044	0.007	0.019	0.004	0.036	0.696	0.696
2	0.581	0.067	0.357	0.028	0.203	0.867	0.867
3	0.977	0.406	1.000	0.183	0.633	0.979	0.979
4	0.999	0.868	0.909	0.635	0.921	1.000	1.000
5	1.000	0.984	0.729	0.931	0.987	0.923	0.923
6	1.000	0.998	0.556	0.991	0.998	0.775	0.775
7	1.000	1.000	0.407	0.999	1.000	0.596	0.596
8	1.000	1.000	0.287	1.000	1.000	0.426	0.426
9	1.000	1.000	0.196	1.000	1.000	0.288	0.288
10	1.000	1.000	0.132	1.000	1.000	0.187	0.187
11	1.000	1.000	0.132	1.000	1.000	0.187	0.187
12	1.000	1.000	0.132	1.000	1.000	0.187	0.187
13	1.000	1.000	0.132	1.000	1.000	0.187	0.187
14	1.000	1.000	0.132	1.000	1.000	0.187	0.187
15	1.000	1.000	0.132	1.000	1.000	0.187	0.187
16	1.000	1.000	0.132	1.000	1.000	0.187	0.187
17	1.000	1.000	0.132	1.000	1.000	0.187	0.187
18	1.000	1.000	0.132	1.000	1.000	0.187	0.187
19	1.000	1.000	0.132	1.000	1.000	0.187	0.187
20	1.000	1.000	0.132	1.000	1.000	0.187	0.187

Table 14. Estimated time series of fully selected fishing mortality rates for commercial handlines (F.cH.L), headboat (F.HB.L), recreational (F.GR.L) landings (L) and discards (D). Also shown is Full F, the maximum F at age summed across fleets, which may not equal the sum of fully selected F's because of dome-shaped selectivities.

Year	F.cH.L	F.HB.L	F.GR.L	F.cH.D	F.HB.D	F.GR.D	Full F
1950	0.030	0.000	0.000	0.000	0.000	0.000	0.030
1951	0.042	0.000	0.000	0.000	0.000	0.000	0.042
1952	0.032	0.000	0.000	0.000	0.000	0.000	0.032
1953	0.033	0.000	0.000	0.000	0.000	0.000	0.033
1954	0.050	0.000	0.000	0.000	0.000	0.000	0.050
1955	0.043	0.022	0.043	0.000	0.000	0.000	0.108
1956	0.044	0.026	0.049	0.000	0.000	0.000	0.118
1957	0.083	0.029	0.056	0.000	0.000	0.000	0.167
1958	0.063	0.033	0.063	0.000	0.000	0.000	0.157
1959	0.072	0.036	0.069	0.000	0.000	0.000	0.176
1960	0.078	0.040	0.076	0.000	0.000	0.000	0.193
1961	0.101	0.045	0.086	0.000	0.000	0.000	0.230
1962	0.089	0.050	0.096	0.000	0.000	0.000	0.234
1963	0.072	0.055	0.106	0.000	0.000	0.000	0.232
1964	0.084	0.060	0.116	0.000	0.000	0.000	0.259
1965	0.094	0.066	0.127	0.000	0.000	0.000	0.286
1966	0.101	0.069	0.132	0.000	0.000	0.000	0.300
1967	0.144	0.072	0.138	0.000	0.000	0.000	0.353
1968	0.196	0.077	0.148	0.000	0.000	0.000	0.418
1969	0.136	0.080	0.154	0.000	0.000	0.000	0.368
1970	0.139	0.081	0.156	0.000	0.000	0.000	0.374
1971	0.132	0.090	0.173	0.000	0.000	0.000	0.394
1972	0.125	0.100	0.192	0.000	0.000	0.000	0.416
1973	0.096	0.110	0.212	0.000	0.000	0.000	0.417
1974	0.166	0.125	0.239	0.000	0.000	0.000	0.528
1975	0.244	0.148	0.284	0.000	0.000	0.000	0.672
1976	0.286	0.167	0.321	0.000	0.000	0.000	0.771
1977	0.381	0.190	0.365	0.000	0.000	0.000	0.931
1978	0.513	0.220	0.423	0.000	0.000	0.000	1.149
1979	0.456	0.232	0.447	0.000	0.000	0.000	1.129
1980	0.530	0.278	0.534	0.000	0.000	0.000	1.334
1981	0.598	0.230	0.597	0.000	0.000	0.006	1.419
1982	0.629	0.184	0.342	0.000	0.000	0.005	1.148
1983	0.809	0.256	0.571	0.000	0.000	0.002	1.625
1984	0.388	0.133	0.909	0.000	0.000	0.024	1.432
1985	0.285	0.193	1.109	0.000	0.000	0.043	1.597
1986	0.271	0.087	0.528	0.000	0.000	0.076	0.906
1987	0.251	0.152	0.287	0.000	0.000	0.037	0.699
1988	0.164	0.135	0.299	0.000	0.000	0.029	0.605
1989	0.183	0.078	0.324	0.000	0.000	0.021	0.589
1990	0.145	0.090	0.052	0.000	0.000	0.044	0.300
1991	0.101	0.091	0.227	0.000	0.000	0.075	0.441
1992	0.118	0.087	0.761	0.031	0.003	0.037	0.977
1993	0.442	0.226	0.292	0.034	0.007	0.129	0.966
1994	0.410	0.142	0.349	0.041	0.007	0.120	0.910
1995	0.378	0.179	0.272	0.058	0.011	0.139	0.850
1996	0.329	0.116	0.203	0.039	0.004	0.034	0.652
1997	0.335	0.170	0.941	0.043	0.005	0.029	1.452
1998	0.259	0.095	0.278	0.022	0.003	0.032	0.631
1999	0.216	0.121	0.693	0.014	0.003	0.147	1.040
2000	0.227	0.128	0.698	0.014	0.003	0.204	1.067
2001	0.350	0.146	0.399	0.016	0.006	0.205	0.904
2002	0.282	0.139	0.397	0.038	0.007	0.151	0.835
2003	0.186	0.062	0.288	0.010	0.003	0.175	0.548
2004	0.232	0.132	0.348	0.005	0.038	0.400	0.744
2005	0.200	0.127	0.436	0.041	0.046	0.341	0.808
2006	0.181	0.145	0.602	0.003	0.010	0.066	0.928
2007	0.355	0.231	0.412	0.007	0.038	0.151	1.001
2008	0.398	0.164	0.788	0.006	0.043	0.298	1.365
2009	0.468	0.189	0.505	0.014	0.070	0.292	1.179
2010	0.008	0.003	0.001	0.050	0.058	0.210	0.325
2011	0.001	0.011	0.001	0.120	0.041	0.033	0.195
2012	0.009	0.018	0.203	0.062	0.043	0.132	0.433
2013	0.034	0.011	0.109	0.056	0.031	0.056	0.278
2014	0.068	0.031	0.371	0.059	0.015	0.095	0.597

Table 15. Estimated instantaneous fishing mortality rate (per yr) at age.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.000	0.015	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
1951	0.001	0.021	0.041	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
1952	0.000	0.016	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
1953	0.000	0.017	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
1954	0.001	0.025	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
1955	0.004	0.065	0.108	0.102	0.092	0.081	0.071	0.062	0.056	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051
1956	0.004	0.071	0.118	0.111	0.100	0.088	0.076	0.066	0.058	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
1957	0.005	0.098	0.167	0.159	0.147	0.133	0.120	0.108	0.100	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
1958	0.006	0.095	0.157	0.149	0.134	0.119	0.104	0.091	0.082	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
1959	0.006	0.106	0.176	0.166	0.151	0.134	0.117	0.103	0.092	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085
1960	0.007	0.116	0.193	0.182	0.165	0.146	0.128	0.113	0.101	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093
1961	0.008	0.137	0.230	0.218	0.199	0.177	0.157	0.139	0.126	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117
1962	0.008	0.141	0.234	0.220	0.199	0.175	0.152	0.132	0.117	0.107	0.107	0.107	0.107	0.107	0.107	0.107	0.107	0.107	0.107	0.107
1963	0.009	0.142	0.232	0.216	0.192	0.166	0.141	0.119	0.103	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092
1964	0.010	0.158	0.259	0.242	0.216	0.187	0.160	0.136	0.118	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106
1965	0.011	0.175	0.286	0.268	0.239	0.207	0.177	0.151	0.131	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118
1966	0.011	0.183	0.300	0.281	0.251	0.218	0.187	0.160	0.140	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
1967	0.012	0.211	0.353	0.333	0.302	0.268	0.235	0.207	0.185	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170
1968	0.014	0.247	0.418	0.398	0.365	0.328	0.293	0.263	0.240	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224
1969	0.013	0.223	0.368	0.347	0.312	0.274	0.237	0.206	0.182	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165
1970	0.013	0.226	0.374	0.352	0.317	0.278	0.241	0.210	0.186	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169
1971	0.015	0.240	0.394	0.369	0.330	0.287	0.245	0.210	0.184	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165
1972	0.016	0.256	0.416	0.388	0.344	0.296	0.250	0.211	0.182	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.161
1973	0.017	0.261	0.417	0.385	0.337	0.285	0.234	0.191	0.158	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136
1974	0.020	0.324	0.528	0.494	0.439	0.380	0.323	0.274	0.237	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212
1975	0.024	0.407	0.672	0.632	0.568	0.497	0.429	0.372	0.328	0.298	0.298	0.298	0.298	0.298	0.298	0.298	0.298	0.298	0.298	0.298
1976	0.028	0.466	0.771	0.725	0.652	0.573	0.496	0.431	0.381	0.347	0.347	0.347	0.347	0.347	0.347	0.347	0.347	0.347	0.347	0.347
1977	0.032	0.558	0.931	0.880	0.797	0.706	0.619	0.545	0.489	0.450	0.450	0.450	0.450	0.450	0.450	0.450	0.450	0.450	0.450	0.450
1978	0.038	0.682	1.149	1.091	0.995	0.890	0.789	0.704	0.639	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593
1979	0.039	0.677	1.129	1.066	0.965	0.854	0.747	0.657	0.588	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540
1980	0.047	0.802	1.334	1.259	1.138	1.006	0.878	0.770	0.688	0.631	0.631	0.631	0.631	0.631	0.631	0.631	0.631	0.631	0.631	0.631
1981	0.054	0.851	1.419	1.342	1.219	1.083	0.953	0.843	0.759	0.701	0.701	0.701	0.701	0.701	0.701	0.701	0.701	0.701	0.701	0.701
1982	0.040	0.668	1.148	1.102	1.023	0.937	0.855	0.785	0.731	0.694	0.694	0.694	0.694	0.694	0.694	0.694	0.694	0.694	0.694	0.694
1983	0.054	0.954	1.625	1.551	1.428	1.293	1.163	1.053	0.970	0.911	0.911	0.911	0.911	0.911	0.911	0.911	0.911	0.911	0.911	0.911
1984	0.080	0.900	1.432	1.326	1.169	0.999	0.835	0.696	0.591	0.517	0.517	0.517	0.517	0.517	0.517	0.517	0.517	0.517	0.517	0.517
1985	0.109	1.034	1.597	1.459	1.262	1.049	0.844	0.671	0.539	0.446	0.446	0.446	0.446	0.446	0.446	0.446	0.446	0.446	0.446	0.446
1986	0.109	0.599	0.906	0.830	0.733	0.631	0.535	0.453	0.390	0.347	0.347	0.347	0.347	0.347	0.347	0.347	0.347	0.347	0.347	0.347
1987	0.062	0.444	0.699	0.649	0.581	0.508	0.439	0.381	0.336	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305
1988	0.052	0.391	0.605	0.557	0.490	0.419	0.350	0.292	0.248	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217
1989	0.043	0.373	0.589	0.546	0.485	0.419	0.355	0.302	0.261	0.233	0.233	0.233	0.233	0.233	0.233	0.233	0.233	0.233	0.233	0.233
1990	0.053	0.201	0.300	0.277	0.253	0.229	0.206	0.187	0.173	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163
1991	0.092	0.317	0.441	0.393	0.340	0.287	0.237	0.195	0.163	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140
1992	0.075	0.113	0.533	0.977	0.891	0.718	0.545	0.399	0.291	0.221	0.180	0.156	0.142	0.142	0.142	0.142	0.142	0.142	0.142	0.142
1993	0.170	0.172	0.546	0.966	0.899	0.785	0.678	0.594	0.534	0.496	0.480	0.471	0.466	0.466	0.466	0.466	0.466	0.466	0.466	0.466
1994	0.170	0.173	0.511	0.910	0.853	0.746	0.644	0.562	0.503	0.464	0.445	0.434	0.428	0.428	0.428	0.428	0.428	0.428	0.428	0.428
1995	0.210	0.204	0.504	0.850	0.784	0.681	0.587	0.512	0.459	0.426	0.411	0.402	0.397	0.397	0.397	0.397	0.397	0.397	0.397	0.397
1996	0.078	0.092	0.357	0.652	0.616	0.544	0.478	0.425	0.387	0.363	0.352	0.345	0.342	0.342	0.342	0.342	0.342	0.342	0.342	0.342
1997	0.080	0.138	0.775	1.452	1.342	1.114	0.887	0.697	0.558	0.467	0.416	0.386	0.369	0.369	0.369	0.369	0.369	0.369	0.369	0.369
1998	0.058	0.074	0.338	0.631	0.594	0.515	0.439	0.376	0.331	0.301	0.286	0.277	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272
1999	0.167	0.179	0.583	1.040	0.953	0.786	0.620	0.481	0.379	0.312	0.275	0.253	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241
2000	0.224	0.222	0.612	1.067	0.976	0.805	0.636	0.495	0.392	0.324	0.287	0.265	0.252	0.252	0.252	0.252	0.252	0.252	0.252	0.252
2001	0.230	0.214	0.524	0.904	0.839	0.722	0.611	0.519	0.453	0.410	0.389	0.377	0.369	0.369	0.369	0.369	0.369	0.369	0.369	0.369
2002	0.198	0.193	0.490	0.835	0.767	0.651	0.540	0.449	0.384	0.342	0.321	0.308	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301
2003	0.189	0.169	0.330	0.548	0.505	0.431	0.358	0.299	0.255	0.227	0.211	0.202	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197
2004	0.444	0.367	0.505	0.744	0.667	0.561	0.462	0.381	0.324	0.286	0.267	0.256	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
2005	0.429	0.369	0.546	0.808	0.718	0.592	0.474	0.379	0.309	0.264	0.241	0.227	0.219	0.219	0.219	0.219	0.219	0.219	0.219	0.219
2006	0.082	0.106	0.504	0.928	0.851	0.698	0.547	0.420	0.328	0.268	0.236	0.217	0.206	0.206	0.206	0.206	0.206	0.206	0.206	0.206
2007	0.197	0.190	0.572	1.001	0.922	0.785	0.654	0.548	0.472	0.424	0.402	0.388	0.381	0.381	0.381	0.381	0.381	0.381	0.381	0.381
2008	0.351	0.327	0.790	1.365	1.259	1.061	0.867	0.705	0.587	0.509	0.467	0.442	0.428	0.428	0.428	0.428	0.428	0.428	0.428	0.428
2009	0.377	0.335	0.701	1.179	1.092	0.942	0.800	0.684	0.600	0.546	0.519	0.503	0.493	0.493	0.493	0.493	0.493	0.493	0.493	0.493
2010	0.190	0.246	0.302	0.325	0.308	0.268	0.220	0.174	0.137	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109
2011	0.056	0.092	0.159	0.195	0.195	0.184	0.169	0.156	0.145	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136
2012	0.126	0.177	0.270	0.385	0.433	0.416	0.384	0.352	0.327	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308
2013	0.063	0.096	0.165	0.247	0.278	0.271	0.255	0.239	0.226	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217
2014	0.081	0.134	0.272	0.488	0.595	0.597	0.575	0.553	0.536	0.523	0.523	0.523	0.523	0.523	0.523	0.523	0.523	0.523	0.523	0.523

Table 16. Estimated total landings at age in numbers (1000 fish)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.15	3.18	4.42	3.40	2.68	2.17	1.78	1.47	1.23	1.04	0.87	0.74	0.63	0.53	0.46	0.39	0.33	0.28	0.24	1.42
1951	0.21	4.33	6.00	4.61	3.63	2.94	2.41	2.00	1.67	1.40	1.18	1.00	0.85	0.72	0.62	0.53	0.45	0.38	0.33	1.93
1952	0.16	3.37	4.66	3.56	2.80	2.27	1.86	1.54	1.29	1.08	0.91	0.77	0.66	0.56	0.48	0.41	0.35	0.30	0.25	1.49
1953	0.17	3.49	4.84	3.69	2.89	2.34	1.92	1.59	1.33	1.12	0.94	0.80	0.68	0.58	0.49	0.42	0.36	0.30	0.26	1.54
1954	0.25	5.23	7.22	5.53	4.33	3.47	2.85	2.36	1.97	1.66	1.40	1.19	1.01	0.86	0.73	0.62	0.53	0.45	0.39	2.28
1955	1.28	13.11	15.14	10.73	7.66	5.46	3.91	2.85	2.14	1.65	1.39	1.18	1.00	0.85	0.73	0.62	0.53	0.45	0.38	2.27
1956	1.43	14.31	15.81	10.88	7.71	5.53	3.97	2.89	2.16	1.67	1.41	1.20	1.02	0.86	0.74	0.63	0.54	0.46	0.39	2.30
1957	1.80	19.43	21.69	14.56	10.30	7.63	5.77	4.42	3.47	2.79	2.38	2.03	1.72	1.46	1.25	1.06	0.91	0.77	0.66	3.90
1958	1.87	18.78	20.00	12.86	8.60	6.07	4.47	3.38	2.61	2.06	1.78	1.52	1.30	1.11	0.94	0.80	0.68	0.58	0.50	2.94
1959	2.07	20.84	22.23	14.03	9.12	6.22	4.49	3.42	2.69	2.16	1.88	1.63	1.40	1.19	1.02	0.87	0.74	0.63	0.54	3.18
1960	2.27	22.72	23.89	15.01	9.58	6.34	4.42	3.29	2.60	2.13	1.88	1.64	1.42	1.22	1.05	0.89	0.76	0.65	0.56	3.27
1961	2.63	26.61	27.70	17.18	10.99	7.22	4.94	3.60	2.82	2.34	2.10	1.86	1.63	1.41	1.22	1.04	0.89	0.76	0.65	3.83
1962	2.82	27.36	27.52	16.52	10.30	6.66	4.42	3.08	2.29	1.84	1.66	1.50	1.33	1.16	1.01	0.87	0.75	0.64	0.55	3.22
1963	2.97	27.51	27.12	15.83	9.51	5.96	3.87	2.59	1.84	1.40	1.24	1.13	1.02	0.90	0.79	0.69	0.60	0.51	0.44	2.58
1964	3.27	30.37	29.87	17.45	10.33	6.37	4.11	2.78	1.96	1.47	1.27	1.13	1.03	0.93	0.83	0.73	0.64	0.55	0.47	2.78
1965	3.60	33.23	32.04	18.51	10.98	6.67	4.24	2.85	2.02	1.50	1.27	1.10	0.98	0.90	0.81	0.73	0.64	0.56	0.48	2.85
1966	3.75	34.62	32.80	18.48	10.87	6.64	4.17	2.77	1.96	1.47	1.23	1.05	0.91	0.81	0.74	0.67	0.60	0.53	0.46	2.77
1967	4.12	39.44	37.31	20.74	12.06	7.44	4.81	3.24	2.32	1.77	1.50	1.26	1.07	0.93	0.84	0.77	0.70	0.62	0.55	3.33
1968	4.60	45.27	41.71	22.60	13.00	7.95	5.20	3.59	2.59	1.98	1.66	1.41	1.19	1.02	0.88	0.79	0.73	0.66	0.59	3.69
1969	4.45	41.20	36.20	18.32	10.03	5.88	3.65	2.43	1.71	1.26	1.05	0.88	0.75	0.63	0.54	0.47	0.42	0.39	0.35	2.29
1970	4.50	41.71	37.47	18.79	9.74	5.54	3.38	2.20	1.55	1.15	0.95	0.79	0.67	0.57	0.48	0.41	0.36	0.32	0.29	2.01
1971	4.89	43.93	38.92	19.85	10.14	5.41	3.17	2.01	1.36	1.00	0.83	0.68	0.57	0.48	0.41	0.35	0.30	0.26	0.23	1.68
1972	5.32	46.36	40.09	20.22	10.52	5.54	3.05	1.86	1.23	0.87	0.72	0.60	0.50	0.41	0.35	0.30	0.25	0.22	0.19	1.40
1973	5.64	47.03	39.45	19.37	9.91	5.27	2.83	1.59	0.99	0.67	0.55	0.46	0.38	0.31	0.26	0.22	0.19	0.16	0.14	1.01
1974	6.64	56.69	47.28	23.21	11.90	6.50	3.73	2.20	1.38	0.96	0.77	0.63	0.52	0.44	0.36	0.30	0.26	0.22	0.19	1.33
1975	8.07	68.46	52.98	24.83	12.79	7.03	4.15	2.60	1.68	1.15	0.91	0.74	0.60	0.50	0.42	0.35	0.29	0.25	0.21	1.47
1976	9.14	75.92	53.42	22.22	10.96	6.07	3.61	2.31	1.58	1.10	0.84	0.67	0.54	0.45	0.37	0.31	0.26	0.22	0.18	1.25
1977	10.58	86.81	56.66	21.00	9.31	5.02	3.06	2.02	1.43	1.06	0.83	0.64	0.51	0.42	0.34	0.29	0.24	0.20	0.17	1.11
1978	14.05	99.72	58.13	19.09	7.62	3.74	2.26	1.54	1.13	0.88	0.73	0.57	0.44	0.35	0.29	0.24	0.20	0.17	0.14	0.88
1979	10.71	110.30	50.31	13.73	4.83	2.13	1.16	0.77	0.58	0.46	0.39	0.33	0.26	0.20	0.16	0.13	0.11	0.09	0.08	0.46
1980	18.74	92.31	61.46	13.42	3.97	1.57	0.78	0.48	0.36	0.29	0.26	0.22	0.19	0.15	0.11	0.09	0.08	0.06	0.05	0.31
1981	6.92	140.13	41.58	12.61	3.03	1.03	0.47	0.27	0.19	0.16	0.15	0.13	0.11	0.09	0.07	0.06	0.05	0.04	0.03	0.18
1982	8.19	41.94	51.95	6.85	2.30	0.64	0.25	0.14	0.09	0.07	0.07	0.06	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.09
1983	33.62	89.92	26.30	14.91	2.11	0.78	0.24	0.11	0.06	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.06
1984	40.69	231.80	31.13	3.65	2.23	0.35	0.14	0.05	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.02
1985	21.95	275.57	93.74	5.84	0.77	0.54	0.10	0.04	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1986	5.94	78.76	65.45	10.28	0.74	0.12	0.10	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1987	13.77	34.83	38.03	16.77	2.85	0.23	0.04	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	9.94	101.82	21.62	12.63	5.78	1.03	0.08	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	3.13	76.74	72.25	8.61	5.30	2.60	0.50	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.55	12.95	31.62	16.82	2.14	1.44	0.79	0.17	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.86	8.15	17.20	23.66	12.46	1.55	1.00	0.52	0.11	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.86	1.45	7.45	15.83	23.95	13.19	1.66	1.05	0.52	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.16	4.80	7.21	5.38	4.62	7.54	5.23	0.87	0.76	0.53	0.14	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.29	1.58	31.30	5.15	1.56	1.39	2.54	1.97	0.37	0.35	0.26	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	0.11	2.31	9.64	23.40	1.55	0.48	0.47	0.96	0.83	0.17	0.17	0.13	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.23	0.85	12.91	6.56	6.71	0.46	0.16	0.17	0.40	0.37	0.08	0.09	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00
1997	0.58	6.96	12.78	20.54	4.43	4.48	0.32	0.11	0.12	0.27	0.25	0.05	0.06	0.04	0.01	0.00	0.00	0.00	0.00	0.00
1998	0.35	1.92	17.79	4.12	2.26	0.52	0.65	0.06	0.03	0.04	0.10	0.10	0.02	0.03	0.02	0.01	0.00	0.00	0.00	0.00
1999	0.97	6.46	20.79	24.15	2.38	1.27	0.30	0.39	0.04	0.02	0.02	0.06	0.06	0.01	0.02	0.01	0.00	0.00	0.00	0.00
2000	1.03	7.68	34.15	14.73	6.74	0.69	0.42	0.12	0.17	0.02	0.01	0.01	0.04	0.04	0.01	0.01	0.01	0.00	0.00	0.00
2001	0.47	5.69	33.54	20.94	3.59	1.74	0.21	0.16	0.06	0.11	0.01	0.01	0.01	0.04	0.04	0.01	0.01	0.01	0.00	0.00
2002	0.39	3.82	32.55	24.65	6.27	1.09	0.58	0.08	0.07	0.03	0.05	0.01	0.00	0.01	0.02	0.02	0.00	0.01	0.00	0.00
2003	0.35	2.30	16.20	19.52	6.20	1.59	0.30	0.18	0.03	0.02	0.01	0.02	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
2004	0.14	3.43	18.32	20.09	10.83	3.40	0.93	0.19	0.12	0.02	0.02	0.01	0.02	0.00	0.00	0.00	0.01	0.01	0.00	0.00
2005	0.08	1.13	20.17	15.88	7.82	4.26	1.44	0.42	0.09	0.06	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00
2006	1.85	0.74	7.28	18.37	6.35	3.19	1.89	0.70	0.22	0.05	0.04	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01
2007	0.99	14.08	4.38	5.71	5.88	2.14	1.28	0.94	0.43	0.17	0.05	0.04	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01
2008	1.64	12.91	108.42	3.68	1.96	2.12	0.88	0.60	0.49	0.25	0.11	0.03	0.03	0.01	0.01	0.00	0.01	0.00	0.00	0.01
2009	0.36	8.72	52.86	55.37	0.69	0.39	0.52	0.27	0.23	0.22	0.13	0.06	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.01
2010	0.01	0.09	0.61	0.44	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.04	0.12	0.38	0.62	0.24	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.21	1.38	1.10	3.15	7.38	3.56	1.59	0.02	0.02	0.04	0.02	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00
2013	0.29	0.91	2.95	1.22	1.70	3.01	1.43	0.66	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
2014	2.05	4.85	7.71	12.22	2.64	2.94	5.15	2.51	1.19	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.01	0.00	0.00	0.00

Table 17. Estimated landings at age in whole weight (1000 lb)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.23	10.91	25.93	28.87	29.74	29.30	27.94	26.00	23.77	21.43	19.11	16.90	14.85	12.98	11.29	9.80	8.48	7.32	6.31	37.46
1951	0.31	14.85	35.16	39.13	40.32	39.72	37.87	35.25	32.22	29.04	25.90	22.90	20.13	17.59	15.31	13.28	11.49	9.92	8.55	50.77
1952	0.24	11.56	27.30	30.21	31.11	30.65	29.22	27.20	24.86	22.41	19.98	17.67	15.53	13.57	11.81	10.25	8.87	7.66	6.60	39.17
1953	0.25	11.96	28.35	31.34	32.09	31.59	30.12	28.03	25.63	23.10	20.60	18.22	16.01	13.99	12.18	10.57	9.14	7.89	6.80	40.38
1954	0.37	17.92	42.31	46.94	48.01	47.00	44.79	41.68	38.10	34.35	30.63	27.09	23.80	20.80	18.10	15.71	13.59	11.73	10.11	60.04
1955	1.90	44.94	88.76	91.14	84.97	73.81	61.40	50.32	41.23	34.14	30.44	26.92	23.66	20.67	17.99	15.61	13.51	11.66	10.05	59.67
1956	2.12	49.06	92.67	92.35	85.57	74.88	62.41	50.92	41.70	34.49	30.90	27.33	24.01	20.98	18.26	15.85	13.71	11.84	10.20	60.57
1957	2.66	66.58	127.19	123.65	114.28	103.19	90.75	78.07	66.90	57.72	52.08	46.28	40.67	35.54	30.93	26.84	23.22	20.05	17.28	102.57
1958	2.76	64.35	117.27	109.24	95.40	82.12	70.30	59.64	50.28	42.65	38.86	34.78	30.71	26.83	23.35	20.27	17.53	15.14	13.04	77.45
1959	3.06	71.44	130.31	119.17	101.20	84.10	70.59	60.26	51.89	44.74	41.07	37.13	33.01	28.98	25.23	21.89	18.94	16.35	14.09	83.66
1960	3.36	77.88	140.07	127.46	106.24	85.83	69.47	58.06	50.20	44.09	41.07	37.40	33.59	29.70	25.97	22.54	19.50	16.83	14.51	86.13
1961	3.89	91.20	162.41	145.85	121.88	97.62	77.74	63.46	54.35	48.42	45.99	42.49	38.45	34.33	30.24	26.36	22.81	19.69	16.97	100.75
1962	4.17	93.79	161.32	140.27	114.23	90.09	69.48	54.30	44.18	38.03	36.35	34.24	31.43	28.28	25.16	22.09	19.20	16.58	14.29	84.82
1963	4.39	94.27	158.98	134.41	105.55	80.70	60.88	45.77	35.45	28.87	27.12	25.71	24.07	21.97	19.69	17.46	15.29	13.26	11.42	67.84
1964	4.84	104.11	175.10	148.17	114.63	86.16	64.68	49.10	37.90	30.41	27.72	25.83	24.33	22.65	20.59	18.40	16.27	14.21	12.30	73.05
1965	5.33	113.91	187.84	157.19	121.81	90.26	66.59	50.23	39.04	31.11	27.79	25.13	23.26	21.79	20.20	18.31	16.31	14.39	12.55	74.87
1966	5.55	118.65	192.33	156.94	120.58	89.79	65.56	48.79	37.80	30.41	26.96	23.89	21.46	19.76	18.43	17.04	15.40	13.69	12.06	72.73
1967	6.09	135.19	218.75	176.16	133.80	100.67	75.63	57.16	44.80	36.70	32.77	28.82	25.38	22.67	20.78	19.33	17.82	16.07	14.26	87.70
1968	6.81	155.17	244.56	191.90	144.27	107.59	81.70	63.31	50.00	40.98	36.40	32.24	28.17	24.66	21.94	20.06	18.61	17.11	15.40	97.05
1969	6.58	141.20	212.22	155.54	111.30	79.50	57.36	42.80	33.00	26.09	22.86	20.14	17.72	15.40	13.43	11.91	10.86	10.05	9.22	60.21
1970	6.66	142.95	219.69	159.57	108.05	74.89	53.11	38.87	29.87	23.83	20.68	17.97	15.74	13.77	11.92	10.36	9.16	8.33	7.70	52.83
1971	7.22	150.56	228.17	168.58	112.53	73.23	49.85	35.40	26.32	20.67	18.09	15.58	13.45	11.71	10.21	8.81	7.64	6.74	6.12	44.12
1972	7.86	158.91	235.04	171.67	116.70	74.97	47.99	32.76	23.68	18.04	15.75	13.68	11.70	10.05	8.71	7.57	6.51	5.63	4.96	36.74
1973	8.34	161.19	231.30	164.49	109.92	71.30	44.49	28.09	19.17	13.96	12.01	10.41	8.98	7.64	6.53	5.65	4.89	4.20	3.63	26.66
1974	9.82	194.31	277.19	197.05	132.05	87.90	58.69	38.82	26.56	19.79	16.86	14.39	12.38	10.62	9.00	7.68	6.62	5.72	4.90	35.09
1975	11.93	234.65	310.63	210.86	141.90	95.14	65.25	45.91	32.44	23.71	19.88	16.81	14.25	12.20	10.42	8.80	7.48	6.44	5.55	38.57
1976	13.51	260.20	313.18	188.70	121.59	82.11	56.71	40.81	30.41	22.71	18.41	15.31	12.86	10.84	9.24	7.87	6.63	5.63	4.83	32.88
1977	15.65	297.52	332.16	178.30	103.27	67.93	48.18	35.61	27.61	22.03	18.24	14.67	12.12	10.12	8.50	7.22	6.14	5.16	4.37	29.07
1978	20.78	341.77	340.79	162.10	84.51	50.65	35.48	27.23	21.84	18.20	15.97	13.11	10.48	8.61	7.16	6.00	5.08	4.31	3.61	23.26
1979	15.84	378.05	294.97	116.57	53.64	28.78	18.20	13.60	11.14	9.45	8.61	7.49	6.11	4.86	3.98	3.30	2.75	2.33	1.97	12.21
1980	27.72	316.40	360.32	113.92	44.09	21.22	12.24	8.43	6.86	6.05	5.68	5.13	4.44	3.60	2.85	2.32	1.92	1.60	1.35	8.17
1981	10.24	480.28	243.79	107.07	33.64	13.92	7.38	4.75	3.64	3.24	3.19	2.97	2.66	2.29	1.85	1.46	1.19	0.98	0.82	4.82
1982	12.11	143.75	304.56	58.16	25.55	8.67	4.00	2.40	1.75	1.48	1.47	1.43	1.32	1.18	1.01	0.82	0.64	0.52	0.43	2.45
1983	49.72	308.20	154.17	126.64	23.41	10.58	3.78	1.85	1.18	0.90	0.82	0.80	0.77	0.71	0.63	0.54	0.43	0.34	0.28	1.52
1984	60.17	794.47	182.49	31.03	24.69	4.69	2.21	0.82	0.41	0.27	0.22	0.20	0.20	0.19	0.17	0.15	0.13	0.10	0.08	0.43
1985	32.46	944.51	549.57	49.55	8.51	7.31	1.53	0.79	0.32	0.17	0.13	0.11	0.10	0.09	0.09	0.08	0.07	0.06	0.05	0.24
1986	8.78	269.96	383.70	87.30	8.16	1.58	1.59	0.40	0.25	0.12	0.08	0.06	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.13
1987	20.37	119.36	222.98	142.38	31.59	3.04	0.62	0.68	0.19	0.13	0.07	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.09
1988	14.70	349.00	126.73	107.28	64.09	13.89	1.33	0.27	0.30	0.08	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.05
1989	4.62	263.01	423.59	73.11	58.77	35.15	7.85	0.79	0.17	0.21	0.07	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.05
1990	0.81	44.38	185.36	142.80	23.71	19.47	12.35	3.01	0.34	0.08	0.11	0.03	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.03
1991	1.27	27.92	100.86	200.93	138.21	20.92	15.70	9.13	2.06	0.22	0.06	0.07	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.02
1992	2.78	7.42	53.44	146.99	272.27	175.94	25.12	17.69	9.63	2.04	0.21	0.05	0.06	0.02	0.01	0.01	0.00	0.00	0.00	0.02
1993	0.51	24.52	51.70	49.96	52.50	100.68	79.34	14.74	14.04	10.36	2.91	0.36	0.09	0.13	0.04	0.03	0.02	0.01	0.01	0.05
1994	0.94	8.09	224.49	47.87	17.73	18.54	38.57	33.28	6.73	6.86	5.34	1.52	0.19	0.05	0.07	0.02	0.02	0.01	0.01	0.03
1995	0.36	11.83	69.13	217.35	17.60	6.36	7.14	16.19	15.24	3.32	3.60	2.88	0.84	0.11	0.03	0.04	0.01	0.01	0.00	0.02
1996	0.73	4.35	92.61	60.94	76.26	6.11	2.39	2.93	7.28	7.38	1.71	1.89	1.53	0.45	0.06	0.01	0.02	0.01	0.00	0.01
1997	1.89	35.57	91.67	190.78	50.33	59.83	4.82	1.86	2.23	5.34	5.29	1.19	1.29	1.05	0.31	0.04	0.01	0.01	0.00	0.01
1998	1.13	9.84	127.57	38.29	25.70	6.93	9.90	1.00	0.49	0.72	2.05	2.27	0.55	0.62	0.51	0.15	0.02	0.00	0.01	0.01
1999	3.12	33.04	149.08	224.28	27.03	17.00	4.59	6.52	0.65	0.31	0.45	1.27	1.38	0.34	0.38	0.31	0.09	0.01	0.00	0.01
2000	3.34	39.26	244.93	136.85	76.62	9.16	6.43	1.97	3.21	0.36	0.19	0.30	0.89	1.03	0.25	0.28	0.23	0.07	0.01	0.01
2001	1.53	29.08	240.58	194.49	40.85	23.28	3.25	2.77	1.05	2.09	0.28	0.17	0.28	0.87	1.00	0.24	0.27	0.22	0.06	0.02
2002	1.27	19.50	233.47	228.92	71.29	14.53	8.80	1.32	1.22	0.49	1.04	0.14	0.09	0.15	0.46	0.52	0.13	0.14	0.11	0.04
2003	1.13	11.77	116.17	181.29	70.47	21.23	4.59	3.01	0.49	0.49	0.21	0.46	0.06	0.04	0.07	0.21	0.24	0.06	0.06	0.07
2004	0.47	17.53	131.36	186.59	123.04	45.30	14.07	3.21	2.24	0.39	0.41	0.19	0.41	0.06	0.04	0.06	0.19	0.22	0.05	0.12
2005	0.25	5.77	144.69	147.44	88.90	56.90	21.86	7.15	1.72	1.26	0.23	0.25	0.11	0.26	0.04	0.02	0.04	0.12	0.13	0.11
2006	5.99	3.76	52.22	170.65	72.14	42.50	28.76	11.74	4.08	1.04	0.81	0.15	0.17	0.08	0.18	0.03	0.02	0.03	0.08	0.16
2007	3.20	72.01	31.41	53.06	66.83	28.53	19.39	15.81	7.94	3.37	1.03	0.90	0.18	0.21	0.10	0.22	0.03	0.02	0.03	0.30
2008	5.30	65.99	777.58	34.16	22.28	28.34	13.37	10.08	9.02	4.88	2.20	0.68	0.60	0.12	0.14	0.07	0.15	0.02	0.01	0.22
2009	1.16	44.57	379.12	514.22	7.81	5.26	7.92	4.54	4.16	4.41	2.74	1.34	0.43	0.40	0.08	0.09	0.04	0.10	0.01	0.15
2010	0.01	0.31	3.59	3.70	2.16	0.04	0.03	0.06	0.04	0.04	0.05	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
2011	0.06	0.40	2.21	5.29	2.63	1.11	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.31	4.74	6.44	26.75	81.86	48.10	24.99	0.43	0.38	0.75	0.54	0.59	0.69	0.45	0.22	0.07	0.07	0.01	0.02	0.05
2013	0.43	3.14	17.32	10.36	18.89	40.76	22.54	11.69	0.20	0.18	0.36	0.26	0.28	0.32	0.21	0.10	0.03	0.03	0.01	0.03
2014	3.03	16.62	45.20	103.79	29.28	39.74	80.99	44.37	23.01	0.40	0.35	0.69	0.50	0.54	0.62	0.40	0.20	0.06	0.06	0.07

Table 18. Estimated time series of landings in number (1000 fish) for commercial handlines (L.cH), headboat (L.HB), and recreational (L.GR).

Year	L.cH	L.HB	L.GR	Total
1950	27.42	0.00	0.00	27.42
1951	37.19	0.00	0.00	37.19
1952	28.76	0.00	0.00	28.76
1953	29.72	0.00	0.00	29.72
1954	44.33	0.00	0.00	44.33
1955	36.79	12.50	24.03	73.33
1956	36.00	13.65	26.24	75.90
1957	64.75	14.80	28.46	108.01
1958	46.24	15.95	30.67	92.86
1959	50.36	17.10	32.88	100.34
1960	52.26	18.25	35.09	105.60
1961	63.24	19.91	38.27	121.41
1962	52.51	21.56	41.44	115.51
1963	40.67	23.21	44.62	108.50
1964	45.69	24.86	47.79	118.35
1965	48.48	26.51	50.96	125.96
1966	49.37	26.67	51.26	127.30
1967	66.45	26.82	51.56	144.84
1968	82.30	26.98	51.85	161.13
1969	53.61	27.13	52.15	132.90
1970	53.13	27.29	52.45	132.87
1971	48.87	29.98	57.62	136.47
1972	44.52	32.68	62.80	139.99
1973	33.12	35.37	67.97	136.45
1974	54.33	38.06	73.13	165.52
1975	70.45	40.75	78.28	189.48
1976	71.02	41.21	79.18	191.42
1977	80.12	41.64	79.94	201.70
1978	89.01	42.15	81.01	212.17
1979	72.51	42.65	82.03	197.18
1980	68.92	43.10	82.88	194.90
1981	77.71	36.04	93.54	207.30
1982	56.95	19.57	36.36	112.89
1983	69.20	30.70	68.48	168.38
1984	65.98	31.16	213.00	310.14
1985	59.19	50.34	289.08	398.61
1986	44.17	16.62	100.66	161.45
1987	34.27	24.98	47.33	106.58
1988	35.76	36.50	80.69	152.95
1989	48.85	23.44	96.90	169.19
1990	33.49	20.91	12.09	66.49
1991	16.96	13.85	34.70	65.52
1992	9.02	5.30	51.76	66.08
1993	18.59	7.35	11.33	37.27
1994	20.28	8.23	18.34	46.85
1995	17.95	8.83	13.49	40.27
1996	14.20	5.54	9.34	29.08
1997	11.11	5.77	34.14	51.02
1998	10.26	4.74	13.02	28.02
1999	10.48	6.84	39.63	56.94
2000	12.11	8.44	45.35	65.90
2001	23.06	12.03	31.58	66.67
2002	21.54	12.94	35.16	69.64
2003	15.05	5.71	25.99	46.76
2004	17.84	10.84	28.86	57.54
2005	13.10	8.90	29.41	51.42
2006	8.09	5.94	26.69	40.71
2007	11.60	6.89	17.65	36.14
2008	32.31	18.96	81.86	133.14
2009	43.09	21.59	55.20	119.87
2010	0.82	0.48	0.06	1.36
2011	0.06	1.36	0.06	1.48
2012	0.79	2.13	15.65	18.56
2013	3.19	1.52	7.57	12.28
2014	7.34	5.91	28.17	41.43

Table 19. Estimated time series of landings in whole weight (1000 lb) for commercial handlines (L.cH), headboat (L.HB), and recreational (L.GR).

Year	L.cH	L.HB	L.GR	Total
1950	368.63	0.00	0.00	368.63
1951	499.70	0.00	0.00	499.70
1952	385.89	0.00	0.00	385.89
1953	398.23	0.00	0.00	398.23
1954	593.09	0.00	0.00	593.09
1955	493.22	105.93	203.67	802.82
1956	483.81	114.97	221.04	819.82
1957	866.94	123.01	236.48	1226.44
1958	612.32	129.91	249.76	991.98
1959	657.49	136.74	262.89	1057.12
1960	670.79	143.41	275.70	1089.90
1961	795.93	153.63	295.34	1244.90
1962	645.66	163.10	313.54	1122.29
1963	488.58	172.63	331.86	993.08
1964	537.31	182.43	350.69	1070.44
1965	557.78	191.69	368.47	1117.94
1966	554.15	189.47	364.19	1107.81
1967	724.84	186.75	358.97	1270.55
1968	864.48	182.55	350.89	1397.93
1969	537.75	177.84	341.82	1057.41
1970	512.58	175.69	337.69	1025.96
1971	457.01	190.97	367.03	1015.00
1972	406.30	206.25	396.37	1008.92
1973	296.36	221.28	425.20	942.84
1974	477.77	235.40	452.29	1165.46
1975	599.73	244.12	468.97	1312.82
1976	570.61	234.09	449.75	1254.45
1977	594.71	222.34	426.84	1243.89
1978	593.69	207.82	399.42	1200.93
1979	421.33	195.83	376.68	993.85
1980	385.74	194.51	374.06	954.31
1981	378.97	153.31	397.88	930.16
1982	309.36	92.50	171.84	573.70
1983	316.90	114.65	255.74	687.28
1984	253.57	108.41	741.15	1103.13
1985	250.84	199.46	1145.43	1595.74
1986	219.37	76.97	466.06	762.40
1987	191.52	121.00	229.22	541.74
1988	173.52	157.11	347.30	677.93
1989	266.49	117.07	483.99	867.55
1990	226.34	130.66	75.54	432.54
1991	143.49	106.70	267.24	517.43
1992	104.31	55.81	553.60	713.72
1993	220.05	71.74	110.20	402.00
1994	195.62	65.24	149.48	410.34
1995	177.50	76.95	117.61	372.05
1996	138.63	47.22	80.82	266.67
1997	110.45	50.34	292.73	453.52
1998	89.60	36.98	101.15	227.74
1999	93.62	56.30	319.94	469.86
2000	104.16	66.92	354.33	525.41
2001	196.59	95.95	249.84	542.38
2002	188.26	106.15	289.22	583.64
2003	138.39	49.06	224.67	412.12
2004	171.79	95.91	258.25	525.96
2005	129.55	78.86	268.85	477.26
2006	86.17	56.55	251.83	394.56
2007	114.62	57.01	132.92	304.55
2008	251.77	137.88	585.56	975.21
2009	364.50	173.55	440.50	978.54
2010	6.45	3.13	0.53	10.11
2011	0.57	10.61	0.61	11.79
2012	8.14	15.62	173.72	197.49
2013	31.59	9.97	85.58	127.13
2014	65.47	34.07	290.38	389.92

Table 20. Estimated time series of discard mortalities in numbers (1000 fish) for commercial handline (D.cH), headboat (D.HB), and recreational (D.GR).

Year	D.cH	D.HB	D.GR	Total
1950	.	.	.	.
1951	.	.	.	.
1952	.	.	.	.
1953	.	.	.	.
1954	.	.	.	.
1955	.	.	.	.
1956	.	.	.	.
1957	.	.	.	.
1958	.	.	.	.
1959	.	.	.	.
1960	.	.	.	.
1961	.	.	.	.
1962	.	.	.	.
1963	.	.	.	.
1964	.	.	.	.
1965	.	.	.	.
1966	.	.	.	.
1967	.	.	.	.
1968	.	.	.	.
1969	.	.	.	.
1970	.	.	.	.
1971	.	.	.	.
1972	.	.	.	.
1973	.	.	.	.
1974	.	.	.	.
1975	.	.	.	.
1976	.	.	.	.
1977	.	.	.	.
1978	.	.	.	.
1979	.	.	.	.
1980	.	.	.	.
1981	.	.	1.64	.
1982	.	.	1.64	.
1983	.	.	1.64	.
1984	.	0.03	22.88	.
1985	.	0.04	23.71	.
1986	.	0.01	23.71	.
1987	.	0.02	23.71	.
1988	.	0.03	18.60	.
1989	.	0.02	7.17	.
1990	.	0.02	7.17	.
1991	.	0.01	7.18	.
1992	9.41	0.93	10.36	20.70
1993	8.03	1.29	25.24	34.56
1994	10.15	1.44	24.64	36.23
1995	10.12	1.55	18.85	30.52
1996	9.95	0.97	7.57	18.49
1997	10.75	1.01	6.13	17.90
1998	7.76	0.83	9.91	18.51
1999	6.55	1.20	60.22	67.96
2000	6.98	1.48	91.96	100.42
2001	7.27	2.11	75.02	84.40
2002	14.33	2.27	45.67	62.27
2003	4.02	1.00	58.97	63.99
2004	1.16	6.95	74.04	82.16
2005	4.89	3.66	27.11	35.66
2006	2.31	6.38	44.32	53.01
2007	5.24	26.60	106.68	138.51
2008	4.77	27.24	189.49	221.50
2009	5.50	21.21	88.94	115.65
2010	6.63	14.24	51.39	72.26
2011	15.29	11.80	9.54	36.63
2012	7.30	13.34	40.79	61.43
2013	7.33	13.33	23.98	44.65
2014	10.27	13.29	81.60	105.15

Table 21. Estimated time series of discard mortalities in whole weight (1000 lb) for commercial handlines (D.cH), headboat (D.HB), and recreational (D.GR).

Year	D.cH	D.HB	D.GR	Total
1950	.	.	.	.
1951	.	.	.	.
1952	.	.	.	.
1953	.	.	.	.
1954	.	.	.	.
1955	.	.	.	.
1956	.	.	.	.
1957	.	.	.	.
1958	.	.	.	.
1959	.	.	.	.
1960	.	.	.	.
1961	.	.	.	.
1962	.	.	.	.
1963	.	.	.	.
1964	.	.	.	.
1965	.	.	.	.
1966	.	.	.	.
1967	.	.	.	.
1968	.	.	.	.
1969	.	.	.	.
1970	.	.	.	.
1971	.	.	.	.
1972	.	.	.	.
1973	.	.	.	.
1974	.	.	.	.
1975	.	.	.	.
1976	.	.	.	.
1977	.	.	.	.
1978	.	.	.	.
1979	.	.	.	.
1980	.	.	.	.
1981	.	.	3.64	.
1982	.	.	2.81	.
1983	.	.	2.30	.
1984	.	0.04	36.96	.
1985	.	0.08	48.66	.
1986	.	0.03	52.70	.
1987	.	0.03	35.92	.
1988	.	0.06	35.34	.
1989	.	0.05	18.90	.
1990	.	0.05	22.52	.
1991	.	0.03	20.20	.
1992	18.22	1.36	15.15	34.73
1993	21.41	3.00	58.84	83.25
1994	26.51	2.91	49.73	79.14
1995	30.59	3.68	44.84	79.11
1996	22.09	1.67	12.98	36.74
1997	25.86	2.04	12.40	40.30
1998	17.22	1.50	17.91	36.64
1999	14.24	2.17	108.94	125.35
2000	15.85	2.79	173.59	192.23
2001	19.08	4.50	160.28	183.87
2002	39.71	4.88	98.45	143.04
2003	10.15	1.94	114.26	126.35
2004	3.82	17.99	191.53	213.34
2005	19.50	10.73	79.57	109.79
2006	3.27	8.03	55.84	67.14
2007	11.00	51.00	204.53	266.53
2008	11.71	55.03	382.85	449.60
2009	17.64	55.16	231.34	304.14
2010	46.44	74.33	268.35	389.12
2011	127.64	53.36	43.17	224.17
2012	63.78	56.41	172.53	292.72
2013	58.36	45.05	81.02	184.43
2014	67.88	32.74	201.06	301.68

Table 22. Estimated status indicators, benchmarks, and related quantities from the base run of the Beaufort catch-age model, conditional on estimated current selectivities averaged across fleets. Also presented are median values and measures of precision (standard errors, SE) from the Monte Carlo/Bootstrap analysis. Rate estimates (F) are in units of y^{-1}*; status indicators are dimensionless; and biomass estimates are in units of metric tons or pounds, as indicated. Spawning stock biomass (SSB) is measured as population fecundity (number of eggs). L refers to landings and R to recruitment*

Quantity	Units	Estimate	Median	SE
$F_{30\%}$	y^{-1}	0.15	0.15	0.01
$85\% F_{30\%}$	y^{-1}	0.12	0.13	0.01
$75\% F_{30\%}$	y^{-1}	0.11	0.11	0.01
$65\% F_{30\%}$	y^{-1}	0.10	0.10	0.01
$F_{30\%}$	y^{-1}	0.15	0.15	0.01
$F_{40\%}$	y^{-1}	0.10	0.11	0.01
$B_{\mathrm{F30\%}}$	metric tons	3693	3628	599
$\mathrm{SSB}_{\mathrm{F30\%}}$	Eggs (1E8)	329948	299651	88001
MSST	Eggs (1E8)	247461	224739	66001
$L_{\mathrm{F30\%}}$	1000 lb whole	459	450	79
$R_{\mathrm{F30\%}}$	number fish	449774	467165	107594
$L_{85\%\mathrm{F30\%}}$	1000 lb whole	442	433	76
$L_{75\%\mathrm{F30\%}}$	1000 lb whole	425	417	73
$L_{65\%\mathrm{F30\%}}$	1000 lb whole	403	396	69
$F_{2012-2014}/F_{30\%}$	—	2.84	2.63	0.85
$\mathrm{SSB}_{2014}/\mathrm{MSST}$	—	0.18	0.20	0.11
$\mathrm{SSB}_{2014}/\mathrm{SSB}_{\mathrm{F30\%}}$	—	0.14	0.15	0.08

Table 23. Results from sensitivity runs of the Beaufort catch-age model. Current F represented by geometric mean of last three assessment years. Runs should not all be considered equally plausible.

Run	Description	$F_{30\%}$	$SSB_{F30\%}$ (1E8 Eggs)	$L_{F30\%}$ (1000 lb)	$F_{current}/F_{30\%}$	$SSB_{end}/SSB_{F30\%}$	R0(1000)	sigmaR	Finit
Base	—	0.147	329948	459	2.84	0.18	331	0.79	0.03
S1	remove 2008/9 from FD	0.147	329929	468	2.86	0.18	330	0.79	0.03
S2	upweight FI 10X	0.146	332402	438	2.07	0.28	325	0.82	0.03
S3	upweight FD 3X	0.146	344879	448	1.71	0.36	338	0.82	0.03
S4	FD only	0.145	332259	325	1.19	0.64	347	0.74	0.03
S5	M upper	0.169	246562	424	1.65	0.4	430	0.82	0.03
S6	M lower	0.133	406658	470	3.73	0.12	285	0.75	0.03
S7	Disc. M lower	0.147	328444	520	2.12	0.24	317	0.83	0.03
S8	Disc. M upper	0.146	335957	424	2.82	0.2	354	0.72	0.03
S9	Longer CVID index	0.147	334145	470	1.99	0.3	344	0.76	0.03
S10	Smooth 1984/5 MRIP peak	0.147	328483	462	2.53	0.22	327	0.8	0.03
S11	h=0.84	0.146	396289	525	3.56	0.11	497	0.6	0.03
S12	Truncated HB disc. index	0.147	331524	470	2.6	0.21	334	0.78	0.03
S13	Ageing error matrix	0.144	334881	409	1.63	0.39	319	0.85	0.03
S14	Batch number lower	0.154	220597	468	2.47	0.24	330	0.79	0.03
S15	Batch number upper	0.146	362022	465	2.63	0.21	333	0.78	0.03
S16	Drop HB disc. index	0.147	331560	470	2.59	0.21	334	0.78	0.03
S17	Higher landings	0.147	441258	654	1.94	0.25	406	0.89	0.03
S18	Lower landings	0.146	232011	298	3.36	0.18	258	0.64	0.03
S19	Higher discards	0.146	338021	500	2.6	0.19	362	0.7	0.03
S20	Lower discards	0.147	327352	561	1.89	0.26	306	0.87	0.03
S21	Dome-shaped selectivity for cH	0.15	355593	490	2.28	0.23	333	0.87	0.03
S22	Separate video and trap indices	0.143	331956	391	1.58	0.41	341	0.76	0.03
S23	FI index only	0.146	330170	436	2.75	0.18	342	0.75	0.03
S24	Continuity	0.102	817833	501	5.97	0.06	114	1.18	0.04
S25	Split q for HB CPUE	0.147	331168	466	2.61	0.2	333	0.79	0.03
S26	1978 start year	0.147	299224	418	2.93	0.19	320	0.7	0.2
S27	Estimate selex for all ages	0.148	328522	465	2.61	0.2	332	0.78	0.03

Table 24. Projection results with fishing mortality rate fixed at $F = 0$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $SSB \geq SSB_{F30\%}$. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	433	318	0.11	0.11	63179	62191	0	0	0	0	70	69	275	280	0.000
2016	438	319	0.22	0.22	95361	89833	28	28	238	240	64	60	321	309	0.002
2017	443	326	0.00	0.00	143309	131164	0	0	0	0	0	0	0	0	0.024
2018	446	326	0.00	0.00	206168	184119	0	0	0	0	0	0	0	0	0.115
2019	448	327	0.00	0.00	274970	242176	0	0	0	0	0	0	0	0	0.295
2020	449	327	0.00	0.00	345142	301374	0	0	0	0	0	0	0	0	0.524
2021	450	336	0.00	0.00	414438	358962	0	0	0	0	0	0	0	0	0.728
2022	450	331	0.00	0.00	482022	415322	0	0	0	0	0	0	0	0	0.867
2023	451	331	0.00	0.00	545065	468649	0	0	0	0	0	0	0	0	0.944
2024	451	329	0.00	0.00	604252	519617	0	0	0	0	0	0	0	0	0.980
2025	451	336	0.00	0.00	658370	567486	0	0	0	0	0	0	0	0	0.993
2026	451	335	0.00	0.00	707432	609743	0	0	0	0	0	0	0	0	0.997
2027	451	337	0.00	0.00	752572	650367	0	0	0	0	0	0	0	0	0.999
2028	451	332	0.00	0.00	792812	686122	0	0	0	0	0	0	0	0	1.000
2029	451	339	0.00	0.00	828614	718519	0	0	0	0	0	0	0	0	1.000
2030	451	332	0.00	0.00	861116	747989	0	0	0	0	0	0	0	0	1.000
2031	451	332	0.00	0.00	890065	774562	0	0	0	0	0	0	0	0	1.000
2032	452	333	0.00	0.00	915468	798510	0	0	0	0	0	0	0	0	1.000
2033	452	331	0.00	0.00	937967	818661	0	0	0	0	0	0	0	0	1.000
2034	452	331	0.00	0.00	957633	837215	0	0	0	0	0	0	0	0	1.000
2035	452	331	0.00	0.00	975027	851811	0	0	0	0	0	0	0	0	1.000
2036	452	332	0.00	0.00	990389	865858	0	0	0	0	0	0	0	0	1.000
2037	452	331	0.00	0.00	1003941	879543	0	0	0	0	0	0	0	0	1.000
2038	452	330	0.00	0.00	1015893	891407	0	0	0	0	0	0	0	0	1.000
2039	452	331	0.00	0.00	1026433	901818	0	0	0	0	0	0	0	0	1.000
2040	452	334	0.00	0.00	1035726	910888	0	0	0	0	0	0	0	0	1.000
2041	452	334	0.00	0.00	1043919	917917	0	0	0	0	0	0	0	0	1.000
2042	452	333	0.00	0.00	1051142	925184	0	0	0	0	0	0	0	0	1.000
2043	452	334	0.00	0.00	1057509	930483	0	0	0	0	0	0	0	0	1.000
2044	452	333	0.00	0.00	1063121	935301	0	0	0	0	0	0	0	0	1.000

Table 25. Projection results with fishing mortality rate fixed at $F = F_{\mathrm{current}}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F30\%}}$*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	433	318	0.11	0.11	63179	62191	0	0	0	0	70	69	275	280	0.000
2016	438	319	0.22	0.22	95361	89833	28	28	238	240	64	60	321	309	0.002
2017	443	326	0.42	0.40	113401	104810	67	58	630	554	117	98	664	568	0.012
2018	445	324	0.42	0.40	115947	106677	61	52	632	552	104	89	605	520	0.020
2019	445	324	0.42	0.40	112762	104136	53	46	575	503	97	83	545	474	0.026
2020	444	323	0.42	0.40	107612	99756	48	42	526	465	93	80	504	442	0.027
2021	444	330	0.42	0.40	102646	95823	45	40	493	438	92	79	480	423	0.026
2022	444	325	0.42	0.40	98614	92194	44	39	471	421	91	78	466	412	0.025
2023	443	325	0.42	0.40	95365	89455	43	38	457	409	90	78	459	407	0.023
2024	443	323	0.42	0.40	92923	87335	43	37	447	402	90	78	456	403	0.021
2025	443	328	0.42	0.40	91093	85712	42	37	441	396	90	78	453	401	0.019
2026	443	328	0.42	0.40	89770	84710	42	37	437	392	90	78	451	401	0.018
2027	442	329	0.42	0.40	88859	84008	42	37	434	391	90	78	450	400	0.017
2028	442	324	0.42	0.40	88218	83886	42	37	432	390	90	78	449	399	0.016
2029	442	330	0.42	0.40	87775	83543	42	37	430	388	89	78	449	398	0.016
2030	442	324	0.42	0.40	87477	83245	42	37	429	386	89	78	448	398	0.015
2031	442	324	0.42	0.40	87274	82990	42	37	429	385	89	77	448	397	0.016
2032	442	325	0.42	0.40	87134	82718	42	37	428	385	89	77	448	396	0.015
2033	442	324	0.42	0.40	87038	82568	42	37	428	386	89	77	448	395	0.014
2034	442	324	0.42	0.40	86973	82432	41	37	428	386	89	77	448	395	0.014
2035	442	323	0.42	0.40	86929	82550	41	37	427	385	89	77	448	395	0.014
2036	442	324	0.42	0.40	86899	82392	41	36	427	384	89	77	448	396	0.014
2037	442	323	0.42	0.40	86879	82185	41	36	427	382	89	77	448	395	0.015
2038	442	323	0.42	0.40	86865	82157	41	37	427	382	89	77	448	395	0.015
2039	442	323	0.42	0.40	86856	82381	41	37	427	382	89	77	448	395	0.015
2040	442	325	0.42	0.40	86849	82349	41	36	427	383	89	77	448	395	0.016
2041	442	326	0.42	0.40	86845	82326	41	36	427	382	89	77	448	394	0.015
2042	442	324	0.42	0.40	86842	82228	41	36	427	381	89	77	448	395	0.016
2043	442	326	0.42	0.40	86840	81916	41	36	427	381	89	78	448	397	0.015
2044	442	325	0.42	0.40	86838	81856	41	37	427	384	89	77	448	397	0.015

Table 26. Projection results with fishing mortality rate fixed at $F = F_{30\%}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{F30\%}$. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	433	318	0.11	0.11	63179	62191	0	0	0	0	70	69	275	280	0.000
2016	438	319	0.22	0.22	95361	89833	28	28	238	240	64	60	321	309	0.002
2017	443	326	0.15	0.15	131924	120312	26	25	248	238	44	41	257	242	0.013
2018	446	325	0.15	0.15	167969	149287	29	27	310	291	44	41	280	260	0.035
2019	447	326	0.15	0.15	199533	174399	30	27	342	316	44	40	289	266	0.066
2020	448	326	0.15	0.15	225598	194937	30	28	365	334	44	40	293	270	0.101
2021	448	335	0.15	0.15	246922	211288	31	28	384	350	44	40	296	272	0.138
2022	449	330	0.15	0.15	264596	225488	31	29	399	363	44	41	298	276	0.179
2023	449	330	0.15	0.15	278426	237594	32	29	412	374	44	41	301	279	0.216
2024	449	328	0.15	0.15	289565	247269	32	29	422	383	44	41	305	283	0.250
2025	449	335	0.15	0.15	298198	254920	33	30	430	391	44	41	307	285	0.281
2026	449	333	0.15	0.15	304895	261223	33	30	436	397	44	41	310	288	0.308
2027	450	335	0.15	0.15	310349	266014	33	30	441	402	44	41	311	290	0.330
2028	450	331	0.15	0.15	314532	270208	33	31	445	407	44	41	313	292	0.349
2029	450	337	0.15	0.15	317768	273495	33	31	448	411	44	41	314	293	0.368
2030	450	331	0.15	0.15	320416	275987	33	31	450	413	44	41	315	294	0.381
2031	450	331	0.15	0.15	322497	278522	33	31	452	415	44	41	315	294	0.393
2032	450	332	0.15	0.15	324086	280402	33	31	454	416	44	42	316	295	0.406
2033	450	330	0.15	0.15	325337	281499	34	31	455	418	44	41	316	295	0.414
2034	450	330	0.15	0.15	326297	282647	34	31	456	418	44	41	316	295	0.421
2035	450	330	0.15	0.15	327060	283723	34	31	456	420	45	41	317	296	0.426
2036	450	331	0.15	0.15	327664	283885	34	31	457	420	45	41	317	296	0.431
2037	450	330	0.15	0.15	328143	284982	34	31	457	420	45	41	317	297	0.432
2038	450	329	0.15	0.15	328521	285897	34	31	458	421	45	42	317	296	0.434
2039	450	330	0.15	0.15	328821	286158	34	31	458	421	45	41	317	296	0.438
2040	450	332	0.15	0.15	329058	286806	34	31	458	422	45	41	317	296	0.437
2041	450	333	0.15	0.15	329245	286990	34	31	458	422	45	42	317	296	0.437
2042	450	331	0.15	0.15	329392	286589	34	31	459	422	45	42	318	297	0.439
2043	450	332	0.15	0.15	329509	286831	34	31	459	422	45	42	318	297	0.437
2044	450	331	0.15	0.15	329601	286885	34	31	459	423	45	42	318	298	0.441

Table 27. Projection results with fishing mortality rate fixed at $F = 98\%F_{30\%}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F30\%}}$. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	433	318	0.11	0.11	63179	62191	0	0	0	0	70	69	275	280	0.000
2016	438	319	0.22	0.22	95361	89833	28	28	238	240	64	60	321	309	0.002
2017	443	326	0.14	0.15	132142	120531	26	24	243	234	43	40	253	237	0.013
2018	446	325	0.14	0.15	168656	149926	29	27	305	286	43	40	275	255	0.036
2019	447	326	0.14	0.15	200805	175527	29	27	337	312	43	40	285	262	0.068
2020	448	326	0.14	0.15	227494	196622	30	27	361	330	43	40	289	266	0.106
2021	449	335	0.14	0.15	249432	213487	31	28	380	346	43	40	292	269	0.146
2022	449	330	0.14	0.15	267688	228151	31	28	395	359	43	40	294	272	0.189
2023	449	330	0.14	0.15	282038	240783	32	29	408	371	43	40	297	275	0.231
2024	449	328	0.14	0.15	293642	250767	32	29	418	380	43	40	301	280	0.266
2025	449	335	0.14	0.15	302674	258727	32	29	427	388	43	40	304	282	0.299
2026	450	333	0.14	0.15	309711	265387	32	30	433	395	44	41	306	285	0.329
2027	450	335	0.14	0.15	315456	270490	33	30	438	400	44	41	308	287	0.353
2028	450	331	0.14	0.15	319881	274810	33	30	442	405	44	41	309	289	0.375
2029	450	337	0.14	0.15	323315	278357	33	30	445	408	44	41	311	290	0.395
2030	450	331	0.14	0.15	326130	280969	33	30	448	411	44	41	311	291	0.409
2031	450	331	0.14	0.15	328348	283573	33	30	450	413	44	41	312	291	0.423
2032	450	332	0.14	0.15	330049	285533	33	31	451	414	44	41	313	292	0.438
2033	450	330	0.14	0.15	331391	286798	33	31	453	416	44	41	313	292	0.444
2034	450	330	0.14	0.15	332423	287929	33	31	454	417	44	41	313	293	0.452
2035	450	330	0.14	0.15	333245	289119	33	31	454	418	44	41	314	293	0.459
2036	450	331	0.14	0.15	333898	289259	33	31	455	419	44	41	314	293	0.462
2037	450	330	0.14	0.15	334416	290483	33	31	455	418	44	41	314	294	0.464
2038	450	329	0.14	0.15	334827	291449	33	31	456	419	44	41	314	293	0.466
2039	450	330	0.14	0.15	335152	291671	33	31	456	420	44	41	314	294	0.468
2040	450	332	0.14	0.15	335410	292341	33	31	456	420	44	41	314	293	0.472
2041	450	333	0.14	0.15	335614	292681	33	31	457	420	44	41	314	294	0.471
2042	450	331	0.14	0.15	335776	292225	33	31	457	421	44	41	314	294	0.473
2043	450	332	0.14	0.15	335903	292374	33	31	457	420	44	41	314	294	0.474
2044	450	332	0.14	0.15	336005	292681	33	31	457	421	44	41	314	295	0.474

Table 28. Projection results with fishing mortality rate fixed at $F = F_{\text{rebuild}}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\text{SSB} \geq \text{SSB}_{\text{F30\%}}$. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	433	318	0.11	0.11	63179	62191	0	0	0	0	70	69	275	280	0.000
2016	438	319	0.22	0.22	95361	89833	28	28	238	240	64	60	321	309	0.002
2017	443	326	0.14	0.14	132192	120903	26	24	242	227	43	39	251	230	0.015
2018	446	325	0.14	0.14	168813	150773	29	26	303	279	43	39	274	249	0.043
2019	447	326	0.14	0.14	201095	177328	29	26	336	305	43	39	284	257	0.084
2020	448	326	0.14	0.14	227929	199358	30	27	360	324	43	39	288	261	0.130
2021	449	335	0.14	0.14	250008	217453	30	27	379	341	43	39	291	265	0.179
2022	449	330	0.14	0.14	268398	232004	31	28	395	355	43	39	294	268	0.229
2023	449	330	0.14	0.14	282869	244493	31	28	407	367	43	39	296	272	0.272
2024	449	328	0.14	0.14	294580	255214	32	29	418	377	43	40	300	276	0.312
2025	449	335	0.14	0.14	303705	263434	32	29	426	385	43	40	303	278	0.349
2026	450	333	0.14	0.14	310821	270054	32	29	432	391	43	40	305	281	0.375
2027	450	335	0.14	0.14	316634	275260	33	30	437	396	43	40	307	283	0.400
2028	450	331	0.14	0.14	321115	279990	33	30	441	402	44	40	309	285	0.418
2029	450	337	0.14	0.14	324596	283568	33	30	445	406	44	40	310	286	0.438
2030	450	331	0.14	0.14	327450	286804	33	30	447	408	44	40	311	287	0.453
2031	450	331	0.14	0.14	329701	289246	33	30	449	411	44	40	311	288	0.463
2032	450	332	0.14	0.14	331428	290867	33	30	451	412	44	40	312	288	0.473
2033	450	330	0.14	0.14	332791	292379	33	30	452	413	44	40	312	288	0.482
2034	450	330	0.14	0.14	333840	293534	33	30	453	414	44	40	313	289	0.489
2035	450	330	0.14	0.14	334676	293969	33	30	454	415	44	40	313	289	0.492
2036	450	331	0.14	0.14	335341	294605	33	30	454	416	44	40	313	289	0.494
2037	450	330	0.14	0.14	335868	295473	33	30	455	416	44	40	313	290	0.499
2038	450	329	0.14	0.14	336286	295664	33	30	455	417	44	40	313	290	0.502
2039	450	330	0.14	0.14	336618	296527	33	30	456	417	44	40	314	289	0.502
2040	450	332	0.14	0.14	336880	297106	33	30	456	417	44	40	314	289	0.504
2041	450	333	0.14	0.14	337089	297412	33	30	456	417	44	40	314	290	0.508
2042	450	331	0.14	0.14	337253	297014	33	30	456	418	44	40	314	290	0.509
2043	450	332	0.14	0.14	337384	297057	33	30	456	418	44	40	314	290	0.509
2044	450	332	0.14	0.14	337487	297250	33	31	456	418	44	40	314	291	0.508

Table 29. Projection results with fishing mortality rate applied only to discards. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $SSB \geq SSB_{F30\%}$*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	433	318	0.11	0.11	63179	62191	0	0	0	0	70	69	275	280	0.000
2016	438	319	0.10	0.11	100608	94609	0	0	0	0	70	69	356	355	0.003
2017	444	327	0.10	0.11	144065	131070	0	0	0	0	75	70	446	430	0.024
2018	446	326	0.10	0.11	187212	165608	0	0	0	0	74	69	488	462	0.084
2019	448	327	0.10	0.11	227447	197122	0	0	0	0	73	69	507	474	0.174
2020	449	327	0.10	0.11	262938	224721	0	0	0	0	73	69	516	478	0.266
2021	449	335	0.10	0.11	294015	248495	0	0	0	0	73	69	522	484	0.348
2022	449	330	0.10	0.11	321514	269130	0	0	0	0	73	69	528	491	0.420
2023	450	330	0.10	0.11	344650	287029	0	0	0	0	73	70	535	498	0.480
2024	450	328	0.10	0.11	364487	301454	0	0	0	0	74	70	545	508	0.528
2025	450	335	0.10	0.11	380884	313969	0	0	0	0	74	71	553	517	0.565
2026	450	334	0.10	0.11	394436	323960	0	0	0	0	74	71	560	523	0.595
2027	450	336	0.10	0.11	406107	332409	0	0	0	0	74	72	566	530	0.620
2028	450	331	0.10	0.11	415654	339809	0	0	0	0	75	72	571	536	0.642
2029	450	337	0.10	0.11	423519	347017	0	0	0	0	75	72	575	540	0.660
2030	450	331	0.10	0.11	430322	352218	0	0	0	0	75	72	578	543	0.676
2031	450	331	0.10	0.11	436005	356899	0	0	0	0	75	72	581	546	0.687
2032	450	332	0.10	0.11	440632	360429	0	0	0	0	75	72	583	547	0.697
2033	450	330	0.10	0.11	444495	363434	0	0	0	0	75	72	585	549	0.704
2034	450	330	0.10	0.11	447648	365646	0	0	0	0	75	72	587	550	0.710
2035	451	330	0.10	0.11	450306	367705	0	0	0	0	75	72	588	551	0.715
2036	451	331	0.10	0.11	452546	369251	0	0	0	0	75	72	589	551	0.718
2037	451	330	0.10	0.11	454432	370451	0	0	0	0	75	72	590	552	0.722
2038	451	329	0.10	0.11	456019	371148	0	0	0	0	75	72	591	553	0.726
2039	451	330	0.10	0.11	457353	372734	0	0	0	0	76	72	592	555	0.728
2040	451	333	0.10	0.11	458476	373439	0	0	0	0	76	72	592	554	0.729
2041	451	333	0.10	0.11	459420	374145	0	0	0	0	76	73	593	555	0.732
2042	451	331	0.10	0.11	460214	374960	0	0	0	0	76	73	593	556	0.733
2043	451	332	0.10	0.11	460882	375981	0	0	0	0	76	73	594	557	0.734
2044	451	332	0.10	0.11	461443	376468	0	0	0	0	76	73	594	557	0.736

Table 30. Parameter estimates from selected ASPIC surplus production model runs 318 (continuity), 319 (updated continuity), 320 (best configuration), and 323 (best configuration with B_1/K fixed) All parameter values are rounded to 3 significant digits. MSY, B_1, and K are in units of 1000 pounds. Catchability parameters correspond to the commercial (q_1), headboat (q_2), headboat-at-sea (q_3), and CVID (q_4) indices.

Run	F/F_{MSY}	B/B_{MSY}	B_1/K	MSY	F_{MSY}	q_1	q_2	q_3	q_4	B_1	K
318	2.15	0.53	0.467	805	0.313	9.35e-07	7.14e-07			2400	5140
319	0.614	1.3	1.94	802	0.314	9.42e-07	7.14e-07			9930	5110
320	0.531	1.48	0.91	805	0.322	8.69e-07	6.98e-07	2.98e-07	4.04e-07	4560	5010
323	0.53	1.47	0.467	807	0.321	8.74e-07	7e-07	2.99e-07	4.02e-07	2350	5030

8 Figures

Figure 1. Indices of abundance used in fitting the assessment model. HB indicates the headboat logbook index; Handline indicated the the commercial handline logbook index; HB Disc indicated the headboat discard observer index, CVT indicates the SERFS chevron trap index; VID indicates the SERFS video index, and CVID indicates the combined chevron trap and video index. The CVT and VID indices were only used during sensitivity runs.

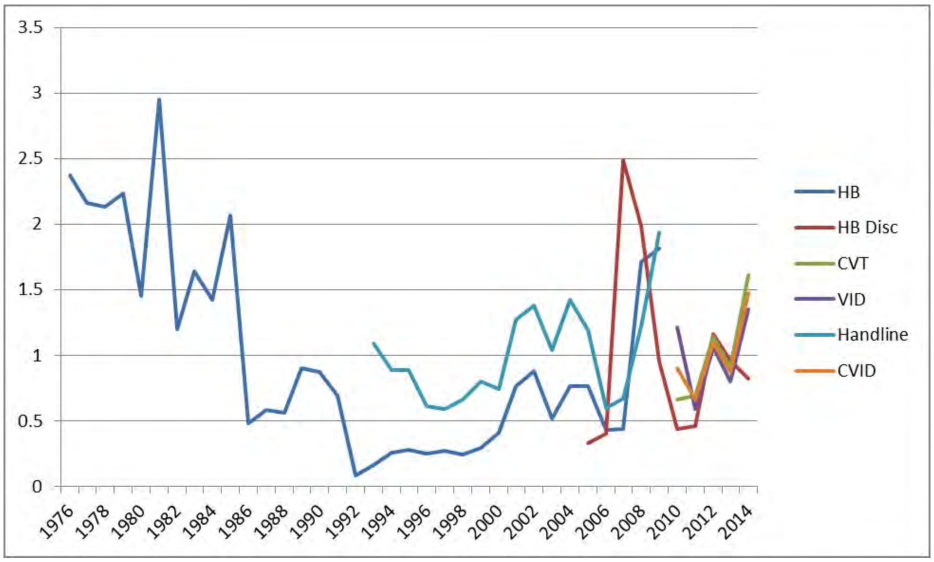


Figure 2. Mean total length at age (mm) and estimated upper and lower 95% confidence intervals of the population.

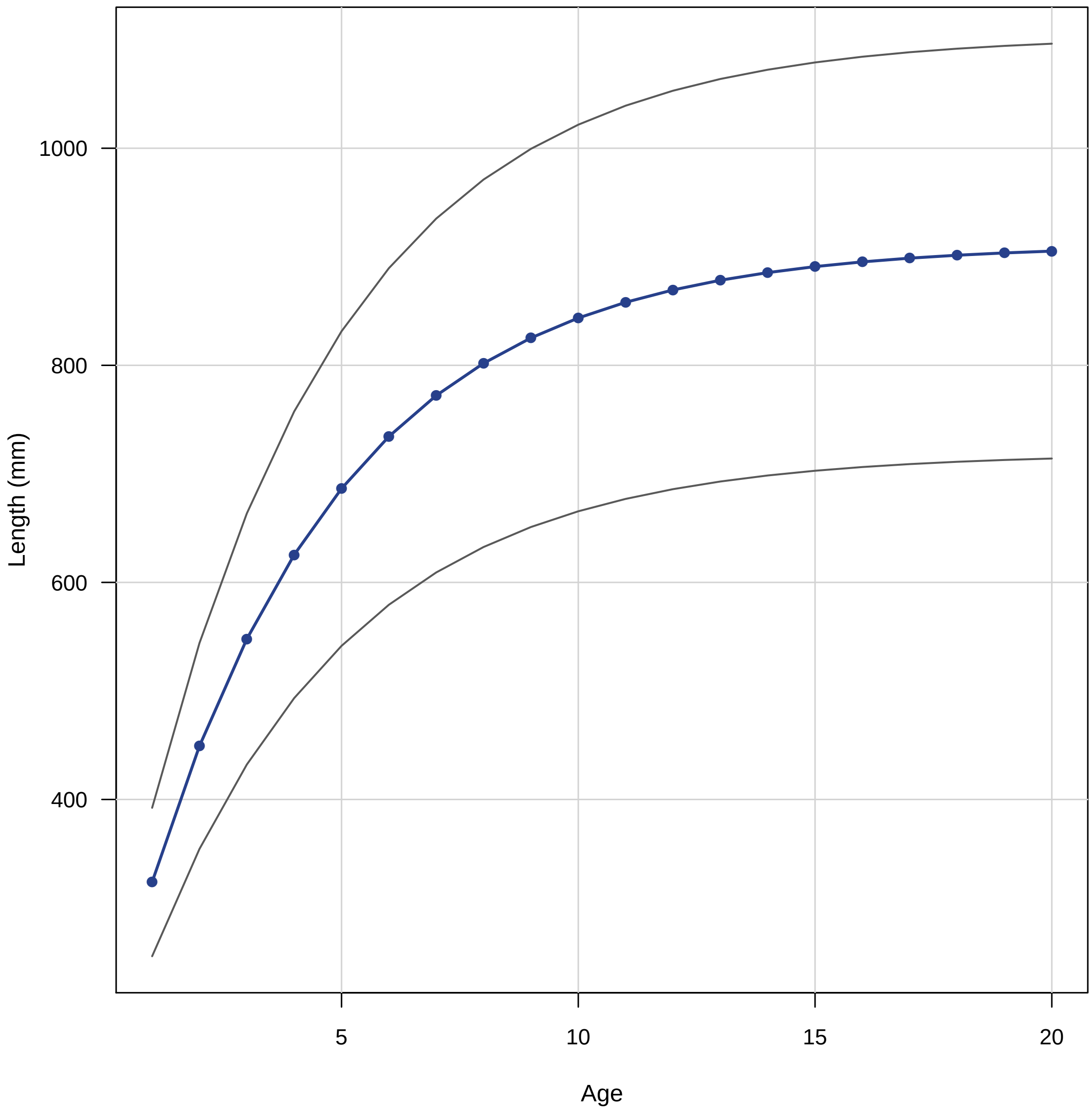


Figure 3. Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, CVT to MARMAP chevron trap, cH to commercial handline, HB to headboat and GR to general recreational.

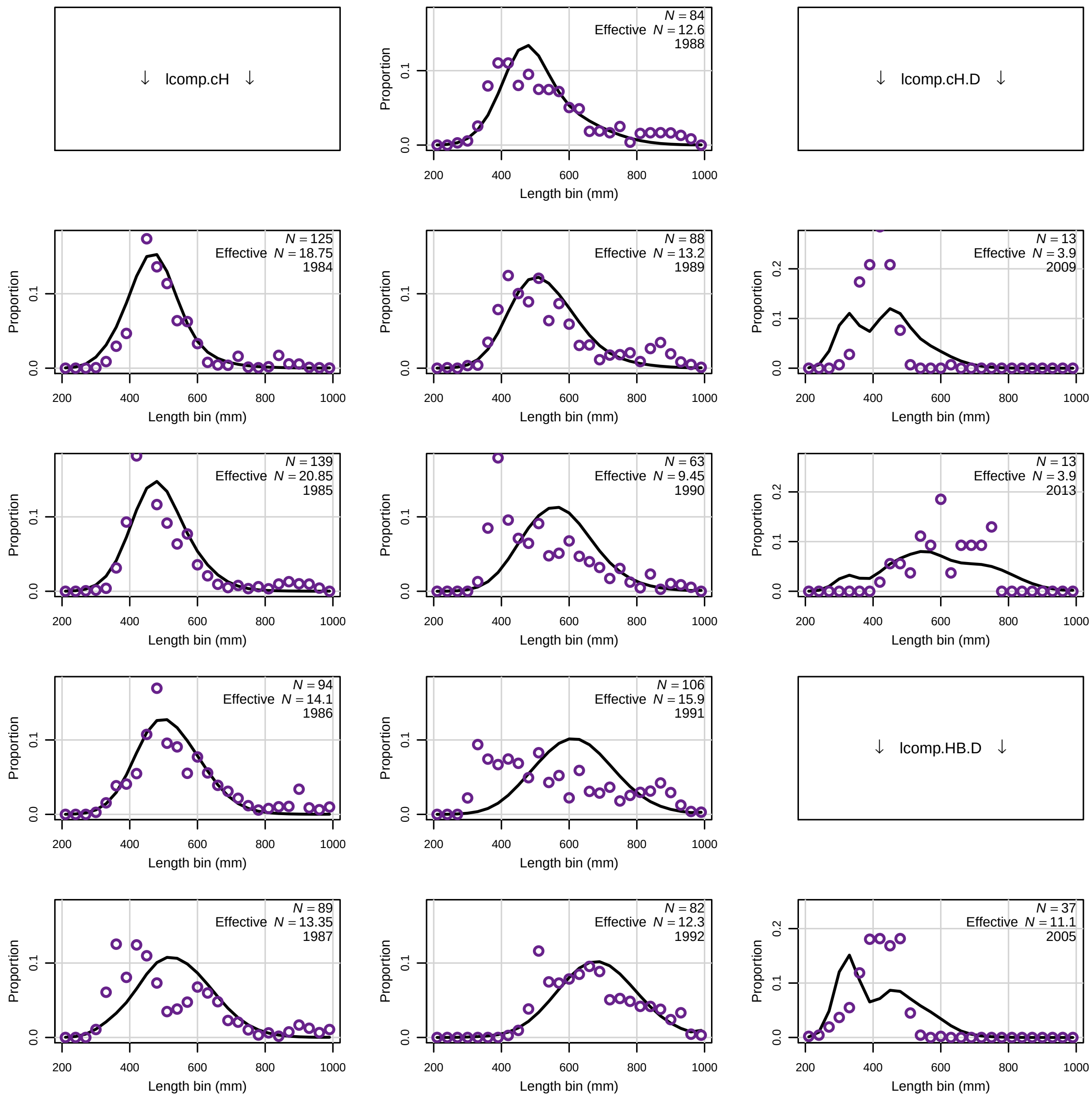


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

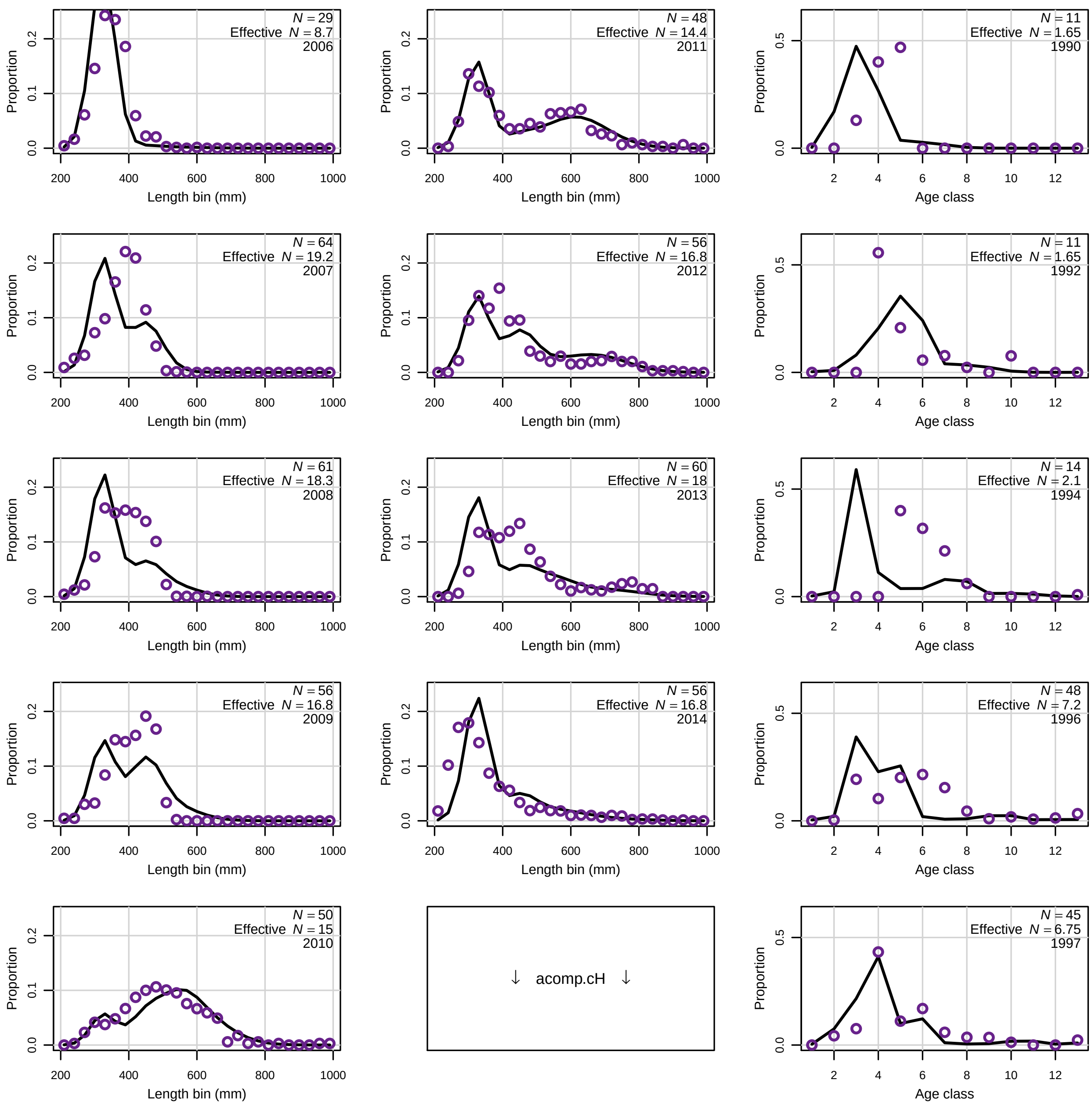


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

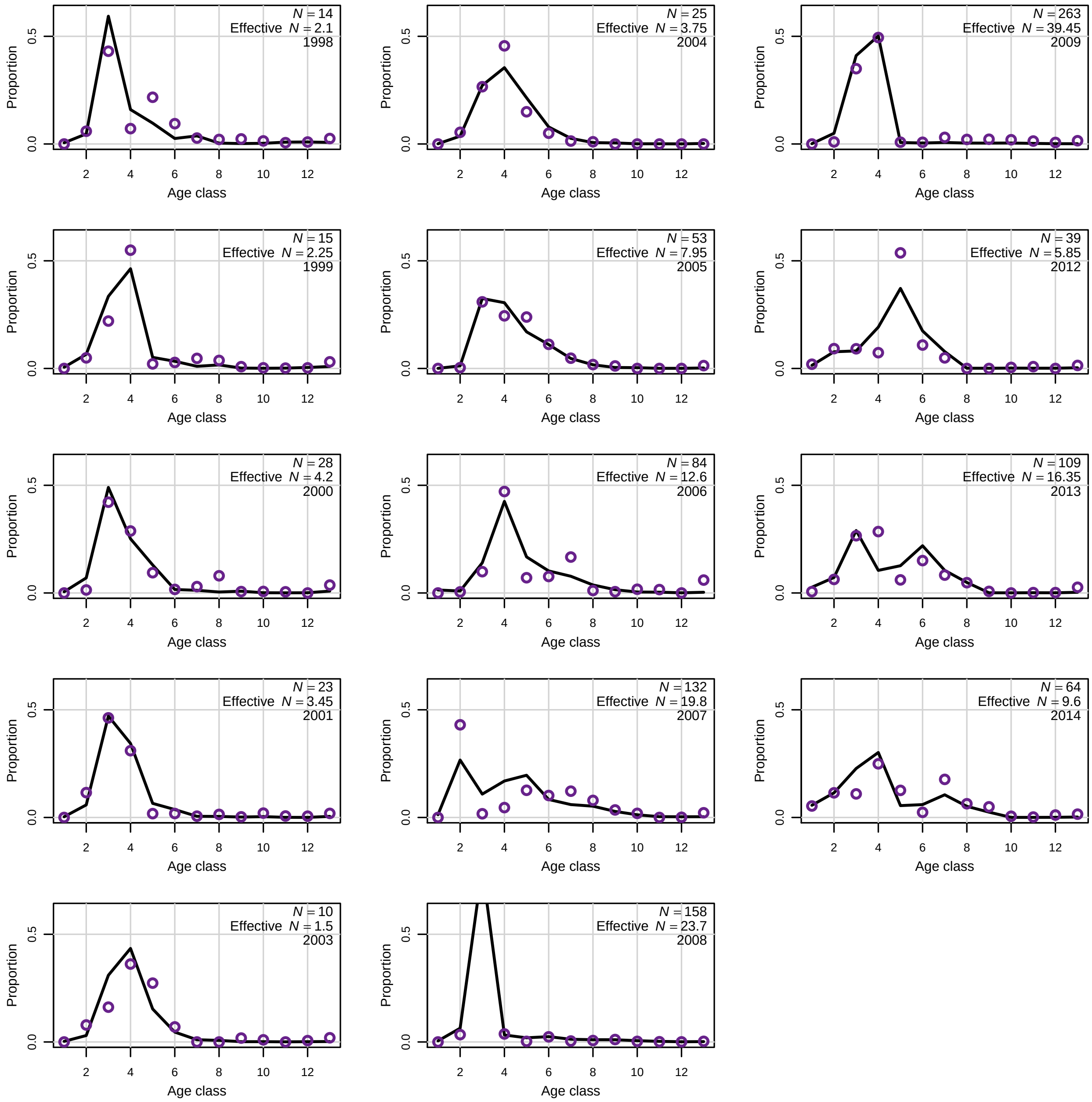


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

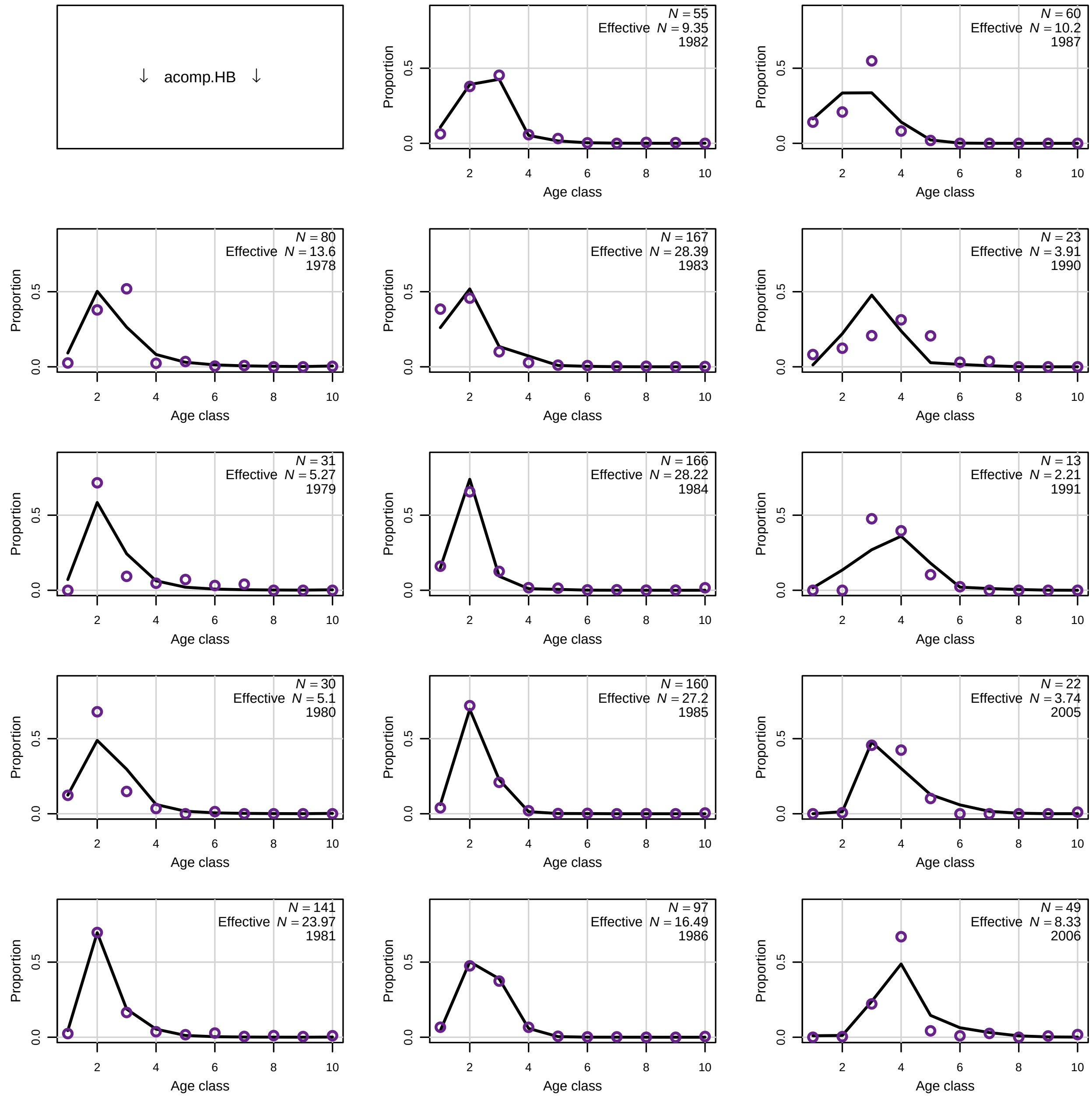


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

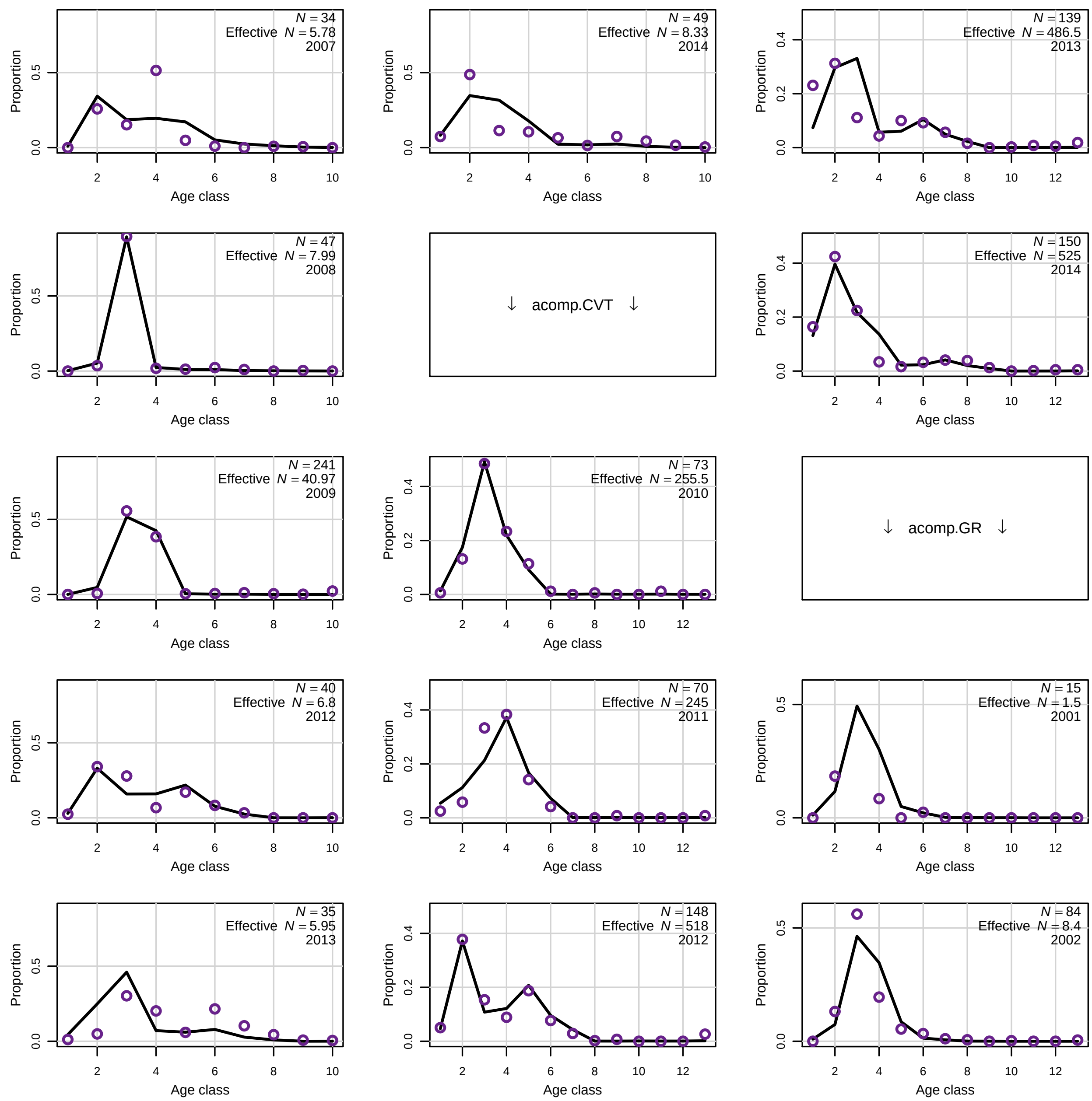


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

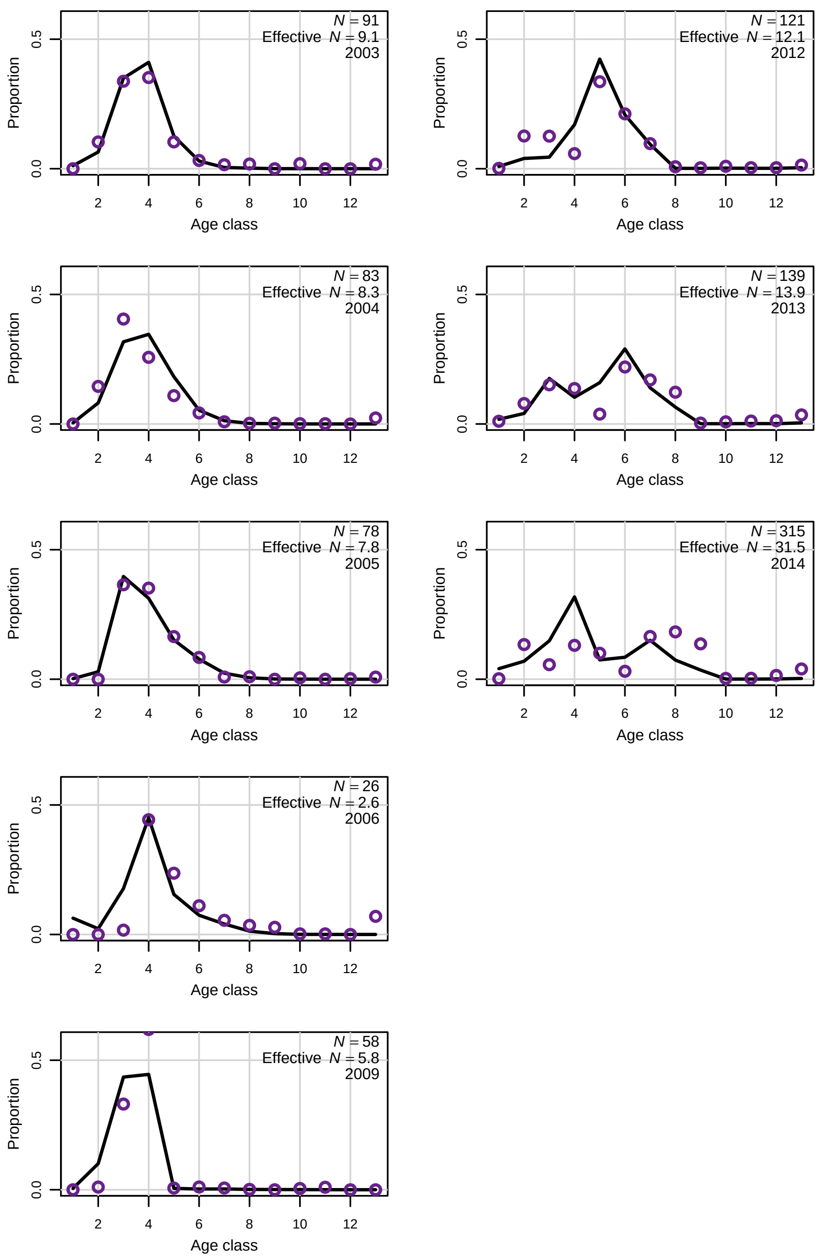


Figure 4. Observed (open circles) and estimated (solid line, circles) commercial handline landings in 1000 lb whole weight.

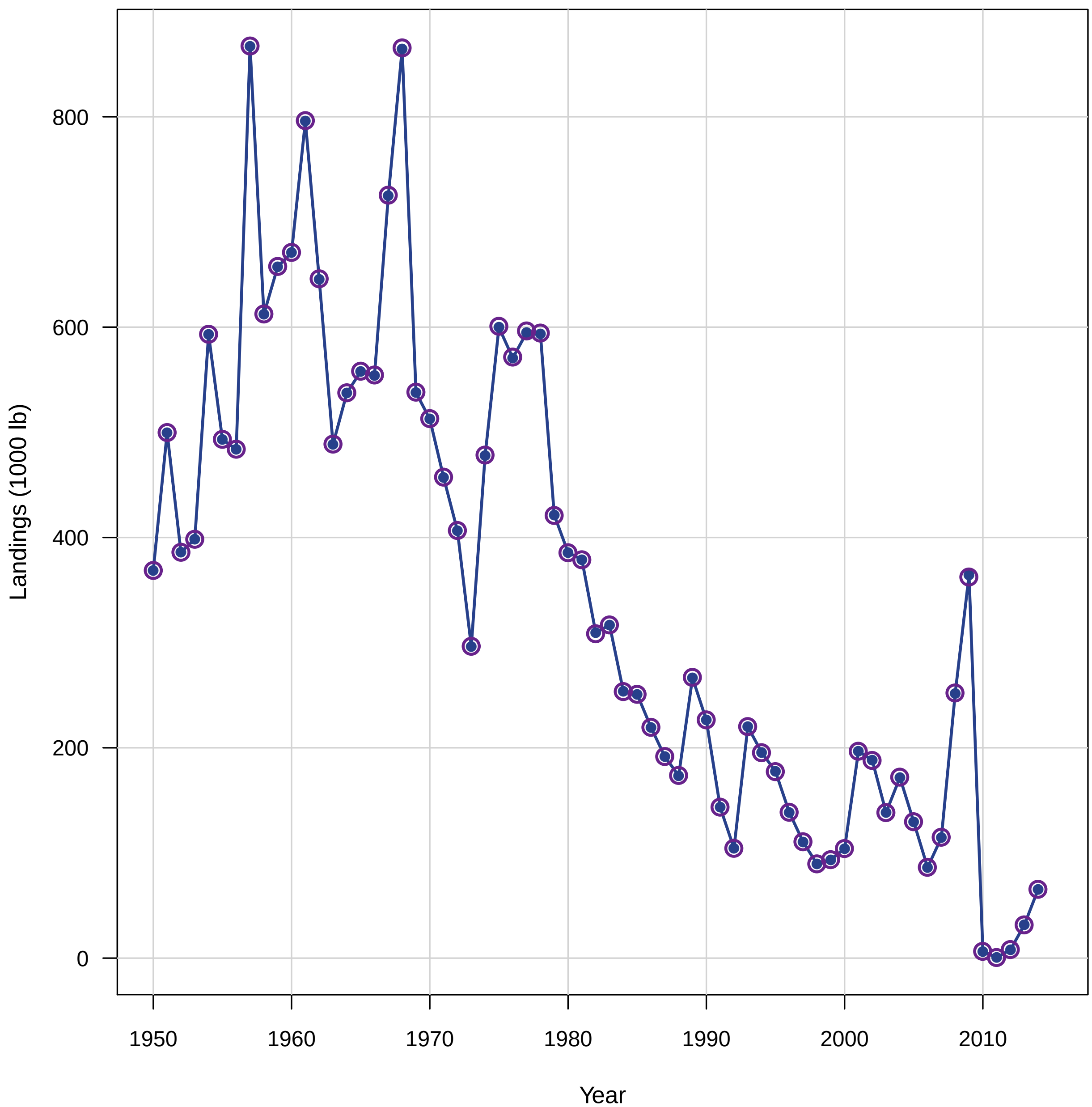


Figure 5. Observed (open circles) and estimated (solid line, circles) headboat landings in 1000s of fish.

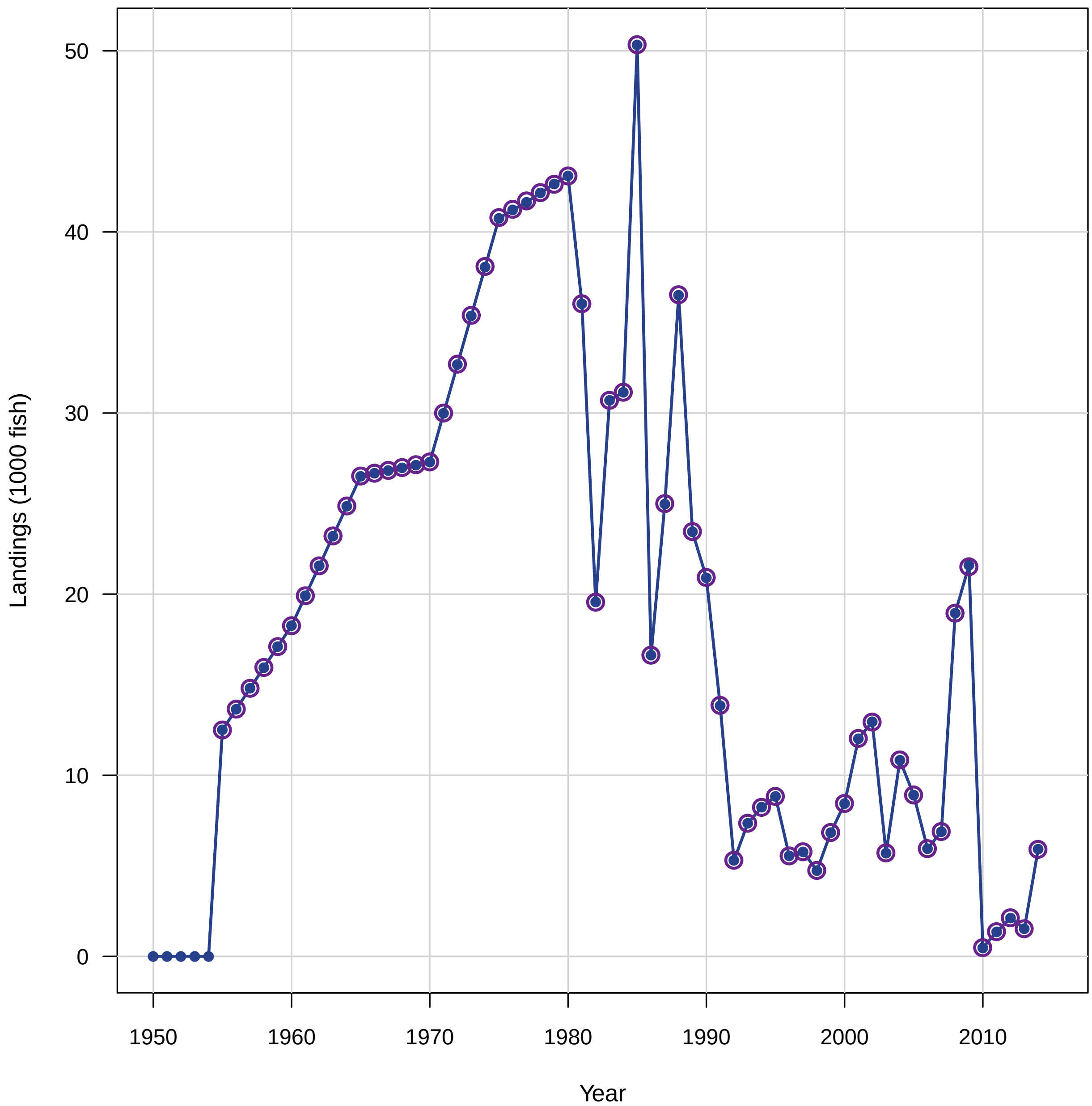


Figure 6. Observed (open circles) and estimated (solid line, circles) general recreational landings in 1000s of fish.

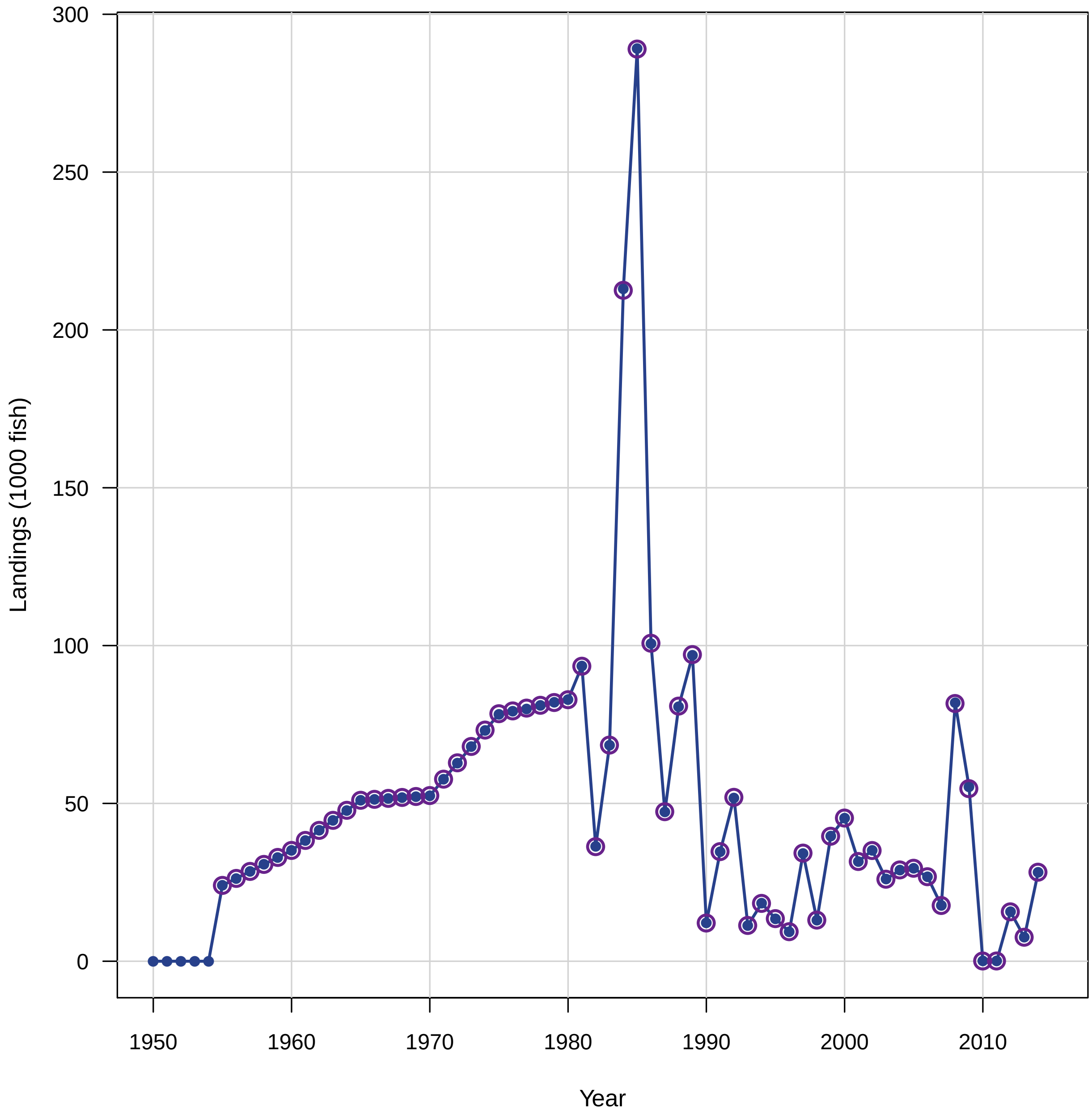


Figure 7. Observed (open circles) and estimated (solid line, circles) commercial handline discard mortalities.

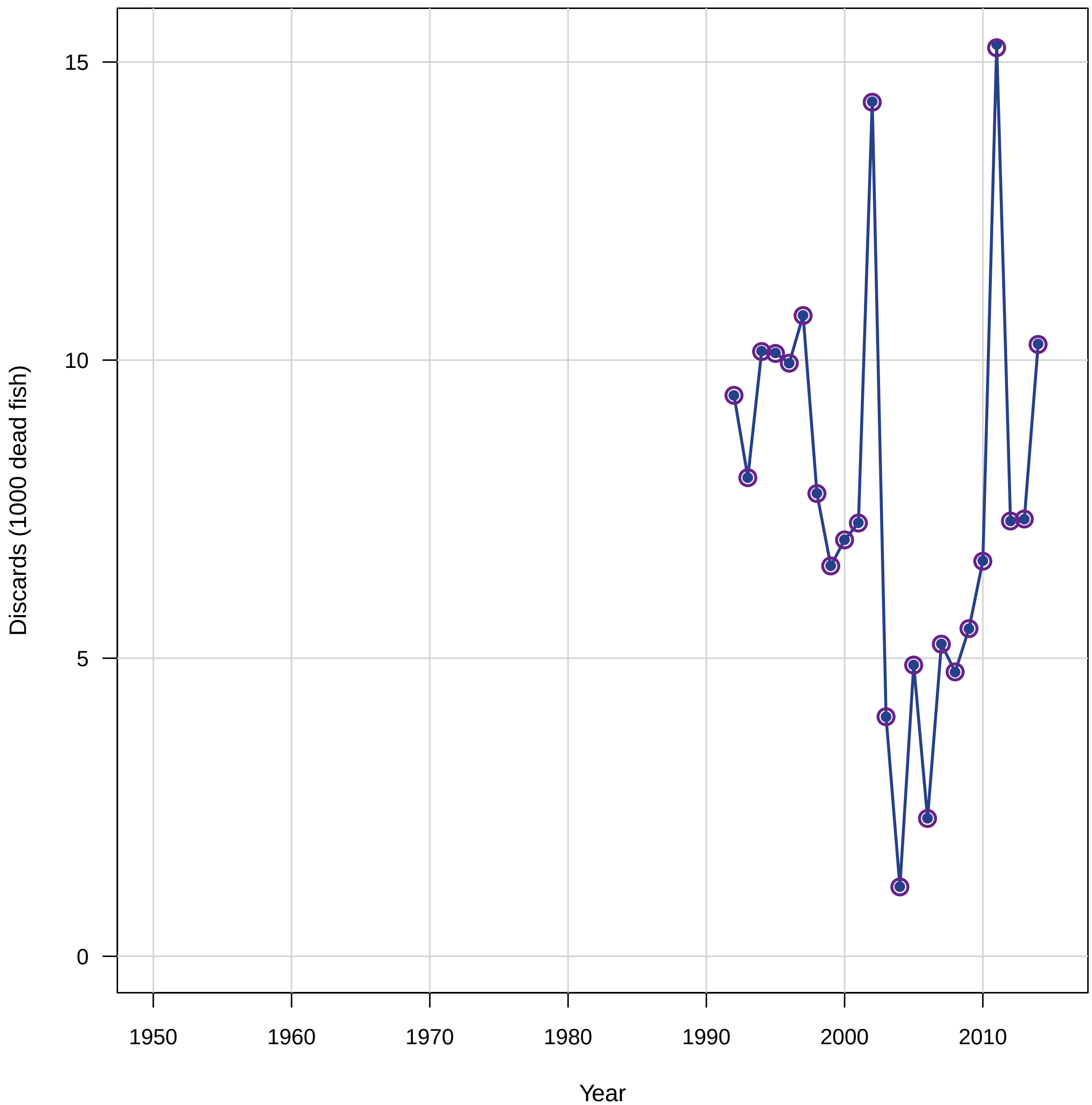


Figure 8. Observed (open circles) and estimated (solid line, circles) headboat discard mortalities.

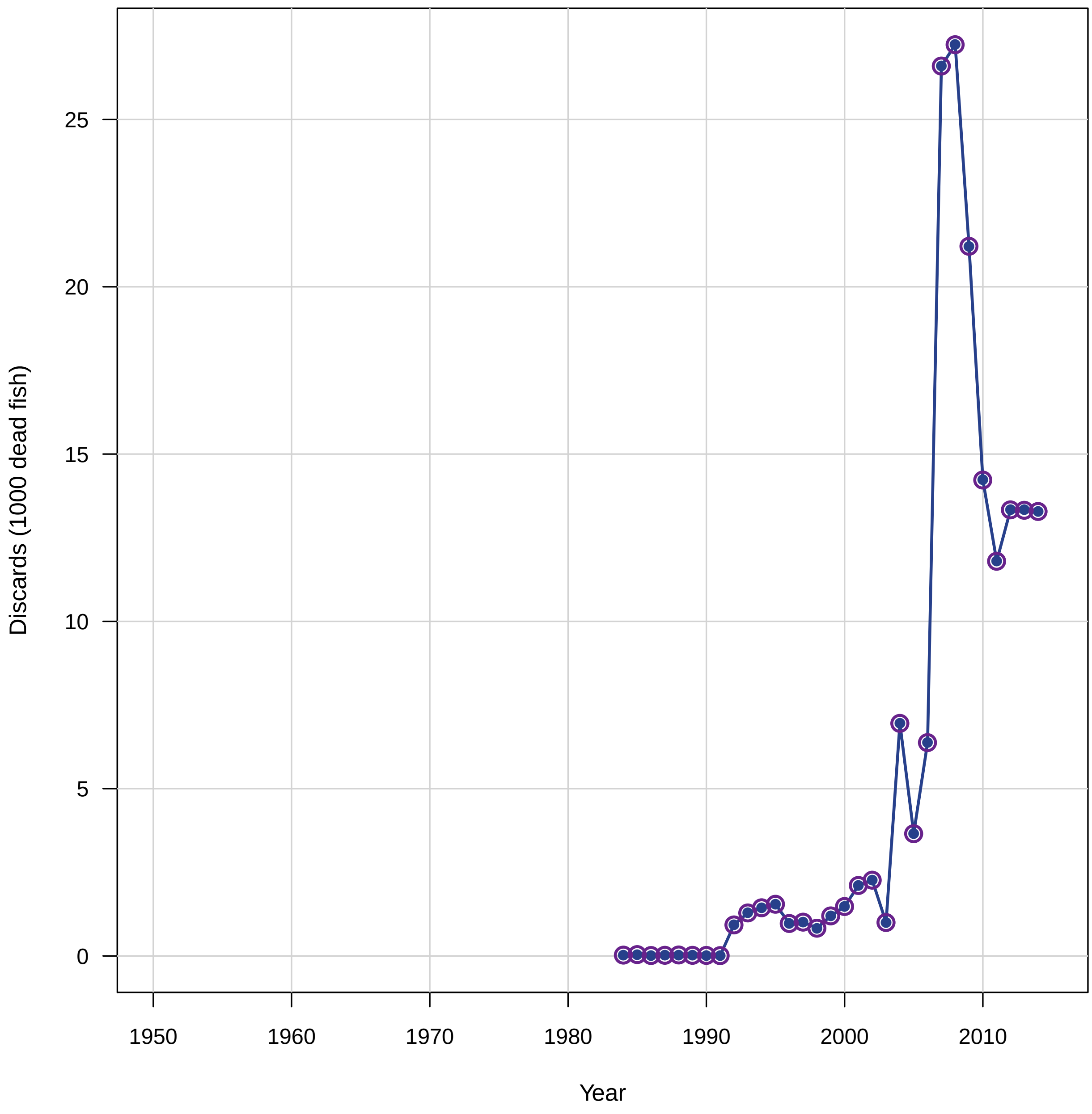


Figure 9. Observed (open circles) and estimated (solid line, circles) general recreational discard mortalities.

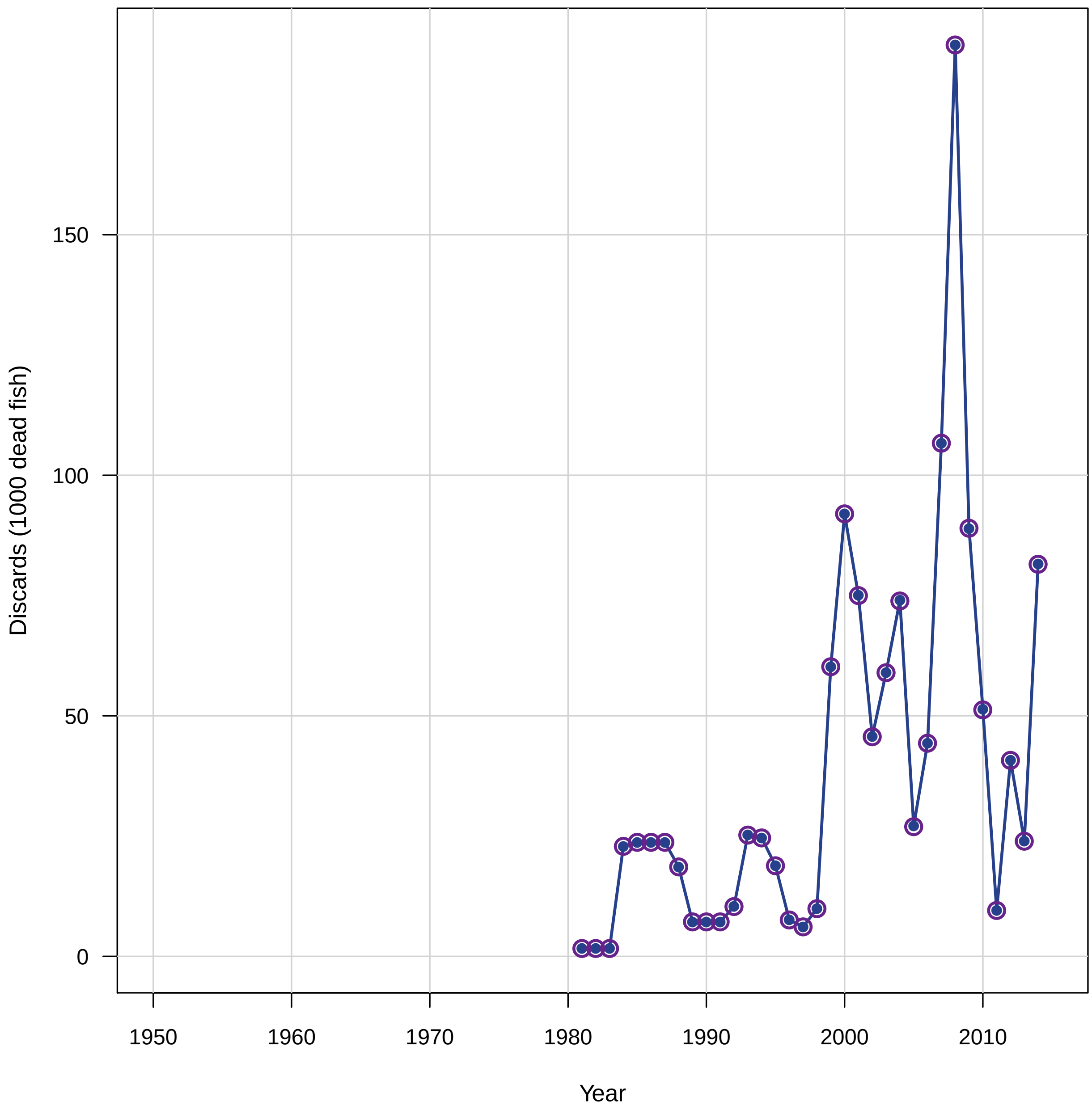


Figure 10. Observed (open circles) and estimated (solid line, circles) index of abundance from the SERFS combined trap and video index. The error bars represent the annual CV provided by the GLM standardization divided by the likelihood weight on the index.

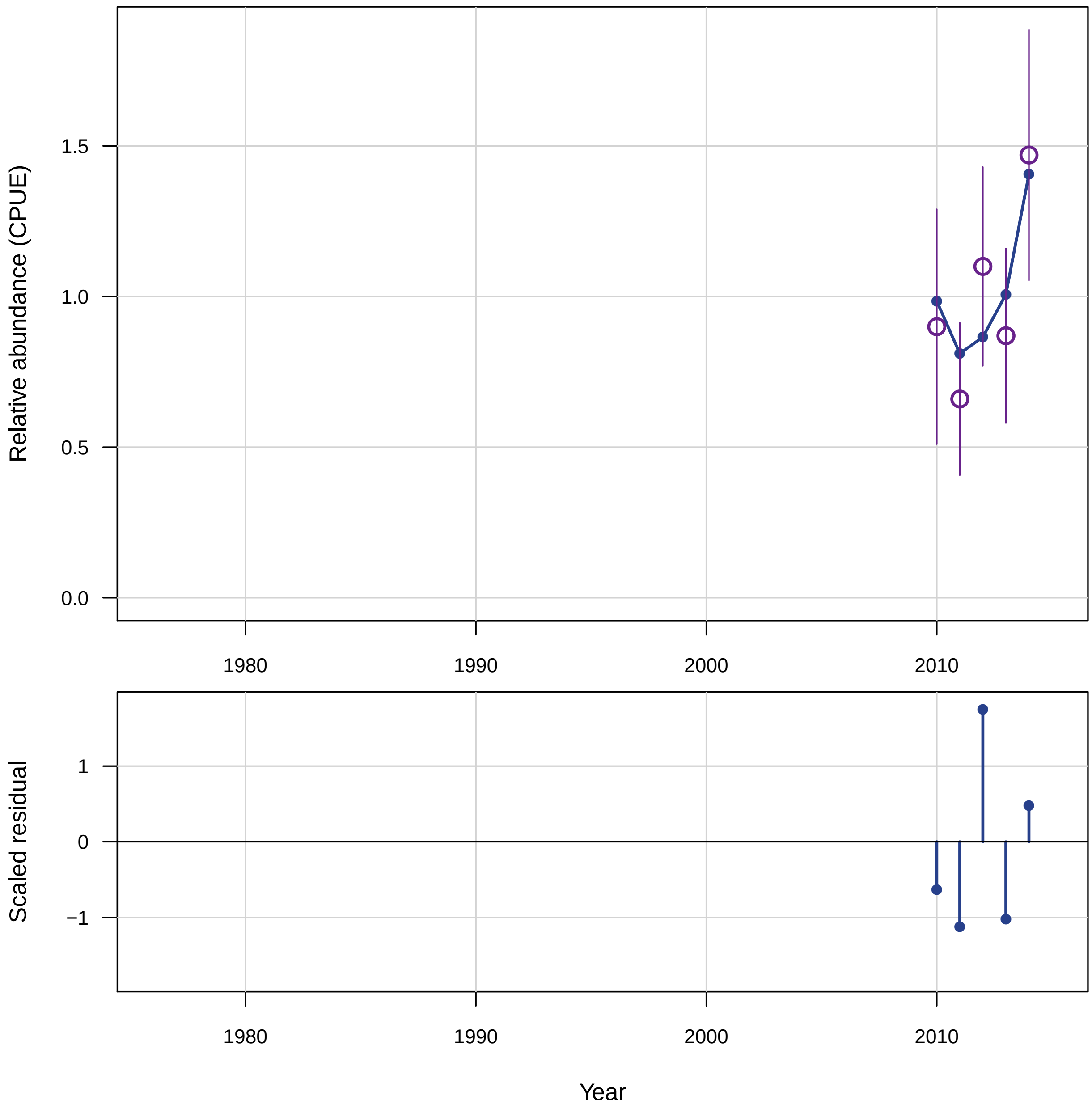


Figure 11. Observed (open circles) and estimated (solid line, circles) index of abundance from the commercial handline fleet. The error bars represent the annual CV of the index (0.2) divided by the likelihood weight on the index.

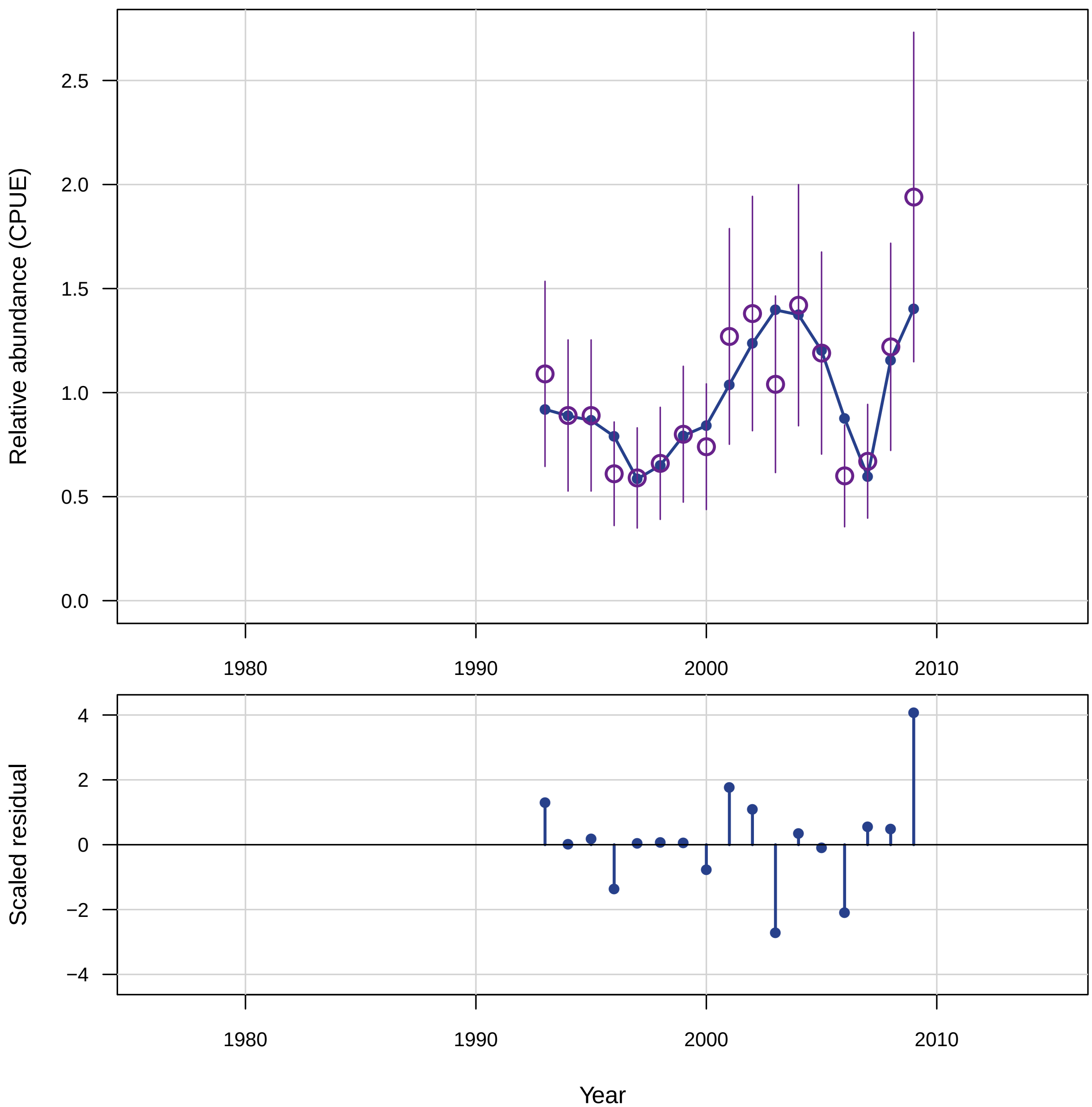


Figure 12. Observed (open circles) and estimated (solid line, circles) abundance from the headboat fleet. The error bars represent the annual CV of the index (0.2) divided by the likelihood weight on the index.

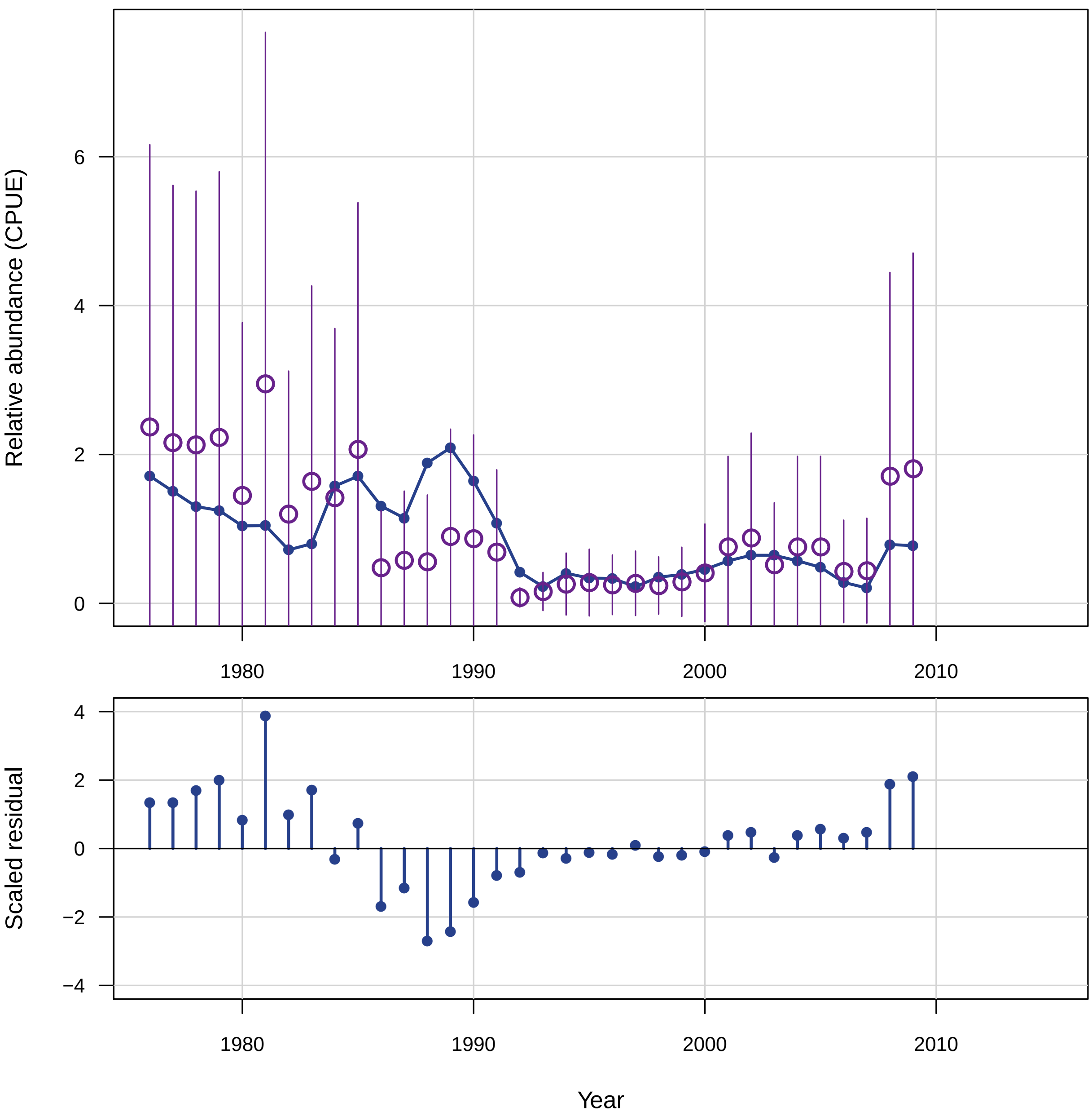


Figure 13. Observed (open circles) and estimated (solid line, circles) abundance from the headboat fleet (discards). The error bars represent the annual CV provided by the GLM standardization divided by the likelihood weight on the index.

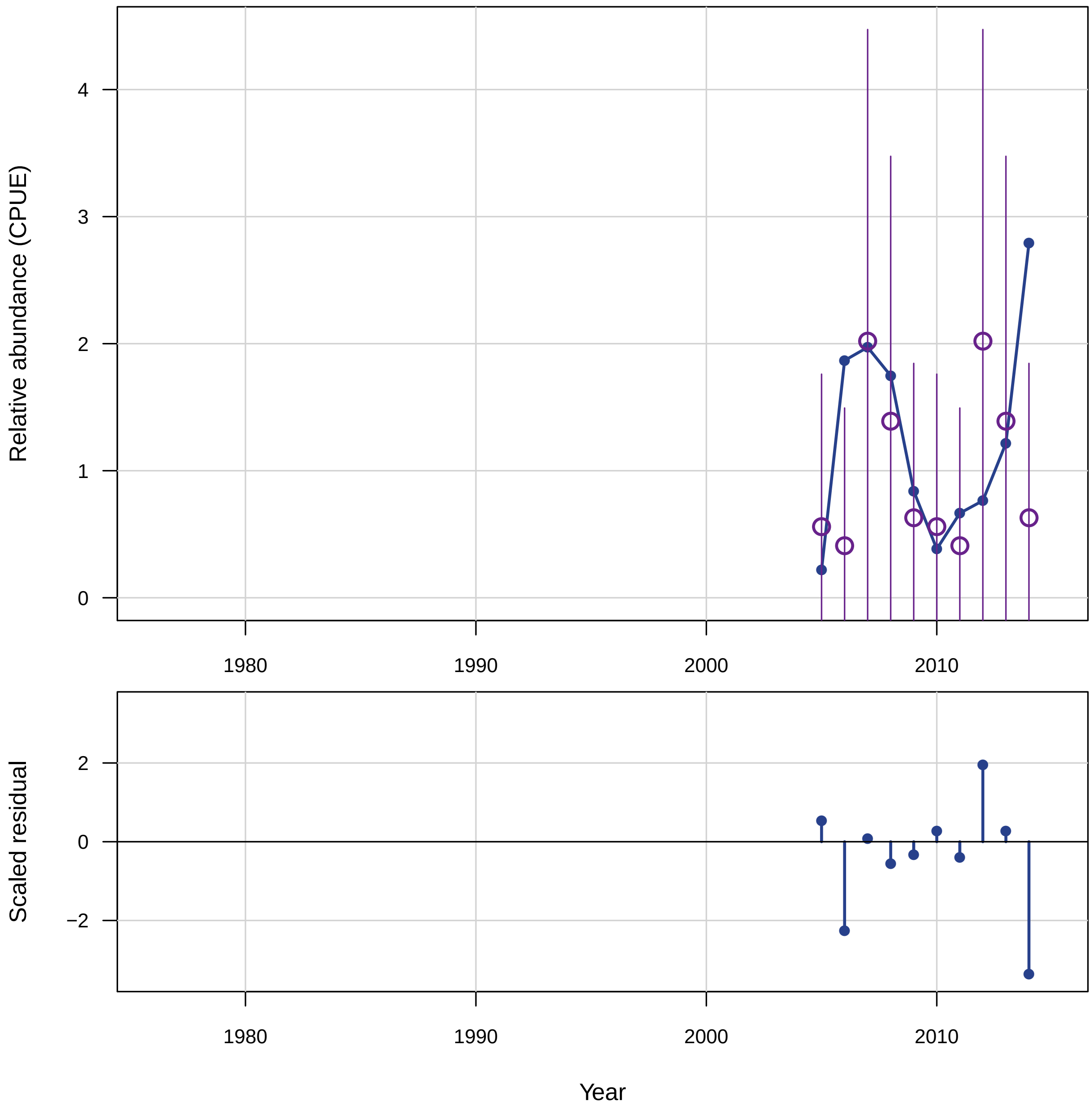


Figure 14. Estimated abundance at age at start of year.

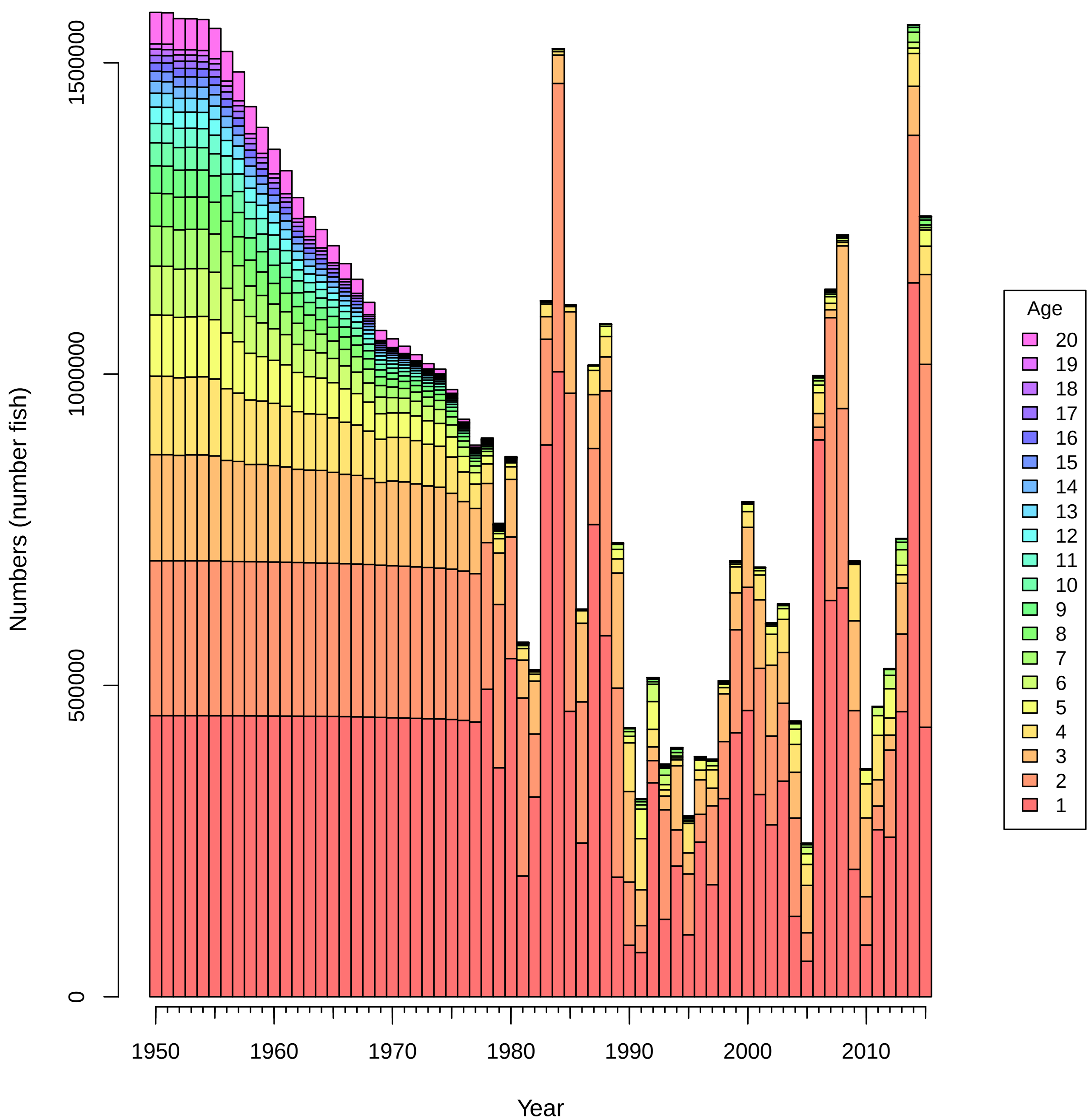


Figure 15. Top panel: Estimated recruitment of age-1 fish. Horizontal dashed line indicates $R_{F30\%}$. Bottom panel: log recruitment residuals.

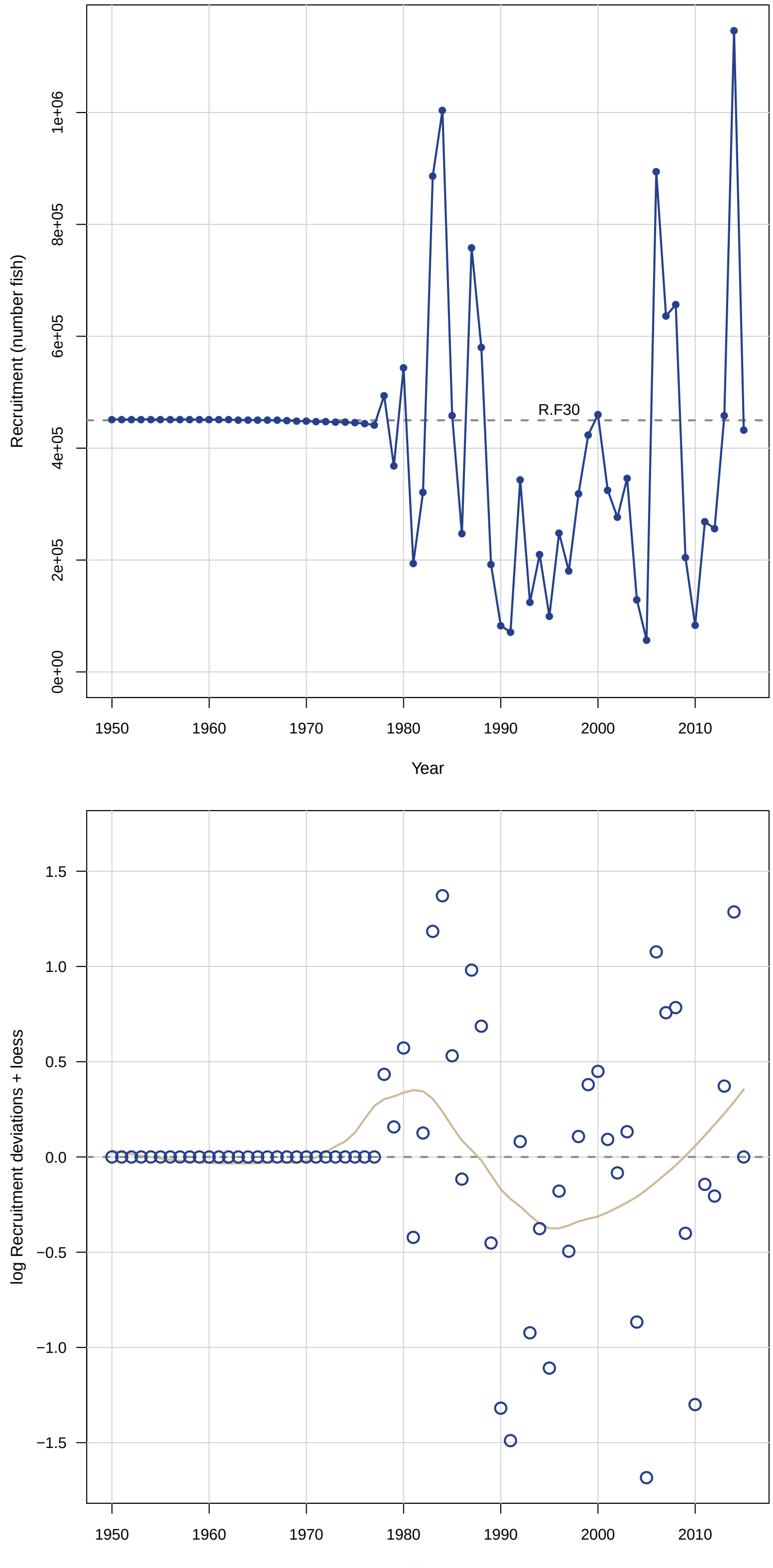


Figure 16. Estimated biomass at age at start of year.

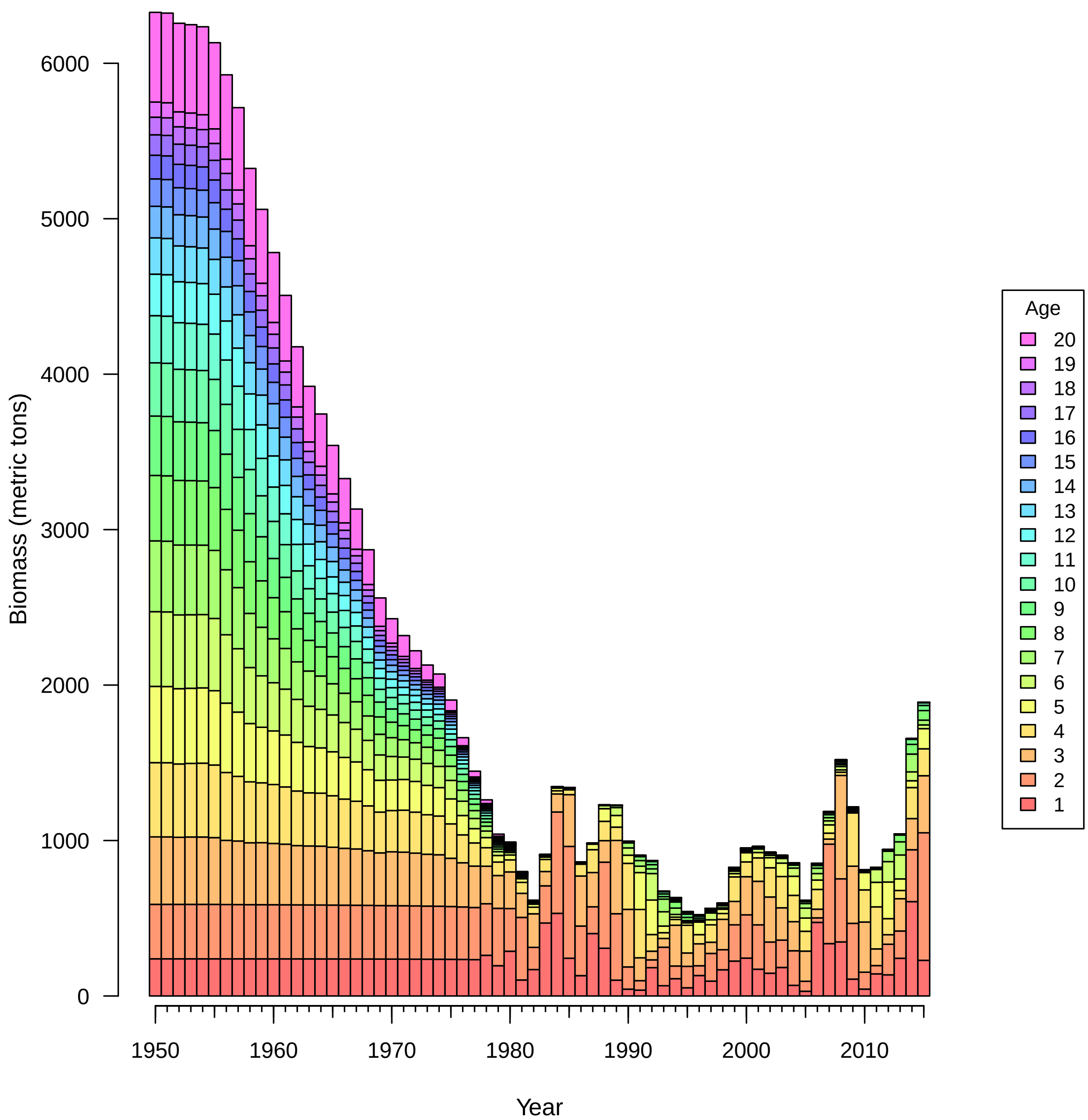
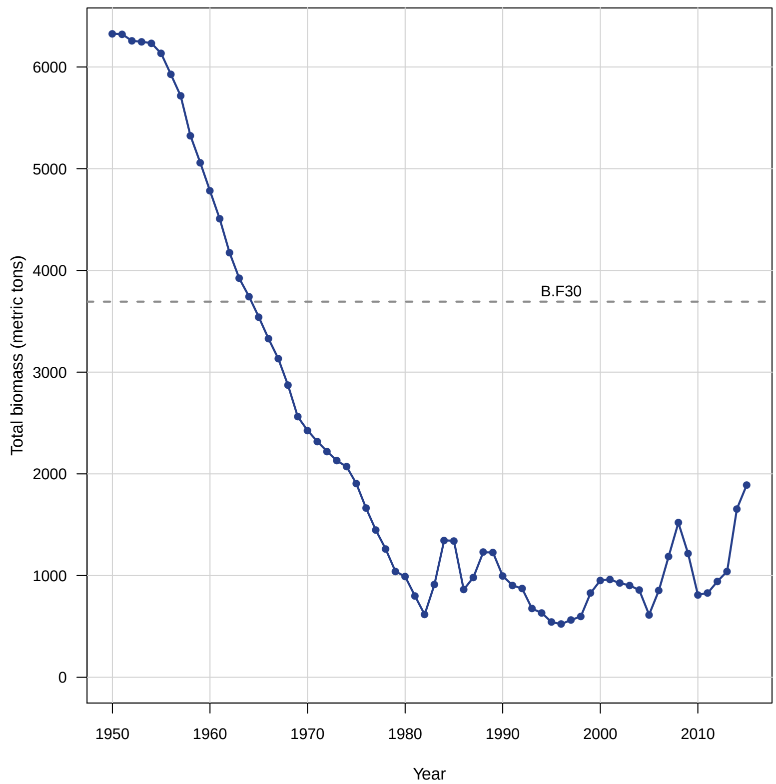


Figure 17. Top panel: Estimated total biomass (metric tons) at start of year. Horizontal dashed line indicates $B_{F30\%}$. Bottom panel: Estimated spawning stock (population fecundity) at time of peak spawning.



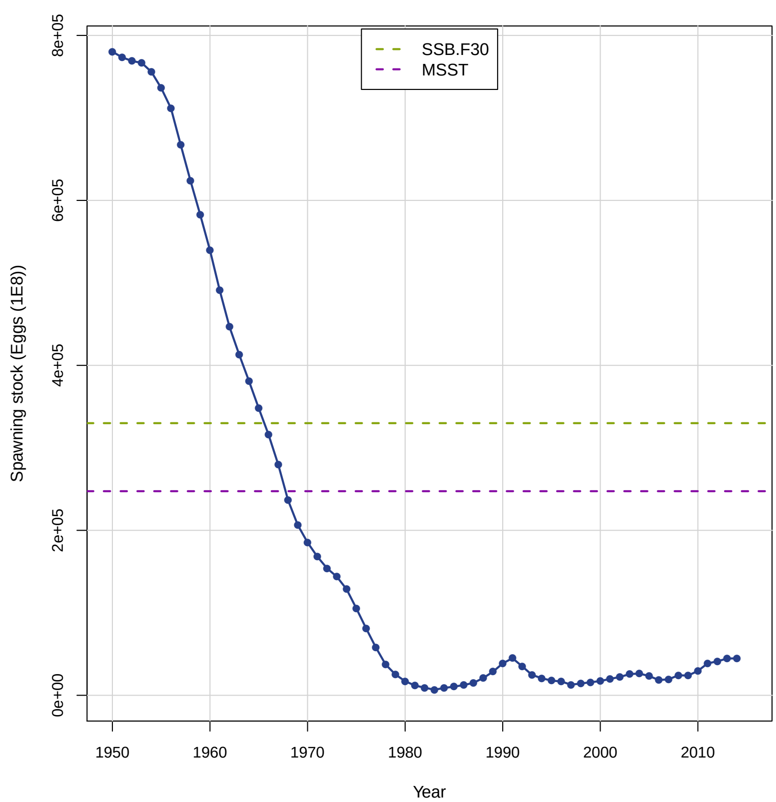


Figure 18. Monte Carlo Bootstrap estimates of population abundance. Top panel is all ages, and the bottom panel represents age 2+.

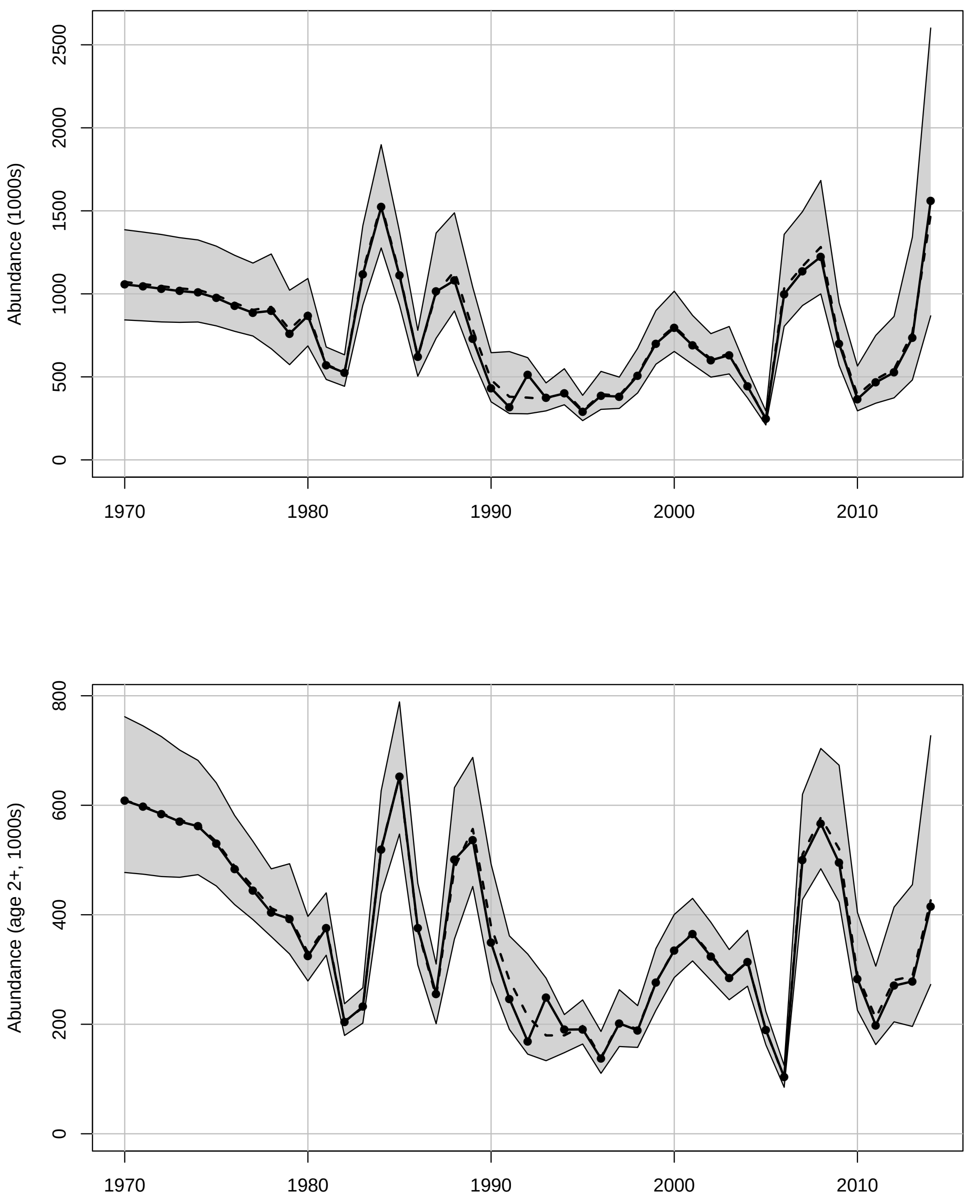


Figure 19. Selectivity of SERFS index.

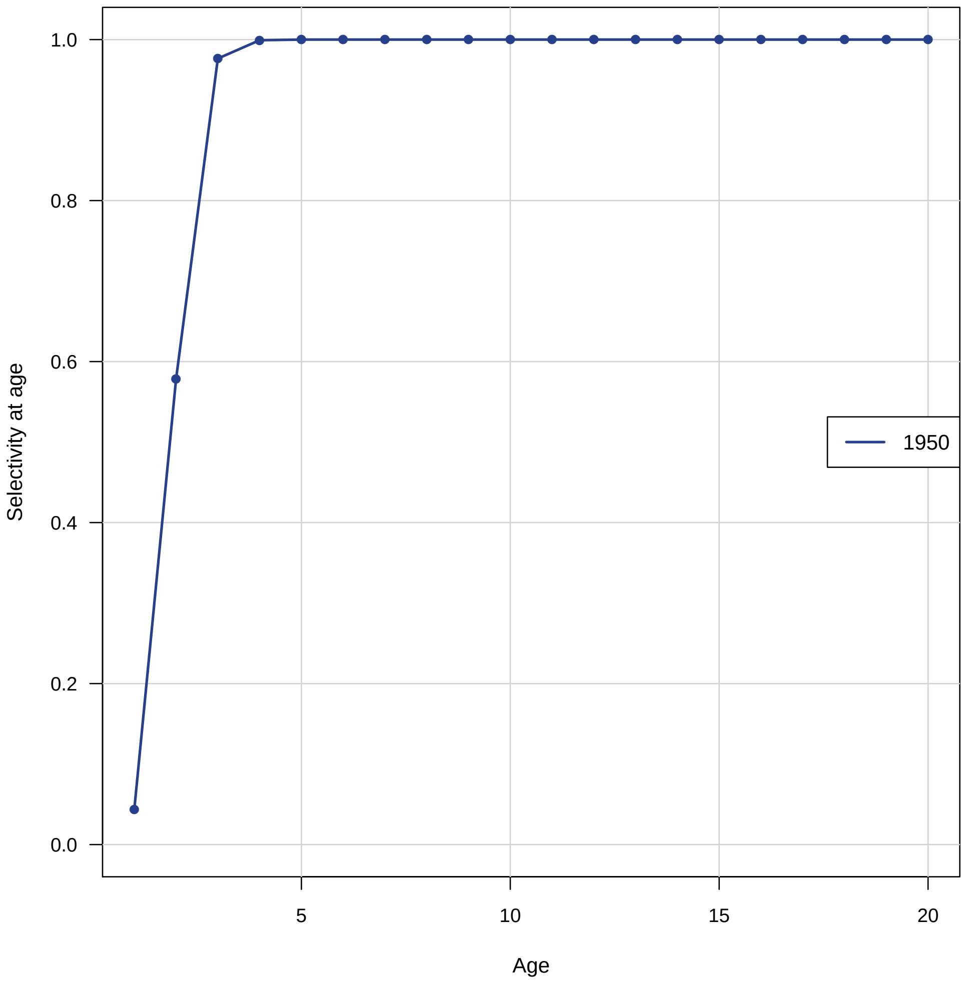


Figure 20. Selectivities of commercial handline landings. The legend indicates the first year each selectivity curve applies to the fleet.

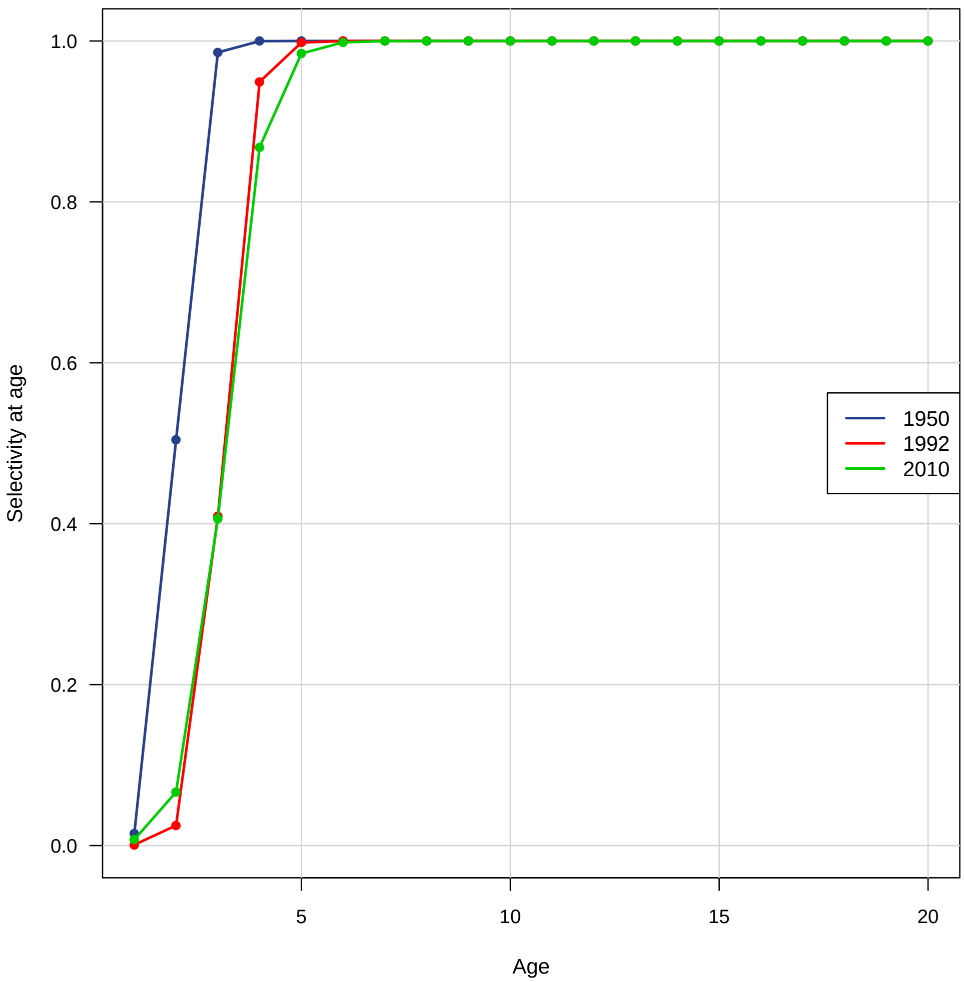


Figure 21. Selectivities of headboat landings. The legend indicates the first year each selectivity curve applies to the fleet.

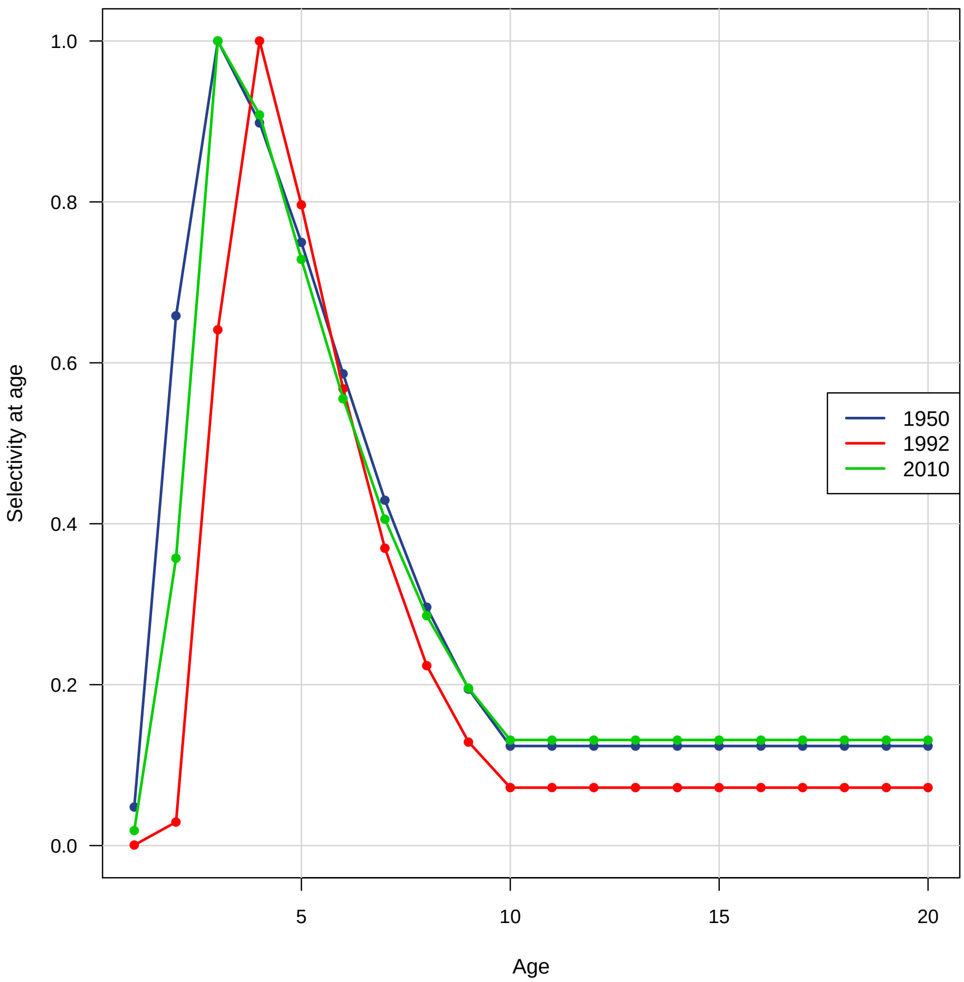


Figure 22. Selectivities of general recreational landings. The legend indicates the first year each selectivity curve applies to the fleet.

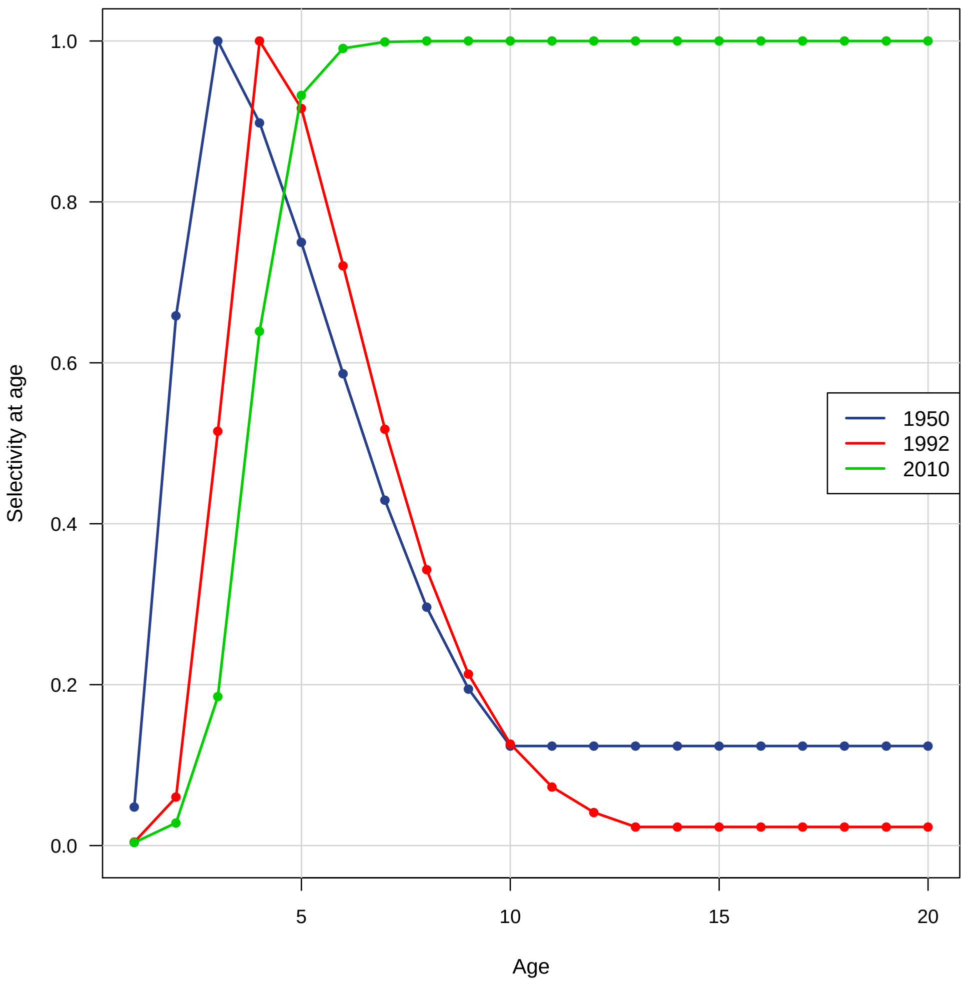


Figure 23. Selectivities of commercial handline discards. The legend indicates the first year each selectivity curve applies to the fleet.

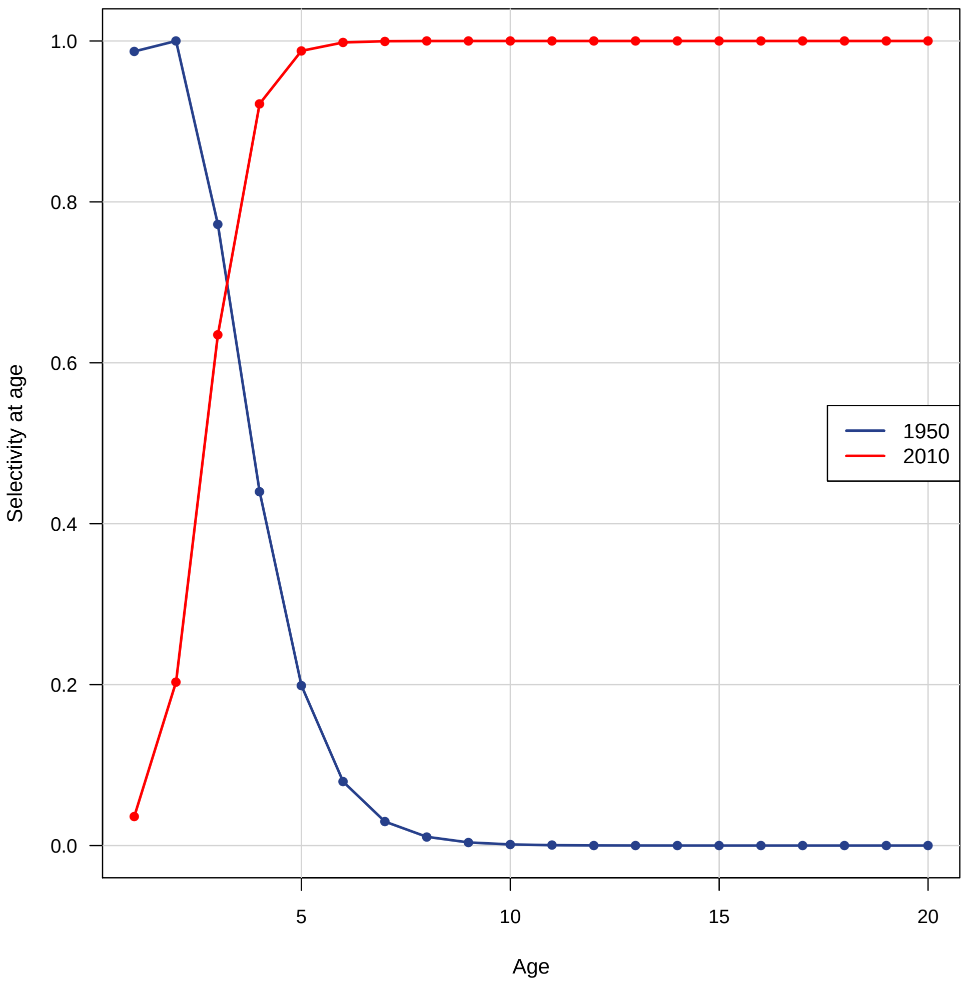


Figure 24. Selectivities of headboat discards. The legend indicates the first year each selectivity curve applies to the fleet.

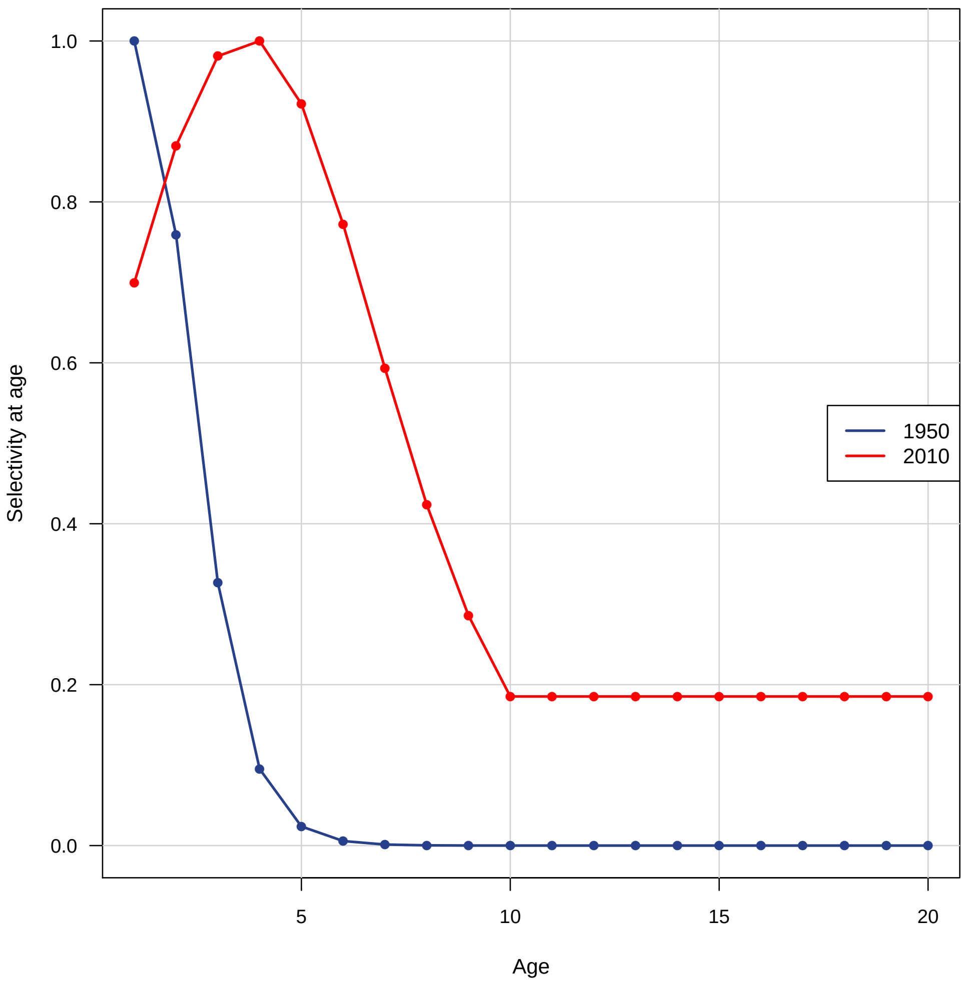


Figure 25. Selectivities of general recreational discards. The legend indicates the first year each selectivity curve applies to the fleet.

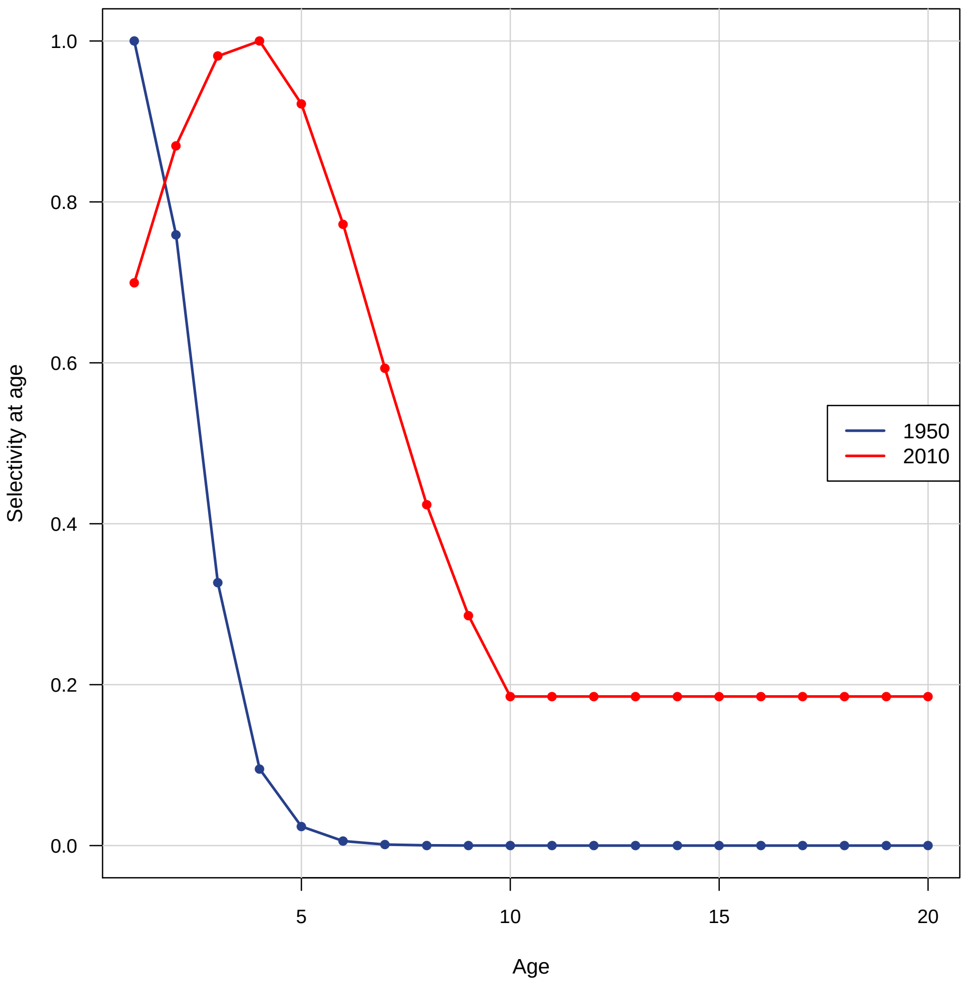


Figure 26. Average selectivity of discards(top left), landings (top right), and total weighted average (bottom) from the terminal assessment years, weighted by geometric mean F's from the last three assessment years, and used in computation of benchmarks and projections.

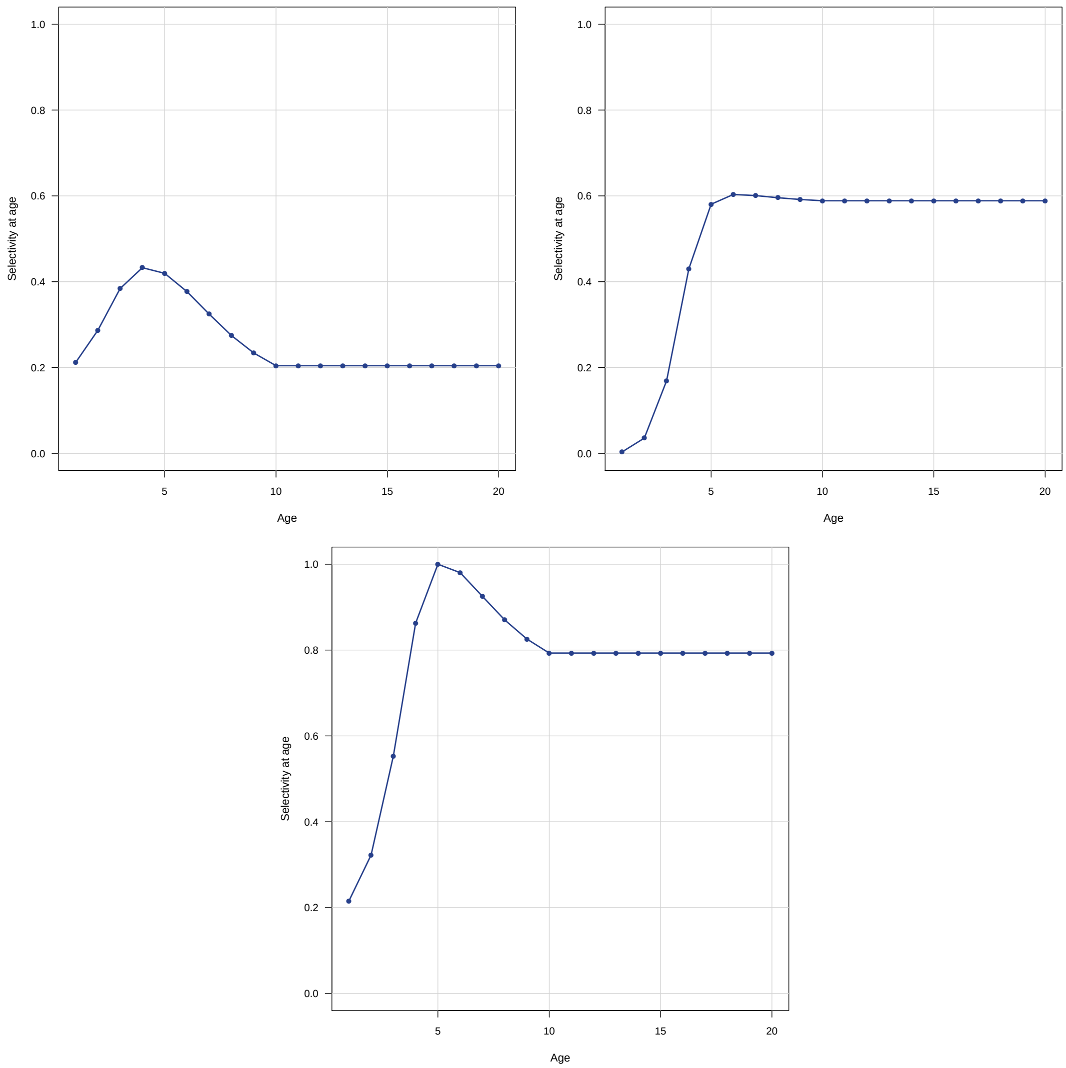


Figure 27. Estimated fully selected fishing mortality rate (per year) by fleet. cH refers to commercial handlines, HB to headboat, GR to general recreational, and D refers to discard mortality.

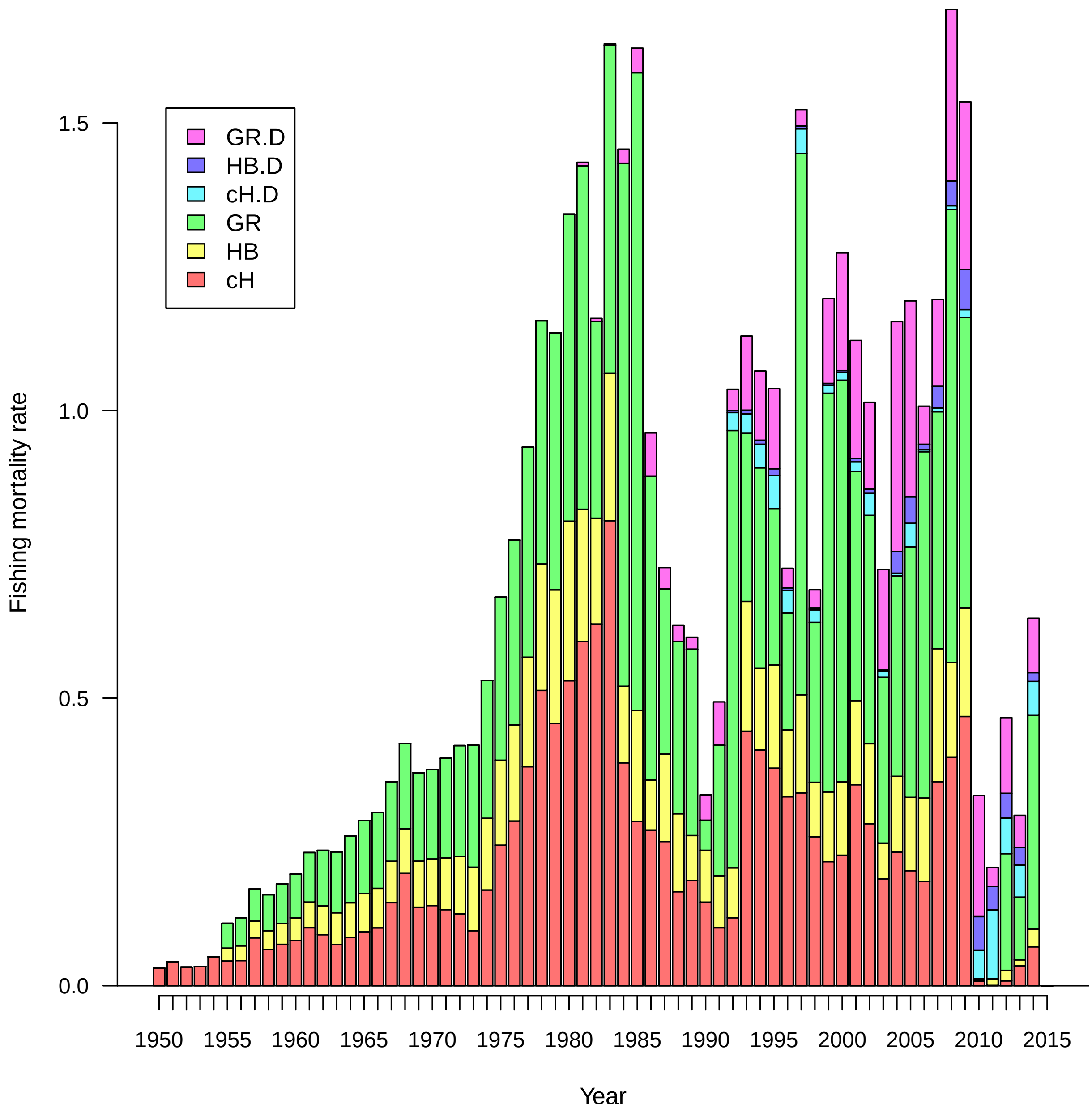


Figure 28. Estimated landings in numbers by fleet from the catch-age model. cH refers to commercial handlines, HB to headboat, and GR to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of $L_{\mathrm{F30\%}}$ *in numbers.*

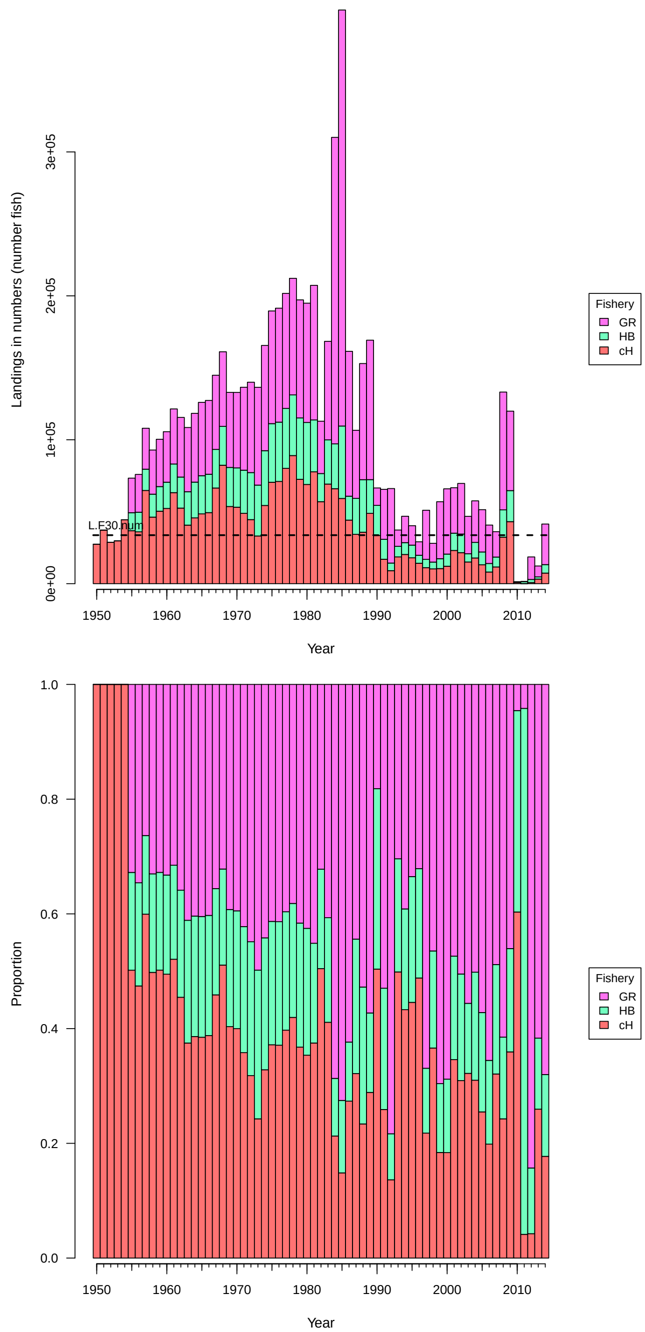


Figure 29. Estimated landings in whole weight by fleet from the catch-age model. cH refers to commercial handlines, HB to headboat, and GR to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of $L_{F30\%}$ in weight.

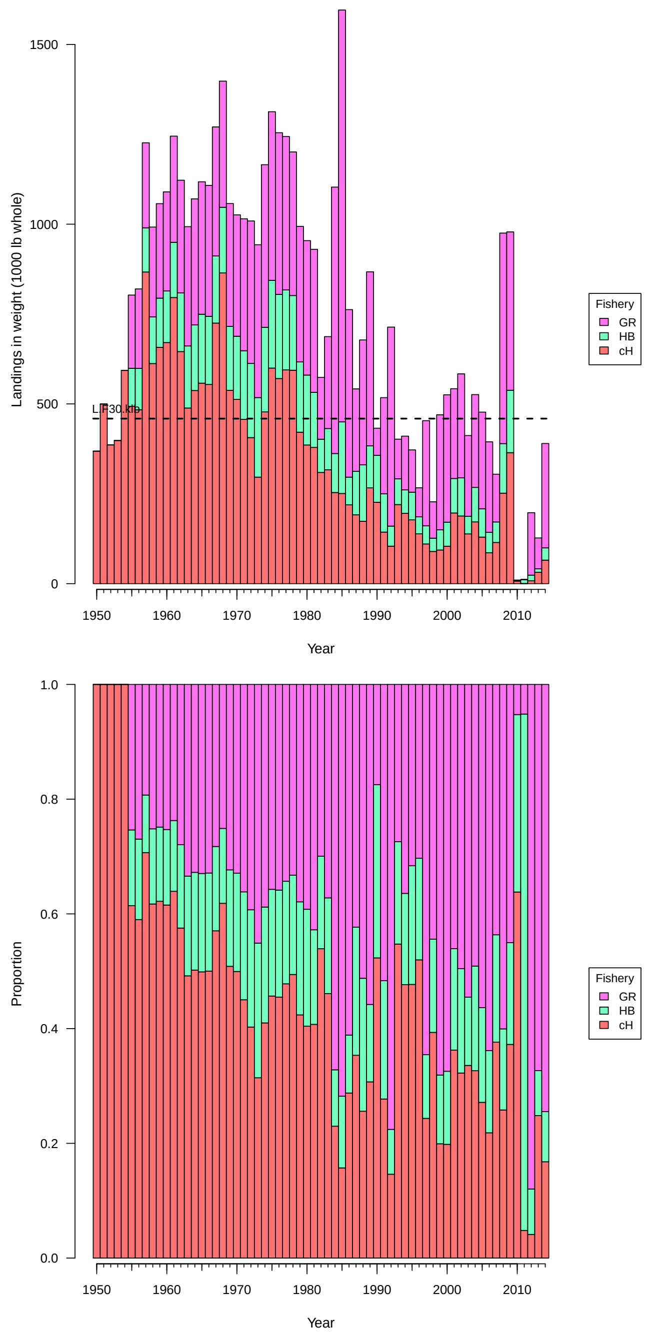


Figure 30. Estimated discard mortalities by fleet from the catch-age model. cH refers to commercial lines, hb to headboat, rec to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of $D_{F_{30\%}}$ in numbers.

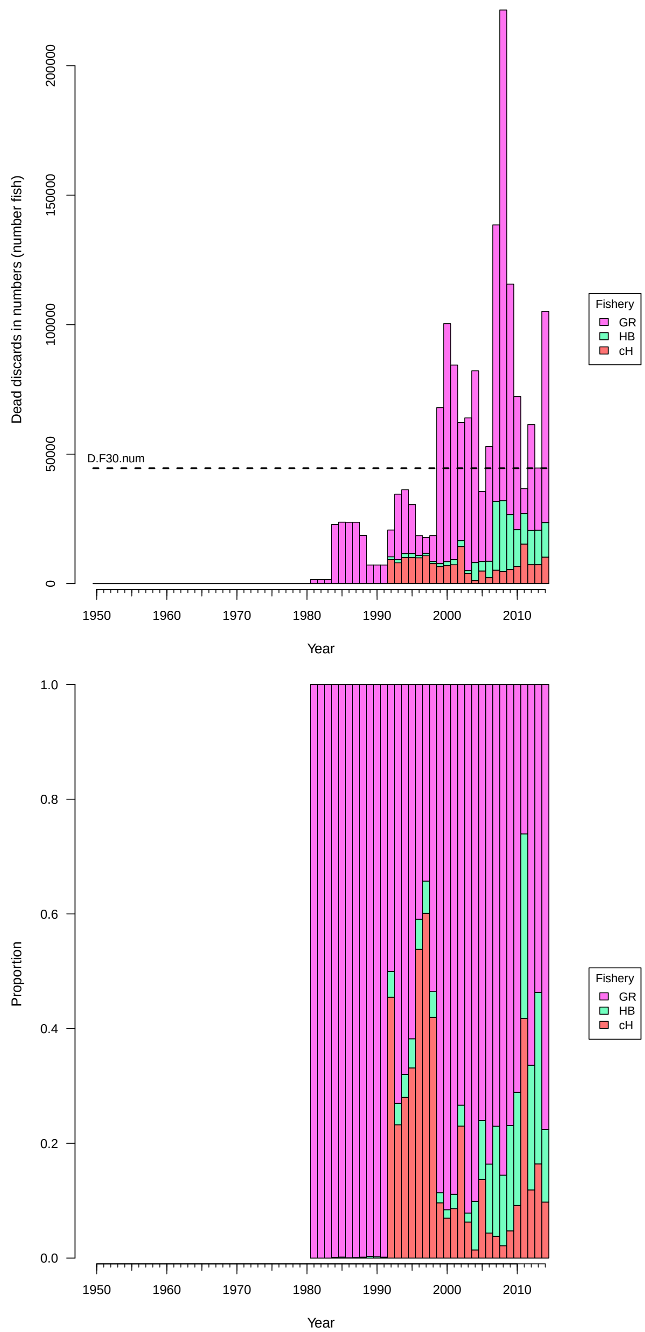
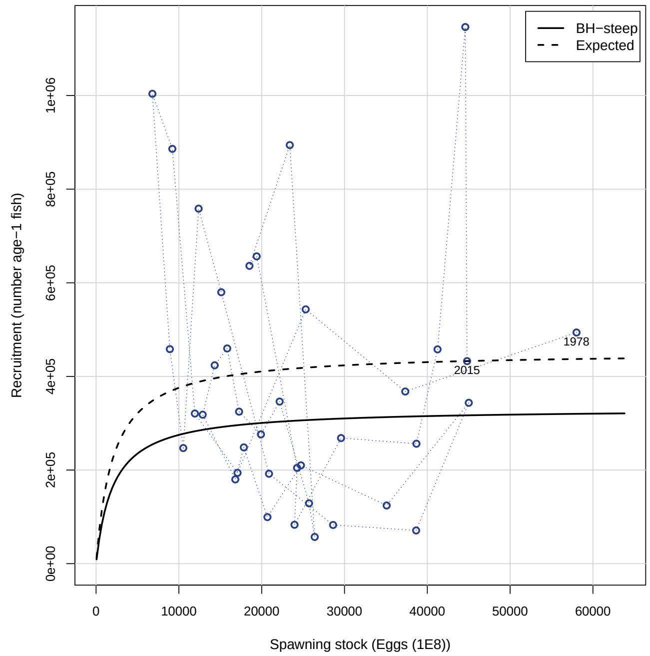


Figure 31. Top panel: Beverton–Holt spawner-recruit curves, with and without lognormal bias correction. The expected (upper) curve was used for computing management benchmarks. Bottom panel: log of recruits (number age-1 fish) per spawner as a function of spawners.



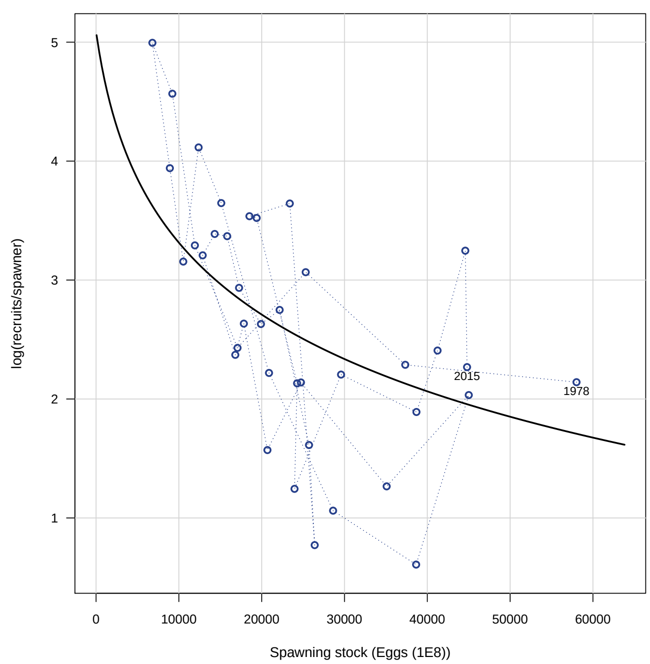


Figure 32. Probability densities of spawner-recruit quantities R0 (unfished recruitment of age-1 fish), steepness (fixed at 0.99), unfished spawners per recruit, and standard deviation of recruitment residuals in log space. Solid vertical lines represent point estimates or values from the base run of the Beaufort Assessment Model; dashed vertical lines represent medians from the MCB runs.

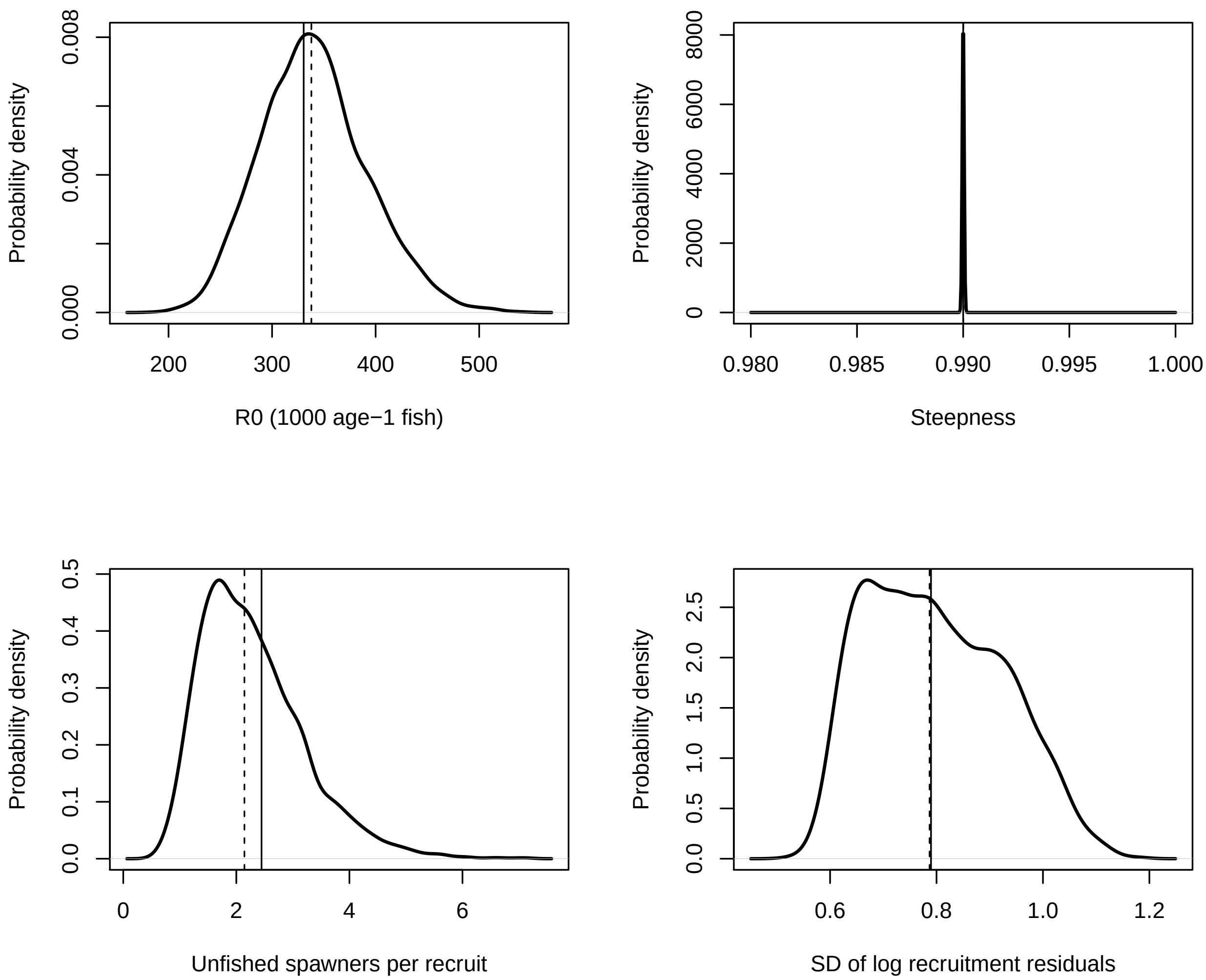


Figure 33. Yield per recruit based on average selectivity from the end of the assessment period.

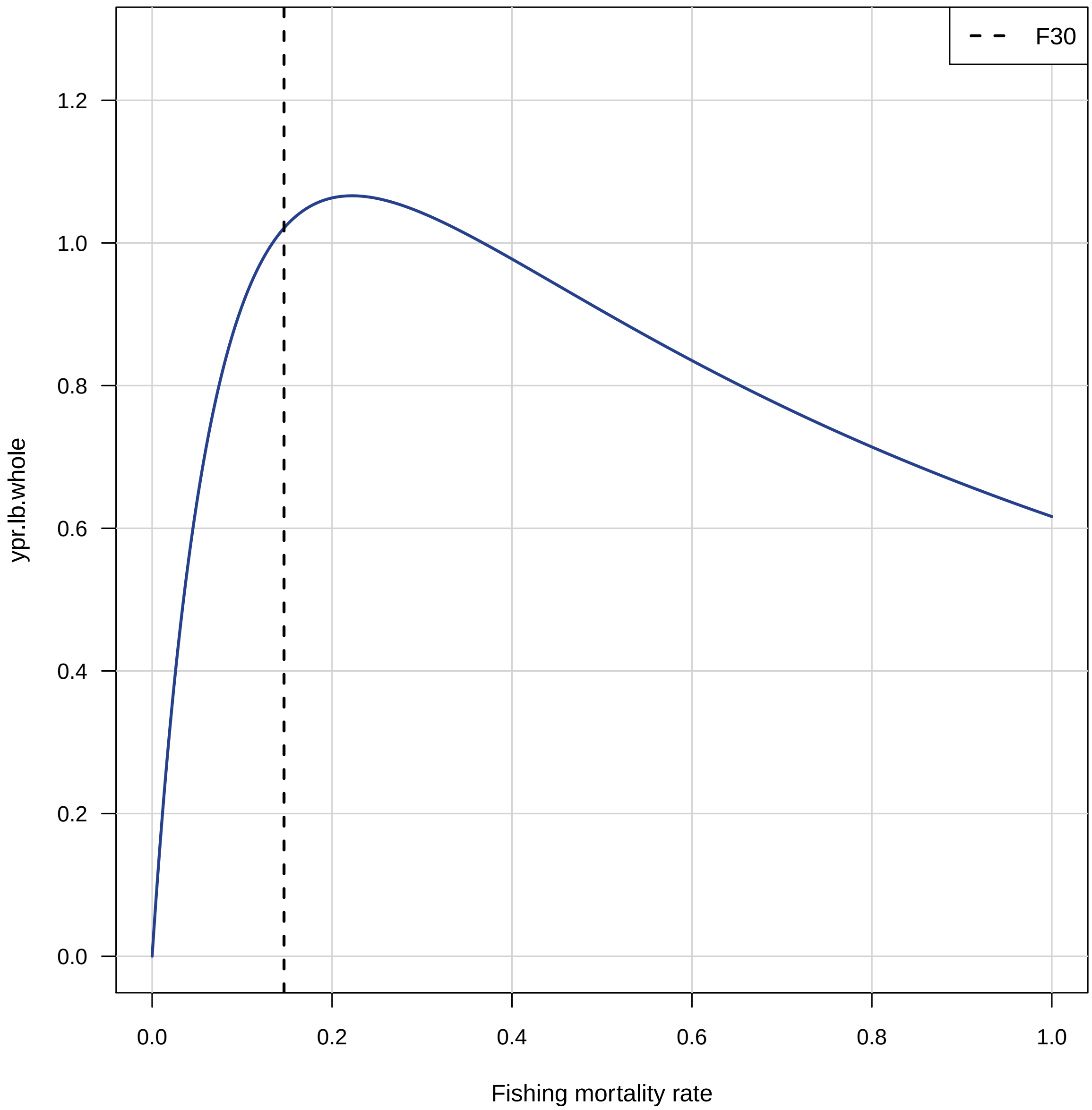


Figure 34. Spawning potential ratio (spawning biomass per recruit relative to that at the unfished level), from which the X% level of SPR provides $F_{X\%}$. SPR is based on average selectivity from the end of the assessment period.

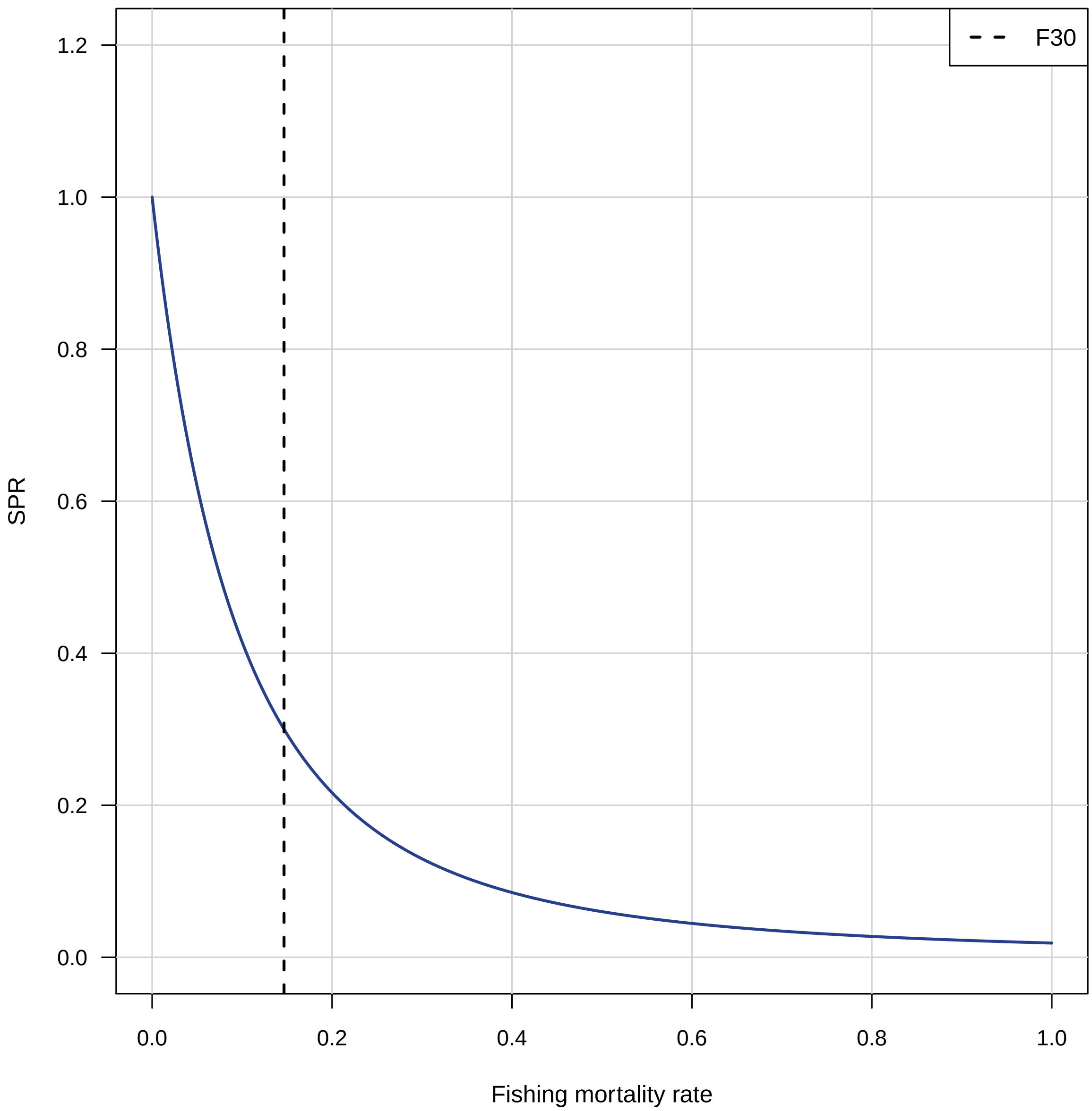


Figure 35. Equilibrium spawning biomass based on average selectivity from the end of the assessment period.

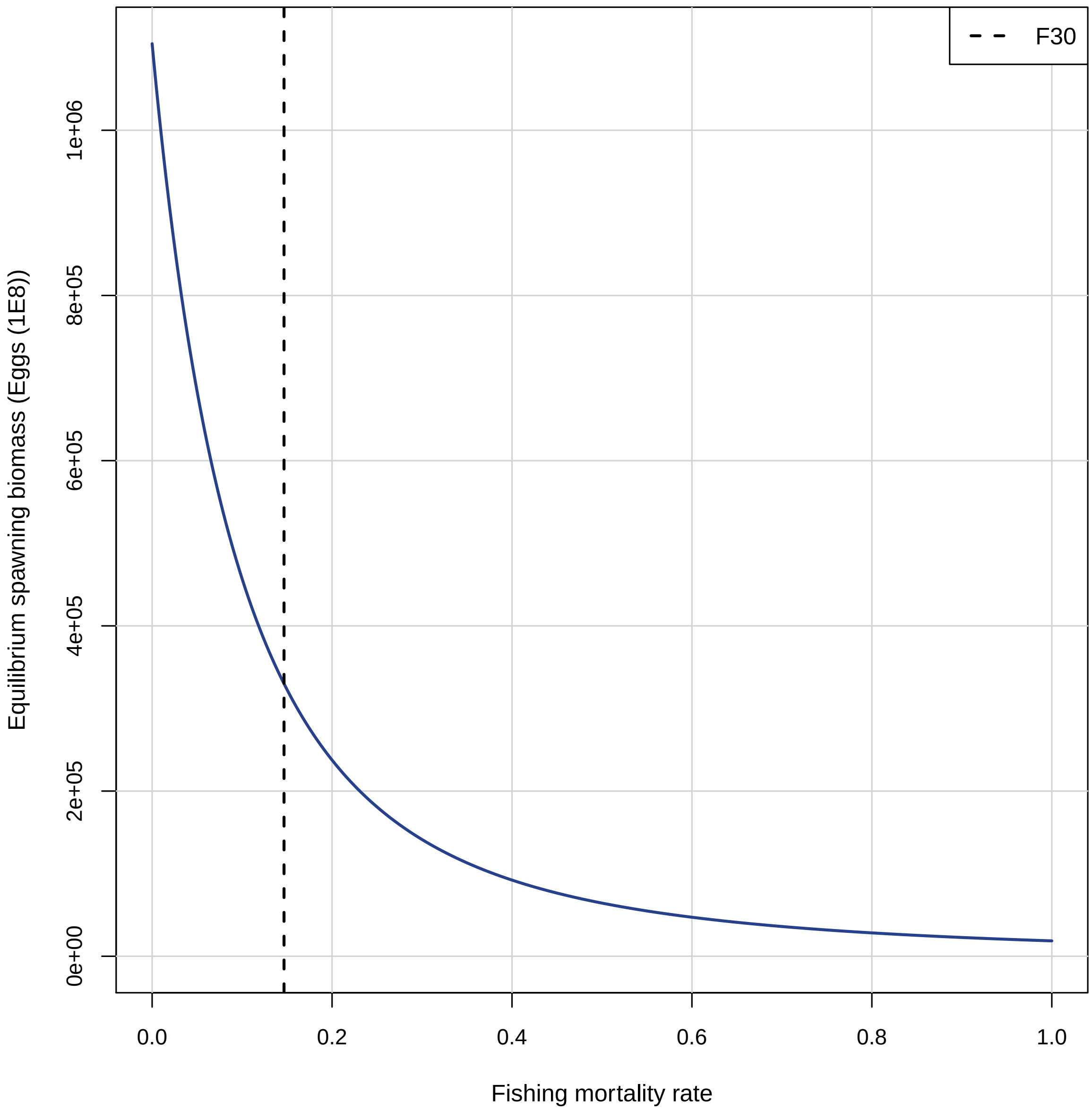


Figure 36. Probability densities of $F_{30\%}$-related benchmarks from MCB analysis of the Beaufort Assessment Model. Solid vertical lines represent point estimates from the base run; dashed vertical lines represent median values.

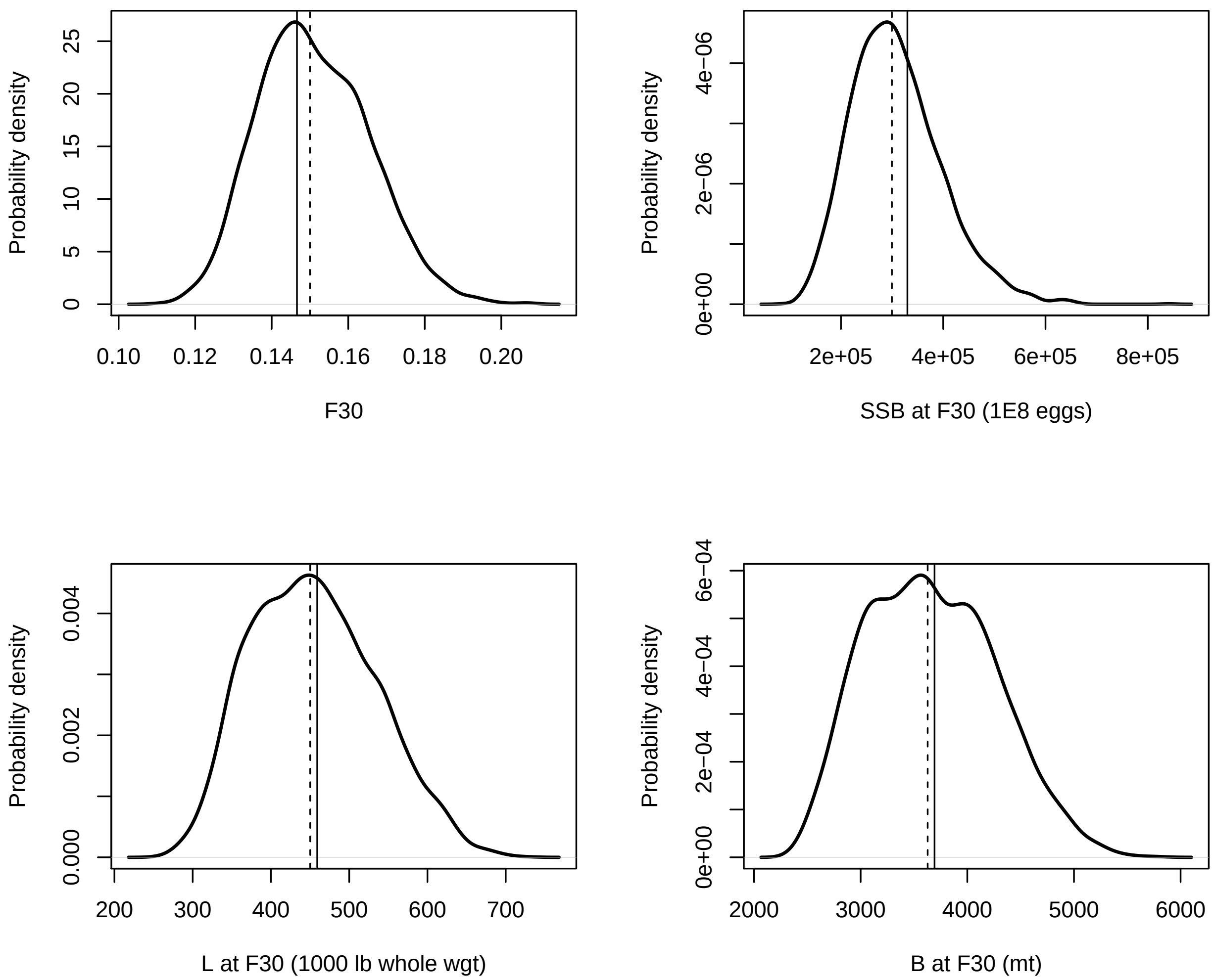
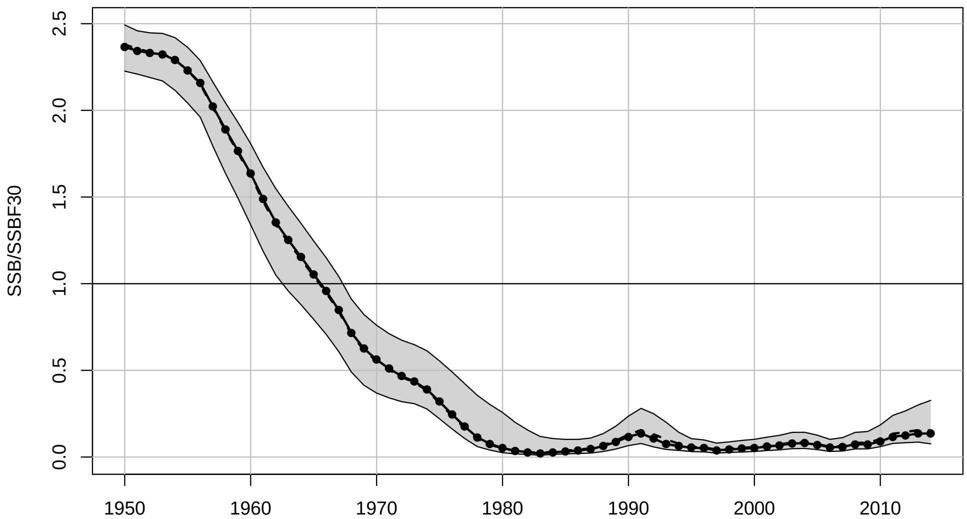


Figure 37. Estimated time series relative to benchmarks. Solid line indicates estimates from base run of the Beaufort Assessment Model; dashed lines represent median values; gray error bands indicate 5^{th} *and* 95^{th} *percentiles of the MCB trials. Top panel: spawning biomass relative to* $\mathrm{SSB}_{\mathrm{F30\%}}$*. Bottom panel: F relative to* $F_{30\%}$*.*



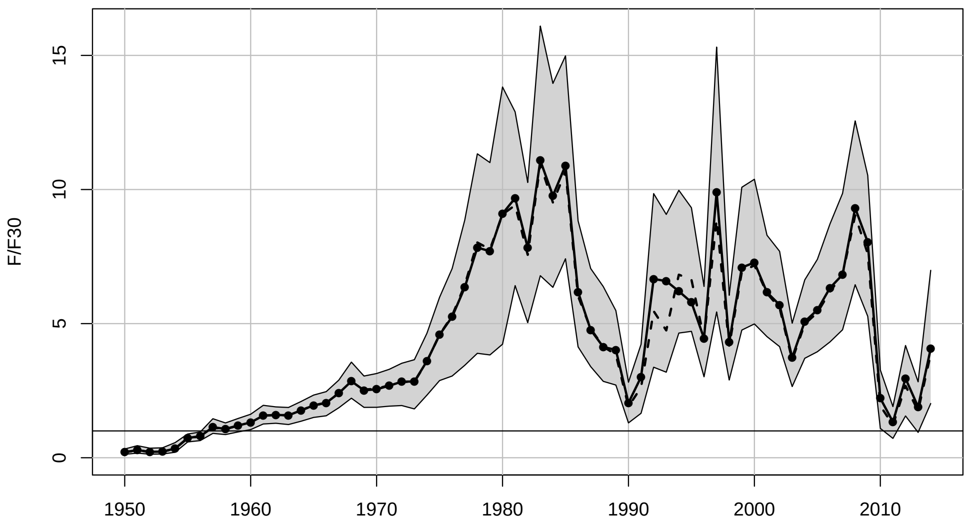


Figure 38. Probability densities of terminal status estimates from MCB analysis of the Beaufort Assessment Model. Solid vertical lines represent point estimates from the base run; dashed vertical lines represent median values.

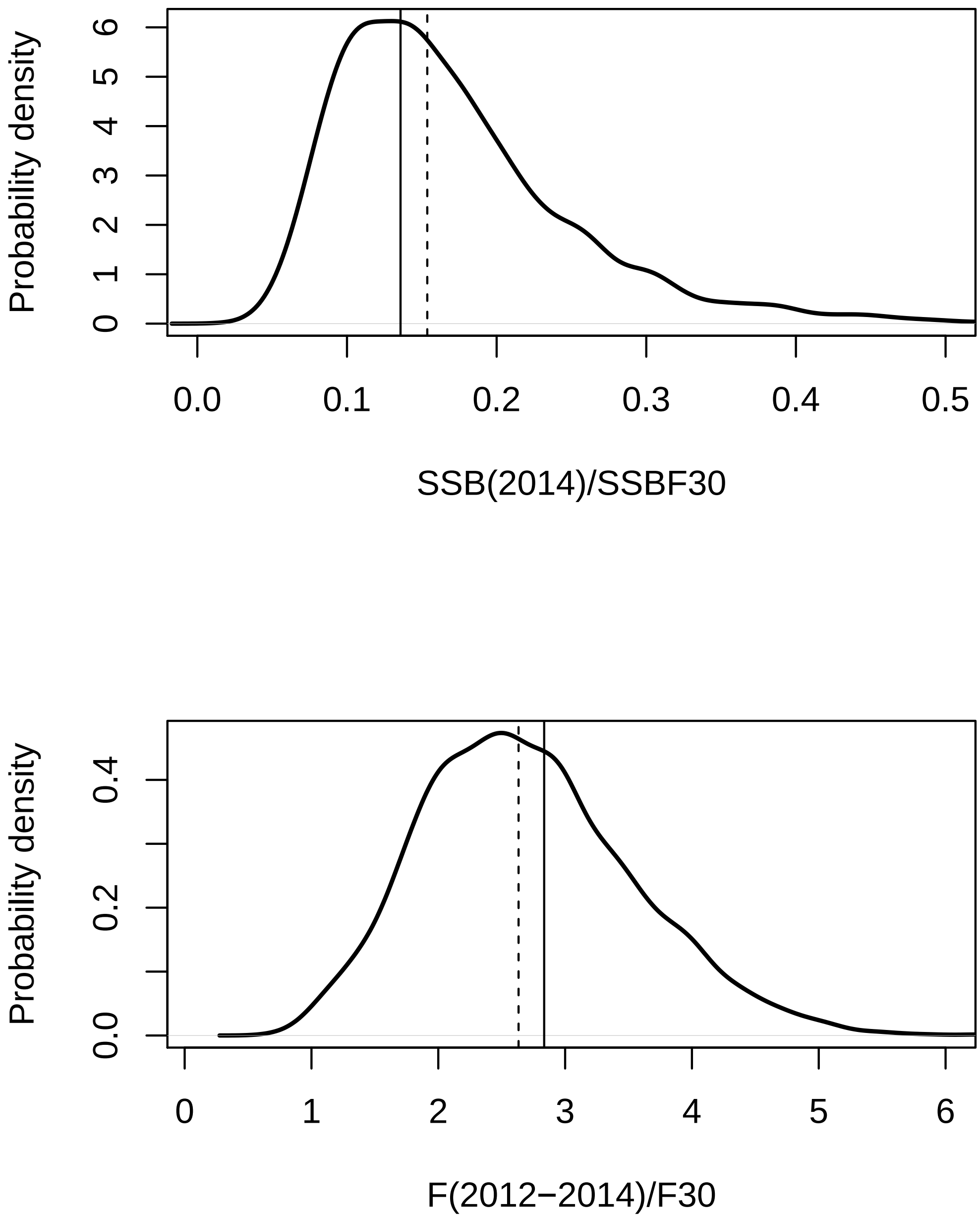


Figure 39. Phase plots of terminal status estimates from MCB analysis of the Beaufort Assessment Model. The intersection of crosshairs indicates estimates from the base run; lengths of crosshairs defined by 5^{th} and 95^{th} percentiles. Proportion of runs falling in each quadrant indicated.

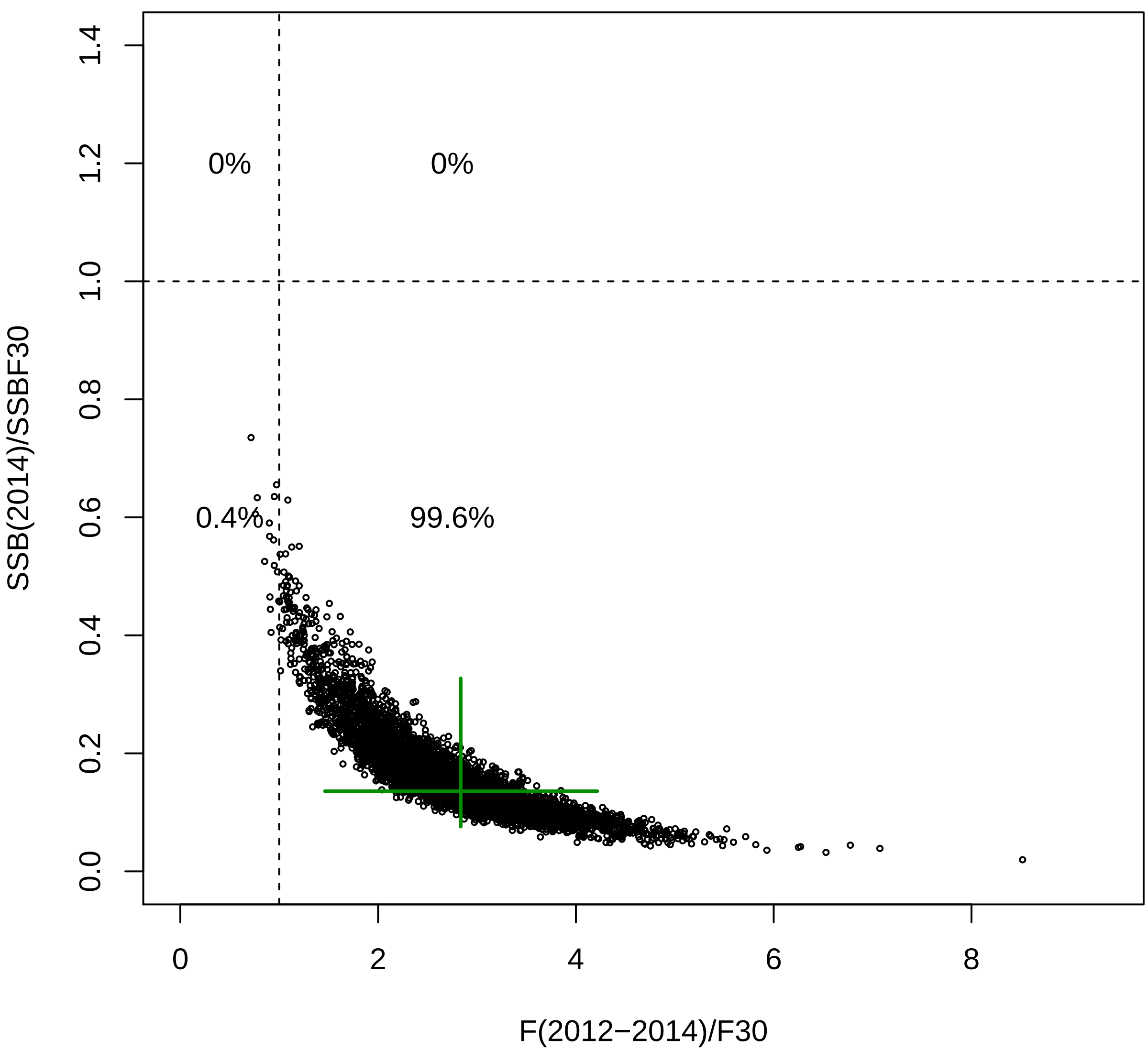


Figure 40. Sensitivity to changes in natural mortality (sensitivity runs S5 and S6). Top panel: Ratio of F to $F_{30\%}$. *Bottom panel: Ratio of* SSB *to* $SSB_{F30\%}$.

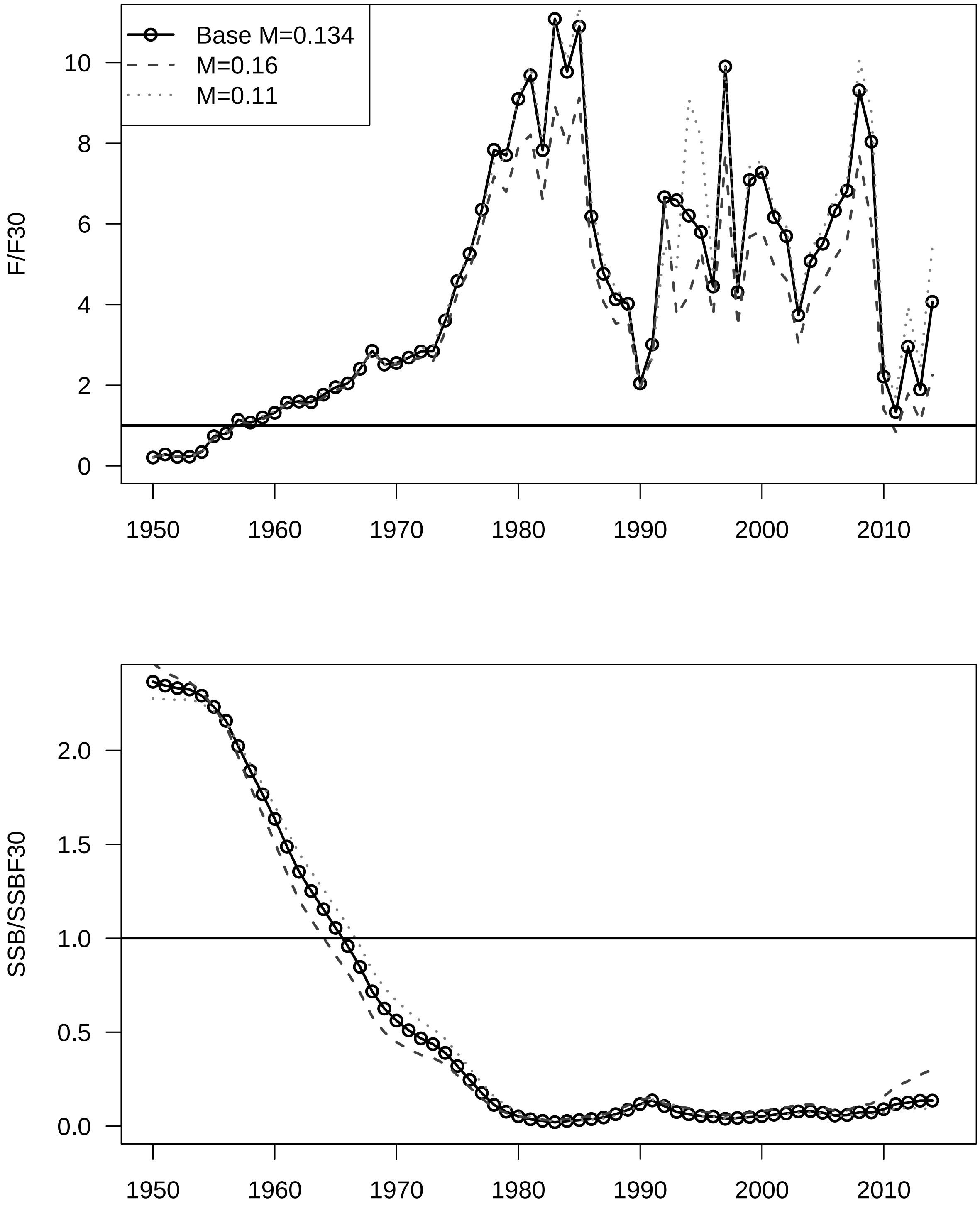


Figure 41. Sensitivity to steepness (sensitivity run S11). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

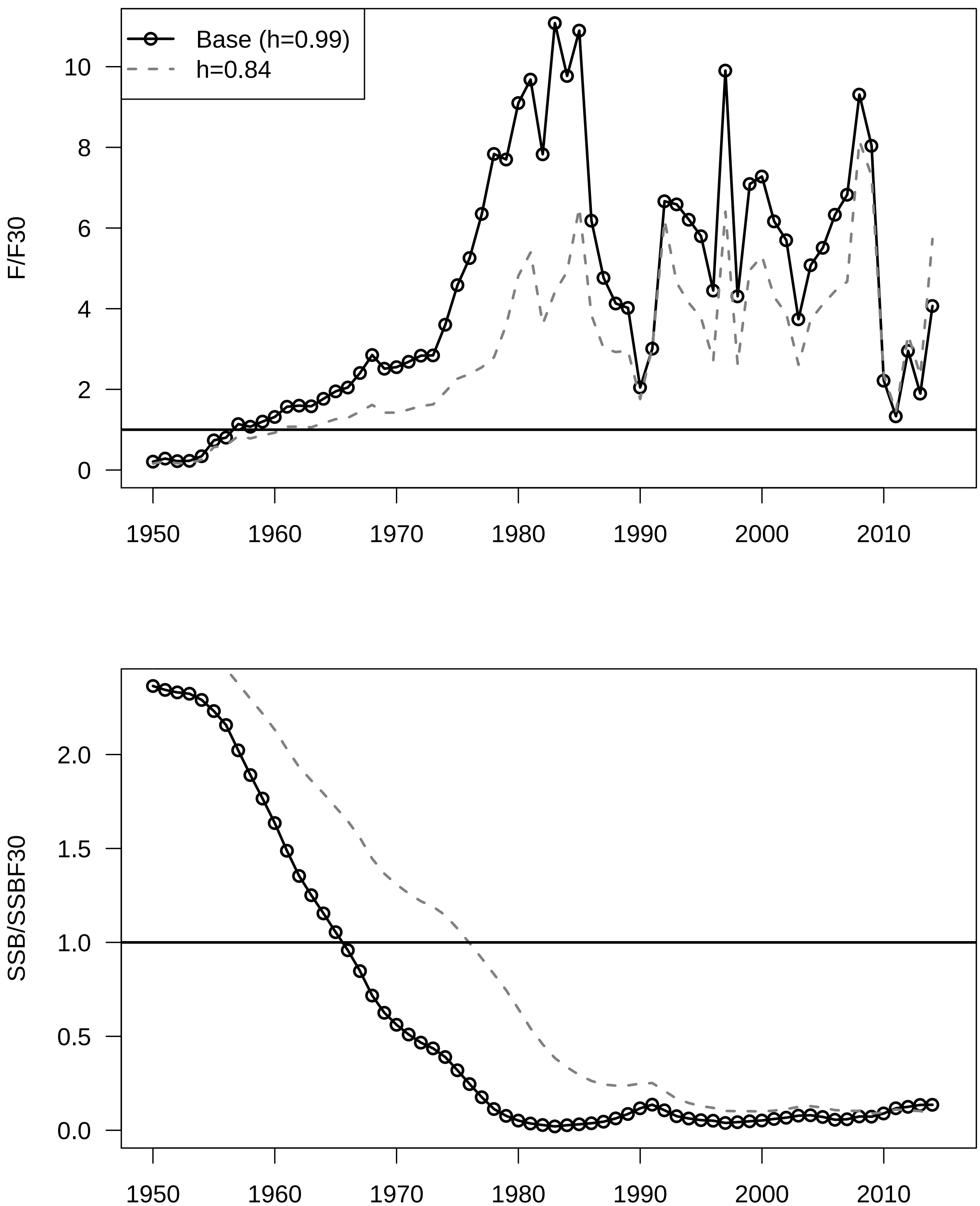


Figure 42. Sensitivity to start year (1978 compared to 1950) (sensitivity run S26). Top panel: Ratio of F to $F_{30\%}$. *Bottom panel: Ratio of* SSB *to* $SSB_{F30\%}$.

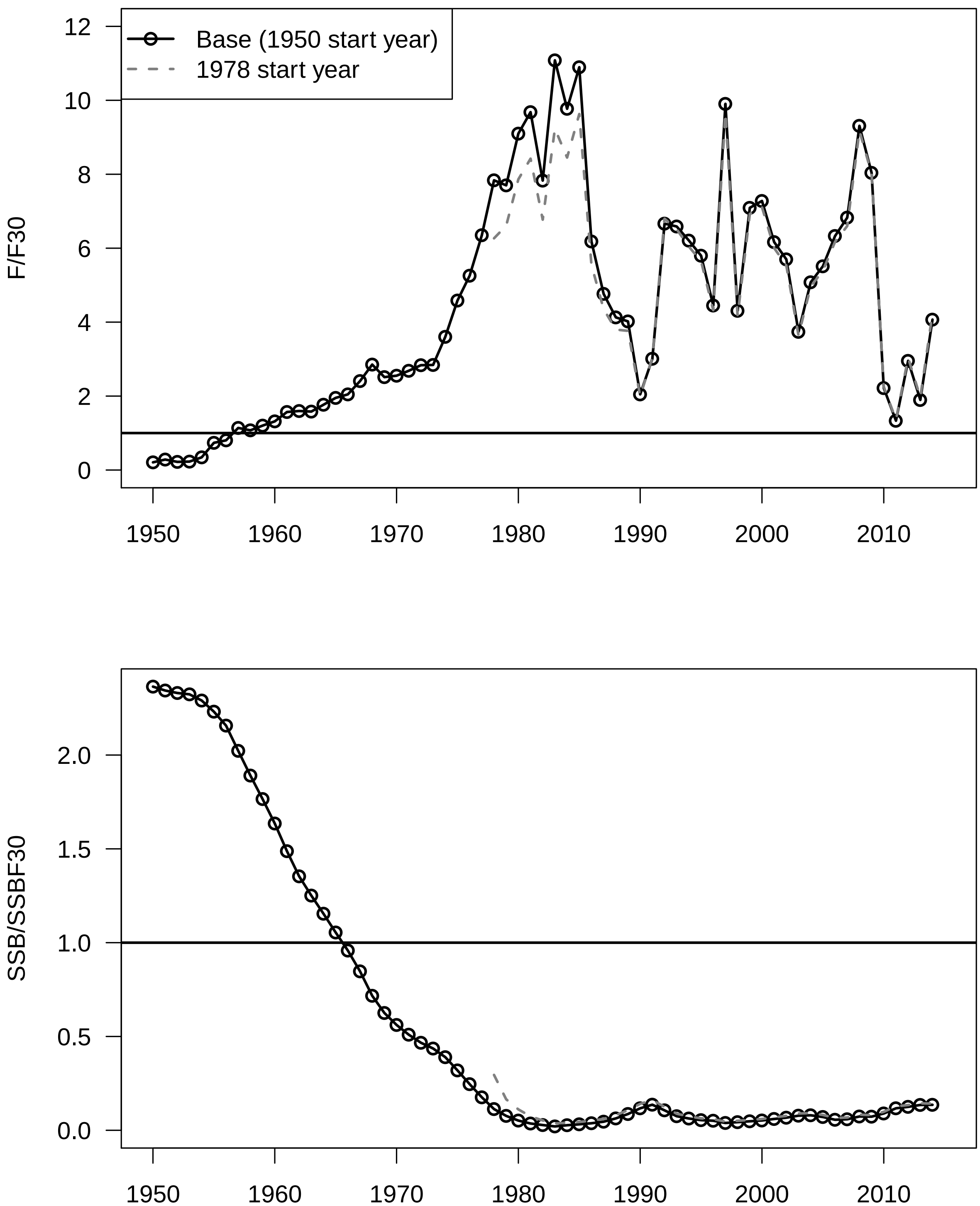


Figure 43. Sensitivity to aging error matrix (sensitivity run S13). Top panel: Ratio of F to $F_{30\%}$*. Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{F30\%}$.

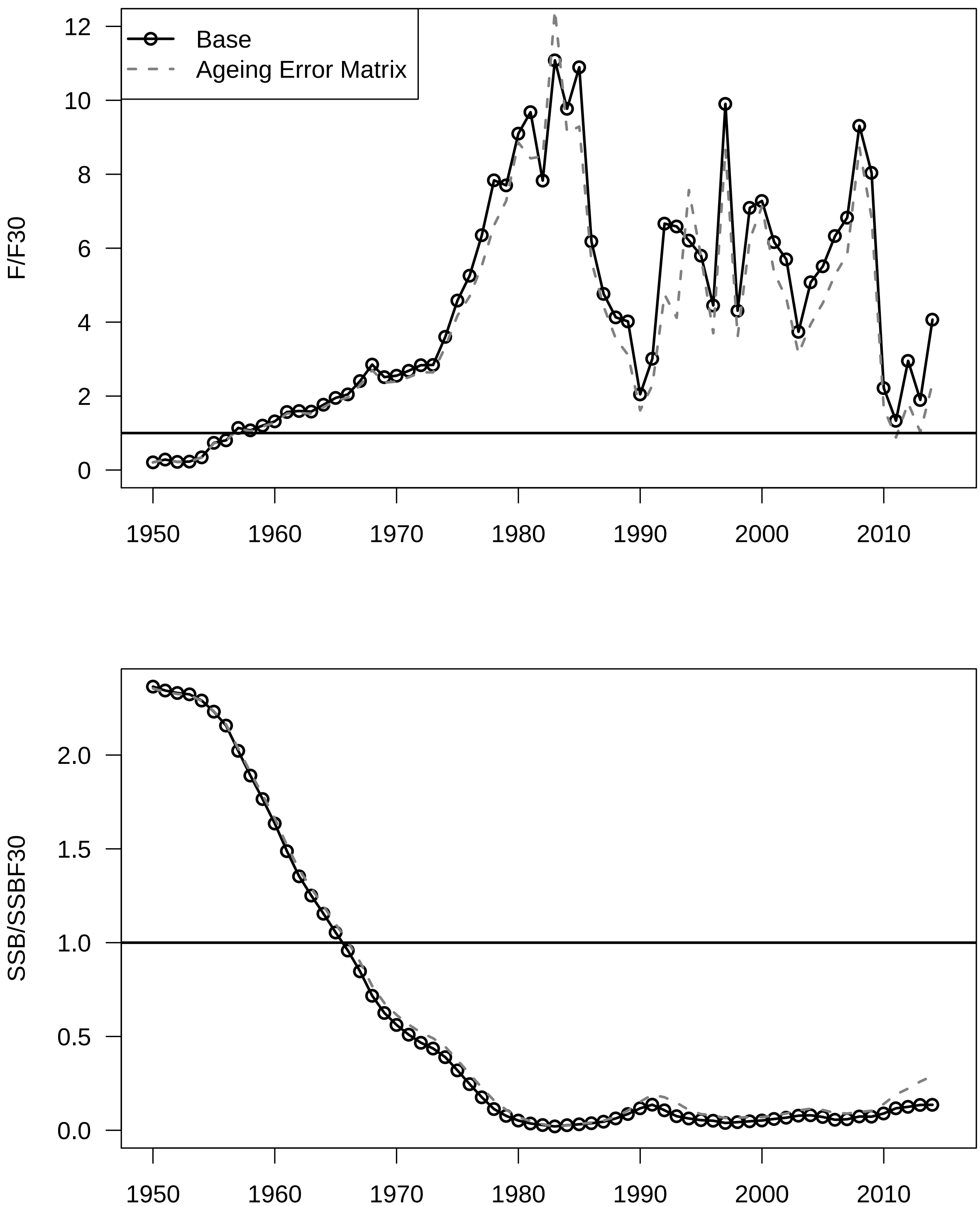


Figure 44. Sensitivity to batch number (sensitivity runs S14 and S15). Top panel: Ratio of F to $F_{30\%}$. *Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

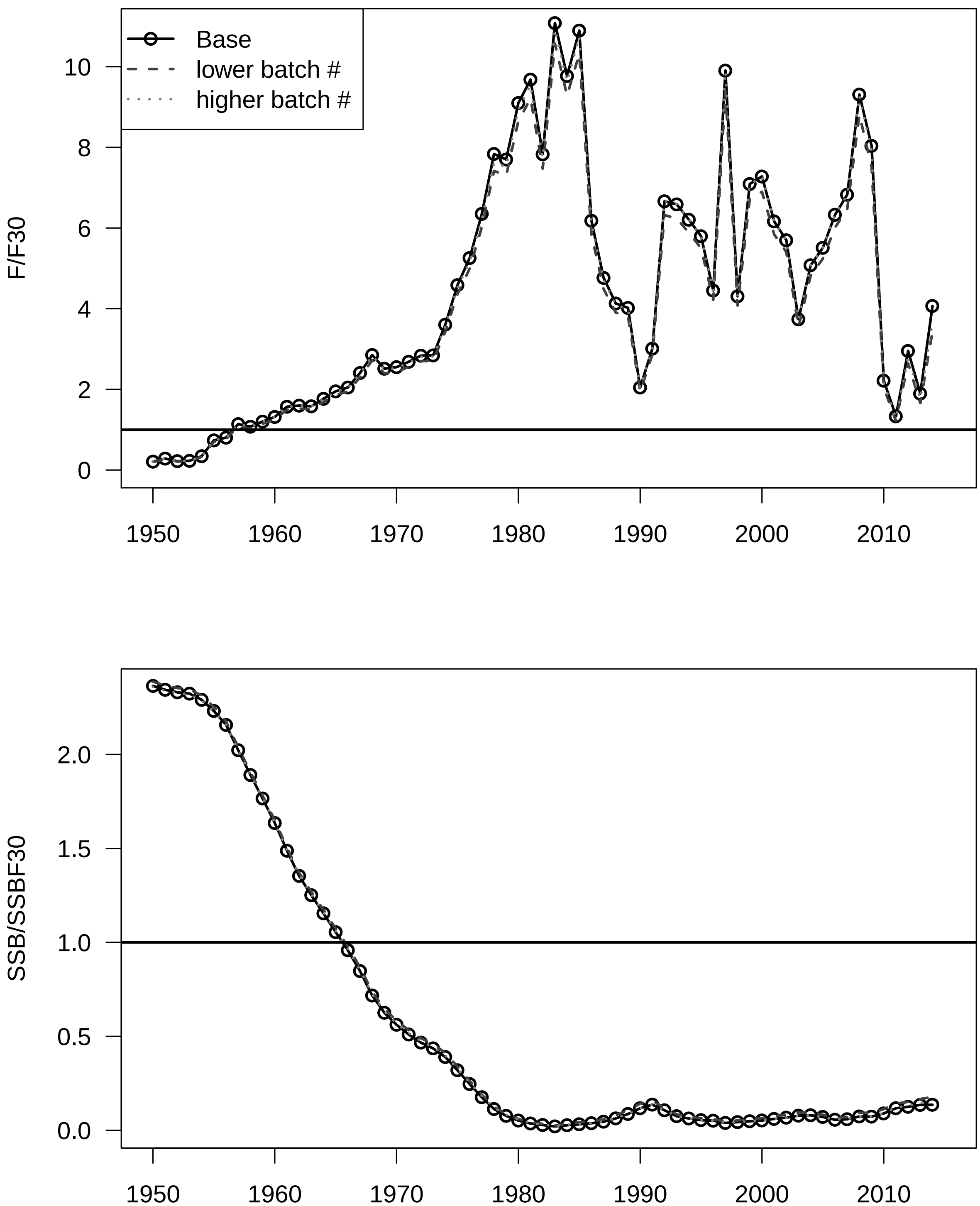


Figure 45. Sensitivity to various changes to SERFS video and trap indices (sensitivity runs S2, S9, S22 and S23). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\text{SSB}_{\text{F30\%}}$.

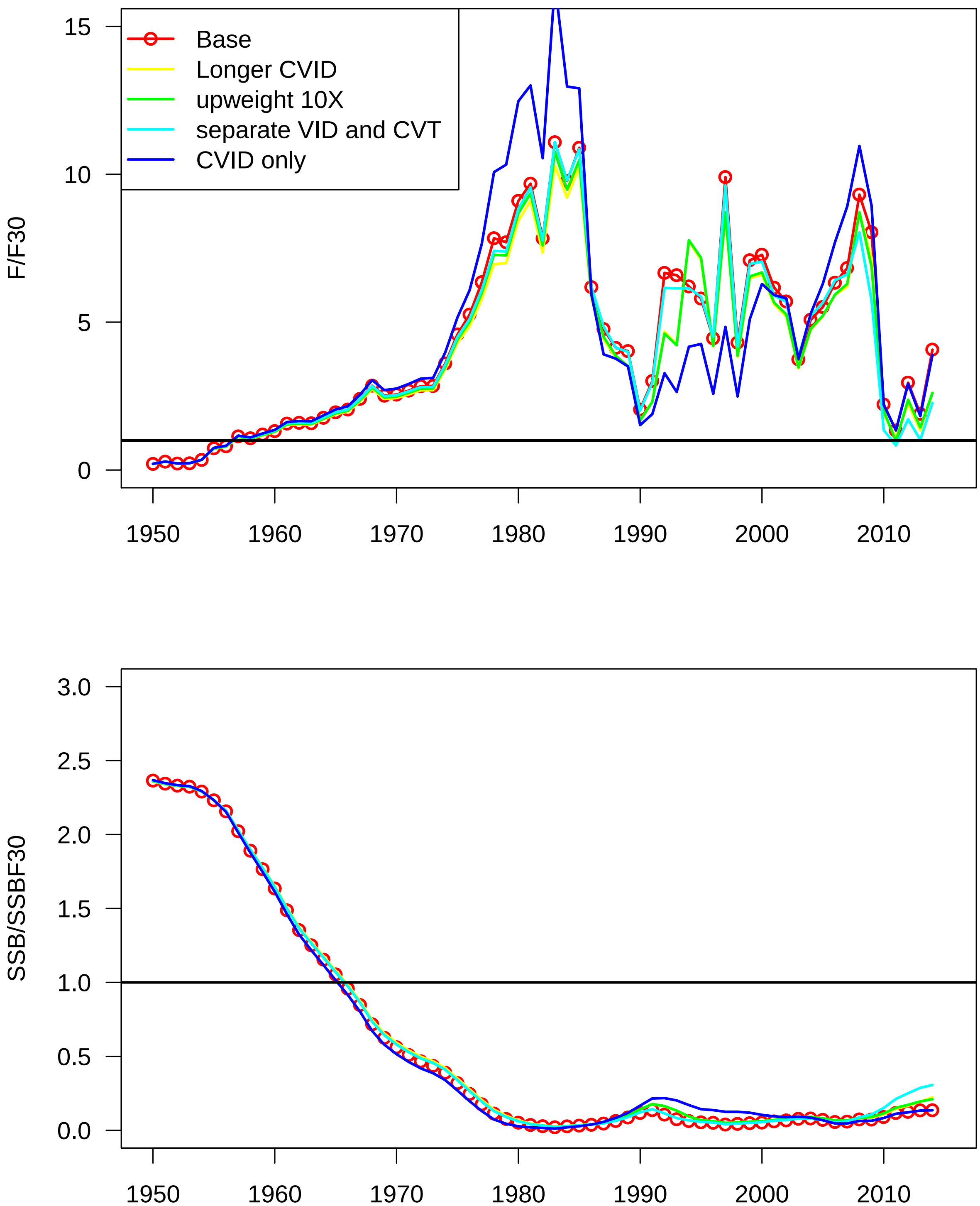


Figure 46. Sensitivity to discard mortality (sensitivity run S7 and S8). Top panel: Ratio of F to $F_{30\%}$. *Bottom panel: Ratio of* SSB *to* $SSB_{F30\%}$.

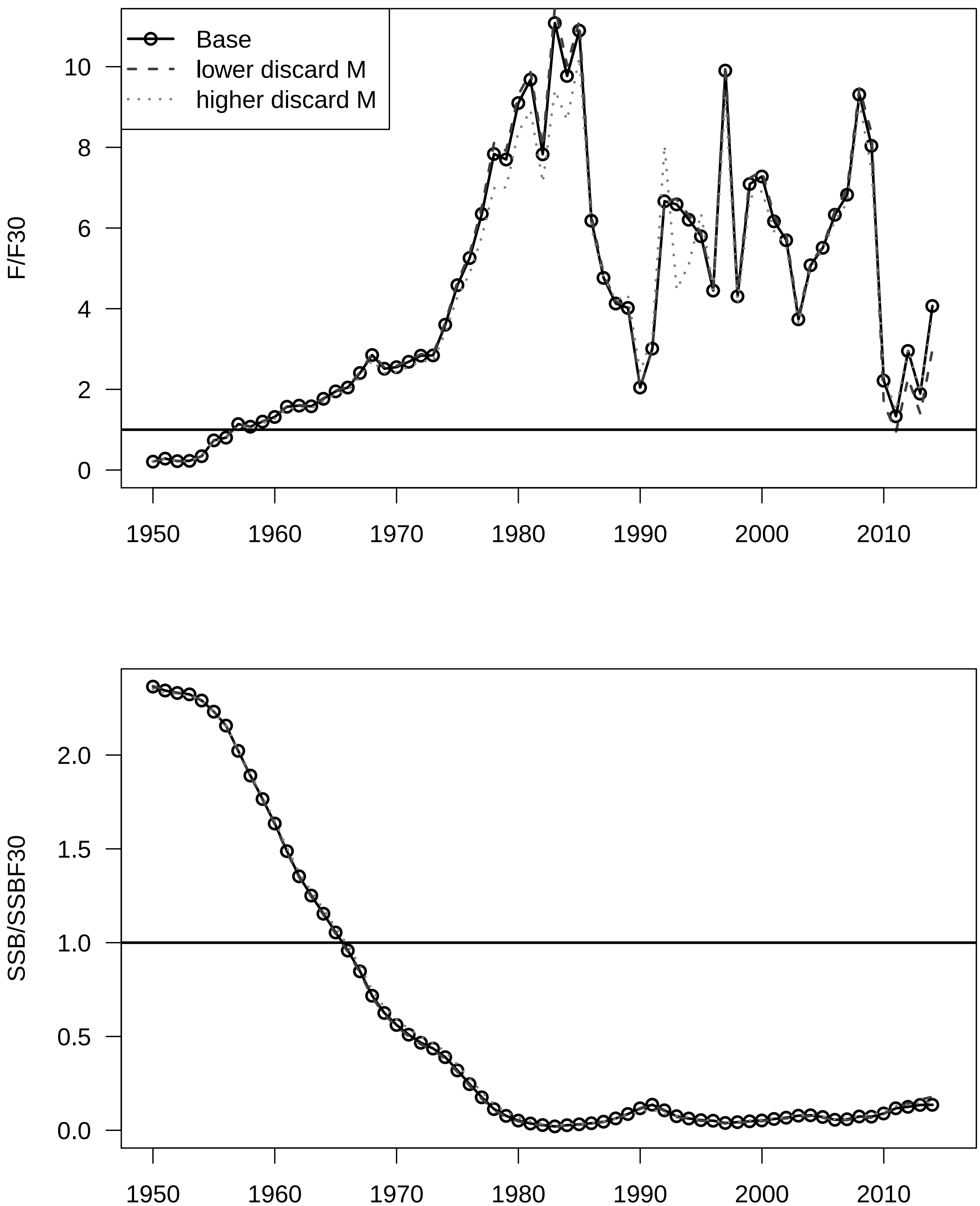
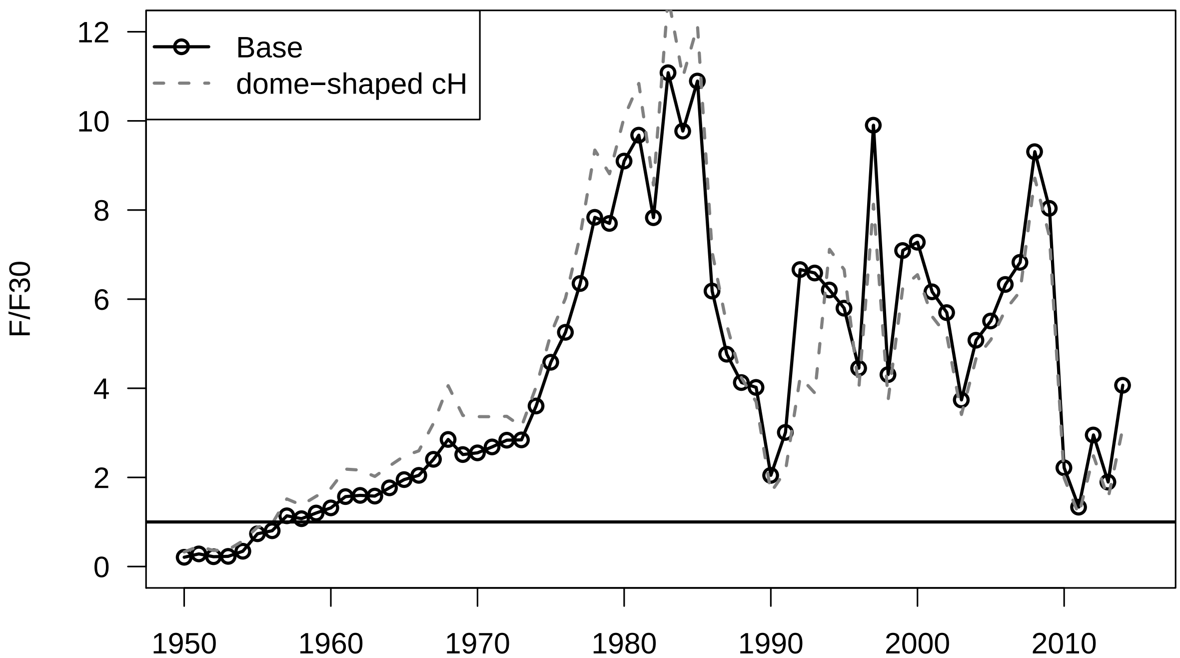


Figure 47. Sensitivity to dome-shaped selectivity for commercial handline (sensitivity run S21). Top panel: Ratio of F *to* $F_{30\%}$*. Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$*.*



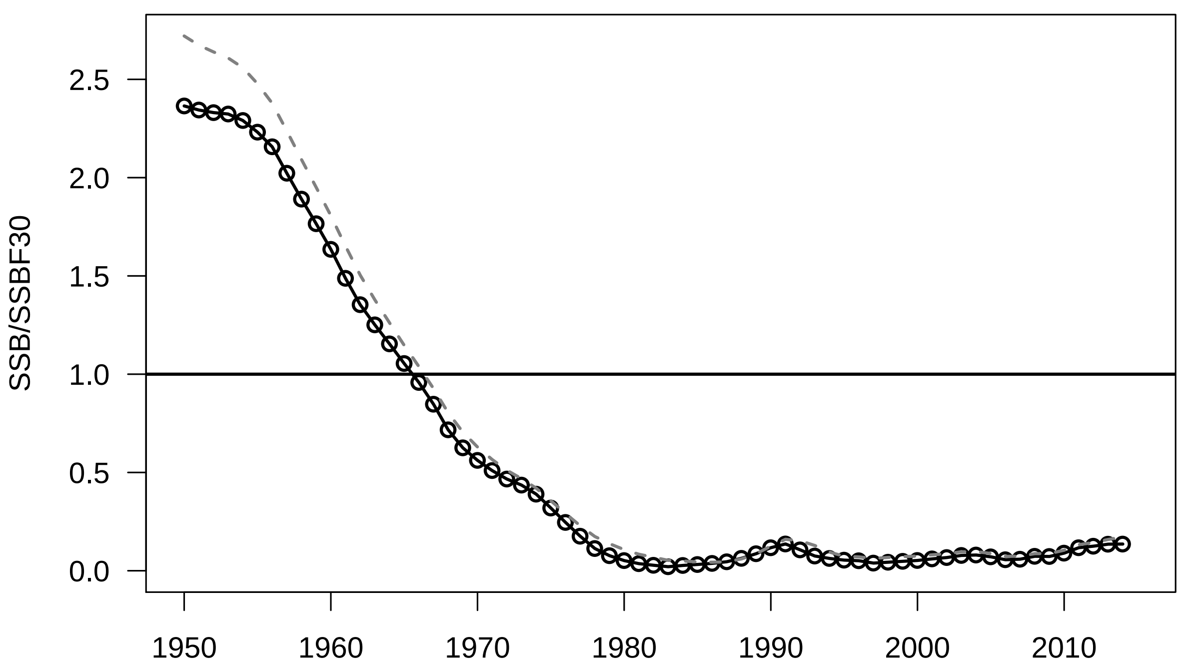


Figure 48. Sensitivity to various changes to fishery dependent indices (sensitivity runs S1, S3, S4, and S25). Top panel: Ratio of F *to* $F_{30\%}$*. Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

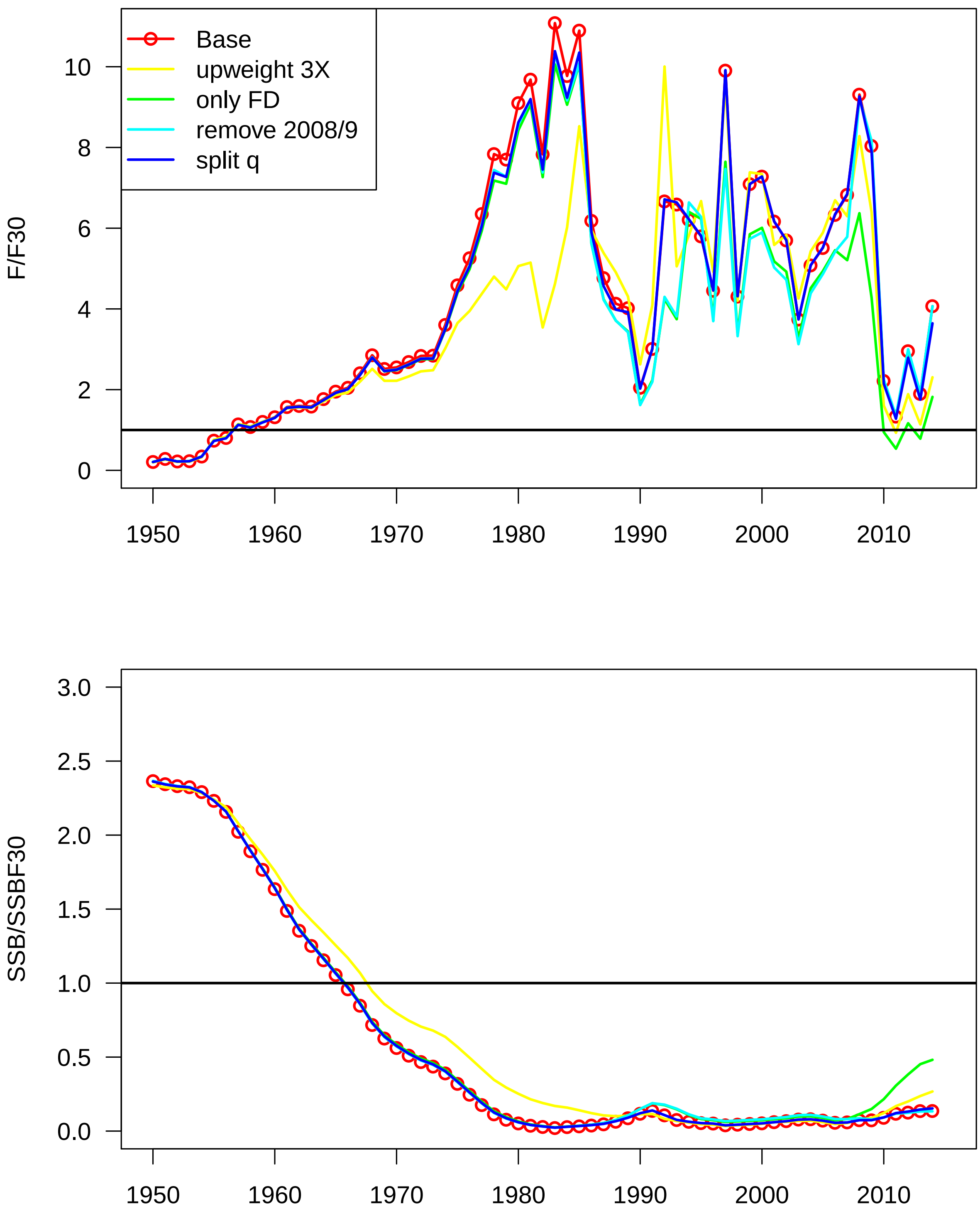


Figure 49. Sensitivity to not fixing selectivities (sensitivity run S27). Top panel: Ratio of F to $F_{30\%}$. *Bottom panel: Ratio of* SSB *to* $SSB_{F30\%}$.

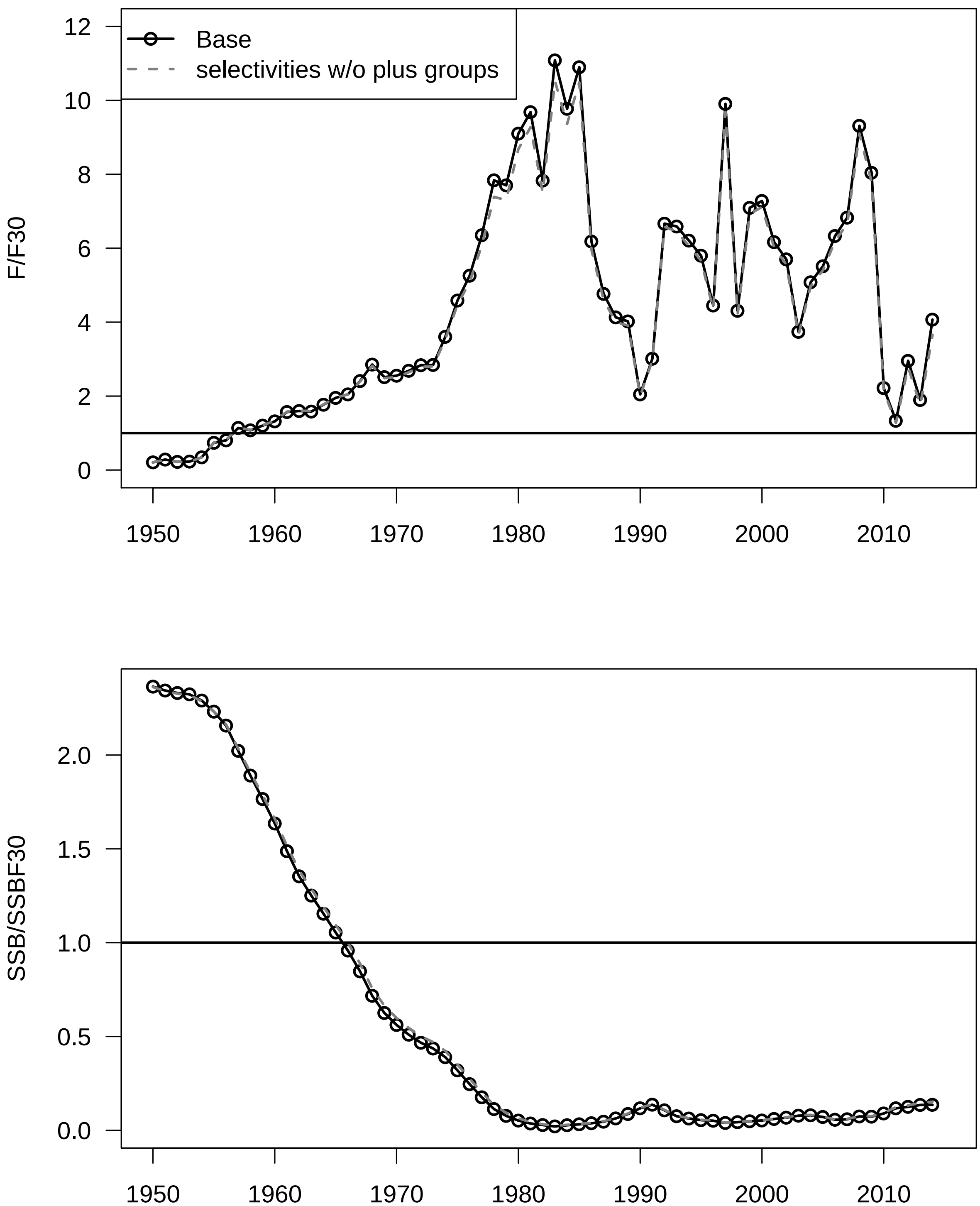


Figure 50. Sensitivity to dropping or truncating headboat discard index (sensitivity runs S12 and S16). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

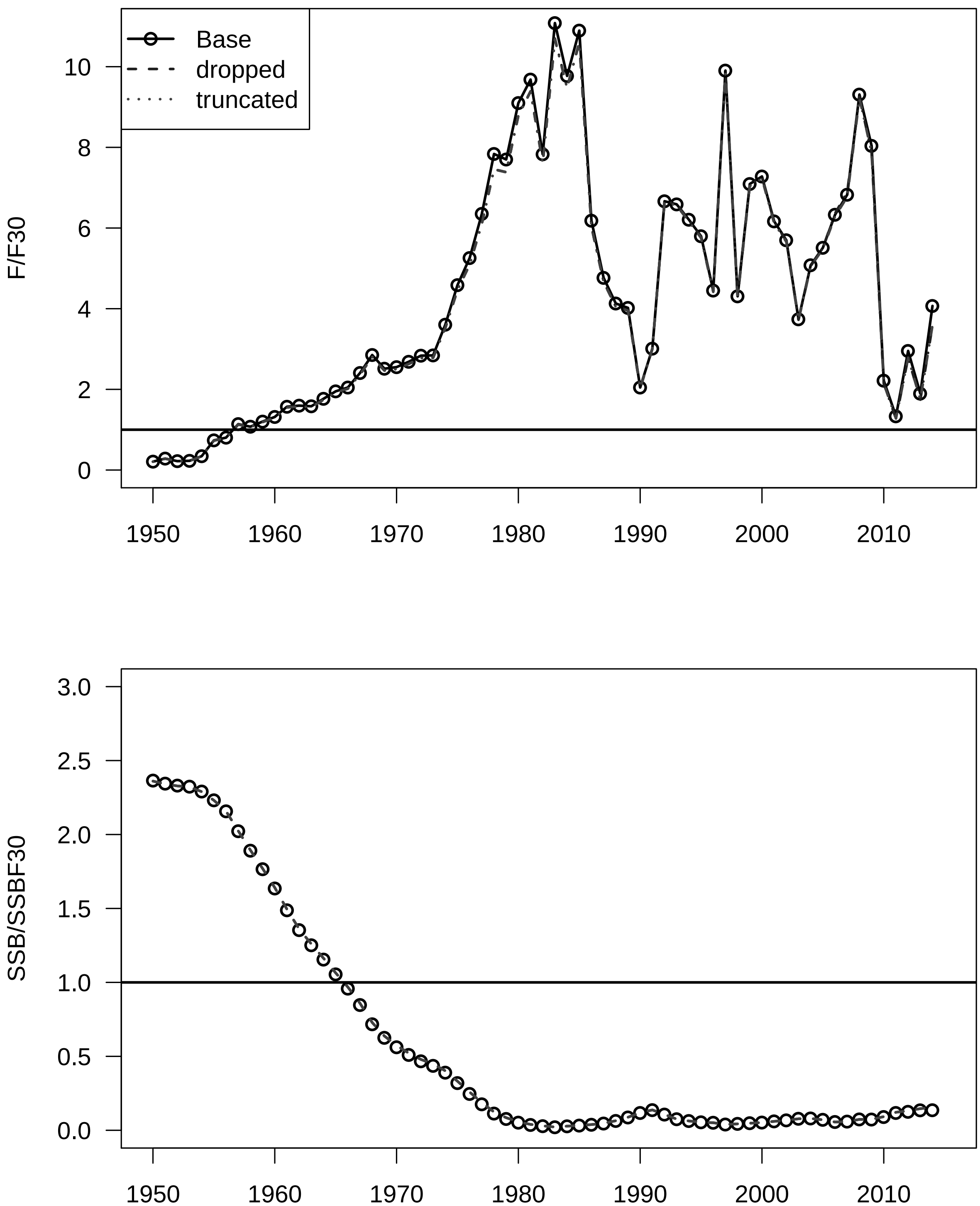


Figure 51. Sensitivity to higher or lower estimates of landings and discards (sensitivity runs S17–S20). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\text{SSB}_{\text{F30\%}}$.

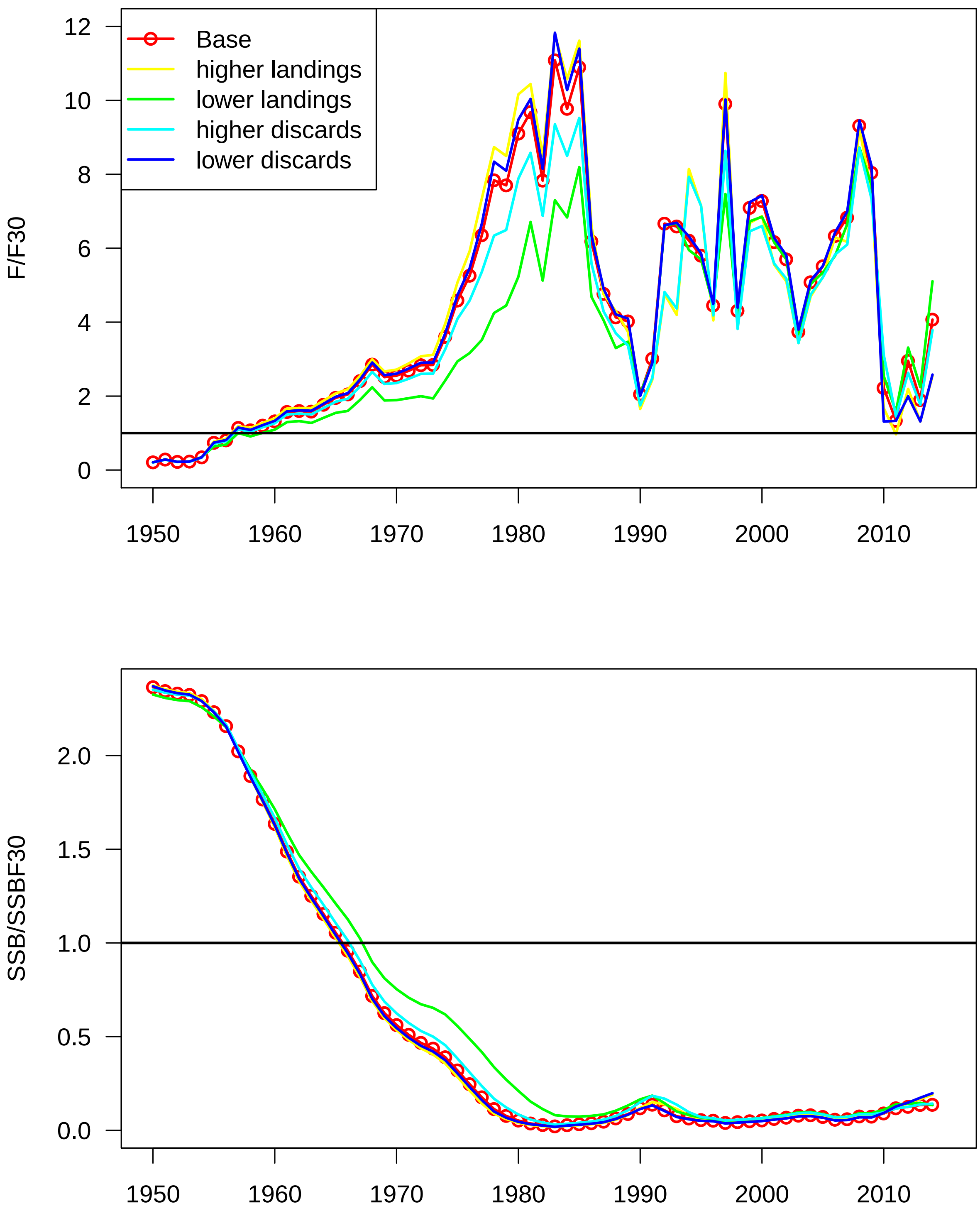


Figure 52. Sensitivity to smoothed 1984 and 1985 MRIP landings (sensitivity run S10). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

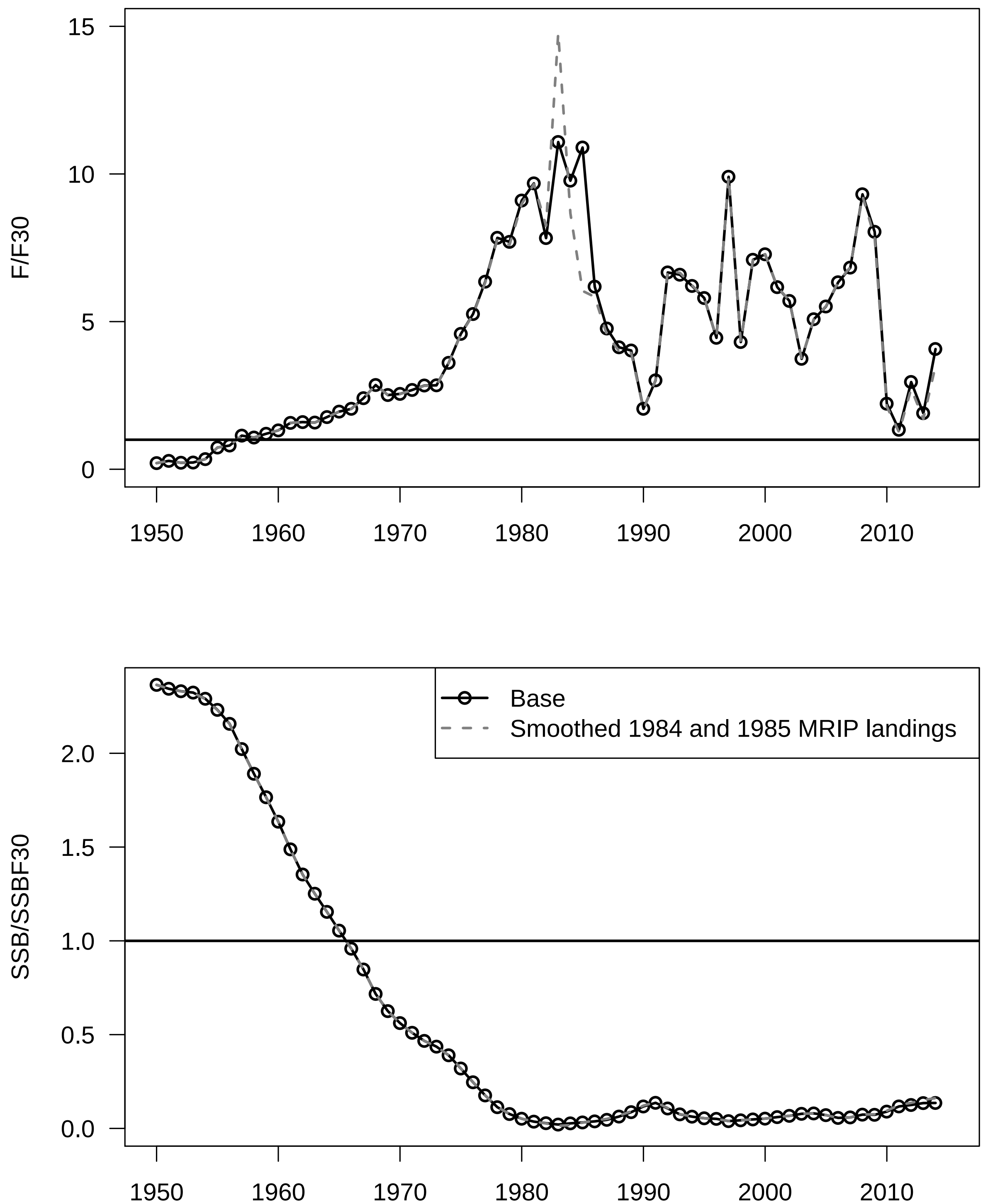


Figure 53. Sensitivity to continuity assumptions from SEDAR 24 (sensitivity run S24). Top panel: Ratio of F to $F_{30\%}$*. Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

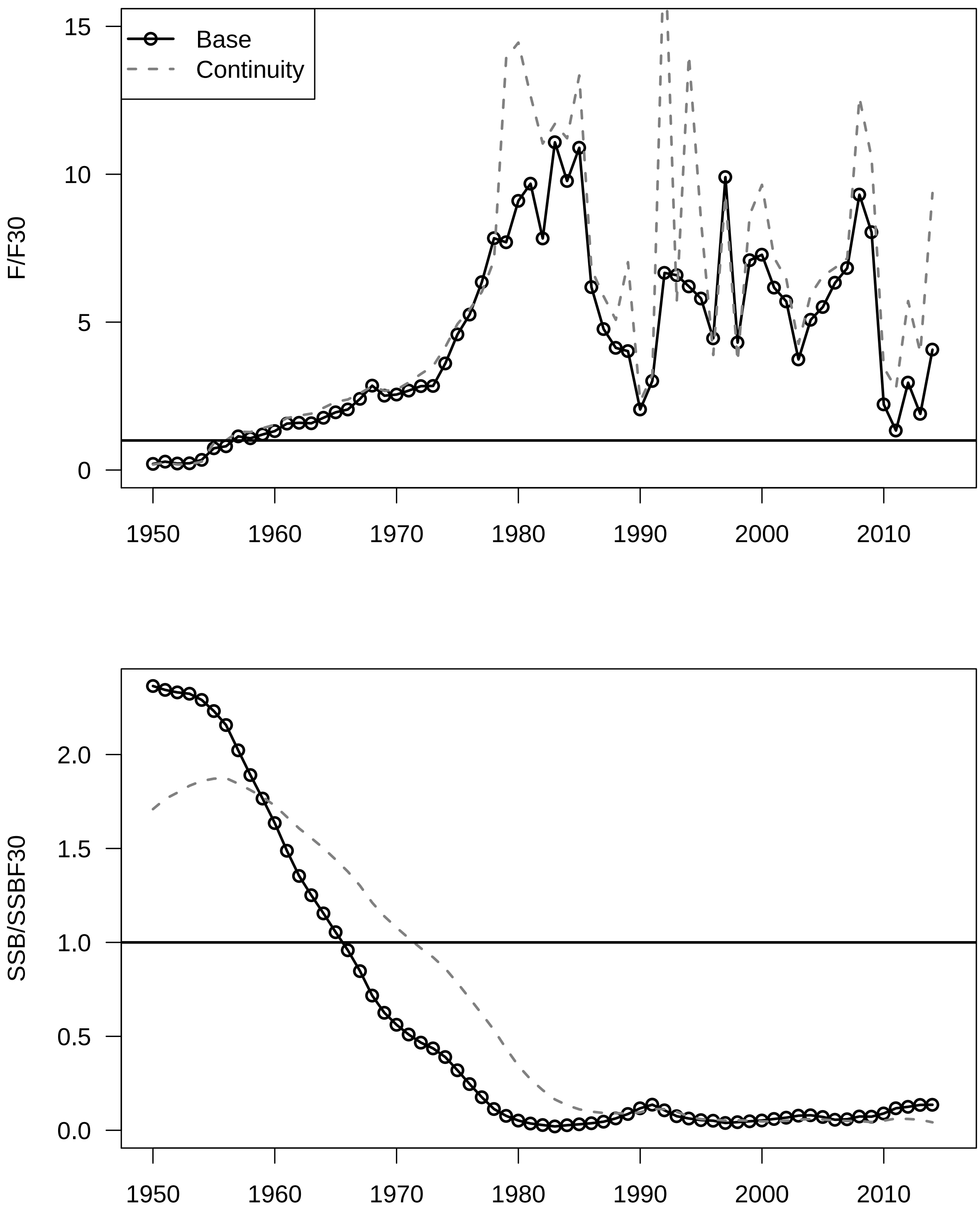


Figure 54. Phase plot of terminal status indicators from sensitivity runs of the Beaufort Assessment Model.

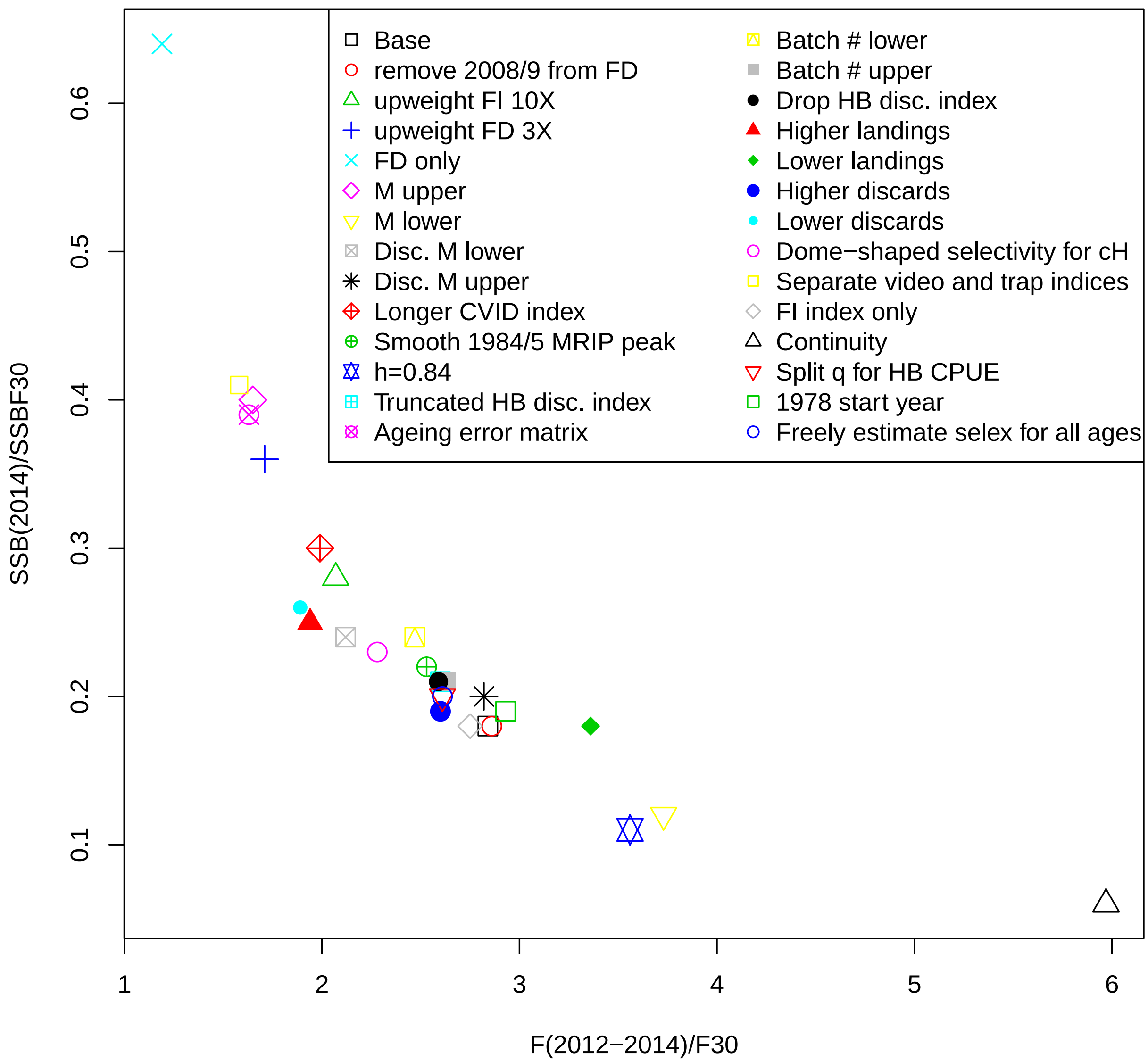


Figure 55. Retrospective analyses. Sensitivity to terminal year of data. Top panel: Fishing mortality rates. Middle panel: Recruits. Bottom panel: Spawning biomass. Closed circles show terminal-year estimates. Imperceptible lines overlap results of the base run.

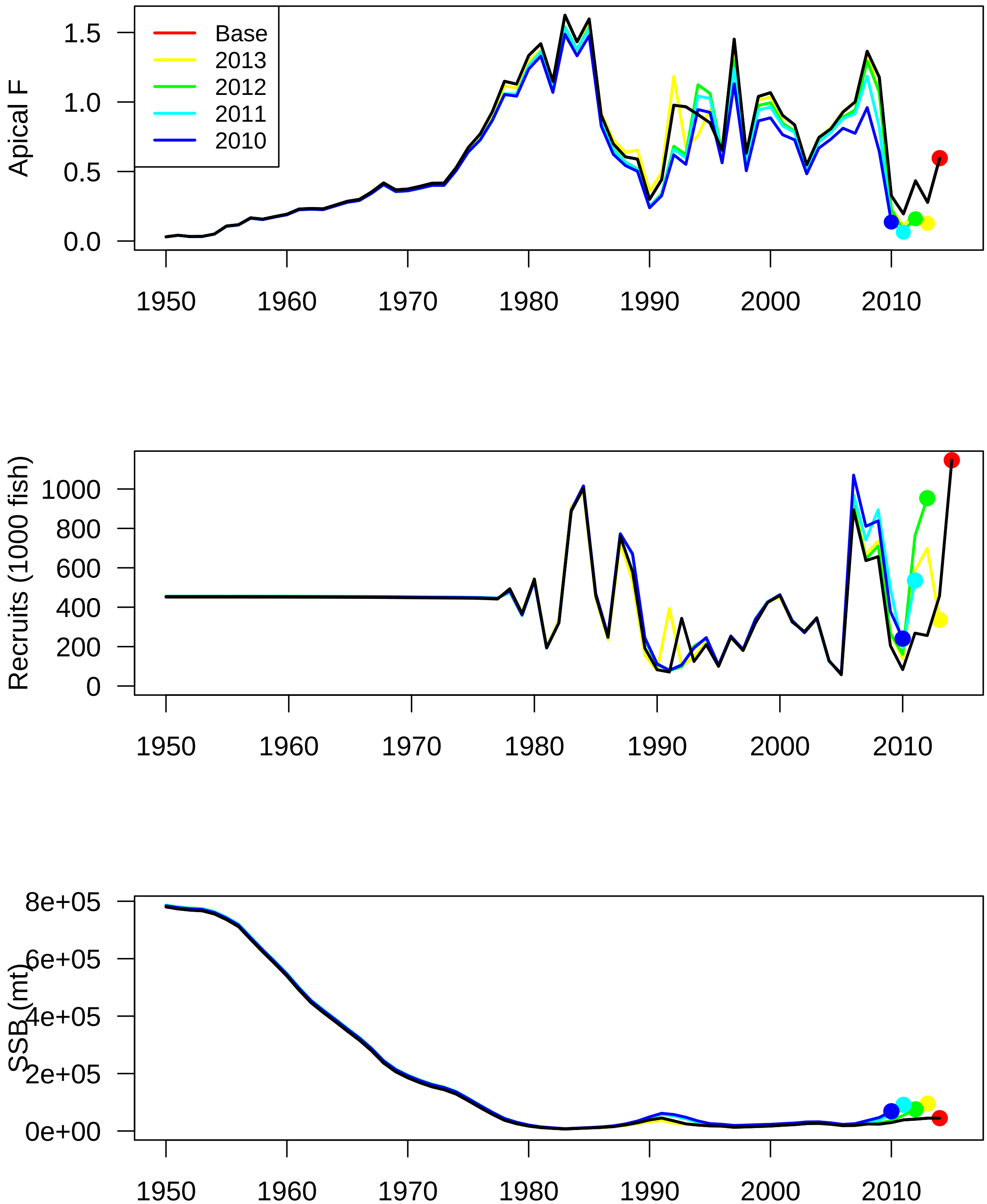


Figure 56. Projection results under scenario 1—fishing mortality rate at $F = 0$. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $SSB_{F30\%}$.

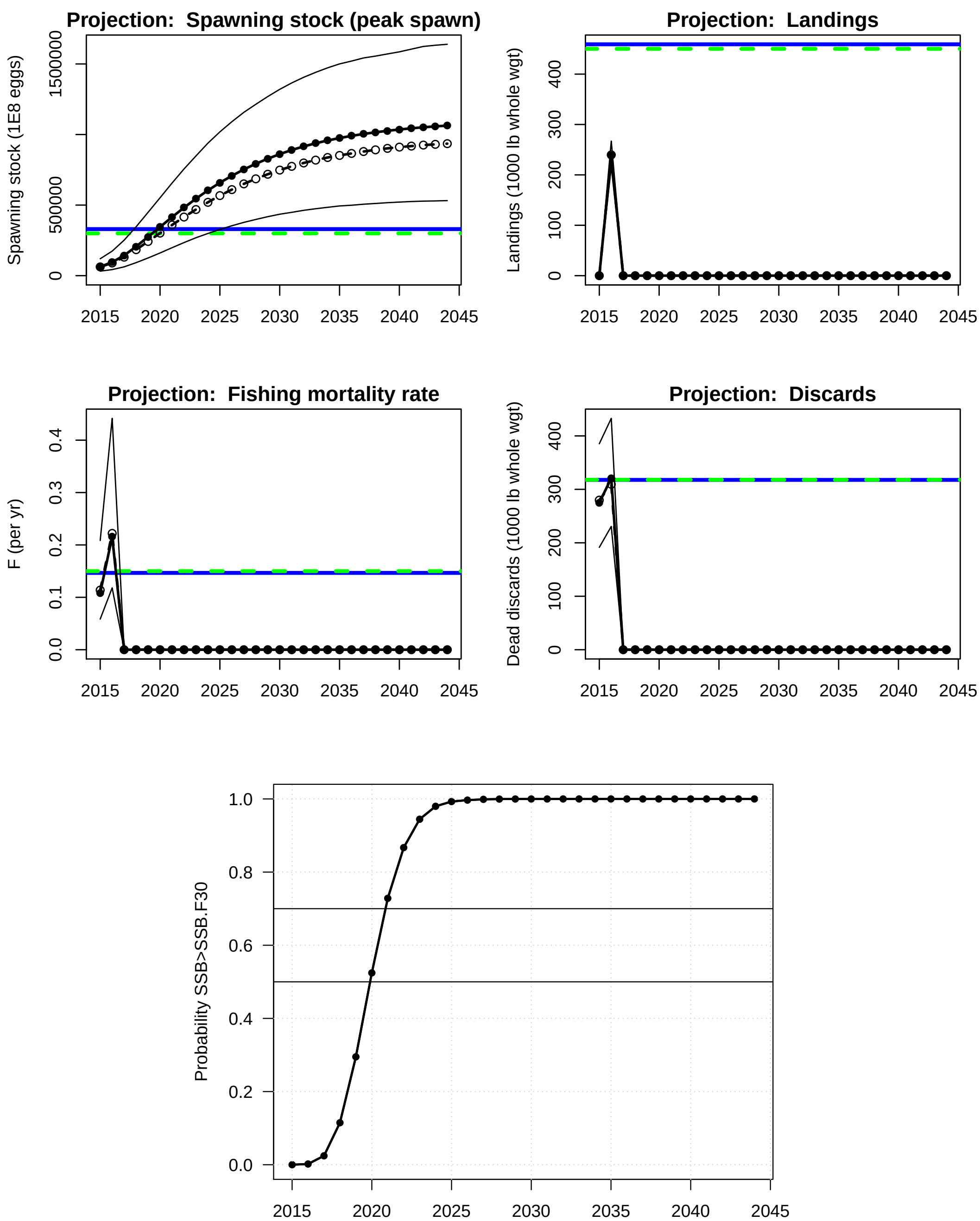


Figure 57. Projection results under scenario 2—fishing mortality rate at $F = F_{\text{current}}$. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\text{SSB}_{\text{F30\%}}$.

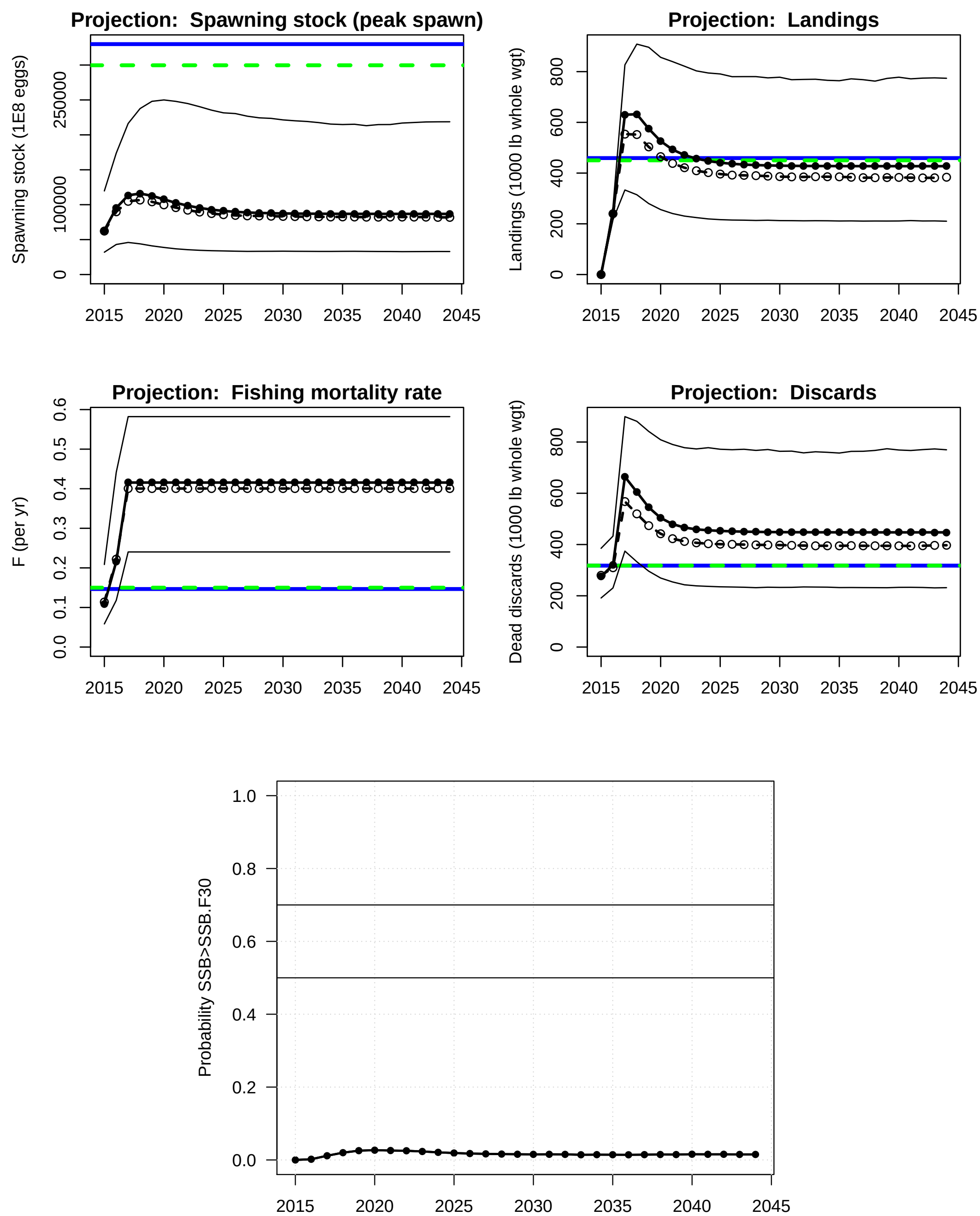


Figure 58. Projection results under scenario 3—fishing mortality rate at $F = F_{30\%}$. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F30\%}}$.

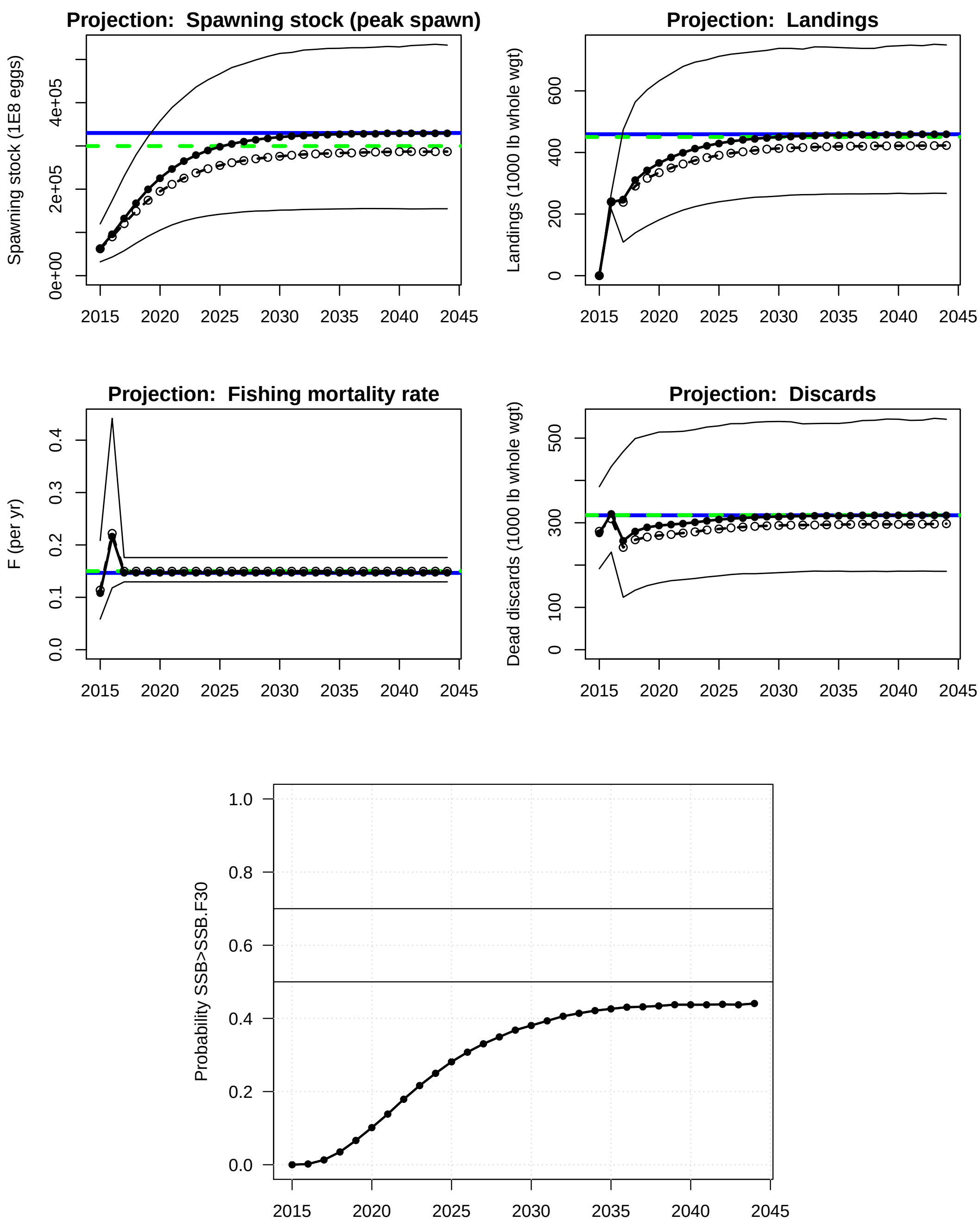


Figure 59. Projection results under scenario 4—fishing mortality rate at $F = 98\%F_{30\%}$. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F30\%}}$.

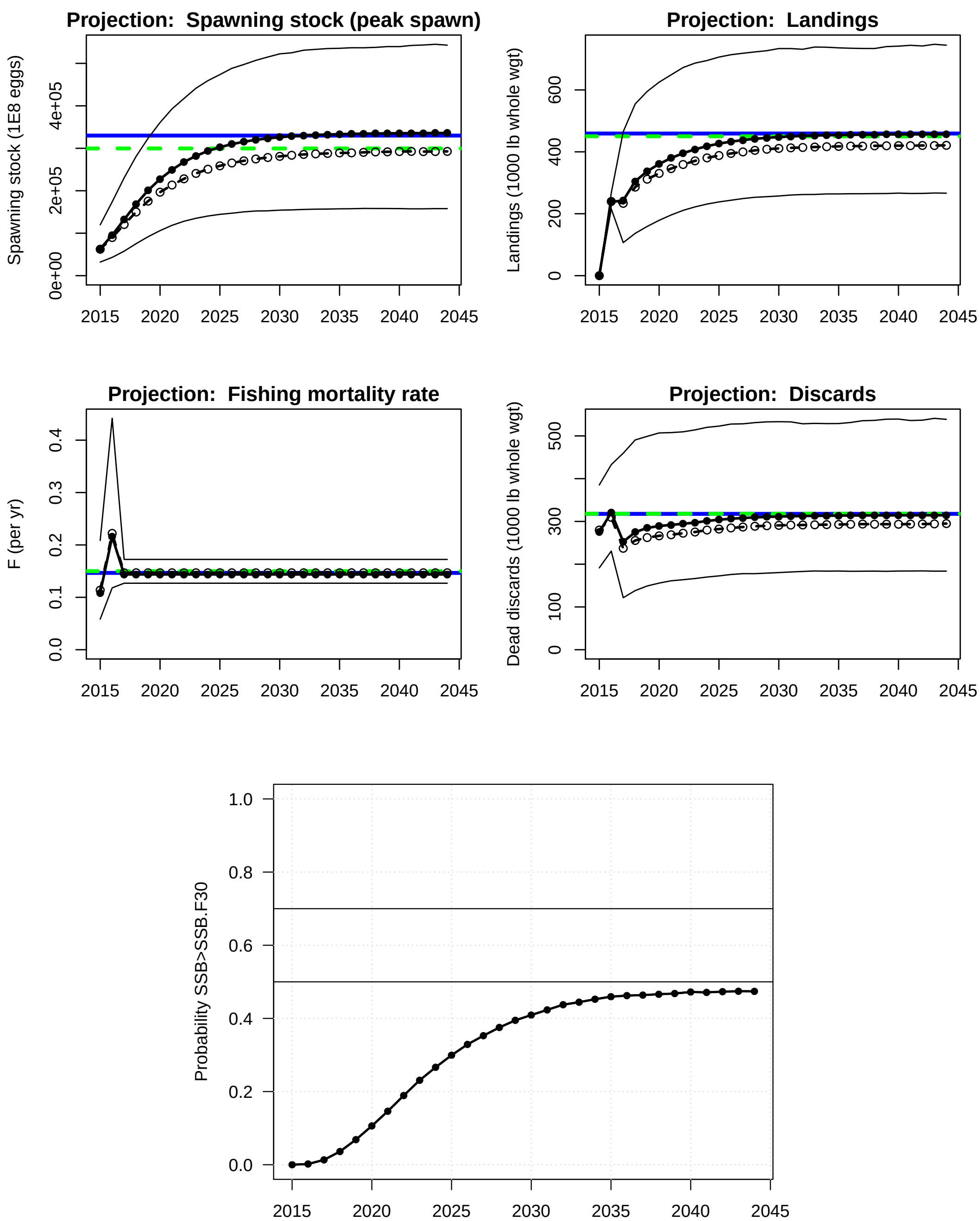


Figure 60. Projection results under scenario 5—fishing mortality rate at $F = F_{\text{rebuild}}$, with rebuilding probability of 0.5 in 2044. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\text{SSB}_{\text{F30\%}}$.

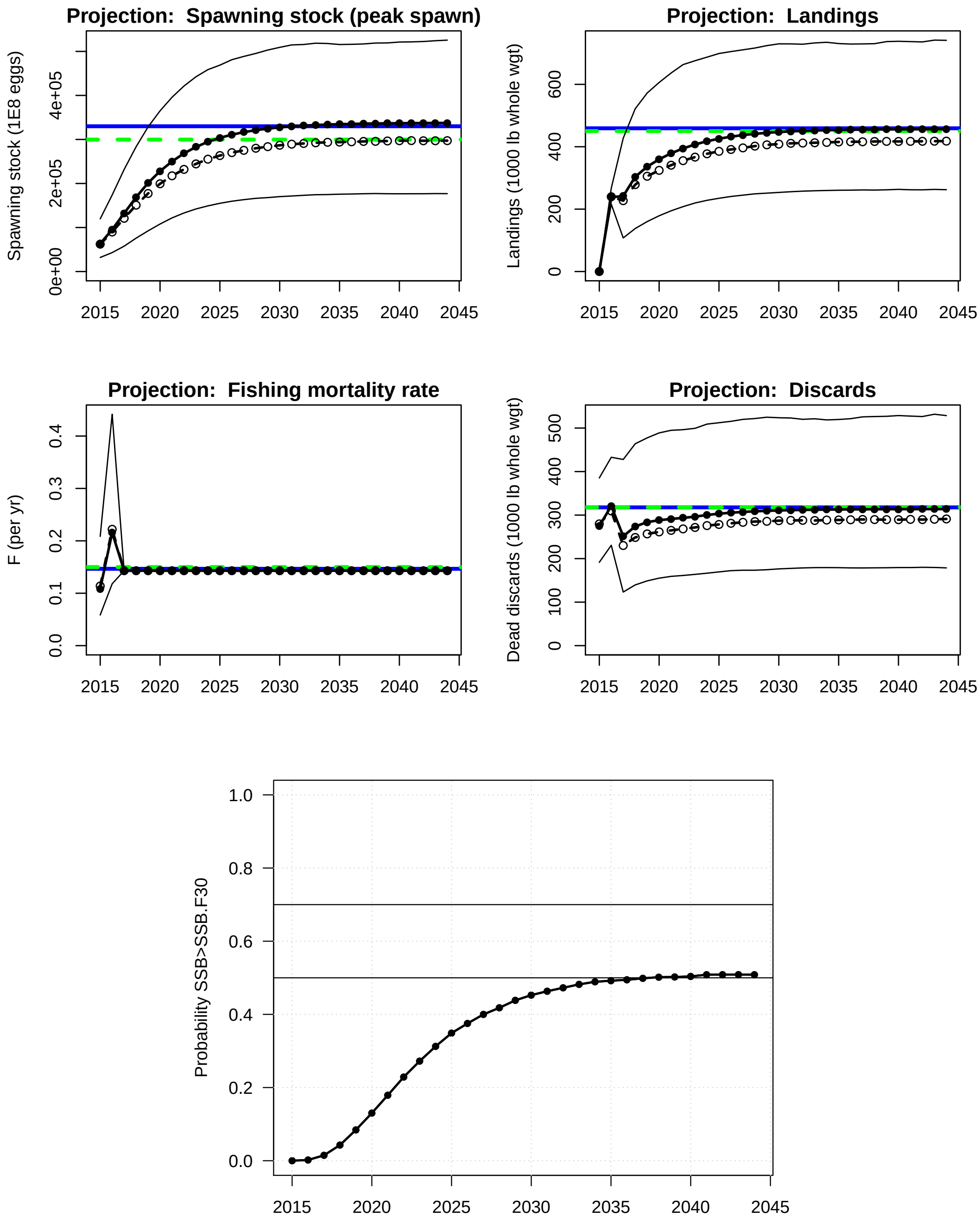


Figure 61. Projection results under scenario 6—fishing mortality rate set to average discard mortality rate only. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} *and* 95^{th} *percentiles of replicate projections. Solid horizontal lines mark* $F_{30\%}$*-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific* $\mathrm{SSB}_{\mathrm{F30\%}}$.

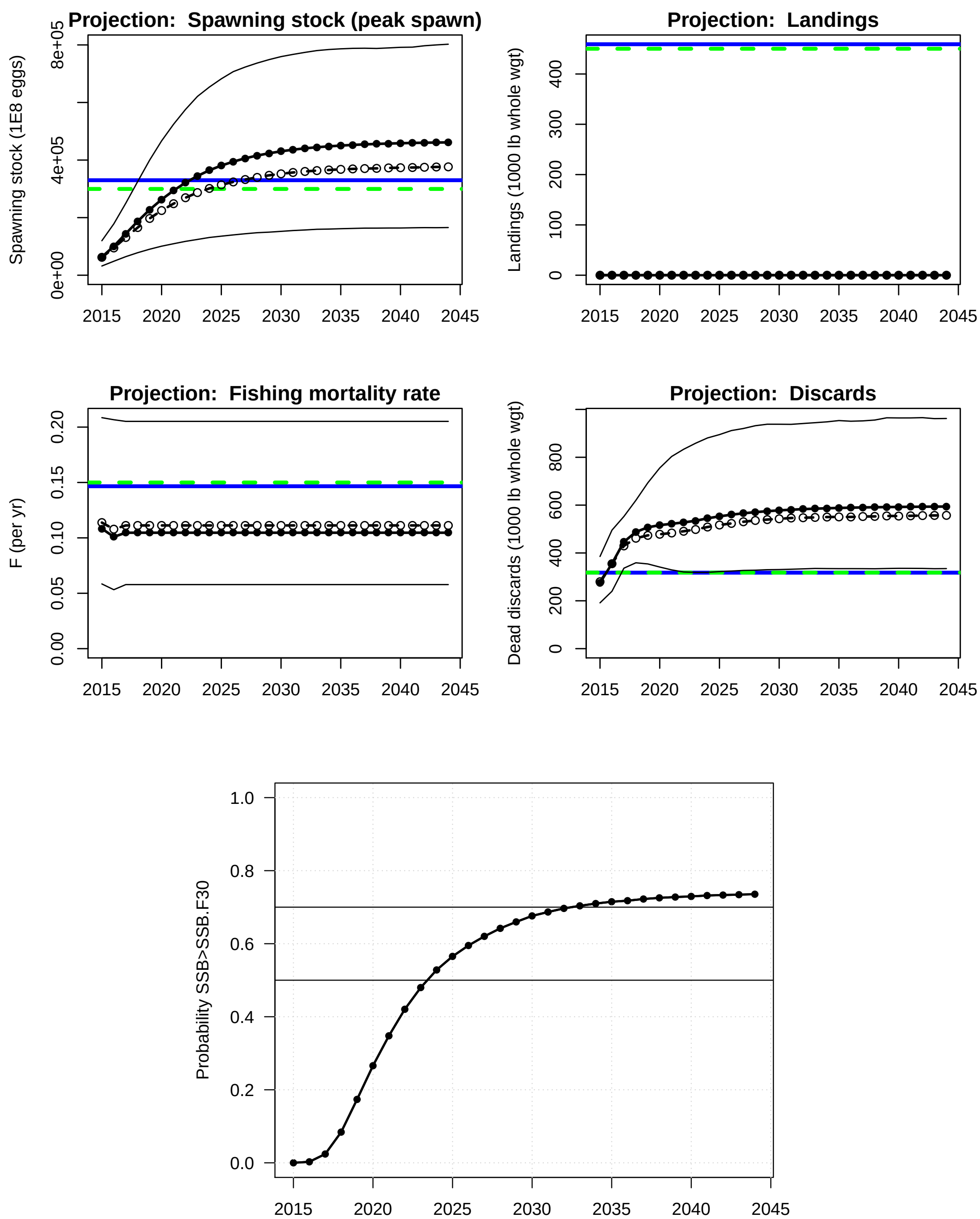


Figure 62. Abundance indices observed (obs.) and predicted (pred.) by the ASPIC surplus production model, and observed total removals (100,000 lbs) for South Atlantic red snapper. Comm = commercial, HB = headboat, HB.at.sea = headboat at sea discards, CVID = combined chevron trap-video index.

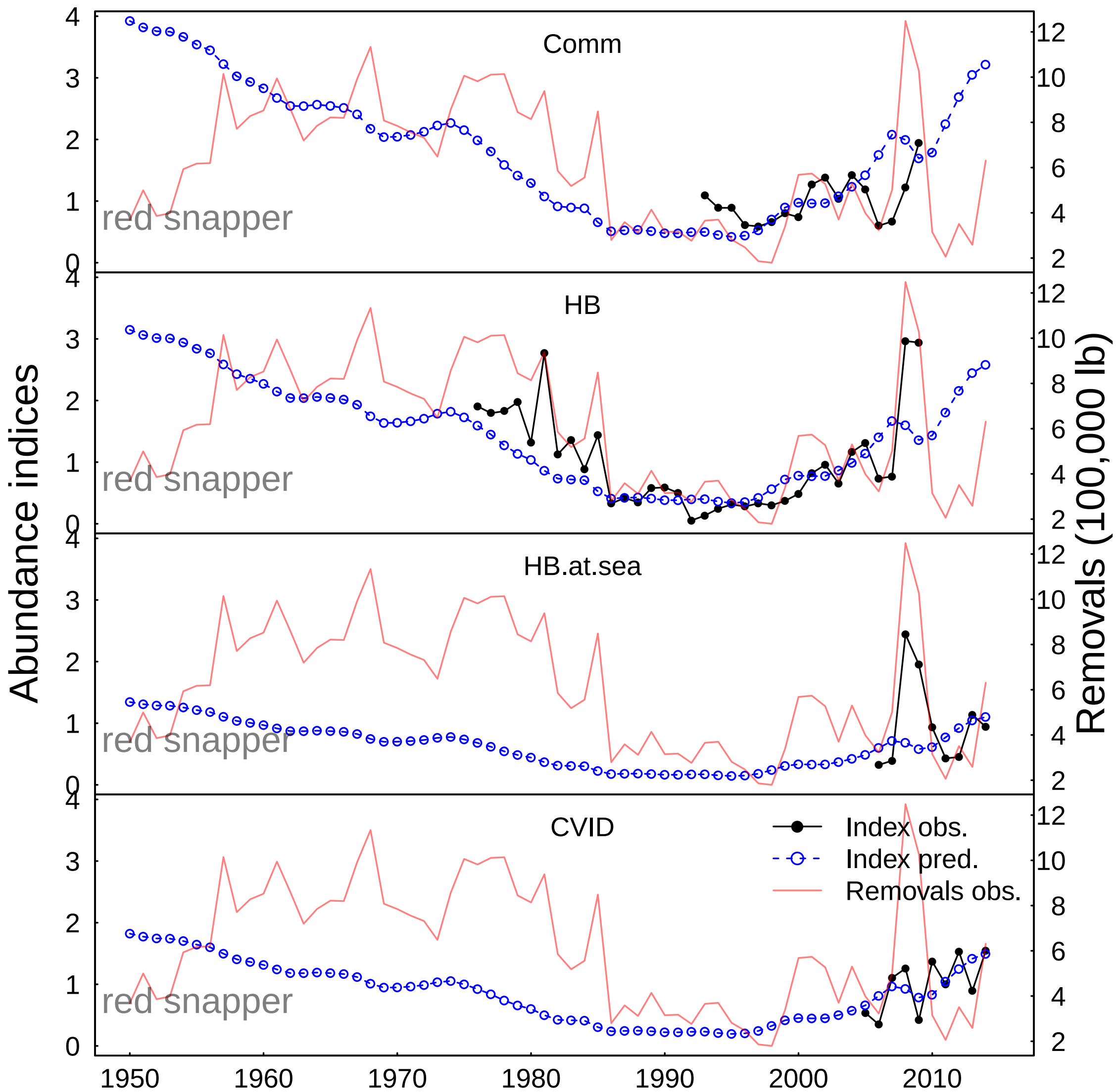


Figure 63. Prior distributions (blue shapes) and estimated parameter values (vertical black lines) for the South Atlantic red snapper ASPIC surplus production model.

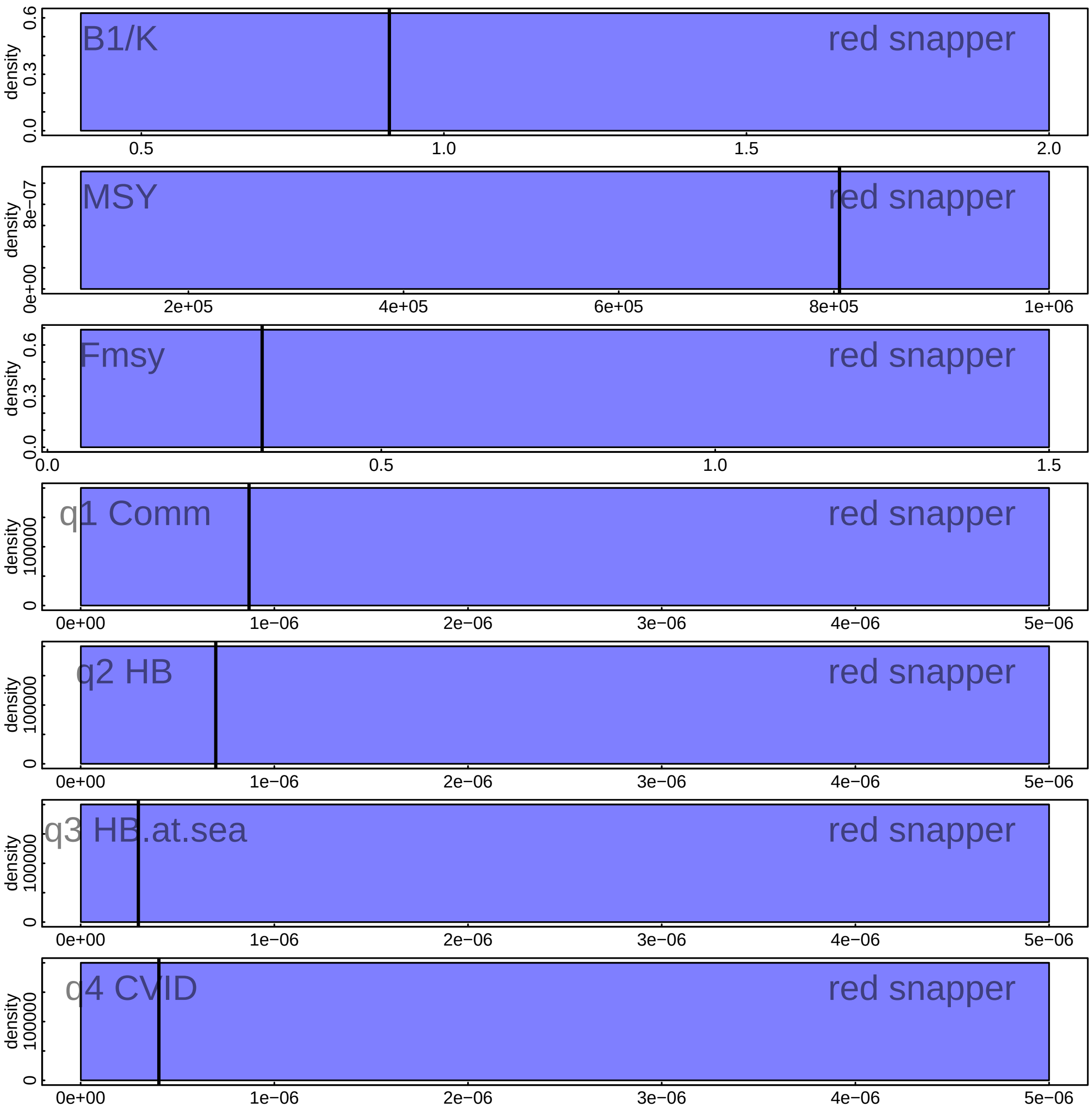


Figure 64. Bootstrap parameter values from ASPIC surplus production model run 320. Thick vertical lines represent ASPIC parameter estimates (solid) and 95% bootstrap percentile confidence intervals (dashed). Thin solid vertical lines are drawn at one in plots of F/F_{MSY} and B/B_{MSY} for reference.

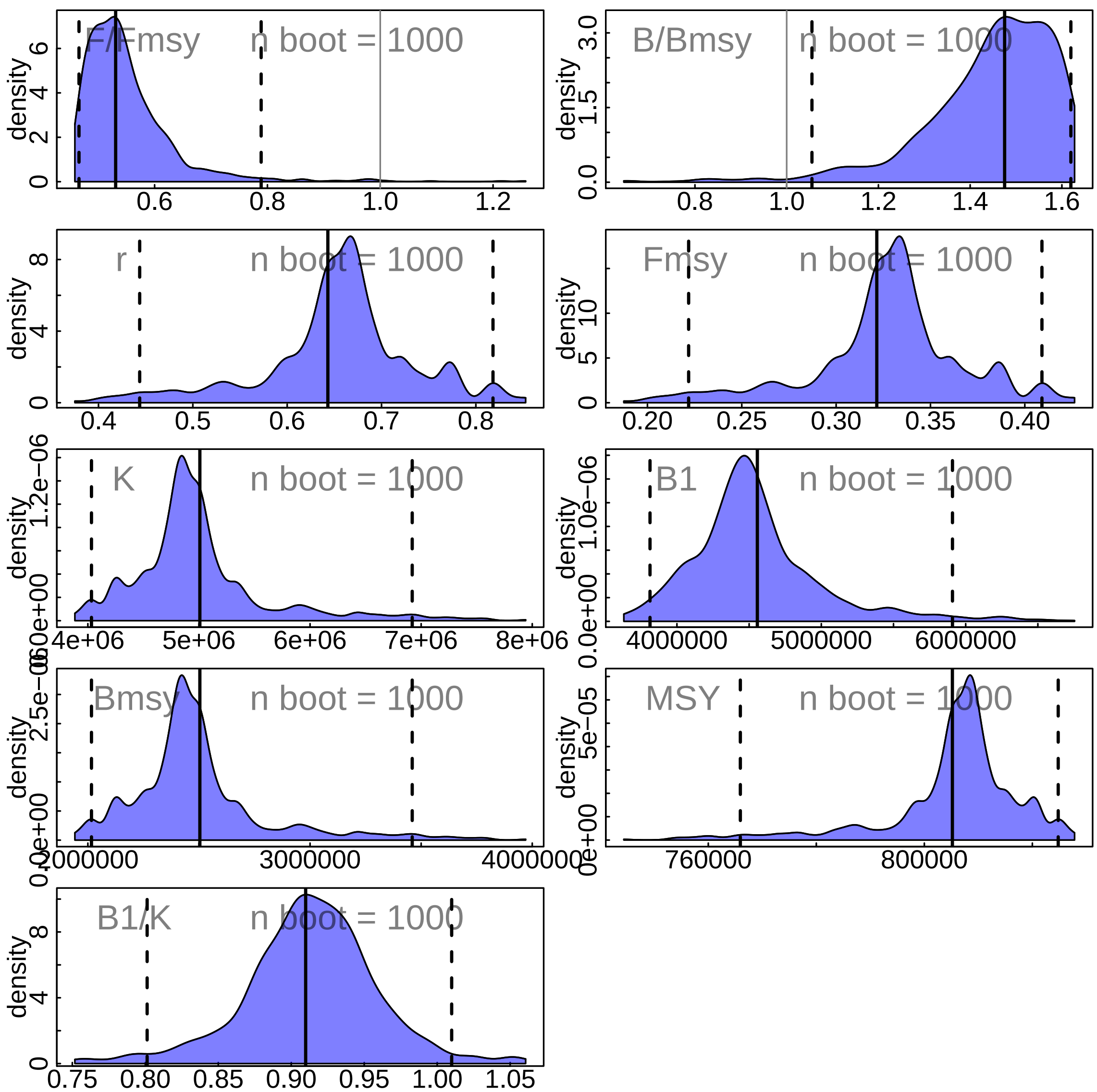
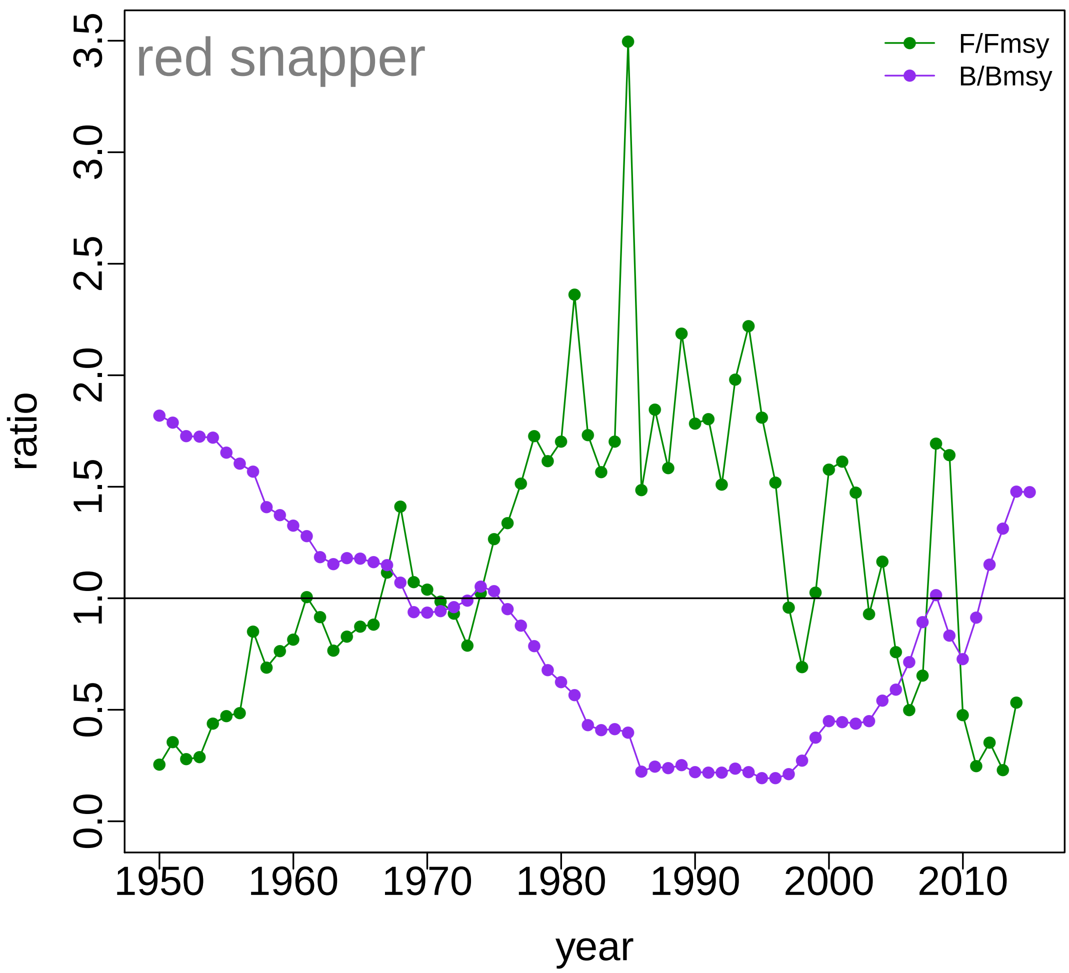


Figure 65. ASPIC surplus production model estimates of relative fishing rate (F/F_{MSY}) and biomass (B/B_{MSY}).



Appendix A Abbreviations and symbols

Table 31. Acronyms and abbreviations used in this report

Symbol	Meaning
ABC	Acceptable Biological Catch
AW	Assessment Workshop (here, for red snapper)
ASY	Average Sustainable Yield
B	Total biomass of stock, conventionally on January 1
BAM	Beaufort Assessment Model (a statistical catch-age formulation)
CPUE	Catch per unit effort; used after adjustment as an index of abundance
CV	Coefficient of variation
CVID	SERFS combined chevron trap and video survey
DW	Data Workshop (here, for red snapper)
F	Instantaneous rate of fishing mortality
$F_{30\%}$	Fishing mortality rate at which $F_{30\%}$ can be attained
F_{MSY}	Fishing mortality rate at which MSY can be attained
FL	State of Florida
FHWAR	The National Survey of Fishing, Hunting, and Wildlife-Associated Recreation Survey
GA	State of Georgia
GLM	Generalized linear model
K	Average size of stock when not exploited by man; carrying capacity
kg	Kilogram(s); 1 kg is about 2.2 lb.
klb	Thousand pounds; thousands of pounds
lb	Pound(s); 1 lb is about 0.454 kg
m	Meter(s); 1 m is about 3.28 feet.
M	Instantaneous rate of natural (non-fishing) mortality
MARMAP	Marine Resources Monitoring, Assessment, and Prediction Program, a fishery-independent data collection program of SCDNR
MCB	Monte Carlo/Bootstrap, an approach to quantifying uncertainty in model results
MFMT	Maximum fishing-mortality threshold; a limit reference point used in U.S. fishery management; often based on F_{MSY}
mm	Millimeter(s); 1 inch = 25.4 mm
MRFSS	Marine Recreational Fisheries Statistics Survey, a data-collection program of NMFS, predecessor of MRIP
MRIP	Marine Recreational Information Program, a data-collection program of NMFS, descended from MRFSS
MSST	Minimum stock-size threshold; a limit reference point used in U.S. fishery management. The SAFMC has defined MSST for red snapper as $(1 - M)\mathrm{SSB}_{\mathrm{MSY}} = 0.7\mathrm{SSB}_{\mathrm{MSY}}$.
MSY	Maximum sustainable yield (per year)
mt	Metric ton(s). One mt is 1000 kg, or about 2205 lb.
N	Number of fish in a stock, conventionally on January 1
NC	State of North Carolina
NMFS	National Marine Fisheries Service, same as “NOAA Fisheries Service”
NOAA	National Oceanic and Atmospheric Administration; parent agency of NMFS
OY	Optimum yield; SFA specifies that OY $\leq$ MSY.
PSE	Proportional standard error
R	Recruitment
SAFMC	South Atlantic Fishery Management Council (also, Council)
SC	State of South Carolina
SCDNR	Department of Natural Resources of SC
SDNR	Standard deviation of normalized residuals
SEDAR	SouthEast Data Assessment and Review process
SERFS	Southeast Regional Fishery-independent Sampling
SFA	Sustainable Fisheries Act; the Magnuson–Stevens Act, as amended
SL	Standard length (of a fish)
SRHS	Southeast Region Headboat Survey, conducted by NMFS-Beaufort laboratory
SPR	Spawning potential ratio
SSB	Spawning stock biomass; mature biomass of males and females
$\mathrm{SSB}_{\mathrm{MSY}}$	Level of SSB at which MSY can be attained
$\mathrm{SSB}_{\mathrm{F30\%}}$	Level of SSB at which $F_{30\%}$ can be attained
TIP	Trip Interview Program, a fishery-dependent biodata collection program of NMFS
TL	Total length (of a fish), as opposed to FL (fork length) or SL (standard length)
VPA	Virtual population analysis, an age-structured assessment
WW	Whole weight, as opposed to GW (gutted weight)
yr	Year(s)

Appendix B Parameter estimates from the Beaufort Assessment Model

```
# Number of parameters = 366  Objective function value = -1956.14  Maximum gradient component = 5.96937e-005
# Linf:
911.360000000
# K:
0.240000000000
# t0:
-0.330000000000
# len_cv_val:
0.107710207376
# Linf_L:
927.000000000
# K_L:
0.220000000000
# t0_L:
-0.660000000000
# len_cv_val_L:
0.138554456778
# Linf_20:
938.000000000
# K_20:
0.170000000000
# t0_20:
-2.41000000000
# len_cv_val_20:
0.100000029485
# log_Nage_dev:
 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
 0.00000000000 0.00000000000 0.00000000000
# log_R0:
12.7083722877
# steep:
0.990000000000
# rec_sigma:
0.789660384622
# R_autocorr:
0.00000000000
# log_rec_dev:
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 -0.116188568848 0.981085231489 0.686667445781 -0.451643590208 -1.31878122068 -1.48911312114 0.0811371437489
 -0.922992309386 -0.376167909813 -1.10841151212 -0.179202090276 -0.494969822897 0.107396220451 0.379878264774
 0.449377221761 0.0921864288671 -0.0837258040958 0.132548488808 -0.866607533977 -1.68351876147 1.07673003520
 0.757318324702 0.784222329636 -0.400893545137 -1.30002703800 -0.143801874907 -0.205256786125 0.371955484101 1.28619711286
# selpar_A50_cH1:
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# selpar_slope_cH1:
4.22252038494
# selpar_A50_cH2:
3.11132259576
# selpar_slope_cH2:
3.29722528688
# selpar_A50_cH3:
3.16773149230
# selpar_slope_cH3:
2.26236442631
# selpar_A50_HB1:
1.89259972912
# selpar_slope_HB1:
3.53054368964
# selpar_A502_HB1:
3.80005950304
# selpar_slope2_HB1:
0.517452712579
# selpar_A50_HB2:
2.96232318521
# selpar_slope_HB2:
3.93119690694
# selpar_A502_HB2:
2.25027736370
# selpar_slope2_HB2:
0.623141401382
# selpar_A50_HB3:
2.26872846556
# selpar_slope_HB3:
3.35767716522
# selpar_A502_HB3:
2.18384991290
# selpar_slope2_HB3:
0.442165092203
# selpar_A50_GR2:
3.11131983608
# selpar_slope_GR2:
2.71842181046
# selpar_A502_GR2:
2.97495905159
# selpar_slope2_GR2:
0.591538961216
# selpar_A50_GR3:
3.72167063151
```

```
# selpar_slope_GR3:
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# selpar_slope_HB2_D:
0.486497868227
# selpar_A502_HB2_D:
1.23869212362
# selpar_slope2_HB2_D:
1.49507820428
# selpar_A50_HB3_D:
1.58012985774
# selpar_slope_HB3_D:
0.528978297814
# selpar_A502_HB3_D:
4.19509675681
# selpar_slope2_HB3_D:
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# selpar_A50_cH2_D:
0.973730965601
# selpar_slope_cH2_D:
0.497473120570
# selpar_A502_cH2_D:
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# selpar_slope2_cH2_D:
1.03489131779
# selpar_A50_cH3_D:
2.71203348201
# selpar_slope_cH3_D:
1.91711364986
# selpar_A50_CVT:
1.90730549321
# selpar_slope_CVT:
3.40818432774
# log_q_cH:
-6.25844174272
# log_q_HB:
-11.8453332840
# log_q_HB_D:
-12.7700652995
# log_q_CVT:
-12.1646316437
# M_constant:
0.134000000000
# log_avg_F_cH:
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# log_F_dev_cH:
 -1.50640443619 -1.19606666129 -1.44779804593 -1.41419831960 -1.00552018315 -1.16337121283 -1.14440240712
 -0.502111212050 -0.780960903034 -0.648434784587 -0.561311694188 -0.311131629420 -0.437655809103 -0.650106776150
 -0.492830411543 -0.383282298421 -0.313110376106 0.0486587829093 0.354139697066 -0.00766574024572 0.0139446490799
 -0.0387686996753 -0.0969873687998 -0.363586238903 0.190944332318 0.574817113965 0.733215705057 1.01835913030
 1.31698563960 1.19810115281 1.34930048050 1.47007706688 1.51993777210 1.77135221040 1.03585841546 0.729834701485
 0.676887588441 0.600817043938 0.172933692896 0.284213531392 0.0552230838463 -0.311689646371 -0.151579848805
 1.16846031835 1.09173838465 1.01167578821 0.871008513755 0.891002581286 0.633043158379 0.450325741185
 0.500384533551 0.932614621671 0.716786005286 0.300996123848 0.524106797328 0.374376210489 0.275972078585
 0.947680107534 1.06128618693 1.22472756668 -2.80995484932 -5.47691169818 -2.78283576102 -1.38423640564 -0.708873090477
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# log_F_dev_HB:
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 -0.542293203423 -0.448402107890 -0.358566400629 -0.263741224832 -0.227013272218 -0.180391560433 -0.113609359653
 -0.0748011913017 -0.0632384700369 0.0431176191044 0.149563624258 0.246508551309 0.368190750885 0.537236484677
 0.661712395070 0.791476042563 0.936442804895 0.991328649085 1.16873523320 0.981619425524 0.758050799224
 1.08759847472 0.433321436118 0.805994430928 0.0103147826406 0.565029945025 0.451350187065 -0.0956221833689
 0.0439287036212 0.0487781883903 0.00470594165115 0.961918734776 0.497089398881 0.731754552306 0.297891330481
 0.681478883611 0.0927081289701 0.339350804695 0.391214325591 0.527670309816 0.477499713349 -0.327838468814
 0.423821917999 0.390563878751 0.519614539358 0.985941504161 0.644212206360 0.782283643821 -3.42347033019 -2.09076149162
 -1.55576844436 -2.09687352859 -1.03254040721
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# log_F_dev_GR:
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 -0.295558319401 -0.283999521379 -0.177710329929 -0.0713434319796 0.0255017203914 0.147092735903 0.315971480922
 0.440545044930 0.569523398454 0.715623993134 0.771313514093 0.948535472682 1.06116075246 0.503257392687 1.01569096953
 1.48147444378 1.67974724108 0.937110843678 0.329739748713 0.370480455580 0.449522531037 -1.37817128845 0.0927475607962
 1.30270808844 0.346328084582 0.523710915901 0.272923172864 -0.0165978450950 1.51563969896 0.296162200291 1.21003604027
 1.21748133442 0.656736598730 0.652819295633 0.332171187873 0.522250562431 0.746012751879 1.06931621751 0.689710601244
 1.33812486224 0.893754437193 -5.37375787731 -5.61379561482 -0.0184348910426 -0.640272823186 0.586184086417
# log_avg_F_cH_D:
-3.73353664537
# log_F_dev_cH_D:
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 -0.523731278719 -0.569880122668 -0.375438654243 0.470982344992 -0.867713112224 -1.62483732369 0.533077355969
 -1.95064679219 -1.28747200456 -1.32824320794 -0.567093445156 0.735814373727 1.61352129256 0.949591879322
 0.846759620716 0.903543604624
# log_avg_F_HB_D:
-5.79644061647
# log_F_dev_HB_D:
 -4.71391630350 -3.71970901904 -4.24142341991 -4.56012299479 -4.20180378046 -4.00481204664 -3.36454338245 -3.26224582130
  0.0901217913932 0.770686051314 0.839774983440 1.32324787838 0.361352389058 0.442727954169 -0.124655874267
  -0.0370543321215 0.0780347286159 0.641015729367 0.901150739278 -0.0256535397639 2.51436057142 2.71597771725
   1.14292945111 2.51505782970 2.64689926556 3.13112075694 2.95417502377 2.59545904401 2.65113555734 2.31820752654
   1.62250552559
# log_avg_F_GR_D:
```

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-2.71035756204
# log_F_dev_GR_D:
 -2.42503054076 -2.50099432141 -3.38722052527 -1.00203912450 -0.447369409911 0.129573824294 -0.585607931015 -0.844764777417
 -1.16994513942 -0.406879027687 0.123321112551 -0.584026154680 0.660802503276 0.592823729801 0.738070257363 -0.671535139188
 -0.840415497560 -0.730881501787 0.794714817227 1.12276860438 1.12756166661 0.818937371024 0.965919231288 1.79365010697
 1.63318630174 -0.00432480925527 0.817903500109 1.50061375511 1.47865474555 1.15184581026 -0.702657019111 0.682903492790
  -0.180988960775 0.351429049406
# F_init:
0.0296007209743
```

9. South Atlantic and Gulf of Mexico Comparison (TOR #10)

This section addresses AW ToR 10: Compare and contrast productivity measures and assessment assumptions between the Gulf of Mexico and South Atlantic stocks. Comparisons are presented in Table 31.

A template of Table 31 was prepared by the SEDAR41 Assessment Panel, with guidance from SAFMC Council members attending the Assessment Workshop. Input for the South Atlantic stock was based on this (SEDAR41) assessment. Input for the Gulf of Mexico stock was based on the most recent (SEDAR31 update) assessment of that stock, and values were provided or reviewed by assessment scientists from the NMFS-Miami laboratory.

Table 31. Productivity measures and assessment assumptions from the South Atlantic (SA, SEDAR41) and Gulf of Mexico (GoM, SEDAR31 update) stocks of red snapper.

Productivity measure/assumption	SA	GoM	Comments
Reproductive output	Fecundity (eggs/female)	Fecundity (eggs/female)	SA units = $1X10^8$ eggs/female
Age at 50% maturity	1.2	NA	GoM: Age at 50% maturity was not used in the stock assessment model. Instead, a fixed vector of fecundity (eggs) at age was used.
Natural mortality	M=0.13	M=0.09	SA max age = 51. SA age dependent M was based on a scaled version of the Charnov estimator. GoM max age = 48. GoM age dependent M (ages 2+; age 0 and 1 M fixed) was based on a scaled version of the Lorenzen estimator.
Assessment model type	Statistical catch at age	Statistical catch at age	SA software = BAM (implemented in AD Model Builder) GoM software = Stock Synthesis (implemented in AD Model Builder; two areas modeled E and W of the Mississippi River; Single S/R relationship.
Assessment time frame	1950–2014	1872–2013	GoM: terminal year of data = 2013

			except for landings for which provisional 2014 estimates were available
Spawner-recruit model	Beverton-Holt	Beverton-Holt	SA: fixed steepness = 0.99 to model recruitment as variable around an average value. GoM: To fix projected recruitments at "recent" levels, steepness and σ_R were fixed.
Spawner-recruit model parameter values	h=0.99 log(R0)=12.71 σ_R=0.79	h=0.99 log(R0)=12.04 σ_R=0.3	SA: steepness fixed, R0 and σ_R estimated. R0 in number age-1 fish. GoM: There is evidence that observed recruitments have generally increased in recent years. Therefore, R0 was estimated for two time blocks (pre 1984 and 1984-present). Ln(R0) = 12.04 from recent time period. R0 in 1000s age-0 fish.
Modeled population recruitment age	Age=1	Age=0	GOM: Age 0 included in because of shrimp bycatch mortality.
Growth model	von Bertalanffy	von Bertalanffy	
Growth model parameter values	Linf=911.36mm (TL)	Linf=85.6374cm (Max TL) K=0.19	SA: Fixed in the assessment,

	K=0.24 t0=–0.33	t0=–0.39	estimated external to the model. Separate growth model applied to landings during the period of the 20-inch size limit. GoM: Fixed in the assessment; Parameters determined using a censored-regression approach to account for the effect of size limits (available data are generally from fishery dependent sources).
Scale of total removals over assessment time frame	Mean=0.82 mp Min=0.24 Max=1.64	Mean = 6.7 mp Min=0.52 mp Max = 18.45 mp	Total Removals (landings + dead discards) in millions of lb (mp)
MSY (or proxy)	0.46 mp	12.9 mp	SA: F30 proxy assuming average recruitment GoM: Equilibrium *Retained* Yield at $SSB_{SPR26\%}$
Fmsy (or proxy)	0.147	0.0494	SA: proxy=F30 GoM: $F_{SPR26\%}$ used as proxy
Bmsy (or proxy)	3692 mt	220.9 mp	SA: Total biomass (all ages 1+) at F30 GOM: Total biomass (all ages 0+) at $SSB_{SPR26\%}$
SSBmsy (or proxy)	3.3E+13 eggs	1.28E+12 eggs	SA: F30 proxy assuming average recruitment GoM: In units of

			1000s. Equilibirum SSB @ $F_{SPR26\%}$
F SPR values	$F_{SPR30\%}$=0.147	$F_{SPR26\%}$ = 0.0494	GOM: $F_{SPR26\%}$
Fleets/Indices modeled (selectivity assumptions)	Commercial handline (flat-topped), trap/video survey (flat-topped), headboat (domed), general recreational (domed, flat-topped since 2010)	**FLEETS:** COM_VL_E: ***RW*** COM_VL_W: ***RW*** COM_LL_E: ***RW*** COM_LL_W: ***RW*** MRIP(PB,CB)_E: ***RW*** MRIP(PB,CB)_W: ***RW*** HB_E: ***RW*** HB_W: ***RW*** COM_CLOSED SEASON_E: ***RW*** COM_CLOSED SEASON_W: ***RW*** REC_CLOSED SEASON_E: ***MIRROR MRIP(PB,CB)_E*** REC_CLOSED SEASON_W: ***MIRROR MRIP(PB,CB)_W*** SHRIMP BYCATCH_E: ***RW*** SHRIMP BYCATCH_W: ***RW*** **INDICES:** SEAMAP VIDEO_E: ***RW*** SEAMAP VIDEO_W: ***RW*** SEAMAP LARVAL_E: ***SSB*** SEAMAP LARVAL_W: ***SSB*** SUMMER GROUNDFISH_E: ***RW*** SUMMER GROUNDFISH_W: ***RW*** FALL GROUNDFISH_E: ***RW***	GOM: ***RW*** = Random Walk, Each age as random walk from previous age – can be dome shaped; ***MIRROR***: Use selectivity from another fleet; ***SSB:*** Sets expected survey selectivity such that abundance indexes spawning biomass; ***LOG***: Logistic or "Flat-topped".

		FALL GROUNDFISH_W: ***RW*** NMFS BOTTOM LL_E: ***MIRROR NMFS BOTTOM LL_W*** NMFS BOTTOM LL_W: ***LOG*** REM_OPER_VEHICLE_E: ***RW*** NMFS BOTTOM LL_E: ***RW*** COM_HL_E: ***MIRROR COM_HL_E Fleet*** COM_HL_W: ***MIRROR MRIP(PB,CB)_E Fleet*** MRIP(PB,CB)_E: ***MIRROR MRIP(PB,CB)_W Fleet*** MRIP(PB,CB)_W: ***MIRROR MRIP(PB,CB)_W Fleet*** HB_E: ***MIRROR HB_E Fleet*** HB_W: ***MIRROR HB_W Fleet***	
Fleet Modeled Retention Assumption	NA	Logistic: As a function of size.	SA: Dead discards modeled as having their own selectivities and fishing rates. GOM: For each fishery, retention was modeled using a logistic function. “Retained” fish are “landed.” Fish that were not retained were discarded. Dead

			discards were estimated by applying the relevant discard mortality rate. Retention does not apply to surveys.
Time varying catchability?	Y	N	SA: Explored in sensitivity analysis
Time varying selectivity?	Y	Y	SA: Three time blocks based on regulatory periods – 1950–1991, 1992–2009, 2010–current. GOM: 2007-2014; A new selectivity function was estimated for change in commercial selectivity with implementation of IFQ. GOM: 2008-2010 and 2011-2014; New selectivity functions were estimated for the recreational fisheries due to implementation of circle hooks and other regulatory effects (on fishing behavior).
Time varying retention?	NA	Y	GOM: Retention functions for recreational and commercial fisheries were re-estimated at all changes in size-limits. For the

			commercial fisheries, the asymptote (retention at sizes larger than the minimum size limit) was allowed to be <100% after the imposition of IFQ to account for regulatory discards not due to minimum size.

SEDAR

Southeast Data, Assessment, and Review

SEDAR 41

South Atlantic Red Snapper

SECTION IV: Research Recommendations

April 2016

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

Contents

IV. Research Recommendations

1. Data Workshop

1.1 Life History

Red Snapper Mini Season

If this program, along with continued closure of the fishery, is to extend into future seasons, an exploration of methods to further incentivize angler participation would be useful. After brief interviews with participants from the recreational fishers group at SEDAR 41, the following suggestions were provided to increase angler participation:

- Free fish cleaning at donation site.
- As people may be tired after being out on the water all day and with busy boat ramps, short questionnaire from a biologist on-site could be used instead of the anglers filling the forms out or requiring fishermen to fill out a survey online after they return home.
- Advertise data collection at local bait & tackle shops.
- Use NOAA's announcement system on weather radio channel where they also announce season closures, etc. Since fishermen are frequently monitoring this channel for weather updates, it could be an effective communication route to announce the collection information (drop locations, reward information, etc.).
- Dry storage areas are a good place to sample; many people store boats there instead of trailering home.

Life History Research

- More research on red snapper movements and migrations in Atlantic waters is needed. Available data and the results of studies in the Gulf of Mexico indicate high site fidelity, but that tropical storms may cause greater than normal movement that might help dispersal to depleted areas. This needs to be confirmed in the South Atlantic. Additional acoustic and traditional tagging is needed on known spawning locations to document spawning migrations or aggregations, and return of fish to non-spawning areas.
- Evaluate more thoroughly the data/sample collection during the mini-season to improve utility for assessments. This should include what samples should be collected (e.g. reproductive information).
- Possible changes in life history parameters, in particular relative to reproduction, need to be further investigated.
- Much is unknown about the early life history of Red Snapper, in particular relative to spawning areas, larval and juvenile stages, including habitat and dispersal.
- Alternative methods of reproductive output. The methods described in Klibansky's SEDAR41-DW49 may provide a more accurate estimate of reproductive output than

previously used. Further investigation into this modeling effort and use for future assessments should be investigated.
- Duration of spawning indicators. The definition of spawning indicators has received significant discussion recently. As this has significant implications for the estimates of reproductive output, further research is needed to define consistent criteria for spawning indicators in finfish.
- Continuing the age reading comparisons and calibrations between labs on a reference collection of known age fish would be beneficial for determining a more accurate aging error matrix and would provide accuracy to the age composition data.

1.2 Commercial Statistics

Landings

- Improve gear and effort data for each trip.
- Standardize methodology for developing average proportions to parse out unclassified landings.

Discards

- Investigate the validity and magnitude of “no discard” trips. This may include fisher interviews throughout the region.
- Examine potential impacts of “no discard” trips on estimated discards.
- Improve discard logbook data collections via program expansion or more detailed reporting (i.e. electronic logbooks, etc.)
- Establish an observer program that is representative of the fisheries in the South Atlantic

Biosampling

- Establish an observer program that is representative of the fisheries in the South Atlantic.
- Angler education with regards to recording depths on paper logbooks (i.e. standardized units); validation of additions to the logbook form still needed.
- Standardize TIP sampling protocol to get representative samples at the species level.
- Standardize TIP data extraction.

1.3 Recreational Statistics

- Complete analysis of available historic photos for trends in CPUE and mean size of landed Red Snapper and Gray Triggerfish for pre-1981 time period. (Ultimately all species).
- Formally archive data and photos for all other SEDAR target species.
- For Hire Survey (FHS) should collect additional variables (e.g. depth fished).
- Increasing sample sizes for at-sea headboat observers (i.e. number of trips sampled).

- Compute variance estimate for headboat landings.
- Mandatory logbooks for all federally permitted for-hire vessels.

1.4 Indices

- Compare existing methods and/or develop new methods to define effective effort in fishery dependent data.
- Estimate selectivity of video gear in the SERFS.
    - Tagging, stereo cameras
- For video reading, evaluate methods to score water clarity and habitat.
- Evaluate effect of (non) independence between chevron traps and videos, including methods to combine the indices.
- Continue exploring the use of continuous predictor variables (e.g., splines or polynomials) for ZIP and ZINB standardization models.
- Headboat at-sea observer program needs depth data from all states (not just FL) and increased coverage overall.
- SCDNR charterboat logbook program should be replicated by other states.
- Develop fishery independent hook-gear index (S41-DW08).

2. Assessment Workshop

- Increased fishery independent information, in particular reliable indices of abundance and age compositions.
- Red Snapper were modeled in this assessment as a unit stock off the southeastern U.S. For any stock, variation in exploitation and life-history characteristics might be expected at finer geographic scales. Modeling such sub-stock structure would require more data, such as information on the movements and migrations of adults and juveniles, as well as spatial patterns of larval dispersal and recruitment. In addition, it is unknown whether a spatial model would improve the assessment.
- More research to describe the life history of Red Snapper is needed, including more work to identify the location of juveniles before they recruit to the fishery.
- The effects on environmental variation on the changes in recruitment or survivorship.
- The Florida sampling program, during the mini-season in particular, provided invaluable data to this assessment. Programs such as these would be useful in all South Atlantic states, particularly if the management regulations continue to make established methods of index development or composition sampling from fleets less regular or possible.

3. Review Workshop

The Review Panel considers the first three of the following bullets to be the highest priority for assessment improvement.

- Increased fishery independent information, particularly maintaining reliable indices of abundance and composition data streams.
- Improve the reliability of discard data as an abundance index by improving knowledge of private recreational fisherman behavior.
- Research to determine the spatial distribution (horizontal and vertical) of large adult Red Snapper using tracking and telemetry.
- The Review Panel reiterates various research recommendations focused on Red Snapper population structure in the South Atlantic. Red Snapper were modeled in this assessment as a unit stock off the southeastern U.S. For any stock, variation in exploitation and life-history characteristics might be expected at finer geographic scales. Modeling such sub-stock structure would require more data, such as information on the movements and migrations of adults and juveniles, as well as spatial patterns of larval dispersal and recruitment, and spatially-explicit data of all types used in the assessment model. It is unclear whether a spatially-explicit model would improve the assessment. Given the robust ocean circulation in the South Atlantic Bight conditions creating population sub-structure. The research effort necessary to support such an effort would be extensive and probably unjustified on stock assessment improvement grounds, however, it would be needed to support MPA placement, performance evaluation, etc.
- More research to describe the juvenile life history of Red Snapper is needed, including more work to identify the location of juveniles before they recruit to the fishery.
- The effects of environmental variation on the changes in recruitment or survivorship.
- Investigate possible historical changes in sexual maturity. The current estimate of age of sexual maturity is low and unusual for other Lutjanids. Is it right or a compensatory response to heavy exploitation?
- Continue conducting studies to develop a time series of batch fecundity to obtain information on the inter-annual variation in reproductive output.

SEDAR

Southeast Data, Assessment, and Review

SEDAR 41

South Atlantic Red Snapper

SECTION V: Review Workshop Report

April 2016

SEDAR
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1. Introduction

1.1 Workshop Time and Place

The SEDAR 41 Review Workshop for South Atlantic Red Snapper (*Lutjanus campechanus*) was held March 15-18, 2016 in North Charleston, SC. Review Panel members were presented all information generated throughout the Data (DW) and Assessment (AW) Workshops and webinars, and the Review Workshop (RW) Panel then developed a consensus review and analysis of the stock assessment model and inputs according to a number of SEDAR Terms of Reference.

1.2 Terms of Reference

1. Evaluate the data used in the assessment, including discussion of the strengths and weaknesses of data sources and decisions, and consider the following:
    a) Are data decisions made by the DW and AW sound and robust?
    b) Are data uncertainties acknowledged, reported, and within the normal or expected levels?
    c) Are data properly applied within the assessment model?
    d) Are data input series reliable and sufficient to support the assessment approach and findings?

2. Evaluate and discuss the strengths and weaknesses of the methods used to assess the stock, taking into account the available data, and consider the following:
    a) Are methods scientifically sound and robust?
    b) Are assessment models configured properly and used consistent with standard practices?
    c) Are the methods appropriate for the available data?

3. Evaluate the assessment findings and consider the following:
    a) Are abundance, exploitation, and biomass estimates reliable, consistent with input data and population biological characteristics, and useful to support status inferences?
    b) Is the stock overfished? What information helps you to reach this conclusion?
    c) Is the stock undergoing overfishing? What information helps you reach this conclusion?
    d) Is there an informative stock recruitment relationship? Is the stock recruitment curve reliable and useful for evaluation of productivity and future stock conditions?
    e) Are the quantitative estimates of the status determination criteria for this stock reliable? If not, are there other indicators that may be used to inform managers about stock trends and conditions?

4. Evaluate the stock projections, including discussing the strengths and weaknesses, and consider the following:
   a) Are the methods consistent with accepted practices and available data?
   b) Are the methods appropriate for the assessment model and outputs?
   c) Are the results informative and robust, and are they useful to support inferences of probably future conditions?
   d) Are key uncertainties acknowledged, discussed, and reflected in the projection results?

5. Consider how uncertainties in the assessment, and their potential consequences, are addressed.
   a) Comment on the degree to which methods used to evaluate uncertainty reflect and capture the significant sources of uncertainty in the population, data sources, and assessment methods.
   b) Ensure that the implications of uncertainty in technical conclusions are clearly stated.

6. Consider the research recommendations provided by the Data and Assessment workshops and make any additional recommendations or prioritizations warranted.
   a) Clearly denote research and monitoring that could improve the reliability of, and information provided by, future assessments.
   b) Provide recommendations on possible ways to improve the SEDAR process.

7. Consider whether the stock assessment constitutes the best scientific information available using the following criteria as appropriate: relevance, inclusiveness, objectivity, transparency, timeliness, verification, validation, and peer review of fishery management information.

8. Compare and contrast assessment uncertainties between the Gulf of Mexico and South Atlantic stocks.

9. Provide guidance on key improvements in data or modeling approaches which should be considered when scheduling the next assessment.

10. Prepare a Peer Review Summary summarizing the Panel's evaluation of the stock assessment and addressing each Term of Reference. Develop a list of tasks to be completed following the workshop. Complete and submit the Peer Review Summary Report in accordance with the project guidelines.

1.3 List of Participants

REVIEW WORKSHOP PANELISTS

Luiz Barbieri	Review Panel Chair	SAFMC SSC
Mike Armstrong	Reviewer	CIE
Jon Helge Vølstad	Reviewer	CIE
Stephen Smith	Reviewer	CIE
Steve Cadrin	Reviewer	SAFMC SSC
Churchill Grimes	Reviewer	SAFMC SSC

ANALYTICAL REPRESENTATIVES

Kevin Craig	Lead Analyst, GTF	SEFSC Beaufort
Kate Siegfried	Lead Analyst, RS	SEFSC Beaufort
Kyle Shertzer	Assessment Team	SEFSC Beaufort
Erik Williams	Assessment Team	SEFSC Beaufort
Rob Cheshire*	Assessment Team	SEFSC Beaufort
Eric Fitzpatrick*	Assessment Team	SEFSC Beaufort

APPOINTED OBSERVERS

Rusty Hudson	Recreational/Commercial	FL / SFA
Robert Johnson	For-Hire	FL

APPOINTED COUNCIL REPRESENTATIVES

Zack Bowen	Council Member	SAFMC
Mark Brown	Council Member	SAFMC
Chris Conklin	Council Member	SAFMC

COUNCIL AND AGENCY STAFF

Julia Byrd	Coordinator	SEDAR
Julie O'Dell	Admin	SEDAR / SAFMC
Chip Collier	Fishery Biologist	SAMFC
Mike Errigo	Fishery Biologist	SAFMC
Nick Farmer	Fishery Biologist	SERO

WORKSHOP ATTENDEES

Joey Ballenger, SCDNR
Peter Barile, SFA
Myra Brouwer, SAFMC
John Carmichael, SAFMC
Brian Cheuvront, SAFMC
Lora Clarke, PEW

Amy Dukes, SCDNR
Jimmy Hull, FL fisherman
Julie Neer, SAFMC
Adam Nelson, FL fisherman
David Nelson, FL fisherman
Michael Nelson, FL fisherman
Paul Nelson, FL fisherman
Marcel Reichert, SCDNR
Tracey Smart, SCDNR

*Appointees marked with a * were appointed to the workshop panel but did not attend the workshop.

1.4 Document List

SEDAR 41 review workshop working papers and reference documents.

Document #	Title	Authors
	Documents Prepared for the Review Workshop	
SEDAR41-RW01	Addendum to SEDAR41-DW16: Report on Life History of South Atlantic Gray Triggerfish, *Balistes capriscus*, from Fishery-Independent Sources: UPDATE on analyses of maturity, spawning fraction, and sex ratio	Kolmos et al. 2016
SEDAR41-RW02	Age structured production model (ASPM) for U.S. South Atlantic Red Snapper (*Lutjanus campechanus*)	SFB-NMFS 2016
SEDAR41-RW03	Age structured production model (ASPM) for U.S. South Atlantic Gray Triggerfish (*Balistes capriscus*)	SFB-NMFS 2016
SEDAR41-RW04	Red Snapper: Additional BAM diagnostics, analyses, and code	SFB-NMFS 2016
SEDAR41-RW05	Model Diagnostics and Source Code for SEDAR 41 Gray Triggerfish (*Balistes capriscus*) Benchmark Stock Assessment	SFB-NMFS 2016
	Reference Documents	
SEDAR41-RD01	List of documents and working papers for SEDAR 32 (South Atlantic Blueline Tilefish and Gray Triggerfish) – all documents available on the SEDAR website.	SEDAR 32
SEDAR41-RD02	List of documents and working papers for SEDAR 9 (Gulf of Mexico Gray Triggerfish, Greater Amberjack, and Vermilion Snapper) – all documents available on the SEDAR website.	SEDAR 9
SEDAR41-RD03	2011 Gulf of Mexico Gray Triggerfish Update Assessment	SEDAR 2011
SEDAR41-RD04	List of documents and working papers for SEDAR 24 (South Atlantic Red Snapper) – all documents available on the SEDAR website.	SEDAR 24
SEDAR41-RD05	List of documents and working papers for SEDAR 31 (Gulf of Mexico Red Snapper) – all documents available on the SEDAR website.	SEDAR 31

SEDAR41-RD06	List of documents and working papers for SEDAR 15 (South Atlantic Red Snapper and greater amberjack) – all documents available on the SEDAR website.	SEDAR 15
SEDAR41-RD07	2009 Gulf of Mexico Red Snapper update assessment	SEDAR 2009
SEDAR41-RD08	List of documents and working papers for SEDAR 7 (Gulf of Mexico Red Snapper) – all documents available on the SEDAR website.	SEDAR 7
SEDAR41-RD09	SEDAR 24 South Atlantic Red Snapper: management quantities and projections requested by the SSC and SERO	NMFS - Sustainable Fisheries Branch 2010
SEDAR41-RD10	Total removals of Red Snapper (*Lutjanus campechanus*) in 2012 from the US South Atlantic	NMFS - Sustainable Fisheries Branch 2013
SEDAR41-RD11	Amendment 17A to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region	SAFMC 2010
SEDAR41-RD12	Amendment 28 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region	SAFMC 2013
SEDAR41-RD13	Total removals of Red Snapper (*Lutjanus campechanus*) in 2013 from the U.S. South Atlantic	NMFS - Sustainable Fisheries Branch 2014
SEDAR41-RD14	South Atlantic Red Snapper (*Lutjanus campechanus*) monitoring in Florida for the 2012 season	Sauls et al. 2013
SEDAR41-RD15	South Atlantic Red Snapper (*Lutjanus campechanus*) monitoring in Florida for the 2013 season	Sauls et al. 2014
SEDAR41-RD16	A directed study of the recreational Red Snapper fisheries in the Gulf of Mexico along the West Florida shelf	Sauls et al. 2014
SEDAR41-RD17	Using generalized linear models to estimate selectivity from short-term recoveries of tagged red drum *Sciaenops ocellatus*: Effects of gear, fate, and regulation period	Bacheler et al. 2009
SEDAR41-RD18	Direct estimates of gear selectivity from multiple tagging experiments	Myers and Hoenig 1997

SEDAR41-RD19	Examining the utility of alternative video monitoring metrics for indexing reef fish abundance	Schobernd et al. 2014
SEDAR41-RD20	An evaluation and power analysis of fishery independent reef fish sampling in the Gulf of Mexico and U.S. South Atlantic	Conn 2011
SEDAR41-RD21	Consultant's Report: Summary of the MRFSS/MRIP Calibration Workshop	Boreman 2012
SEDAR41-RD22	2013 South Atlantic Red Snapper Annual Catch Limit and Season Length Projections	SERO 2013
SEDAR41-RD23	Southeast Reef Fish Survey Video Index Development Workshop	Bacheler and Carmichael 2014
SEDAR41-RD24	Observer Coverage of the 2010-2011 Gulf of Mexico Reef Fish Fishery	Scott-Denton and Williams
SEDAR41-RD25	Circle Hook Requirements in the Gulf of Mexico: Application in Recreational Fisheries and Effectiveness for Conservation of Reef Fishes	Sauls and Ayala 2012
SEDAR41-RD26	GADNR Marine Sportfish Carcass Recovery Project	Harrell 2013
SEDAR41-RD27	Catch Characterization and Discards within the Snapper Grouper Vertical Hook-and-Line Fishery of the South Atlantic United States	Gulf and South Atlantic Fisheries Foundation 2008
SEDAR41-RD28	A Continuation of Catch Characterization and Discards within the Snapper Grouper Vertical Hook-and-Line Fishery of the South Atlantic United States	Gulf and South Atlantic Fisheries Foundation 2010
SEDAR41-RD29	Continuation of Catch Characterization and Discards within the Snapper Grouper Vertical Hook-and-Line Fishery of the South Atlantic United States	Gulf and South Atlantic Fisheries Foundation 2013
SEDAR41-RD30	Amendment 1 and Environmental Assessment and Regulatory Impact Review to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region	SAFMC 1988
SEDAR41-RD31	Final Rule for Amendment 1 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region	Federal Register 1989
SEDAR41-RD32	Population Structure and Genetic Diversity of Red Snapper (Lutjanus campechanus) in the U.S.	Gold and Portnoy 2013

	South Atlantic and Connectivity with Red Snapper in the Gulf of Mexico	
SEDAR41-RD33	Oogenesis and fecundity type of Gulf of Mexico gray triggerfish reflects warm water environmental and parental care	Lang and Fitzhugh 2014
SEDAR41-RD34	Depth-related Distribution of Postjuvenile Red Snapper in Southeastern U.S. Atlantic Ocean Waters: Ontogenetic Patterns and Implications for Management	Mitchell et al. 2014
SEDAR41-RD35	Gray Triggerfish Age Workshop	Potts 2013
SEDAR41-RD36	Age, Growth, and Reproduction of Gray Triggerfish *Balistes capriscus* Off the Southeastern U.S. Atlantic Coast	Kelly 2014
SEDAR41-RD37	Assessment of Genetic Stock Structure of Gray Triggerfish (*Balistes capriscus*) in U.S. Waters of the Gulf of Mexico and South Atlantic Regions	Saillant and Antoni 2014
SEDAR41-RD38	Genetic Variation of Gray Triggerfish in U.S. Waters of the Gulf of Mexico and Western Atlantic Ocean as Inferred from Mitochondrial DNA Sequences	Antoni et al. 2011
SEDAR41-RD39	Characterization of the U.S. Gulf of Mexico and South Atlantic Penaeid and Rock Shrimp Fisheries Based on Observer Data	Scott-Denton et al. 2012
SEDAR41-RD40	Does hook type influence the catch rate, size, and injury of grouper in a North Carolina commercial fishery	Bacheler and Buckel 2004
SEDAR41-RD41	Fishes associated with North Carolina shelf-edge hardbottoms and initial assessment of a proposed marine protected area	Quattrini and Ross 2006
SEDAR41-RD42	Growth of grey triggerfish, *Balistes capriscus*, based on growth checks of the dorsal spine	Ofori-Danson 1989
SEDAR41-RD43	Age Validation and Growth of Gray Triggerfish, *Balistes capriscus*, In the Northern Gulf of Mexico	Fioramonti 2012
SEDAR41-RD44	A review of the biology and fishery for Gray Triggerfish, *Balistes capriscus*, in the Gulf of Mexico	Harper and McClellan 1997

SEDAR41-RD45	Stock structure of gray triggerfish, *Balistes capriscus*, on multiple spatial scales in the Gulf of Mexico	Ingram 2001
SEDAR41-RD46	Evaluation of the Efficacy of the Current Minimum Size Regulation for Selected Reef Fish Based on Release Mortality and Fish Physiology	Burns and Brown-Peterson 2008
SEDAR41-RD47	Population Structure of Red Snapper from the Gulf of Mexico as Inferred from Analysis of Mitochondrial DNA	Gold et al. 1997
SEDAR41-RD48	Successful Discrimination Using Otolith Microchemistry Among Samples of Red Snapper *Lutjanus campechanus* from Artificial Reefs and Samples of *L.campechanus* Taken from Nearby Oil and Gas Platforms	Nowling et al. 2011
SEDAR41-RD49	Population Structure and Variation in Red Snapper (Lutjanus campechanus) from the Gulf of Mexico and Atlantic Coast of Florida as Determined from Mitochondrial DNA Control Region Sequence	Garber et al. 2003
SEDAR41-RD50	Population assessment of the Red Snapper from the southeastern United States	Manooch et al. 1998
SEDAR41-RD51	Otolith Microchemical Fingerprints of Age-0 Red Snapper, *Lutjanus campechanus*, from the Northern Gulf of Mexico	Patterson et al. 1998
SEDAR41-RD52	Implications of reef fish movement from unreported artificial reef sites in the northern Gulf of Mexico	Addis et al. 2013
SEDAR41-RD53	Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species	Then et al. 2014
SEDAR41-RD54	Length selectivity of commercial fish traps assessed from in situ comparisons with stereo-video: Is there evidence of sampling bias?	Langlois et al. 2015
SEDAR41-RD55	MRIP Calibration Workshop II – Final Report	Carmichael and Van Vorhees (eds.) 2015
SEDAR41-RD56	Total Removals of Red Snapper (*Lutjanus campechanus*) in 2014 from the U.S. South Atlantic	SEFSC 2015
SEDAR41-RD57	Assessing reproductive resilience: an example with South Atlantic Red Snapper *Lutjanus campechanus*	Lowerre-Barbiere et al. 2015

SEDAR41-RD58	Overview of sampling gears and standard protocols used by the Southeast Reef Fish Survey and its partners	Smart et al. 2014
SEDAR41-RD59	MRIP Transition Plan for the Fishing Effort Survey	Atlantic and Gulf Subgroup of the MRIP Transition Team 2015
SEDAR41-RD60	Technical documentation of the Beaufort Assessment Model (BAM)	Williams and Shertzer 2015
SEDAR41-RD61	Stock Assessment of Red Snapper in the Gulf of Mexico 1872-2013, with Provisional 2014 Landings: SEDAR Update Assessment	Cass-Calay et al. 2015
SEDAR41-RD62	Excerpt from the December 2013 SAFMC SEDAR Committee Minutes (pages 11-21 where SEDAR 41 ToR were discussed)	SAFMC SEDAR Committee
SEDAR41-RD63	Population structure of Red Snapper (*Lutjanus campechanus)* in U.S. waters of the western Atlantic Ocean and the northeastern Gulf of Mexico	Hollenbeck et al. 2015
SEDAR41-RD64	SEDAR31-AW04: The Effect of Hook Type on Red Snapper Catch	Saul and Walter 2013
SEDAR41-RD65	SEDAR31-AW12: Estimation of hook selectivity on Red Snapper (*Lutjanus campechanus*) during a fishery independent survey of natural reefs in the Gulf of Mexico	Pollack et al. 2013
SEDAR41-RD66	Effect of Circle Hook Size on Reef Fish Catch Rates, Species Composition, and Selectivity in the Northern Gulf of Mexico Recreational Fishery	Patterson et al. 2012
SEDAR41-RD67	Effect of trawling on juvenile Red Snapper (*Lutjanus campechanus*) habitat selection and life history parameters	Wells et al. 2008
SEDAR41-RD68	SEDAR24-AW05: Selectivity of Red Snapper in the southeast U.S. Atlantic: dome-shaped or flat topped?	SFB-SEFSC 2010
SEDAR41-RD69	Hierarchical analysis of multiple noisy abundance indices	Conn 2010
SEDAR41-RD70	Data weighting in statistical fisheries stock assessment models	Francis 2011
SEDAR41-RD71	Corrigendum to Francis 2011 paper	Francis

SEDAR41-RD72	Quantifying annual variation in catchability for commercial and research fishing	Francis et al. 2003
SEDAR41-RD73	Evolutionary assembly rules for fish life histories	Charnov et al. 2012
SEDAR41-RD74	User's Guide for ASPIC Suite, version 7: A Stock-Production Model Incorporating Covariates and auxiliary programs	Prager 2015
SEDAR41-RD75	Standing and Special Reef Fish SSC, September 2015 Meeting Summary (see pages 4-7 for SEDAR 43 review)	Gulf of Mexico Standing and Special Reef Fish SSC
SEDAR41-RD76	Standing and Special Reef Fish SSC, January 2016 Meeting Summary (see pages 2-7 for SEDAR 43 review)	Gulf of Mexico Standing and Special Reef Fish SSC
SEDAR41-RD77	SEDAR 43 Gulf of Mexico Gray Triggerfish Stock Assessment Report	SEDAR 43
SEDAR41-RD78	Review of 2014 SEDAR 31 Gulf of Mexico Red Snapper Update Assessment	Gulf of Mexico Standing and Special Reef Fish SSC
SEDAR41-RD79	Influence of soak time and fish accumulation on catches of reef fishes in a multispecies trap survey	Bacheler et al. 2013

2. Review Panel Report

Executive Summary

The Review Workshop (RW) Panel was presented outputs and results of the SEDAR 41 South Atlantic Red Snapper stock assessment. The primary assessment model used was the Beaufort Assessment Model (BAM), a software package that implements a statistical catch-at-age framework. The formulation is an age-structured population model that is fit using standard statistical methods to data available from surveys and fishing fleets, such as landings, discards, indices of abundance, age compositions, and length compositions. The modeling framework is nearly identical to other common assessment packages, such Age Structure Assessment Program (ASAP) and Stock Synthesis (SS), and the programming language (AD Model Builder) is the same across all three. A secondary, surplus-production model (Stock Production Model Incorporating Covariates, ASPIC) provided a comparison of model results. The Review Panel concluded that the data used in the assessment were generally sound and robust. Likewise, data generally were applied properly and uncertainty in data inputs was appropriately acknowledged. Numerous sensitivity analyses and exploration of alternative scenarios were also presented during the RW, all of which agreed with the base model run conclusions of stock status. Note that a follow-up webinar on 8 April 2016 was necessary to continue discussion of projections and finalize the SEDAR 41 RW process. Based on these results the Review Panel concluded that the stock is overfished and overfishing is occurring. The current level of spawning stock biomass (SSB_{2014}) is estimated to be about 22% of MSST (SSB_{2014}/MSST= 0.22), and the current level of fishing mortality is about 2 ½ times $F_{30\%SPR}$ ($F_{2012-2014}/F_{30\%SPR}$= 2.52). Although the Review Panel concluded that assessment results represent the best available science, there were significant areas of uncertainty identified in both the data and in components to the model. The most significant sources of this uncertainty include: the stock-recruitment relationship, the composition and magnitude of recreational discards, potential changes in CPUE catchability, and the selectivities for the different fishery fleets. The Review Panel recognized that the perception of current selectivity used to derive reference points and projections is conditional on poorly-informed assumptions regarding recent fishing behavior. During the most recent years of the stock assessment series (i.e., the 2010-2014 moratorium), recreational discards are one of the most important and most uncertain sources of information. Also, a strong retrospective pattern in apical F indicates the base BAM model is very sensitive to terminal year of data and suggests higher uncertainty in exploitation status.

2.1 Statements Addressing Each ToR

1. Evaluate the data used in the assessment, including discussion of the strengths and weaknesses of data sources and decisions, and consider the following:
    e) Are data decisions made by the DW and AW sound and robust?

f) Are data uncertainties acknowledged, reported, and within the normal or expected levels?
g) Are data properly applied within the assessment model?
h) Are data input series reliable and sufficient to support the assessment approach and findings?

General comments

Data decisions made by the DW and AW were sound and robust. The Review Panel acknowledges the considerable efforts of the DW and AW to compile the data and evaluate their strengths and weaknesses. The development of input data and parameters for the BAM and ASPIC models required an extremely thorough compilation and evaluation of all available data at the DW. Modifications made subsequently by the AW were fully explained.

Data uncertainties were acknowledged, reported, and were within the normal or expected levels. Where this could be ascertained from information provided to the RW. Data on fishery catches and length/age compositions, and fishery-dependent and independent relative abundance indices, varied widely in coverage and quality. Complex manipulations and standardisation methods were often required to try and develop coherent time series from diverse data sources of differing designs, coverage and accuracy, and the combined data will have biases that in some cases are poorly understood especially in earlier years of the time series. All decisions made by the DW and AW in compiling data were explained and justified in detail. Data quality metrics were provided by the DW in terms of numbers of samples, CVs, or alternative plausible data series or biological parameter values. These were used by the AW to weight data series in the assessment model, estimate the uncertainty in the assessment results using the Monte Carlo/bootstrap method, or to explore the sensitivity of the assessment to data decisions and uncertainty. The sensitivity analyses were carried out altering one input at a time, and did not explore the impact of combinations of adjustments.

The data were properly applied within the assessment model. Any issues with application of the data such as time periods for fitting, use of length and age data from the same sampling schemes, or weighting of data according to data quality metrics, were explored at the SEDAR-41 RW if not previously evaluated by the DW and AW.

Data input series were applied if considered reliable and sufficient to support the assessment approach and findings. Reliability and sufficiency was evaluated based on a-priori criteria where possible, supported by data quality metrics such as numbers of samples or CVs and by model fits. The assessment is supported primarily by a wide range of fishery-dependent data covering landings and discards, and therefore is heavily driven by these data and assumptions related to their reliability and use. An additional fishery-independent trap survey data set unfortunately covers only the period since 2010 due to very low incidence of Red Snapper catches prior to the recent increase in abundance due to strong year classes.

An evaluation of the strengths and weaknesses of the data sources and decisions is given below for each type of data used.

Life history parameters

Life history data and assumptions used in the Red Snapper assessment include stock structure, reproductive biology and natural mortality. The assessment was sensitive to estimates of natural mortality (M) as is generally the case, although sensitivity to trends in M could not be evaluated as there is no information on this. An age-dependent, year-invariant estimate of M was determined by a meta-analysis approach using growth parameters and maximum observed age. Reproductive biology was included in the model by computing total annual egg production at age based on maturity, length, number of batches and batch fecundity, thus allowing the effect of age structure on reproductive output to be reflected in setting SSB reference points and stock status. This represents a significant change from previous assessments. Interannual variation in fecundity, a possible source of uncertainty, was not able to be included as historical information was not available. The low estimate of age at first maturity in females (43% at age 1) was considered by the RW to be unusual for snappers, and it was speculated if it has declined as a compensatory response to heavy exploitation. Annual maturity data from the SERFS chevron trap survey could not be used to test this because sample collections have been from different areas in different time periods.

Fishery removals

Reconstruction of a historical series of commercial and recreational fishery removals (landings and dead discards) was made back to 1950 to allow a sufficient burn-in period for the BAM model as well as to establish a period of stable age structure and low fishing mortality. Creation of a series of removals estimates since 1950 required a large number of decisions to infer historical values from more recent data or to calibrate data series where design has changed. This included calibration factors to adjust NMFS Marine Recreational Fisheries Statistics Survey (MRFSS) surveys catch estimates from 1981 to 2003 to be consistent with catches from the Marine Recreational Information Programme (MRIP: 2004 to present), and to develop combined recreational landings back to 1955 using effort data from the National Survey of Fishing, Hunting, and Wildlife-Associated Recreation Survey (FHWAR: SEDAR41-DW17) combined with average MRFSS and SRHS CPUE data for 1981-83.

The recording of landings of the commercial handline fleets have improved in accuracy over time, and the DW proposed CVs that could be used for MCB uncertainty analysis in the assessment. Recreational landings of headboats are estimated from the Southeast Region Headboat Survey (SRHS) logbook scheme which has improved in quality over time due to introduction of mandatory reporting in 1996 and improved logbook supply from 2008 onwards. Private boat and charter boat landings since early 1980s were estimated from MRFSS/MRIP, which has a robust and peer-reviewed statistical design that has substantially reduced bias and improved precision over time, and for which CVs are estimated directly based on efficient estimators.

Discards estimates are inherently less reliable than landings for both the commercial and recreational fleets, and for the commercial handline fleet involved extrapolating observations for 2002-2009 to other years back to 1992, with zero discards assumed prior to that due to low minimum landing size. Similarly, headboat discard estimates are available from logbooks and some at-sea observation since 2004 but had to be extrapolated back in time based on changes in length frequencies recorded by dockside sampling before and after changes in minimum landing sizes, with zero discards assumed pre-1984. All these data manipulations introduce additional error in the time series. Discards estimates from MRFSS/MRIP are self-reported by anglers intercepted at landing sites and are not verified.

Sample sizes and allocation in MRIP have not been sufficient to provide reliable estimates of Red Snapper landings or discards for the very brief mini-seasons since 2012, and alternative data sources from State surveys were also used for these periods, based on collaboration between MRIP staff and State laboratories which the Review Panel was advised is continuing to develop options for future sampling, which the Review Panel encourages.

Discarding of Red Snapper has increased over time due to changes in minimum landing size to 20 inches in 1992 and increases in abundance of young fish from above-average year classes in some recent years. The introduction of the moratorium in 2010 and 2011, and the small commercial catch limits and recreational bag limits in the mini seasons for 2012 onwards, have resulted in most of the catch now being discarded. Estimates of discards are of poorer quality than for landings, and are often self-reported with no verification although some data are available from at-sea observations. The Review Panel notes that under the current management regime the quality of total fishery removals estimates may therefore have deteriorated significantly. The BAM model has estimated a very strong 2013 year class, based mainly on recreational discards data and CVID Chevron trap survey data. Preliminary 2015 CVID data shown to the Review Panel confirmed this by showing increased numbers of 2-year-olds. The accuracy of future BAM estimates for this year class, and projections of its contribution to future biomass and fishery catches will depend on quality of discard estimates to quantify the fishery removals. The Review Panel supports any initiatives to improve quality of discards estimates particularly as the BAM model requires these and any landings estimates to be treated as precise.

Length and age compositions

The AW used age composition data in preference to length composition data in BAM where both data exist, and length composition data were fitted only for commercial handline from 1984 to 1992, commercial discards in 2009 and 2013, and headboat discards from 2005 to 2014. Age compositions were fitted for commercial handline landings from 1990 onwards, for headboat landings in two widely separated blocks in the 1980s and 2000s, for general recreational landings since 2001, and for the CVID survey from 2010. The CVID age data were found towards the end of the Review Workshop to have not been converted to calendar ages, and revised data were provided along with some preliminary assessment results which indicated some relatively small changes to the overall assessment results and stock status.

The Review Panel heard testimony from recreational and commercial fishermen, documented also in SEDAR 41-RW6, expressing concern that the BAM assessment underestimates the numbers of large, older Red Snappers. In their experience these fish occur more frequently in midwater than is the case for smaller snappers, which are strongly benthic and therefore are less likely to enter traps, and also have behaviour and distribution that makes them less probable to be caught by commercial handline, suggesting that all fisheries have domed selectivity. The scientific sampling of fishery catches shows that the incidence of large snappers is lowest in headboats operating inshore, highest in commercial lines operating in deeper water on average, and intermediate in recreational private and charter boats which typically operate in intermediate depths. The age composition of Red Snappers caught in the Chevron trap survey, which extends across a wide depth range, is closer to the composition of commercial handline. Broad spatial coverage of the commercial fishery and survey has been used by the DW and AW to justify asymptotic selectivity for these catches. The relative selectivity of the different fisheries is shown clearly by the size and age compositions in samples collected over time, but it is more difficult to prove that the commercial fishery and Chevron trap survey have asymptotic selectivity based purely on model diagnostics or spatial fishery distribution. The Review Panel did not see any empirical data from independent studies to confirm the selection pattern for commercial handline or chevron traps. Studies are needed to provide independent data showing how Red Snapper behaviour and depth distribution affects the probability of encounter with a fishing operation or trap, and the probability of being caught when encountering the gear, to help define selectivity patterns and resolve the different perspectives on abundance of large snappers during the rebuilding period. The Review Panel suggests some approaches later in this report.

Relative abundance indices

The Review Panel considers the rationale for including abundance indices from the fisheries-independent combined CVID trap/video survey (2010-2014) and data from three fisheries-dependent CPUE series in the BAM stock assessment model to be reasonable. The combination of trap/video survey indices of abundance for the years 2010-2014 is clearly supported since the video camera is mounted on the traps, and thus cannot be considered independent observations. The three fishery dependent indices of relative abundance consisted of data from headboat logbooks (1976–2009), headboat discards (2005–2014), and commercial handline logbooks (1993–2009). The CPUE series were standardized to account for potential biases related to spatial and temporal coverage, and trip type, among other factors. The application of the method of Stephens and MacCall (2004), which takes into account other species than Red Snapper to subset trips in Red Snapper habitats, seems reasonable. The CPUE series had data gaps that required imputations to fill in the missing data points. The pragmatic method of indexing recreational catches against commercial landings and then applying a multiplier to back calculate historic landings, and the imputed values for years with zero discards based on averaging across the current and two adjacent years were considered to be reasonable. The CPUE values from commercial handline and headboat fisheries are likely to be biased indices of abundance for the stock since relatively more fishing effort will be spent in areas with high catch rates (before the 2010 moratorium) , and since the spatial coverage cannot be controlled like in a fishery-independent survey. HB CPUE series cover shallower waters where younger and smaller Red Snapper occur disproportionately more than in the deeper water where the commercial handline fishery spends more effort. A combination of the CPUE series external to the model based on their spatial/depth coverage is an alternative that might be explored in future assessments.

The various sources of systematic errors (e.g., spatial coverage, selectivity) and random errors (e.g., sample sizes) in each individual relative abundance series are well documented. There is some indication of lower discards in the HB fishery immediately following the moratorium (Figure 1; SEDAR41-DW14), which could suggest changes in fishing patterns to avoid snapper catches. The Review Panel is of the opinion that changes in management actions such as the moratorium, mini-season and reductions in bag limits that are expected to alter fishing behavior and hence catchability in fishery-dependent indices should inform decisions on inclusion of data or periods of data in assessments. A member of the SAFMC stated on record that the behavior of anglers has changed substantially since the moratorium, to avoid catching and discarding Red Snapper. The Review Panel, therefore, considers the fishery CPUE series to be applicable only to 2009, the year before the moratorium. CPUE series are also likely to be affected by technology creep in catchability due to improvements in fishing gear, positioning (GPS) and communication systems, and also by rising fuel costs in recent years.

The application of the data in the model follows common practice and appears sound. However, since the CPUE indices of abundance partly cover different depths/areas it should be noted that they do not individually cover the entire stock. Of particular concern is that the age and length composition of data from the headboat fishery likely differ from the data from the commercial fishery that tends to operate in deeper waters. Also, the precision of the CPUE series differs depending on survey design and sample sizes. The results of the stock assessment modeling depend on the relative weights assigned to different data sets. However, there is no consensus amongst practitioners as to the best approach to data weighting. This stock assessment follows the common practice of weighting compositional catch data and abundance indices in two stages. The input data are first assigned relative weights before the model is run, and then iteratively weighted during a model run to improve model fit. Ideally, stage 1 weighting would use information about sample sizes (primary sampling units, and lower level sample sizes) and the way in which the data were collected (i.e., multi-stage survey designs), through calculated precision and effective sample sizes (Francis 2011; Pennington and Vølstad 1994). In particular, abundance indices by cohorts are likely to have different precision due to differences in the number of primary sampling units (e.g., trips, or trap-sets) where the cohorts are caught (Aanes and Vølstad 2015). In general, the multi-stage sampling can introduce complex correlation structures among cohorts, and drastically reduce the effective sample sizes for estimating compositions, and indices of cohorts (Aanes and Vølstad 2015). This would allow different weighting to each data point. The current assessment appears to largely apply ad-hoc weighting of input data. In particular weighting of the fishery-independent abundance indices (across cohorts) in the base model is poorly justified. The inclusion of CPUE indices with fixed CVs (relative standard error) of 0.2 (i.e., equal weights) follows Francis (2003), based on the argument that the CVs of the fishery dependent indices do not reflect true variation in abundance. However, since sample sizes vary over the years, a fixed CV could cause bias. An estimate of the variance of CPUE indices based only on the between-trip variability in CPUE may indeed underestimate the true variance of the CPUE abundance indices if catchability varies over time, which is likely. Pennington and Godø (1995) estimated the actual variance of survey abundance indices by cross-calibrating independent VPA estimates and survey catch per tow indices. For the current BAM assessment, the fishery-independent trap data could potentially be used for cross-calibration of CPUE indices, but since the fishery-independent index only is considered to be from 2010 onwards this is problematic. A pragmatic alternative to the fixed CV of 0.2 for the CPUE series could be to apply this value for an average sample size (number of trips) for each series, and then adjust the CV for actual sample sizes every year.

The input data series appears adequate to support the assessment results and findings. However, the CPUE series are likely to have large uncertainties as measures of abundance, and the trap/video index only covers the recent years. In particular, the fishery-dependent CPUE abundance indices after 2010 are based on discards, and may be biased downwards if the HB and commercial fishery successfully avoids areas with high abundance of snappers.

2. Evaluate and discuss the strengths and weaknesses of the methods used to assess the stock, taking into account the available data, and consider the following:
    d) Are methods scientifically sound and robust?
    e) Are assessment models configured properly and used consistent with standard practices?
    f) Are the methods appropriate for the available data?

The Review Panel agrees with the DW and AW decisions and confirms that the methods are sound and relatively robust. Many stock assessment decisions are somewhat subjective, but alternative decisions were considered and the final decisions were generally well justified. Sensitivity analyses explored a wide range of data decisions, model assumptions and model configurations to examine the robustness of stock status determination. The Monte Carlo Bootstrap procedure also explored many combinations of alternative data and model assumptions.

The Review Panel concluded that the assessment models were reasonably configured and are consistent with standard practices. The BAM is the approved assessment method for many stocks in the South Atlantic Snapper-Grouper complex and is well suited to the fishery-dependent and fishery-independent information available (e.g., life history information, commercial landings and discards, recreational landings and discards, standardized CPUE indices, trap survey indices, length and age sampling). The model has many assumptions and many estimated parameters, but the base model configuration appears to have reasonable assumptions and parameter estimates. The ASPIC model and an Age-Structured Production Model were also applied to aggregate catch and stock biomass indices to provide alternative perspectives on stock status. However, the age-aggregate models do not consider length and age composition data. Although the interpretation of length and age composition data are conditional on assumed forms of selectivity and estimates of selectivity at age, the Review Panel agrees with the AW that length and age composition information is an important source of information. Catch curves of age composition data were provided as exploratory information on trends in maturity, but results are not considered to be a valid basis for status determination, because estimates are imprecise and the implicit assumption of constant mortality rate at age do not appear to be valid. The BAM base configuration is considered to be the most appropriate basis for status determination, because it fully considers important information on demographic structure, including regulated changes in selectivity, age-based maturity and fecundity, and variable recruitment of new age classes. The base configuration of BAM from the AW (‘base’) was revised with corrected age compositions of the Chevron Trap survey. Results and diagnostics from the AW base model and the corrected base model (‘newbase’) were similar. The review of methods was based on the Assessment Workshop report and the corrected base model, but conclusions from the RW were confirmed with corrected results.

During the most recent years of the stock assessment series (i.e., the 2010-2014 moratorium), recreational discards are one of the most important sources of information for the assessment. Unfortunately, recreational discards are also one of the most uncertain sources of information. Despite the imprecision in estimates of recreational catch, the BAM base configuration is conditional on catch estimates (e.g., the input CV for catch was 0.05). Exploratory analyses that allow error in landings could not produce a solution, but the Review Panel requested an exploratory analysis that allowed error in the estimates of recreational discards, assuming the MRIP estimates of CV. Exploratory assessment models with more or less catch had similar estimates for the last 30 years (BAM runs S17–S20).

Fishery CPUE indices suggest a greater recent increase in stock biomass and lower mortality (BAM run S4). However, the Review Panel agrees that the fishery-independent index is informative and should be included in the assessment model. Considering the Chevron Trap Survey and Video Survey as separate indices (BAM run S22) also estimates a greater recent increase in stock biomass and lower mortality, but the Review Panel agrees that the two series are not independent and should not be considered as separate indicators of stock trends. An alternative model configuration that included the entire series of Chevron Trap Survey provided similar estimates as the base model.

Accurate interpretation of length and age composition data relies on accurate assumptions about the form of selectivity and estimates of selectivity at age in the fisheries and the survey. The commercial fishery is assumed to be asymptotic (i.e., ‘flat topped’), and the model estimated that all Red Snapper older than age-4 have been fully vulnerable to the commercial fishery since the minimum legal size regulation in 1992. The Review Panel agrees that the flat-topped selectivity assumption for the commercial fishery is justified, because the commercial fishery covers the entire resource area and targets large fish. Assuming ‘dome-shaped’ selectivity (i.e., oldest ages are not full vulnerable) for the commercial fishery (BAM run S21) produced similar results as the base model.

Selectivity of the headboat fleet was assumed to be dome-shaped, and the model estimated full selectivity at ages 3-4 and low selectivity of ages 10+. Selectivity of the general recreational fleet was also assumed to be dome shaped until 2010, with full selectivity at ages 3-4 and low selectivity of ages 10+. Results were not sensitive to how selectivity was estimated for ages 10+ (BAM run S31).

Since 2010 (during the moratorium, mini-seasons and 1-fish bag limit), selectivity of the general recreational fleet was assumed to be flat-topped, with full selection at ages 6+. The Review Panel could not agree on whether the flat-topped assumption is well-justified. The Review Panel requested a sensitivity analysis in which selectivity of the recent general recreational fleet was assumed to be the same as the recent headboat fleet.

Results suggest that the model does not fit age composition data well, underestimating catch at older ages, and estimates are not sensitive to the selectivity assumption of the recent general recreational fleet (Appendix A).

The Review Panel recognizes that the perception of current selectivity used to derive reference points and projections is conditional on poorly-informed assumptions regarding recent fishing behavior, and projections of alternative management scenarios should consider alternative selectivity assumptions that are consistent with each scenario. For example, alternatives that do not allow recreational landings (e.g., moratoria with no mini-seasons) should not assume the *status quo* composite selectivity that includes a flat-topped selectivity for general recreational landings.

The form of selectivity of the Chevron Trap Survey was assumed to be flat topped, and the model estimated that all Red Snapper older than age-3 are fully vulnerable to the trap survey. Public comment suggested that traps may not catch large Red Snapper as efficiently as small Red Snapper. However, some of the largest and oldest samples available are from the trap survey, and efforts to estimate lower selectivity of older ages produced estimates near full selectivity.

The flat-topped selectivity assumption for the Chevron Trap survey implies that relative abundance of old fish is represented by the survey. The assumed shift from dome-shaped selectivity to flat-topped selectivity of the general recreational fishery implies that the recent increase in catch of larger and older fish reflects a shift in selectivity, rather than a proportional increase in the abundance of older fish in the population. Alternative interpretations would require evidence that larger, older Red Snapper are not fully vulnerable to the fishery or the survey.

Attempts to sample larger and older Red Snapper than sampled in the fisheries or trap survey have not been successful. Mitchell et al. (2014 Marine and Coastal Fisheries 6: 142-155 and SEDAR41-RD34) investigated length-specific depth distributions of Red Snapper in the South Atlantic region from two fishery-independent surveys targeting hard-bottom habitats, and reported "*no evidence of a positive relationship between depth and age or length. Additionally, age and length distributions of Red Snapper ≥ 50 cm FL did not differ between fishery-independent surveys and the commercial hook-and-line fishery. These results provide no support for assertions of greater abundances of older and larger Red Snapper in deeper SE USA waters*."

The information available on size selectivity of Red Snapper by survey traps is equivocal on the form of selectivity. Wells et al. (2008, Fisheries Research 89: 294–299 and SEDAR31-RD36) compared catch rates of trawls, small fish traps, chevron traps, and underwater video for sampling Red Snapper in the Gulf of Mexico. They concluded that "*the chevron trap is most effective for sampling adults, while trawls were the most effective gear for sampling age-0 fish*." DeVries et al. (2012, SEDAR31-DW28) compared size samples of Red Snapper from traps and cameras and found that "*the traps* *do select against most Red Snapper >650 mm TL, although fish that large appear to be uncommon in the survey area based on the few stereo measurements obtained*" and "*distributions of the trap fish and that from the stereo images, like in 2011, were very similar*." Therefore, there is insufficient evidence to reject the selectivity assumptions in the assessment. However, the assumptions of asymptotic selectivity of the trap survey and recent recreational fishery should be investigated further in future assessments.

3. Evaluate the assessment findings and consider the following:
    a) Are abundance, exploitation, and biomass estimates reliable, consistent with input data and population biological characteristics, and useful to support status inferences?

The Review panel accepted the new base model with the corrected age compositions for the CVID survey index as the best available model to provide advice for the South Atlantic red snapper fishery. However, the review panel did have concerns such as those discussed below.

The recent Red Snapper fishery comprises two periods of distinct exploitation patterns where the period up to and including 2009 consist of commercial and recreational fisheries with a moratorium on fishing from 2010 to the present. Since 2010 removals albeit reduced have continued through mini-seasons and discard mortality from the headboat and general recreational fishery. This change in the fishery has complicated the monitoring of the fishery because the fishery dependent indices (catch rates from the commercial handline, general recreational and headboat fleets) end in 2009. The SERFS combined video and trap survey index, CVID was introduced in this assessment to cover the moratorium period from 2010 to the present. The annual Red Snapper discard rate from the headboat fleet for 2005 to the present is used to link the fishery dependent indices in the earlier period with the CVID during the moratorium period.

The reliability of model estimates of abundance, biomass and exploitation depend on how well the monitoring indices included in the model track the population trends over time. In this assessment fishery dependent catch rates were used for the pre-moratorium period and were replaced by the CVID survey index for 2010 to the present. The MRIP annual red snapper discard rate from the headboat fleet for 2005 to the present was the only index that spanned the two time periods.

The consistency of the stock status determinations for this combination of monitoring indices was evaluated through a series of sensitivity runs. These runs indicated that the determination of stock status was actually fairly insensitive to changes such as using the longer time series for the CVID (S9), removing the CVID (S4), up-weighting the fishery dependent indices (S3), dropping the headboat discard index for 2010 to the present (S12), dropping the headboat discard index altogether (S16) or only using the CVID

(S23). All indices were well fit by the data, except for the headboat discard rate in the most recent years (Figure 13 of document).

All of these results suggest that the population trends in the model results probably have as much or more to do with the very close fit of the model to the landings, discard data, and associated age compositions as they do with the trends in the monitoring data. CVs were set to 0.05 for the landings and discards, which seems unreasonably low for the MRIP estimates of the latter but a higher CV of 0.20 for discards was investigated in MCB study and the results did not indicate a change in stock status from the base case.

b) Is the stock overfished? What information helps you reach this conclusion?

The estimated abundance for 2014 was at levels not seen in the model since the mid-1960s (Fig. 14 in the assessment report) however the 2014 population mainly consisted of ages 1-4 years (96% by number). Despite these high abundance levels the stock is overfished as $SSB_{2014}/SSB_{F30\%}$ =0.16 due to the lack of older fish in the population.

c) Is the stock undergoing overfishing? What information helps you reach this conclusion?

The review panel could not find any evidence against the overfishing determination in the assessment but did have a number serious concerns that are discussed below. The panel also reflected on issues with using apical fishing mortality to monitor the impact of the fishery on the stock over time (*see item e below*)

The determination of overfishing in the assessment relies on the geometric mean of apical F summed across fleets each year over 2012–2014 period. Currently, $F_{2012-2104}/F_{30\%}$=2.52. The retrospective analysis indicated that there was a substantial increase in apical F for 2010 to 2013 with the addition of the 2014 data (Figure 55 in the assessment report). The individual results for the different runs were not presented and it is not known whether the ages at which the apical F's occurred changed with the addition of 2014 data.

Given the retrospective pattern, it is likely that had the red snapper assessment been done a year ago, evidence for overfishing would have been much weaker than presented here. The main change between 2013 and 2014 was that landings and discards by the general recreational fleet were much higher in 2014 vs. 2013 by about 3.7 times for numbers landed and 3.4 times for discard numbers. Estimated increase in weight landed by the general recreational fleet was 3.4 times the 2013 landings. Fishing mortalities associated with general recreational landings and discards make up 78% of the 2014 apical F estimate (Table 14 in the assessment report). The mini-season in 2014 was longer than in previous years and recruits in 2014 were the highest in the time series.

The current determination that overfishing is occurring while the fishery is under moratorium generated much discussion during the panel review. The moratorium has not resulted in a complete closure as there have been landings from mini-seasons in 2011–2014 and removals due to discards during these seasons and throughout the year for recreational fisheries. The estimated fishing mortalities (Figure 27, in the assessment report) reflect the large decrease expected with the introduction of the moratorium in 2010. However since 2010 fishing mortalities have increased from this low point mainly due to discard mortalities and catches from the general recreational fishery. A comparison of mean Fs at ages 1, 2, 3, 4, and 5+ indicates that while fishing mortality was greatly reduced on all age groups in 2010, fishing mortality greatly increased on the older age 4 and 5+ group by 2014 while the Fs for the younger group ages level continued to be lower. The moratorium appears to have been a benefit to the younger fish but not so for fish 4 years and older as interpreted by the selectivity curves used for the moratorium years.

The panel asked for a sensitivity run to investigate the impact of the flat topped selectivity curve assumed for the general recreational fishery by substituting the domed curve used for headboats for 2010–2014. The domed selectivity did not result in any substantial change in stock status from the base case. The fishing mortalities-at-age were not presented by gear so it was not possible to see which age corresponded to apical F for the general recreational landings or discards for either selectivity curve.

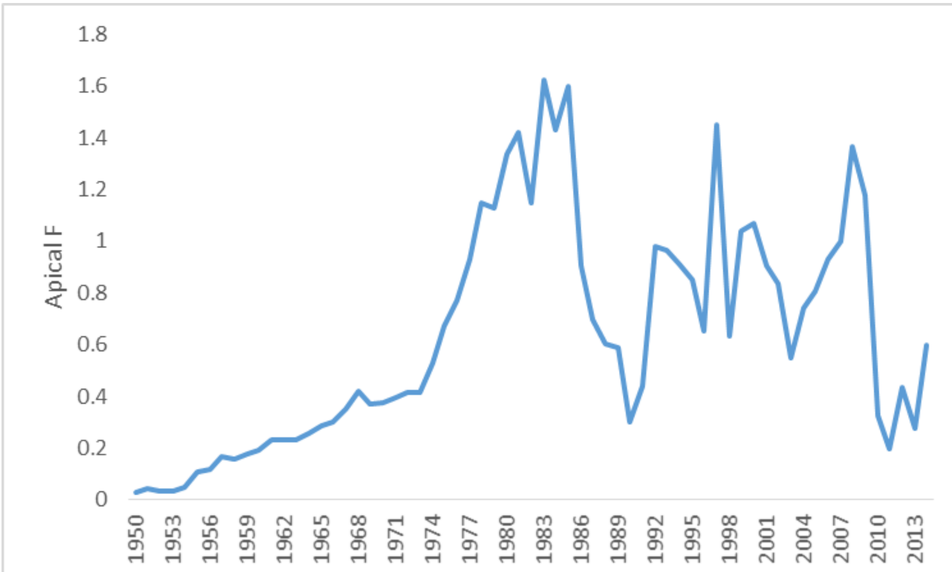
d) Is there an informative stock recruitment relationship? Is the stock recruitment curve reliable and useful for evaluation of productivity and future stock conditions?

The stock recruitment curve was not informative and inference was based on setting steepness to 0.99 and assuming average recruitment. Mean annual recruitment was assumed and lognormal deviations around that mean were estimated in the model.

Recruitment is typically not well estimated in the last year of stock assessments, because there is little information to inform the estimate. The estimate of strong recruitment in the last year of the assessment is supported by the high CVID index as well as the length composition of the headboat fleet. Review Workshop participants reported continued signals of strong recruitment in 2015 fishery and survey data. The Review Panel recognizes that projections are largely dependent on the estimate of recent recruitment, but the estimates of abundance at age from the base model is the most reliable basis for stock status determination and projection.

e) Are the quantitative estimates of the status determination criteria for this stock reliable? If not, are there other indicators that may be used to inform managers about stock trends and conditions?

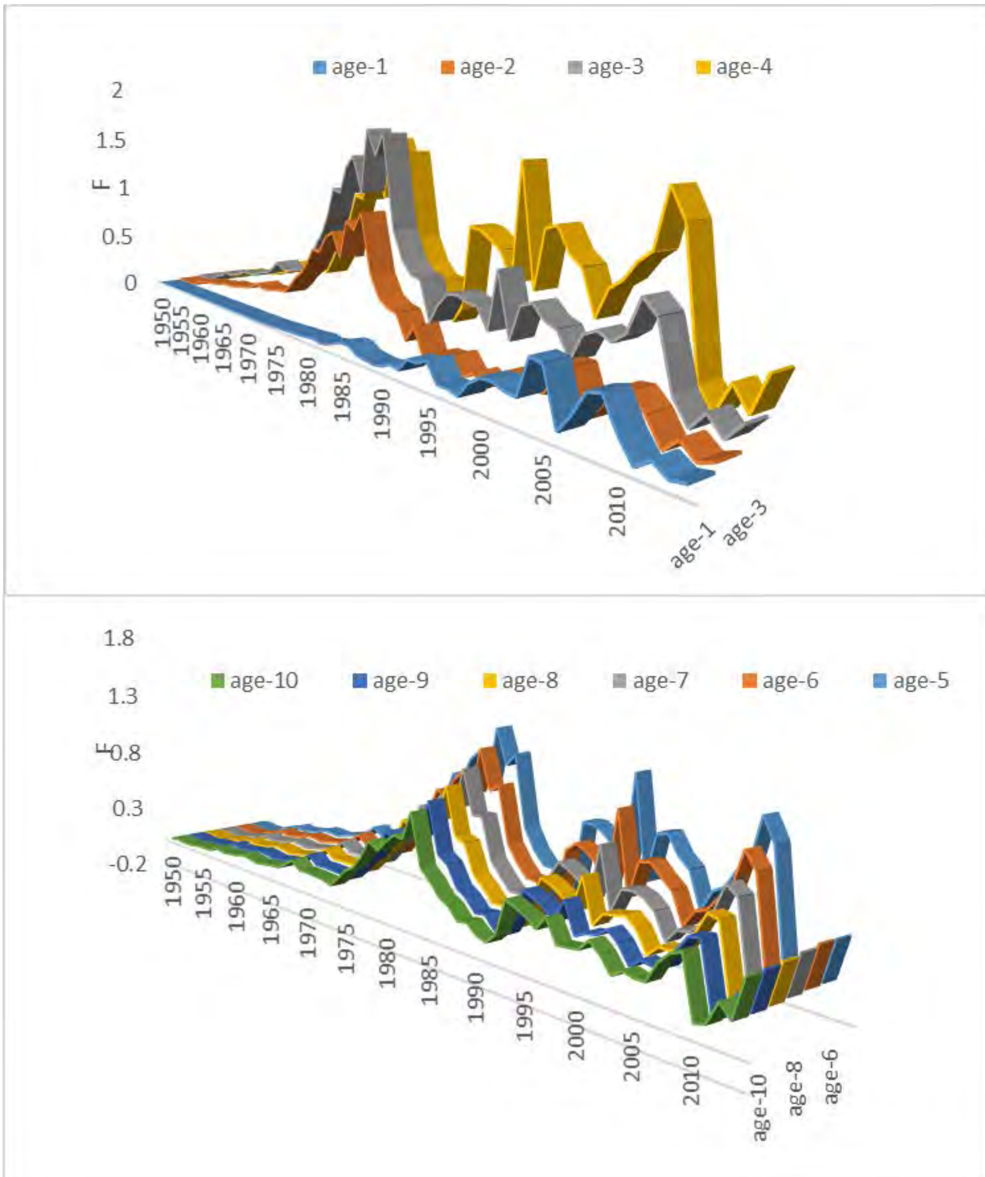
Evaluating trends in F over time requires a metric that is comparable among years and reflects exploitation across a range of ages. Apical F (maximum F at age, Figure 1) is based on a different range of ages among years, because of changing fleet contributions and fleet selectivities. Apical F also does not reflect F for partially selected ages.



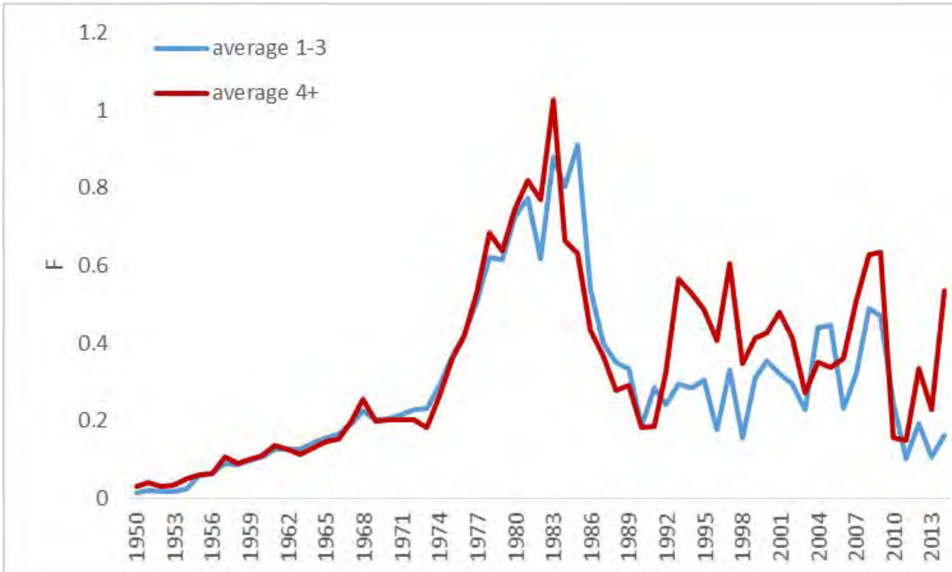
Deciding on a more appropriate metric of F for Red Snapper is challenging because of the complexity of patterns in estimated F at age:

- Age-1 F has one peak in 2004. F was negligible until the mid-1990s, peaked at 0.4 in 2004, then decreased to ~0.1 since 2010.
- Age-2 F had one peak at 1.0 in 1985. F decreased to ~0.1 in the late 1990s, increased to 0.2-0.3 from 1999 to 2010, then decreased to ~0.1 since 2010.
- Age-3 F also had a major peak at 1.6 in the early 1980s, decreased to 0.3-0.5 in the early 1990s, increased to a minor peak of 0.8 in 2008 and decreased to 0.2-0.3 since 2010.
- Age-4 F had three peaks at >1.0 in the early 1980s, 1.5 in 1997 and 1.4 in 2008, then increasing from 0.2 in 2010 to 0.5 in 2014.
- Ages 5 and older have similar patterns in F (three peaks in the early 1980s, 1997 and 2008-2009, then increasing from 2010 to 2014). For most of the time series F

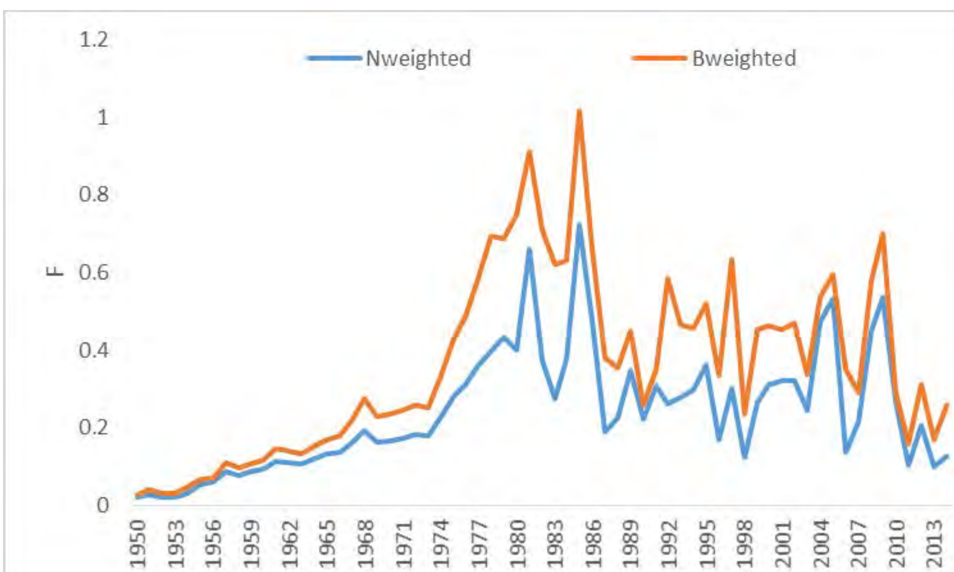
decreases with age, but since 2010, F at ages 5+ is similar, increasing from ~0.2 in 2010 to ~0.5 in 2014.



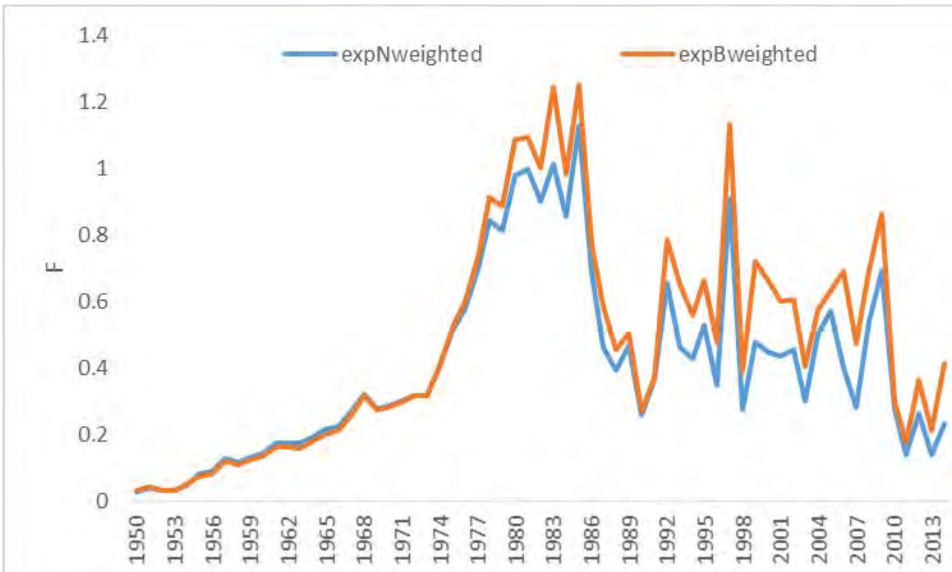
Alternative metrics of F will reflect these patterns differently. Simple average F at age can reflect trends for similar ages (e.g., ages 2-3, ages 4+), and show different recent trends. During the moratorium, F remained low for ages 1-3, but more than tripled for ages 4+.



Average F can be weighted by abundance at age or biomass at age to measure the average F exerted on the entire stock. With young ages typically having greater abundance, abundance weighted average F reflects patterns of F at young ages. Biomass peaks at different ages over the assessment time series (age-20 in 1950, age-2 in 2014), so biomass weighted average F reflects a varying age range.



Average F can also be weighted by exploitable abundance (the product of abundance at age and selectivity at age) or exploitable biomass (the product of biomass at age and selectivity at age) to measure the average F exerted on the exploitable stock. The two exploitable stock average F's are similar, but the exploitable biomass weighted F reflects older ages (e.g., more than doubles during the moratorium) and the exploitable abundance weighted F reflects younger ages (e.g., remains low during the moratorium.



The overfishing limit ($F_{30\%SPR}$) can be expressed in the same currency as the measure of F from the stock assessment. $F_{30\%}$ is currently expressed as Apical F, assuming the average selectivity for the last three years of the stock assessment, which peaks at age-5 (e.g., $F_{30\%}$ expressed as age-5 F is 0.15). All forms of $F_{30\%SPR}$ expressed as an average F are less than age-5 F, because they include some partially recruited ages. According to all of the alternative F metrics considered, overfishing is occurring, but to varying degrees.

Metric	2012-2014 Geo.Mean	F30%	F/F30%
F(age-5)	0.43	0.15	2.8
F(ages 1-3)	0.15	0.06	2.7
F(age-4+)	0.35	0.12	2.8
F(Nwtd)	0.14	0.08	1.8
F(Bwtd)	0.24	0.11	2.1
F(expNwtd)	0.20	0.10	2.0
F(expBwtd)	0.31	0.12	2.5

In conclusion, despite the Review Panel's concurrence that the base BAM configuration can be used for stock status determination the Panel has clearly expressed caveats on some key aspects such as selectivity changes, given the number of parameters being fitted vs. data quality. All the assessment runs clearly show a stock that is abundant at younger ages but overfished in terms of egg production and very slowly recovering. However it is of some concern that the retrospective analysis indicates a substantial upward adjustment of recent F's with addition of 2014 data. Remove 2014 data and the recent Fs are down to around the $F_{30\%}$ reference point (apical values). SSB's are correspondingly adjusted down. The recent strong year classes (age 1 in 2006-2008) appear more stable, but these are feeding progressively into the 5+ age groups from 2010 onwards, the period for which the model sees more adult fish and "wants" to estimate asymptotic selectivity for the general recreational fishery. The Panel expressed concerns that no diagnostics (e.g. parameter correlation tables) were provided to evaluate whether the model has an issue estimating fully selected F's in 2014 vs. recruitment estimates for the strong year classes. There is a potential large uncertainty in the F estimates from the assessment including 2014 data. Some of the age composition data are very well fitted in 2014 – the CVID comps are fitted extremely closely (perhaps too closely!) in 2012 and 2014 and close in 2013, whilst the general recreational age comps are fitted very poorly in 2014 despite a very large sample size and may be an indication of problems with the data for this fishery in 2014. Further, the retrospective analysis indicated that there was a substantial increase in apical F for 2010 to 2013 with the addition of the 2014 data. It is likely that had the red snapper assessment been done up to and including 2013 data, that evidence for overfishing would have been very much weaker than presented here.

4. Evaluate the stock projections, including discussing the strengths and weaknesses, and consider the following:
    e) Are the methods consistent with accepted practices and available data?
    f) Are the methods appropriate for the assessment model and outputs?
    g) Are the results informative and robust, and are they useful to support inferences of probably future conditions?
    h) Are key uncertainties acknowledged, discussed, and reflected in the projection results?

Projections were run to predict stock status in years after the assessment, 2015–2044. The structure of the projection model was the same as that of the assessment model, and parameter estimates were those from the assessment. A single selectivity curve was applied to calculate landings and one for discards, averaged across fleets using geometric mean F's from the last three years of the assessment period, similar to computation of $LF_{30\%}$ benchmarks (§3.22). Expected values of SSB (time of peak spawning), F, recruits, and removals were represented by deterministic projections using parameter estimates from the base run. These projections were built on the spawner-recruit relationship (h =

0.99) with bias correction, and were thus consistent with estimated benchmarks in the sense that long-term fishing at $F_{30\%}$ would yield $LF_{30\%}$ from a stock size at $SSB_{30\%}$. Uncertainty in future time series was quantified through stochastic projections that extended the Monte Carlo/Bootstrap (MCB) fits of the stock assessment model.

The projection method is consistent with those used widely in SEDAR assessments based on statistical models such as BAM and Stock Synthesis, and is consistent with the available data. The method used stochastic projections that extended the Monte Carlo/ Bootstrap (MCB) fits of the assessment model with added stochasticity in recruitment, and hence the propagation of uncertainty from the assessment into the projection period is internally consistent.

The Review Panel concluded that the Red Snapper stock projections provided for SEDAR 41 are appropriate for the BAM assessment model and outputs. The results of the projections are informative and robust, and are useful to support inferences of probable future conditions. The projections provide the information needed to develop management advice, showing projections for F=0; $F=F_{CURRENT}$ (geometric mean of the last 3 years); $F=F_{30\%}$; $F=F_{TARGET}$; $F=F_{REBUILD}$ (max exploitation that rebuilds in greatest allowed time (2044). An additional projection was carried out with F from discards only. Each projection shows the 10th and 90th percentiles of the replicate projections allowing an evaluation of the probability of overfishing occurring, or the stock being overfished, for each year in the rebuilding time frame up to 2044. The projections are robust in terms of propagating realistic levels of uncertainty from the accepted base model run.

Key uncertainties in the projections are acknowledged, discussed, and reflected in the projection results. The MCB runs included ranges of values of natural mortality, discard mortality and fecundity at age agreed by the AW, together with bootstrap selection of data using well-justified error distributions and additional random process error in recruitment conditional on the fitted stock recruit pattern with steepness fixed at 0.99. Initial age structure at the start of 2015 was computed by the assessment model, and fishing rates for the projection started in 2017 following an initialization period in 2015-2016 where fishing mortality rates were derived to represent the management measures in place.

5. Consider how uncertainties in the assessment, and their potential consequences, are addressed.
    c) Comment on the degree to which methods used to evaluate uncertainty reflect and capture the significant sources of uncertainty in the population, data sources, and assessment methods.
    d) Ensure that the implications of uncertainty in technical conclusions are clearly stated.

The Review Panel is concerned that many of the reported uncertainties on quantities of interest are a consequence of the assumed (and fixed) observation variance parameters. No clear evidence of the appropriateness of these assumed values has been presented.

Because of the large number of parameters in BAM a thorough evaluation of convergence and model sensitivity is necessary, but difficult. Uncertainties in the assessment were explored through (1) a mixed Monte Carlo and bootstrap (MCB) analysis to quantify random errors in the assessment output; (2) sensitivity analysis around the base BAM run; and (3) the use of alternative assessment models. The Monte Carlo Bootstrap procedure also explored many combinations of alternative data and model assumptions. In the bootstrapping of observed data on landings, information from the headboat program was used to specify a decreasing CV by time blocks (i.e. CV = 0.15 for 1981-1995, CV = 0.1 for 1996-2007, and CV = 0.05 thereafter). These CVs reflect random errors. However, landings from the headboat fishery are monitored through mandatory logbooks, and thus should in principle have zero sampling errors for the vessels in the sampling frame. The CVs may reasonably reflect random errors in reporting. However, various sources of systematic errors (bias) are not reflected through these CVs. It is known that under-reporting of trips does occur, that catch data may not always be 100% accurate (for example due to recall bias if logbooks are not filled in immediately after each trip), and that other variations in reporting likely occur. Because the distribution of such systematic errors is unknown, it is not possible to quantify the magnitude of the resulting uncertainty in the landings.

The input data on catch composition and abundance indices by cohort are obtained from multi-stage sampling programs where fishing trips typically are the primary sampling units (PSUs) for fisheries data, and locations/standardizes trap catches (90 min soak time) are the PSUs for the chevron trap. Substantial correlations can be expected in age or length composition data sets that are constructed from samples/sub-samples from multiple catches (whether from fisheries-independent surveys or fisheries) (e.g., Aanes and Vølstad 2015). The BAM model itself and the MCB is not likely to realistically account for complex error structure in data weighting without prior estimates of the actual variance-covariance matrices for the input data. The robust multinomial approach with number of PSU's as proxy effective sample sizes employed in the uncertainty evaluation of the BAM can only partly reflect the complex error structure. Ideally, it would be possible to run bootstrap resampling on the PSU's to create replicated BAM runs that reflect the complexity in input data, but given the complexity and configuration of BAM this is not possible. The Review Panel therefore considers the uncertainty in the assessment to be appropriately addressed given these restrictions.

The sensitivity analyses were used to explore a wide range of data decisions, model assumptions and model configurations to examine the robustness of stock status determination. The model was run for a plausible range of values for each factor. The

Review Panel noted that the sensitivity testing by alternating one factor at a time, although commonly done, may not fully reflect the uncertainty in model outputs from a complex model such as BAM with a large number of parameters where many are likely to be correlated (e.g., Saltelli and Annoni (2010). Global sensitivity analysis (Saltelli et al. 2008) may be used to untangle the contribution of single factors/parameters and interactions between parameters to the overall variability in model output. Anderson et al. (2011) provide an excellent overview of the literature, and many examples of applications of global sensitivity analysis to Integrated Assessment Models in climate research, and some of these are likely to be applicable to the BAM model. The following is a description of each of the model runs provided to the reviewers during the course of the RW:

S12: (based on the old base model) The headboat discard index was truncated to only include years 2005-2009.

S16: (based on the old base model) The headboat discard index was dropped entirely.

S32: (based on the old base model) The general recreational fleet was set to have the same selectivity as headboat in the last time block (dome-shaped, 2010-2014).

DroppedHBdiscindex: same as S16, except starting with the new base model (corrected chevron trap age compositions).

TruncatedHBdiscindex: same as S12, except starting with the new base model (corrected chevron trap age compositions).

Model uncertainty was mainly explored by running ASPIC (Version 7.03, 2005) that relies on length-age aggregated catch and CPUE indices, with no compositional catch being included. The ASPIC runs resulted in biomass estimates above B_{MSY} and estimates of F below F_{MSY}, and hence do not place the stock in the "overfished-overfishing" category. The difference between the ASPIC and the BAM results can however be explained by the fact that ASPIC does not take into account the age-structure of the catches and the stock. Thus, a biomass made up largely by recruits can result in a stock status of not overfished-overfishing. In addition to ASPIC, a simple catch curve analysis was performed that tended to support the Z values estimated from the BAM. Therefore, despite the many uncertainties and the concerns expressed above the BAM base configuration is therefore considered to provide the most appropriate basis for status determination, despite many sources of uncertainty.

6. Consider the research recommendations provided by the Data and Assessment workshops and make any additional recommendations or prioritizations warranted.
   a) Clearly denote research and monitoring that could improve the reliability of, and information provided by, future assessments.
   b) Provide recommendations on possible ways to improve the SEDAR process.

The Review Panel considers the first three of the following bullets to be the highest priority for assessment improvement.

- Increased fishery independent information, particularly maintaining reliable indices of abundance and composition data streams.
- Improve the reliability of discard data as an abundance index by improving knowledge of private recreational fisherman behavior.
- Research to determine the spatial distribution (horizontal and vertical) of large adult Red Snapper using tracking and telemetry.
- The Review Panel reiterates various research recommendations focused on Red Snapper population structure in the South Atlantic. Red Snapper were modeled in this assessment as a unit stock off the southeastern U.S. For any stock, variation in exploitation and life-history characteristics might be expected at finer geographic scales. Modeling such sub-stock structure would require more data, such as information on the movements and migrations of adults and juveniles, as well as spatial patterns of larval dispersal and recruitment, and spatially-explicit data of all types used in the assessment model. It is unclear whether a spatially-explicit model would improve the assessment. Given the robust ocean circulation in the South Atlantic Bight conditions creating population sub-structure. The research effort necessary to support such an effort would be extensive and probably unjustified on stock assessment improvement grounds, however, it would be needed to support MPA placement, performance evaluation, etc.
- More research to describe the juvenile life history of Red Snapper is needed, including more work to identify the location of juveniles before they recruit to the fishery.
- The effects of environmental variation on the changes in recruitment or survivorship.
- Investigate possible historical changes in sexual maturity. The current estimate of age of sexual maturity is low and unusual for other Lutjanids. Is it right or a compensatory response to heavy exploitation?
- Continue conducting studies to develop a time series of batch fecundity to obtain information on the inter-annual variation in reproductive output.

7. Consider whether the stock assessment constitutes the best scientific information available using the following criteria as appropriate: relevance, inclusiveness, objectivity, transparency, timeliness, verification, validation, and peer review of fishery management information.

The Review Panel considers that the BAM assessment for Red Snapper constitutes the best scientific information available, and fulfils the following criteria:

Relevance: The SEDAR 41 assessment is highly relevant as the Red Snapper stock is depleted and undergoing rebuilding under a moratorium with limited landings permitted and most catches being discarded. The data and assessment provide the best means of establishing the rate of recovery of the stock, determining if measures are preventing overfishing, and providing information that can be used to adjust management actions where appropriate.

Inclusiveness: The SEDAR 41 assessment includes all data that have been quality assured and proved adequate for use in the assessment. This includes data from State as well as Federal sampling schemes where needed, for example to estimate discards during the mini-season where MRIP sampling is too limited for such a short season length.

Objectivity: The SEDAR 41 BAM model is a highly objective procedure based on well-tested statistical modeling principles, and using data sets and assumptions that have been rigorously documented and reviewed through the SEDAR data, assessment and peer-review process. Where fully objective decisions are difficult to make, such as some decisions on scenarios for historic catches where evidence is lacking, the uncertainties around the decisions made have been explored and included in sensitivity analyses and the Monte Carlo Bootstrap evaluation of assessment uncertainty.

Transparency: All outputs of the data, assessment and review workshops in SEDAR 41 are fully documented and publicly available. The discussions at the review workshop are also recorded for record. All data sets are thoroughly explored and the quality of data on which the assessment is based is documented and transparent, as are all decisions related to the choice of assessment model, how it is implemented, and the results of the base run and sensitivity and uncertainty analyses.

Timeliness: The SEDAR process in general is arranged to provide timely fishery management advice where it is needed, and to ensure that assessments are benchmarked and reviewed at appropriate intervals.

Verification: The SEDAR 41 assessment process and deliverables comply with legal requirements under the Magnuson Stevens Act (2007) for developing and monitoring of fishery management plans and providing information on stock status.

Validation: The SEDAR 41 process is designed to meet the needs of fishery managers for peer-reviewed stock assessments and associated advice on stock status and future catches, and the process is open and fully transparent to the fishery managers and to stakeholders from commercial and recreational fisheries, conservation groups or others with a stake in the outcomes and who have opportunity to give their views on record.

Peer review: The SEDAR 41 process includes full peer-review by experts appointed by the Center for Independent Experts (CIE, University of Miami) and by reviewers from the SAFMC SSC. The review panel report and the independent CIE reviews are publicly available

8. Compare and contrast assessment uncertainties between the Gulf of Mexico and South Atlantic stocks.

   Both the South Atlantic and Gulf of Mexico Red Snapper stock assessments have multiple uncertainties. The table below summarizes the significant sources of assessment uncertainty in the population, data sources, and assessment methods for both stocks.

Sources of Uncertainty	**South Atlantic (SEDAR 41)**	**Gulf of Mexico (SEDAR 31)**
Population	• Juvenile life history, including the location of juveniles before they recruit to the fishery • Spatial distribution (horizontal and vertical) of large adult Red Snapper • Variability in batch fecundity and spawning frequency with size and age • Effects of environmental variation on changes in recruitment • Density-dependent changes in growth, reproduction, and natural mortality	• Population structure and connectivity between eastern and western Gulf (for both adults and juveniles) • The use and effect of artificial reef structures on red snapper population abundance, age and length composition, and spatial distribution Effects of environmental variation on changes in recruitment • Density-dependent changes in growth, reproduction, and natural mortality
	• Limited fishery independent indices of abundance • No fishery independent index of abundance for early juveniles	• Limited fishery independent index of abundance for early juveniles • Limited information on the magnitude, size, and age composition of discards

Data Sources	• Changes in selectivity, catch, and discard data due to changes in fisher behavior within and outside the mini-season • Poor information on the magnitude, size, and age composition of discards • Poorly-informed selectivity functions for most fleets	• Poorly-informed selectivity functions for most fleets
Assessment Methods	• Uninformative Stock-Recruitment relationship (had to use proxy reference points) • Uncertainty for certain parameters and data inputs was fixed to chosen values that could be considered arbitrary (e.g., CV for landings and discards set = 0.05) • Model uncertainty was mainly explored by running an alternative Stock Production Model	• Uninformative Stock-Recruitment relationship (had to use proxy reference points) • Uncertainty for certain parameters and data inputs was fixed to chosen values that could be considered arbitrary (e.g., CV for landings set = 0.05 and for discards = 0.5) • Model uncertainty was not explicitly explored by the use of different models

9. Provide guidance on key improvements in data or modeling approaches which should be considered when scheduling the next assessment.

The RW Panel recommends that given the data and model complexities inherently associated with stock assessment of South Atlantic Red Snapper, more realistic timelines be considered for the next assessment.

Additionally, given that the input data on catch-at-age and abundance indices by cohort are likely to be cluster-correlated (Nelson 2014), and therefore have low effective sample sizes, it is problematic that the BAM model has a very large number of parameters. It would therefore make sense to provide alternative runs using more parsimonious models to get a wider evaluation of the robustness of the assessment. One recommended candidate is a statistical assessment model (XSAM) (Sondre Aanes, Norwegian Computing Center) recently applied in the ICES Benchmark Assessment for Norwegian Spring Spawning Herring, and approved as the standard assessment model. This model template is based on a state-space model and structural time series models for fish stock assessment (inspired by Gudmundsson 1994), and includes the DTU Aqua SAM model (Nielsen and Berg 2014) that is widely used in ICES as a special case. The main advantage of this XSAM model template is that it can utilize the sampling distributions derived from analysis of sample survey data (estimated catch-at-age, and abundance indices at age) by giving appropriate weights to input-data points. It is coded in TMB (R library) which is efficient for nonlinear models with latent variables.

Another important point in addressing future assessments of South Atlantic Red Snapper is that it would be extremely useful for the Review Panel to see direct estimates of total removals by age-class across fleets (each fleet is essentially a stratum when it comes to estimating the age-composition of removals). This would allow the Panel to see how well cohorts are tracked in the fisheries data. The selectivity by fleet is only relevant when trying to use the fishery-dependent data as indices of abundance. However, selectivity in this context is muddled by the spatial coverage of each fleet. For example, two fleets using same gear (with same selectivity) would end up with different age-compositions if they operate in different areas (depths), if in fact the population by age-class differs by area (depths), which seems to the case for Red Snapper. Therefore, the Review Panel has struggled to understand how multiple abundance indices from fisheries-dependent data that each only covers portions of the stock can be pooled within the BAM model to yield representative indices for the entire stock. In the suggestions made above regarding the use of alternative assessment models (Gudmundsson 1994, and refinements by Aanes), input data from fisheries are total estimates across fleets of yearly removals by age-class and have an associated variance-covariance matrix that reflects the complex cluster sampling.

Another recommendation from the Review Panel concerns the process used for standardization of the CVID index of abundance. The CVID index was derived from fitting a Zero-Inflated Negative Binomial (ZINB) generalized linear model to individual catches with polynomials (degree) of depth (3), temperature (2) and Latitude (7) fit to catches greater than zero and polynomials (degree) of depth (3) and Latitude (4) fit to the zero-inflation portion of the model. Standardized index for each year was based on converting each covariate (all continuous except year) to a sequence of a small number of evenly space values over the range of each covariate over all the years. These converted covariates were used to predict catches over all years with the effect added and then averaged within each year to give annual indices. The variances of these indices were estimated by bootstrapping observed catches and associated covariates and running each bootstrap through the above process. This standardization approach amounts to predicting the catch expected for the mean of the converted covariates. Bootstrapping the individual Chevron trap sets implicitly assumes that the covariates are a random sample from a population of potential covariate values. In this case, the range of covariate values will vary over bootstrap samples and so will mean of the converted covariates. This may be appropriate in a case of a one-off analysis of the survey data for any one year but the focus of standardization is to have a fixed set of covariate variables. In addition, changes in the range of the covariates in the bootstrap samples may not support the original fitted model, especially for coefficients of high degree polynomials.

As an alternative, bootstrapping of the residuals from the original model fit to the data may be more appropriately estimate the variance of the standardized survey index. In this case the residuals (in the appropriate scale) are randomly combined with the predicted values to give new observations that are then used to fit the ZINB model. The range of the covariates and mean of the converted covariates will stay the same over all of the bootstrap replications and the variances of the annual indices will be a function of the variability of the residuals from the fitted model.

10. Prepare a Peer Review Summary summarizing the Panel's evaluation of the stock assessment and addressing each Term of Reference. Develop a list of tasks to be completed following the workshop. Complete and submit the Peer Review Summary Report in accordance with the project guidelines.

    This report constitutes the Review Panel's summary evaluation of the stock assessment and discussion of the Terms of Reference. The Review Panel will complete edits to its report and submit a final document to the SEDAR program for inclusion in the full set of documents associated with SEDAR 41.

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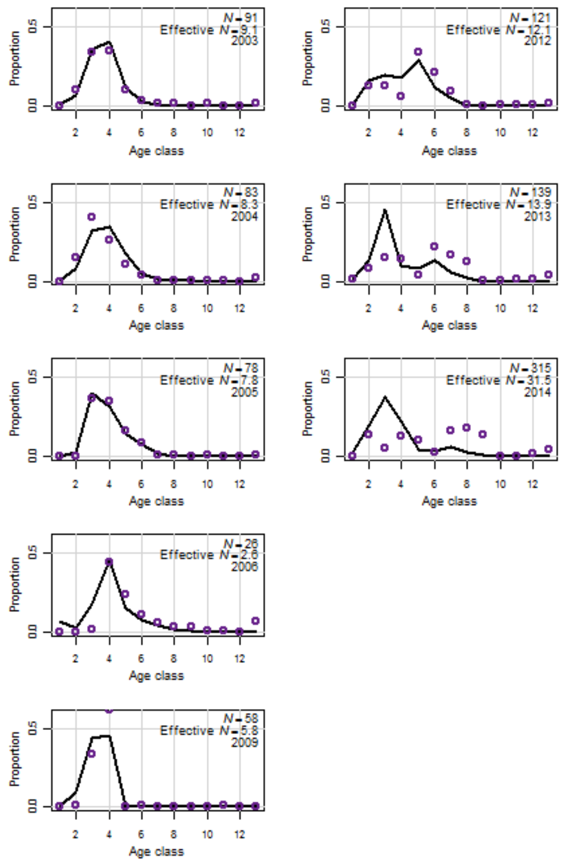
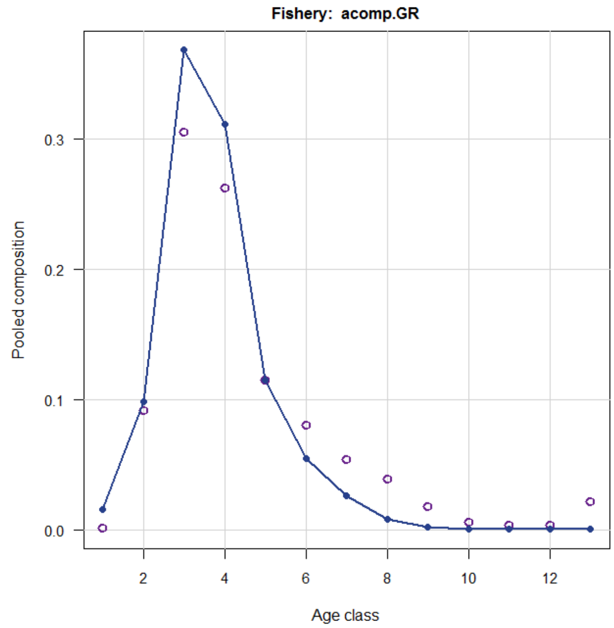
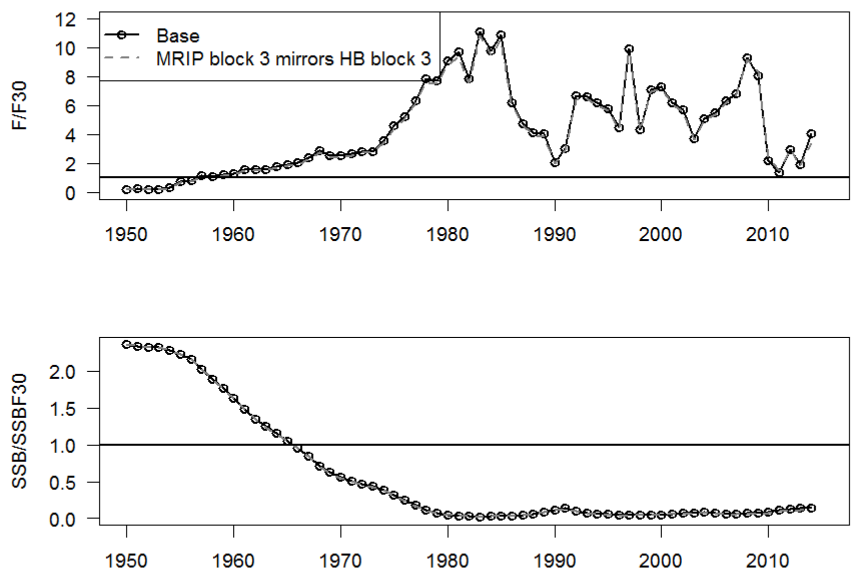
2.2 Summary Results of Analytical Requests

Additional analyses were provided to the Review Panel for consideration at the Panel's request. These materials are provided in Appendix A to the Review Workshop Report.

Appendix A. BAM sensitivity run assuming that selectivity of the general recreational fleet 2010-2014 is the same as the headboat fleet (block 3).




Fishery: acomp.GR
Pooled composition
Age class


Base
MRIP block 3 mirrors HB block 3
F/F30
SSB/SSBF30

SEDAR

Southeast Data, Assessment, and Review

SEDAR 41

South Atlantic Red Snapper

SECTION VI: Addenda 1

April 2016

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

Stock Assessment of Red Snapper off the Southeastern United States

SEDAR Benchmark Assessment

Southeast Fisheries Science Center

National Marine Fisheries Service

Last revision: April, 2016

Document History

February, 2016 Original release.

March, 2016 This release incorporates some of the corrections made during the Review Workshop, including corrected age composition data from the MARMAP program.

April, 2016 This release incorporates all of the corrections made during the Review Workshop, including corrected chevron trap age composition data. The corrections resulted in a new base run, for which iterative reweighting of the likelihood components and the starting value analysis were re-run. The new base run results, including updated uncertainty analyses and projections are included. The sensitivities and retrospectives, however, are unchanged. The Reviewers did not request that sensitivities or retrospectives be re-run because the base run changes were relatively small.

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2 Data Review and Update

The input data for this assessment are described below, with focus on modifications from the SEDAR41 DW.

2.1 Data Review

In this benchmark assessment, the Beaufort assessment model (BAM) was fitted to data sources developed during the SEDAR 41 DW with some modifications and additions.

Model input compiled during the DW

- Life history: Life history meristics, population growth, female maturity, proportion female, number of batches at age, size-dependent batch fecundity, and discard mortality
- Landings and discards: Commercial handline landings and discards, Headboat landings and discards, Recreational landings and discards
- Indices of abundance: Commercial handline, Headboat, Headboat discards, SERFS chevron trap, SERFS video

Model input modified or developed after the DW

- Life history: Fishery-dependent growth estimates, Growth estimates during the 20 inch size regulation, Age–specific natural mortality
- Landings and discards: changes to the recreational discards
- Indices of abundance: Fishery–independent indices combined (Chevron trap and Video)
- Length compositions: Commercial handline, Headboat, Recreational
- Age compositions: Commercial handline, Headboat, Recreational, Chevron trap

2.2 Data Update

2.2.1 Life History

Estimates of the von Bertalanffy growth parameters were provided by the DW for the population as a whole: (911mm, 0.24yr^{-1}, and -0.33yr). Two alternative von Bertalanffy curves were generated: one for all fisheries when no size limit was in place, and another to represent the fish captured by all fisheries under a 20 inch size limit regulation. Age-specific mortality was updated due to an error in the original calculation which forced the t_0 value to 0. Life-history information is summarized in Tables 1 and 2.

2.2.2 Landings and Discards

The fleet structure to be modeled was decided after the DW. The general recreational fleet comprises the charterboat and private boat fleets, while the headboat fleet stands alone. The decision was made to separate headboat from all other recreational fishing modes because length compositions diverge later in the time series. The general recreational fleet discards contained some zeros (years 1982, 1986, and 1990) that the panel considered unlikely to be accurate due to the magnitude of the surrounding years' values. The decision was made by the panel to fill in the zeros with the lowest observed discards in the regulatory time block of the zero value. Total removals as used in the assessment are in Table 3.

2.2.3 Indices of Abundance

The DW provided a SERFS chevron trap and video index separately. However, because the data are collected from the same sampling platforms (i.e. cameras mounted on the chevron traps), the two indices are not independent measures of abundance. Therefore, the panel decided to combine the two using the Conn (2010) method for combining indices. All indices and their corresponding CVs are shown in Table 4, and Figure 1 shows the indices as recommended by the data workshop plotted with the new CVID index for comparison. Fishery dependent indices of abundance were assumed to have CVs of 0.2, which is consistent with Francis (2003).

2.2.4 Length Compositions

Length compositions for all data sources were developed in 3-cm bins over the range 21–99 cm (labeled at bin center). All lengths below and above the minimum and maximum bins were pooled. The commercial handline, general recreational and headboat lengths were weighted by the region and landings (SEDAR41-AW05 2015). For inclusion, length compositions in any given year had to meet the sample size criteria of $nfish > 30$ and $ntrips \geq 10$ (Table 5). Furthermore, the AW panel decided to eliminate length comps where age comps were available. There were conflicts between the length compositions and age compositions, and the panel thought, given the relative ease of ageing this species and the fact the model is age-structured, the age compositions would provide more informative signals of year-class strength and better represent the catch in each fleet or survey.

2.2.5 Age Compositions

For age composition data, the upper range was pooled at 13 years old because a very small proportion of the data exist past age 13. The age compositions were weighted by the length compositions in attempt to address bias in selection of fish to be aged. For inclusion, age compositions in any given year had to meet the sample size criteria of $nfish > 10$ and $ntrips \geq 10$ (Table 5). Age composition was preferred over length composition when both were available from a given fleet in a given year. Age compositions were further corrected at the Review Workshop (SEDAR41-RW07 2016).

2.2.6 Additional Data Considerations

Size limits were in place beginning in 1983 (12 inch minimum size limit TL), and changed in 1992 (20 inch minimum size limit TL). A moratorium was put in place for Red Snapper in 2010, and three subsequent mini-seasons were allowed (2011-2014) with no size limit. The panel examined size composition data and determined that three time blocks should be used to account for size limits, or the lack thereof: 1950-1991, 1992-2009, and 2010-2014. Data available for this assessment are summarized in Tables 1–5.

3 Stock Assessment Methods

3.1 Overview

The primary model discussed during the Assessment Workshop (AW) was a statistical catch-age model implemented using the Beaufort Assessment Model (BAM) software (Williams and Shertzer 2015). BAM applies a statistical catch-age formulation, coded using AD Model Builder (Fournier et al. 2012). BAM is referred to as an integrated analysis because it uses all population dynamics-relevant data (e.g. removals, length and age compositions, and indices of abundance) in a single modeling framework. In contrast, production models (e.g. ASPIC or ASPM) or catch curve analyses only use subsets of the available data and often require simplifying assumptions. In essence, the catch-age model simulates a population forward in time while including fishing processes (Quinn and Deriso 1999; Shertzer et al. 2008). Quantities to be estimated are systematically varied until characteristics of the simulated population matches available data on the real population. The model is similar in structure to Stock Synthesis (Methot 1989; 2009). Versions of BAM have been used in previous SEDAR assessments of reef fishes in the U.S. South Atlantic, such as Red Porgy, Black Sea Bass, Tilefish, Blueline Tilefish, Gag, Greater Amberjack, Red Grouper, Snowy Grouper, and Vermilion Snapper, as well as in the previous SEDAR assessments of Red Snapper (SEDAR24 2010). In addition, a surplus production model implemented using ASPIC and a catch curve analysis (SEDAR41-AW08 2015) were used to provide supplementary information.

3.2 Data Sources

The catch-age model included data from three fleets that caught Red Snapper in southeastern U.S. waters: general recreational (charter and private boat), commercial handlines (hook-and-line), and recreational headboats. The model was fitted to data on annual landings (in numbers for the recreational fleets, in whole weight for commercial fleet); annual discards (in numbers for all fleets), annual length compositions of removals; annual age compositions of landings and surveys; three fishery dependent indices of abundance (commercial handlines, headboat, and headboat discards); and one fishery independent index of abundance (combined SERFS chevron trap and SERFS video index). Removals included landings and dead discards, assuming the mortality rates provided by the Data Workshop. Data used in the model are tabulated in §2 of this report.

3.3 Model Configuration

The assessment time period was 1950–2014. A general description of the assessment model follows.

3.4 Stock dynamics

In the assessment model, new biomass was acquired through growth and recruitment, while abundance of existing cohorts experienced exponential decay from fishing and natural mortality. The population was assumed closed to immigration and emigration. The model included age classes $1 - 20^+$, where the oldest age class 20^+ allowed for the accumulation of fish (i.e., plus group).

3.5 Initialization

Initial (1950) numbers at age assumed the stable age structure computed from expected recruitment and the initial, age-specific total mortality rate. That initial mortality was the sum of natural mortality and fishing mortality, where fishing mortality was the product of an initial fishing rate (F_{init}) and F-weighted average selectivity. The initial fishing rate was estimated using a prior centered around $F_{\text{init}} = 0.03$. The assumption matches what was used for SEDAR24 with the justification that the value should be small given the relatively low volume of landings prior to the assessment period. The initial recruitment in 1950 was assumed to be the expected value from the spawner-recruit curve. For the remainder of the initialization period (1950–1977), recruitment was assumed equal to expected values. Without sufficient age/length composition data prior to 1978, there is little information to estimate those historic recruitment deviations with accuracy.

3.6 Natural mortality rate

The natural mortality rate (M) was assumed constant over time, but decreasing with age. The form of M as a function of age was based on Charnov et al. (2013), a change from SEDAR24 which based natural mortality on the findings of Lorenzen (1996). The Charnov et al. (2013) approach inversely relates the natural mortality at age to somatic growth. As in previous SEDAR assessments, the age-dependent estimates of M_a were rescaled to provide the same fraction of fish surviving from age 4 through the oldest observed age (51 yr) as would occur with constant $M = 0.134$. This approach using cumulative mortality allows that fraction at the oldest age to be consistent with the findings of Then et al. (2014).

3.7 Growth

Mean size at age of the population, fishery removals under no size limit, and fishery removals under a 20 inch size limit (total length, TL) were modeled with the von Bertalanffy equation, and weight at age (whole weight, WW) was modeled as a function of total length (Figure 2, Table 2). Parameters of growth and conversions (TL-WW) were treated as input to the assessment model. For fitting length composition data, the distribution of size at age was assumed normal with a CV estimated by the assessment model for each growth curve.

3.8 Female maturity and sex ratio

Female maturity was modeled with a logistic function; parameters for this model and a vector of maturity at age were provided by the DW and treated as input to the assessment model (Table 2). The sex ratio was assumed to be 50:50, as recommended by the DW.

3.9 Spawning stock

Spawning biomass was modeled as population fecundity (number of eggs). For Red Snapper, peak spawning was considered to occur at the end of June. This included information on batch size as a function of age, as well as information on the number of annual batches as a function of age (SEDAR41-DW49 (2015) and Fitzhugh et al. (2012)).

3.10 Recruitment

Expected recruitment of age-1 fish was predicted from spawning biomass using the Beverton–Holt spawner-recruit model. Steepness, h, is a key parameter of this model, and unfortunately it is often difficult to estimate reliably (Conn et al. 2010). In this assessment, many initial attempts to estimate steepness resulted in a value near its upper bound of 1.0, indicating that the data were insufficient for estimation. Likelihood profiling showed that the value was likely above 0.92, and was unreliably estimated between 0.92 and 0.98. The AW Panel decided to assume an average annual recruitment while estimating lognormal deviations around that average. This was achieved by fixing steepness at $h = 0.99$.

3.11 Landings

Time series of landings from three fleets were modeled: commercial handline (1950–2014), general recreational (1955–2014), and headboat (1955–2014). Landings were modeled with the Baranov catch equation (Baranov 1918) and were fitted in either weight or numbers, depending on how the data were collected (1000 lb whole weight for commercial fleets, and 1000 fish for recreational). The DW provided observed landings back to the first assessment year (1950) for the commercial fleet and back to 1955 for the recreational fleets. However, sampling of headboats began in 1972 and other recreational sectors in 1981. Thus, historic landings of the recreational fleets were estimated indirectly by the DW using the FHWAR ratio method (SEDAR41 41dw17). Historic landings were considered (and treated) in this assessment as a primary source of uncertainty.

3.12 Discards

As with landings, discard mortalities (in units of 1000 fish) were modeled with the Baranov catch equation (Baranov 1918), which required estimates of discard selectivities and release mortality probabilities. Discards were assumed to have fleet-specific, year-specific mortality probabilities, as suggested by the DW. Until 2007, the rate for commercial handlines was 0.48, and 0.38 thereafter. Until 2011, the general recreational and headboat rate was 0.37, with 0.285 thereafter. Annual discard mortalities, as fit by the model, were computed by multiplying total discards (tabulated in the DW report) by the fleet-specific and year-specific discard mortality rate. For general recreational and headboat fleets, discard time series were assumed to begin in 1981; for the commercial handlines fleet, discards were modeled starting in 1992 corresponding to the implementation of the 20-inch size limit.

3.13 Fishing

For each time series of removals (landings and discards), the assessment model estimated a separate full fishing mortality rate (F). Age-specific rates were then computed as the product of full F and selectivity at age. The across-fleet annual F was represented by apical F, computed as the maximum of F at age summed across fleets.

3.14 Selectivities

Selectivity curves applied to landings were estimated using a parametric approach. This approach applies plausible structure on the shape of the curves, and achieves greater parsimony than occurs with unique parameters for each age. Flat-topped selectivities were modeled as a two-parameter logistic function. Dome-shaped selectivities were modeled by combining two logistic functions: a two-parameter logistic function to describe the ascending limb of the curve, and a two-parameter logistic function to describe the descending limb. To model landings, the AW Panel recommended flat-topped selectivity for commercial handlines and dome-shaped selectivity for headboat and the general recreational fleets.

The assessment panel devoted substantial discussion and exploration to the pattern (flat-topped or dome-shaped) of selectivity at age. Several working papers and scientific literature (SEDAR24-AW05, SEDAR24-AW09, SEDAR24-AW12, SEDAR31-AW04, SEDAR31-AW12, SEDAR41-DW50, SEDAR41-DW08, Patterson et al. (2012), Wells et al. (2008), and Mitchell et al. (2014)) helped guide the panel's decisions by providing insight into selectivity based on length and age compositions, depth distributions of fishing effort, skill levels of fishermen, and how circumstances contrasted between the Atlantic and Gulf of Mexico. The choice of flat-topped selectivity for commercial handlines landings and dome-shaped for all others was based on several criteria. Two related considerations were the fleet-specific depths of fishing effort and the distribution of age at depth. In general, the commercial handlines fleet fish

in deeper water than other fleets, and although there was only weak correlation between depth and age of older fish (5^+), younger fish (1–5) were more readily caught in shallower depths (SEDAR24-AW05, and Mitchell et al. (2014)). It was also suggested that commercial gear and fishermen can better handle larger fish (SEDAR24-AW12). Catch curve data were consistent with the hypothesis that older fish are more vulnerable to the commercial handlines fleet than to recreational fleets (SEDAR41-AW08 2015).

Selectivity of each fleet was fixed within each block of size-limit regulations, but was permitted to vary among blocks where possible or reasonable. Fisheries experienced four blocks of size-limit regulations (no limit prior to 1983, 12-inch limit during 1983–1991, 20-inch limit during 1992–2009, and no size limit during the moratorium/miniseasons 2010–2014). However, the panel combined blocks one and two after seeing that the 12-inch size limit had a negligible effect on the selectivity pattern. Age and length composition data are critical for estimating selectivity parameters, and ideally, a model would have sufficient composition data from each fleet over time to estimate distinct selectivities in each period of regulations. That was not the case here, and thus additional assumptions were applied to define selectivities, as follows. Because the general recreational fleet had little age or length composition data prior to 1998, this fleet mirrored the headboat fleet until the final time block. All domed-shaped selectivities meant to characterize landings were configured so as not to allow a selectivity of 0 at older ages, which was considered implausible. Size and age composition data show larger, older fish are caught by all fleets. However, the selectivity functions would reach zero before the plus group age of 20. Therefore, the panel examined the age composition data and used the information they contained to create a plus group for the selectivities. Headboat selectivities were fixed as constant after age 10 at the value estimated for age 10. For the general recreational fleet, the constant age at which we fixed selectivity was 13. These plus groups were consistent with how the age composition data were fitted.

Selectivities of discards were estimated in a similar fashion to the landings in that the general recreational fleet discards mirrored the headboat fleet discards. Both the commercial handline discards and the headboat discards had sufficient length composition to estimate selectivities.

Selectivities of fishery dependent indices were the same as those of the relevant fleet. The fishery independent CVID index selectivity was assumed logistic and informed by the SERFS chevron trap age compositions.

3.15 Indices of abundance

The model was fit to three fishery dependent indices of relative abundance (headboat 1976–2009; headboat discards 2005–2014; and commercial handlines 1993–2009), and one fishery independent index of abundance (SERFS combined video and trap, CVID). Predicted indices were conditional on selectivity of the corresponding fleet or survey, and were computed from abundance at the midpoint of the year or, in the case of commercial handlines, biomass. The headboat discard index tracks small fish (less than 20 inches) and was included as a measure of recruitment strength.

3.16 Catchability

In the BAM, catchability scales indices of relative abundance to the estimated population at large. For the base model, the AW Panel recommended a time-invariant catchability.

A sensitivity run adopted a time-varying catchability for the headboat index. In this formulation, catchability was estimated in two stanzas, pre- and post-1992. Choice of the year 1992 was based on the implementation of a fishery management plan that may have changed fishing behavior.

3.17 Biological reference points

Biological reference points (benchmarks) were calculated based on the fishing rate that would allow a stock to attain 30% of the maximum spawning potential which would have been obtained in the absence of fishing mortality. Computed benchmarks included the MSY proxy, fishing mortality rate at $F_{30\%}$, total biomass at $F_{30\%}$, and spawning stock at $F_{30\%}$ (Gabriel and Mace 1999). In this assessment, spawning stock measures total eggs of the mature stock. These benchmarks are conditional on the estimated selectivity functions and the relative contributions of each fleet's fishing mortality. The selectivity pattern used here was the effort-weighted selectivities at age, with effort from each fleet estimated as the full F averaged over the last three years of the assessment.

3.18 Fitting criterion

The fitting criterion was a penalized likelihood approach in which observed removals (landings and discards) were fit closely, and observed composition data and abundance indices were fit to the degree that they were compatible. Removals and index data were fit using lognormal likelihoods. Length and age composition data were fit using robust multinomial likelihoods (Francis 2011), and only from years that met minimum sample size criteria ($nfish > 30$ and $ntrips \geq 10$) for length compositions and ($nfish > 10$ and $ntrips \geq 10$) for age compositions. Commercial and headboat discard length composition minimum sample size threshold was set lower ($nfish > 10$) due to the fact that the discard composition data were the only information available to estimate selectivity.

The model includes the capability for each component of the likelihood to be weighted by user-supplied values. For data components, these weights were applied by either adjusting CVs (lognormal components) or adjusting effective sample sizes (multinomial components). In this application to Red Snapper, CVs of landings and discards (in arithmetic space) were assumed equal to 0.05, to achieve a close fit to these time series yet allowing some imprecision. In practice, the small CVs are a matter of computational convenience, as they help achieve the desired result of close fits to the landings, while avoiding having to solve the Baranov equation iteratively (which is complex when there are multiple fisheries). Weights on other data components (indices, age/length compositions) were adjusted iteratively, starting from initial weights as follows. The CVs of indices were set equal to the values estimated by the GLMs used for standardization or at the fixed value of 0.2 for the headboat and commercial handline indices. Effective sample sizes of the multinomial components were assumed equal to the number of trips sampled annually, rather than the number of fish measured, reflecting the belief that the basic sampling unit occurs at the level of trip. These initial weights were then adjusted until standard deviations of normalized residuals were near 1.0 (Francis 2011). In sensitivity runs, weights on the fishery dependent indices were adjusted upward to explore their effects (not because up-weighted runs were considered equally plausible).

For parameters defining selectivities, CV of size at age, and σ_R, normal priors were applied to maintain parameter estimates near reasonable values, and to prevent the optimization routine from drifting into parameter space with negligible gradient in the likelihood. For σ_R, the prior mean (0.6) and standard deviation (0.25) were based on Beddington and Cooke (1983) and Mertz and Myers (1996).

3.19 Configuration of a base run

The base run was configured as described above. This configuration does not necessarily represent reality better than all other possible configurations, and thus this assessment attempted to portray uncertainty in point estimates through sensitivity analyses and through a Monte-Carlo/bootstrap approach (described below).

3.20 Sensitivity analyses

Sensitivity runs were chosen to investigate issues that arose specifically with this benchmark assessment. They were intended to demonstrate directionality of results with changes in inputs or simply to explore model behavior, and not all were considered equally plausible. These model runs vary from the base run as follows:

- S1: Remove the 2008 and 2009 years from the handline and headboat indices
- S2: Upweight fishery independent index further than was explored in the Assessment Workshop (10X likelihood weight after the iterative reweighting)
- S3: Upweight handline and headboat indices (3X likelihood weight after iterative reweighting)
- S4: Fishery dependent indices only
- S5: High value of M
- S6: Low value of M
- S7: Low discard mortality probabilities (commercial handlines rate set to 0.38 or 0.28, all recreational set to 0.27 or 0.20)
- S8: High discard mortality probabilities (commercial handlines rate set to 0.58 or 0.48, all recreational set 0.45 or 0.36)
- S9: Longer combined chevron trap and video (CVID) index (2005-2014)
- S10: Reduced general recreational landings in 1984 and 1985 by taking the geometric mean of surrounding years
- S11: Steepness $h = 0.84$
- S12: Headboat discard index excluded after 2009
- S13: Ageing error matrix included
- S14: Low value for age-specific number of batches
- S15: High value for age-specific number of batches
- S16: Headboat discard index dropped
- S17: High landings
- S18: Low landings
- S19: High discards
- S20: Low discards
- S21: Dome-shaped selectivity for commercial handline fleet
- S22: Separate video and trap index rather than a single CVID index
- S23: Fishery independent index only
- S24: Continuity run: changes include SEDAR24 values such as M, steepness, maturity, and SSB
- S25: Two time blocks for Headboat logbook index catchability (pre- and post-1992)
- S26: Retrospective - 1 year of data
- S27: Retrospective - 2 years of data
- S28: Retrospective - 3 years of data
- S29: Retrospective - 4 years of data

- S30: Use 1978 as the starting year, applied a loose prior to the estimation of F_{init} that corresponds to the geometric mean of the fishing mortality for 1950-1977
- S31: Estimate selectivities without fixing a plus group (for the selectivity estimation)

Sensitivities 5, 6, 14, 15, and 17-20 used the 10th and 90th quantiles (as the low and the high respectively) from the bootstraps of the observed data described in the uncertainty analysis methods (Section 3.24).

3.21 Parameters Estimated

The model estimated annual fishing mortality rates of each fleet, selectivity parameters, catchability coefficients associated with indices, parameters of the spawner-recruit model (except steepness), annual recruitment deviations, and CV of size at age for each age and growth relationship.

3.22 Per Recruit and Equilibrium Analyses

Yield per recruit and spawning potential ratio were computed as functions of F, as were equilibrium landings and spawning biomass. Equilibrium landings and discards were also computed as functions of biomass B, which itself is a function of F. As in the computation of benchmarks (described in §3.23), per recruit and equilibrium analyses applied the most recent selectivity patterns averaged across fleets, weighted by each fleet's F from the last three years of the assessment (2012–2014).

3.23 Benchmark/Reference Point Methods

In this assessment of Red Snapper, the quantities $F_{30\%}$, $\mathrm{SSB}_{\mathrm{F30\%}}$, $B_{\mathrm{F30\%}}$, and $L_{\mathrm{F30\%}}$ were estimated as proxies for MSY-based reference points. Steepness was not reliably estimable, so the stock-recruit relationship was not used to identify a maximum yield. Instead, steepness was fixed at 0.99 in order to assume an average level of recruitment while estimating deviations around the mean. $F_{30\%}$ was used in the rebuilding plan for Red Snapper, therefore, it was used here to generate fishing benchmarks. However, because the stock-recruitment relationship was not estimated, assumptions about recruitment are required to generate biomass benchmarks. Here, equilibrium recruitment was assumed equal to expected recruitment (arithmetic average). On average, expected recruitment is higher than that estimated directly from the spawner-recruit curve, because of lognormal deviation in recruitment. Thus, in this assessment, the method of benchmark estimation accounted for lognormal deviation by including a bias correction in equilibrium recruitment. The bias correction (ς) was computed from the variance (σ_R^2) of recruitment deviation in log space: $\varsigma = \exp(\sigma_R^2/2)$. Then, equilibrium recruitment (R_{eq}) associated with any F is,

$$R_{eq} = \frac{R_0 \left[\varsigma 0.8 h \Phi_F - 0.2(1-h)\right]}{(h-0.2)\Phi_F} \tag{1}$$

where R_0 is virgin recruitment, h is steepness which is fixed in this assessment, and $\Phi_F = \phi_F/\phi_0$ is spawning potential ratio given growth, maturity, and total mortality at age (including natural and fishing mortality rates). Because steepness is fixed at 0.99, R_{eq} as a function of F is approximately a straight line. The R_{eq} and mortality schedule imply an equilibrium age structure and an average sustainable yield (ASY). The estimate of $F_{30\%}$ is the F giving 30% of the SPR, and the estimate of $L_{\mathrm{F30\%}}$ is that ASY. The estimate of $\mathrm{SSB}_{\mathrm{F30\%}}$ follows from the corresponding equilibrium age structure, as does the estimate of discard mortalities $D_{F30\%\}}$, here separated from ASY (and consequently, $L_{\mathrm{F30\%}}$).

Estimates of $L_{\mathrm{F30\%}}$ and related benchmarks are conditional on selectivity pattern. The selectivity pattern used here was an average of terminal-year selectivities from each fleet, where each fleet-specific selectivity was weighted in proportion to its corresponding estimate of F averaged over the last three years (2012–2014). If the selectivities or relative fishing mortalities among fleets were to change, so would the estimates of $L_{\mathrm{F30\%}}$ and related benchmarks.

The maximum fishing mortality threshold (MFMT) is defined by the SAFMC as $F_{30\%}$, and the minimum stock size threshold (MSST) as 75%$\mathrm{SSB_{F30\%}}$. Overfishing is defined as $F >$ MFMT and overfished as SSB < MSST. However, because this stock is currently under a rebuilding plan, increased emphasis is given to SSB relative to $\mathrm{SSB_{F30\%}}$ (rather than MSST), as $\mathrm{SSB_{F30\%}}$ is the rebuilding target. Current status of the stock is represented by SSB in the latest assessment year (2014), and current status of the fishery is represented by the geometric mean of F from the latest three years (2012–2014). Recent SEDAR assessments have considered the mean over the terminal three years to be a more robust metric.

3.24 Uncertainty and Measures of Precision

As in SEDAR24, this assessment used a mixed Monte Carlo and bootstrap (MCB) approach to characterize uncertainty in results of the base run. Monte Carlo and bootstrap methods (Efron and Tibshirani 1993; Manly 1997) are often used to characterize uncertainty in ecological studies, and the mixed approach has been applied successfully in stock assessment, including Restrepo et al. (1992), Legault et al. (2001), SEDAR4 (2004), and many South Atlantic SEDAR assessments since SEDAR19 (2009). The approach is among those recommended for use in SEDAR assessments (SEDAR Procedural Guidance 2010).

The approach translates uncertainty in model input into uncertainty in model output, by fitting the model many times with different values of "observed" data and key input parameters. A chief advantage of the approach is that the results describe a range of possible outcomes, so that uncertainty is characterized more thoroughly than it could be by any single fit or handful of sensitivity runs. A minor disadvantage of the approach is that computational demands are relatively high.

In this assessment, the BAM was successively re-fit in $n = 4000$ trials that differed from the original inputs by bootstrapping on data sources, and by Monte Carlo sampling of several key input parameters. The value of $n = 4000$ was chosen because a minimum of 3000 runs were desired, and it was anticipated that not all runs would converge or otherwise be valid. Of the 4000 trials, approximately 5.2% were discarded, because the model did not properly converge (in most cases, an estimated quantity was at its upper bound). This left $n = 3791$ MCB trials used to characterize uncertainty, which was sufficient for convergence of standard errors in management quantities.

The MCB analysis should be interpreted as providing an approximation to the uncertainty associated with each output. The results are approximate for two related reasons. First, not all combinations of Monte Carlo parameter inputs are equally likely, as biological parameters might be correlated. Second, all runs are given equal weight in the results, yet some might provide better fits to data than others.

3.24.1 Bootstrap of observed data

To include uncertainty in the indices of abundance, multiplicative lognormal errors were applied through a parametric bootstrap. To implement this approach in the MCB trials, random variables ($x_{s,y}$) were drawn for each year y of time series s from a normal distribution with mean 0 and variance $\sigma^2_{s,y}$ [that is, $x_{s,y} \sim N(0, \sigma^2_{s,y})$]. Annual observations were then perturbed from their original values ($\hat{O}_{s,y}$),

$$O_{s,y} = \hat{O}_{s,y}[\exp(x_{s,y} - \sigma^2_{s,y}/2)] \qquad (2)$$

The term $\sigma^2_{s,y}/2$ is a bias correction that centers the multiplicative error on the value of 1.0. Standard deviations in log space were computed from CVs in arithmetic space, $\sigma_{s,y} = \sqrt{\log(1.0 + CV^2_{s,y})}$. As used for fitting the base run, CVs of indices of abundance were those provided by, or modified from, the data providers (tabulated in Table 4 of this assessment report).

Uncertainty was modeled for historical commercial landings similarly to the indices, and by the CVs provided by the commercial working group at the DW. No commercial discard CVs, headboat landings CVs, or headboat discard CVs by year were provided, therefore the panel had to make some assumptions. We assumed a value of $CV = 0.20$ for commercial discards and headboat discards. For headboat landings, we used information from the headboat program to assume a decreasing CV by time blocks (i.e. $CV = 0.15$ 1981-1995, $CV = 0.1$ for 1996-2007, and $CV = 0.05$ thereafter). General recreational landings and discards had complementary CVs, and those were used as provided except in a few instances. A CV greater than 1 was capped at 1, which was sufficiently large to represent high uncertainty but not so high that bootstrapped values caused implausible time series. The panel thought the resulting draws sufficiently represented uncertainty in spite of the dampening of a few years' CVs (Table 6).

Uncertainty in age and length compositions were included by drawing new distributions for each year of each data source, following a multinomial sampling process. Ages (or lengths) of individual fish were drawn at random with replacement using the cell probabilities of the original data. For each year of each data source, the number of fish sampled was the same as in the original data.

3.24.2 Monte Carlo sampling

In each successive fit of the model, several parameters were fixed (i.e., not estimated) at values drawn at random from distributions described below.

3.25 Natural mortality

A vector of age-specific natural mortality was provided by the Life History Working Group. They used the Charnov et al. (2013) estimator scaled to the Then et al. (2014) max age asymptotic M, and then used the uncertainty around the determination of maximum age to provide an upper and lower bound to the M vector. The Assessment Panel thought the upper ($M = 0.14$) and lower ($M = 0.12$) bound were too similar to the base vector to represent the true uncertainty around M. Instead, the AW Panel wanted to carry the uncertainty forward in both maximum age and the parameters of the Then et al. (2014) estimator of asymptotic M:

$$M = aT^b_{max} \tag{3}$$

To estimate uncertainty in a and b, we acquired the data of Then et al. (2014) and conducted a bootstrap of $n = 10,000$ iterations, drawing from the original data set with replacement. For each MCB iterations, one of the 10,000 fits was drawn at random, thus maintaining any correlation structure between a and b. We then drew T_{max} from a uniform distribution and calculated asymptotic M. For the age-dependent vector, we started with the Charnov age-dependent curve, and scaled it to the M estimate we calculated in the previous steps. A new M value was drawn and a new age-dependent vector was calculated for each MCB trial.

3.26 Discard mortality

The discard mortality working group provided an upper and lower bound for each time block (pre- and post-regulation) and fishery (commercial and recreational). Commercial rates before 2007 ranged from 38% to 58%, and 2007 to present ranged from 28% to 48%. Recreational rates before 2011 ranged from 27% to 45%, and 2011 on ranged from 20% to 36%. The rates decreased in response to the implementation of circle hooks, which are meant to cause fewer fatal bycatch events. We drew the rate for the earlier time period for each fleet from a truncated normal distribution with mean equal to the point estimate and a standard deviation devised to provide a 95% confidence interval similar to what the working group provided above. For the later time period for each fleet we also drew from a truncated normal distribution created similarly as in the previous step but with the upper bound fixed at the random draw from the earlier time period. The last step is meant to ensure that the second value is not larger than the first, so as to maintain the feature that discard mortality has decreased due to the circle hook regulation.

3.27 Batch Fecundity

Prior to the MCB analysis, a bootstrap procedure was run on the data set used to estimate batch fecundity at age for the base run. For each of 10000 bootstrap runs, the 69 paired observations of batch fecundity and fish length were sampled 69 times with replacement, the regression model refit, and the bootstrap parameters estimates saved to a data matrix. Once all bootstraps were run, the parameter matrix was trimmed by removing runs where either parameter value was outside of its 95% confidence interval. The parameters were found to be highly correlated, so during the MCB analysis, pairs of parameters were randomly drawn, with replacement, from the trimmed bootstrap parameter matrix. For each MCB run, predicted batch fecundity at age was calculated using a set of bootstrap parameters and a vector of length at age.

3.28 Batch number

Prior to the MCB analysis, a similar but separate bootstrap procedure was run on the data set used to estimate batch number at age for the base run. For each of 10000 bootstrap runs, the 1472 paired observations of spawning indicator presence, fish length, and day of the year were sampled 1472 times with replacement and the regression model refit. Predicted batch number at age was then calculated from the bootstrap parameter estimates and a vector of length at age, and the vectors saved to a data matrix. Once all bootstraps were run, the batch number at age matrix was trimmed by first summing batch number at age for each run, yielding lifetime batch number; runs where lifetime batch number was outside of the 95% confidence interval were trimmed. During the MCB analysis, a vector of batch number at age was randomly drawn, with replacement, from the trimmed bootstrap batch number at age matrix for each MCB run.

3.29 Projections

Projections were run to predict stock status in years after the assessment, 2015–2044. The year 2044 is the last year of the current rebuilding plan.

The structure of the projection model was the same as that of the assessment model, and parameter estimates were those from the assessment. Any time-varying quantities, such as recreational selectivity, were fixed to the most recent values of the assessment period. A single selectivity curve was applied to calculate removals, averaged across fleets using geometric mean Fs from the last three years of the assessment period, similar to computation of $L_{\mathrm{F30\%}}$ benchmarks (§3.23).

Expected values of SSB (time of peak spawning), F, recruits, and removals were represented by deterministic projections using parameter estimates from the base run. These projections were built on the spawner-recruit relationship with steepness fixed ($h = 0.99$) and with bias correction, and were thus consistent with estimated benchmarks in the sense that long-term fishing at $F_{30\%}$ would yield $L_{\mathrm{F30\%}}$ from a stock size at $\mathrm{SSB}_{\mathrm{F30\%}}$. Uncertainty in future time series was quantified through stochastic projections that extended the Monte Carlo/Bootstrap (MCB) fits of the stock assessment model.

3.29.1 Initialization of projections

Initial age structure at the start of 2015 was computed by the assessment model.

Fishing rates that define the projections were assumed to start in 2017. Because the assessment period ended in 2014, the projections required an initialization period (2015–2016). For 2015, a moratorium year, the landings selectivity was set to 0 and the discard selectivity was rescaled to peak at 1. Then, an optimization routine solved for the F that matched the current dead discards (mean of 2012-2014) in numbers. In 2016, a similar routine soved for the F that matched current landings (mean of 2012-2014), assuming a mini-season would occur.

3.29.2 Uncertainty of projections

To characterize uncertainty in future stock dynamics, stochasticity was included in replicate projections, each an extension of a single MCB assessment model fit. Thus, projections carried forward uncertainties in natural mortality, reproduction, landings, discards, and discard mortalities, as well as in estimated quantities such as selectivity curves, and in initial (start of 2015) abundance at age.

Initial and subsequent recruitment values were generated with stochasticity using a Monte Carlo procedure, in which the estimated Beverton–Holt model (i.e. R_0, σ_R estimated, and $h = 0.99$) of each MCB fit was used to compute mean annual recruitment values ($\bar{R}_y$). Variability was added to the mean values by choosing multiplicative deviations at random from a lognormal distribution,

$$R_y = \bar{R}_y \exp(\epsilon_y). \tag{4}$$

Here ϵ_y was drawn from a normal distribution with mean 0 and standard deviation σ_R, where σ_R is the standard deviation from the relevant MCB fit.

The procedure generated 20,000 replicate projections of MCB model fits drawn at random (with replacement) from the MCB runs. In cases where the same MCB run was drawn, projections would still differ as a result of stochasticity in projected recruitment streams. Central tendencies were represented by the deterministic projections of the base run, as well as by medians of the stochastic projections. Precision of projections was represented graphically by the 10^{th} and 90^{th} percentiles of the replicate projections.

3.30 Rebuilding time frame

Based on results from the previous SEDAR24 benchmark assessment, Red Snapper is currently under a rebuilding plan. In this plan, the terminal year is 2044, and rebuilding is defined by the criterion that projection replicates achieve stock recovery (i.e., $\mathrm{SSB}_{2044} \geq \mathrm{SSB}_{\mathrm{F30\%}}$) with probability of at least 50%. Here, the probability of stock recovery in each year of the rebuilding plan was computed as the proportion of stochastic projections where $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F30\%}}$, with $\mathrm{SSB}_{\mathrm{F30\%}}$ taken to be iteration-specific (i.e., from that particular MCB run).

Projection scenarios Five projection scenarios were considered.

- Scenario 1: $F = 0$
- Scenario 2: $F = F_{\text{current}}$
- Scenario 3: $F = F_{30\%}$
- Scenario 4: $F_{target} = 98\% F_{30\%}$
- Scenario 5: $F = F_{\text{rebuild}}$, with rebuilding probability of 0.5 in 2044
- Scenario 6: Discards only

The F_{current} is represented by the geometric mean of fishing mortalities from 2012-2014. The F_{rebuild} is defined as the maximum F that achieves rebuilding in the allowable time frame. The discards only scenario treated the initialization year 2016 the same as 2015 (discards only), and then applied the mean F (from 2015-2016) forward starting in 2017.

3.31 Surplus Production Model

3.31.1 Overview

A logistic surplus production model, implemented in ASPIC (Version 7.03; Prager 2005), was used to estimate stock status of Red Snapper off the southeastern U.S. While primary assessment of the stock was performed using the age-structured BAM, the surplus production approach was intended as a complement, for additional comparison with the age-structured model's results. More specifically, this model focuses on the dynamics of the removals as they relate to the indices of abundance, while ignoring any age data or age-structure in the population.

3.31.2 Data Sources

Data sources supplied to a production model include a time series of removals (i.e. landings plus dead discards) and one or more indices of abundance (i.e. catch per unit of effort). These inputs should be in units of biomass (i.e. weight), therefore some of the data developed at the SEDAR41 DW required additional formatting. These changes are detailed below.

Removals

The available removals time series comprised commercial landings (1950-2014), recreational landings (1955-2014), commercial dead discards (1992-2014), and recreational dead discards (1981-2014), in pounds, summed by year.

Commercial Landings

The SEDAR41 DW reported commercial landings in pounds, thus these data did not need to be modified for the production model.

Recreational landings

During the SEDAR41 DW, recreational landings for the historical period (1955-1980) were estimated in numbers of individuals using the The National Survey of Fishing, Hunting, and Wildlife-Associated Recreation Survey (FHWAR) census method (see SEDAR41-DW17). For the contemporary period (1981-2014), the SEDAR-41 DW reported Southeast Region Headboat Survey (SRHS) and Marine Recreational Information Program (MRIP) recreational landings in numbers and weights. Recreational landings from this period did not need to be modified, but were used to convert historical landings to weight.

Following a similar approach used in SEDAR24, recreational landings in weight and numbers for all fleets were combined by year for the first three years of the contemporary period; dividing annual landings in weight by landings in numbers produced annual mean weight estimates. The average of these three mean weights (3.4 lb) was then multiplied by the historical landings in numbers to convert them to weight. The historical and combined contemporary recreational landings series were then joined to produce a single time series of recreational landings, in pounds.

Dead Discards

Discard estimates were generated in numbers at the SEDAR-41 DW. Since many discarded fish survive after release, discard mortality rates were applied to discards in numbers to calculate dead discards. For commercial discards, a discard mortality rate of 0.48 was applied prior to regulations in 2007, and a rate of 0.38 was applied from 2007 onward. For recreational discards, a discard mortality rate of 0.37 was applied prior to regulations in 2011, and a rate of 0.285 was applied from 2011 onward.

Mean weight of commercial discards was estimated by converting lengths of commercial discards to weights using data and a conversion equation supplied by the SEDAR-41 DW, and then calculating the average weight of these individuals. The data on lengths of commercial discards were divided into two time periods before (2007-2009) and after (2010-2013) the fishery was closed. The average estimated weights of commercial discards from each time period (before = 2.93 lb; after = 8.84 lb) were multiplied by discards in numbers, for years before and after the closure, respectively.

Mean weight of recreational discards was estimated by converting lengths of recreational headboat-at-sea observer discards to weights using data and a conversion equation supplied by the SEDAR-41 DW, and then calculating the average weight of these individuals. Year-specific mean weight estimates were multiplied by recreational discards in numbers for corresponding years when available (2005-2014). For years prior to 2005 where year-specific mean weights were not available, discards in numbers were multiplied by the average mean weight across the available years before the 2010 closure (1.96 lb).

Indices of Abundance

Five indices of abundance were produced by the SEDAR-41 DW for Red Snapper: commercial logbook handline index (hereafter commercial handline; units = lb kept per hook-hour), headboat (number of fish kept per angler), headboat-at-sea-observer (number of fish caught $<20''$ per angler), Southeast Reef Fish Survey (SERFS) chevron trap (number of fish caught per trap), and the SERFS video (number of fish observed per video). The commercial handline index was already in weight and did not need to be converted. The headboat index was converted to pounds by multiplying by year-specific mean weights, generated by dividing headboat landings in pounds by landings in numbers for each year. The headboat-at-sea-observer index was converted to pounds by multiplying by the same mean weights used to convert recreational discards to weight. The SERFS chevron trap and video indices were converted to weights by multiplying by year-specific mean weights calculated from combined recreational (headboat and MRIP) landings in weight divided by landings in numbers.

3.31.3 Model Configuration and Equations

Production modeling used the model formulation and ASPIC software (version 7.03) of Prager (1994; 2005). This is an observation-error estimator of the continuous-time form of the Schaefer (logistic) production model (Schaefer 1954; 1957). Estimation was conditioned on catch. The logistic model for population growth is the simplest form of a differential equation which satisfies a number of ecologically realistic constraints, such as a carrying capacity (a consequence of limited resources). When written in terms of stock biomass, this model specifies that

$$\frac{dB_t}{dt} = rB_t - \frac{r}{K}B_t^2 \quad (5)$$

where B_t is biomass in year t, r is the intrinsic rate of increase in absence of density dependence, and K is carrying capacity (Schaefer 1954; 1957). This equation may be rewritten to account for the effects of fishing by introducing an instantaneous fishing mortality term, F_t :

$$\frac{dB_t}{dt} = (r - F_t)B_t - \frac{r}{K}B_t^2 \quad (6)$$

By writing the term F_t as a function of catchability coefficients and effort expended by fishermen in different fisheries, Prager (1994) showed how to estimate model parameters from time series of yield and effort.

For Red Snapper, the model proved difficult to fit. It was configured using various combinations of removals, indices, starting dates, prior distributions and starting values, resulting in approximately 324 configurations. Many of these runs were completed during early model development but many others incorporated small changes to data inputs or model specifications suggested by AW panel members during the Assessment Workshop. As the BAM developed, most of these runs became obsolete and are not presented here. The run configured according to recommendations by the SEDAR41 AW panel is presented here. This model configuration (run 320) contained removals from 1950 to 2014 and the four indices used in the BAM (Comm, HB, HB-at-sea, CVID) from 1976 to 2014. Following the recommendations of the AW panel, the CVID index was upweighted by a factor of three (i.e. CVs divided by three), and the headboat-at-sea index was shifted forward by one year, since it indexes younger fish than the other indices.

Three other runs (318, 319, and 323) are also presented to relate the main run (320) to ASPIC results from the previous Red Snapper assessment (SEDAR 24). All three runs contain only the commercial and headboat indices, starting in 1993 and 1976 respectively, and removals starting in 1950. But in run 318 (the continuity run), the final year of removals and indices is 2009, as in SEDAR 24, while in run 319 (the updated continuity run) the final year of removals and indices is 2014, as in the BAM for the current assessment. Since both the commercial and headboat indices ended in 2009 the only difference between the continuity run and updated continuity run is the removals estimates from 2010-2014. Finally a run was completed (run 323; best configuration $\frac{B_1}{K}$ fixed) that is identical to the best configuration run, but with $\frac{B_1}{K}$ fixed at the estimate for the continuity run, for reasons described below.

To evaluate the uncertainty in the model fit and parameter estimates of the best configuration run, 1000 bootstrap runs were conducted. Percentile confidence intervals were also calculated for parameters.

4 Stock Assessment Results

4.1 Measures of Overall Model Fit

In general, the Beaufort assessment model (BAM) fit well to the available data. Predicted length compositions from the commercial handline and discards from the commercial and headboat fleets were reasonably close to observed data in most years, as were predicted age compositions (Figure 3). The model was configured to fit observed commercial and recreational removals closely (Figures 4–9). Fits to indices of abundance generally captured the observed trends but not all annual fluctuations (Figures 10–13).

4.2 Parameter Estimates

Estimates of all parameters from the catch-age model are shown in Appendix B. Estimates of management quantities and some key parameters are reported in sections below.

4.3 Stock Abundance and Recruitment

In general, estimated abundance at age showed truncation of the older ages through most of the assessment period, but with some signs of increase during the last decade (Figure 14; Table 7). Total estimated abundance was at its lowest value in the early 1990s, but near its highest levels at the end of the time series, comparable to those in the early 1970s, but with a more truncated age structure. The MCB results reflect the same patterns with their associated uncertainties for total abundance and abundance of age 2+ (Figure 18). Annual number of recruits is shown in Table 7 (age-1 column) and in Figure 15. The highest recruitment values were predicted to have occurred in the mid-1980s, 2006, and the terminal year of the model (2014).

4.4 Total and Spawning Biomass

Estimated biomass at age followed a similar pattern as abundance at age (Figure 16; Table 9). Total biomass and spawning biomass showed similar trends—general decline through to the early-1990s, and relatively stable or slowly increasing patterns since the mid-1990s (Figure 17; Table 10). Terminal year estimates are at levels not seen since the 1970s.

4.5 Selectivity

Selectivity of the SERFS index is shown in Figure 19, and selectivities of landings from commercial and recreational fleets are shown in Figures 20, 21, and 22. Selectivities of discards from commercial and recreational fleets are shown in Figures 23, 24, and 25. In the most recent years, full selection occurred near ages 2–4, depending on the fleet and time block.

Average selectivities of landings, dead discards, and the total weighted average of all selectivities were computed from F-weighted selectivities in the most recent three assessment years (Figure 26). This average selectivity was used in computation of point estimates of benchmarks, as well as in projections. All selectivities from each time block, including average selectivities, are tabulated in Tables 11, 12, and 13.

4.6 Fishing Mortality and Removals

Estimates of total F at age are shown in Table 15. In any given year, the maximum F at age (i.e., apical F) may be less than that year's sum of fully selected Fs across fleets. This inequality is due to the combination of two features of estimated selectivities: full selection occurs at different ages among gears and several sources of mortality have dome-shaped selectivity.

Estimated time series of landings and discards are shown in Tables 16, 17, 18, 19. Table 20 shows total landings at age in numbers, and Table 21 in weight. Table 22 shows total discards at age in numbers, and Table 23 in weight. Landings have been dominated by the general recreational and commercial handline fleet until recent years when the general recreational fleet became the dominant source of removals (Tables 16 and 17). Also since 2010, total landings remained below the level at $L_{\mathrm{F30\%}}$ (Figure 29).

Estimated discard mortalities occurred on a smaller scale than landings until the implementation of regulations and the use of mini-seasons, and have been above the $D_{F_{30\%}}$ level for most of the moratorium years (Tables 18 and 19, and Figure 30).

4.7 Spawner-Recruitment Parameters

The Beverton–Holt spawner-recruit curve is shown in Figure 31, along with the effect of density dependence on recruitment, depicted graphically by recruits per spawner as a function of spawning stock (1E8 Eggs). Values of recruitment-related parameters were as follows: steepness $h = 0.99$ (fixed), unfished age-1 recruitment $\widehat{R_0} = 330503$, and standard deviation of recruitment residuals in log space $\widehat{\sigma}_R = 0.79$ (which resulted in bias correction of $\varsigma = 1.37$). Uncertainty in these quantities was estimated through the MCB analysis (Figure 32).

4.8 Per Recruit and Equilibrium Analyses

Yield per recruit and spawning potential ratio were computed as functions of F. These computations applied the most recent selectivity patterns averaged across fleets, weighted by F from the last three years (2012–2014) (Figures 33 and 34).

As in per recruit analyses, equilibrium landings and spawning biomass were computed as functions of F (Figure 35). $F_{30\%}$ is used as a proxy for MSY, and the corresponding landings and spawning biomass are $L_{\mathrm{F30\%}}$ and $\mathrm{SSB}_{\mathrm{F30\%}}$.

4.9 Benchmarks / Reference Points

As described in §3.23, biological reference points (benchmarks) were derived analytically assuming equilibrium dynamics, corresponding to the spawner-recruit curve with fixed steepness $h = 0.99$ (Figure 31). Reference points estimated were $F_{30\%}$, $L_{\mathrm{F30\%}}$, $B_{\mathrm{F30\%}}$ and $\mathrm{SSB}_{\mathrm{F30\%}}$. Based on $F_{30\%}$, three possible values of F at optimum yield (OY) were considered—$F_{\mathrm{OY}} = 65\% F_{30\%}$, $F_{\mathrm{OY}} = 75\% F_{30\%}$, and $F_{\mathrm{OY}} = 85\% F_{30\%}$—and for each, the corresponding yield was computed. Standard errors of benchmarks were approximated as those from MCB analysis (§3.24).

Maximum likelihood estimates (base run) of benchmarks, as well as median values from MCB analysis, are summarized in Table 24. Point estimates of $L_{\mathrm{F30\%}}$-related quantities were $F_{30\%} = 0.15$ (y^{-1}), $L_{\mathrm{F30\%}} = 430$ (1000 lb), $B_{\mathrm{F30\%}} = 3647$ (mt), and $\mathrm{SSB}_{\mathrm{F30\%}} = 328552$ (1E8 Eggs). Median estimates were $F_{30\%} = 0.15$ (y^{-1}), $L_{\mathrm{F30\%}} = 419$ (1000 lb), $B_{\mathrm{F30\%}} = 3534$ (mt), and $\mathrm{SSB}_{\mathrm{F30\%}} = 294166$ (1E8 Eggs). Distributions of these benchmarks from the MCB analysis are shown in Figure 36.

4.10 Status of the Stock and Fishery

Estimated time series of stock status $SSB/SSB_{F30\%}$ showed general decline throughout the beginning of the assessment period, a leveling off, and then a modest increase since 2010 (Figure 37, Table 10). Base-run estimates of spawning biomass have remained below the threshold (MSST) since the early-1970s. Current stock status was estimated in the base run to be $SSB/SSB_{F30\%} = 0.16$ (Table 24), indicating that the stock has not yet recovered to $SSB_{F30\%}$. Median values from the MCB analysis indicated similar results $SSB/SSB_{F30\%}$ =0.17. The uncertainty analysis suggested that the terminal estimate of stock status is robust (Figures 38, 39). Of the MCB runs, 100% indicated that the stock was below $SSB_{F30\%}$ in 2014. Age structure estimated by the base run showed fewer older fish in the last few decades than the (equilibrium) age structure expected at $L_{F30\%}$ (Figure 40). However, there is improvement in the terminal year(2014), particularly for ages younger than ten.

The estimated time series of $F/F_{30\%}$ suggests that overfishing has occurred throughout most of the assessment period (Table 10, Figure 37). Current fishery status in the terminal year, with current F represented by the geometric mean from 2012–2014, was estimated by the base run to be $F/F_{30\%} = 2.52$ (Table 24). The fishery status was also robust (Figures 38, 39). Of the MCB runs, approximately 98.7% agreed with the base run that the stock is currently experiencing overfishing.

4.11 Sensitivity and Retrospective Analyses

Sensitivity runs, described in §3.3, were used for exploring data or model issues that arose during the assessment process, for evaluating implications of assumptions in the base assessment model, and for interpreting MCB results in terms of expected effects of input parameters. In some cases, sensitivity runs are simply a tool for better understanding model behavior, and therefore all runs are not considered equally plausible in the sense of alternative states of nature. Time series of $F/F_{30\%}$ and $SSB/SSB_{F30\%}$ are plotted to demonstrate sensitivity to the changing conditions in each run. The sensitivity of the base run to changes in natural mortality, steepness, dome-shaped selectivity for the commercial handline fleet, various index adjusts for both the fishery dependent indices and fishery independent index, the use of an ageing error matrix and high and low levels of landings and discards was explored (Figures 41–53). Sensitivity 24 is a version of a continuity run in that various assumptions made about parameters for SEDAR 24 were adopted for this sensitivity (e.g. higher discard mortalities, lower M, using gonad weight as a proxy for SSB, different female maturity and fecundity information, higher max age, lower steepness, different time of year for peak spawning, and fixed recruitment standard deviation). Time series of stock and fishery status estimated by this assessment are similar to those from the previous, SEDAR24 assessment (Figure 54). Trends in $F/F_{30\%}$ from the two assessments generally track each other, though the magnitude of the variations differ. Trends in $SSB/SSB_{F30\%}$ track each other, though there is divergence at the end of the time series where the current model estimates a more optimistic stock status.

None of the sensitivities show a recovered stock in 2014. A couple sensitivities suggest the stock is undergoing less overfishing than is estimated in the base. However, those runs eliminate the fishery independent index entirely, or upweight the fishery dependent indices to the point of swamping out any signal from the survey data. The vast majority of runs agree with the status indicated by the base run (Figure 55, Table 25). Results appeared to be most sensitive to natural mortality and steepness.

Retrospective analyses suggest a pattern of overestimating fishing mortality in the terminal year, however, the trend is less apparent for SSB (Figure 56).

4.12 Projections

Projections based on $F = 0$ allowed the spawning stock to grow such that the majority of replicate projections recovered to $\text{SSB}_{\text{F30\%}}$ by 2025 (Figure 57, Table 26), however the stock is already in a rebuilding plan so other projections were also requested in the TORs. This was not the case for projections based on $F = F_{\text{current}}$ (Figure 58, Table 27), or if the fishing rate were reduced to $F_{30\%}$ (Figure 59, Table 28) or F_{target} (Figure 60, Table 29). By design, projections based on $F = F_{\text{rebuild}}$ showed recovery with the desired probability in 2044 (Figure 61, Table 30). The projection with discard mortality only showed similar trajectories to the run assuming no other fishing mortality(Table 31 and Figure 62).

4.13 Surplus Production Model

4.13.1 Model Fit

For the best configuration run, model predictions underestimated observed values for the headboat index for the first ten years of the time series (1976-1985; Figure 63). They also underestimated the commercial index during the first five years of that series (1993-1997), while overestimating the headboat index for those same years. The model provided a very poor fit to the headboat-at-sea discard index (2006-2014) but produced a much better fit to the upweighted CVID index (2005-2014). The model did not fit high index values in 2008 and 2009 very closely, but predicted a slight decline from 2007-2009 followed by an increasing trend from 2010 to 2014.

4.13.2 Parameter Estimates and Uncertainty

The ASPIC model fits three main parameters ($\frac{B_1}{K}$, MSY, and F_{MSY}) as well as catchability coefficients (q_i) for each index i. Several other parameters can then be derived from these estimates: $r = 2F_{MSY}$, $K = \frac{2MSY}{F_{MSY}}$ and $B_{MSY} = \frac{K}{2}$. Recent status indicators $\frac{F}{F_{MSY}}$ and $\frac{B}{B_{MSY}}$ are calculated with the most recent estimates of F (2014) and B (2015). Estimates of the main parameters and recent status indicators for all four runs are presented in Table 32. Prior distributions and model estimates of the main parameters for the best configuration run are presented in Figure 64.

Across all runs, most of the main parameters varied very little (e.g. CV $MSY = 0.0027$; CV $F_{MSY} = 0.014$). By contrast $\frac{B_1}{K}$ varied widely (CV $\frac{B_1}{K} = 0.74$), due to variation in B_1 (CV $B_1 = 0.74$) rather than K (CV $K = 0.013$; Table 32). Among bootstrap runs based on the best configuration, distributions of $\frac{B_1}{K}$, MSY, and F_{MSY} were unimodal and relatively symmetrical (Figure 65).

4.13.3 Status of the Stock and Fishery

In the current best configuration run of the surplus production model, $\frac{B}{B_{MSY}}$ is greater than one, suggesting that the South Atlantic stock of Red Snapper is not overfished. The 95% bootstrap percentile confidence intervals for $\frac{B}{B_{MSY}}$ do not contain one (Figure 65). Since the surplus production model estimates that $\frac{F}{F_{MSY}}$ is less than one, the stock is considered to not be undergoing overfishing (Table 32; Figure 66). The 95% bootstrap percentile confidence intervals for $\frac{F}{F_{MSY}}$ do not contain one (Figure 65).

4.13.4 Interpretation

Status indicators in the continuity run (318), agree with the surplus production model from SEDAR 24 that South Atlantic Red Snapper were overfished and undergoing overfishing in 2009 (Table 32). However, in the updated continuity run (319), which is identical to the continuity run except for the 2010-2014 addition of landings data from 2010-2014, the surplus production model suggests that the stock is no longer overfished or undergoing overfishing. Despite several differences between the updated continuity run and the best configuration run (320), described above, most of the parameter estimates and status indicators are similar (Table 32). However the model estimate of $\frac{B_1}{K}$ is much lower in the best configuration run, driven by a lower estimate of B_1. After observing this difference, run 323 was configured by taking the best configuration run and fixing $\frac{B_1}{K}$ at the estimate from the continuity run to investigate potential influence. Fixing $\frac{B_1}{K}$ at this much lower value had little effect on status or most parameters, but caused the estimate of B_1 to go much lower.

As described above, the only data that go into a surplus production model are biomass of removals and abundance indices. Therefore such a model does not make use of many other sources of information such as sex, maturity, growth, fecundity, or population age and size structure. Because such data are available for Red Snapper, a model that uses them would be preferred for a detailed assessment on which to base management.

5 Discussion

5.1 Comments on the Assessment

Estimated benchmarks played a central role in this assessment. Values of $\mathrm{SSB}_{\mathrm{F30\%}}$ and $F_{30\%}$ were used to gauge the status of the stock and fishery to be consistent with established definitions of $MFMT$ and the existing rebuilding plan. The computation of the benchmarks was conditional on selectivity. If selectivity patterns change in the future, for example as a result of new size limits or different relative catch allocations among sectors, estimates of benchmarks would likely change as well.

The base run of the BAM indicated that the stock remains overfished $\mathrm{SSB}/\mathrm{SSB}_{\mathrm{F30\%}}$ =0.16, and that overfishing is occurring $F/F_{30\%}$ =2.52, though at a lower rate than in 2009 (F/F_{MSY} =4.12 for SEDAR 24). Median values from the MCB analyses were in qualitative agreement with those results. This assessment estimates that, since 2010, the stock has been increasing at a modest rate and is now at levels not seen since the 1970s.

In addition to including the more recent years of data, this benchmark assessment contained several modifications to the previous data of SEDAR24, such as the use of APAIS-adjusted MRIP estimates instead of MRFSS, a new method for the reconstruction of historic recreational catch, the inclusion of a new fishery-independent survey, and the corresponding age composition data. Furthermore, life-history information was updated, including female maturity, sex ratio, growth, natural mortality, fecundity, and meristics. The assessment model itself was also modernized to the current version of BAM. The sum of these improvements should result in a more robust assessment.

In general, fishery dependent indices of abundance may not track actual abundance well, because of factors such as hyperdepletion or hyperstability. Furthermore, this issue can be exacerbated by management measures. In this assessment, the commercial handline and headboat indices generated from logbook data, were not extended beyond 2009 because of the moratorium on Red Snapper. In general, management measures in the southeast U.S. have made the continued utility of fishery dependent indices will be questionable. This situation amplifies the importance of fishery independent sampling and sampling programs conducted by the states.

Many assessed stocks in the southeast U.S. have shown histories of heavy exploitation. High rates of fishing mortality can lead to adaptive responses in life-history characteristics, such as growth and maturity schedules. Such adaptations can affect expected yield and stock recovery, and thus resource managers might wish to consider possible evolutionary effects of fishing in their management plans (Dunlop et al. 2009; Enberg et al. 2009). Indeed, Red Snapper have a very young age at maturity relative to their maximum lifespan, and some have hypothesized that this may be an adaptive response to exploitation.

Because steepness could not be estimated reliably in this assessment, its value in the base run was fixed at 0.99. Fixing steepness at its upper bound was not meant to imply that the stock has perfect compensation at any exploitation or stock level. Rather, it was a computational convenience to use the stock recruitment curve with $h = 0.99$ in order to treat recruitment as an average through time while estimating deviations around that average. Thus MSY-based management quantities are not appropriate, and the AW Panel provided the proxy of $F_{30\%}$ as was used for management subsequent to the last assessment.

The assessment start year was 1950, so as to include the period of largest landings. To initialize the model in 1950, the initial age structure was assumed to be in equilibrium, based on natural mortality at age and F_{init}. Average recruitment was assumed until the recruitment deviations could be estimated at the onset of the composition data (1978). These assumptions are common in assessment models, and they were tested with sensitivity runs where the start was 1978 and with different values of F_{init}. The end results were qualitatively similar, which indicates that the base run is not sensitive to these assumptions.

A complementary analysis was conducted using a surplus production model (ASPIC). ASPIC treats the stock as a pooled biomass and ignores the age structure in the population and the landings. It is unable to take into account that different ages are differentially vulnerable to fishing and therefore was not able to incorporate the (time-varying) selectivities used in the BAM. ASPIC is also not able to take into account that the reproductive contribution of this species increases with age or that there is variability in recruitment through time. ASPIC is useful in examining the relationship between removals and the indices. However, for a long-lived species with age-based data available, the catch-age model (BAM) provides the best illustration of the stock and is a better indicator of stock status, because it can account for the age structure of the population and landings and for year-class strength.

5.2 Comments on the Projections

Projections should be interpreted in light of the model assumptions and key aspects of the data. Some major considerations are the following:

- In general, projections of fish stocks are highly uncertain, particularly in the long term (e.g., beyond 5–10 years).
- Although projections included many major sources of uncertainty, they did not include structural (model) uncertainty. That is, projection results are conditional on one set of functional forms used to describe population dynamics, selectivity, recruitment, etc.
- Fisheries were assumed to continue fishing at their estimated current proportions of total effort, using the estimated current selectivity patterns. New management regulations that alter those proportions or selectivities would likely affect projection results.
- The first five scenarios of projections assumed no change in the selectivity applied to discards. As stock increase generally begins with the smallest size classes, management action may be needed to meet that assumption.
- The projections assumed that the assumed spawner-recruit relationship applies in the future and that past deviations represent future uncertainty in recruitment. If future recruitment is characterized by runs of large or small year classes, possibly due to environmental or ecological conditions, stock projections may be affected.

- Projections apply the Baranov catch equation to relate F and landings using a one-year time step, as in the assessment. The catch equation implicitly assumes that mortality occurs throughout the year. This assumption is violated when seasonal closures or small intensive fishing seasons are in effect, introducing additional and unquantified uncertainty into the projection results.

5.3 Research Recommendations

- Increased fishery independent information, particularly maintaining reliable indices of abundance and composition data streams
- Red Snapper were modeled in this assessment as a unit stock off the southeastern U.S. For any stock, variation in exploitation and life-history characteristics might be expected at finer geographic scales. Modeling such sub-stock structure would require more data, such as information on the movements and migrations of adults and juveniles, as well as spatial patterns of larval dispersal and recruitment. In addition, it is unclear whether a spatial model would improve the assessment.
- More research to describe the juvenile life history of Red Snapper is needed, including more work to identify the location of juveniles before they recruit to the fishery.
- The effects of environmental variation on the changes in recruitment or survivorship.
- The Florida sampling program, during the miniseason in particular, provided invaluable data to this assessment. Programs such as these would be useful in all South Atlantic states, particularly if the management regulations continue to make established methods of index development or composition sampling from fleets less regular or possible.

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7 Tables

Table 1. Life-history characteristics at age, including average body total length (TL) and weight (mid-year), proportion female, annual proportion females mature, and natural mortality at age. The CV of length was estimated by the assessment model; other values were treated as input.

Age	Avg. TL (mm)	Avg. TL (in)	CV length	Avg. Whole weight (kg)	Avg. Whole weight (lb)	Fem. maturity	Proportion Female	Nat. mortality
1	323.9	12.8	0.11	0.53	1.17	0.43	0.5	0.595
2	449.3	17.7	0.11	1.41	3.10	0.73	0.5	0.364
3	547.9	21.6	0.11	2.55	5.62	0.91	0.5	0.271
4	625.4	24.6	0.11	3.78	8.34	0.97	0.5	0.222
5	686.4	27.0	0.11	5.00	11.02	0.99	0.5	0.193
6	734.4	28.9	0.11	6.12	13.49	1.00	0.5	0.174
7	772.2	30.4	0.11	7.11	15.67	1.00	0.5	0.162
8	801.9	31.6	0.11	7.96	17.54	1.00	0.5	0.153
9	825.2	32.5	0.11	8.67	19.12	1.00	0.5	0.146
10	843.6	33.2	0.11	9.26	20.42	1.00	0.5	0.142
11	858.1	33.8	0.11	9.74	21.48	1.00	0.5	0.138
12	869.4	34.2	0.11	10.13	22.34	1.00	0.5	0.135
13	878.4	34.6	0.11	10.45	23.04	1.00	0.5	0.133
14	885.4	34.9	0.11	10.70	23.59	1.00	0.5	0.132
15	891.0	35.1	0.11	10.90	24.04	1.00	0.5	0.130
16	895.3	35.2	0.11	11.06	24.39	1.00	0.5	0.129
17	898.7	35.4	0.11	11.19	24.67	1.00	0.5	0.129
18	901.4	35.5	0.11	11.29	24.89	1.00	0.5	0.128
19	903.5	35.6	0.11	11.37	25.07	1.00	0.5	0.128
20	905.2	35.6	0.11	11.43	25.21	1.00	0.5	0.127

Table 2. Size (TL) in inches and weight in pounds (lb) at age as applied to the population (Pop), fishery–dependent portion of the population (FD), and fishery–dependent portion of the population during the 20 mm size limit (FD20). The CV of length was estimated by the assessment model; other values were treated as input through the von Bertalanffy growth parameters.

Age	Pop.TL	CV.Pop.TL	Pop.lb	FD.TL	CV.FD.TL	FD.lb	FD20.TL	CV.FD20.TL	FD20.lb
1	12.8	0.11	1.2	11.2	0.14	0.8	16.2	0.1	2.4
2	17.7	0.11	3.1	16.2	0.14	2.4	19.5	0.1	4.1
3	21.6	0.11	5.6	20.2	0.14	4.6	22.2	0.1	6.1
4	24.6	0.11	8.3	23.4	0.14	7.2	24.5	0.1	8.2
5	27.0	0.11	11.0	26.0	0.14	9.8	26.5	0.1	10.3
6	28.9	0.11	13.5	28.1	0.14	12.3	28.1	0.1	12.4
7	30.4	0.11	15.7	29.7	0.14	14.7	29.5	0.1	14.3
8	31.6	0.11	17.5	31.1	0.14	16.7	30.6	0.1	16.0
9	32.5	0.11	19.1	32.1	0.14	18.5	31.6	0.1	17.6
10	33.2	0.11	20.4	33.0	0.14	20.0	32.5	0.1	19.0
11	33.8	0.11	21.5	33.7	0.14	21.3	33.2	0.1	20.3
12	34.2	0.11	22.3	34.2	0.14	22.4	33.7	0.1	21.4
13	34.6	0.11	23.0	34.7	0.14	23.3	34.2	0.1	22.4
14	34.9	0.11	23.6	35.0	0.14	24.0	34.7	0.1	23.2
15	35.1	0.11	24.0	35.3	0.14	24.6	35.0	0.1	23.9
16	35.2	0.11	24.4	35.6	0.14	25.0	35.3	0.1	24.5
17	35.4	0.11	24.7	35.7	0.14	25.4	35.6	0.1	25.1
18	35.5	0.11	24.9	35.9	0.14	25.8	35.8	0.1	25.5
19	35.6	0.11	25.1	36.0	0.14	26.0	36.0	0.1	25.9
20	35.6	0.11	25.2	36.1	0.14	26.2	36.1	0.1	26.2

Table 3. Observed time series of landings(L) and discards(D) for commercial lines (cH), headboat (HB), and general recreational (GR). Commercial landings are in units of 1000 lb whole weight. Recreational landings and discards and commercial discards are in units of 1000 fish. Confidential data have been redacted.

Year	cH.L	HB.L	GR.L	cH.D	HB.D	GR.D
1950	368.657	.	.	.	.	.
1951	499.765	.	.	.	.	.
1952	385.930	.	.	.	.	.
1953	398.279	.	.	.	.	.
1954	593.207	.	.	.	.	.
1955	493.315	12.501	24.035	.	.	.
1956	483.907	13.652	26.248	.	.	.
1957	867.291	14.803	28.460	.	.	.
1958	612.508	15.953	30.673	.	.	.
1959	657.736	17.104	32.885	.	.	.
1960	671.075	18.255	35.098	.	.	.
1961	796.374	19.908	38.276	.	.	.
1962	645.983	21.561	41.454	.	.	.
1963	488.789	23.214	44.633	.	.	.
1964	537.589	24.867	47.811	.	.	.
1965	558.108	26.520	50.989	.	.	.
1966	554.506	26.676	51.288	.	.	.
1967	725.503	26.831	51.587	.	.	.
1968	865.520	26.986	51.885	.	.	.
1969	538.190	27.142	52.184	.	.	.
1970	513.023	27.297	52.483	.	.	.
1971	457.393	29.995	57.670	.	.	.
1972	406.641	32.693	62.857	.	.	.
1973	296.560	35.391	68.044	.	.	.
1974	478.352	38.088	73.231	.	.	.
1975	600.790	40.786	78.418	.	.	.
1976	571.504	41.246	79.303	.	.	.
1977	596.339	41.707	80.187	.	.	.
1978	594.356	42.167	81.072	.	.	.
1979	420.936	42.627	81.957	.	.	.
1980	385.485	43.087	82.842	.	.	.
1981	378.759	36.031	93.458	.	.	4.435
1982	308.445	19.553	36.294	.	.	4.435
1983	316.818	30.698	68.469	.	.	4.435
1984	253.431	31.146	212.547	.	0.069	61.825
1985	250.824	50.336	288.971	.	0.111	64.088
1986	219.440	16.625	100.736	.	0.037	64.088
1987	191.701	24.996	47.373	.	0.055	64.088
1988	173.689	36.527	80.821	.	0.08	50.274
1989	266.942	23.453	97.147	.	0.052	19.383
1990	226.542	20.919	12.092	.	0.046	19.383
1991	143.546	13.857	34.717	.	0.03	19.383
1992	104.374	5.301	51.908	19.603	2.51	27.994
1993	220.153	7.347	11.326	16.725	3.478	68.149
1994	195.319	8.225	18.313	21.134	3.894	66.54
1995	177.312	8.826	13.482	21.068	4.178	50.89
1996	138.671	5.543	9.342	20.727	2.624	20.445
1997	110.595	5.770	34.238	22.392	2.732	16.574
1998	89.602	4.741	13.015	16.171	2.244	26.789
1999	93.595	6.836	39.579	13.641	3.236	162.71
2000	104.165	8.437	45.347	14.552	3.994	248.597
2001	196.697	12.028	31.587	15.141	5.694	202.665
2002	187.967	12.931	35.062	29.848	6.122	123.362
2003	138.342	5.706	25.977	8.372	2.701	159.329
2004	172.083	10.842	28.914	2.425	18.79	199.638
2005	129.700	8.907	29.443	10.177	9.876	72.855
2006	86.382	5.945	26.769	4.817	17.233	119.735
2007	114.973	6.889	17.646	13.778	71.886	288.276
2008	252.146	18.943	81.638	12.553	73.609	511.984
2009	362.386	21.507	54.666	14.466	57.327	240.516
2010	6.448	0.477	0.062	17.438	38.443	138.478
2011	− − −	− − −	0.062	40.107	41.391	33.484
2012	8.142	2.127	15.628	19.214	46.782	142.961
2013	31.600	1.520	7.588	19.302	46.74	83.992
2014	65.443	5.904	28.186	27.008	46.612	285.962

Table 4. Observed indices of abundance and CVs from commercial line (cH), headboat (HB), combined chevon trap and video (CVID), and headboat discard (HB.D).

Year	cH	cH CV	HB	HB CV	CVID	CVID CV	HB.D	HB.D CV
1976	.	.	2.37	0.2	.	.	.	.
1977	.	.	2.16	0.2	.	.	.	.
1978	.	.	2.13	0.2	.	.	.	.
1979	.	.	2.23	0.2	.	.	.	.
1980	.	.	1.45	0.2	.	.	.	.
1981	.	.	2.95	0.2	.	.	.	.
1982	.	.	1.20	0.2	.	.	.	.
1983	.	.	1.64	0.2	.	.	.	.
1984	.	.	1.42	0.2	.	.	.	.
1985	.	.	2.07	0.2	.	.	.	.
1986	.	.	0.48	0.2	.	.	.	.
1987	.	.	0.58	0.2	.	.	.	.
1988	.	.	0.56	0.2	.	.	.	.
1989	.	.	0.90	0.2	.	.	.	.
1990	.	.	0.87	0.2	.	.	.	.
1991	.	.	0.69	0.2	.	.	.	.
1992	.	.	0.08	0.2	.	.	.	.
1993	1.09	0.2	0.16	0.2	.	.	.	.
1994	0.89	0.2	0.26	0.2	.	.	.	.
1995	0.89	0.2	0.28	0.2	.	.	.	.
1996	0.61	0.2	0.25	0.2	.	.	.	.
1997	0.59	0.2	0.27	0.2	.	.	.	.
1998	0.66	0.2	0.24	0.2	.	.	.	.
1999	0.80	0.2	0.29	0.2	.	.	.	.
2000	0.74	0.2	0.41	0.2	.	.	.	.
2001	1.27	0.2	0.76	0.2	.	.	.	.
2002	1.38	0.2	0.88	0.2	.	.	.	.
2003	1.04	0.2	0.52	0.2	.	.	.	.
2004	1.42	0.2	0.76	0.2	.	.	.	.
2005	1.19	0.2	0.76	0.2	.	.	0.56	0.30
2006	0.60	0.2	0.43	0.2	.	.	0.41	0.37
2007	0.67	0.2	0.44	0.2	.	.	2.02	0.17
2008	1.22	0.2	1.71	0.2	.	.	1.39	0.21
2009	1.94	0.2	1.81	0.2	.	.	0.63	0.27
2010	.	.	.	.	0.90	0.26	0.56	0.30
2011	.	.	.	.	0.66	0.23	0.41	0.37
2012	.	.	.	.	1.10	0.18	2.02	0.17
2013	.	.	.	.	0.87	0.20	1.39	0.21
2014	.	.	.	.	1.47	0.17	0.63	0.27

Table 5. Sample sizes (number of trips) of length compositions (len) or age compositions (age) by survey or fleet. Data sources are commercial lines (cH), headboat (HB), headboat discard (HB.D), general recreational (GR),and MARMAP chevron trap (CVT).

Year	len.cH	len.cH.D	len.HB.D	age.cH	age.HB	age.GR	age.CVT
1978	.	.	.	.	80	.	.
1979	.	.	.	.	31	.	.
1980	.	.	.	.	30	.	.
1981	.	.	.	.	141	.	.
1982	.	.	.	.	55	.	.
1983	.	.	.	.	167	.	.
1984	125	.	.	.	166	.	.
1985	139	.	.	.	160	.	.
1986	94	.	.	.	97	.	.
1987	89	.	.	.	60	.	.
1988	84	.	.	.	.	.	.
1989	88	.	.	.	.	.	.
1990	63	.	.	11	23	.	.
1991	106	.	.	.	13	.	.
1992	82	.	.	11	.	.	.
1993	.	.	.	.	.	.	.
1994	.	.	.	14	.	.	.
1995	.	.	.	.	.	.	.
1996	.	.	.	48	.	.	.
1997	.	.	.	45	.	.	.
1998	.	.	.	14	.	.	.
1999	.	.	.	15	.	.	.
2000	.	.	.	28	.	.	.
2001	.	.	.	23	.	15	.
2002	.	.	.	.	.	84	.
2003	.	.	.	10	.	91	.
2004	.	.	.	25	.	83	.
2005	.	.	37	53	22	78	.
2006	.	.	29	84	49	26	.
2007	.	.	64	132	34	.	.
2008	.	.	61	158	47	.	.
2009	.	13	56	263	241	58	.
2010	.	.	50	.	.	.	73
2011	.	.	48	.	.	.	70
2012	.	.	56	39	40	121	148
2013	.	13	60	109	35	139	139
2014	.	.	56	64	49	315	150

Table 6. Coefficients of variation used for the MCB bootstraps of landings and discards. Commercial handline landings (cv.L.cH), headboat landings (cv.L.HB), general recreational landings (cv.L.GR), commercial handline discards (cv.D.cH), headboat discards (cv.D.HB), and general recreational discards (cv.D.GR).

Year	CV.L.cH	CV.L.HB	CV.L.GR	CV.D.cH	CV.D.HB	CV.D.GR
1950	0.25	–	–	–	–	–
1951	0.25	–	–	–	–	–
1952	0.25	–	–	–	–	–
1953	0.25	–	–	–	–	–
1954	0.25	–	–	–	–	–
1955	0.25	0.59	0.59	–	–	–
1956	0.25	0.59	0.59	–	–	–
1957	0.25	0.59	0.59	–	–	–
1958	0.25	0.59	0.59	–	–	–
1959	0.25	0.59	0.59	–	–	–
1960	0.25	0.59	0.59	–	–	–
1961	0.25	0.59	0.59	–	–	–
1962	0.20	0.59	0.59	–	–	–
1963	0.20	0.59	0.59	–	–	–
1964	0.20	0.59	0.59	–	–	–
1965	0.20	0.59	0.59	–	–	–
1966	0.20	0.59	0.59	–	–	–
1967	0.20	0.59	0.59	–	–	–
1968	0.20	0.59	0.59	–	–	–
1969	0.20	0.59	0.59	–	–	–
1970	0.20	0.59	0.59	–	–	–
1971	0.20	0.59	0.59	–	–	–
1972	0.20	0.59	0.59	–	–	–
1973	0.20	0.59	0.59	–	–	–
1974	0.20	0.59	0.59	–	–	–
1975	0.20	0.59	0.59	–	–	–
1976	0.20	0.59	0.59	–	–	–
1977	0.20	0.59	0.59	–	–	–
1978	0.10	0.59	0.59	–	–	–
1979	0.10	0.59	0.59	–	–	–
1980	0.10	0.59	0.59	–	–	–
1981	0.10	0.15	0.27	–	–	1.00
1982	0.10	0.15	0.34	–	–	1.00
1983	0.10	0.15	0.18	–	–	1.00
1984	0.10	0.15	0.22	–	0.20	0.56
1985	0.10	0.15	0.20	–	0.20	1.34
1986	0.05	0.15	0.29	–	0.20	1.00
1987	0.05	0.15	0.20	–	0.20	1.00
1988	0.05	0.15	0.28	–	0.20	1.33
1989	0.05	0.15	0.21	–	0.20	1.18
1990	0.05	0.15	0.29	–	0.20	1.00
1991	0.05	0.15	0.31	–	0.20	1.00
1992	0.05	0.15	0.19	0.20	0.20	0.79
1993	0.05	0.15	0.22	0.20	0.20	0.68
1994	0.05	0.15	0.27	0.20	0.20	0.81
1995	0.05	0.15	0.29	0.20	0.20	0.53
1996	0.05	0.10	0.42	0.20	0.20	1.00
1997	0.05	0.10	0.52	0.20	0.20	0.54
1998	0.05	0.10	0.24	0.20	0.20	0.96
1999	0.05	0.10	0.23	0.20	0.20	0.47
2000	0.05	0.10	0.23	0.20	0.20	0.45
2001	0.05	0.10	0.18	0.20	0.20	0.42
2002	0.05	0.10	0.17	0.20	0.20	0.56
2003	0.05	0.10	0.20	0.20	0.20	0.47
2004	0.05	0.10	0.21	0.20	0.20	0.29
2005	0.05	0.10	0.24	0.20	0.20	0.23
2006	0.05	0.10	0.26	0.20	0.20	0.31
2007	0.05	0.10	0.24	0.20	0.20	0.26
2008	0.05	0.05	0.27	0.20	0.20	0.36
2009	0.05	0.05	0.25	0.20	0.20	0.38
2010	0.05	0.05	1.00	0.20	0.20	0.39
2011	0.05	0.05	1.00	0.20	0.20	0.34
2012	0.05	0.05	0.17	0.20	0.20	0.39
2013	0.05	0.05	0.18	0.20	0.20	0.31
2014	0.05	0.05	0.11	0.20	0.20	0.21

Table 7. Estimated total abundance at age (1000 fish) at start of year.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
1950	449.22	247.68	170.03	125.98	97.96	78.41	63.97	52.81	44.00	36.91	31.09	26.29	22.30	18.96	16.13	13.75	11.73	10.01	8.55	50.39	1576.19
1951	449.22	247.68	169.95	125.84	97.85	78.32	63.89	52.75	43.95	36.87	31.06	26.26	22.28	18.93	16.11	13.73	11.72	10.00	8.54	50.33	1575.30
1952	449.21	247.64	169.17	124.42	96.65	77.36	63.11	52.11	43.41	36.42	30.68	25.94	22.00	18.70	15.91	13.56	11.57	9.88	8.44	49.72	1565.90
1953	449.21	247.67	169.80	124.98	96.45	77.13	62.92	51.95	43.28	36.31	30.58	25.86	21.94	18.65	15.86	13.52	11.54	9.85	8.41	49.57	1565.46
1954	449.20	247.66	169.73	125.30	96.78	76.89	62.66	51.73	43.10	36.16	30.46	25.76	21.85	18.57	15.80	13.47	11.49	9.81	8.38	49.36	1564.14
1955	449.18	247.60	168.55	123.19	95.39	75.84	61.41	50.65	42.20	35.40	29.82	25.22	21.39	18.18	15.47	13.19	11.25	9.60	8.20	48.33	1550.05
1956	449.15	246.82	161.79	115.43	89.10	71.71	58.73	48.62	40.82	34.47	29.17	24.67	20.93	17.79	15.13	12.90	11.01	9.39	8.02	47.28	1512.93
1957	449.11	246.69	160.25	109.72	82.74	66.48	55.19	46.28	39.04	33.26	28.35	24.09	20.43	17.36	14.77	12.59	10.75	9.17	7.83	46.16	1480.29
1958	449.02	246.42	156.50	103.47	74.89	58.87	48.87	41.61	35.60	30.51	26.25	22.46	19.14	16.27	13.84	11.80	10.07	8.59	7.34	43.25	1424.79
1959	448.93	246.31	156.55	102.01	71.41	53.96	43.90	37.44	32.57	28.34	24.54	21.20	18.20	15.54	13.22	11.27	9.62	8.21	7.01	41.31	1391.54
1960	448.83	246.12	154.88	100.16	69.16	50.62	39.65	33.19	28.96	25.64	22.56	19.62	17.00	14.62	12.50	10.65	9.09	7.76	6.63	39.05	1356.67
1961	448.70	245.91	153.27	97.44	66.83	48.32	36.72	29.64	25.42	22.60	20.25	17.89	15.61	13.55	11.67	9.99	8.53	7.28	6.21	36.62	1322.46
1962	448.54	245.59	150.21	92.92	62.71	45.14	33.97	26.67	22.09	19.33	17.42	15.67	13.89	12.14	10.55	9.10	7.80	6.66	5.69	33.51	1279.61
1963	448.35	245.35	149.19	90.72	59.69	42.37	31.83	24.80	20.03	16.96	15.05	13.62	12.29	10.91	9.55	8.31	7.18	6.15	5.26	30.98	1248.59
1964	448.19	245.13	148.67	90.32	58.52	40.59	30.14	23.49	18.87	15.59	13.41	11.95	10.84	9.81	8.72	7.64	6.66	5.75	4.94	29.08	1228.30
1965	448.00	244.82	146.30	87.59	56.77	38.86	28.26	21.83	17.57	14.47	12.15	10.49	9.38	8.53	7.72	6.88	6.03	5.26	4.55	26.91	1202.38
1966	447.78	244.48	143.83	83.89	53.67	36.85	26.52	20.12	16.08	13.29	11.14	9.40	8.14	7.29	6.63	6.02	5.36	4.71	4.11	24.59	1173.89
1967	447.52	244.25	142.54	81.34	50.72	34.40	24.87	18.69	14.69	12.07	10.16	8.54	7.23	6.27	5.62	5.13	4.66	4.15	3.65	22.25	1148.74
1968	447.14	243.86	138.94	76.45	46.63	30.87	22.08	16.69	13.01	10.52	8.81	7.44	6.28	5.32	4.62	4.15	3.79	3.44	3.07	19.18	1112.31
1969	446.56	243.33	134.48	69.80	41.05	26.64	18.64	13.97	10.97	8.81	7.27	6.11	5.18	4.38	3.71	3.23	2.91	2.65	2.41	15.60	1067.71
1970	446.00	243.09	136.78	71.05	39.52	24.76	17.00	12.48	9.74	7.88	6.46	5.35	4.51	3.83	3.24	2.76	2.40	2.16	1.97	13.41	1054.40
1971	445.51	242.75	136.22	71.85	40.00	23.71	15.73	11.34	8.67	6.97	5.76	4.74	3.94	3.33	2.83	2.40	2.04	1.78	1.60	11.41	1042.55
1972	445.02	242.19	134.05	70.19	39.79	23.70	14.94	10.45	7.87	6.22	5.11	4.24	3.50	2.91	2.46	2.10	1.78	1.52	1.32	9.69	1029.05
1973	444.53	241.60	131.55	67.58	38.16	23.25	14.79	9.87	7.24	5.65	4.58	3.78	3.15	2.60	2.17	1.84	1.57	1.33	1.13	8.23	1014.59
1974	444.13	241.07	130.24	66.28	36.86	22.46	14.69	9.94	6.99	5.33	4.27	3.47	2.88	2.40	1.99	1.66	1.41	1.20	1.02	7.18	1005.47
1975	443.41	240.15	122.70	58.66	32.39	19.56	12.88	9.02	6.46	4.74	3.73	3.00	2.45	2.03	1.70	1.41	1.17	1.00	0.85	5.82	973.13
1976	441.88	238.74	113.20	47.87	24.95	15.11	9.96	7.10	5.31	4.00	3.04	2.39	1.93	1.58	1.31	1.10	0.91	0.76	0.65	4.34	926.13
1977	439.39	237.15	106.54	40.05	18.55	10.68	7.13	5.13	3.93	3.11	2.43	1.85	1.47	1.19	0.97	0.81	0.68	0.56	0.47	3.08	885.17
1978	490.53	234.78	97.34	32.10	13.27	6.85	4.40	3.23	2.52	2.06	1.70	1.33	1.02	0.81	0.65	0.54	0.45	0.37	0.31	1.97	896.22
1979	364.63	260.57	86.07	23.54	8.57	4.00	2.33	1.67	1.35	1.13	0.97	0.80	0.63	0.48	0.38	0.31	0.26	0.21	0.18	1.09	759.17
1980	539.16	193.50	95.37	21.16	6.43	2.66	1.41	0.92	0.73	0.63	0.56	0.48	0.40	0.31	0.24	0.19	0.16	0.13	0.11	0.63	865.15
1981	188.64	284.03	62.99	19.16	4.77	1.68	0.80	0.49	0.36	0.31	0.28	0.25	0.22	0.18	0.14	0.11	0.09	0.07	0.06	0.34	564.97
1982	310.46	98.55	87.42	11.30	3.86	1.12	0.46	0.25	0.17	0.14	0.13	0.12	0.10	0.09	0.07	0.06	0.05	0.04	0.03	0.16	514.58
1983	881.10	164.58	36.72	20.79	2.93	1.11	0.36	0.16	0.10	0.07	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.08	1108.34
1984	1003.36	460.16	45.09	5.03	3.18	0.52	0.23	0.09	0.04	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.03	1517.89
1985	460.99	510.01	130.11	7.76	1.00	0.76	0.15	0.08	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.02	1111.02
1986	239.59	227.42	126.82	19.69	1.41	0.23	0.22	0.05	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	615.54
1987	777.07	117.93	88.26	38.83	6.79	0.55	0.10	0.11	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	1029.73
1988	582.89	403.01	53.57	33.38	16.14	3.11	0.28	0.05	0.06	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	1092.54
1989	205.82	305.21	192.51	22.39	15.32	8.13	1.71	0.16	0.03	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	751.35
1990	74.19	108.79	149.15	82.42	10.47	7.82	4.50	1.02	0.10	0.02	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	438.55
1991	64.46	38.66	62.94	85.31	50.50	6.76	5.26	3.13	0.73	0.08	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	317.88
1992	340.40	32.10	19.84	31.51	46.94	30.06	4.31	3.56	2.23	0.54	0.06	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	511.60
1993	121.03	173.87	19.93	9.01	10.26	17.14	13.10	2.23	2.12	1.47	0.38	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	370.63
1994	211.20	55.67	101.85	8.95	2.97	3.75	7.11	6.07	1.12	1.14	0.82	0.22	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	400.93
1995	95.70	97.71	32.66	47.33	3.09	1.12	1.60	3.37	3.14	0.62	0.65	0.48	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	287.63
1996	254.92	42.19	55.32	15.13	17.00	1.23	0.50	0.79	1.81	1.78	0.36	0.39	0.29	0.08	0.01	0.00	0.00	0.00	0.00	0.00	391.80
1997	175.72	129.95	26.80	29.72	6.58	7.93	0.62	0.28	0.46	1.09	1.10	0.23	0.25	0.19	0.05	0.01	0.00	0.00	0.00	0.00	380.98
1998	322.87	89.20	78.53	9.48	6.09	1.56	2.37	0.23	0.12	0.24	0.62	0.66	0.14	0.15	0.12	0.03	0.00	0.00	0.00	0.00	512.43
1999	431.59	167.93	57.66	43.21	4.25	2.93	0.82	1.36	0.14	0.08	0.16	0.42	0.45	0.10	0.11	0.08	0.02	0.00	0.00	0.00	711.30
2000	451.11	201.06	98.26	24.93	13.14	1.45	1.19	0.39	0.75	0.09	0.05	0.11	0.29	0.31	0.07	0.07	0.06	0.02	0.00	0.00	793.35
2001	325.68	197.11	112.51	41.74	7.54	4.48	0.59	0.57	0.22	0.45	0.06	0.03	0.07	0.20	0.22	0.05	0.05	0.04	0.01	0.00	691.61
2002	267.02	141.35	111.28	52.27	14.75	2.93	1.97	0.29	0.31	0.12	0.27	0.03	0.02	0.05	0.13	0.14	0.03	0.03	0.02	0.01	593.01
2003	346.59	119.25	80.97	52.75	19.33	6.02	1.36	1.02	0.17	0.19	0.08	0.18	0.02	0.01	0.03	0.08	0.09	0.02	0.02	0.02	628.22
2004	127.74	156.98	70.30	44.78	25.23	9.94	3.38	0.83	0.66	0.11	0.13	0.06	0.13	0.02	0.01	0.02	0.06	0.07	0.01	0.03	440.49
2005	52.24	43.69	75.59	32.70	17.68	11.07	4.92	1.86	0.49	0.42	0.07	0.09	0.04	0.09	0.01	0.01	0.02	0.04	0.05	0.03	241.14
2006	943.19	17.60	20.48	33.34	12.08	7.37	5.31	2.67	1.12	0.32	0.29	0.05	0.06	0.03	0.06	0.01	0.01	0.01	0.03	0.06	1044.08
2007	660.20	480.92	11.04	9.33	10.82	4.38	3.17	2.67	1.53	0.71	0.21	0.20	0.04	0.05	0.02	0.05	0.01	0.00	0.01	0.06	1185.42
2008	741.35	300.00	280.11	4.83	2.94	3.82	1.79	1.48	1.39	0.86	0.41	0.13	0.12	0.02	0.03	0.01	0.03	0.00	0.00	0.04	1339.38
2009	115.07	295.70	156.90	106.44	1.21	0.84	1.31	0.73	0.70	0.73	0.48	0.24	0.08	0.07	0.01	0.02	0.01	0.02	0.00	0.03	680.57
2010	148.33	40.21	142.83	64.82	33.03	0.42	0.33	0.59	0.37	0.37	0.41	0.28	0.14	0.05	0.04	0.01	0.01	0.00	0.01	0.02	432.28
2011	220.73	69.37	22.60	84.06	39.43	21.06	0.28	0.24	0.44	0.28	0.30	0.33	0.22	0.11	0.04	0.04	0.01	0.01	0.00	0.02	459.57
2012	241.50	115.17	44.07	14.82	56.34	27.27	15.03	0.21	0.18	0.34	0.22	0.23	0.25	0.17	0.09	0.03	0.03	0.01	0.01	0.02	515.98
2013	547.75	117.10	66.89	25.69	8.24	31.47	15.89	9.17	0.13	0.12	0.23	0.15	0.16	0.17	0.12	0.06	0.02	0.02	0.00	0.02	823.39
2014	941.88	285.09	74.50	43.72	16.48	5.35	21.02	10.91	6.44	0.09	0.08	0.16	0.11	0.11	0.13	0.09	0.04	0.01	0.01	0.02	1406.27
2015	434.25	475.21	171.85	42.81	21.87	7.94	2.65	10.81	5.79	3.51	0.05	0.05	0.09	0.06	0.06	0.07	0.05	0.02	0.01	0.02	1177.17

Table 8. Estimated biomass at age (mt) at start of year

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
1950	237.8	348.7	433.2	476.8	489.8	479.8	454.7	420.3	381.5	341.8	302.9	266.5	233.1	202.9	175.8	152.1	131.3	113.0	97.2	576.1	6315.3
1951	237.8	348.7	433.0	476.3	489.2	479.2	454.2	419.8	381.1	341.5	302.6	266.2	232.8	202.6	175.6	151.9	131.1	112.9	97.1	575.5	6309.1
1952	237.8	348.6	431.0	470.9	483.2	473.4	448.6	414.6	376.4	337.3	298.9	262.9	229.9	200.1	173.5	150.1	129.5	111.5	95.9	568.4	6242.6
1953	237.8	348.6	432.6	473.0	482.2	472.0	447.3	413.4	375.3	336.2	298.0	262.1	229.2	199.5	173.0	149.6	129.1	111.2	95.6	566.7	6232.5
1954	237.8	348.6	432.4	474.3	483.8	470.5	445.4	411.7	373.7	334.9	296.8	261.0	228.3	198.7	172.2	149.0	128.6	110.7	95.2	564.4	6218.1
1955	237.8	348.6	429.4	466.3	476.9	464.1	436.5	403.1	365.9	327.8	290.5	255.6	223.5	194.6	168.6	145.9	125.9	108.4	93.3	552.5	6115.0
1956	237.8	347.5	412.2	436.9	445.5	438.8	417.5	386.9	353.9	319.2	284.2	250.0	218.7	190.3	165.0	142.7	123.2	106.1	91.2	540.5	5908.0
1957	237.8	347.3	408.3	415.3	413.7	406.8	392.3	368.3	338.5	308.0	276.2	244.1	213.5	185.8	161.1	139.3	120.3	103.5	89.1	527.8	5696.9
1958	237.7	346.9	398.7	391.6	374.4	360.2	347.4	331.1	308.7	282.5	255.8	227.7	200.0	174.1	150.9	130.6	112.7	97.0	83.5	494.5	5306.1
1959	237.7	346.7	398.8	386.1	357.0	330.2	312.1	297.9	282.4	262.4	239.1	214.9	190.2	166.3	144.2	124.7	107.6	92.7	79.7	472.3	5043.0
1960	237.6	346.5	394.6	379.1	345.8	309.7	281.8	264.1	251.1	237.4	219.8	198.9	177.7	156.5	136.3	117.9	101.7	87.6	75.4	446.5	4765.8
1961	237.5	346.2	390.5	368.8	334.1	295.7	261.0	235.9	220.4	209.3	197.3	181.4	163.1	145.0	127.2	110.5	95.4	82.2	70.7	418.7	4490.9
1962	237.5	345.7	382.7	351.7	313.5	276.2	241.5	212.2	191.6	179.1	169.7	158.8	145.1	129.9	115.0	100.7	87.3	75.2	64.7	383.2	4161.2
1963	237.4	345.4	380.1	343.4	298.4	259.3	226.2	197.3	173.6	157.0	146.7	138.0	128.4	116.8	104.1	92.0	80.3	69.5	59.8	354.2	3907.9
1964	237.3	345.1	378.8	341.9	292.6	248.4	214.2	186.9	163.6	144.4	130.7	121.1	113.3	104.9	95.0	84.5	74.5	64.9	56.1	332.5	3730.7
1965	237.2	344.6	372.7	331.5	283.8	237.8	200.9	173.7	152.4	134.0	118.4	106.3	98.0	91.3	84.2	76.1	67.5	59.4	51.7	307.7	3529.2
1966	237.1	344.2	366.4	317.5	268.3	225.5	188.5	160.1	139.5	123.1	108.5	95.2	85.0	78.0	72.3	66.6	60.0	53.1	46.7	281.1	3316.8
1967	236.9	343.8	363.1	307.9	253.6	210.5	176.8	148.7	127.3	111.7	99.0	86.6	75.5	67.1	61.3	56.7	52.1	46.9	41.5	254.4	3121.6
1968	236.7	343.3	354.0	289.4	233.1	188.9	157.0	132.8	112.8	97.4	85.8	75.4	65.6	57.0	50.4	46.0	42.4	38.9	34.9	219.3	2861.0
1969	236.4	342.5	342.6	264.2	205.3	163.0	132.5	111.2	95.2	81.6	70.8	61.9	54.1	46.8	40.5	35.8	32.5	30.0	27.4	178.4	2552.7
1970	236.1	342.2	348.5	268.9	197.6	151.5	120.9	99.3	84.4	73.0	63.0	54.2	47.1	41.0	35.3	30.5	26.9	24.4	22.4	153.3	2420.6
1971	235.8	341.7	347.0	271.9	200.0	145.1	111.8	90.2	75.1	64.5	56.1	48.0	41.1	35.6	30.8	26.5	22.8	20.1	18.2	130.4	2313.1
1972	235.6	340.9	341.5	265.7	199.0	145.0	106.2	83.1	68.2	57.6	49.8	43.0	36.6	31.2	26.9	23.2	19.9	17.1	15.0	110.7	2216.3
1973	235.3	340.1	335.2	255.8	190.8	142.2	105.2	78.6	62.8	52.3	44.6	38.3	32.9	27.9	23.6	20.3	17.5	15.0	12.9	94.1	2125.3
1974	235.1	339.4	331.8	250.9	184.3	137.4	104.4	79.1	60.6	49.3	41.6	35.2	30.1	25.7	21.7	18.3	15.7	13.5	11.6	82.1	2067.9
1975	234.7	338.1	312.6	222.0	162.0	119.7	91.6	71.8	56.0	43.9	36.3	30.4	25.6	21.7	18.5	15.6	13.1	11.3	9.7	66.6	1901.1
1976	233.9	336.1	288.4	181.2	124.7	92.4	70.8	56.5	46.0	37.0	29.6	24.3	20.2	16.9	14.3	12.2	10.2	8.6	7.4	49.6	1660.2
1977	232.6	333.8	271.4	151.6	92.7	65.4	50.7	40.8	34.1	28.8	23.7	18.8	15.3	12.7	10.6	8.9	7.6	6.3	5.3	35.2	1446.4
1978	259.7	330.5	248.0	121.5	66.3	41.9	31.3	25.7	21.9	19.0	16.5	13.5	10.7	8.7	7.1	5.9	5.0	4.2	3.5	22.5	1263.5
1979	193.0	366.8	219.3	89.1	42.9	24.5	16.6	13.3	11.7	10.4	9.4	8.1	6.6	5.2	4.2	3.4	2.9	2.4	2.0	12.4	1044.2
1980	285.4	272.4	243.0	80.1	32.1	16.3	10.0	7.3	6.3	5.8	5.4	4.8	4.1	3.4	2.6	2.1	1.7	1.4	1.2	7.2	992.9
1981	99.9	399.8	160.5	72.5	23.9	10.3	5.7	3.9	3.1	2.9	2.8	2.5	2.3	1.9	1.6	1.2	1.0	0.8	0.7	3.9	800.9
1982	164.4	138.7	222.7	42.8	19.3	6.8	3.2	2.0	1.5	1.3	1.2	1.2	1.1	1.0	0.8	0.7	0.5	0.4	0.3	1.9	611.7
1983	466.4	231.7	93.5	78.7	14.7	6.8	2.5	1.3	0.8	0.6	0.6	0.5	0.5	0.5	0.4	0.3	0.3	0.2	0.2	0.9	901.6
1984	531.2	647.8	114.9	19.0	15.9	3.2	1.6	0.7	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.4	1336.6
1985	244.0	717.9	331.5	29.4	5.0	4.7	1.1	0.6	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.2	1335.7
1986	126.8	320.1	323.1	74.5	7.0	1.4	1.5	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	856.1
1987	411.4	166.0	224.9	147.0	34.0	3.4	0.7	0.8	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	989.0
1988	308.6	567.3	136.5	126.4	80.7	19.0	2.0	0.4	0.5	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1241.9
1989	109.0	429.6	490.4	84.7	76.6	49.7	12.1	1.3	0.3	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1254.7
1990	39.3	153.1	380.0	312.0	52.3	47.9	32.0	8.1	0.9	0.2	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1026.4
1991	34.1	54.4	160.4	322.9	252.5	41.3	37.4	24.9	6.3	0.7	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	935.5
1992	180.2	45.2	50.5	119.2	234.7	184.0	30.6	28.4	19.3	5.0	0.6	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	898.2
1993	64.1	244.8	50.8	34.1	51.3	104.9	93.1	17.7	18.4	13.6	3.7	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	697.3
1994	111.8	78.4	259.5	33.9	14.9	22.9	50.6	48.3	9.8	10.5	8.0	2.2	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	651.2
1995	50.7	137.5	83.2	179.1	15.5	6.9	11.3	26.8	27.2	5.7	6.3	4.9	1.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	556.8
1996	135.0	59.4	140.9	57.3	85.0	7.5	3.6	6.3	15.7	16.4	3.5	3.9	3.0	0.8	0.1	0.0	0.0	0.0	0.0	0.0	538.5
1997	93.0	182.9	68.3	112.5	32.9	48.5	4.4	2.2	4.0	10.1	10.8	2.3	2.6	2.0	0.5	0.1	0.0	0.0	0.0	0.0	577.2
1998	170.9	125.6	200.1	35.9	30.5	9.5	16.9	1.9	1.1	2.2	6.0	6.7	1.5	1.7	1.3	0.3	0.0	0.0	0.0	0.0	611.9
1999	228.5	236.4	146.9	163.5	21.3	17.9	5.8	10.8	1.2	0.7	1.5	4.2	4.7	1.0	1.2	0.9	0.2	0.0	0.0	0.0	846.9
2000	238.8	283.0	250.3	94.4	65.7	8.9	8.5	3.1	6.5	0.8	0.5	1.1	3.0	3.4	0.7	0.8	0.6	0.2	0.0	0.0	970.4
2001	172.4	277.5	286.6	158.0	37.7	27.4	4.2	4.5	1.9	4.2	0.5	0.4	0.8	2.1	2.4	0.5	0.6	0.4	0.1	0.0	982.2
2002	141.4	199.0	283.5	197.8	73.7	17.9	14.0	2.3	2.7	1.1	2.6	0.3	0.2	0.5	1.4	1.5	0.3	0.4	0.3	0.1	941.1
2003	183.5	167.9	206.3	199.7	96.7	36.8	9.6	8.1	1.4	1.7	0.8	1.8	0.2	0.2	0.3	0.9	1.0	0.2	0.3	0.3	917.7
2004	67.6	221.0	179.1	169.5	126.1	60.8	24.1	6.6	5.8	1.0	1.3	0.6	1.3	0.2	0.1	0.2	0.7	0.8	0.2	0.4	867.3
2005	27.7	61.5	192.6	123.8	88.4	67.8	35.0	14.8	4.3	3.9	0.7	0.9	0.4	0.9	0.1	0.1	0.2	0.5	0.5	0.4	624.5
2006	499.3	24.8	52.2	126.2	60.4	45.1	37.7	21.2	9.7	3.0	2.8	0.5	0.7	0.3	0.7	0.1	0.1	0.1	0.4	0.7	885.8
2007	349.5	677.0	28.1	35.3	54.1	26.8	22.5	21.3	13.3	6.5	2.1	2.0	0.4	0.5	0.2	0.5	0.1	0.0	0.1	0.7	1241.1
2008	392.5	422.3	713.6	18.3	14.7	23.4	12.7	11.8	12.0	7.9	4.0	1.3	1.3	0.2	0.3	0.1	0.3	0.0	0.0	0.5	1637.4
2009	60.9	416.3	399.7	402.9	6.1	5.1	9.3	5.8	6.0	6.7	4.7	2.5	0.8	0.8	0.2	0.2	0.1	0.2	0.0	0.3	1328.5
2010	78.5	56.6	363.9	245.3	165.1	2.6	2.4	4.7	3.2	3.5	4.0	2.8	1.5	0.5	0.5	0.1	0.1	0.1	0.1	0.2	935.6
2011	116.9	97.7	57.6	318.2	197.1	128.9	2.0	1.9	3.8	2.6	2.9	3.3	2.3	1.2	0.4	0.4	0.1	0.1	0.0	0.3	937.6
2012	127.8	162.1	112.3	56.1	281.7	166.9	106.8	1.7	1.5	3.1	2.1	2.3	2.7	1.9	1.0	0.3	0.3	0.1	0.1	0.2	1031.0
2013	290.0	164.8	170.4	97.2	41.2	192.6	113.0	73.0	1.1	1.1	2.2	1.5	1.6	1.8	1.3	0.7	0.2	0.2	0.0	0.2	1154.2
2014	498.6	401.3	189.8	165.5	82.4	32.7	149.4	86.8	55.9	0.9	0.8	1.7	1.1	1.2	1.4	1.0	0.5	0.2	0.2	0.2	1671.5
2015	229.9	669.0	437.8	162.0	109.3	48.6	18.9	86.0	50.2	32.5	0.5	0.5	1.0	0.6	0.7	0.8	0.5	0.3	0.1	0.2	1849.3

Table 9. Estimated biomass at age (1000 lb) at start of year

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
1950	524.3	768.8	955.0	1051.2	1079.8	1057.8	1002.4	926.6	841.1	753.5	667.8	587.5	513.9	447.3	387.6	335.3	289.5	249.1	214.3	1270.1	13922.8
1951	524.3	768.8	954.6	1050.1	1078.5	1056.5	1001.3	925.5	840.2	752.9	667.1	586.9	513.2	446.7	387.1	334.9	289.0	248.9	214.1	1268.8	13909.2
1952	524.3	768.5	950.2	1038.2	1065.3	1043.7	989.0	914.0	829.8	743.6	659.0	579.6	506.8	441.1	382.5	330.9	285.5	245.8	211.4	1253.1	13762.6
1953	524.3	768.5	953.7	1042.8	1063.1	1040.6	986.1	911.4	827.4	741.2	657.0	577.8	505.3	439.8	381.4	329.8	284.6	245.2	210.8	1249.4	13740.3
1954	524.3	768.5	953.3	1045.7	1066.6	1037.3	981.9	907.6	823.9	738.3	654.3	575.4	503.3	438.1	379.6	328.5	283.5	244.1	209.9	1244.3	13708.5
1955	524.3	768.5	946.7	1028.0	1051.4	1023.2	962.3	888.7	806.7	722.7	640.4	563.5	492.7	429.0	371.7	321.7	277.6	239.0	205.7	1218.1	13481.3
1956	524.3	766.1	908.7	963.2	982.2	967.4	920.4	853.0	780.2	703.7	626.6	551.2	482.2	419.5	363.8	314.6	271.6	233.9	201.1	1191.6	13024.9
1957	524.3	765.7	900.1	915.6	912.1	896.8	864.9	812.0	746.3	679.0	608.9	538.1	470.7	409.6	355.2	307.1	265.2	228.2	196.4	1163.6	12559.5
1958	524.0	764.8	879.0	863.3	825.4	794.1	765.9	729.9	680.6	622.8	563.9	502.0	440.9	383.8	332.7	287.9	248.5	213.8	184.1	1090.2	11697.9
1959	524.0	764.3	879.2	851.2	787.0	728.0	688.1	656.8	622.6	578.5	527.1	473.8	419.3	366.6	317.9	274.9	237.2	204.4	175.7	1041.2	11117.9
1960	523.8	763.9	869.9	835.8	762.4	682.8	621.3	582.2	553.6	523.4	484.6	438.5	391.8	345.0	300.5	259.9	224.2	193.1	166.2	984.4	10506.8
1961	523.6	763.2	860.9	813.1	736.6	651.9	575.4	520.1	485.9	461.4	435.0	399.9	359.6	319.7	280.4	243.6	210.3	181.2	155.9	923.1	9900.7
1962	523.6	762.1	843.7	775.4	691.1	608.9	532.4	467.8	422.4	394.8	374.1	350.1	319.9	286.4	253.5	222.0	192.5	165.8	142.6	844.8	9173.9
1963	523.4	761.5	838.0	757.1	657.9	571.7	498.7	435.0	382.7	346.1	323.4	304.2	283.1	257.5	229.5	202.8	177.0	153.2	131.8	780.9	8615.4
1964	523.2	760.8	835.1	753.8	645.1	547.6	472.2	412.0	360.7	318.3	288.1	267.0	249.8	231.3	209.4	186.3	164.2	143.1	123.7	733.0	8224.8
1965	522.9	759.7	821.7	730.8	625.7	524.3	442.9	382.9	336.0	295.4	261.0	234.4	216.1	201.3	185.6	167.8	148.8	131.0	114.0	678.4	7780.5
1966	522.7	758.8	807.8	700.0	591.5	497.1	415.6	353.0	307.5	271.4	239.2	209.9	187.4	172.0	159.4	146.8	132.3	117.1	103.0	619.7	7312.3
1967	522.3	757.9	800.5	678.8	559.1	464.1	389.8	327.8	280.6	246.3	218.3	190.9	166.4	147.9	135.1	125.0	114.9	103.4	91.5	560.9	6881.9
1968	521.8	756.8	780.4	638.0	513.9	416.5	346.1	292.8	248.7	214.7	189.2	166.2	144.6	125.7	111.1	101.4	93.5	85.8	76.9	483.5	6307.4
1969	521.2	755.1	755.3	582.5	452.6	359.4	292.1	245.2	209.9	179.9	156.1	136.5	119.3	103.2	89.3	78.9	71.7	66.1	60.4	393.3	5627.7
1970	520.5	754.4	768.3	592.8	435.6	334.0	266.5	218.9	186.1	160.9	138.9	119.5	103.8	90.4	77.8	67.2	59.3	53.8	49.4	338.0	5336.5
1971	519.8	753.3	765.0	599.4	440.9	319.9	246.5	198.9	165.6	142.2	123.7	105.8	90.6	78.5	67.9	58.4	50.3	44.3	40.1	287.5	5099.5
1972	519.4	751.6	752.9	585.8	438.7	319.7	234.1	183.2	150.4	127.0	109.8	94.8	80.7	68.8	59.3	51.1	43.9	37.7	33.1	244.1	4886.1
1973	518.7	749.8	739.0	563.9	420.6	313.5	231.9	173.3	138.5	115.3	98.3	84.4	72.5	61.5	52.0	44.8	38.6	33.1	28.4	207.5	4685.5
1974	518.3	748.2	731.5	553.1	406.3	302.9	230.2	174.4	133.6	108.7	91.7	77.6	66.4	56.7	47.8	40.3	34.6	29.8	25.6	181.0	4558.9
1975	517.4	745.4	689.2	489.4	357.1	263.9	201.9	158.3	123.5	96.8	80.0	67.0	56.4	47.8	40.8	34.4	28.9	24.9	21.4	146.8	4191.2
1976	515.7	741.0	635.8	399.5	274.9	203.7	156.1	124.6	101.4	81.6	65.3	53.6	44.5	37.3	31.5	26.9	22.5	19.0	16.3	109.3	3660.1
1977	512.8	735.9	598.3	334.2	204.4	144.2	111.8	89.9	75.2	63.5	52.2	41.4	33.7	28.0	23.4	19.6	16.8	13.9	11.7	77.6	3188.8
1978	572.5	728.6	546.7	267.9	146.2	92.4	69.0	56.7	48.3	41.9	36.4	29.8	23.6	19.2	15.7	13.0	11.0	9.3	7.7	49.6	2785.5
1979	425.5	808.7	483.5	196.4	94.6	54.0	36.6	29.3	25.8	22.9	20.7	17.9	14.6	11.5	9.3	7.5	6.4	5.3	4.4	27.3	2302.1
1980	629.2	600.5	535.7	176.6	70.8	35.9	22.0	16.1	13.9	12.8	11.9	10.6	9.0	7.5	5.7	4.6	3.7	3.1	2.6	15.9	2189.0
1981	220.2	881.4	353.8	159.8	52.7	22.7	12.6	8.6	6.8	6.4	6.2	5.5	5.1	4.2	3.5	2.6	2.2	1.8	1.5	8.6	1765.7
1982	362.4	305.8	491.0	94.4	42.5	15.0	7.1	4.4	3.3	2.9	2.6	2.6	2.4	2.2	1.8	1.5	1.1	0.9	0.7	4.2	1348.6
1983	1028.2	510.8	206.1	173.5	32.4	15.0	5.5	2.9	1.8	1.3	1.3	1.1	1.1	1.1	0.9	0.7	0.7	0.4	0.4	2.0	1987.7
1984	1171.1	1428.2	253.3	41.9	35.1	7.1	3.5	1.5	0.9	0.7	0.4	0.4	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.9	2946.7
1985	537.9	1582.7	730.8	64.8	11.0	10.4	2.4	1.3	0.7	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.4	2944.7
1986	279.5	705.7	712.3	164.2	15.4	3.1	3.3	0.9	0.7	0.4	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	1887.4
1987	907.0	366.0	495.8	324.1	75.0	7.5	1.5	1.8	0.4	0.4	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2180.4
1988	680.3	1250.7	300.9	278.7	177.9	41.9	4.4	0.9	1.1	0.4	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2737.9
1989	240.3	947.1	1081.1	186.7	168.9	109.6	26.7	2.9	0.7	0.9	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2766.1
1990	86.6	337.5	837.8	687.8	115.3	105.6	70.5	17.9	2.0	0.4	0.7	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2262.8
1991	75.2	119.9	353.6	711.9	556.7	91.1	82.5	54.9	13.9	1.5	0.4	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2062.4
1992	397.3	99.6	111.3	262.8	517.4	405.7	67.5	62.6	42.5	11.0	1.3	0.2	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1980.2
1993	141.3	539.7	112.0	75.2	113.1	231.3	205.3	39.0	40.6	30.0	8.2	0.9	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1537.3
1994	246.5	172.8	572.1	74.7	32.8	50.5	111.6	106.5	21.6	23.1	17.6	4.9	0.7	0.2	0.2	0.0	0.0	0.0	0.0	0.0	1435.6
1995	111.8	303.1	183.4	394.8	34.2	15.2	24.9	59.1	60.0	12.6	13.9	10.8	2.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0	1227.5
1996	297.6	131.0	310.6	126.3	187.4	16.5	7.9	13.9	34.6	36.2	7.7	8.6	6.6	1.8	0.2	0.0	0.0	0.0	0.0	0.0	1187.2
1997	205.0	403.2	150.6	248.0	72.5	106.9	9.7	4.9	8.8	22.3	23.8	5.1	5.7	4.4	1.1	0.2	0.0	0.0	0.0	0.0	1272.5
1998	376.8	276.9	441.1	79.1	67.2	20.9	37.3	4.2	2.4	4.9	13.2	14.8	3.3	3.7	2.9	0.7	0.0	0.0	0.0	0.0	1349.0
1999	503.8	521.2	323.9	360.5	47.0	39.5	12.8	23.8	2.6	1.5	3.3	9.3	10.4	2.2	2.6	2.0	0.4	0.0	0.0	0.0	1867.1
2000	526.5	623.9	551.8	208.1	144.8	19.6	18.7	6.8	14.3	1.8	1.1	2.4	6.6	7.5	1.5	1.8	1.3	0.4	0.0	0.0	2139.4
2001	380.1	611.8	631.8	348.3	83.1	60.4	9.3	9.9	4.2	9.3	1.1	0.9	1.8	4.6	5.3	1.1	1.3	0.9	0.2	0.0	2165.4
2002	311.7	438.7	625.0	436.1	162.5	39.5	30.9	5.1	6.0	2.4	5.7	0.7	0.4	1.1	3.1	3.3	0.7	0.9	0.7	0.2	2074.8
2003	404.5	370.2	454.8	440.3	213.2	81.1	21.2	17.9	3.1	3.7	1.8	4.0	0.4	0.4	0.7	2.0	2.2	0.4	0.7	0.7	2023.2
2004	149.0	487.2	394.8	373.7	278.0	134.0	53.1	14.6	12.8	2.2	2.9	1.3	2.9	0.4	0.2	0.4	1.5	1.8	0.4	0.9	1912.1
2005	61.1	135.6	424.6	272.9	194.9	149.5	77.2	32.6	9.5	8.6	1.5	2.0	0.9	2.0	0.2	0.2	0.4	1.1	1.1	0.9	1376.8
2006	1100.8	54.7	115.1	278.2	133.2	99.4	83.1	46.7	21.4	6.6	6.2	1.1	1.5	0.7	1.5	0.2	0.2	0.2	0.9	1.5	1952.9
2007	770.5	1492.5	61.9	77.8	119.3	59.1	49.6	47.0	29.3	14.3	4.6	4.4	0.9	1.1	0.4	1.1	0.2	0.0	0.2	1.5	2736.2
2008	865.3	931.0	1573.2	40.3	32.4	51.6	28.0	26.0	26.5	17.4	8.8	2.9	2.9	0.4	0.7	0.2	0.7	0.0	0.0	1.1	3609.8
2009	134.3	917.8	881.2	888.2	13.4	11.2	20.5	12.8	13.2	14.8	10.4	5.5	1.8	1.8	0.4	0.4	0.2	0.4	0.0	0.7	2928.8
2010	173.1	124.8	802.3	540.8	364.0	5.7	5.3	10.4	7.1	7.7	8.8	6.2	3.3	1.1	1.1	0.2	0.2	0.2	0.2	0.4	2062.6
2011	257.7	215.4	127.0	701.5	434.5	284.2	4.4	4.2	8.4	5.7	6.4	7.3	5.1	2.6	0.9	0.9	0.2	0.2	0.0	0.7	2067.1
2012	281.8	357.4	247.6	123.7	621.0	368.0	235.5	3.7	3.3	6.8	4.6	5.1	6.0	4.2	2.2	0.7	0.7	0.2	0.2	0.4	2273.0
2013	639.3	363.3	375.7	214.3	90.8	424.6	249.1	160.9	2.4	2.4	4.9	3.3	3.5	4.0	2.9	1.5	0.4	0.4	0.0	0.4	2544.6
2014	1099.2	884.7	418.4	364.9	181.7	72.1	329.4	191.4	123.2	2.0	1.8	3.7	2.4	2.6	3.1	2.2	1.1	0.4	0.4	0.4	3685.0
2015	506.8	1474.9	965.2	357.1	241.0	107.1	41.7	189.6	110.7	71.7	1.1	1.1	2.2	1.3	1.5	1.8	1.1	0.7	0.2	0.4	4077.0

Table 10. Estimated time series of status indicators, fishing mortality, and biomass. Fishing mortality rate is apical F. Total biomass (B, mt) is at the start of the year, and spawning biomass (SSB, 1E8 eggs) at the time of peak spawning (mid-year). The $MSST_{\mathrm{F30}}$ is defined by $\mathrm{MSST} = (1 - M)SSB_{\mathrm{F30}}$, with constant $M = 0.134$.

Year	F	F/F_{30}	B	B/B_{unfished}	SSB	$SSB/SSBB_{\mathrm{F30}}$	$SSB/MSST_{\mathrm{F30}}$
1950	0.031	0.210	6315	0.788	778960	2.371	3.161
1951	0.042	0.287	6309	0.787	771773	2.349	3.132
1952	0.033	0.223	6243	0.779	767209	2.335	3.113
1953	0.034	0.231	6233	0.778	764680	2.327	3.103
1954	0.051	0.347	6218	0.776	753582	2.294	3.058
1955	0.108	0.736	6115	0.763	733829	2.234	2.978
1956	0.117	0.803	5908	0.737	709192	2.159	2.878
1957	0.166	1.139	5697	0.711	664637	2.023	2.697
1958	0.157	1.074	5306	0.662	621070	1.890	2.520
1959	0.176	1.201	5043	0.629	579755	1.765	2.353
1960	0.192	1.316	4766	0.595	536726	1.634	2.178
1961	0.229	1.569	4491	0.560	488083	1.486	1.981
1962	0.233	1.596	4161	0.519	443907	1.351	1.801
1963	0.231	1.579	3908	0.488	410213	1.249	1.665
1964	0.258	1.765	3731	0.466	378434	1.152	1.536
1965	0.285	1.950	3529	0.440	345580	1.052	1.402
1966	0.299	2.046	3317	0.414	313902	0.955	1.274
1967	0.352	2.408	3122	0.390	277381	0.844	1.126
1968	0.418	2.856	2861	0.357	234431	0.714	0.951
1969	0.367	2.510	2553	0.319	204371	0.622	0.829
1970	0.373	2.550	2421	0.302	183530	0.559	0.745
1971	0.392	2.682	2313	0.289	166624	0.507	0.676
1972	0.414	2.831	2216	0.277	152622	0.465	0.619
1973	0.415	2.835	2125	0.265	142706	0.434	0.579
1974	0.527	3.602	2068	0.258	127612	0.388	0.518
1975	0.670	4.585	1901	0.237	104381	0.318	0.424
1976	0.768	5.253	1660	0.207	80264	0.244	0.326
1977	0.929	6.353	1446	0.181	57202	0.174	0.232
1978	1.149	7.857	1263	0.158	36637	0.112	0.149
1979	1.132	7.742	1044	0.130	24769	0.075	0.101
1980	1.334	9.124	993	0.124	16724	0.051	0.068
1981	1.447	9.900	801	0.100	11596	0.035	0.047
1982	1.165	7.969	612	0.076	8961	0.027	0.036
1983	1.717	11.745	902	0.113	6393	0.019	0.026
1984	1.489	10.185	1337	0.167	8512	0.026	0.035
1985	1.617	11.063	1336	0.167	10233	0.031	0.042
1986	0.913	6.242	856	0.107	12176	0.037	0.049
1987	0.701	4.796	989	0.123	14948	0.045	0.061
1988	0.601	4.113	1242	0.155	20904	0.064	0.085
1989	0.577	3.949	1255	0.157	29141	0.089	0.118
1990	0.288	1.968	1026	0.128	39978	0.122	0.162
1991	0.421	2.880	936	0.117	47267	0.144	0.192
1992	0.900	6.157	898	0.112	38229	0.116	0.155
1993	0.887	6.066	697	0.087	27957	0.085	0.113
1994	0.840	5.747	651	0.081	23471	0.071	0.095
1995	0.802	5.483	557	0.069	20207	0.062	0.082
1996	0.610	4.176	539	0.067	18883	0.057	0.077
1997	1.363	9.320	577	0.072	14722	0.045	0.060
1998	0.580	3.965	612	0.076	16002	0.049	0.065
1999	0.968	6.622	847	0.106	17548	0.053	0.071
2000	0.974	6.663	970	0.121	19194	0.058	0.078
2001	0.818	5.598	982	0.123	22085	0.067	0.090
2002	0.773	5.284	941	0.117	24413	0.074	0.099
2003	0.516	3.526	918	0.115	27949	0.085	0.113
2004	0.707	4.836	867	0.108	28594	0.087	0.116
2005	0.774	5.294	624	0.078	25432	0.077	0.103
2006	0.903	6.176	886	0.111	20275	0.062	0.082
2007	0.932	6.372	1241	0.155	21429	0.065	0.087
2008	1.161	7.944	1637	0.204	28100	0.086	0.114
2009	0.948	6.485	1328	0.166	30379	0.092	0.123
2010	0.275	1.881	936	0.117	37902	0.115	0.154
2011	0.178	1.218	938	0.117	48791	0.149	0.198
2012	0.389	2.663	1031	0.129	51799	0.158	0.210
2013	0.239	1.637	1154	0.144	55022	0.167	0.223
2014	0.538	3.680	1672	0.209	54037	0.164	0.219
2015	.	.	1849	0.231	.	.	.

Table 11. Selectivity at age for MARMAP chevron traps (CVT), commercial handlines (cH), headboat (HB), and general recreational (GR) landings (L) and discards (D). For time-varying selectivities, values shown are from selectivity block 1 (1950–1991).

Age	CVT	cH.L	HB.L	GR.L	cH.D	HB.D	GR.D
1	0.065	0.013	0.049	0.049	1.000	1.000	1.000
2	0.634	0.410	0.670	0.670	0.990	0.701	0.701
3	0.977	0.974	1.000	1.000	0.734	0.269	0.269
4	0.999	1.000	0.897	0.897	0.398	0.071	0.071
5	1.000	1.000	0.749	0.749	0.172	0.017	0.017
6	1.000	1.000	0.587	0.587	0.066	0.004	0.004
7	1.000	1.000	0.430	0.430	0.024	0.001	0.001
8	1.000	1.000	0.298	0.298	0.009	0.000	0.000
9	1.000	1.000	0.196	0.196	0.003	0.000	0.000
10	1.000	1.000	0.125	0.125	0.001	0.000	0.000
11	1.000	1.000	0.125	0.125	0.000	0.000	0.000
12	1.000	1.000	0.125	0.125	0.000	0.000	0.000
13	1.000	1.000	0.125	0.125	0.000	0.000	0.000
14	1.000	1.000	0.125	0.125	0.000	0.000	0.000
15	1.000	1.000	0.125	0.125	0.000	0.000	0.000
16	1.000	1.000	0.125	0.125	0.000	0.000	0.000
17	1.000	1.000	0.125	0.125	0.000	0.000	0.000
18	1.000	1.000	0.125	0.125	0.000	0.000	0.000
19	1.000	1.000	0.125	0.125	0.000	0.000	0.000
20	1.000	1.000	0.125	0.125	0.000	0.000	0.000

Table 12. Selectivity at age for MARMAP chevron traps (CVT), commercial handlines (cH), headboat (HB), and general recreational (GR) landings (L) and discards (D). For time-varying selectivities, values shown are from selectivity block 2 (1992–2009).

Age	CVT	cH.L	HB.L	GR.L	cH.D	HB.D	GR.D
1	0.065	0.001	0.001	0.005	1.000	1.000	1.000
2	0.634	0.026	0.031	0.067	0.990	0.701	0.701
3	0.977	0.431	0.689	0.544	0.734	0.269	0.269
4	0.999	0.956	1.000	1.000	0.398	0.071	0.071
5	1.000	0.998	0.772	0.911	0.172	0.017	0.017
6	1.000	1.000	0.532	0.719	0.066	0.004	0.004
7	1.000	1.000	0.334	0.519	0.024	0.001	0.001
8	1.000	1.000	0.195	0.345	0.009	0.000	0.000
9	1.000	1.000	0.109	0.216	0.003	0.000	0.000
10	1.000	1.000	0.059	0.129	0.001	0.000	0.000
11	1.000	1.000	0.059	0.075	0.000	0.000	0.000
12	1.000	1.000	0.059	0.043	0.000	0.000	0.000
13	1.000	1.000	0.059	0.024	0.000	0.000	0.000
14	1.000	1.000	0.059	0.024	0.000	0.000	0.000
15	1.000	1.000	0.059	0.024	0.000	0.000	0.000
16	1.000	1.000	0.059	0.024	0.000	0.000	0.000
17	1.000	1.000	0.059	0.024	0.000	0.000	0.000
18	1.000	1.000	0.059	0.024	0.000	0.000	0.000
19	1.000	1.000	0.059	0.024	0.000	0.000	0.000
20	1.000	1.000	0.059	0.024	0.000	0.000	0.000

Table 13. Selectivity at age for MARMAP chevron traps (CVT), commercial handlines (cH), headboat (HB), and general recreational (GR) landings (L) and discards (D). For time-varying selectivities, values shown are from selectivity block 3 (2010–2014).

Age	CVT	cH.L	HB.L	GR.L	cH.D	HB.D	GR.D
1	0.065	0.006	0.017	0.005	0.038	0.715	0.715
2	0.634	0.066	0.334	0.036	0.222	0.885	0.885
3	0.977	0.447	1.000	0.233	0.672	0.991	0.991
4	0.999	0.902	0.914	0.711	0.937	1.000	1.000
5	1.000	0.991	0.734	0.952	0.991	0.911	0.911
6	1.000	0.999	0.560	0.994	0.999	0.752	0.752
7	1.000	1.000	0.409	0.999	1.000	0.569	0.569
8	1.000	1.000	0.288	1.000	1.000	0.401	0.401
9	1.000	1.000	0.198	1.000	1.000	0.267	0.267
10	1.000	1.000	0.133	1.000	1.000	0.171	0.171
11	1.000	1.000	0.133	1.000	1.000	0.171	0.171
12	1.000	1.000	0.133	1.000	1.000	0.171	0.171
13	1.000	1.000	0.133	1.000	1.000	0.171	0.171
14	1.000	1.000	0.133	1.000	1.000	0.171	0.171
15	1.000	1.000	0.133	1.000	1.000	0.171	0.171
16	1.000	1.000	0.133	1.000	1.000	0.171	0.171
17	1.000	1.000	0.133	1.000	1.000	0.171	0.171
18	1.000	1.000	0.133	1.000	1.000	0.171	0.171
19	1.000	1.000	0.133	1.000	1.000	0.171	0.171
20	1.000	1.000	0.133	1.000	1.000	0.171	0.171

Table 14. Estimated time series of fully selected fishing mortality rates for commercial handlines (F.cH.L), headboat (F.HB.L), recreational (F.GR.L) landings (L) and discards (D). Also shown is Full F, the maximum F at age summed across fleets, which may not equal the sum of fully selected F's because of dome-shaped selectivities.

Year	F.cH.L	F.HB.L	F.GR.L	F.cH.D	F.HB.D	F.GR.D	Full F
1950	0.031	0.000	0.000	0.000	0.000	0.000	0.031
1951	0.042	0.000	0.000	0.000	0.000	0.000	0.042
1952	0.033	0.000	0.000	0.000	0.000	0.000	0.033
1953	0.034	0.000	0.000	0.000	0.000	0.000	0.034
1954	0.051	0.000	0.000	0.000	0.000	0.000	0.051
1955	0.043	0.022	0.043	0.000	0.000	0.000	0.108
1956	0.044	0.025	0.049	0.000	0.000	0.000	0.117
1957	0.084	0.029	0.056	0.000	0.000	0.000	0.166
1958	0.064	0.032	0.062	0.000	0.000	0.000	0.157
1959	0.073	0.036	0.069	0.000	0.000	0.000	0.176
1960	0.079	0.039	0.076	0.000	0.000	0.000	0.192
1961	0.102	0.044	0.086	0.000	0.000	0.000	0.229
1962	0.090	0.050	0.096	0.000	0.000	0.000	0.233
1963	0.073	0.055	0.105	0.000	0.000	0.000	0.231
1964	0.085	0.060	0.115	0.000	0.000	0.000	0.258
1965	0.095	0.066	0.127	0.000	0.000	0.000	0.285
1966	0.102	0.068	0.131	0.000	0.000	0.000	0.299
1967	0.147	0.071	0.137	0.000	0.000	0.000	0.352
1968	0.200	0.076	0.147	0.000	0.000	0.000	0.418
1969	0.139	0.079	0.152	0.000	0.000	0.000	0.367
1970	0.143	0.080	0.154	0.000	0.000	0.000	0.373
1971	0.135	0.089	0.171	0.000	0.000	0.000	0.392
1972	0.128	0.099	0.190	0.000	0.000	0.000	0.414
1973	0.098	0.109	0.210	0.000	0.000	0.000	0.415
1974	0.171	0.123	0.237	0.000	0.000	0.000	0.527
1975	0.251	0.146	0.280	0.000	0.000	0.000	0.670
1976	0.295	0.164	0.316	0.000	0.000	0.000	0.768
1977	0.395	0.186	0.358	0.000	0.000	0.000	0.929
1978	0.536	0.215	0.412	0.000	0.000	0.000	1.149
1979	0.482	0.226	0.435	0.000	0.000	0.000	1.132
1980	0.558	0.271	0.520	0.000	0.000	0.000	1.334
1981	0.653	0.225	0.584	0.000	0.000	0.006	1.447
1982	0.660	0.182	0.338	0.000	0.000	0.006	1.165
1983	0.910	0.257	0.573	0.000	0.000	0.002	1.717
1984	0.458	0.132	0.904	0.000	0.000	0.025	1.489
1985	0.323	0.191	1.099	0.000	0.000	0.044	1.617
1986	0.291	0.086	0.522	0.000	0.000	0.080	0.913
1987	0.263	0.150	0.285	0.000	0.000	0.037	0.701
1988	0.178	0.131	0.290	0.000	0.000	0.029	0.601
1989	0.188	0.076	0.313	0.000	0.000	0.021	0.577
1990	0.143	0.086	0.050	0.000	0.000	0.048	0.288
1991	0.097	0.087	0.217	0.000	0.000	0.086	0.421
1992	0.108	0.082	0.699	0.032	0.003	0.038	0.900
1993	0.394	0.218	0.268	0.035	0.007	0.138	0.887
1994	0.368	0.134	0.328	0.041	0.007	0.125	0.840
1995	0.347	0.174	0.260	0.060	0.012	0.150	0.802
1996	0.301	0.111	0.193	0.039	0.004	0.034	0.610
1997	0.305	0.164	0.887	0.043	0.005	0.030	1.363
1998	0.234	0.087	0.258	0.022	0.003	0.033	0.580
1999	0.198	0.114	0.648	0.014	0.003	0.149	0.968
2000	0.205	0.117	0.640	0.014	0.003	0.213	0.974
2001	0.313	0.133	0.363	0.017	0.006	0.215	0.818
2002	0.256	0.130	0.370	0.039	0.008	0.161	0.773
2003	0.173	0.059	0.274	0.010	0.003	0.182	0.516
2004	0.218	0.128	0.335	0.005	0.040	0.431	0.707
2005	0.188	0.124	0.421	0.044	0.053	0.394	0.774
2006	0.171	0.145	0.588	0.003	0.009	0.063	0.903
2007	0.329	0.226	0.375	0.006	0.037	0.148	0.932
2008	0.341	0.139	0.672	0.006	0.040	0.275	1.161
2009	0.370	0.151	0.405	0.014	0.085	0.355	0.948
2010	0.006	0.003	0.001	0.041	0.050	0.179	0.275
2011	0.000	0.010	0.001	0.103	0.040	0.032	0.178
2012	0.007	0.017	0.165	0.054	0.043	0.132	0.389
2013	0.028	0.011	0.087	0.050	0.028	0.050	0.239
2014	0.058	0.031	0.311	0.055	0.017	0.102	0.538

Table 15. Estimated instantaneous fishing mortality rate (per yr) at age.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.000	0.013	0.030	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
1951	0.001	0.017	0.041	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
1952	0.000	0.013	0.032	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
1953	0.000	0.014	0.033	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
1954	0.001	0.021	0.049	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051
1955	0.004	0.062	0.108	0.102	0.092	0.082	0.071	0.063	0.056	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
1956	0.004	0.068	0.117	0.111	0.100	0.088	0.076	0.066	0.059	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
1957	0.005	0.091	0.166	0.160	0.147	0.134	0.120	0.109	0.101	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095
1958	0.005	0.090	0.157	0.149	0.135	0.119	0.105	0.092	0.082	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076
1959	0.006	0.100	0.176	0.167	0.151	0.134	0.118	0.104	0.093	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
1960	0.007	0.110	0.192	0.183	0.166	0.147	0.129	0.114	0.102	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
1961	0.008	0.129	0.229	0.219	0.199	0.178	0.158	0.141	0.128	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118
1962	0.008	0.134	0.233	0.221	0.199	0.175	0.153	0.133	0.119	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108
1963	0.009	0.137	0.231	0.216	0.193	0.167	0.142	0.120	0.104	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093
1964	0.010	0.152	0.258	0.242	0.216	0.188	0.161	0.137	0.120	0.107	0.107	0.107	0.107	0.107	0.107	0.107	0.107	0.107	0.107	0.107
1965	0.011	0.168	0.285	0.268	0.239	0.208	0.178	0.152	0.133	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119
1966	0.011	0.176	0.299	0.281	0.252	0.219	0.188	0.162	0.141	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127
1967	0.012	0.200	0.352	0.334	0.303	0.269	0.237	0.209	0.188	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173
1968	0.013	0.231	0.418	0.400	0.367	0.331	0.296	0.266	0.244	0.228	0.228	0.228	0.228	0.228	0.228	0.228	0.228	0.228	0.228	0.228
1969	0.013	0.212	0.367	0.347	0.313	0.275	0.239	0.208	0.185	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168
1970	0.013	0.215	0.373	0.352	0.318	0.280	0.243	0.212	0.188	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172
1971	0.015	0.230	0.392	0.369	0.330	0.288	0.247	0.213	0.186	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168
1972	0.016	0.246	0.414	0.387	0.345	0.298	0.252	0.214	0.185	0.164	0.164	0.164	0.164	0.164	0.164	0.164	0.164	0.164	0.164	0.164
1973	0.017	0.254	0.415	0.384	0.337	0.285	0.235	0.193	0.160	0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138
1974	0.020	0.311	0.527	0.494	0.441	0.382	0.326	0.278	0.241	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216
1975	0.024	0.388	0.670	0.633	0.570	0.501	0.434	0.378	0.335	0.304	0.304	0.304	0.304	0.304	0.304	0.304	0.304	0.304	0.304	0.304
1976	0.027	0.443	0.768	0.726	0.655	0.577	0.502	0.438	0.389	0.355	0.355	0.355	0.355	0.355	0.355	0.355	0.355	0.355	0.355	0.355
1977	0.032	0.526	0.929	0.883	0.802	0.714	0.629	0.557	0.501	0.463	0.463	0.463	0.463	0.463	0.463	0.463	0.463	0.463	0.463	0.463
1978	0.038	0.640	1.149	1.098	1.005	0.903	0.805	0.722	0.659	0.614	0.614	0.614	0.614	0.614	0.614	0.614	0.614	0.614	0.614	0.614
1979	0.039	0.641	1.132	1.076	0.978	0.871	0.767	0.679	0.612	0.565	0.565	0.565	0.565	0.565	0.565	0.565	0.565	0.565	0.565	0.565
1980	0.046	0.758	1.334	1.267	1.150	1.021	0.898	0.793	0.713	0.656	0.656	0.656	0.656	0.656	0.656	0.656	0.656	0.656	0.656	0.656
1981	0.054	0.814	1.447	1.380	1.260	1.128	1.001	0.894	0.812	0.754	0.754	0.754	0.754	0.754	0.754	0.754	0.754	0.754	0.754	0.754
1982	0.040	0.623	1.165	1.127	1.050	0.965	0.884	0.815	0.762	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725
1983	0.055	0.931	1.717	1.655	1.532	1.397	1.267	1.157	1.073	1.014	1.014	1.014	1.014	1.014	1.014	1.014	1.014	1.014	1.014	1.014
1984	0.082	0.899	1.489	1.390	1.235	1.066	0.904	0.766	0.662	0.588	0.588	0.588	0.588	0.588	0.588	0.588	0.588	0.588	0.588	0.588
1985	0.112	1.028	1.617	1.485	1.291	1.081	0.879	0.707	0.577	0.485	0.485	0.485	0.485	0.485	0.485	0.485	0.485	0.485	0.485	0.485
1986	0.114	0.583	0.913	0.842	0.747	0.648	0.552	0.472	0.410	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367
1987	0.062	0.425	0.701	0.656	0.589	0.518	0.450	0.392	0.348	0.317	0.317	0.317	0.317	0.317	0.317	0.317	0.317	0.317	0.317	0.317
1988	0.052	0.375	0.601	0.557	0.493	0.424	0.358	0.303	0.260	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230
1989	0.043	0.352	0.577	0.538	0.479	0.416	0.355	0.304	0.264	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237
1990	0.057	0.183	0.288	0.268	0.245	0.223	0.201	0.183	0.169	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160
1991	0.102	0.303	0.421	0.375	0.326	0.275	0.227	0.187	0.156	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135
1992	0.077	0.113	0.518	0.900	0.815	0.657	0.499	0.366	0.268	0.203	0.166	0.143	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130
1993	0.182	0.171	0.530	0.887	0.814	0.705	0.607	0.530	0.476	0.442	0.427	0.418	0.413	0.413	0.413	0.413	0.413	0.413	0.413	0.413
1994	0.176	0.169	0.495	0.840	0.780	0.679	0.584	0.508	0.454	0.419	0.401	0.390	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384
1995	0.224	0.205	0.499	0.802	0.731	0.631	0.542	0.472	0.423	0.391	0.377	0.369	0.364	0.364	0.364	0.364	0.364	0.364	0.364	0.364
1996	0.079	0.090	0.350	0.610	0.570	0.502	0.439	0.390	0.355	0.333	0.322	0.316	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312
1997	0.083	0.140	0.768	1.363	1.247	1.033	0.821	0.644	0.515	0.429	0.381	0.353	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336
1998	0.059	0.072	0.326	0.580	0.540	0.467	0.397	0.340	0.299	0.272	0.258	0.250	0.245	0.245	0.245	0.245	0.245	0.245	0.245	0.245
1999	0.169	0.172	0.567	0.968	0.881	0.726	0.573	0.444	0.350	0.288	0.253	0.232	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220
2000	0.233	0.217	0.585	0.974	0.884	0.729	0.577	0.449	0.356	0.295	0.260	0.240	0.228	0.228	0.228	0.228	0.228	0.228	0.228	0.228
2001	0.240	0.208	0.496	0.818	0.753	0.647	0.547	0.465	0.406	0.368	0.349	0.337	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330
2002	0.211	0.193	0.475	0.773	0.703	0.594	0.493	0.410	0.351	0.312	0.292	0.280	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273
2003	0.197	0.165	0.321	0.516	0.473	0.402	0.335	0.279	0.238	0.212	0.197	0.188	0.183	0.183	0.183	0.183	0.183	0.183	0.183	0.183
2004	0.478	0.367	0.494	0.707	0.630	0.529	0.435	0.359	0.304	0.269	0.251	0.240	0.234	0.234	0.234	0.234	0.234	0.234	0.234	0.234
2005	0.493	0.394	0.548	0.774	0.682	0.561	0.449	0.358	0.293	0.250	0.227	0.213	0.206	0.205	0.205	0.205	0.205	0.205	0.205	0.205
2006	0.079	0.102	0.515	0.903	0.820	0.671	0.524	0.402	0.314	0.255	0.224	0.205	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194
2007	0.194	0.177	0.556	0.932	0.849	0.720	0.600	0.503	0.435	0.391	0.371	0.359	0.352	0.352	0.352	0.352	0.352	0.352	0.352	0.352
2008	0.324	0.284	0.697	1.161	1.066	0.899	0.736	0.600	0.501	0.436	0.399	0.378	0.365	0.365	0.365	0.365	0.365	0.365	0.365	0.365
2009	0.456	0.364	0.613	0.948	0.866	0.745	0.632	0.540	0.475	0.432	0.410	0.397	0.389	0.389	0.389	0.389	0.389	0.389	0.389	0.389
2010	0.165	0.212	0.259	0.275	0.257	0.221	0.179	0.140	0.109	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087
2011	0.056	0.090	0.151	0.178	0.176	0.163	0.149	0.136	0.125	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118	0.118
2012	0.129	0.179	0.268	0.365	0.389	0.366	0.332	0.301	0.276	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258
2013	0.058	0.088	0.154	0.222	0.239	0.229	0.214	0.200	0.188	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180
2014	0.089	0.142	0.283	0.471	0.538	0.528	0.503	0.480	0.461	0.448	0.448	0.448	0.448	0.448	0.448	0.448	0.448	0.448	0.448	0.448

Table 16. Estimated time series of landings in number (1000 fish) for commercial handlines (L.cH), headboat (L.HB), and recreational (L.GR).

Year	L.cH	L.HB	L.GR	Total
1950	26.93	0.00	0.00	26.93
1951	36.52	0.00	0.00	36.52
1952	28.24	0.00	0.00	28.24
1953	29.18	0.00	0.00	29.18
1954	43.53	0.00	0.00	43.53
1955	36.13	12.50	24.03	72.67
1956	35.34	13.65	26.24	75.23
1957	63.51	14.80	28.46	106.77
1958	45.33	15.95	30.67	91.95
1959	49.33	17.10	32.88	99.31
1960	51.16	18.25	35.09	104.50
1961	61.87	19.91	38.27	120.05
1962	51.34	21.56	41.44	114.33
1963	39.73	23.21	44.62	107.56
1964	44.60	24.86	47.79	117.26
1965	47.29	26.51	50.96	124.77
1966	48.12	26.67	51.26	126.05
1967	64.73	26.82	51.56	143.11
1968	80.12	26.98	51.85	158.95
1969	52.14	27.13	52.15	131.43
1970	51.64	27.29	52.45	131.38
1971	47.47	29.98	57.62	135.07
1972	43.21	32.68	62.80	138.68
1973	32.11	35.37	67.96	135.44
1974	52.63	38.06	73.12	163.81
1975	68.18	40.75	78.27	187.20
1976	68.63	41.21	79.17	189.01
1977	77.38	41.63	79.91	198.93
1978	85.92	42.15	81.02	209.09
1979	69.90	42.65	82.05	194.60
1980	66.74	43.10	82.89	192.73
1981	75.05	36.05	93.56	204.66
1982	55.53	19.57	36.37	111.47
1983	66.97	30.70	68.48	166.15
1984	65.07	31.16	213.09	309.32
1985	57.93	50.34	289.25	397.52
1986	43.14	16.62	100.67	160.43
1987	33.32	24.98	47.33	105.63
1988	34.58	36.50	80.68	151.75
1989	47.48	23.44	96.89	167.81
1990	33.05	20.91	12.09	66.04
1991	16.72	13.85	34.69	65.27
1992	9.02	5.30	51.74	66.05
1993	18.25	7.35	11.33	36.93
1994	19.73	8.23	18.34	46.30
1995	17.51	8.83	13.49	39.84
1996	13.89	5.54	9.34	28.76
1997	10.82	5.77	34.09	50.68
1998	10.05	4.74	13.02	27.81
1999	10.30	6.84	39.63	56.77
2000	11.94	8.44	45.34	65.72
2001	22.75	12.03	31.58	66.36
2002	21.22	12.95	35.19	69.36
2003	14.84	5.71	26.00	46.55
2004	17.57	10.84	28.86	57.27
2005	12.92	8.91	29.45	51.28
2006	7.93	5.95	26.72	40.59
2007	11.37	6.89	17.65	35.91
2008	32.18	18.97	81.92	133.07
2009	42.54	21.56	55.03	119.13
2010	0.79	0.48	0.06	1.33
2011	0.06	1.36	0.06	1.48
2012	0.76	2.13	15.62	18.51
2013	3.00	1.52	7.58	12.11
2014	6.85	5.90	28.20	40.95

Table 17. Estimated time series of landings in whole weight (1000 lb) for commercial handlines (L.cH), headboat (L.HB), and recreational (L.GR).

Year	L.cH	L.HB	L.GR	Total
1950	368.63	0.00	0.00	368.63
1951	499.70	0.00	0.00	499.70
1952	385.89	0.00	0.00	385.89
1953	398.23	0.00	0.00	398.23
1954	593.09	0.00	0.00	593.09
1955	493.22	105.73	203.28	802.24
1956	483.81	114.76	220.62	819.19
1957	866.94	122.74	235.96	1225.64
1958	612.31	129.58	249.13	991.03
1959	657.49	136.40	262.23	1056.12
1960	670.79	143.04	274.98	1088.81
1961	795.93	153.19	294.49	1243.61
1962	645.66	162.61	312.60	1120.87
1963	488.58	172.16	330.95	991.69
1964	537.31	181.96	349.77	1069.04
1965	557.78	191.15	367.44	1116.37
1966	554.15	188.90	363.10	1106.15
1967	724.83	186.10	357.71	1268.65
1968	864.47	181.77	349.38	1395.63
1969	537.74	177.12	340.44	1055.30
1970	512.58	175.11	336.56	1024.25
1971	457.00	190.40	365.94	1013.34
1972	406.30	205.69	395.28	1007.27
1973	296.36	220.76	424.19	941.31
1974	477.76	234.74	451.01	1163.51
1975	599.71	243.15	467.08	1309.94
1976	570.55	233.05	447.72	1251.32
1977	594.84	221.32	424.81	1240.97
1978	593.57	206.97	397.81	1198.35
1979	421.45	195.51	376.09	993.05
1980	385.86	194.35	373.78	953.99
1981	379.01	153.11	397.42	929.54
1982	309.48	92.58	172.00	574.06
1983	317.00	113.71	253.63	684.34
1984	253.57	107.60	735.87	1097.04
1985	250.87	198.23	1138.94	1588.04
1986	219.41	76.54	463.49	759.44
1987	191.52	120.33	227.94	539.79
1988	173.51	155.72	344.23	673.46
1989	266.44	116.72	482.48	865.64
1990	226.33	130.06	75.19	431.58
1991	143.47	107.59	269.42	520.47
1992	104.30	55.74	554.98	715.02
1993	220.07	72.66	112.36	405.09
1994	195.69	65.33	151.62	412.64
1995	177.57	77.01	118.32	372.91
1996	138.63	47.09	81.06	266.78
1997	110.39	50.36	292.70	453.45
1998	89.59	36.90	101.25	227.73
1999	93.61	56.35	319.96	469.91
2000	104.14	66.82	354.14	525.10
2001	196.55	96.04	250.68	543.27
2002	188.39	106.65	291.53	586.57
2003	138.42	49.13	225.90	413.45
2004	171.81	96.00	259.47	527.28
2005	129.64	78.63	270.48	478.76
2006	86.21	56.67	252.86	395.73
2007	114.58	56.26	130.36	301.20
2008	251.86	137.53	584.16	973.55
2009	363.61	174.09	441.65	979.35
2010	6.45	3.30	0.54	10.29
2011	0.57	11.11	0.62	12.30
2012	8.14	16.69	177.80	202.63
2013	31.60	10.70	87.43	129.73
2014	65.45	34.90	300.79	401.13

Table 18. Estimated time series of discard mortalities in numbers (1000 fish) for commercial handlines (D.cH), headboat (D.HB), and recreational (D.GR).

Year	D.cH	D.HB	D.GR	Total
1981	.	.	1.64	.
1982	.	.	1.64	.
1983	.	.	1.64	.
1984	.	0.03	22.88	.
1985	.	0.04	23.71	.
1986	.	0.01	23.71	.
1987	.	0.02	23.71	.
1988	.	0.03	18.60	.
1989	.	0.02	7.17	.
1990	.	0.02	7.17	.
1991	.	0.01	7.18	.
1992	9.41	0.93	10.36	20.70
1993	8.03	1.29	25.24	34.56
1994	10.15	1.44	24.64	36.23
1995	10.12	1.55	18.85	30.52
1996	9.95	0.97	7.57	18.49
1997	10.75	1.01	6.13	17.90
1998	7.76	0.83	9.91	18.51
1999	6.55	1.20	60.21	67.96
2000	6.98	1.48	91.96	100.42
2001	7.27	2.11	75.03	84.40
2002	14.33	2.27	45.67	62.27
2003	4.02	1.00	58.97	63.98
2004	1.16	6.95	74.05	82.16
2005	4.89	3.66	27.12	35.67
2006	2.31	6.38	44.31	53.00
2007	5.24	26.60	106.66	138.50
2008	4.77	27.23	189.33	221.33
2009	5.50	21.22	89.08	115.79
2010	6.63	14.24	51.39	72.25
2011	15.28	11.80	9.55	36.62
2012	7.30	13.34	40.83	61.47
2013	7.34	13.33	23.98	44.65
2014	10.26	13.29	81.59	105.14

Table 19. Estimated time series of discard mortalities in whole weight (1000 lb) for commercial handlines (D.cH), headboat (D.HB), and recreational (D.GR).

Year	D.cH	D.HB	D.GR	Total
1981	.	.	3.58	.
1982	.	.	2.74	.
1983	.	.	2.26	.
1984	.	0.04	36.20	.
1985	.	0.08	47.25	.
1986	.	0.03	51.32	.
1987	.	0.03	34.75	.
1988	.	0.06	34.58	.
1989	.	0.05	18.06	.
1990	.	0.05	22.14	.
1991	.	0.03	19.72	.
1992	17.83	1.31	14.63	33.78
1993	21.23	2.94	57.58	81.74
1994	25.87	2.76	47.13	75.75
1995	30.29	3.57	43.56	77.42
1996	21.36	1.58	12.34	35.28
1997	25.68	2.00	12.16	39.84
1998	16.91	1.44	17.21	35.56
1999	13.99	2.10	105.42	121.51
2000	15.83	2.73	169.97	188.53
2001	18.92	4.34	154.59	177.85
2002	39.51	4.72	95.20	139.43
2003	9.92	1.85	108.97	120.73
2004	3.75	17.33	184.56	205.65
2005	19.56	10.44	77.41	107.41
2006	3.18	7.88	54.74	65.79
2007	10.93	50.16	201.15	262.24
2008	11.40	52.20	362.92	426.52
2009	19.76	62.13	260.85	342.73
2010	48.44	74.12	267.57	390.12
2011	133.73	59.28	47.95	240.96
2012	67.07	61.67	188.74	317.48
2013	61.91	43.61	78.43	183.96
2014	71.86	35.54	218.23	325.63

Table 20. Estimated total landings at age in numbers (1000 fish)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.13	2.60	4.40	3.42	2.70	2.18	1.79	1.48	1.24	1.04	0.88	0.75	0.63	0.54	0.46	0.39	0.33	0.28	0.24	1.43
1951	0.18	3.55	5.97	4.64	3.66	2.95	2.42	2.01	1.68	1.41	1.19	1.01	0.86	0.73	0.62	0.53	0.45	0.39	0.33	1.94
1952	0.14	2.76	4.64	3.58	2.82	2.28	1.87	1.55	1.30	1.09	0.92	0.78	0.66	0.56	0.48	0.41	0.35	0.30	0.25	1.50
1953	0.14	2.86	4.81	3.72	2.91	2.35	1.93	1.60	1.34	1.12	0.95	0.80	0.68	0.58	0.49	0.42	0.36	0.31	0.26	1.54
1954	0.22	4.28	7.19	5.57	4.36	3.50	2.87	2.38	1.99	1.67	1.41	1.19	1.01	0.86	0.73	0.63	0.53	0.46	0.39	2.30
1955	1.27	12.41	15.09	10.73	7.66	5.47	3.91	2.86	2.15	1.66	1.40	1.19	1.01	0.86	0.73	0.62	0.53	0.45	0.39	2.28
1956	1.42	13.61	15.74	10.89	7.72	5.54	3.98	2.90	2.17	1.68	1.42	1.20	1.02	0.87	0.74	0.63	0.54	0.46	0.39	2.31
1957	1.76	18.06	21.61	14.59	10.34	7.65	5.79	4.45	3.48	2.80	2.39	2.04	1.73	1.47	1.25	1.07	0.91	0.78	0.66	3.92
1958	1.85	17.77	19.98	12.87	8.61	6.09	4.48	3.39	2.62	2.07	1.79	1.53	1.31	1.11	0.95	0.81	0.69	0.59	0.50	2.96
1959	2.05	19.70	22.17	14.09	9.13	6.23	4.51	3.43	2.70	2.18	1.89	1.63	1.40	1.20	1.02	0.87	0.74	0.63	0.54	3.19
1960	2.25	21.49	23.85	15.04	9.62	6.36	4.43	3.31	2.62	2.14	1.89	1.65	1.43	1.23	1.05	0.90	0.76	0.65	0.56	3.29
1961	2.59	25.03	27.67	17.23	11.03	7.26	4.97	3.62	2.84	2.35	2.11	1.87	1.63	1.42	1.22	1.05	0.89	0.76	0.65	3.84
1962	2.79	26.00	27.52	16.57	10.33	6.68	4.45	3.09	2.30	1.85	1.67	1.51	1.34	1.17	1.02	0.88	0.75	0.64	0.55	3.23
1963	2.96	26.43	27.08	15.89	9.54	5.98	3.89	2.61	1.85	1.40	1.25	1.13	1.02	0.91	0.79	0.69	0.60	0.51	0.44	2.58
1964	3.26	29.14	29.79	17.51	10.39	6.40	4.14	2.80	1.98	1.48	1.27	1.14	1.03	0.93	0.83	0.73	0.64	0.55	0.47	2.78
1965	3.58	31.87	32.00	18.55	11.03	6.72	4.26	2.87	2.04	1.52	1.28	1.11	0.99	0.90	0.82	0.73	0.64	0.56	0.48	2.85
1966	3.73	33.16	32.79	18.54	10.90	6.68	4.21	2.79	1.98	1.48	1.24	1.05	0.91	0.82	0.74	0.68	0.60	0.53	0.46	2.76
1967	4.07	37.36	37.34	20.86	12.13	7.49	4.86	3.28	2.35	1.79	1.51	1.27	1.08	0.94	0.84	0.77	0.70	0.62	0.55	3.33
1968	4.52	42.49	41.93	22.76	13.10	8.01	5.24	3.63	2.62	2.00	1.68	1.42	1.20	1.02	0.89	0.80	0.73	0.66	0.59	3.68
1969	4.39	39.22	36.49	18.46	10.07	5.90	3.67	2.44	1.73	1.28	1.05	0.89	0.75	0.64	0.54	0.47	0.42	0.39	0.35	2.27
1970	4.45	39.70	37.60	19.05	9.83	5.57	3.40	2.22	1.56	1.16	0.95	0.79	0.67	0.57	0.48	0.41	0.36	0.32	0.29	1.99
1971	4.84	42.06	39.04	20.01	10.29	5.47	3.19	2.02	1.37	1.01	0.83	0.69	0.57	0.48	0.41	0.35	0.30	0.26	0.23	1.66
1972	5.28	44.65	40.17	20.37	10.61	5.62	3.09	1.87	1.24	0.88	0.72	0.60	0.50	0.41	0.35	0.30	0.25	0.22	0.19	1.38
1973	5.63	45.75	39.47	19.47	9.98	5.31	2.87	1.61	1.00	0.68	0.55	0.46	0.38	0.31	0.26	0.22	0.19	0.16	0.14	1.00
1974	6.59	54.57	47.26	23.38	12.03	6.58	3.79	2.24	1.40	0.97	0.78	0.63	0.52	0.44	0.36	0.30	0.26	0.22	0.19	1.31
1975	7.97	65.50	53.29	24.96	12.91	7.12	4.21	2.64	1.72	1.16	0.92	0.74	0.60	0.50	0.42	0.35	0.29	0.25	0.21	1.44
1976	9.00	72.56	54.07	22.46	11.02	6.13	3.65	2.35	1.60	1.12	0.85	0.67	0.54	0.44	0.37	0.31	0.26	0.21	0.18	1.22
1977	10.37	82.66	57.63	21.41	9.43	5.06	3.10	2.04	1.45	1.08	0.85	0.65	0.51	0.41	0.34	0.28	0.24	0.20	0.16	1.08
1978	13.67	94.77	59.72	19.56	7.77	3.79	2.27	1.56	1.14	0.89	0.73	0.58	0.44	0.35	0.28	0.23	0.19	0.16	0.13	0.85
1979	10.44	105.38	52.37	14.18	4.94	2.16	1.17	0.77	0.58	0.46	0.39	0.33	0.26	0.20	0.16	0.13	0.10	0.09	0.07	0.44
1980	18.28	88.18	63.34	13.94	4.07	1.58	0.78	0.47	0.35	0.29	0.25	0.22	0.18	0.14	0.11	0.09	0.07	0.06	0.05	0.29
1981	6.67	135.14	43.49	13.17	3.17	1.06	0.48	0.27	0.19	0.15	0.14	0.13	0.11	0.09	0.07	0.05	0.04	0.04	0.03	0.17
1982	7.80	38.79	53.99	6.99	2.32	0.64	0.25	0.13	0.09	0.07	0.06	0.06	0.05	0.04	0.04	0.03	0.02	0.02	0.01	0.08
1983	33.89	85.75	27.36	15.53	2.14	0.78	0.24	0.10	0.06	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.05
1984	41.36	230.37	31.44	3.47	2.09	0.32	0.13	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01
1985	22.33	274.48	93.89	5.51	0.67	0.47	0.08	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1986	5.76	77.38	66.24	10.13	0.68	0.10	0.09	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	14.09	32.57	39.02	16.88	2.78	0.21	0.03	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	9.84	100.98	21.21	12.87	5.75	0.99	0.08	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	3.27	73.50	74.19	8.42	5.34	2.55	0.47	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.46	12.51	31.39	17.23	2.07	1.44	0.76	0.16	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.75	6.86	18.08	23.71	12.77	1.50	0.99	0.50	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.88	1.33	6.63	16.75	23.91	13.36	1.57	1.02	0.49	0.09	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.15	4.69	6.38	4.70	5.21	8.01	5.54	0.85	0.75	0.49	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.30	1.53	30.55	4.49	1.46	1.70	2.92	2.26	0.38	0.36	0.25	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	0.11	2.36	9.36	22.70	1.45	0.48	0.62	1.18	1.01	0.19	0.19	0.14	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.24	0.82	12.82	6.08	6.69	0.45	0.17	0.24	0.50	0.47	0.09	0.10	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00
1997	0.60	7.37	12.12	20.02	4.32	4.74	0.33	0.12	0.17	0.36	0.33	0.06	0.07	0.05	0.01	0.00	0.00	0.00	0.00	0.00
1998	0.36	1.87	17.79	3.71	2.31	0.54	0.72	0.06	0.03	0.05	0.13	0.14	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00
1999	1.03	6.76	20.16	24.04	2.28	1.40	0.33	0.45	0.04	0.02	0.03	0.08	0.08	0.02	0.02	0.01	0.00	0.00	0.00	0.00
2000	1.03	7.88	34.14	13.86	7.07	0.70	0.48	0.13	0.21	0.02	0.01	0.02	0.06	0.06	0.01	0.01	0.01	0.00	0.00	0.00
2001	0.47	5.47	33.33	20.65	3.64	1.97	0.23	0.20	0.07	0.13	0.02	0.01	0.02	0.05	0.06	0.01	0.01	0.01	0.00	0.00
2002	0.39	3.83	31.44	24.66	6.75	1.21	0.71	0.09	0.08	0.03	0.06	0.01	0.00	0.01	0.03	0.03	0.01	0.01	0.01	0.00
2003	0.37	2.28	16.14	18.59	6.60	1.84	0.36	0.23	0.03	0.03	0.01	0.03	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
2004	0.15	3.56	17.89	19.58	10.69	3.76	1.11	0.23	0.16	0.02	0.03	0.01	0.02	0.00	0.00	0.00	0.01	0.01	0.00	0.01
2005	0.07	1.13	20.40	15.00	7.86	4.36	1.65	0.52	0.12	0.09	0.01	0.02	0.01	0.02	0.00	0.00	0.00	0.01	0.01	0.01
2006	2.13	0.68	7.00	17.94	6.21	3.34	2.01	0.82	0.28	0.07	0.05	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.01
2007	1.03	15.05	3.77	5.07	5.68	2.08	1.33	0.99	0.51	0.21	0.06	0.06	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.02
2008	1.78	12.80	109.11	2.97	1.77	2.10	0.87	0.62	0.51	0.28	0.13	0.04	0.03	0.01	0.01	0.00	0.01	0.00	0.00	0.01
2009	0.17	8.68	50.44	57.15	0.64	0.41	0.57	0.28	0.25	0.24	0.15	0.07	0.02	0.02	0.00	0.01	0.00	0.01	0.00	0.01
2010	0.01	0.04	0.61	0.43	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.03	0.19	0.19	0.68	0.27	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.19	1.07	1.99	1.56	7.53	3.80	2.12	0.03	0.03	0.05	0.03	0.03	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00
2013	0.31	0.82	2.39	2.03	0.80	3.14	1.59	0.92	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00
2014	1.57	5.66	7.38	9.51	4.40	1.48	5.85	3.05	1.81	0.03	0.02	0.05	0.03	0.03	0.04	0.02	0.01	0.00	0.00	0.00

Table 21. Estimated landings at age in whole weight (1000 lb)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.19	8.93	25.79	29.05	29.94	29.50	28.13	26.17	23.93	21.57	19.23	17.01	14.95	13.06	11.37	9.86	8.54	7.37	6.35	37.70
1951	0.27	12.15	34.98	39.38	40.58	39.98	38.12	35.48	32.43	29.23	26.07	23.05	20.26	17.70	15.41	13.37	11.57	9.99	8.61	51.09
1952	0.21	9.46	27.20	30.41	31.31	30.84	29.41	27.37	25.02	22.56	20.11	17.79	15.63	13.66	11.89	10.32	8.93	7.70	6.64	39.42
1953	0.21	9.79	28.22	31.58	32.30	31.79	30.32	28.21	25.79	23.25	20.73	18.33	16.11	14.08	12.25	10.63	9.20	7.94	6.84	40.63
1954	0.32	14.69	42.13	47.27	48.39	47.31	45.07	41.94	38.34	34.56	30.82	27.26	23.95	20.93	18.22	15.81	13.68	11.81	10.17	60.41
1955	1.88	42.53	88.50	91.12	84.98	73.96	61.55	50.49	41.43	34.33	30.61	27.07	23.79	20.79	18.09	15.70	13.58	11.73	10.11	60.00
1956	2.10	46.65	92.28	92.45	85.60	74.95	62.61	51.10	41.89	34.67	31.06	27.47	24.14	21.10	18.36	15.93	13.78	11.90	10.25	60.88
1957	2.61	61.90	126.69	123.86	114.71	103.51	91.09	78.49	67.24	58.03	52.36	46.52	40.88	35.72	31.09	26.98	23.34	20.15	17.37	103.11
1958	2.73	60.89	117.16	109.26	95.48	82.38	70.50	59.86	50.56	42.87	39.04	34.94	30.85	26.96	23.46	20.36	17.62	15.21	13.10	77.80
1959	3.03	67.52	129.97	119.63	101.33	84.28	70.92	60.53	52.15	45.01	41.27	37.29	33.16	29.11	25.33	21.98	19.02	16.42	14.15	84.01
1960	3.32	73.64	139.81	127.73	106.76	86.04	69.72	58.41	50.47	44.34	41.30	37.56	33.72	29.81	26.07	22.62	19.57	16.90	14.56	86.45
1961	3.83	85.80	162.22	146.35	122.32	98.25	78.07	63.79	54.75	48.72	46.22	42.71	38.59	34.45	30.34	26.45	22.89	19.76	17.02	101.08
1962	4.13	89.11	161.36	140.67	114.58	90.41	69.95	54.56	44.43	38.31	36.53	34.38	31.56	28.36	25.21	22.14	19.25	16.61	14.32	85.00
1963	4.37	90.60	158.79	134.92	105.84	80.95	61.12	46.10	35.63	29.03	27.28	25.80	24.13	22.03	19.71	17.48	15.30	13.27	11.44	67.90
1964	4.82	99.86	174.68	148.66	115.28	86.58	65.04	49.41	38.25	30.61	27.86	25.97	24.41	22.69	20.64	18.41	16.27	14.22	12.31	73.08
1965	5.30	109.25	187.59	157.48	122.38	90.92	67.05	50.60	39.35	31.42	27.95	25.23	23.37	21.84	20.23	18.34	16.31	14.39	12.55	74.83
1966	5.51	113.66	192.23	157.41	120.96	90.36	66.17	49.21	38.14	30.68	27.21	24.00	21.53	19.83	18.46	17.04	15.41	13.68	12.04	72.62
1967	6.01	128.05	218.94	177.10	134.57	101.31	76.36	57.86	45.29	37.07	33.03	29.06	25.47	22.73	20.84	19.34	17.81	16.06	14.23	87.51
1968	6.68	145.63	245.84	193.23	145.30	108.42	82.38	64.02	50.65	41.43	36.71	32.45	28.36	24.72	21.97	20.09	18.59	17.08	15.37	96.71
1969	6.50	134.42	213.93	156.77	111.76	79.86	57.68	43.07	33.31	26.39	23.03	20.24	17.78	15.45	13.41	11.88	10.84	10.00	9.17	59.80
1970	6.58	136.08	220.46	161.76	109.10	75.34	53.46	39.15	30.09	24.05	20.87	18.07	15.78	13.78	11.93	10.33	9.12	8.30	7.65	52.37
1971	7.16	144.17	228.91	169.90	114.11	73.97	50.18	35.65	26.51	20.81	18.21	15.67	13.48	11.71	10.18	8.79	7.59	6.69	6.07	43.60
1972	7.81	153.02	235.54	172.93	117.68	76.07	48.51	33.00	23.85	18.16	15.81	13.72	11.73	10.04	8.68	7.53	6.48	5.58	4.91	36.22
1973	8.32	156.82	231.40	165.34	110.72	71.89	45.14	28.39	19.31	14.05	12.05	10.40	8.97	7.63	6.50	5.61	4.85	4.16	3.58	26.19
1974	9.75	187.04	277.08	198.53	133.43	89.03	59.51	39.60	26.97	19.98	16.97	14.43	12.38	10.61	8.99	7.64	6.57	5.67	4.86	34.49
1975	11.78	224.50	312.41	211.94	143.28	96.36	66.24	46.64	33.13	24.09	20.03	16.87	14.25	12.16	10.38	8.77	7.43	6.37	5.49	37.84
1976	13.31	248.68	317.01	190.70	122.24	82.91	57.44	41.42	30.87	23.15	18.61	15.35	12.84	10.79	9.17	7.81	6.57	5.56	4.76	32.13
1977	15.33	283.30	337.91	181.77	104.57	68.40	48.71	36.07	27.99	22.32	18.49	14.74	12.08	10.05	8.41	7.13	6.05	5.08	4.29	28.28
1978	20.21	324.82	350.11	166.14	86.21	51.28	35.68	27.45	22.02	18.34	16.01	13.16	10.42	8.49	7.04	5.87	4.96	4.20	3.52	22.42
1979	15.43	361.18	307.01	120.45	54.82	29.25	18.33	13.60	11.16	9.46	8.57	7.42	6.06	4.77	3.88	3.20	2.66	2.24	1.90	11.64
1980	27.04	302.22	371.35	118.41	45.11	21.43	12.26	8.34	6.71	5.90	5.51	4.95	4.26	3.46	2.71	2.20	1.81	1.50	1.26	7.57
1981	9.86	463.20	254.97	111.86	35.18	14.31	7.48	4.77	3.61	3.18	3.10	2.87	2.56	2.19	1.77	1.39	1.12	0.92	0.76	4.45
1982	11.53	132.94	316.51	59.34	25.75	8.71	3.93	2.32	1.66	1.38	1.34	1.29	1.19	1.06	0.90	0.73	0.57	0.46	0.37	2.10
1983	50.12	293.89	160.40	131.84	23.73	10.62	3.79	1.82	1.14	0.86	0.76	0.73	0.70	0.64	0.57	0.48	0.39	0.30	0.24	1.31
1984	61.16	789.58	184.36	29.43	23.21	4.32	2.02	0.76	0.38	0.24	0.20	0.17	0.17	0.16	0.14	0.13	0.11	0.09	0.07	0.34
1985	33.02	940.75	550.47	46.81	7.49	6.36	1.30	0.67	0.27	0.14	0.11	0.09	0.08	0.07	0.07	0.06	0.05	0.05	0.04	0.17
1986	8.52	265.21	388.36	86.04	7.55	1.36	1.35	0.33	0.20	0.10	0.06	0.05	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.09
1987	20.83	111.63	228.76	143.36	30.79	2.78	0.53	0.57	0.15	0.10	0.06	0.04	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.06
1988	14.55	346.10	124.36	109.26	63.81	13.42	1.21	0.23	0.25	0.07	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.04
1989	4.83	251.92	434.95	71.46	59.28	34.54	7.45	0.70	0.14	0.17	0.05	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.03
1990	0.68	42.89	184.03	146.30	22.98	19.42	11.95	2.80	0.29	0.07	0.09	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.02
1991	1.11	23.50	105.98	201.37	141.71	20.23	15.57	8.76	1.89	0.18	0.04	0.06	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.01
1992	2.84	6.80	47.56	155.57	271.80	178.34	23.86	17.14	8.99	1.82	0.17	0.04	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.01
1993	0.49	23.96	45.79	43.65	59.22	106.90	84.06	14.39	13.79	9.71	2.59	0.30	0.07	0.09	0.03	0.02	0.01	0.01	0.01	0.03
1994	0.96	7.85	219.08	41.69	16.65	22.72	44.38	38.03	7.05	7.18	5.32	1.44	0.17	0.04	0.05	0.02	0.01	0.01	0.00	0.02
1995	0.36	12.08	67.12	210.80	16.48	6.46	9.40	19.92	18.55	3.69	4.00	3.04	0.84	0.10	0.02	0.03	0.01	0.01	0.00	0.01
1996	0.77	4.18	91.97	56.48	76.06	5.94	2.51	4.00	9.26	9.26	1.95	2.16	1.67	0.46	0.05	0.01	0.02	0.00	0.00	0.01
1997	1.93	37.69	86.89	185.97	49.12	63.28	4.95	2.06	3.17	7.05	6.86	1.40	1.51	1.17	0.33	0.04	0.01	0.01	0.00	0.01
1998	1.16	9.58	127.60	34.44	26.30	7.15	10.94	1.06	0.55	1.04	2.75	2.99	0.65	0.75	0.58	0.16	0.02	0.00	0.01	0.01
1999	3.32	34.54	144.59	223.31	25.97	18.67	5.05	7.64	0.72	0.37	0.68	1.77	1.89	0.42	0.48	0.37	0.10	0.01	0.00	0.01
2000	3.34	40.31	244.82	128.76	80.34	9.29	7.36	2.24	3.84	0.41	0.23	0.46	1.25	1.41	0.31	0.35	0.27	0.07	0.01	0.01
2001	1.52	27.99	239.04	191.81	41.37	26.28	3.50	3.32	1.24	2.56	0.32	0.20	0.44	1.25	1.40	0.31	0.35	0.27	0.07	0.02
2002	1.25	19.58	225.46	229.06	76.76	16.11	10.78	1.53	1.55	0.61	1.34	0.17	0.11	0.24	0.69	0.77	0.17	0.19	0.15	0.05
2003	1.18	11.64	115.73	172.67	75.05	24.49	5.43	3.90	0.60	0.65	0.27	0.62	0.08	0.05	0.12	0.33	0.37	0.08	0.09	0.09
2004	0.48	18.20	128.33	181.88	121.51	50.18	16.81	3.91	2.99	0.49	0.57	0.25	0.57	0.08	0.05	0.11	0.31	0.34	0.07	0.17
2005	0.24	5.77	146.28	139.34	89.34	58.24	25.02	8.79	2.15	1.72	0.30	0.35	0.15	0.36	0.05	0.03	0.07	0.19	0.21	0.15
2006	6.88	3.47	50.19	166.66	70.63	44.54	30.58	13.90	5.16	1.32	1.12	0.20	0.24	0.11	0.25	0.03	0.02	0.05	0.13	0.25
2007	3.34	76.96	27.02	47.11	64.57	27.81	20.16	16.62	9.28	4.21	1.30	1.24	0.23	0.30	0.13	0.32	0.04	0.03	0.06	0.47
2008	5.74	65.46	782.49	27.62	20.17	28.04	13.21	10.50	9.39	5.58	2.67	0.83	0.80	0.15	0.19	0.09	0.21	0.03	0.02	0.34
2009	0.55	44.37	361.78	530.80	7.27	5.42	8.63	4.80	4.52	4.70	3.17	1.63	0.53	0.53	0.10	0.13	0.06	0.13	0.02	0.23
2010	0.01	0.13	3.55	3.65	2.56	0.04	0.04	0.07	0.05	0.05	0.06	0.04	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
2011	0.04	0.64	1.10	5.79	3.02	1.59	0.02	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.28	3.68	11.67	13.23	83.52	51.39	33.30	0.52	0.49	1.00	0.69	0.76	0.86	0.61	0.32	0.10	0.10	0.02	0.02	0.08
2013	0.45	2.80	14.03	17.20	8.85	42.48	25.01	16.20	0.25	0.24	0.49	0.34	0.37	0.42	0.29	0.15	0.05	0.05	0.01	0.05
2014	2.32	19.41	43.25	80.72	48.79	19.98	92.04	53.90	34.95	0.55	0.52	1.06	0.72	0.78	0.88	0.62	0.32	0.11	0.10	0.12

Table 22. Estimated discards at age in numbers (1000 fish)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1951	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1952	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1953	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1954	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1955	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1956	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1957	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1958	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1959	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1960	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1966	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1967	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.86	0.73	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	1.32	0.25	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	1.48	0.15	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	18.19	4.57	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	14.55	8.49	0.69	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	13.78	8.27	1.60	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	21.00	2.11	0.56	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	12.49	5.81	0.28	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	3.21	3.22	0.74	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	2.64	2.84	1.48	0.22	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	3.99	1.70	1.05	0.39	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	18.16	1.54	0.47	0.29	0.18	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	15.13	18.32	0.88	0.13	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	25.59	5.77	4.69	0.14	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	14.52	12.91	2.00	1.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	14.38	2.22	1.61	0.19	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	9.99	6.88	0.69	0.29	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	13.55	3.35	1.51	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	49.94	15.60	1.99	0.41	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	70.44	25.14	4.49	0.30	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	52.46	25.71	5.62	0.58	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	38.30	17.10	5.84	0.92	0.09	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	46.80	12.96	3.50	0.65	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	37.28	37.29	6.39	1.04	0.15	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	15.63	10.93	7.87	1.02	0.18	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	51.79	0.76	0.31	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2007	87.45	50.52	0.41	0.09	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	155.39	49.94	15.93	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	32.33	67.72	13.41	2.33	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	17.13	6.45	28.12	13.62	6.61	0.07	0.05	0.07	0.03	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	8.98	4.82	2.59	11.66	5.52	2.80	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
2012	21.95	14.87	7.15	2.53	9.10	3.91	1.82	0.02	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
2013	23.03	7.49	6.01	2.58	0.80	2.80	1.25	0.63	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
2014	59.22	26.15	8.81	5.35	1.89	0.55	1.87	0.82	0.42	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00

Table 23. Estimated discards at age in whole weight (1000 lb)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1951	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1952	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1953	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1954	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1955	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1956	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1957	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1958	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1959	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1960	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1966	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1967	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	1.00	2.25	0.28	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	1.54	0.78	0.40	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	1.73	0.46	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	21.23	14.17	0.80	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	16.99	26.36	3.88	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	16.08	25.67	9.01	0.58	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	24.50	6.54	3.14	0.57	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	14.57	18.03	1.57	0.40	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	3.74	9.99	4.13	0.20	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	3.08	8.81	8.34	1.88	0.08	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	4.66	5.27	5.89	3.29	0.62	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	21.19	4.79	2.65	2.46	2.00	0.62	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	17.66	56.84	4.96	1.10	0.60	0.44	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	29.86	17.91	26.36	1.19	0.20	0.11	0.09	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	16.95	40.05	11.23	8.78	0.29	0.05	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	16.78	6.90	9.02	1.56	0.96	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	11.66	21.36	3.86	2.46	0.31	0.19	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	15.81	10.41	8.48	0.61	0.21	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	58.29	48.41	11.17	3.45	0.14	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	82.21	78.02	25.22	2.53	0.53	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	61.22	79.78	31.57	4.84	0.35	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	44.70	53.08	32.81	7.68	1.03	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	54.62	40.23	19.66	5.38	0.75	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	43.51	115.73	35.90	8.65	1.64	0.20	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	18.24	33.92	44.18	8.54	1.95	0.48	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	60.44	2.35	1.73	1.07	0.15	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2007	102.06	156.79	2.29	0.73	0.31	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	181.35	154.98	89.47	0.54	0.11	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	37.73	210.15	75.30	19.43	0.08	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	20.00	20.02	157.95	113.65	72.85	1.00	0.76	1.19	0.63	0.55	0.63	0.45	0.23	0.08	0.08	0.01	0.02	0.01	0.02	0.03
2011	10.48	14.96	14.54	97.29	60.87	37.83	0.55	0.48	0.90	0.59	0.65	0.74	0.52	0.27	0.09	0.09	0.02	0.02	0.01	0.06
2012	25.62	46.14	40.18	21.13	100.31	52.78	28.54	0.36	0.28	0.47	0.32	0.36	0.40	0.28	0.15	0.05	0.05	0.01	0.01	0.04
2013	26.88	23.25	33.74	21.51	8.85	37.78	19.52	10.98	0.15	0.13	0.26	0.18	0.19	0.22	0.15	0.08	0.03	0.03	0.00	0.03
2014	69.11	81.15	49.49	44.63	20.88	7.45	29.36	14.47	7.95	0.11	0.10	0.21	0.14	0.15	0.17	0.12	0.06	0.02	0.02	0.02

Table 24. Estimated status indicators, benchmarks, and related quantities from the base run of the Beaufort catch-age model, conditional on estimated current selectivities averaged across fleets. Also presented are median values and measures of precision (standard errors, SE) from the Monte Carlo/Bootstrap analysis. Rate estimates (F) are in units of y^{-1}*; status indicators are dimensionless; and biomass estimates are in units of metric tons or pounds, as indicated. Spawning stock biomass (SSB) is measured as population fecundity (number of eggs)*

Quantity	Units	Estimate	Median	SE
$F_{30\%}$	y^{-1}	0.15	0.15	0.01
$85\%F_{30\%}$	y^{-1}	0.12	0.13	0.01
$75\%F_{30\%}$	y^{-1}	0.11	0.11	0.01
$65\%F_{30\%}$	y^{-1}	0.10	0.10	0.01
$F_{30\%}$	y^{-1}	0.15	0.15	0.01
$F_{40\%}$	y^{-1}	0.11	0.11	0.01
$B_{\mathrm{F30\%}}$	metric tons	3647	3534	606
$\mathrm{SSB}_{\mathrm{F30\%}}$	Eggs (1E8)	328552	294166	91553
MSST	Eggs (1E8)	246414	220624	68665
$L_{\mathrm{F30\%}}$	1000 lb whole	430	419	77
$R_{\mathrm{F30\%}}$	number fish	447646	456646	110298
$L_{85\%\mathrm{F30\%}}$	1000 lb whole	414	403	74
$L_{75\%\mathrm{F30\%}}$	1000 lb whole	398	387	71
$L_{65\%\mathrm{F30\%}}$	1000 lb whole	378	368	67
$F_{2012-2014}/F_{30\%}$	—	2.52	2.49	0.88
$\mathrm{SSB}_{2014}/\mathrm{MSST}$	—	0.22	0.23	0.13
$\mathrm{SSB}_{2014}/\mathrm{SSB}_{\mathrm{F30\%}}$	—	0.16	0.17	0.10

Table 25. Results from sensitivity runs of the Beaufort catch-age model. Current F represented by geometric mean of last three assessment years. Runs should not all be considered equally plausible.

Run	Description	$F_{30\%}$	$\mathrm{SSB}_{\mathrm{F30\%}}$ (1E8 Eggs)	$L_{\mathrm{F30\%}}$ (1000 lb)	$\mathrm{F}_{\mathrm{current}}/F_{30\%}$	$\mathrm{SSB}_{end}/\mathrm{SSB}_{\mathrm{F30\%}}$	R0(1000)	sigmaR	Finit
Base	—	0.147	329948	459	2.84	0.18	331	0.79	0.03
S1	remove 2008/9 from FD	0.147	329929	468	2.86	0.18	330	0.79	0.03
S2	upweight FI 10X	0.146	332402	438	2.07	0.28	325	0.82	0.03
S3	upweight FD 3X	0.146	344879	448	1.71	0.36	338	0.82	0.03
S4	FD only	0.145	332259	325	1.19	0.64	347	0.74	0.03
S5	M upper	0.169	246562	424	1.65	0.4	430	0.82	0.03
S6	M lower	0.133	406658	470	3.73	0.12	285	0.75	0.03
S7	Disc. M lower	0.147	328444	520	2.12	0.24	317	0.83	0.03
S8	Disc. M upper	0.146	335957	424	2.82	0.2	354	0.72	0.03
S9	Longer CVID index	0.147	334145	470	1.99	0.3	344	0.76	0.03
S10	Smooth 1984/5 MRIP peak	0.147	328483	462	2.53	0.22	327	0.8	0.03
S11	h=0.84	0.146	396289	525	3.56	0.11	497	0.6	0.03
S12	Truncated HB disc. index	0.147	331524	470	2.6	0.21	334	0.78	0.03
S13	Ageing error matrix	0.144	334881	409	1.63	0.39	319	0.85	0.03
S14	Batch number lower	0.154	220597	468	2.47	0.24	330	0.79	0.03
S15	Batch number upper	0.146	362022	465	2.63	0.21	333	0.78	0.03
S16	Drop HB disc. index	0.147	331560	470	2.59	0.21	334	0.78	0.03
S17	Higher landings	0.147	441258	654	1.94	0.25	406	0.89	0.03
S18	Lower landings	0.146	232011	298	3.36	0.18	258	0.64	0.03
S19	Higher discards	0.146	338021	500	2.6	0.19	362	0.7	0.03
S20	Lower discards	0.147	327352	561	1.89	0.26	306	0.87	0.03
S21	Dome-shaped selectivity for cH	0.15	355593	490	2.28	0.23	333	0.87	0.03
S22	Separate video and trap indices	0.143	331956	391	1.58	0.41	341	0.76	0.03
S23	FI index only	0.146	330170	436	2.75	0.18	342	0.75	0.03
S24	Continuity	0.102	817833	501	5.97	0.06	114	1.18	0.04
S25	Split q for HB CPUE	0.147	331168	466	2.61	0.2	333	0.79	0.03
S26	1978 start year	0.147	299224	418	2.93	0.19	320	0.7	0.2
S27	Estimate selex for all ages	0.148	328522	465	2.61	0.2	332	0.78	0.03

Table 26. Projection results with fishing mortality rate fixed at $F = 0$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F30\%}}$. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	434	313	0.11	0.12	70861	64644	0	0	0	0	70	69	284	284	0.001
2016	438	314	0.21	0.23	99227	88895	28	28	244	243	67	62	332	318	0.006
2017	441	318	0.00	0.00	142378	125245	0	0	0	0	0	0	0	0	0.028
2018	444	318	0.00	0.00	200495	174381	0	0	0	0	0	0	0	0	0.110
2019	446	320	0.00	0.00	264749	227588	0	0	0	0	0	0	0	0	0.269
2020	447	319	0.00	0.00	331385	284074	0	0	0	0	0	0	0	0	0.482
2021	448	327	0.00	0.00	398356	340017	0	0	0	0	0	0	0	0	0.682
2022	448	322	0.00	0.00	464175	394134	0	0	0	0	0	0	0	0	0.829
2023	448	323	0.00	0.00	526601	447189	0	0	0	0	0	0	0	0	0.920
2024	449	321	0.00	0.00	585590	497486	0	0	0	0	0	0	0	0	0.965
2025	449	327	0.00	0.00	639992	544455	0	0	0	0	0	0	0	0	0.986
2026	449	324	0.00	0.00	689814	587517	0	0	0	0	0	0	0	0	0.995
2027	449	329	0.00	0.00	735620	628715	0	0	0	0	0	0	0	0	0.998
2028	449	323	0.00	0.00	776696	665729	0	0	0	0	0	0	0	0	0.999
2029	449	328	0.00	0.00	813530	698995	0	0	0	0	0	0	0	0	1.000
2030	449	325	0.00	0.00	846902	728549	0	0	0	0	0	0	0	0	1.000
2031	449	326	0.00	0.00	876659	754214	0	0	0	0	0	0	0	0	1.000
2032	449	323	0.00	0.00	902924	778370	0	0	0	0	0	0	0	0	1.000
2033	449	323	0.00	0.00	926190	799735	0	0	0	0	0	0	0	0	1.000
2034	449	323	0.00	0.00	946624	816889	0	0	0	0	0	0	0	0	1.000
2035	449	323	0.00	0.00	964695	832702	0	0	0	0	0	0	0	0	1.000
2036	449	326	0.00	0.00	980653	847133	0	0	0	0	0	0	0	0	1.000
2037	449	324	0.00	0.00	994731	860374	0	0	0	0	0	0	0	0	1.000
2038	449	323	0.00	0.00	1007148	872161	0	0	0	0	0	0	0	0	1.000
2039	449	322	0.00	0.00	1018096	882631	0	0	0	0	0	0	0	0	1.000
2040	449	325	0.00	0.00	1027750	892432	0	0	0	0	0	0	0	0	1.000
2041	450	325	0.00	0.00	1036261	899851	0	0	0	0	0	0	0	0	1.000
2042	450	326	0.00	0.00	1043764	906517	0	0	0	0	0	0	0	0	1.000
2043	450	326	0.00	0.00	1050377	913518	0	0	0	0	0	0	0	0	1.000
2044	450	325	0.00	0.00	1056207	919348	0	0	0	0	0	0	0	0	1.000

Table 27. Projection results with fishing mortality rate fixed at $F = F_{\text{current}}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), pr.reb = proportion of stochastic projection replicates with $\text{SSB} \geq \text{SSB}_{\text{F30\%}}$. The extension b indicates expected values (deterministic) from the base run; the extension med indicates median values from the stochastic projections.

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	434	313	0.11	0.12	70861	64644	0	0	0	0	70	69	284	284	0.001
2016	438	314	0.21	0.23	99227	88895	28	28	244	243	67	62	332	318	0.006
2017	441	318	0.37	0.37	115357	101306	57	50	541	480	110	93	610	523	0.015
2018	443	317	0.37	0.37	119647	103892	52	45	539	471	101	86	570	487	0.025
2019	443	317	0.37	0.37	119197	102804	47	41	506	439	95	82	527	452	0.031
2020	443	315	0.37	0.37	116562	100566	44	38	477	415	93	79	497	427	0.035
2021	443	322	0.37	0.37	113492	97995	42	36	456	397	91	79	479	413	0.036
2022	443	316	0.37	0.37	110676	95397	41	36	443	386	91	79	468	406	0.036
2023	442	317	0.37	0.37	108184	93542	40	35	433	378	90	78	463	403	0.035
2024	442	314	0.37	0.37	106154	92101	40	35	426	373	90	78	460	400	0.033
2025	442	320	0.37	0.37	104514	91016	40	35	422	369	90	77	458	399	0.032
2026	442	317	0.37	0.37	103258	89757	40	35	418	367	90	78	457	398	0.030
2027	442	322	0.37	0.37	102345	88639	40	34	416	364	90	78	456	397	0.030
2028	442	316	0.37	0.37	101667	88070	39	34	414	363	90	77	455	396	0.028
2029	442	321	0.37	0.37	101178	87571	39	34	413	363	90	78	455	396	0.028
2030	442	317	0.37	0.37	100837	87479	39	34	412	362	90	78	454	395	0.028
2031	442	318	0.37	0.37	100593	87044	39	34	411	361	90	77	454	395	0.029
2032	442	316	0.37	0.37	100419	87033	39	34	411	361	90	77	454	395	0.028
2033	442	315	0.37	0.37	100296	86809	39	34	411	360	90	77	454	395	0.028
2034	442	316	0.37	0.37	100208	86883	39	34	410	361	90	77	453	393	0.027
2035	442	316	0.37	0.37	100148	86965	39	34	410	360	90	77	453	393	0.027
2036	442	318	0.37	0.37	100105	86806	39	34	410	360	90	77	453	393	0.027
2037	442	317	0.37	0.37	100075	86509	39	34	410	360	90	78	453	393	0.027
2038	442	316	0.37	0.37	100055	86749	39	34	410	359	90	77	453	393	0.027
2039	442	314	0.37	0.37	100040	86632	39	34	410	360	90	77	453	393	0.027
2040	442	317	0.37	0.37	100030	86477	39	34	410	360	90	77	453	393	0.028
2041	442	317	0.37	0.37	100022	86663	39	34	410	360	90	77	453	393	0.028
2042	442	318	0.37	0.37	100017	86687	39	34	410	360	90	77	453	394	0.028
2043	442	318	0.37	0.37	100014	86580	39	34	410	358	90	78	453	394	0.028
2044	442	317	0.37	0.37	100011	86656	39	34	410	360	90	77	453	395	0.028

Table 28. Projection results with fishing mortality rate fixed at $F = F_{30\%}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F30\%}}$. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	434	313	0.11	0.12	70861	64644	0	0	0	0	70	69	284	284	0.001
2016	438	314	0.21	0.23	99227	88895	28	28	244	243	67	62	332	318	0.006
2017	441	318	0.15	0.15	130959	114906	25	23	235	221	46	41	262	237	0.016
2018	444	318	0.15	0.15	163158	141018	27	24	281	260	47	42	284	256	0.035
2019	445	319	0.15	0.15	192082	163844	27	25	310	283	47	42	295	265	0.063
2020	446	318	0.15	0.15	216811	183808	28	26	332	301	47	42	301	269	0.093
2021	446	326	0.15	0.15	237794	200505	29	26	351	317	47	42	306	274	0.128
2022	447	321	0.15	0.15	255516	214980	30	27	366	331	47	42	309	278	0.163
2023	447	322	0.15	0.15	269916	226991	30	27	379	341	47	42	313	282	0.199
2024	447	320	0.15	0.15	281741	236878	31	28	389	351	47	43	317	286	0.232
2025	447	325	0.15	0.15	291154	245312	31	28	398	360	48	43	321	289	0.263
2026	447	323	0.15	0.15	298684	252669	31	28	404	366	48	43	323	291	0.289
2027	447	328	0.15	0.15	304844	258556	31	29	409	371	48	43	325	295	0.314
2028	447	322	0.15	0.15	309677	262641	31	29	414	375	48	43	327	296	0.337
2029	447	326	0.15	0.15	313515	267181	32	29	417	380	48	43	328	297	0.355
2030	448	323	0.15	0.15	316655	270533	32	29	420	383	48	44	329	299	0.370
2031	448	324	0.15	0.15	319147	273096	32	29	422	384	48	44	330	300	0.383
2032	448	322	0.15	0.15	321094	275224	32	29	424	386	48	43	330	300	0.396
2033	448	321	0.15	0.15	322637	276256	32	29	425	388	48	43	331	300	0.407
2034	448	322	0.15	0.15	323843	277230	32	29	426	389	48	43	331	300	0.413
2035	448	322	0.15	0.15	324806	277461	32	29	427	390	48	43	332	300	0.418
2036	448	324	0.15	0.15	325573	278447	32	29	427	391	48	43	332	301	0.424
2037	448	323	0.15	0.15	326184	279294	32	29	428	392	48	43	332	302	0.425
2038	448	322	0.15	0.15	326670	280728	32	29	428	392	48	43	332	302	0.428
2039	448	320	0.15	0.15	327056	281441	32	29	429	393	48	43	332	301	0.433
2040	448	324	0.15	0.15	327363	281134	32	29	429	393	48	43	333	302	0.433
2041	448	323	0.15	0.15	327608	281482	32	29	429	394	48	43	333	302	0.434
2042	448	324	0.15	0.15	327802	282269	32	29	429	394	48	44	333	302	0.436
2043	448	325	0.15	0.15	327956	282718	32	29	430	394	48	44	333	303	0.436
2044	448	324	0.15	0.15	328078	282284	32	30	430	394	48	44	333	303	0.440

Table 29. Projection results with fishing mortality rate fixed at $F = 98\% F_{30\%}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{F30\%}$. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	434	313	0.11	0.12	70861	64644	0	0	0	0	70	69	284	284	0.001
2016	438	314	0.21	0.23	99227	88895	28	28	244	243	67	62	332	318	0.006
2017	441	318	0.14	0.15	131178	115118	24	23	230	217	45	41	257	233	0.017
2018	444	318	0.14	0.15	163829	141629	26	24	277	256	46	41	279	251	0.036
2019	445	319	0.14	0.15	193308	164882	27	25	305	279	46	41	291	261	0.065
2020	446	318	0.14	0.15	218633	185412	28	25	328	297	46	41	297	265	0.098
2021	446	326	0.14	0.15	240210	202548	29	26	347	313	46	42	302	270	0.134
2022	447	321	0.14	0.15	258500	217491	29	26	363	327	46	42	305	274	0.172
2023	447	322	0.14	0.15	273418	229903	30	27	376	338	46	42	309	279	0.211
2024	447	320	0.14	0.15	285711	240313	30	27	386	348	47	42	314	283	0.249
2025	447	325	0.14	0.15	295533	249099	31	28	395	357	47	42	317	286	0.281
2026	447	323	0.14	0.15	303416	256851	31	28	401	363	47	43	320	288	0.310
2027	447	328	0.14	0.15	309881	262963	31	28	407	368	47	43	322	291	0.336
2028	447	322	0.14	0.15	314971	267225	31	29	411	373	47	43	323	293	0.363
2029	448	326	0.14	0.15	319024	271916	31	29	415	378	47	43	325	294	0.382
2030	448	323	0.14	0.15	322345	275417	31	29	417	381	47	43	326	295	0.398
2031	448	324	0.14	0.15	324987	278129	32	29	420	382	47	43	326	297	0.413
2032	448	322	0.14	0.15	327059	280450	32	29	421	384	47	43	327	297	0.427
2033	448	321	0.14	0.15	328703	281529	32	29	423	387	47	43	328	297	0.436
2034	448	322	0.14	0.15	329992	282607	32	29	424	387	47	43	328	298	0.445
2035	448	322	0.14	0.15	331023	282838	32	29	425	388	47	43	328	297	0.450
2036	448	324	0.14	0.15	331846	283777	32	29	426	389	47	43	329	298	0.456
2037	448	323	0.14	0.15	332503	284779	32	29	426	390	47	43	329	299	0.458
2038	448	322	0.14	0.15	333026	286185	32	29	427	391	47	43	329	299	0.463
2039	448	320	0.14	0.15	333443	286855	32	29	427	392	47	43	329	299	0.465
2040	448	324	0.14	0.15	333775	286659	32	29	427	392	47	43	329	299	0.466
2041	448	323	0.14	0.15	334039	286968	32	29	427	393	47	43	329	299	0.467
2042	448	324	0.14	0.15	334250	287860	32	29	428	392	47	43	329	300	0.469
2043	448	325	0.14	0.15	334417	288294	32	29	428	392	47	43	330	300	0.471
2044	448	324	0.14	0.15	334551	287938	32	29	428	392	47	43	330	300	0.473

Table 30. Projection results with fishing mortality rate fixed at $F = F_{\text{rebuild}}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\text{SSB} \geq \text{SSB}_{\text{F30\%}}$. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	434	313	0.11	0.12	70861	64644	0	0	0	0	70	69	284	284	0.001
2016	438	314	0.21	0.23	99227	88895	28	28	244	243	67	62	332	318	0.006
2017	441	318	0.14	0.14	131198	115490	24	22	230	212	45	40	257	227	0.018
2018	444	318	0.14	0.14	163892	142614	26	23	276	250	46	40	279	245	0.043
2019	445	319	0.14	0.14	193424	166688	27	24	305	273	46	40	290	255	0.077
2020	446	318	0.14	0.14	218805	188063	28	25	328	292	46	40	297	261	0.116
2021	446	326	0.14	0.14	240439	205874	29	26	347	309	46	41	301	266	0.161
2022	447	321	0.14	0.14	258784	220741	29	26	362	323	46	41	305	270	0.206
2023	447	322	0.14	0.14	273751	233843	30	27	375	334	46	41	309	275	0.251
2024	447	320	0.14	0.14	286089	244677	30	27	386	346	47	41	313	280	0.289
2025	447	325	0.14	0.14	295950	254012	31	28	394	355	47	42	317	283	0.325
2026	447	323	0.14	0.14	303867	261422	31	28	401	361	47	42	319	286	0.353
2027	447	328	0.14	0.14	310362	267854	31	28	407	367	47	42	321	288	0.379
2028	447	322	0.14	0.14	315476	272516	31	28	411	371	47	42	323	289	0.402
2029	448	326	0.14	0.14	319550	276187	31	28	414	375	47	42	324	291	0.422
2030	448	323	0.14	0.14	322888	280048	31	28	417	378	47	42	325	292	0.437
2031	448	324	0.14	0.14	325546	282707	32	29	419	380	47	42	326	293	0.450
2032	448	322	0.14	0.14	327629	284895	32	29	421	382	47	42	327	293	0.462
2033	448	321	0.14	0.14	329283	286318	32	29	423	385	47	42	327	294	0.471
2034	448	322	0.14	0.14	330580	287505	32	29	424	385	47	42	328	294	0.481
2035	448	322	0.14	0.14	331618	288052	32	29	425	386	47	42	328	294	0.486
2036	448	324	0.14	0.14	332447	289099	32	29	425	387	47	42	328	295	0.487
2037	448	323	0.14	0.14	333107	290492	32	29	426	387	47	42	329	296	0.491
2038	448	322	0.14	0.14	333634	291081	32	29	426	388	47	42	329	295	0.495
2039	448	320	0.14	0.14	334054	291632	32	29	427	389	47	42	329	295	0.496
2040	448	324	0.14	0.14	334388	291260	32	29	427	389	47	42	329	296	0.498
2041	448	323	0.14	0.14	334655	291695	32	29	427	390	47	42	329	295	0.498
2042	448	324	0.14	0.14	334867	292066	32	29	427	389	47	42	329	296	0.500
2043	448	325	0.14	0.14	335036	292552	32	29	428	390	47	42	329	297	0.500
2044	448	324	0.14	0.14	335171	292995	32	29	428	390	47	42	329	296	0.501

Table 31. Projection results with fishing mortality rate applied only to discards. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $SSB \geq SSB_{F30\%}$. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	434	313	0.11	0.12	70861	64644	0	0	0	0	70	69	284	284	0.001
2016	438	314	0.10	0.11	105033	94082	0	0	0	0	70	69	355	353	0.006
2017	442	318	0.11	0.12	144176	126495	0	0	0	0	75	70	435	418	0.027
2018	444	318	0.11	0.12	183389	157600	0	0	0	0	75	69	474	445	0.084
2019	446	320	0.11	0.12	220330	186110	0	0	0	0	74	69	493	457	0.161
2020	446	318	0.11	0.12	253560	211337	0	0	0	0	74	70	504	463	0.245
2021	447	326	0.11	0.12	283302	233991	0	0	0	0	74	70	512	470	0.324
2022	447	321	0.11	0.12	309795	253779	0	0	0	0	75	71	519	479	0.392
2023	447	322	0.11	0.12	332590	271031	0	0	0	0	75	71	528	489	0.449
2024	448	320	0.11	0.12	352312	284690	0	0	0	0	75	72	538	498	0.491
2025	448	326	0.11	0.12	368864	296476	0	0	0	0	76	72	546	505	0.527
2026	448	323	0.11	0.12	382827	307651	0	0	0	0	76	72	553	512	0.557
2027	448	328	0.11	0.12	394845	316094	0	0	0	0	76	73	559	518	0.583
2028	448	322	0.11	0.12	404805	323518	0	0	0	0	77	73	564	523	0.604
2029	448	327	0.11	0.12	413161	329865	0	0	0	0	77	73	568	527	0.623
2030	448	324	0.11	0.12	420369	334422	0	0	0	0	77	73	571	530	0.637
2031	448	324	0.11	0.12	426415	338421	0	0	0	0	77	73	574	533	0.651
2032	448	322	0.11	0.12	431412	341926	0	0	0	0	77	73	577	535	0.660
2033	448	321	0.11	0.12	435590	345467	0	0	0	0	77	73	579	536	0.669
2034	448	322	0.11	0.12	439044	348333	0	0	0	0	77	73	581	537	0.675
2035	448	322	0.11	0.12	441960	350054	0	0	0	0	77	73	582	538	0.682
2036	448	324	0.11	0.12	444419	352140	0	0	0	0	77	73	583	539	0.686
2037	448	323	0.11	0.12	446493	354157	0	0	0	0	77	73	584	539	0.689
2038	448	322	0.11	0.12	448241	354692	0	0	0	0	77	74	585	541	0.692
2039	448	320	0.11	0.12	449715	356590	0	0	0	0	77	73	586	541	0.694
2040	448	324	0.11	0.12	450956	356646	0	0	0	0	77	74	587	542	0.698
2041	448	323	0.11	0.12	452001	356525	0	0	0	0	77	74	587	542	0.700
2042	448	325	0.11	0.12	452882	357632	0	0	0	0	77	74	588	544	0.702
2043	448	325	0.11	0.12	453624	358288	0	0	0	0	78	74	588	544	0.704
2044	448	324	0.11	0.12	454249	358585	0	0	0	0	78	74	588	545	0.705

Table 32. Parameter estimates from selected ASPIC surplus production model runs 318 (continuity), 319 (updated continuity), 320 (best configuration), and 323 (best configuration with B_1/K fixed) All parameter values are rounded to 3 significant digits. MSY, B_1, and K are in units of 1000 pounds. Catchability parameters correspond to the commercial (q_1), headboat (q_2), headboat-at-sea (q_3), and CVID (q_4) indices.

Run	F/F_{MSY}	B/B_{MSY}	B_1/K	MSY	F_{MSY}	q_1	q_2	q_3	q_4	B_1	K
318	2.15	0.53	0.467	805	0.313	9.35e-07	7.14e-07			2400	5140
319	0.614	1.3	1.94	802	0.314	9.42e-07	7.14e-07			9930	5110
320	0.531	1.48	0.91	805	0.322	8.69e-07	6.98e-07	2.98e-07	4.04e-07	4560	5010
323	0.53	1.47	0.467	807	0.321	8.74e-07	7e-07	2.99e-07	4.02e-07	2350	5030

8 Figures

Figure 1. Indices of abundance used in fitting the assessment model. HB indicates the headboat logbook index; Handline indicated the the commercial handline logbook index; HB Disc indicated the headboat discard observer index, CVT indicates the SERFS chevron trap index; VID indicates the SERFS video index, and CVID indicates the combined chevron trap and video index. The CVT and VID indices were only used during sensitivity runs.

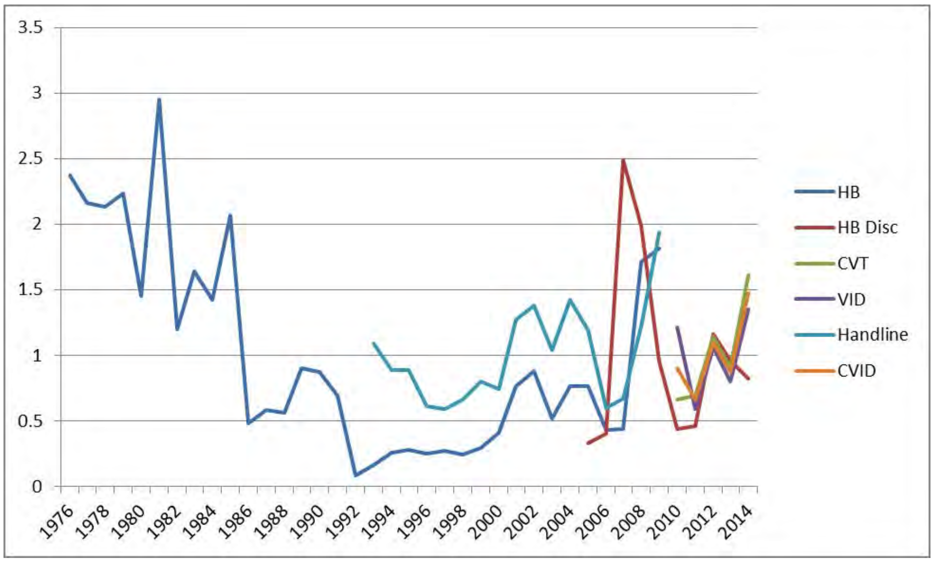


Figure 2. Mean total length at age (mm) and estimated upper and lower 95% confidence intervals of the population.

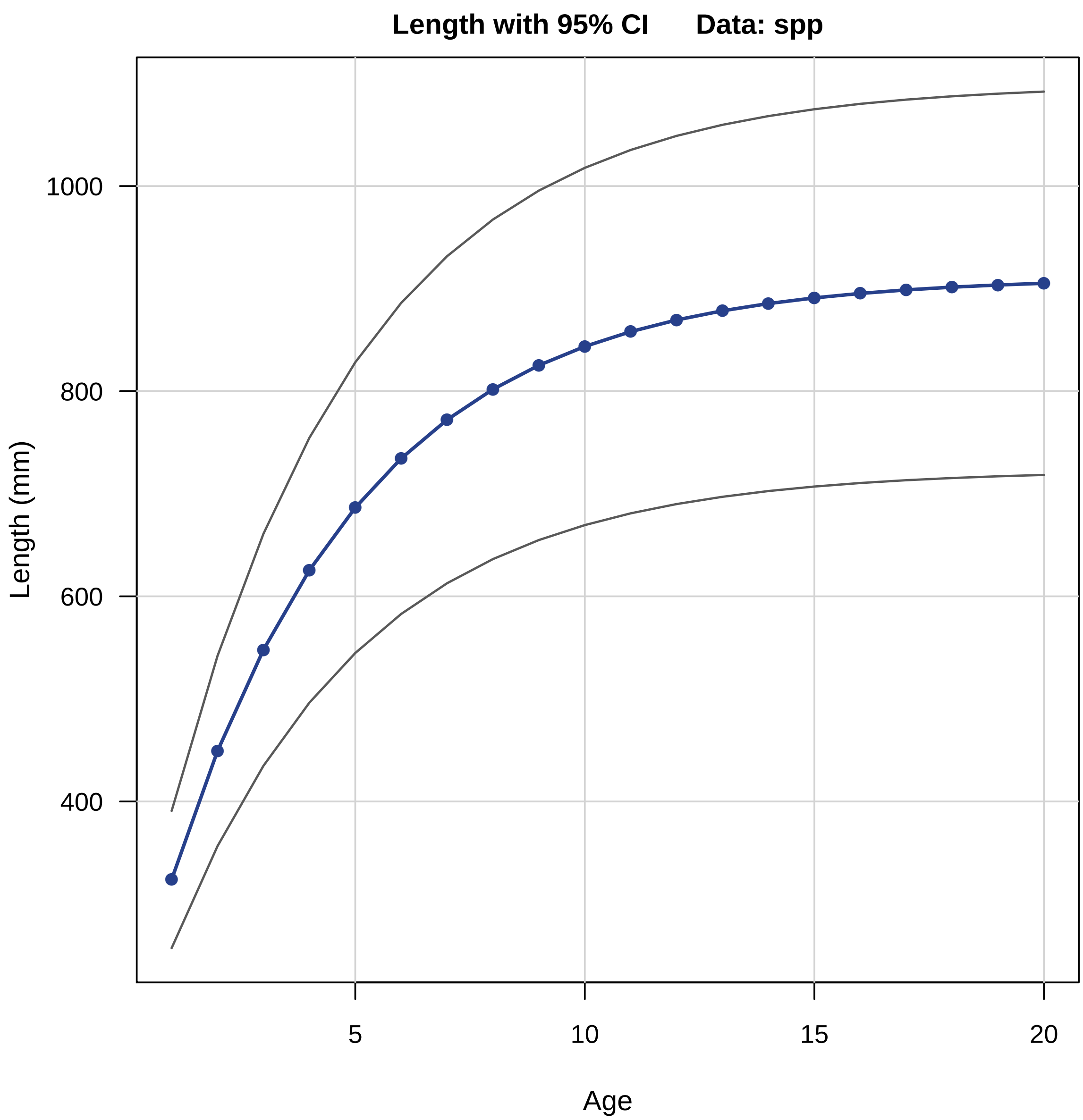


Figure 3. Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, CVT to MARMAP chevron trap, cH to commercial handline, HB to headboat and GR to general recreational.

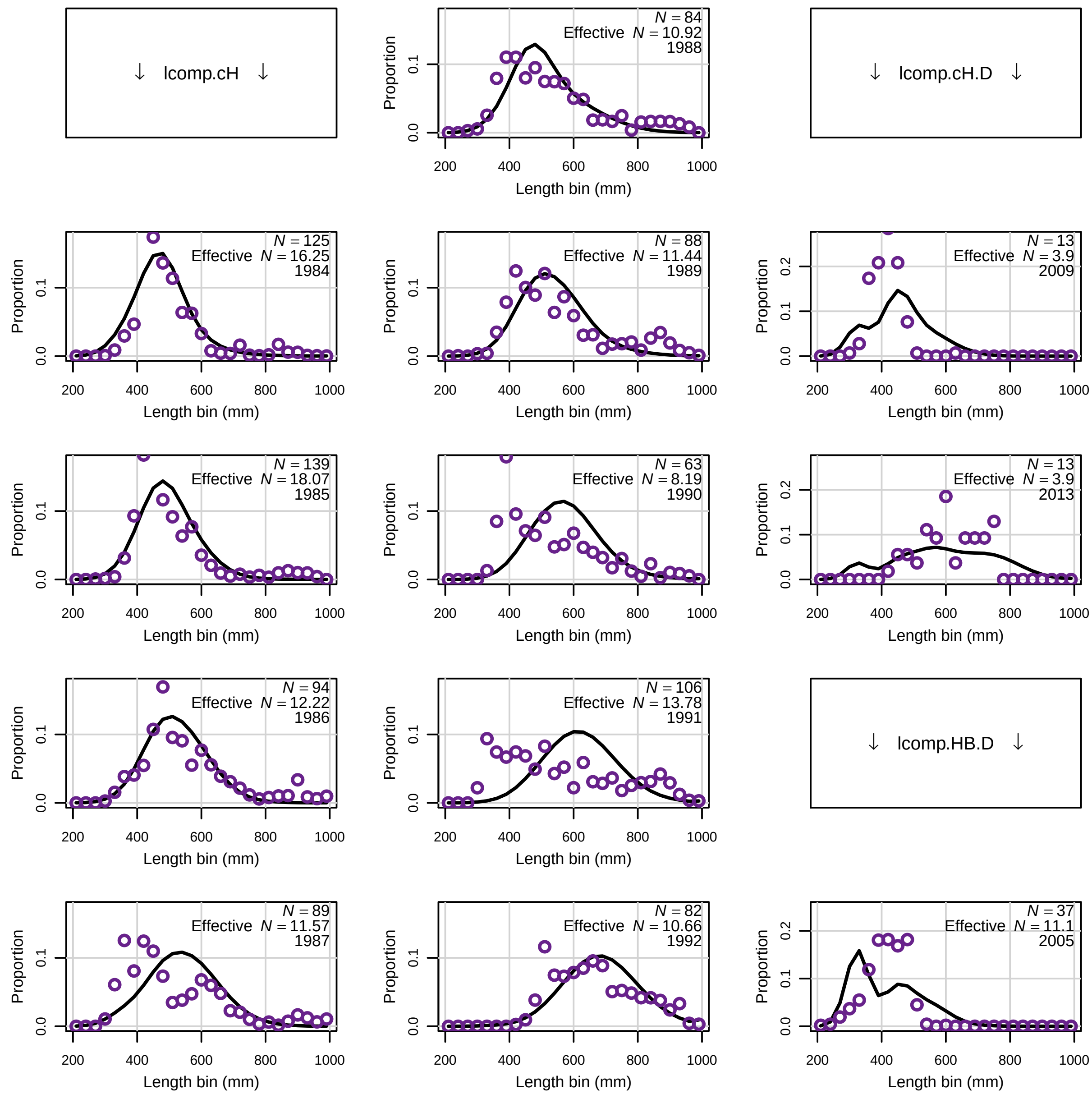


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

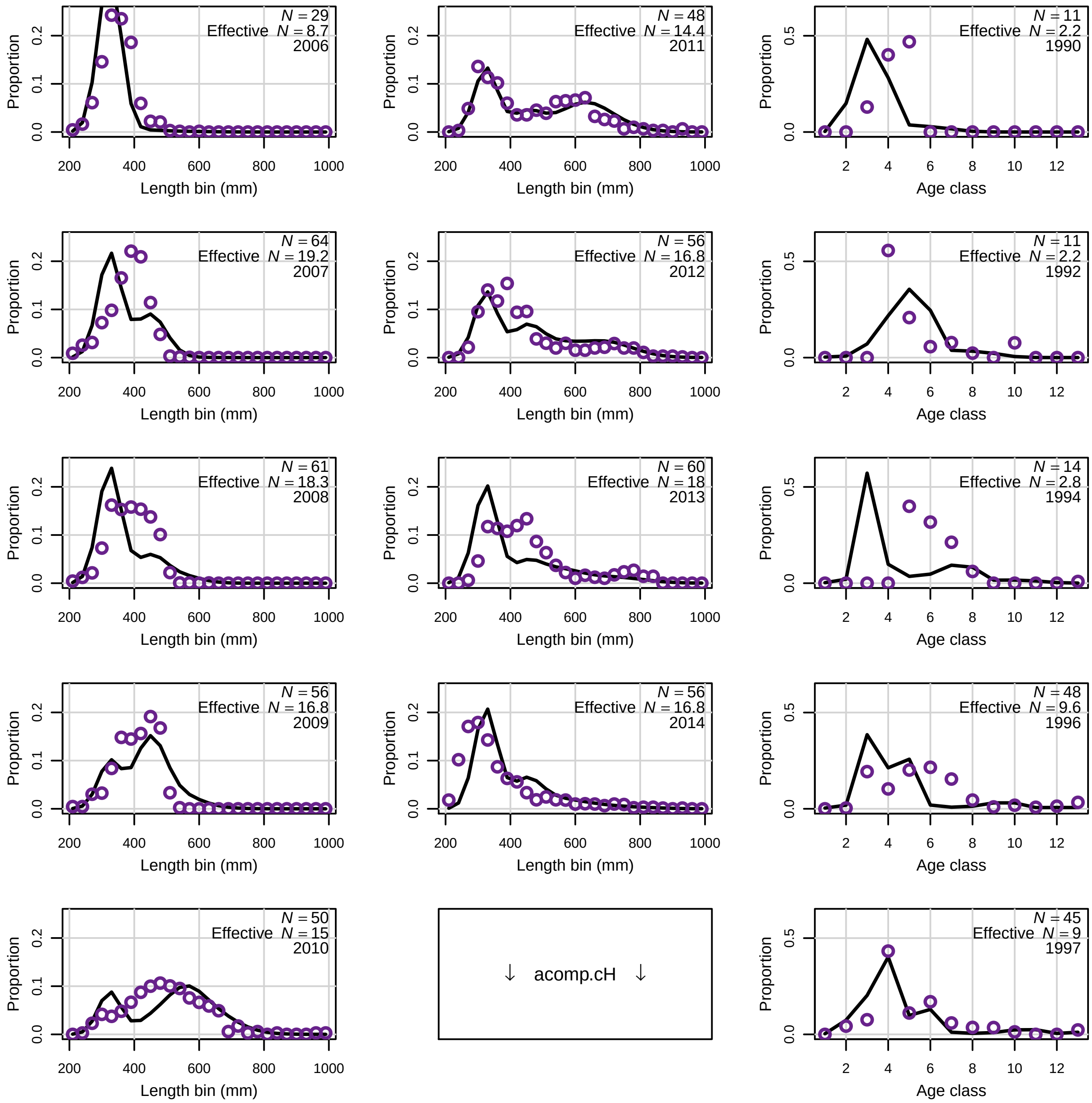


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

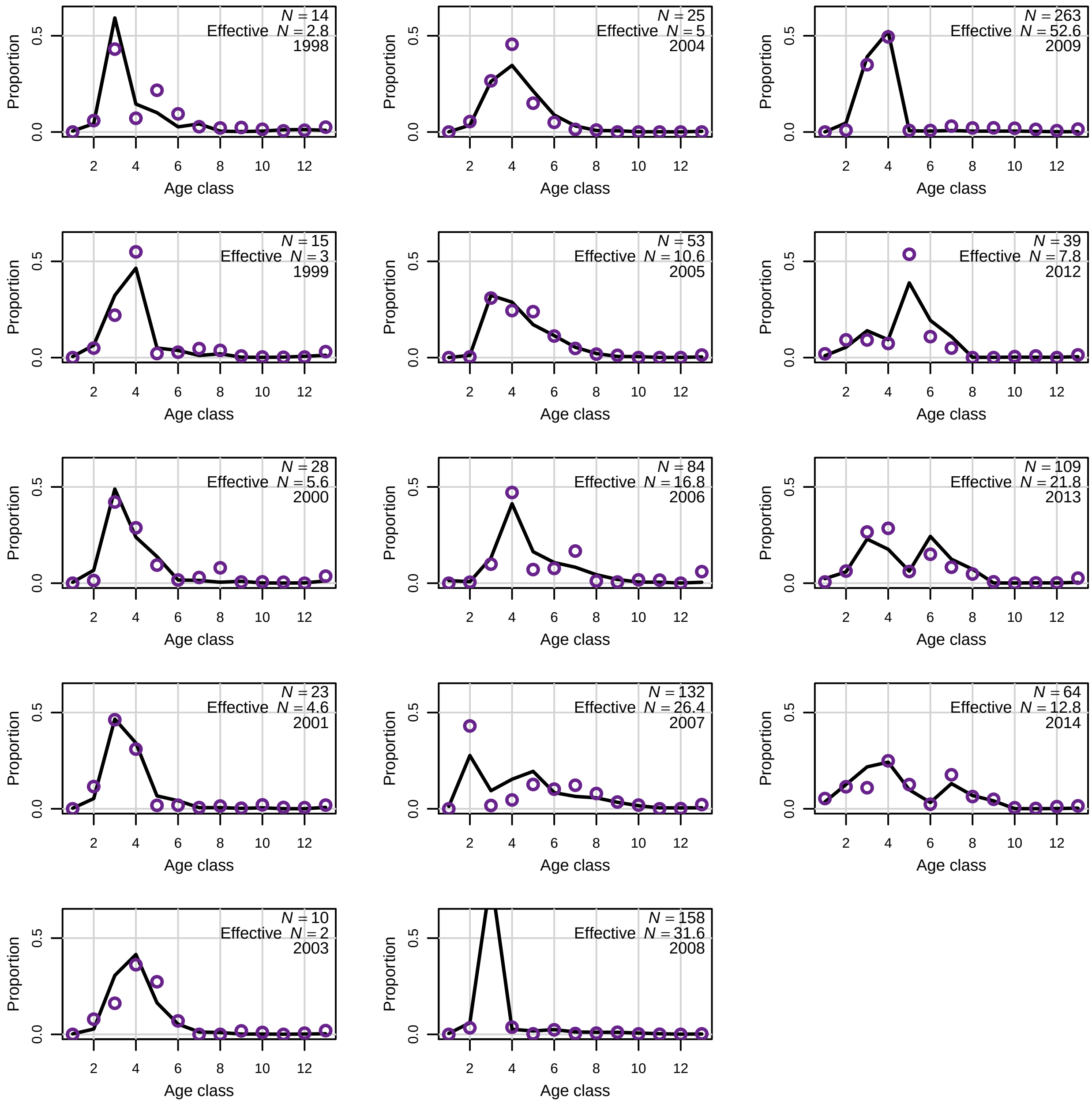


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

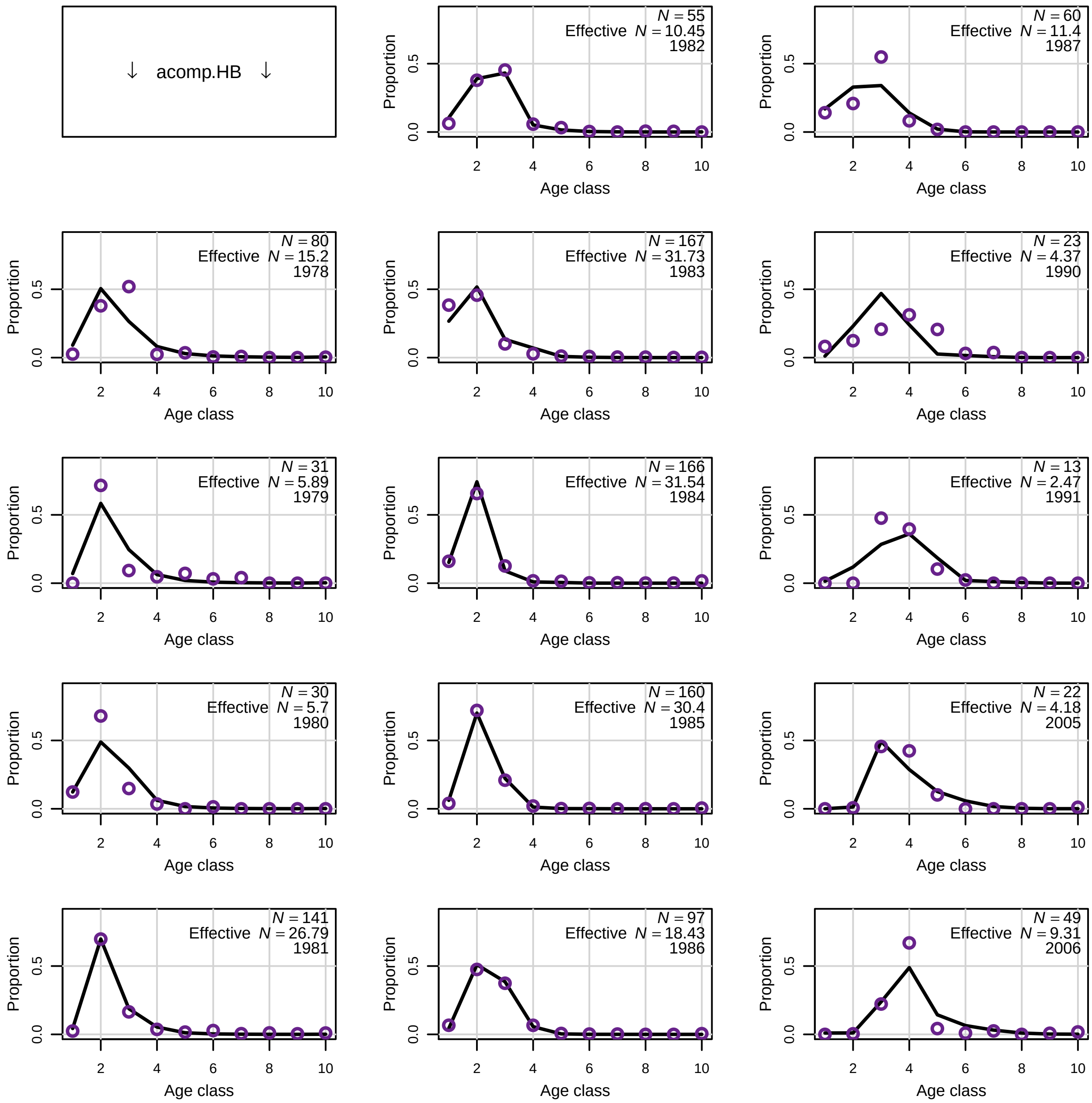


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

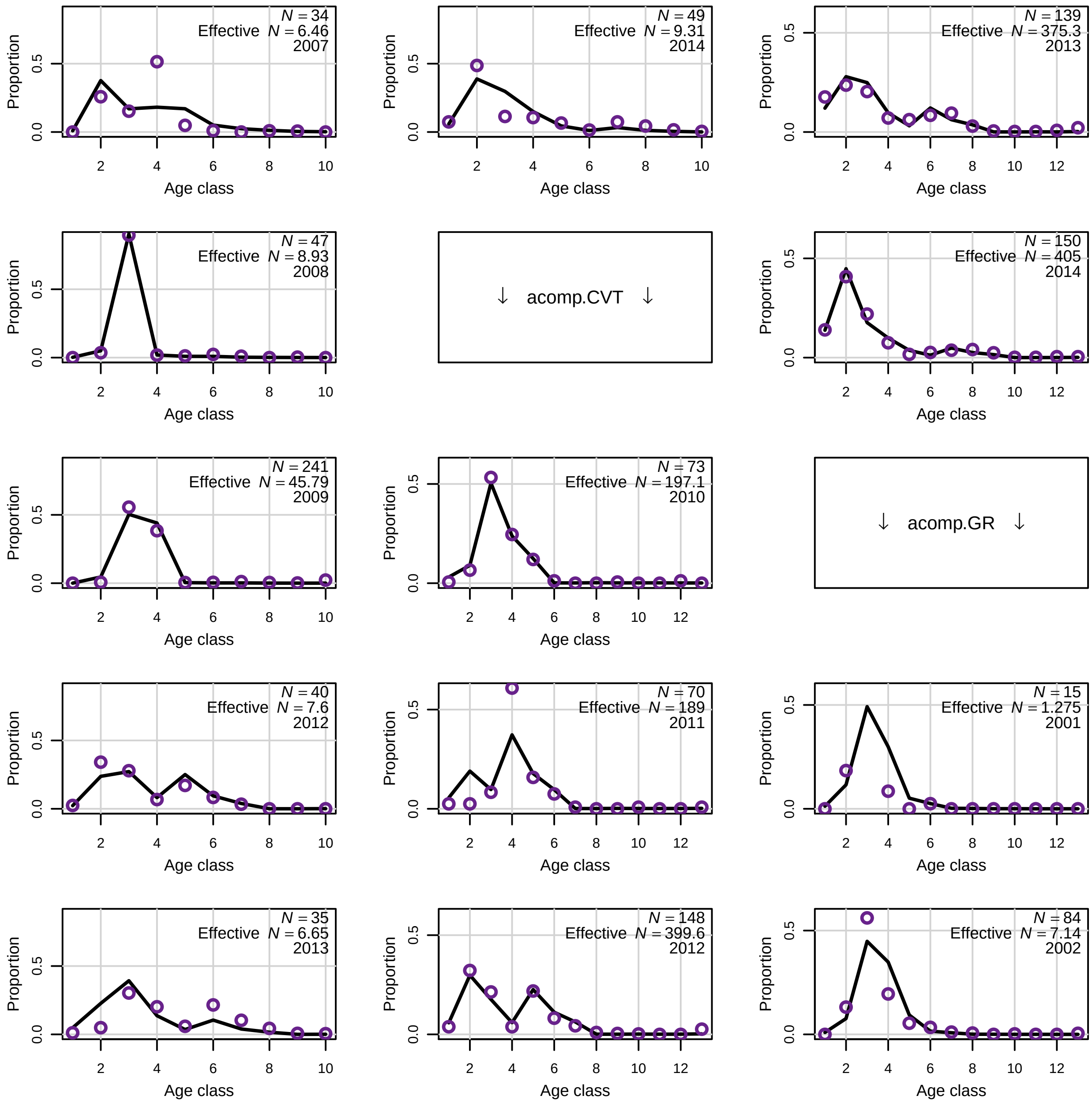


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

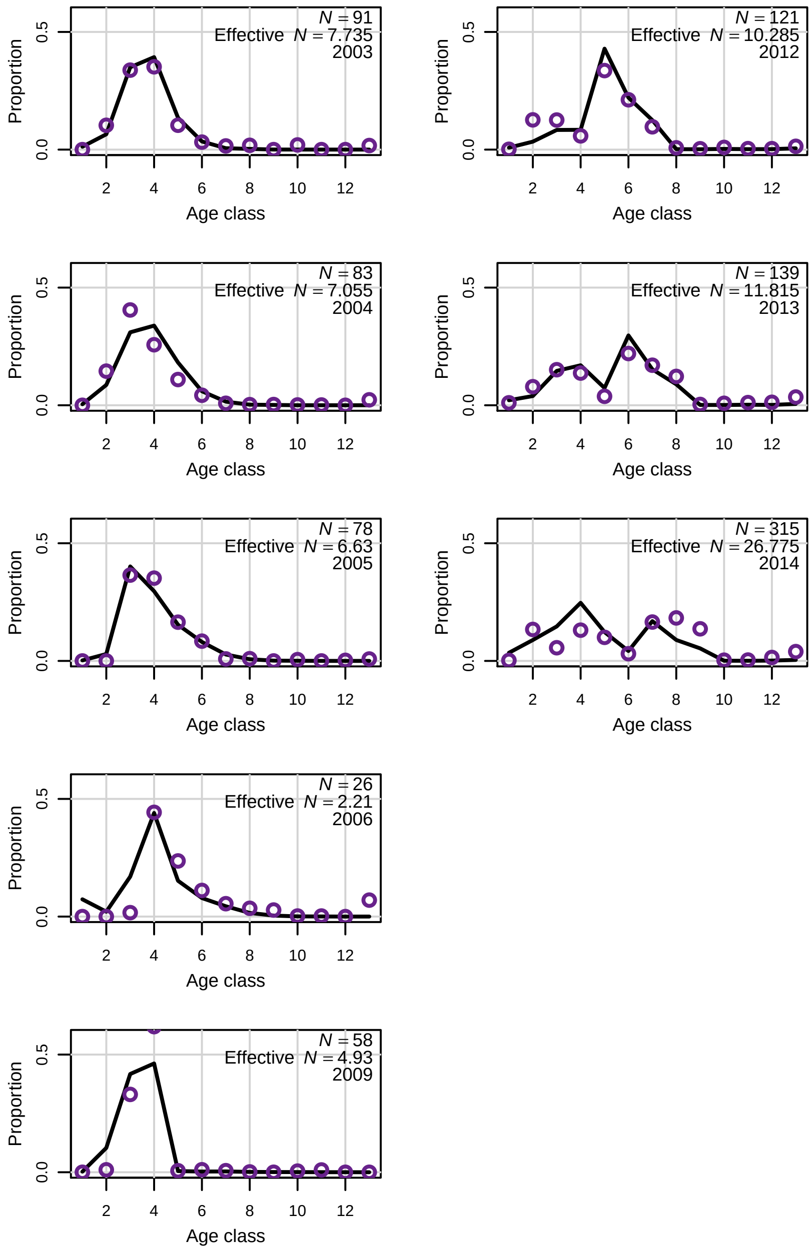


Figure 4. Observed (open circles) and estimated (solid line, circles) commercial handline landings in 1000 lb whole weight.

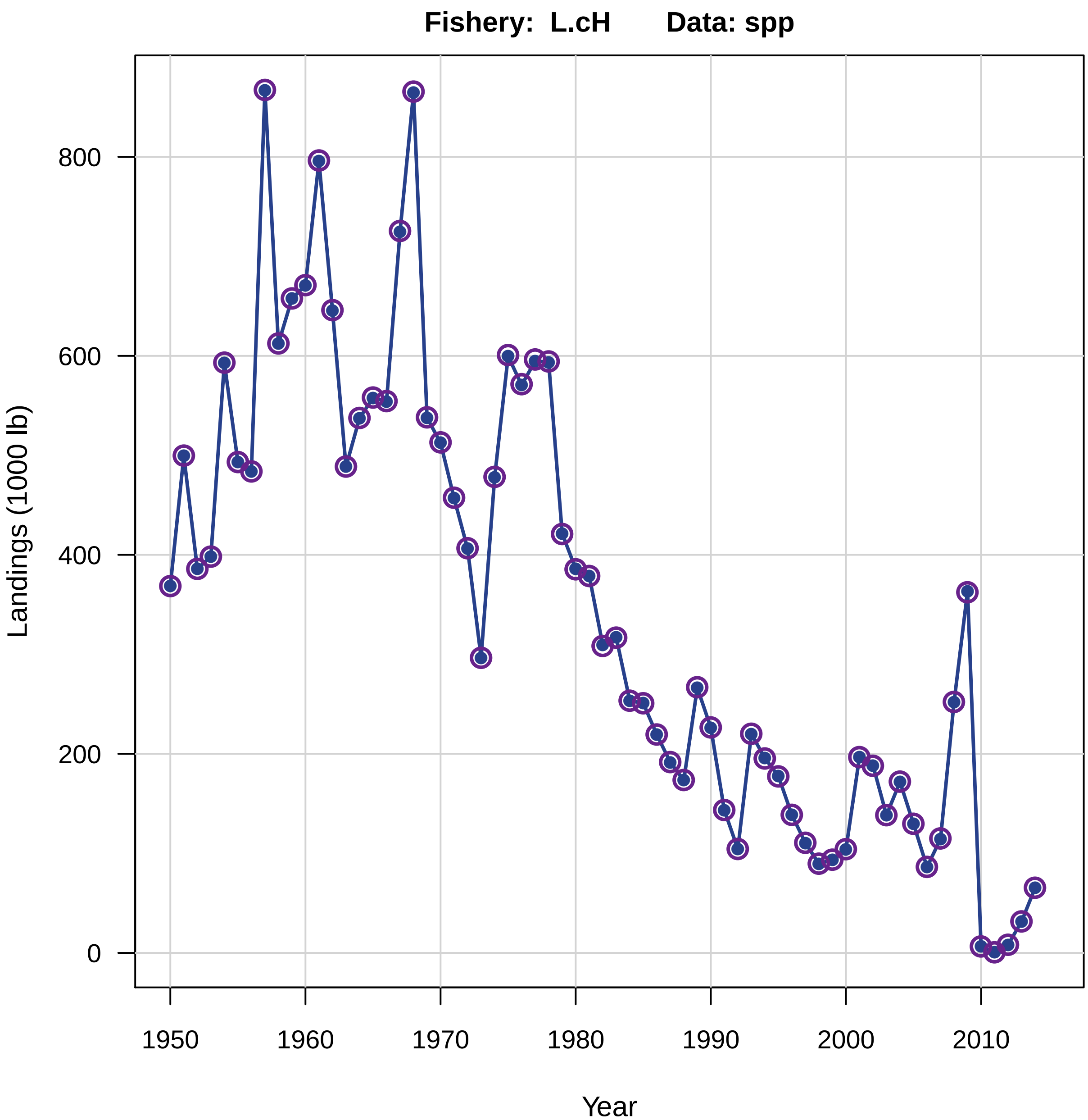


Figure 5. Observed (open circles) and estimated (solid line, circles) headboat landings in 1000s of fish.

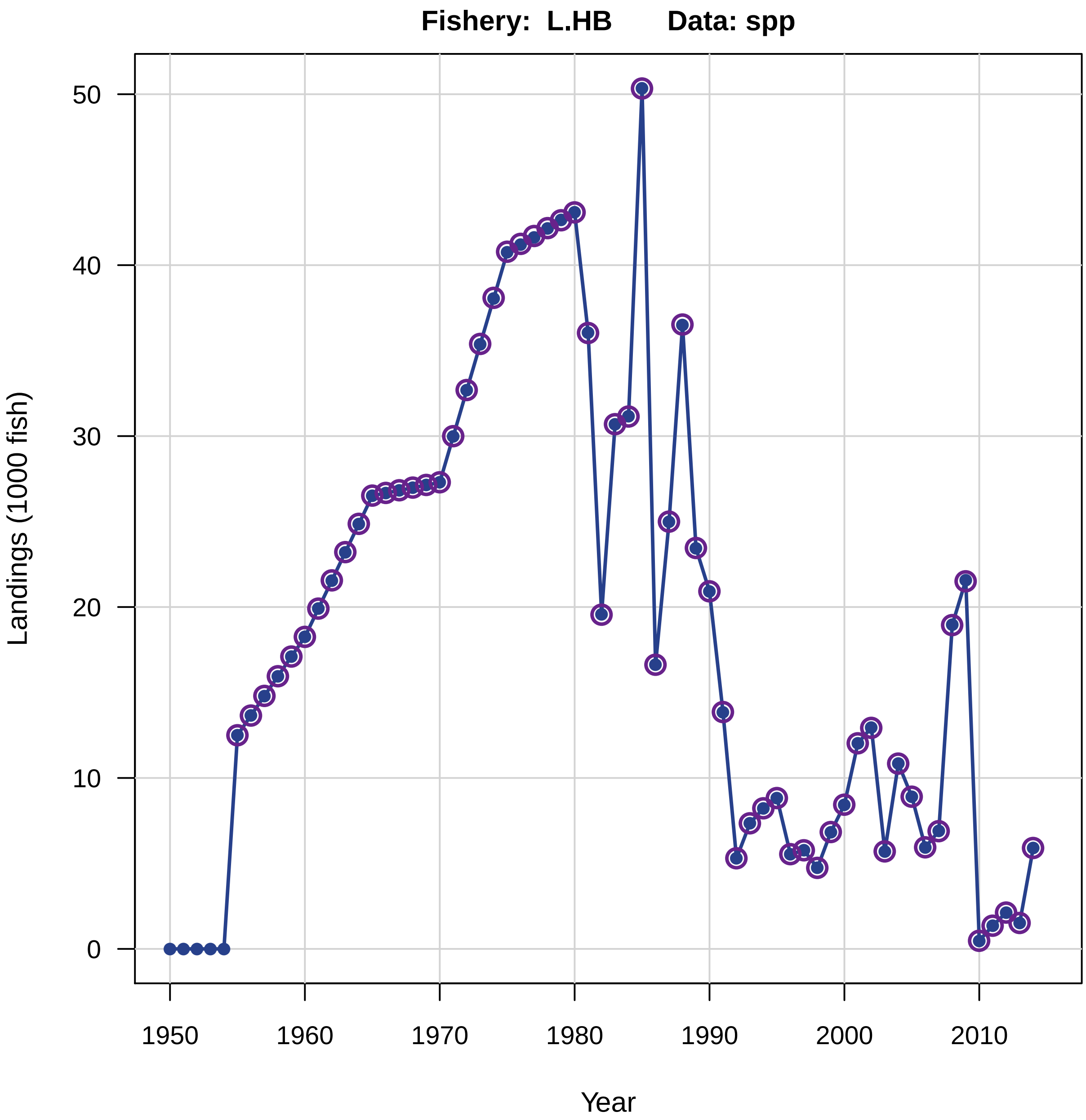


Figure 6. Observed (open circles) and estimated (solid line, circles) general recreational landings in 1000s of fish.

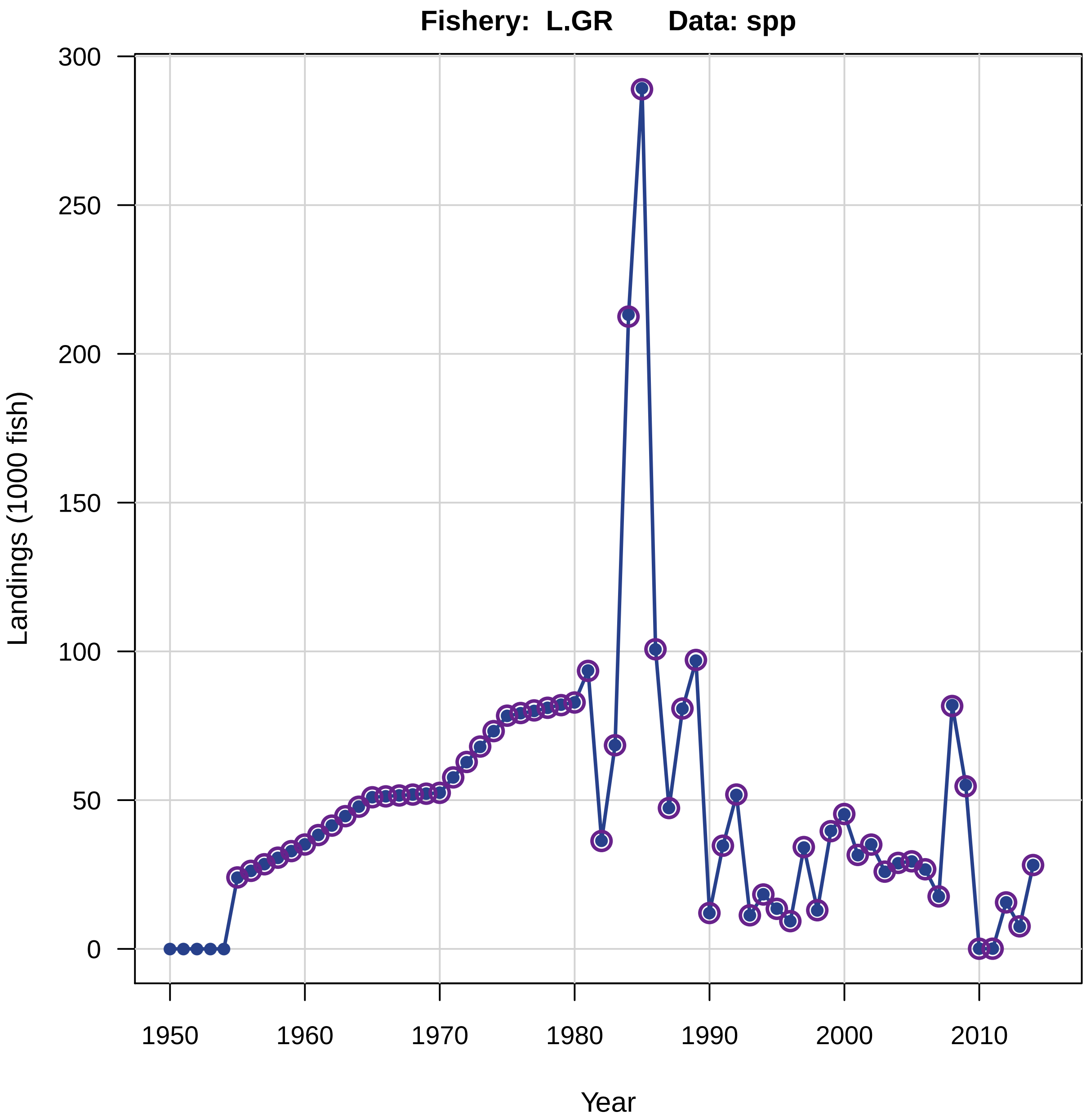


Figure 7. Observed (open circles) and estimated (solid line, circles) commercial handline discard mortalities.

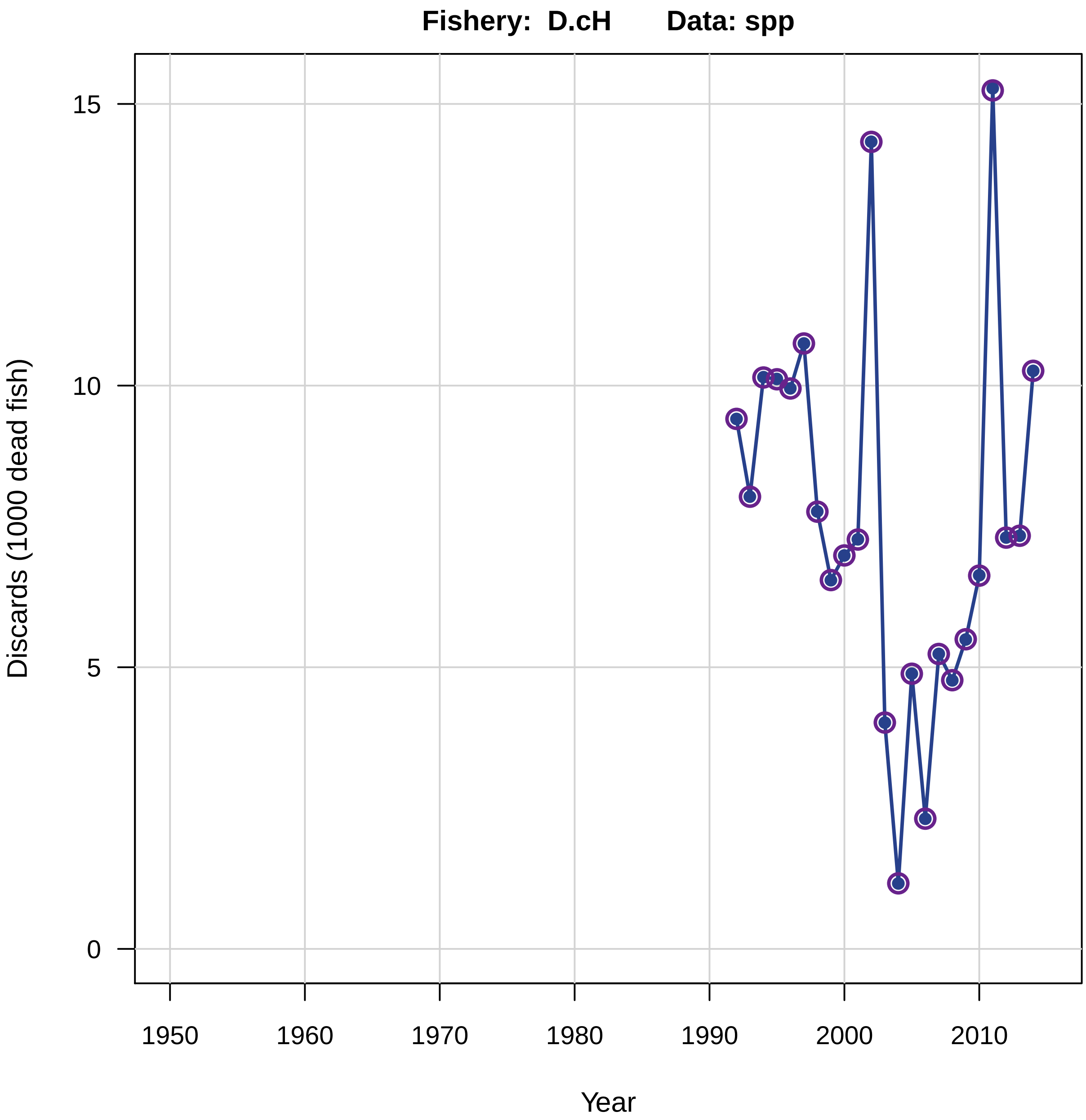


Figure 8. Observed (open circles) and estimated (solid line, circles) headboat discard mortalities.

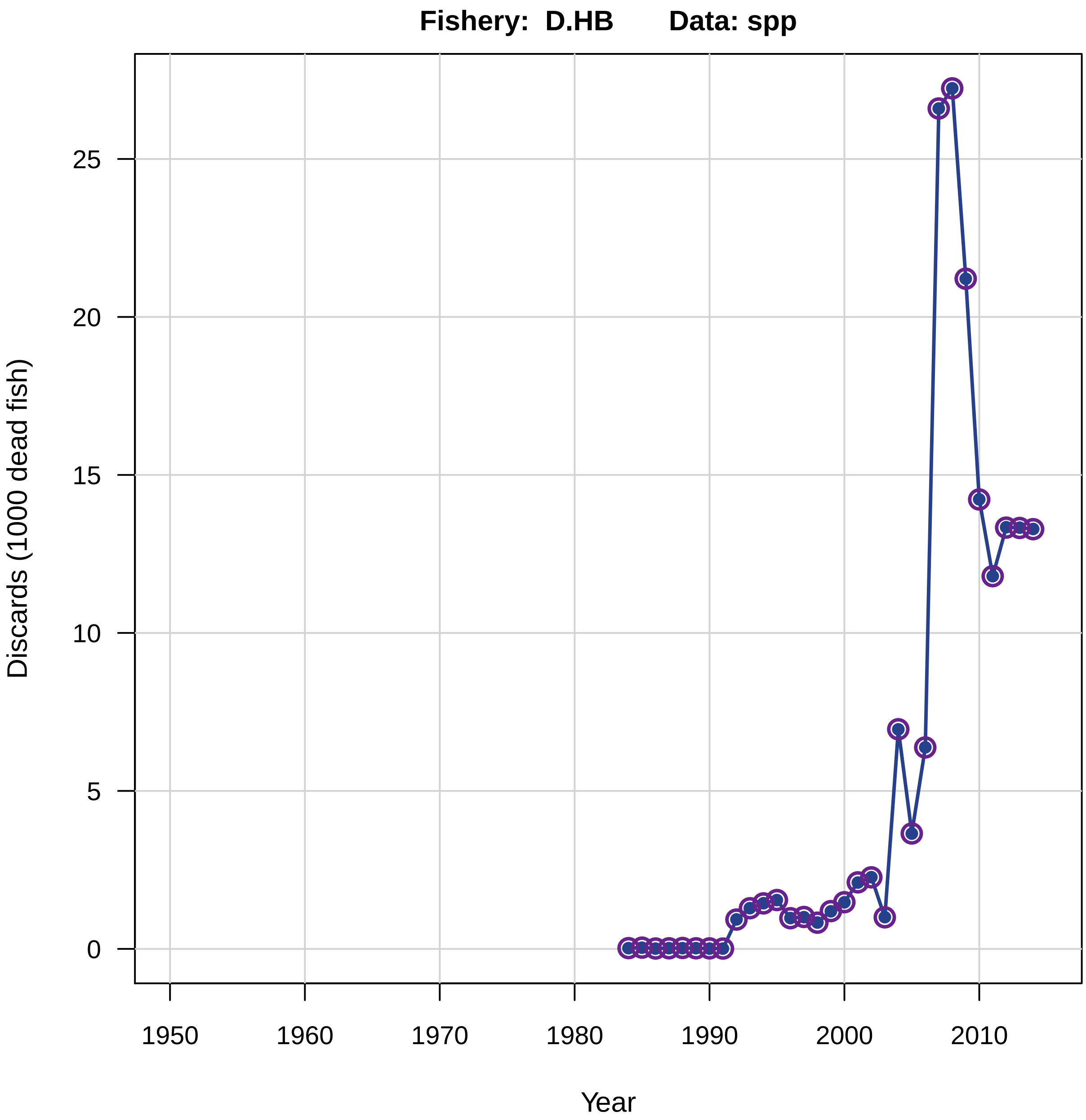


Figure 9. Observed (open circles) and estimated (solid line, circles) general recreational discard mortalities.

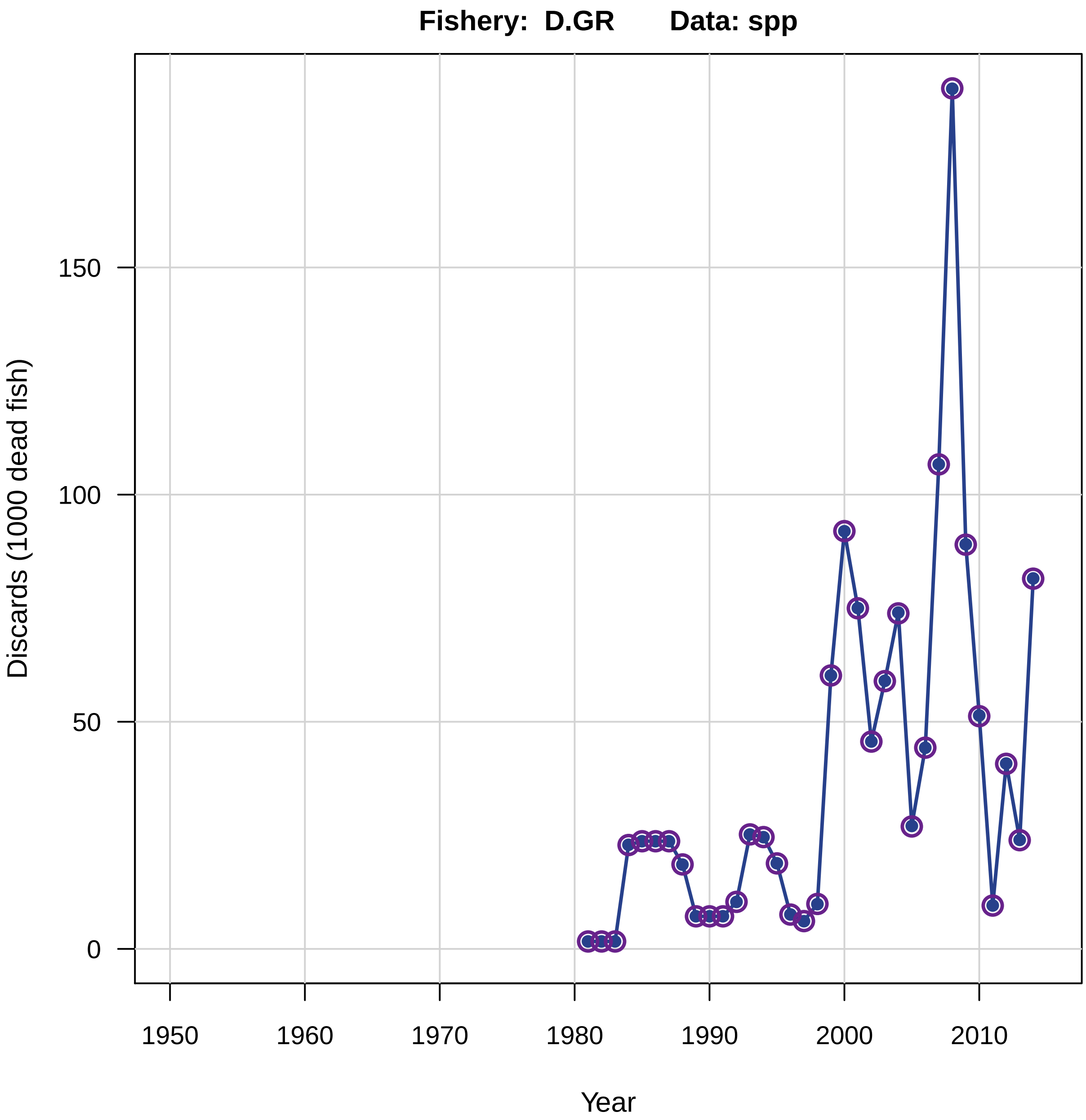


Figure 10. Observed (open circles) and estimated (solid line, circles) index of abundance from the SERFS combined trap and video index. The error bars represent the annual CV provided by the GLM standardization divided by the likelihood weight on the index.

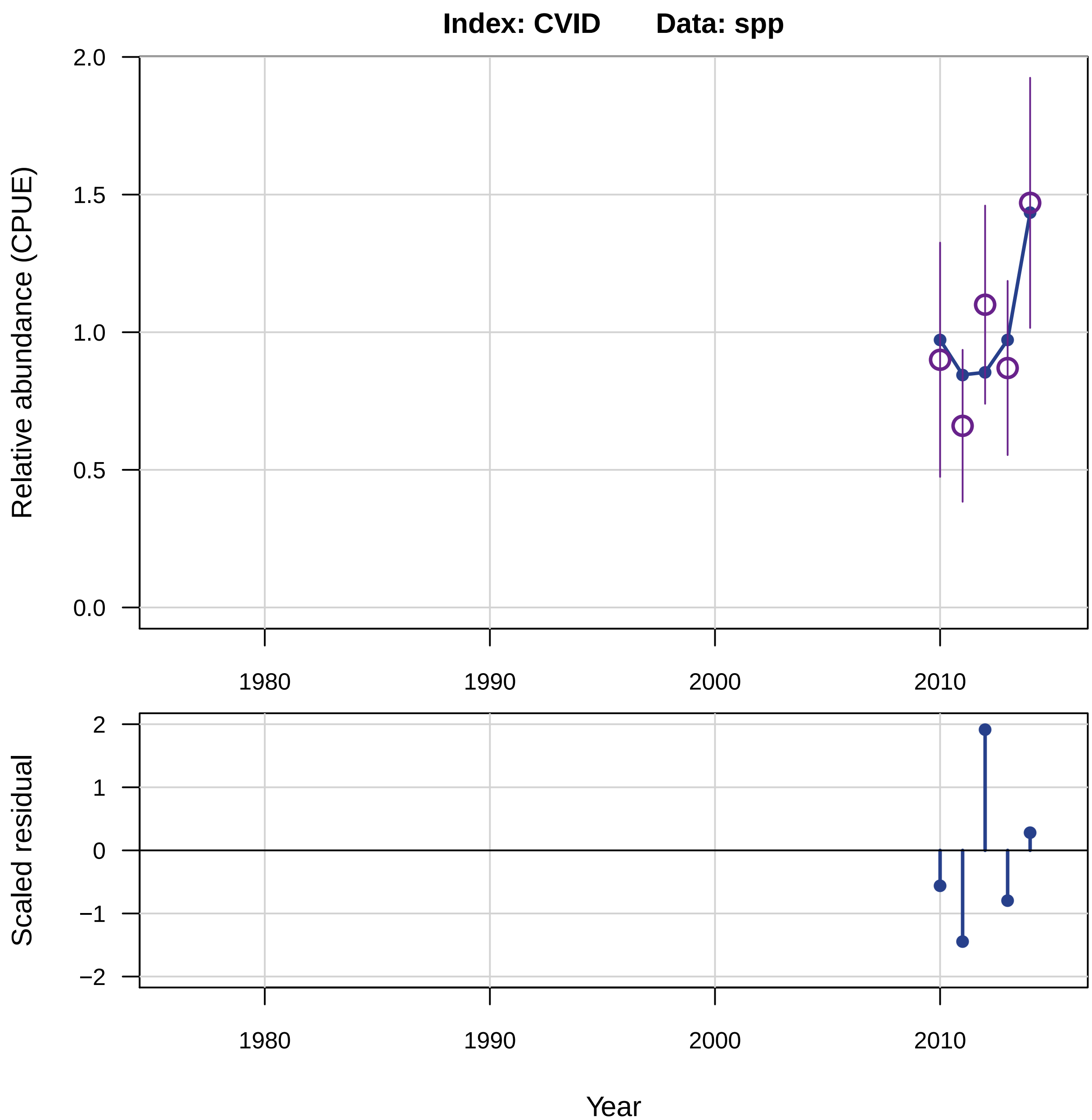


Figure 11. Observed (open circles) and estimated (solid line, circles) index of abundance from the commercial handline fleet. The error bars represent the annual CV of the index (0.2) divided by the likelihood weight on the index.

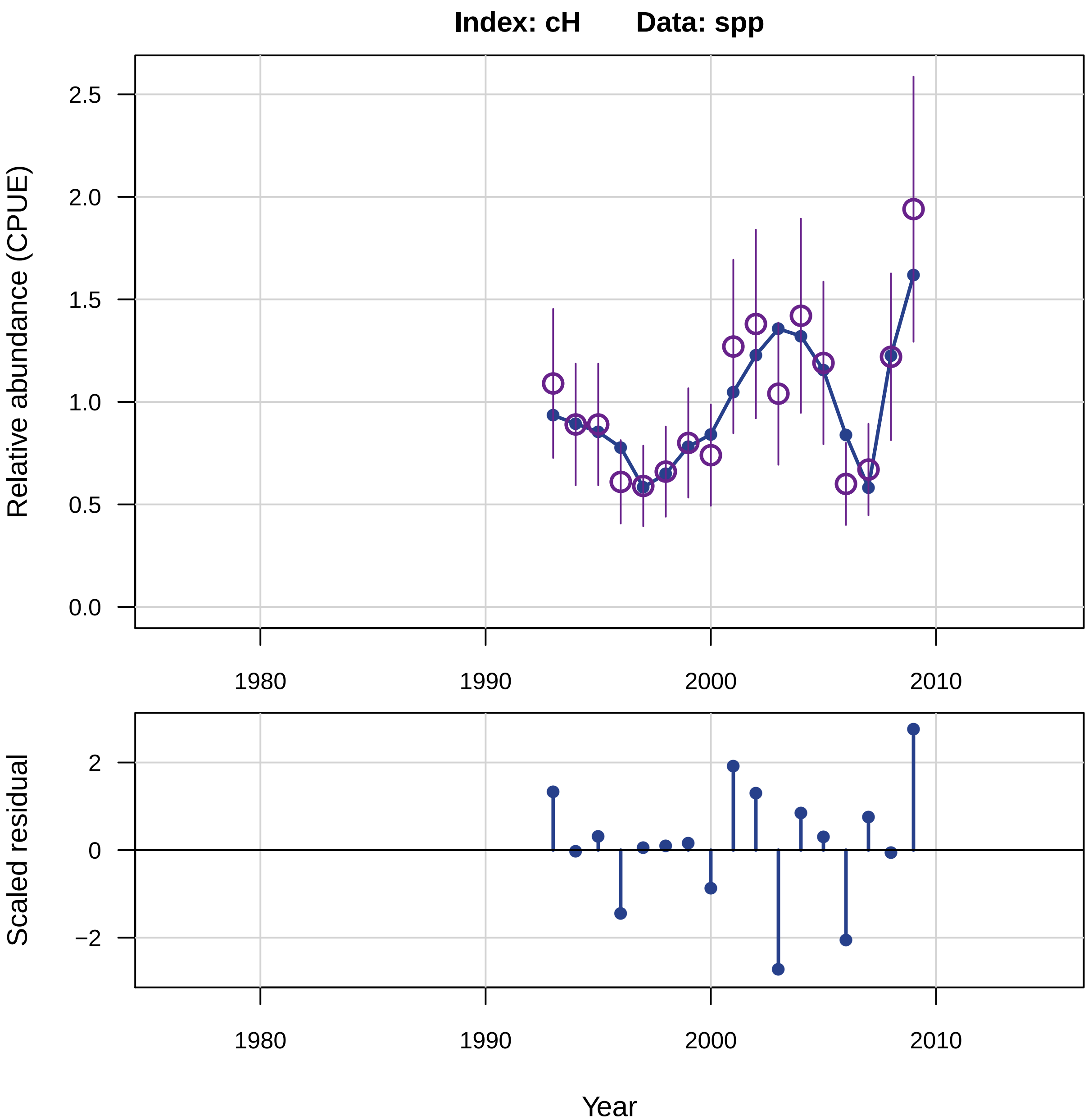


Figure 12. Observed (open circles) and estimated (solid line, circles) abundance from the headboat fleet. The error bars represent the annual CV of the index (0.2) divided by the likelihood weight on the index.

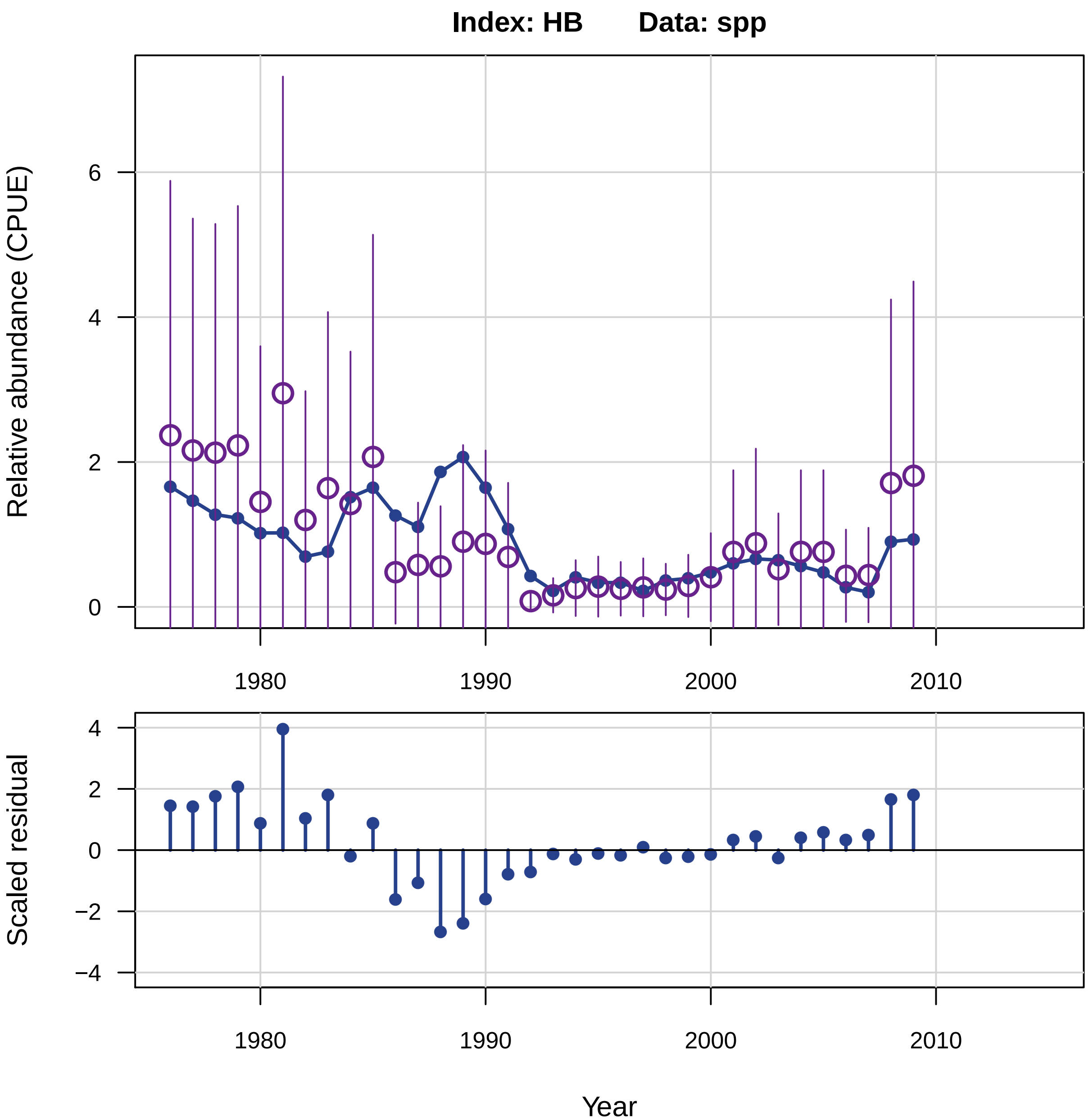


Figure 13. Observed (open circles) and estimated (solid line, circles) abundance from the headboat fleet (discards). The error bars represent the annual CV provided by the GLM standardization divided by the likelihood weight on the index.

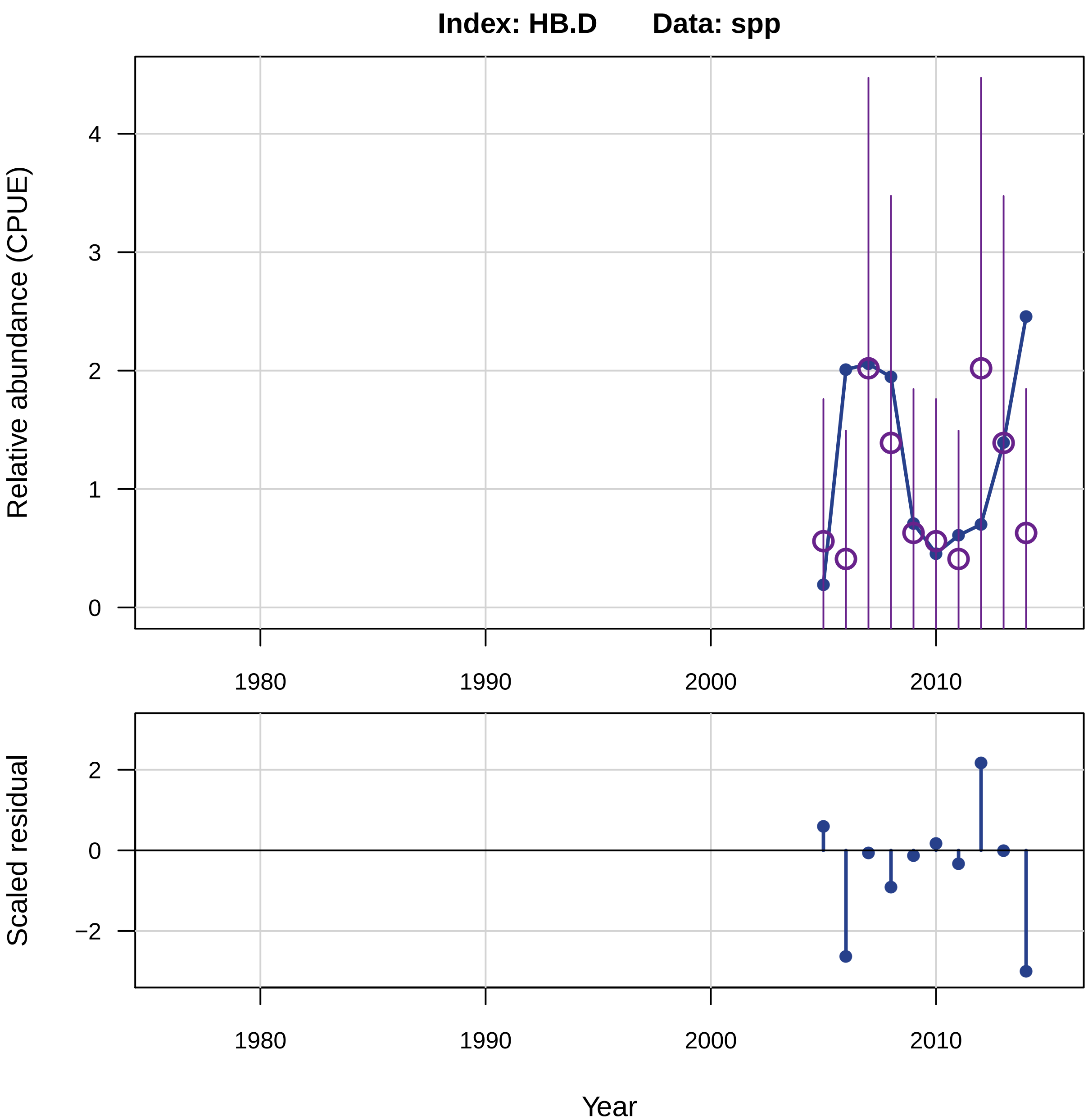


Figure 14. Estimated abundance at age at start of year.

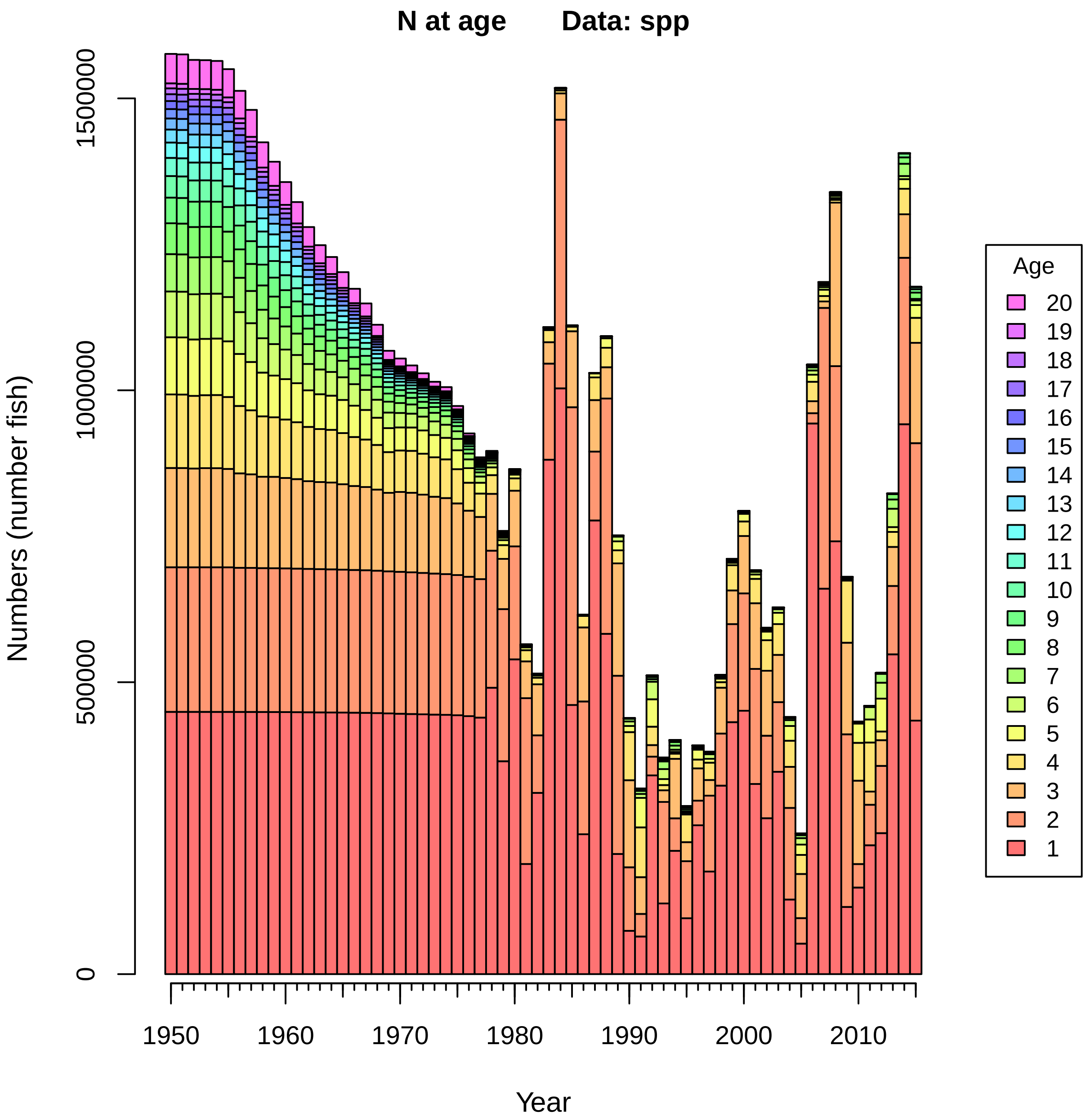


Figure 15. Top panel: Estimated recruitment of age-1 fish. Horizontal dashed line indicates $R_{F30\%}$. Bottom panel: log recruitment residuals.

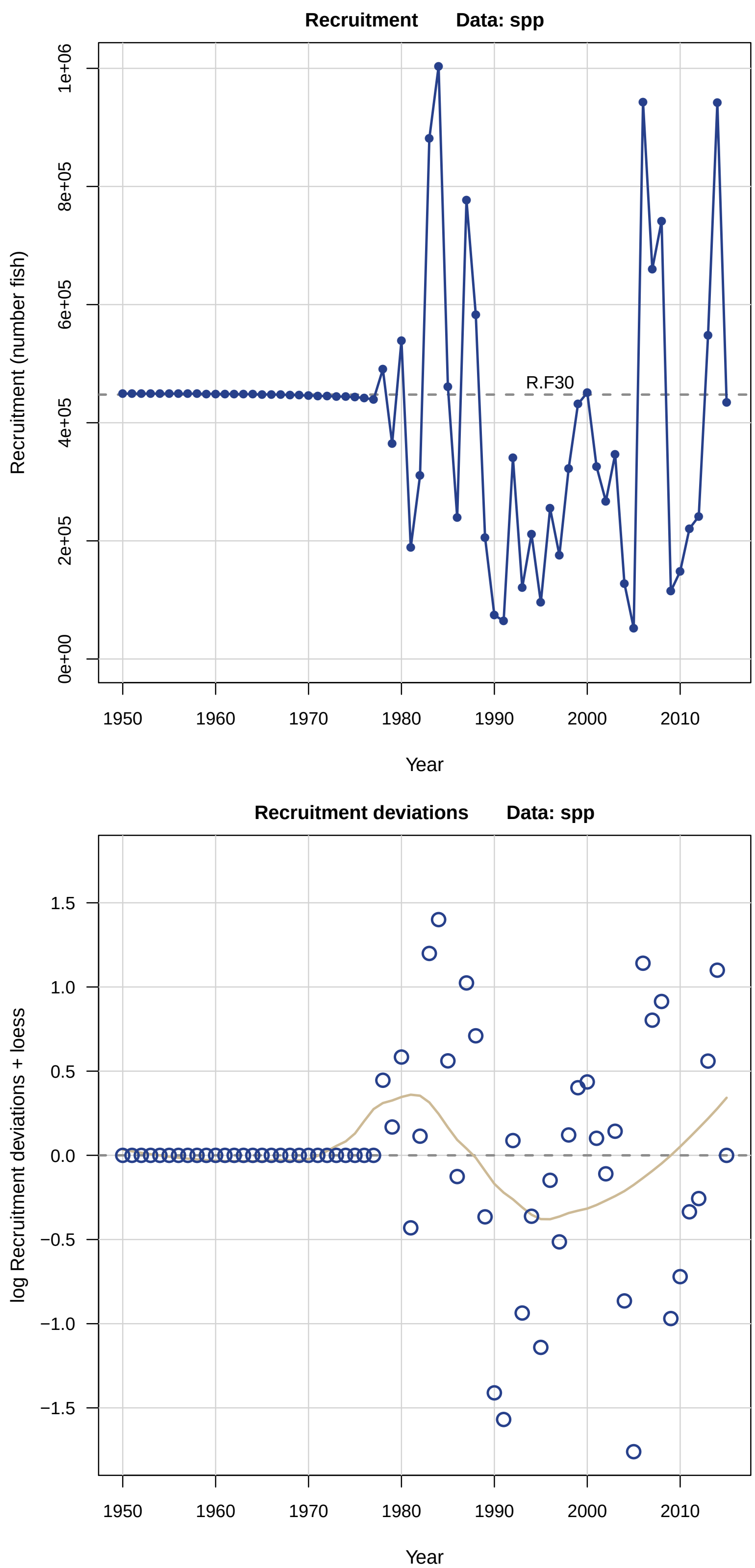


Figure 16. Estimated biomass at age at start of year.

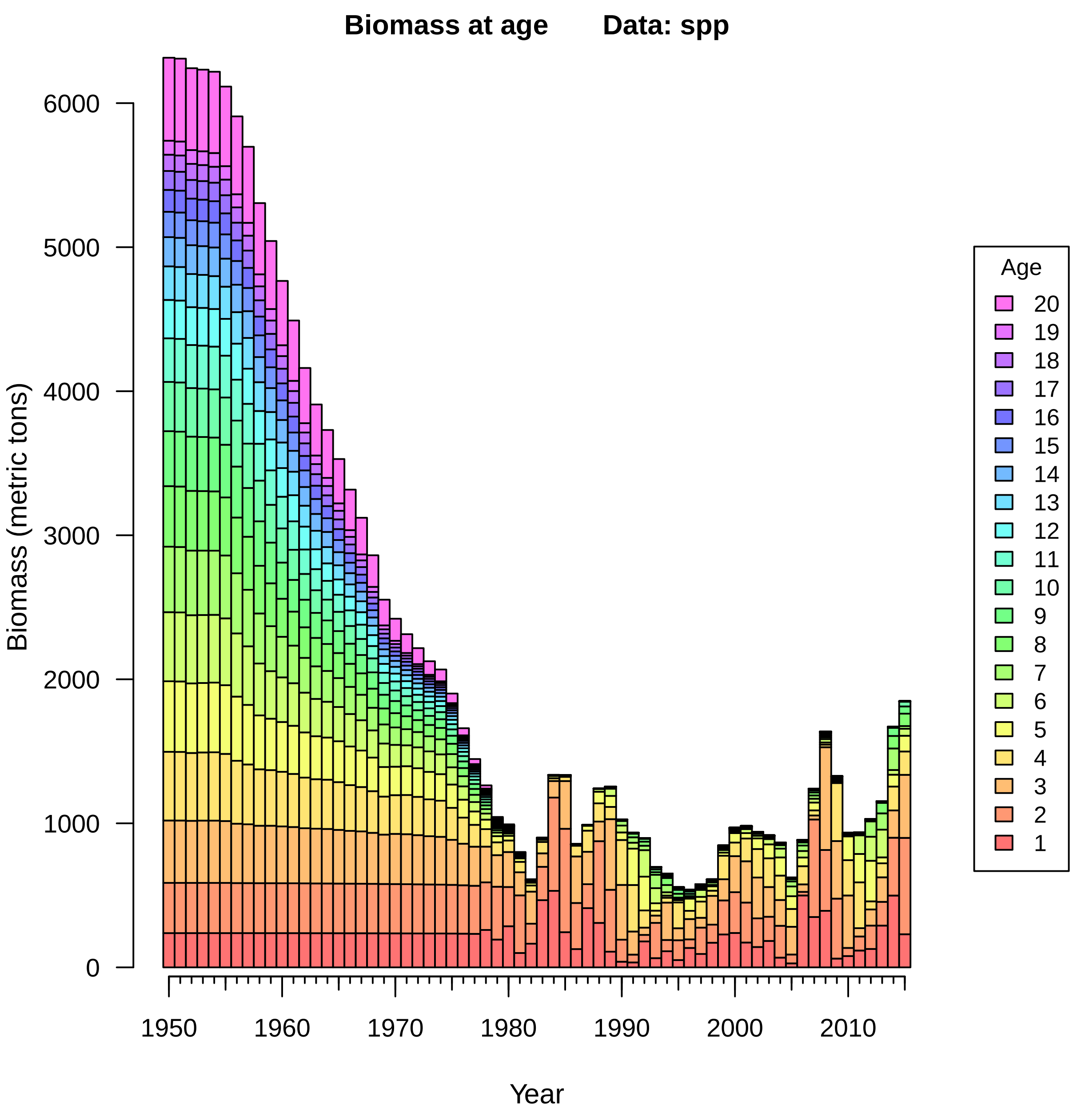


Figure 17. Top panel: Estimated total biomass (metric tons) at start of year. Horizontal dashed line indicates $B_{F30\%}$. *Bottom panel: Estimated spawning stock (population fecundity) at time of peak spawning.*

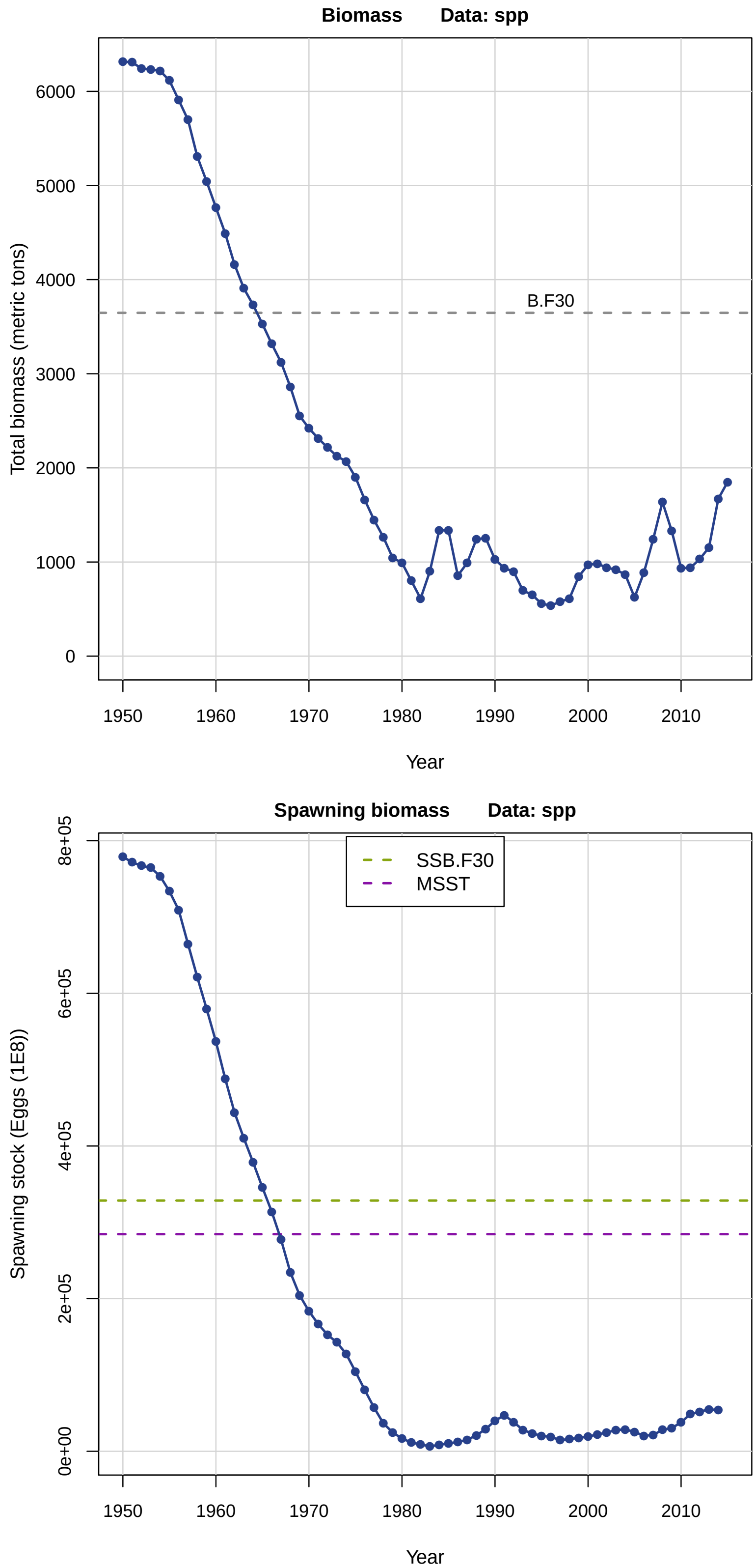
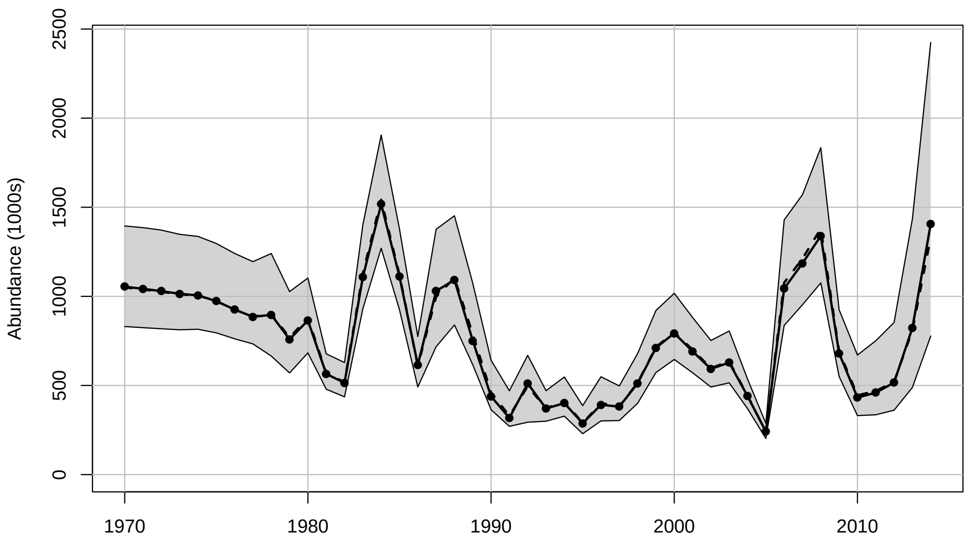


Figure 18. Monte Carlo Bootstrap estimates of population abundance. Top panel is all ages, and the bottom panel represents age 2+.



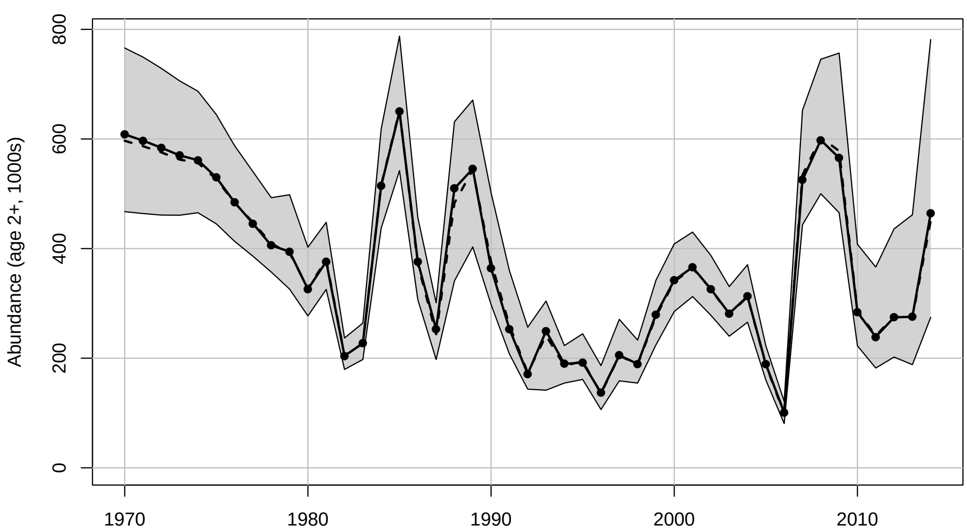


Figure 19. Selectivity of SERFS index.

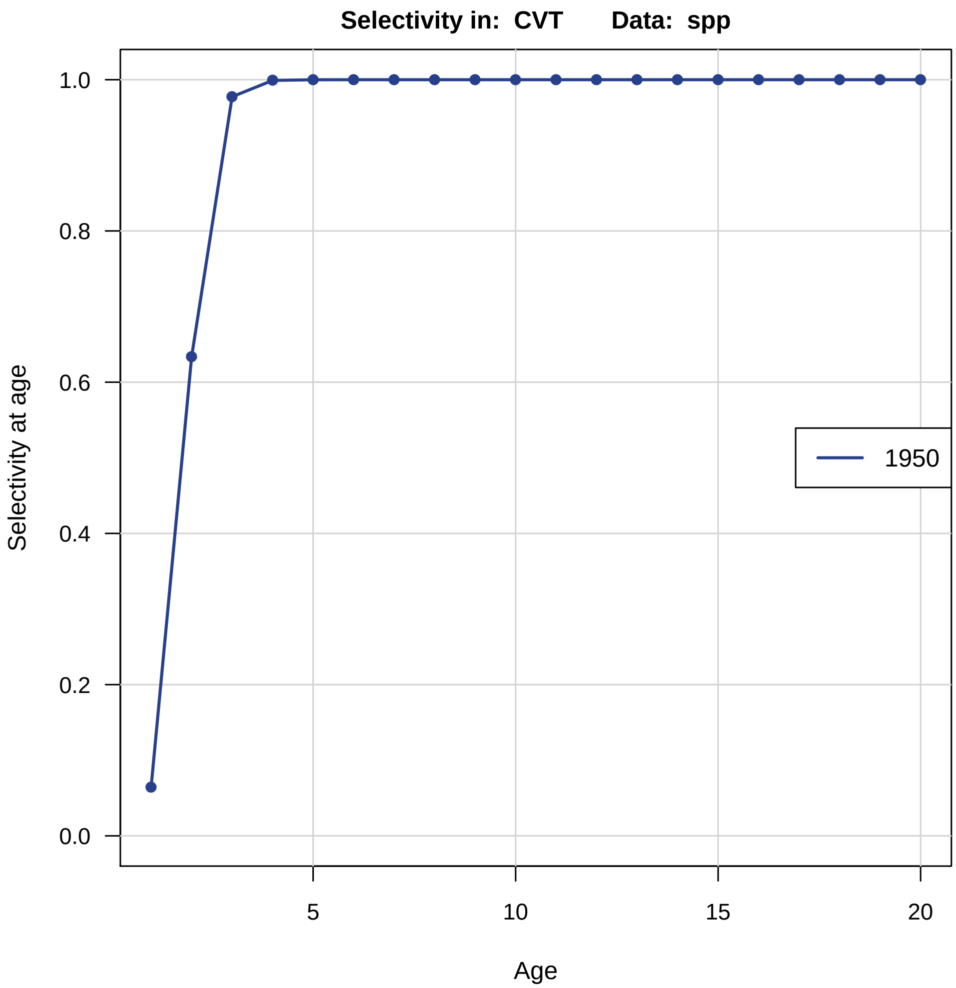


Figure 20. Selectivities of commercial handline landings. The legend indicates the first year each selectivity curve applies to the fleet.

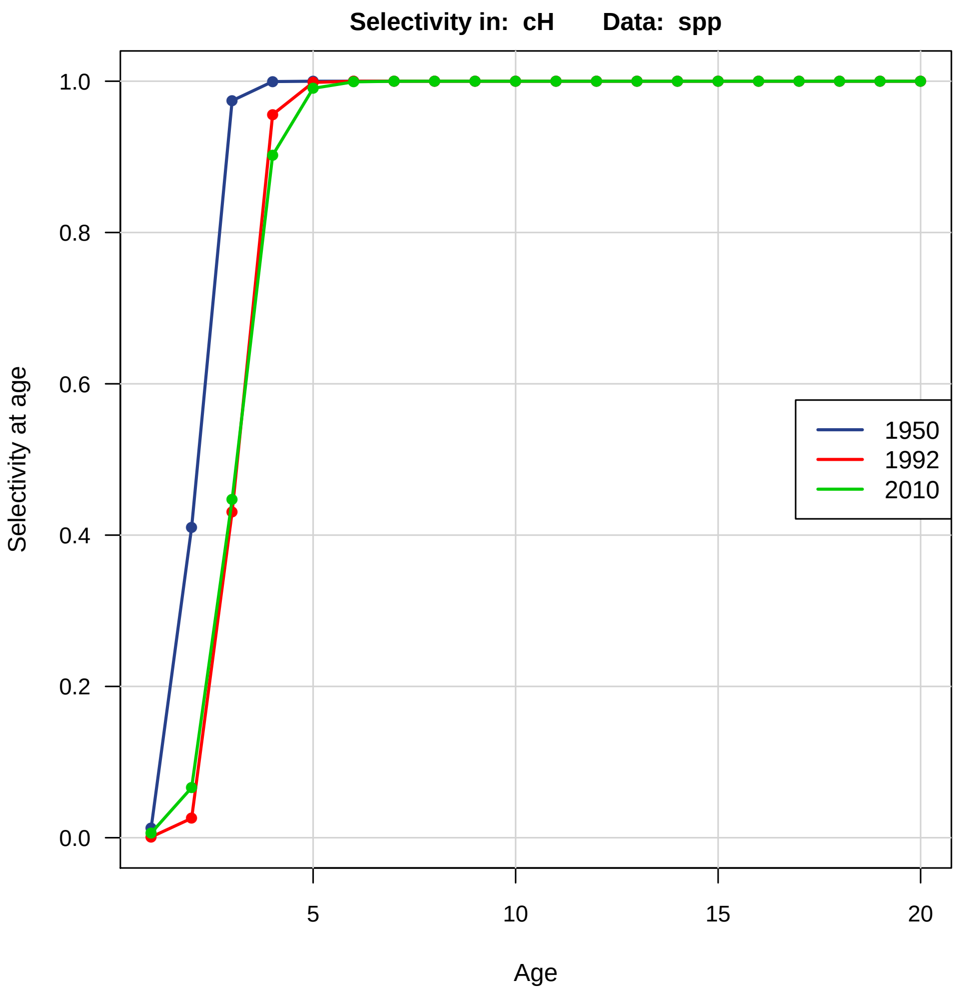


Figure 21. Selectivities of headboat landings. The legend indicates the first year each selectivity curve applies to the fleet.

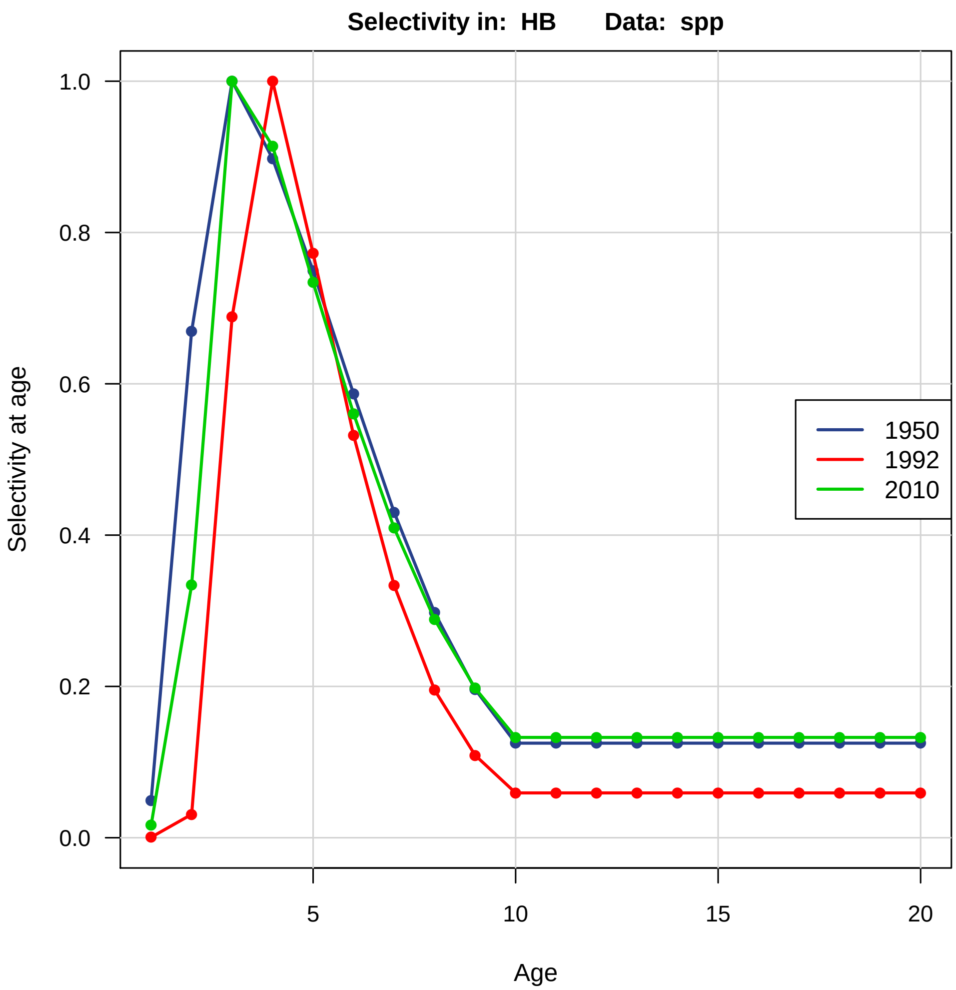


Figure 22. Selectivities of general recreational landings. The legend indicates the first year each selectivity curve applies to the fleet.

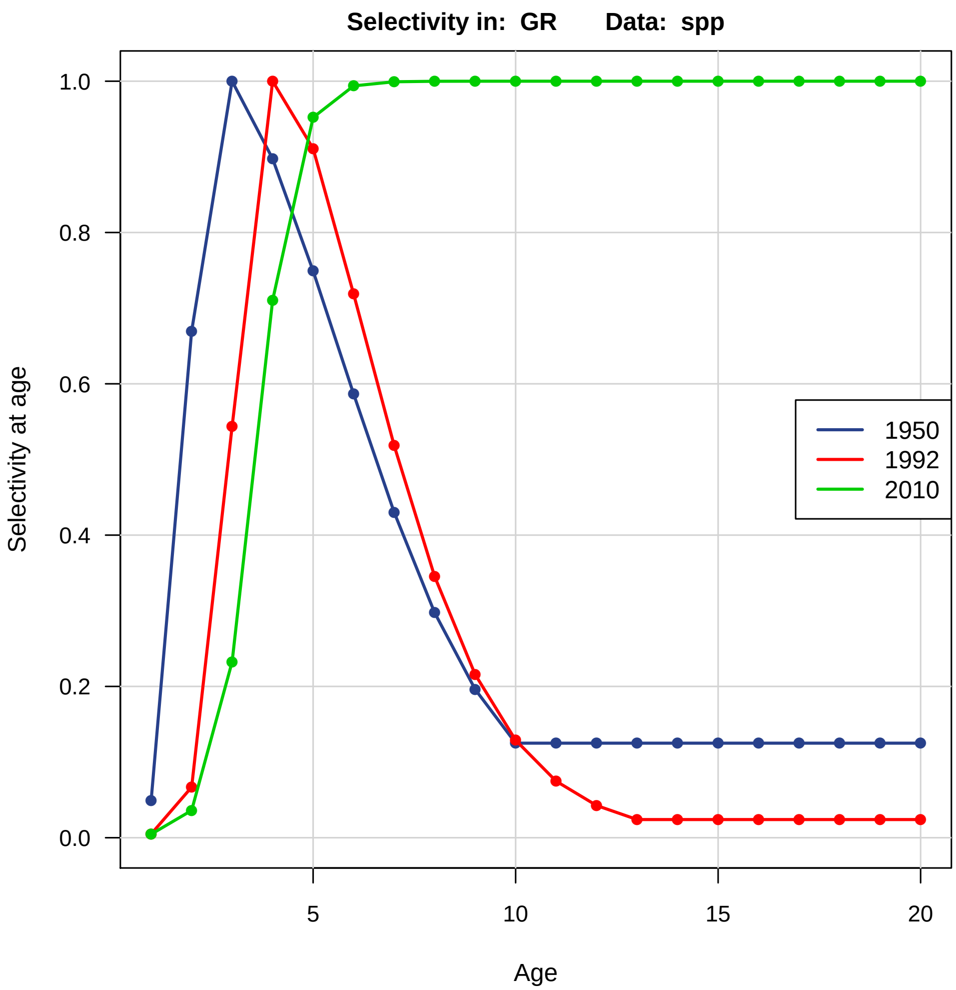


Figure 23. Selectivities of commercial handline discards. The legend indicates the first year each selectivity curve applies to the fleet.

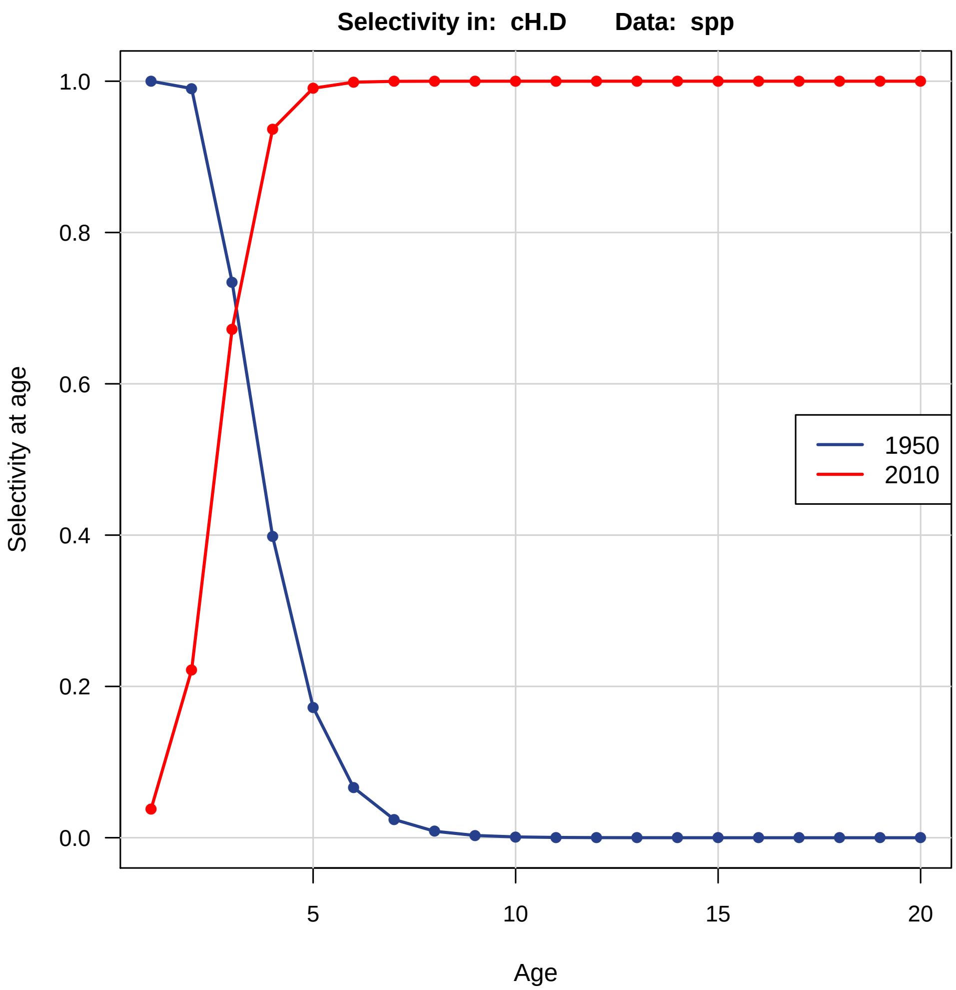


Figure 24. Selectivities of headboat discards. The legend indicates the first year each selectivity curve applies to the fleet.

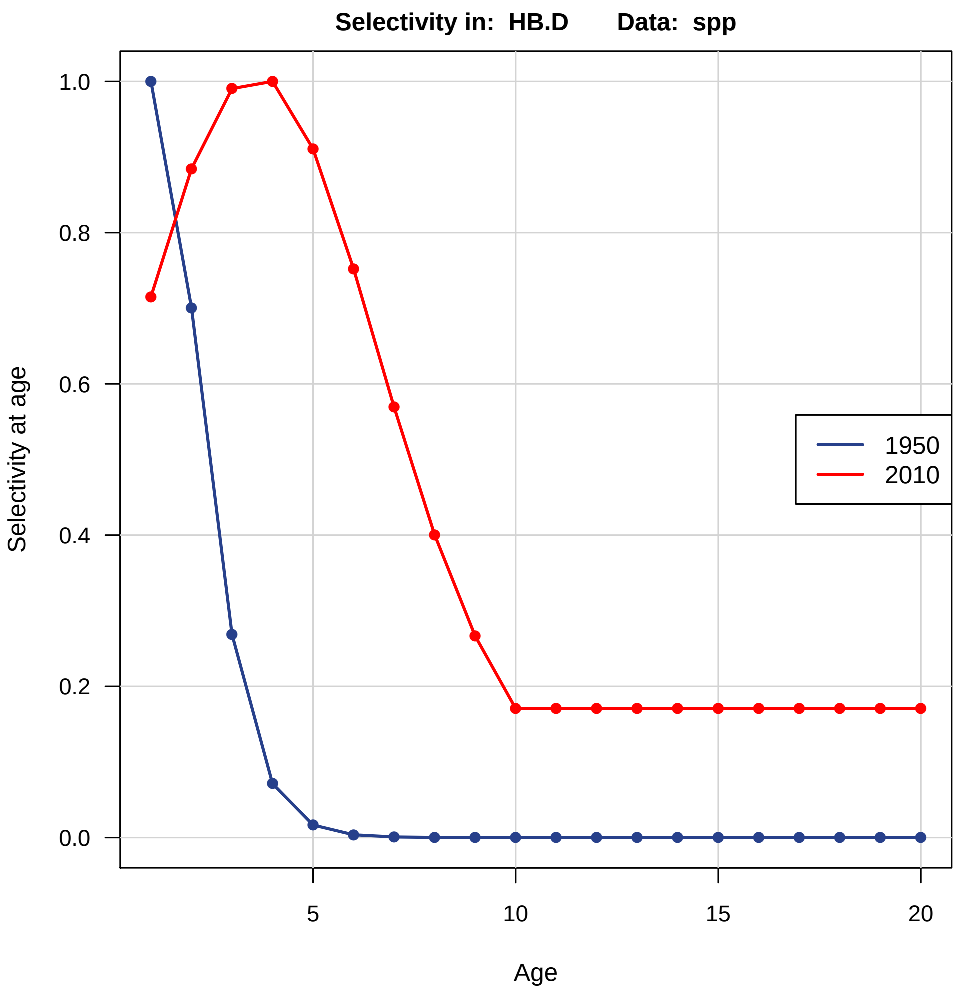


Figure 25. Selectivities of general recreational discards. The legend indicates the first year each selectivity curve applies to the fleet.

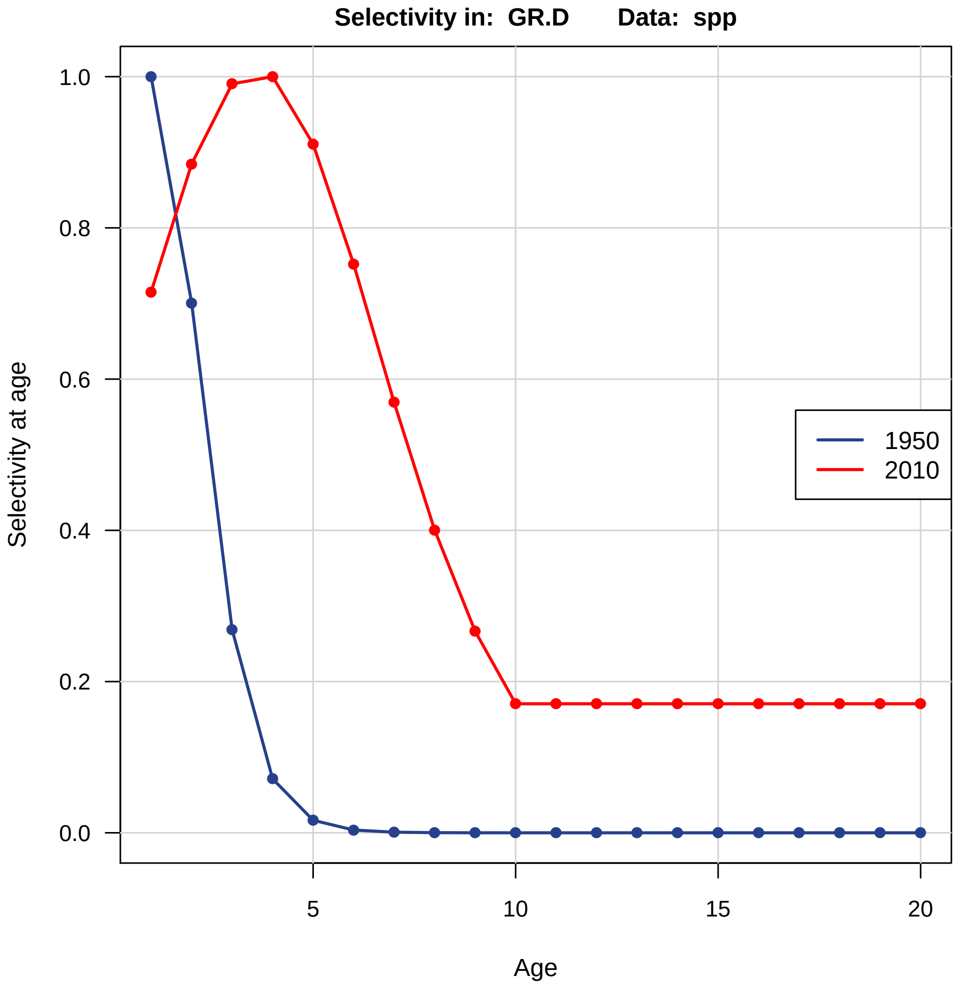


Figure 26. Average selectivity of discards(top left), landings (top right), and total weighted average (bottom) from the terminal assessment years, weighted by geometric mean F's from the last three assessment years, and used in computation of benchmarks and projections.

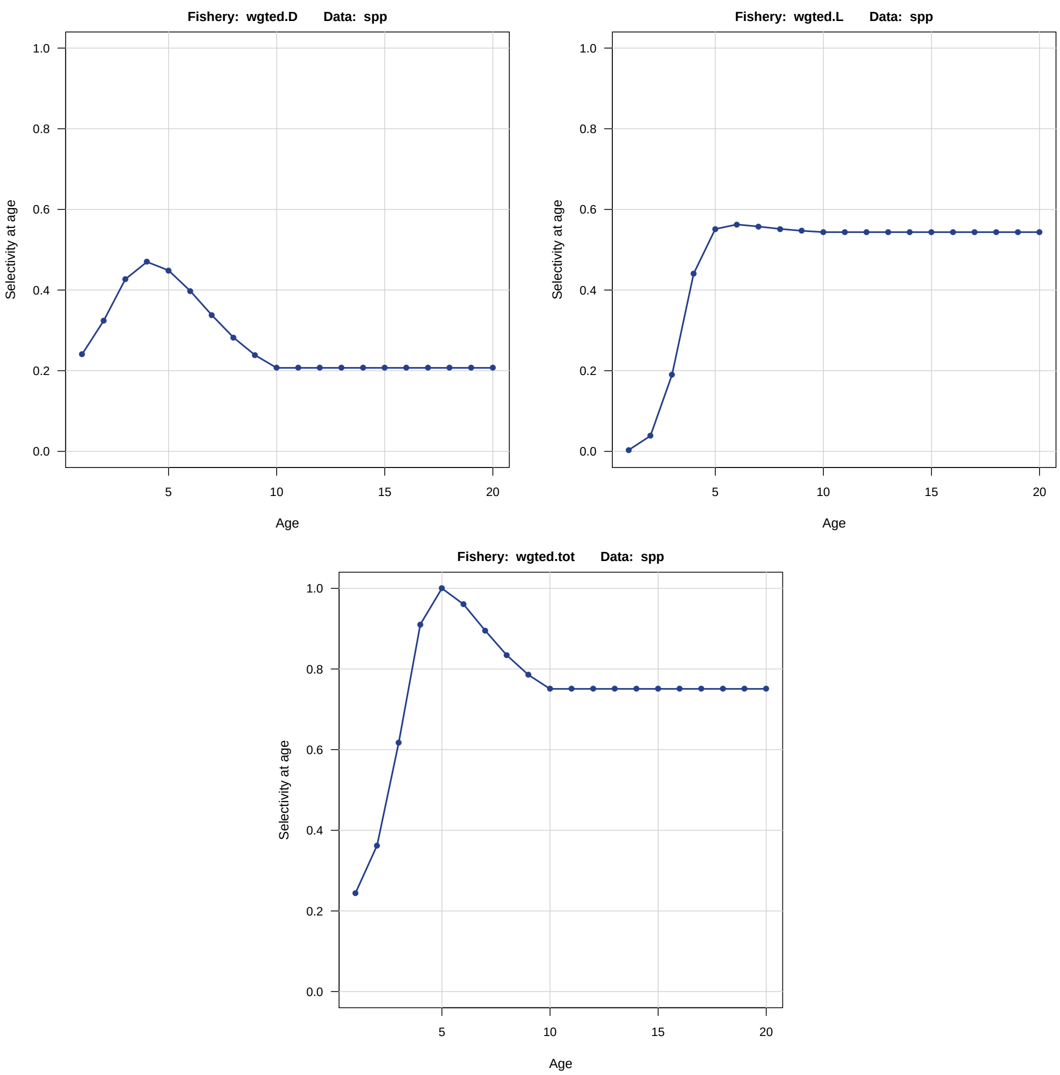


Figure 27. Estimated fully selected fishing mortality rate (per year) by fleet. cH refers to commercial handlines, HB to headboat, GR to general recreational, and D refers to discard mortality.

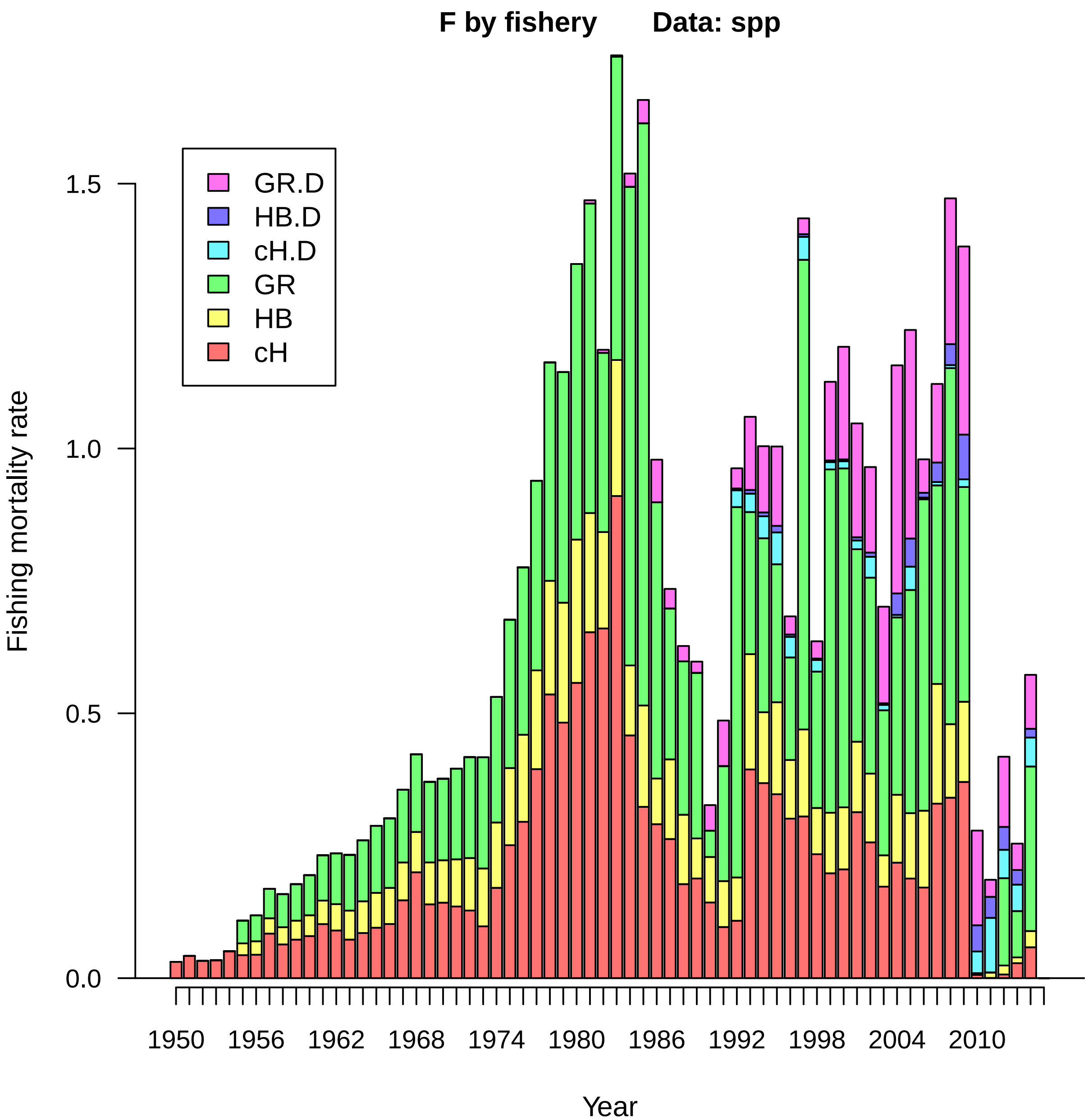


Figure 28. Estimated landings in numbers by fleet from the catch-age model. cH refers to commercial handlines, HB to headboat, and GR to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of $L_{\mathrm{F30\%}}$ in numbers.

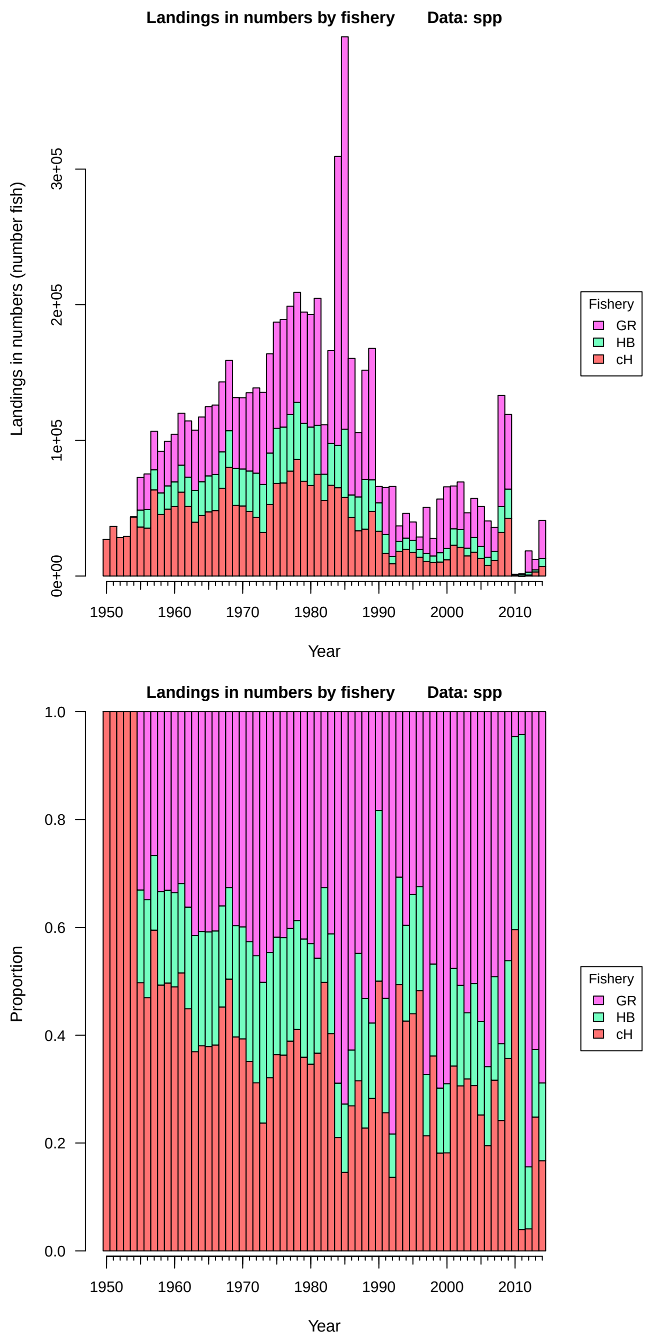


Figure 29. Estimated landings in whole weight by fleet from the catch-age model. cH refers to commercial handlines, HB to headboat, and GR to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of $L_{F30\%}$ in weight.

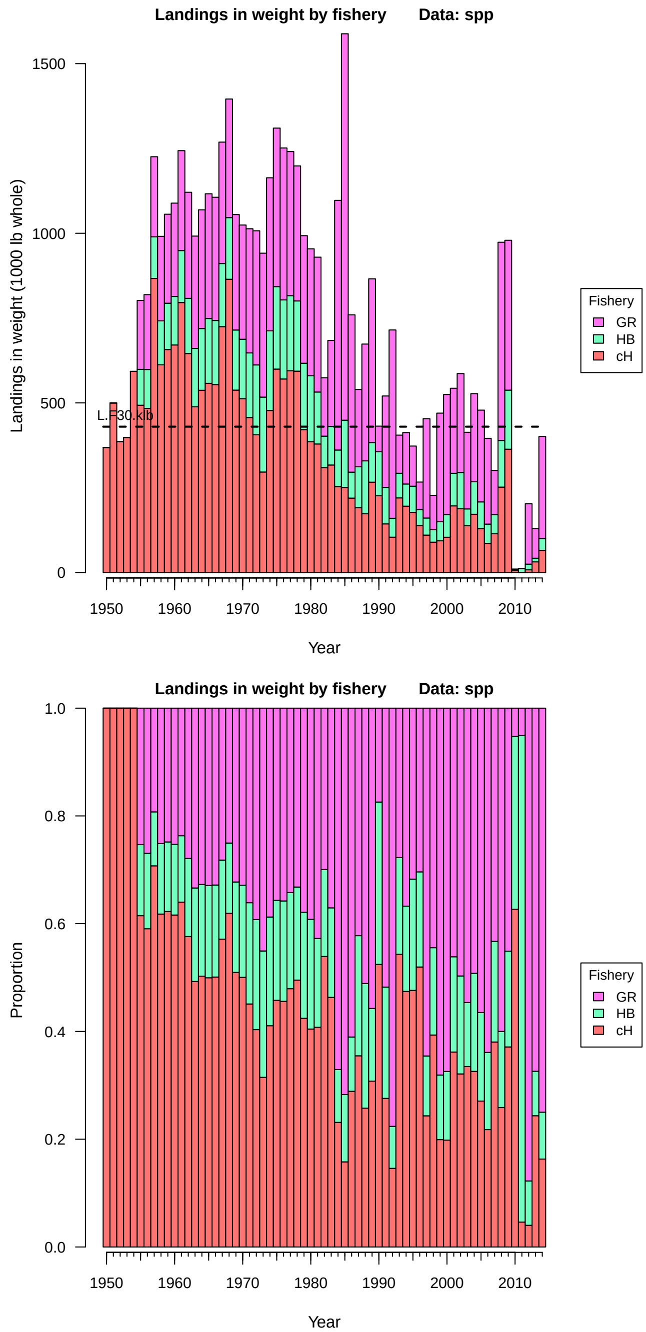


Figure 30. Estimated discard mortalities by fleet from the catch-age model. cH refers to commercial lines, hb to headboat, rec to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of $D_{F_{30\%}}$ in numbers.

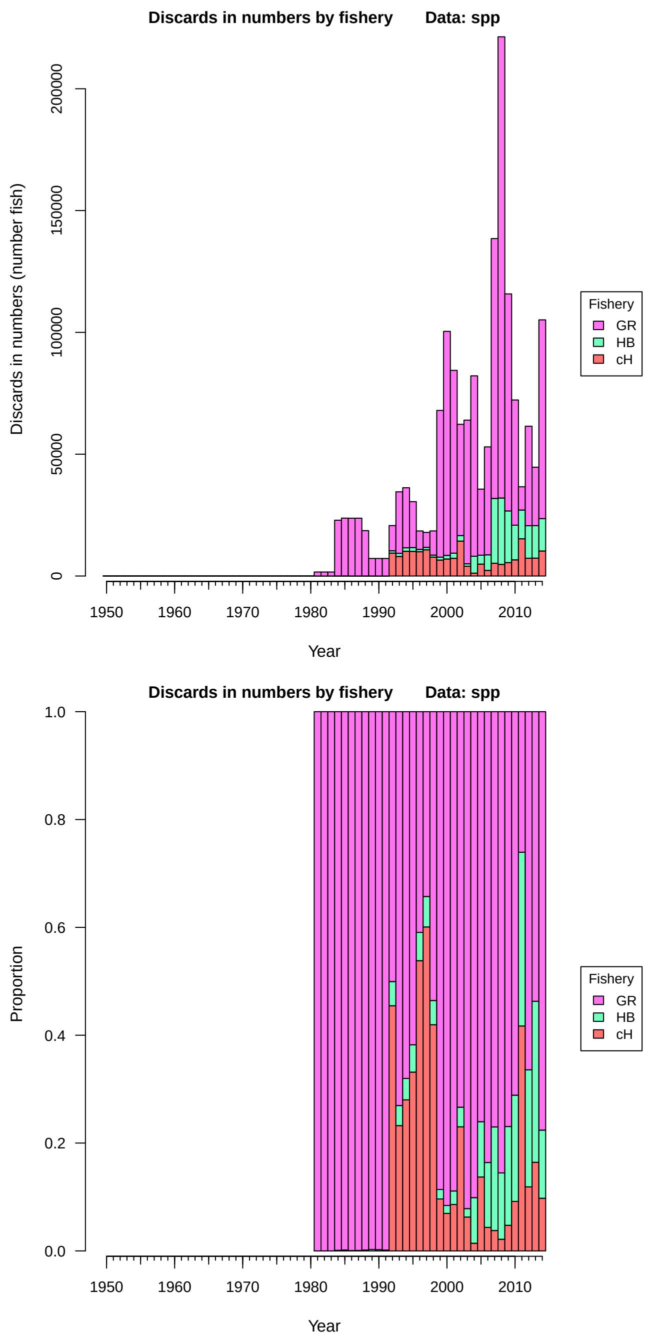


Figure 31. Top panel: Beverton–Holt spawner-recruit curves, with and without lognormal bias correction. The expected (upper) curve was used for computing management benchmarks. Bottom panel: log of recruits (number age-1 fish) per spawner as a function of spawners.

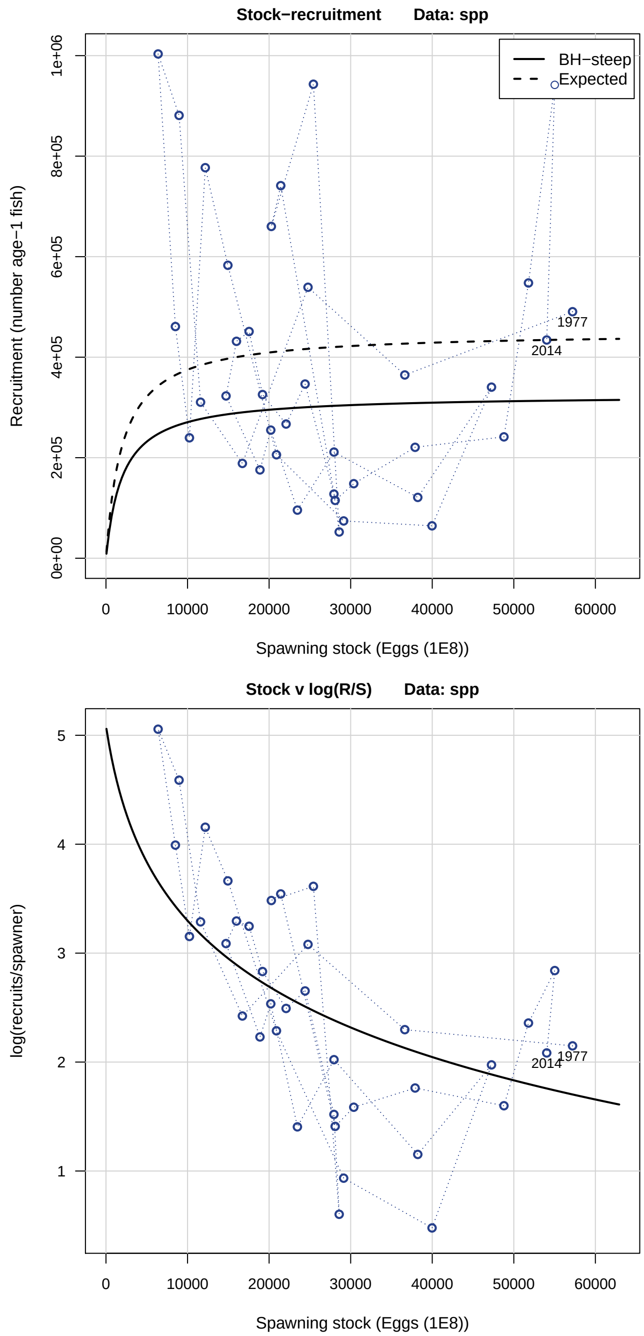


Figure 32. Probability densities of spawner-recruit quantities R0 (unfished recruitment of age-1 fish), steepness (fixed at 0.99), unfished spawners per recruit, and standard deviation of recruitment residuals in log space. Solid vertical lines represent point estimates or values from the base run of the Beaufort Assessment Model; dashed vertical lines represent medians from the MCB runs.

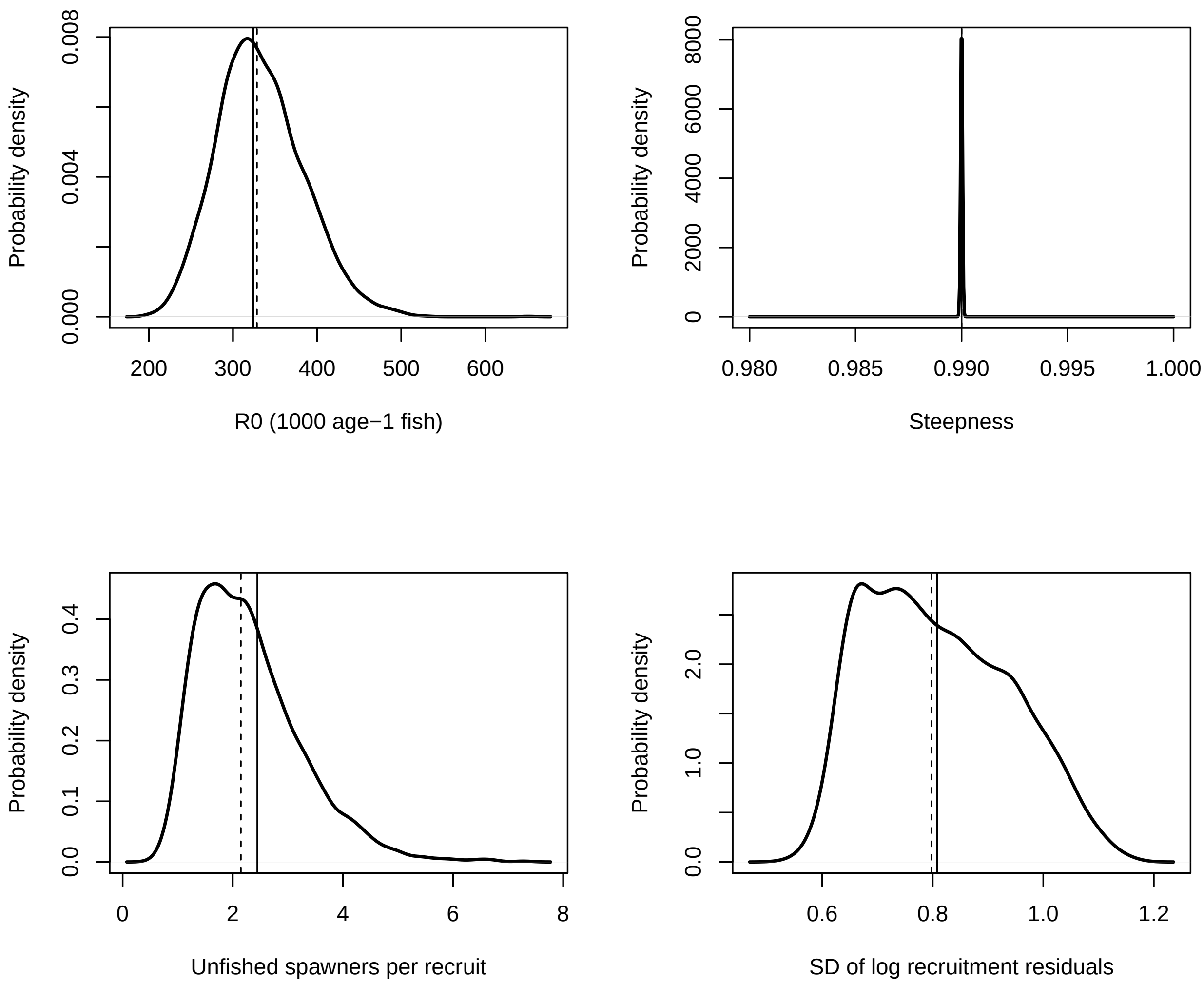


Figure 33. Yield per recruit based on average selectivity from the end of the assessment period.

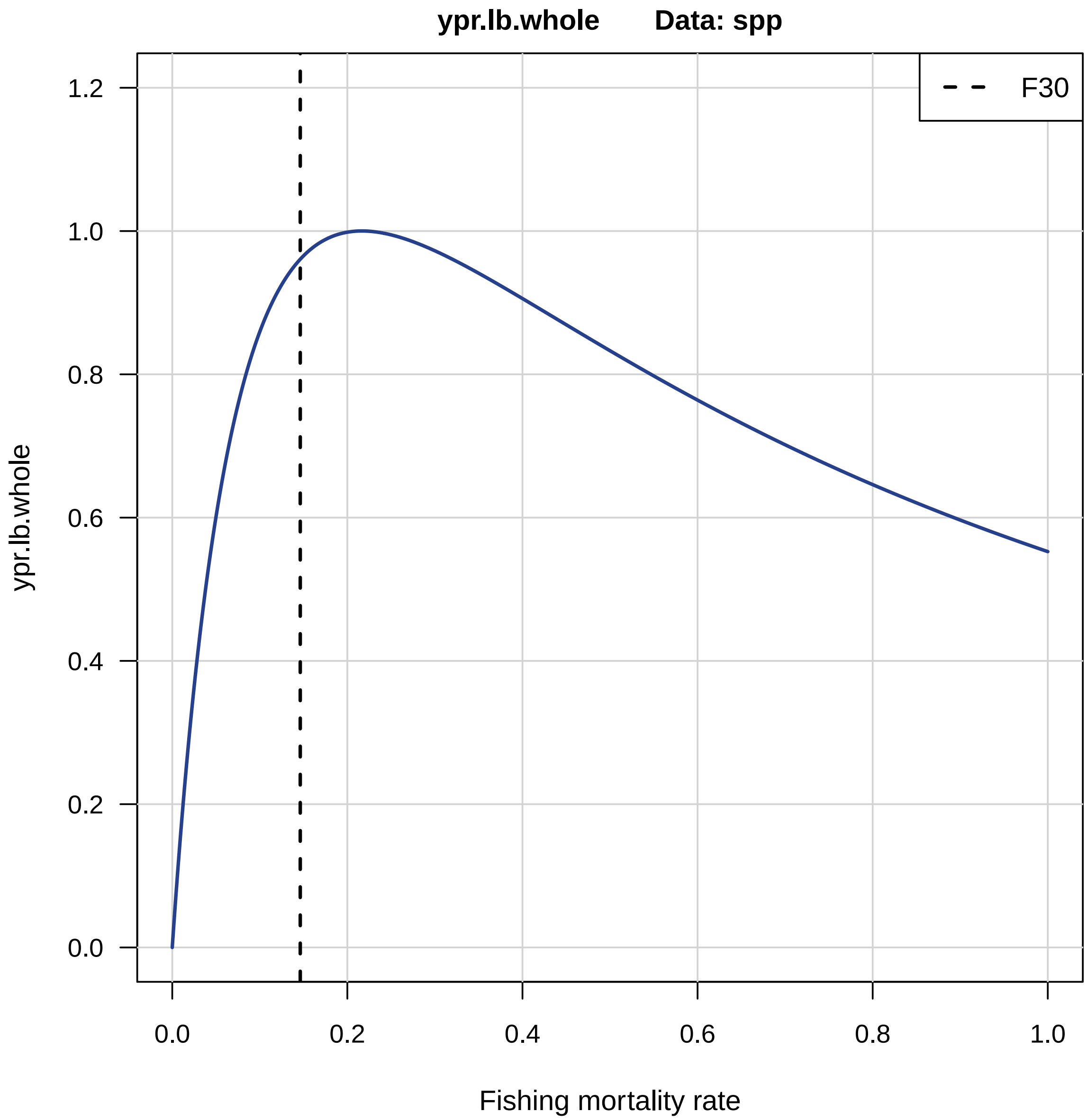


Figure 34. Spawning potential ratio (spawning biomass per recruit relative to that at the unfished level), from which the X% level of SPR provides $F_{X\%}$. SPR is based on average selectivity from the end of the assessment period.

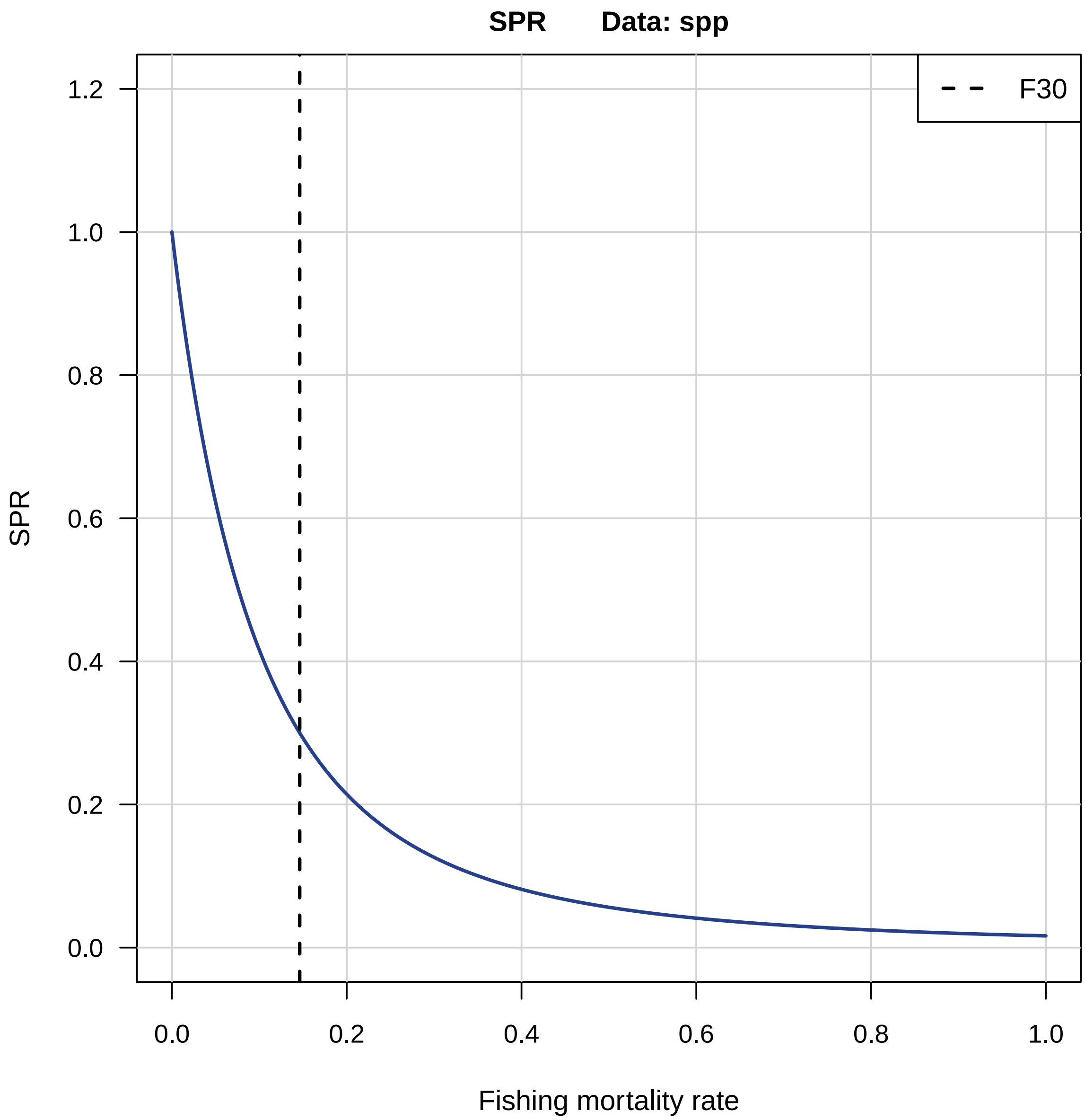


Figure 35. Equilibrium spawning biomass based on average selectivity from the end of the assessment period.

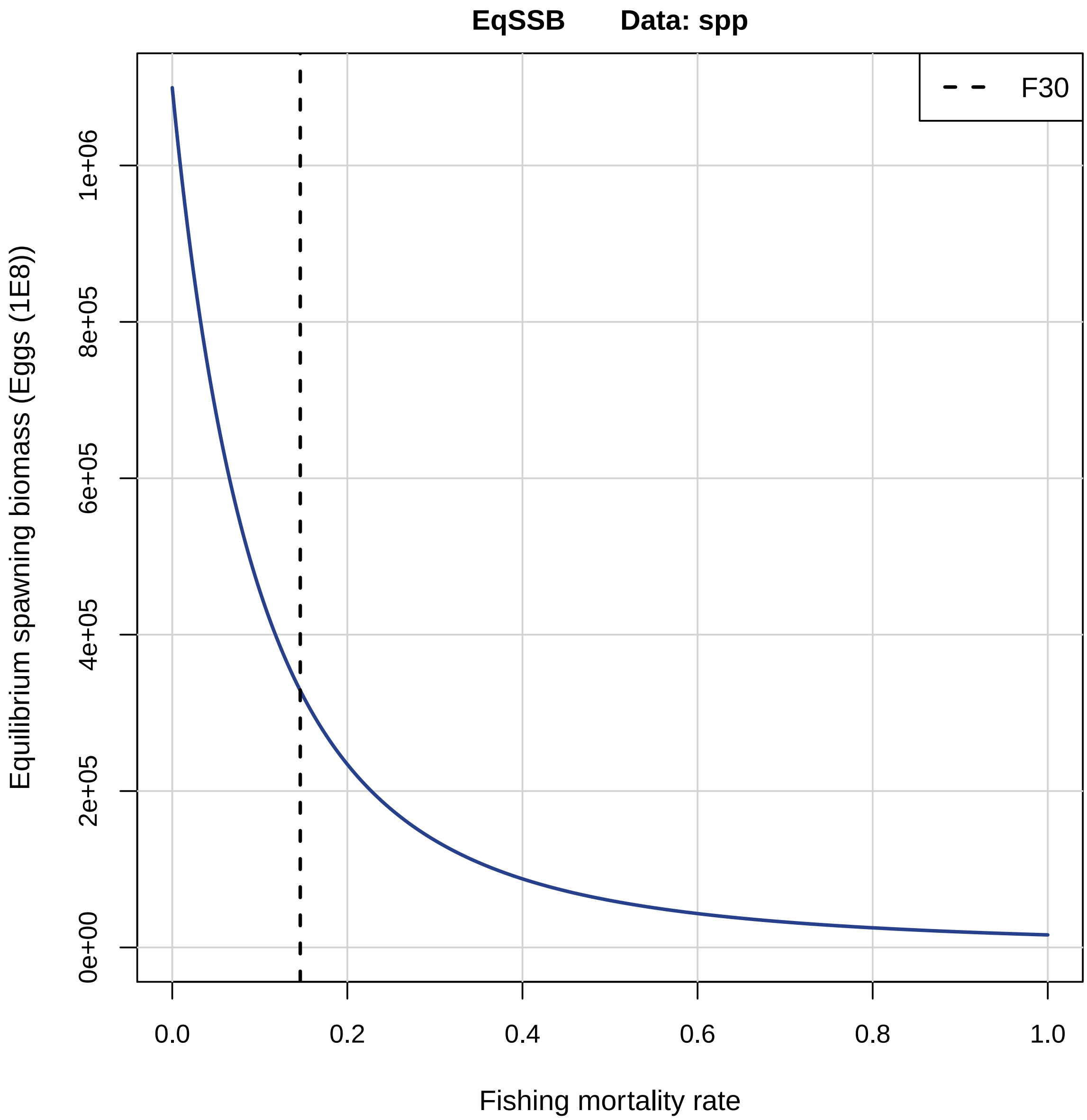


Figure 36. Probability densities of $F_{30\%}$-related benchmarks from MCB analysis of the Beaufort Assessment Model. Solid vertical lines represent point estimates from the base run; dashed vertical lines represent median values.

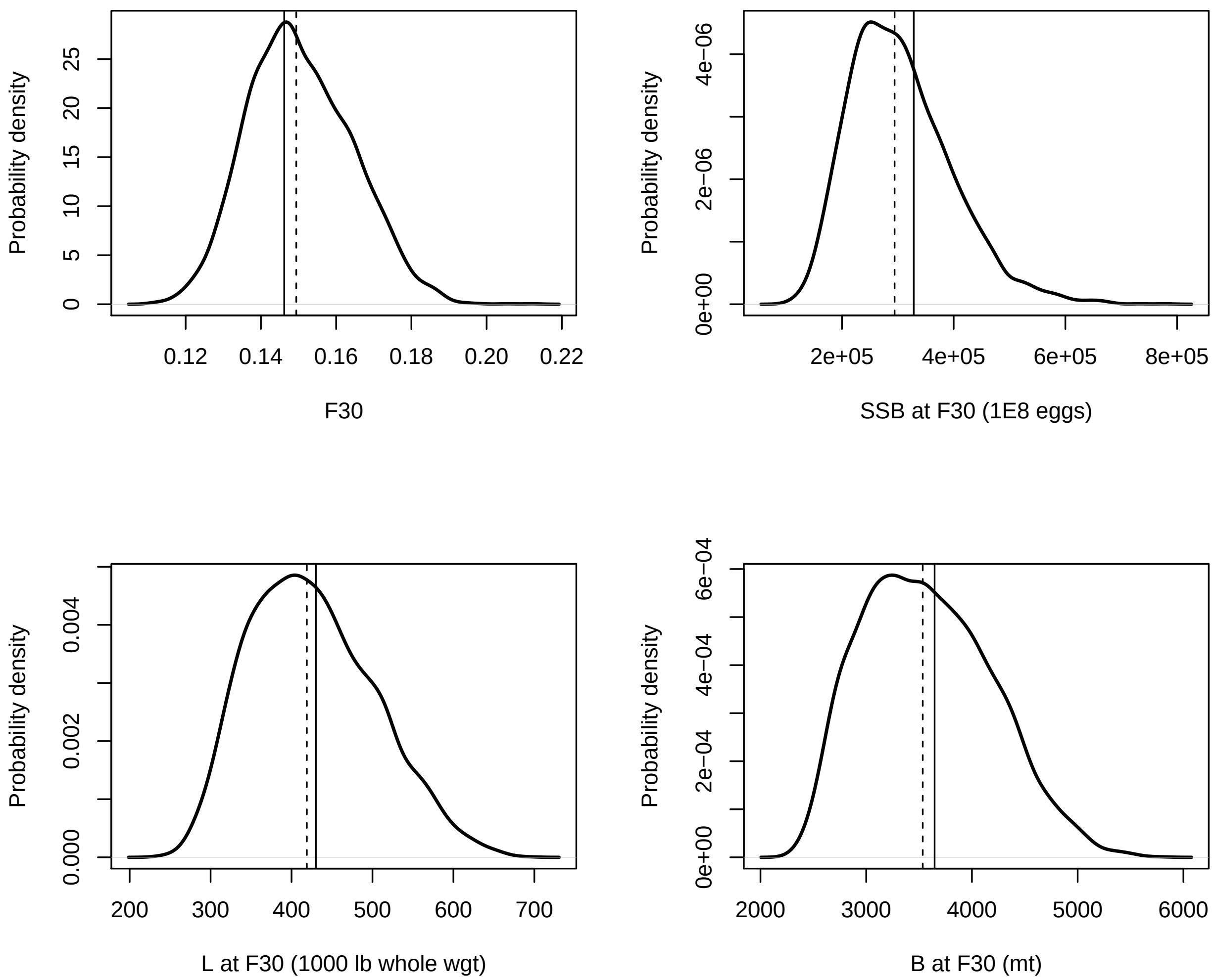


Figure 37. Estimated time series relative to benchmarks. Solid line indicates estimates from base run of the Beaufort Assessment Model; dashed lines represent median values; gray error bands indicate 5^{th} *and* 95^{th} *percentiles of the MCB trials. Top panel: spawning biomass relative to* $\mathrm{SSB}_{\mathrm{F30\%}}$*. Bottom panel: F relative to* $F_{30\%}$*.*

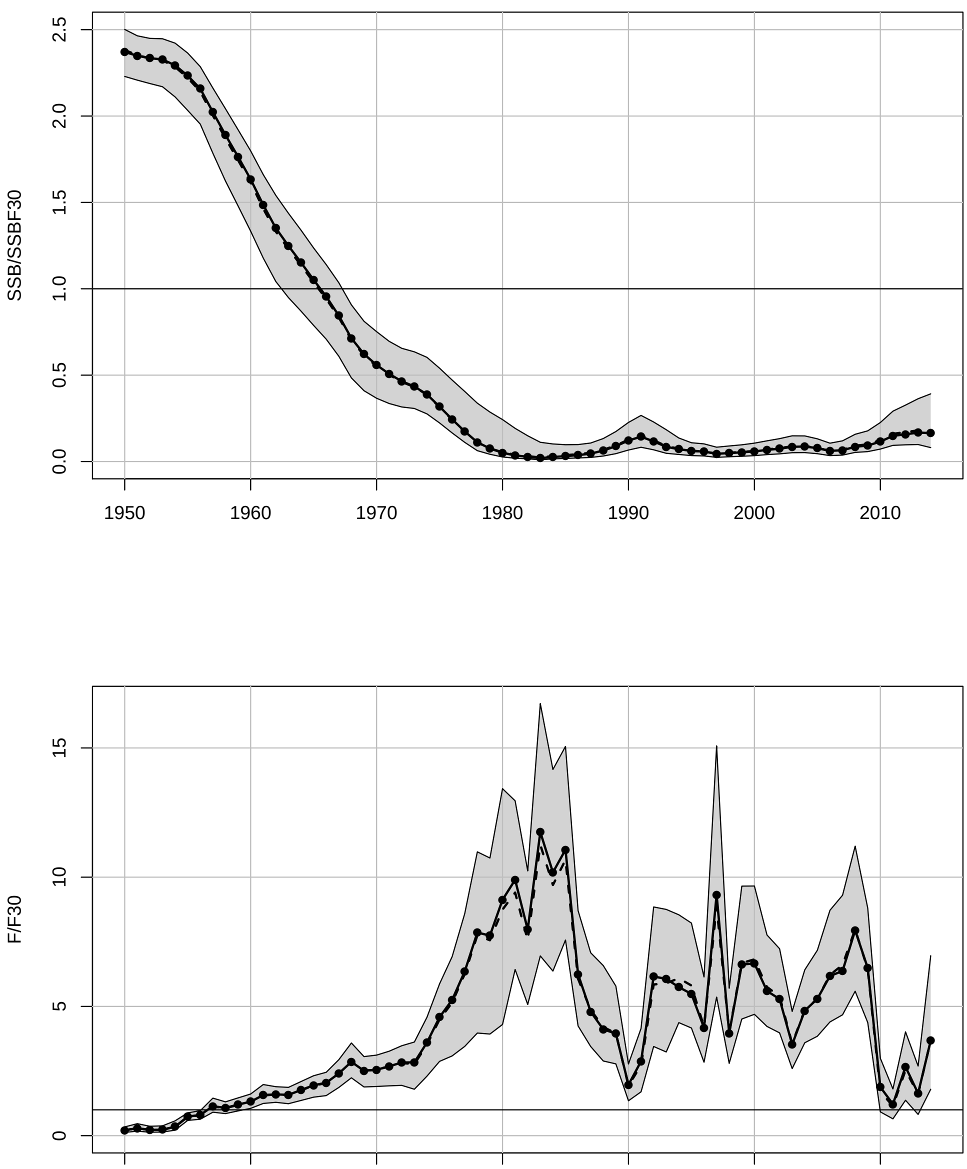
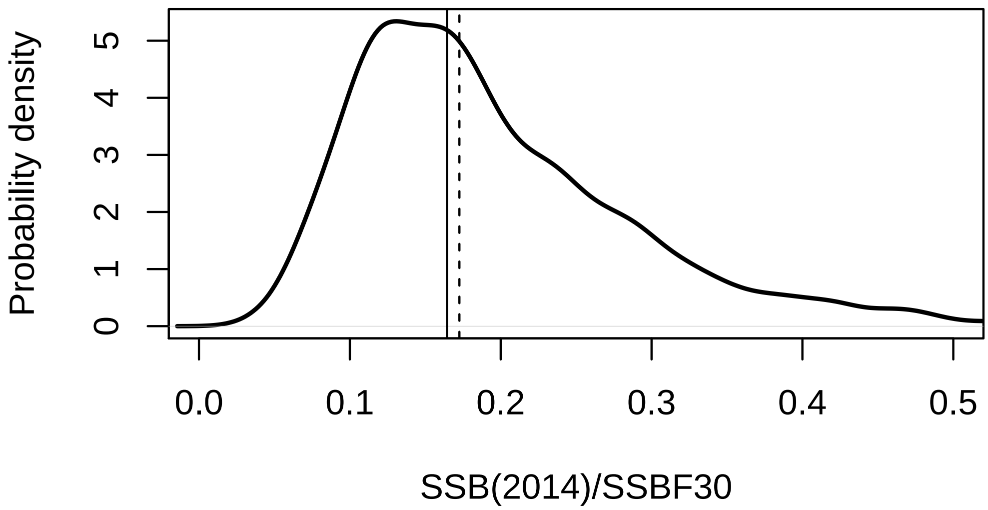


Figure 38. Probability densities of terminal status estimates from MCB analysis of the Beaufort Assessment Model. Solid vertical lines represent point estimates from the base run; dashed vertical lines represent median values.



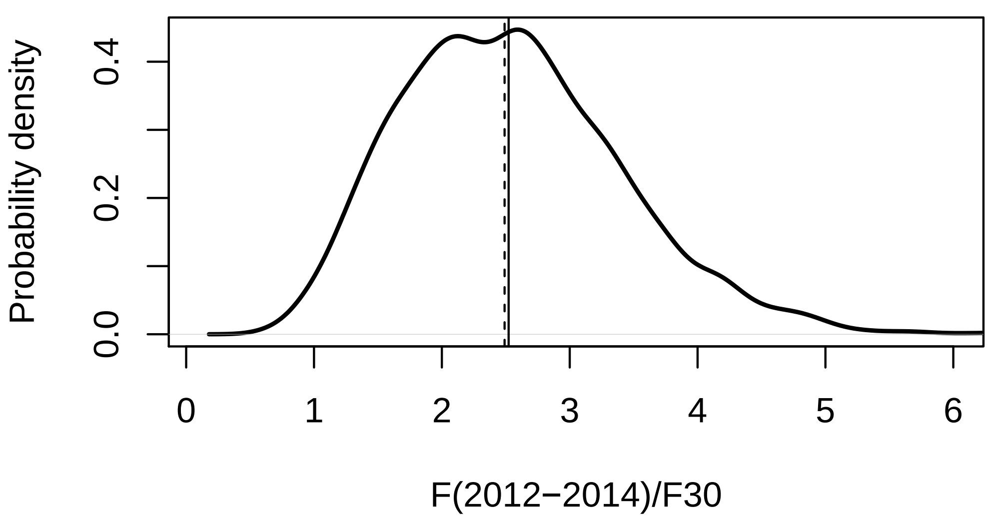


Figure 39. Phase plots of terminal status estimates from MCB analysis of the Beaufort Assessment Model. The intersection of crosshairs indicates estimates from the base run; lengths of crosshairs defined by 5^{th} and 95^{th} percentiles. Proportion of runs falling in each quadrant indicated.

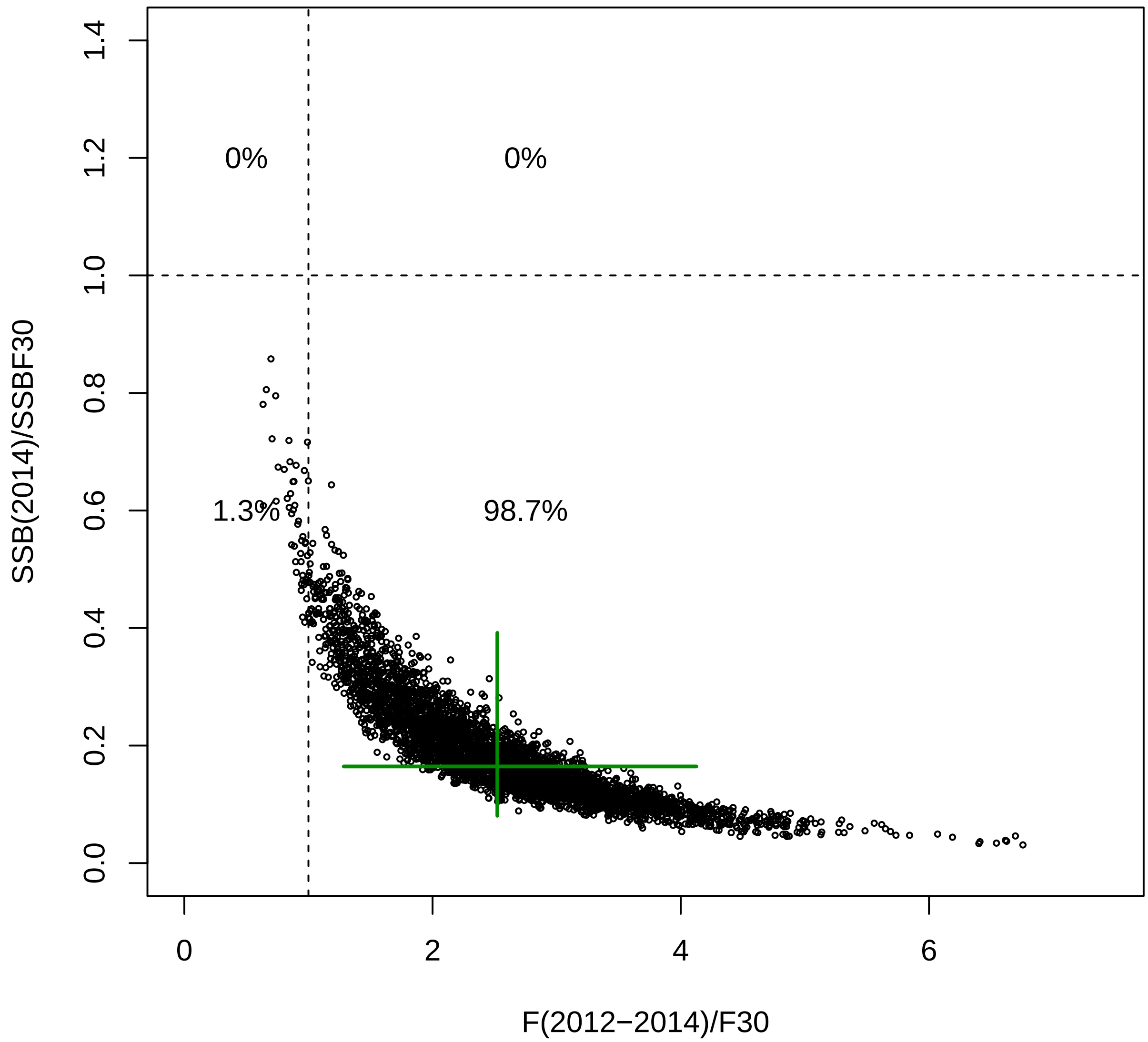


Figure 40. Age structure relative to the equilibrium expected at $F_{30\%}$.

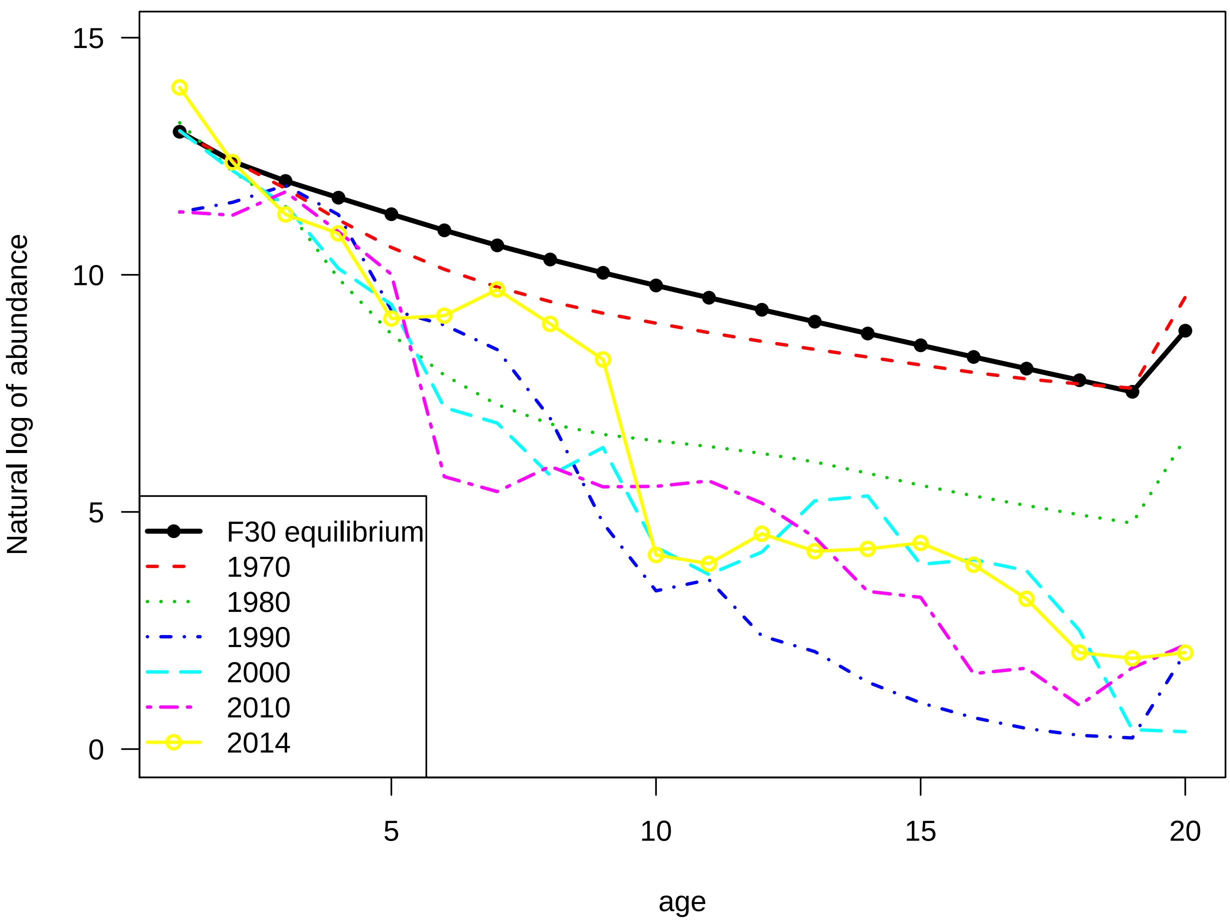


Figure 41. Sensitivity to changes in natural mortality (sensitivity runs S5 and S6). Top panel: Ratio of F to $F_{30\%}$. *Bottom panel: Ratio of* SSB *to* $SSB_{F30\%}$.

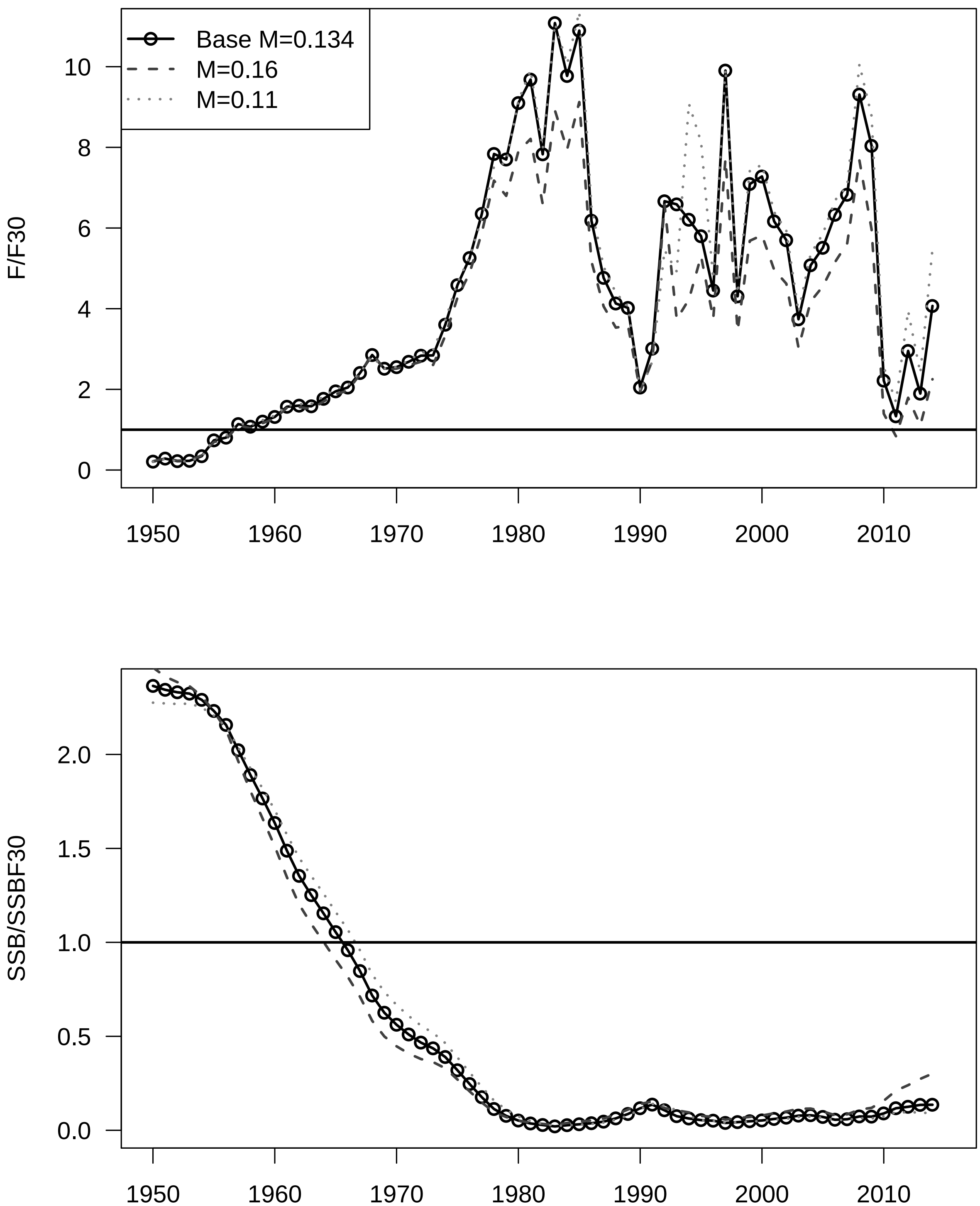


Figure 42. Sensitivity to steepness (sensitivity run S11). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $SSB_{F30\%}$.

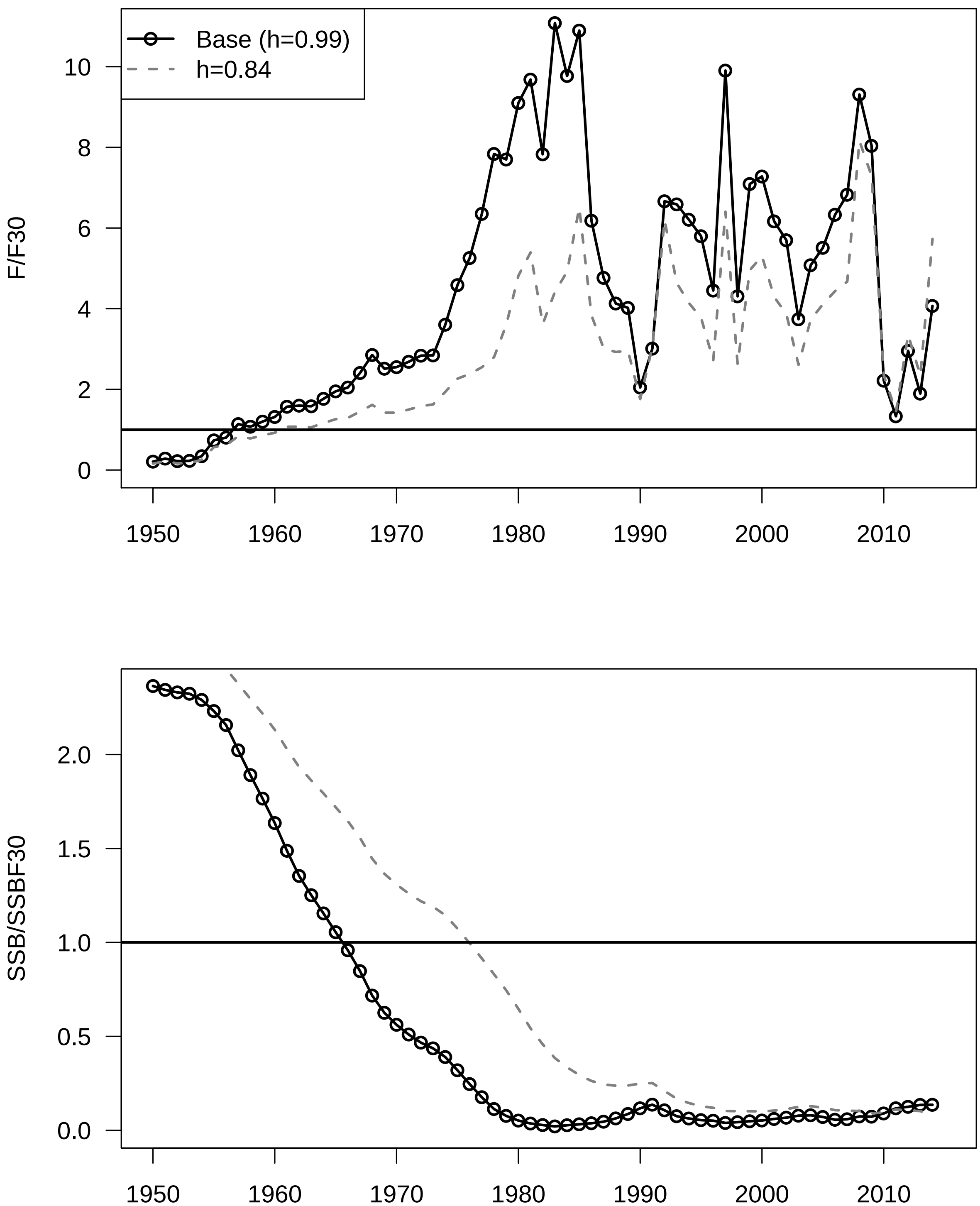


Figure 43. Sensitivity to start year (1978 compared to 1950) (sensitivity run S26). Top panel: Ratio of F to $F_{30\%}$. *Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{F30\%}$.

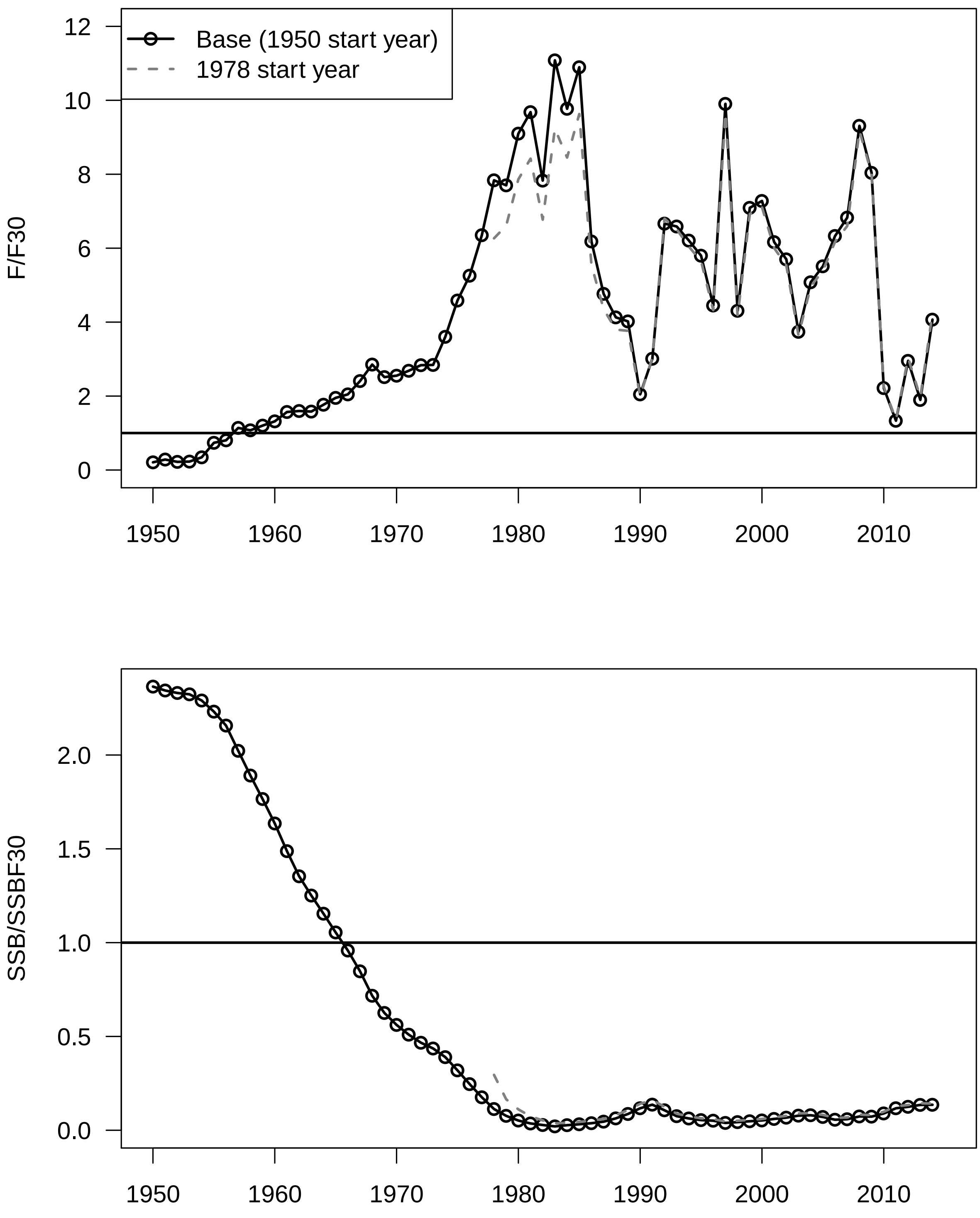


Figure 44. Sensitivity to aging error matrix (sensitivity run S13). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

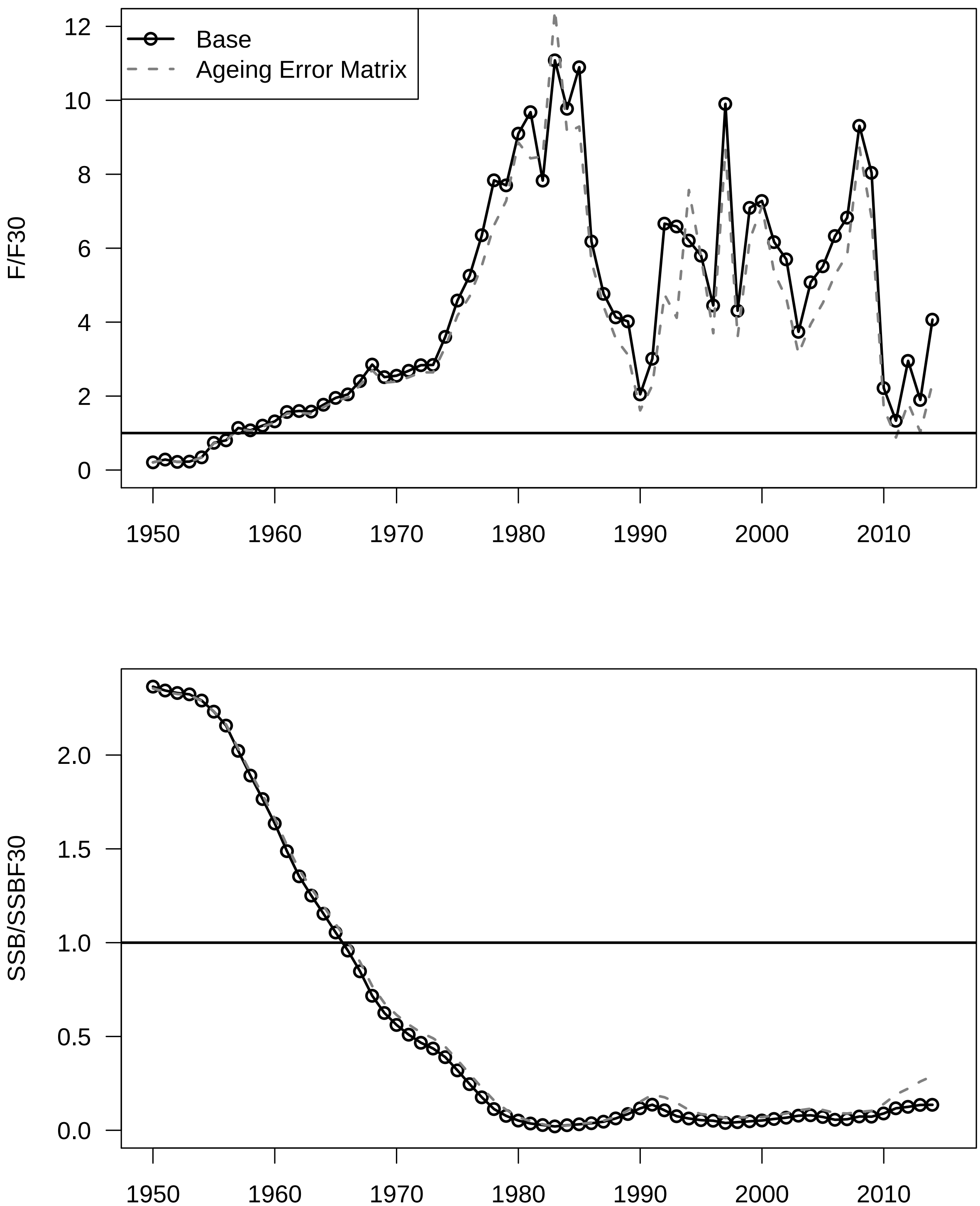
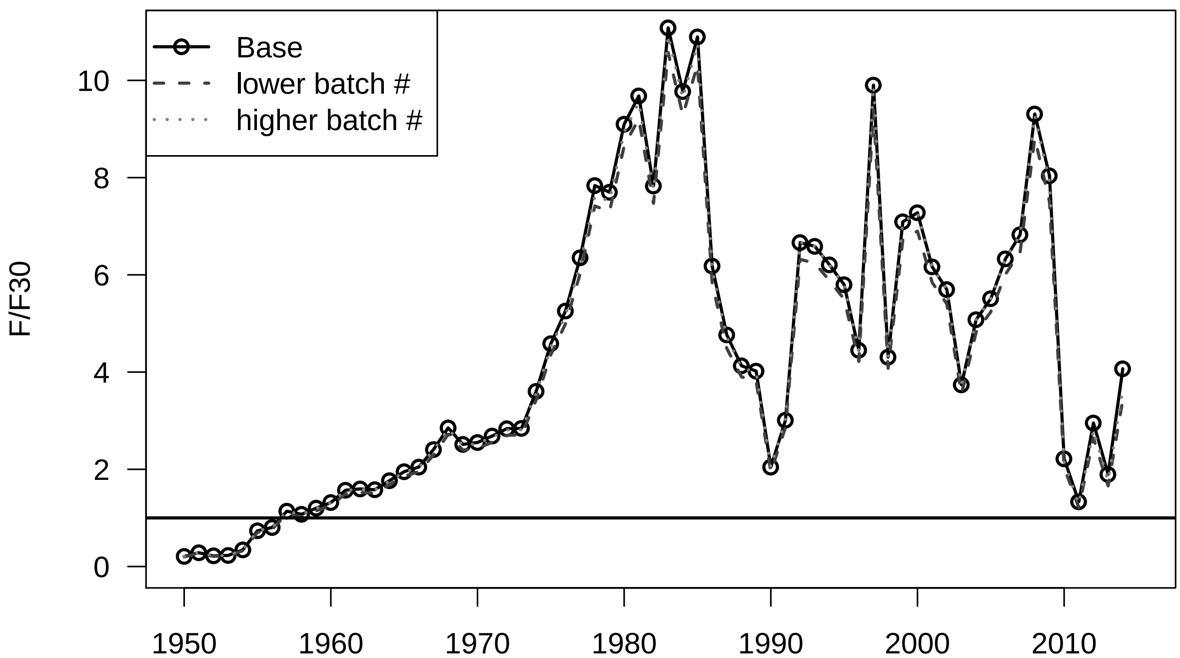


Figure 45. Sensitivity to batch number (sensitivity runs S14 and S15). Top panel: Ratio of F to $F_{30\%}$*. Bottom panel: Ratio of* SSB *to* $SSB_{F30\%}$.



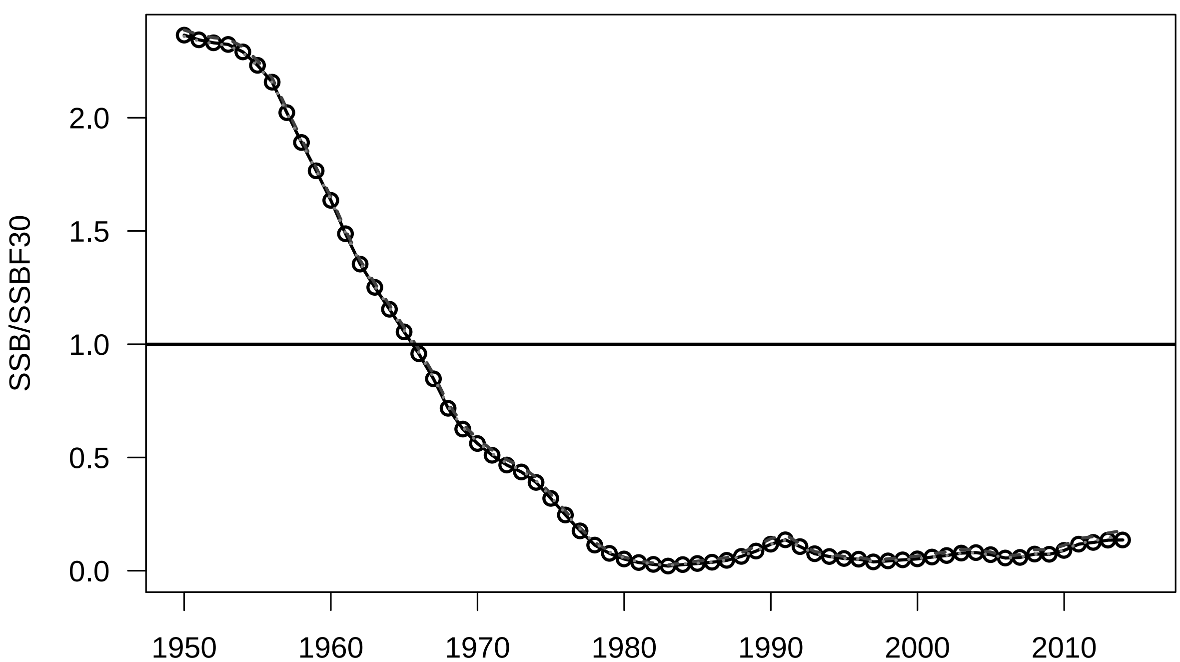
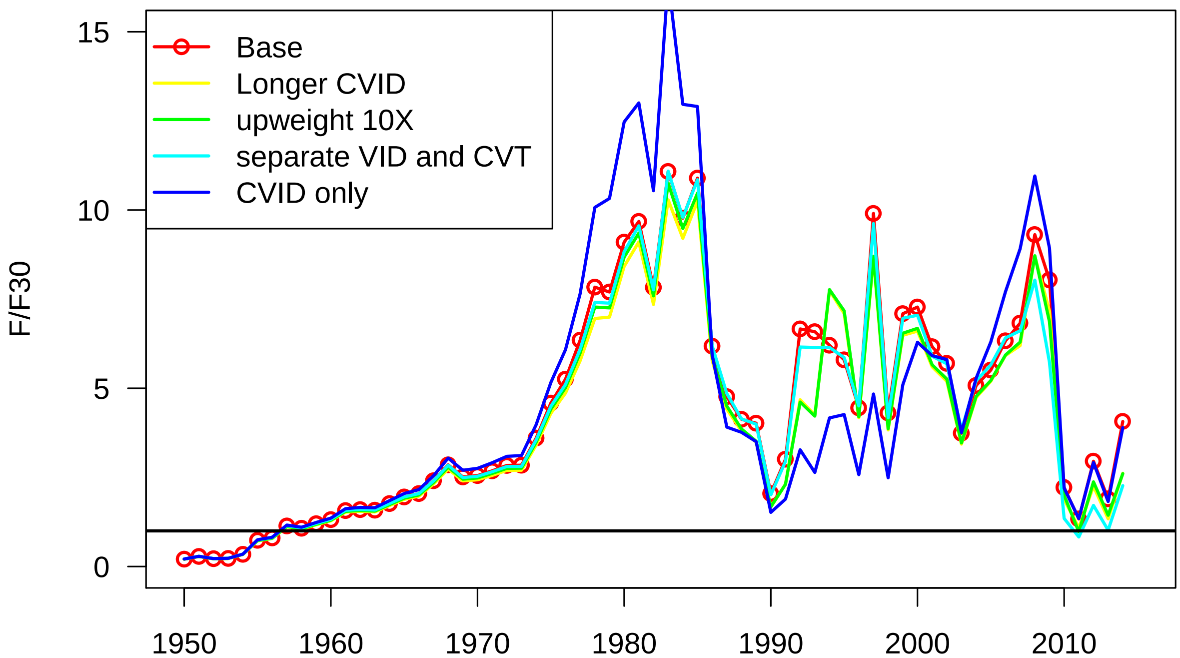


Figure 46. Sensitivity to various changes to SERFS video and trap indices (sensitivity runs S2, S9, S22 and S23). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.



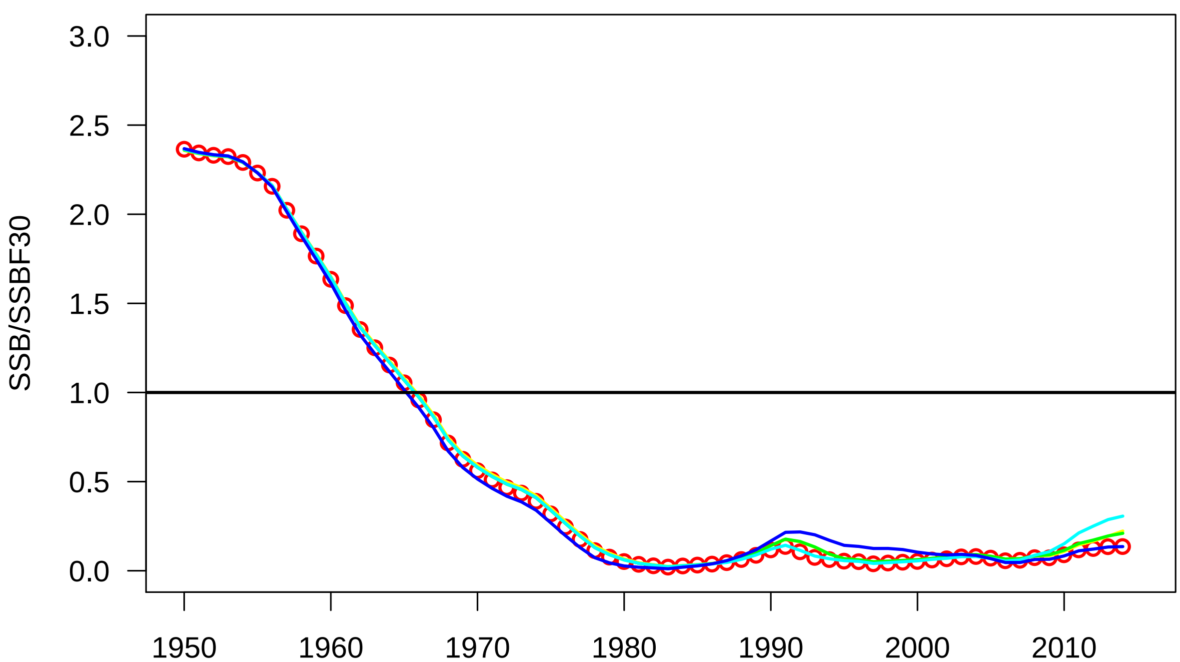


Figure 47. Sensitivity to discard mortality (sensitivity run S7 and S8). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $SSB_{F30\%}$.

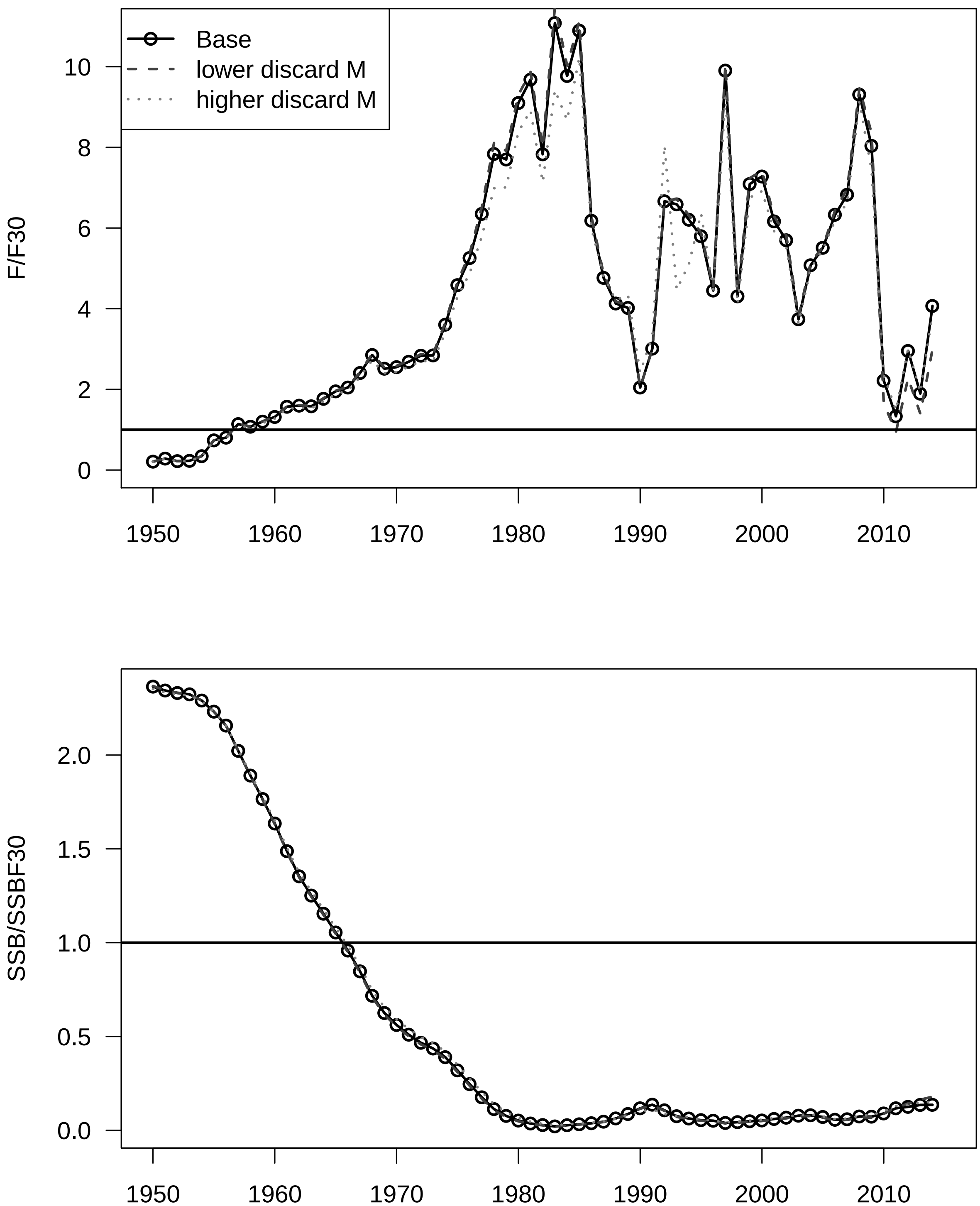


Figure 48. Sensitivity to dome-shaped selectivity for commercial handline (sensitivity run S21). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

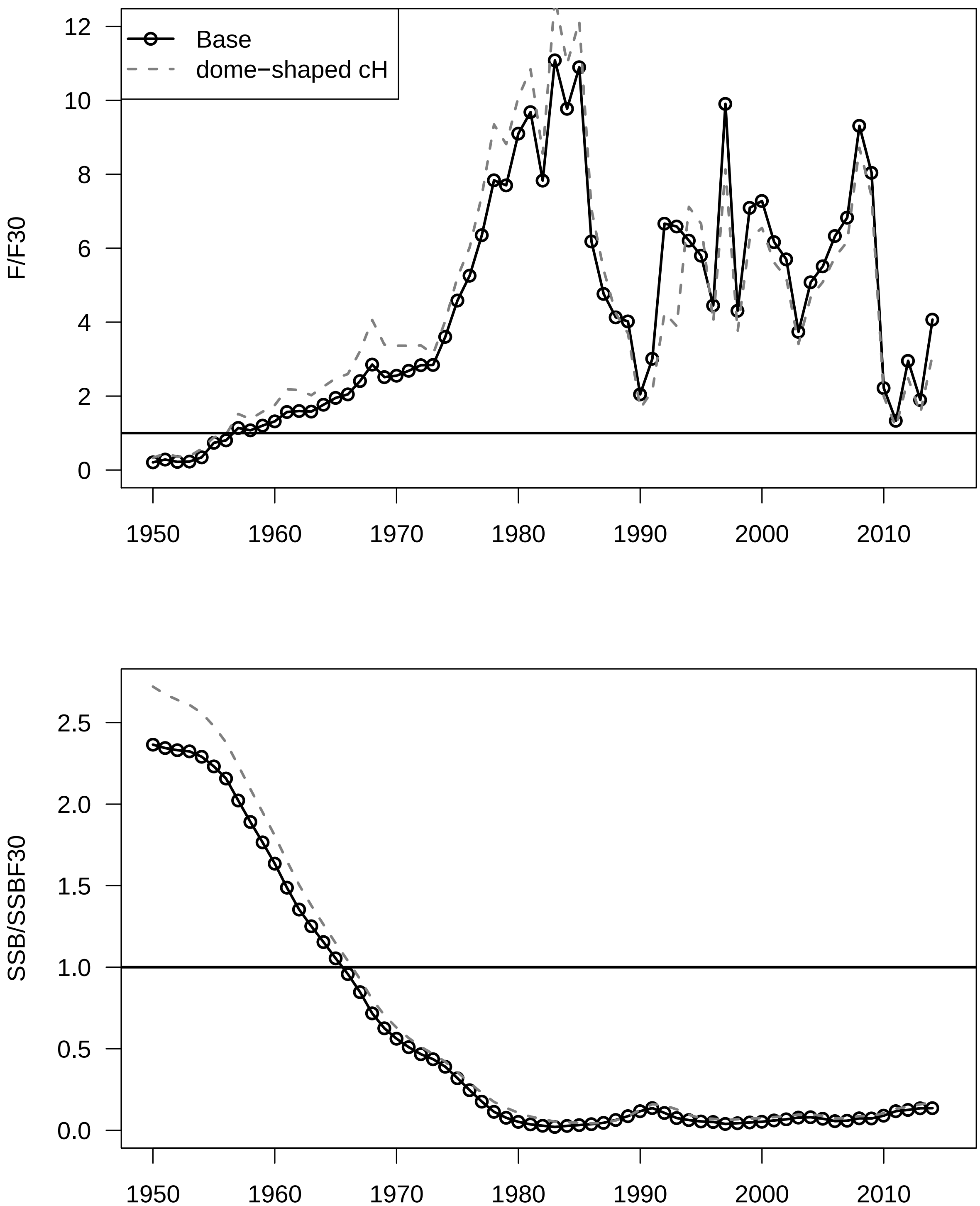


Figure 49. Sensitivity to various changes to fishery dependent indices (sensitivity runs S1, S3, S4, and S25). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

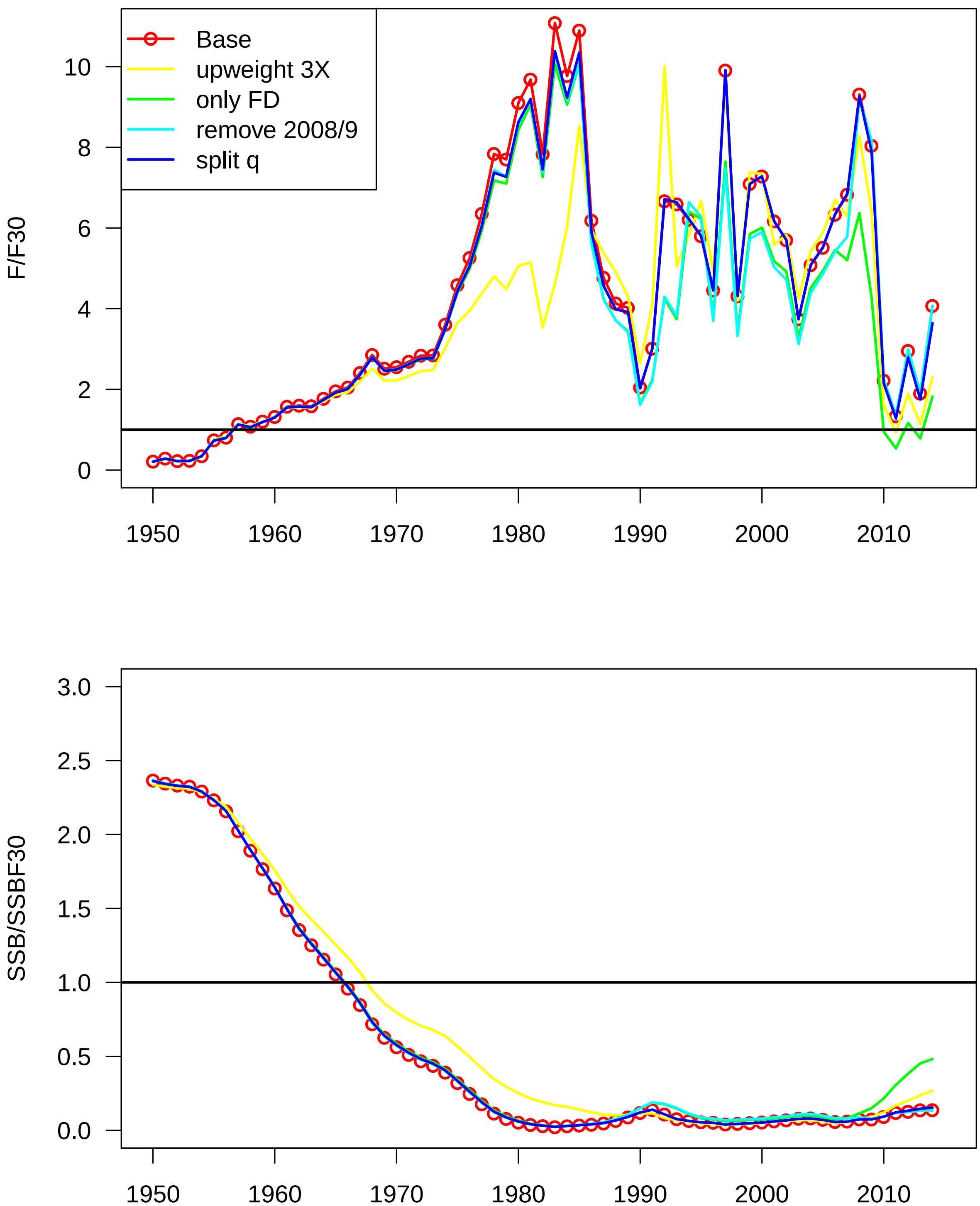


Figure 50. Sensitivity to not fixing selectivities (sensitivity run S27). Top panel: Ratio of F to $F_{30\%}$*. Bottom panel: Ratio of* SSB *to* $SSB_{F30\%}$.

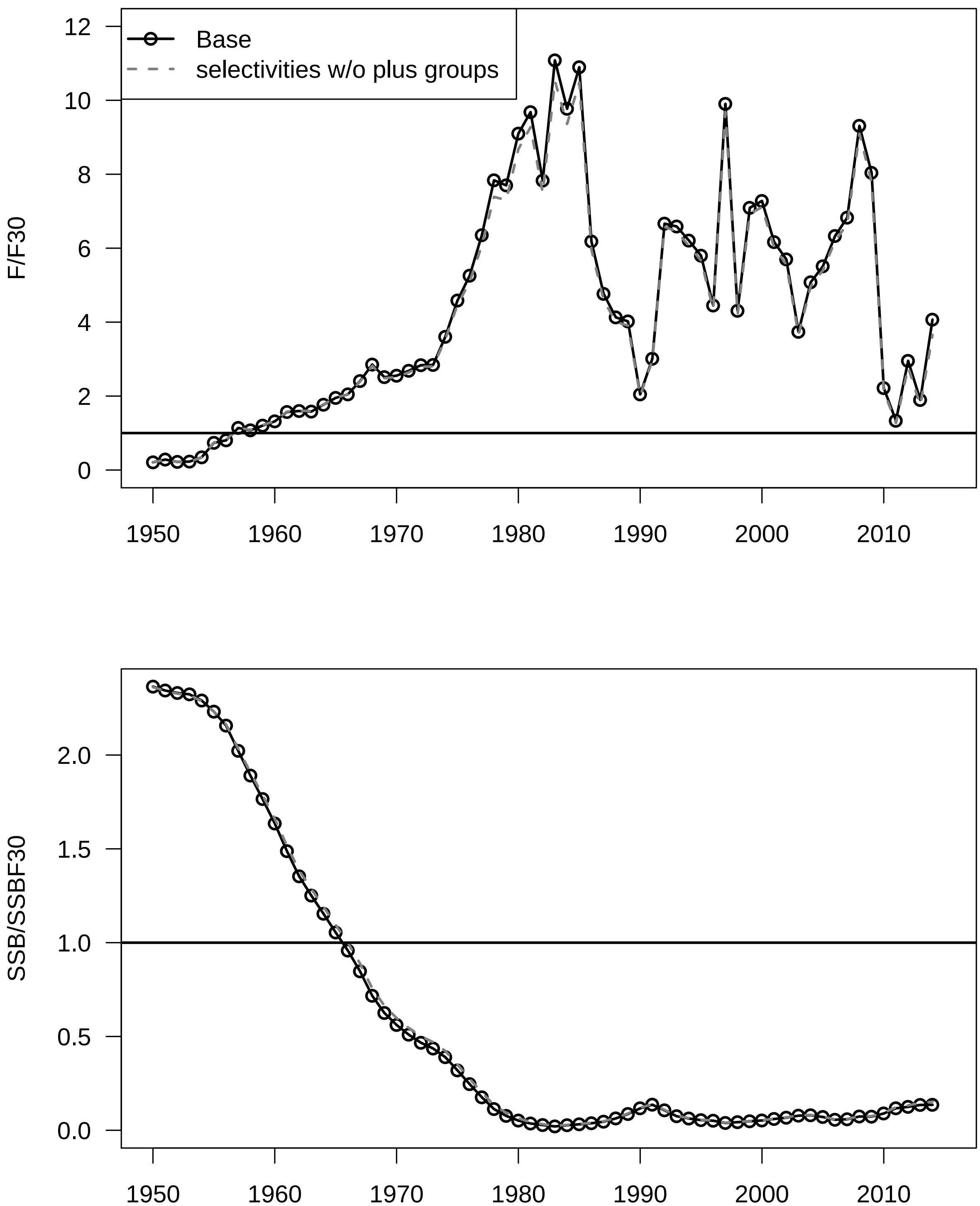


Figure 51. Sensitivity to dropping or truncating headboat discard index (sensitivity runs S12 and S16). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB_{F30\%}}$.

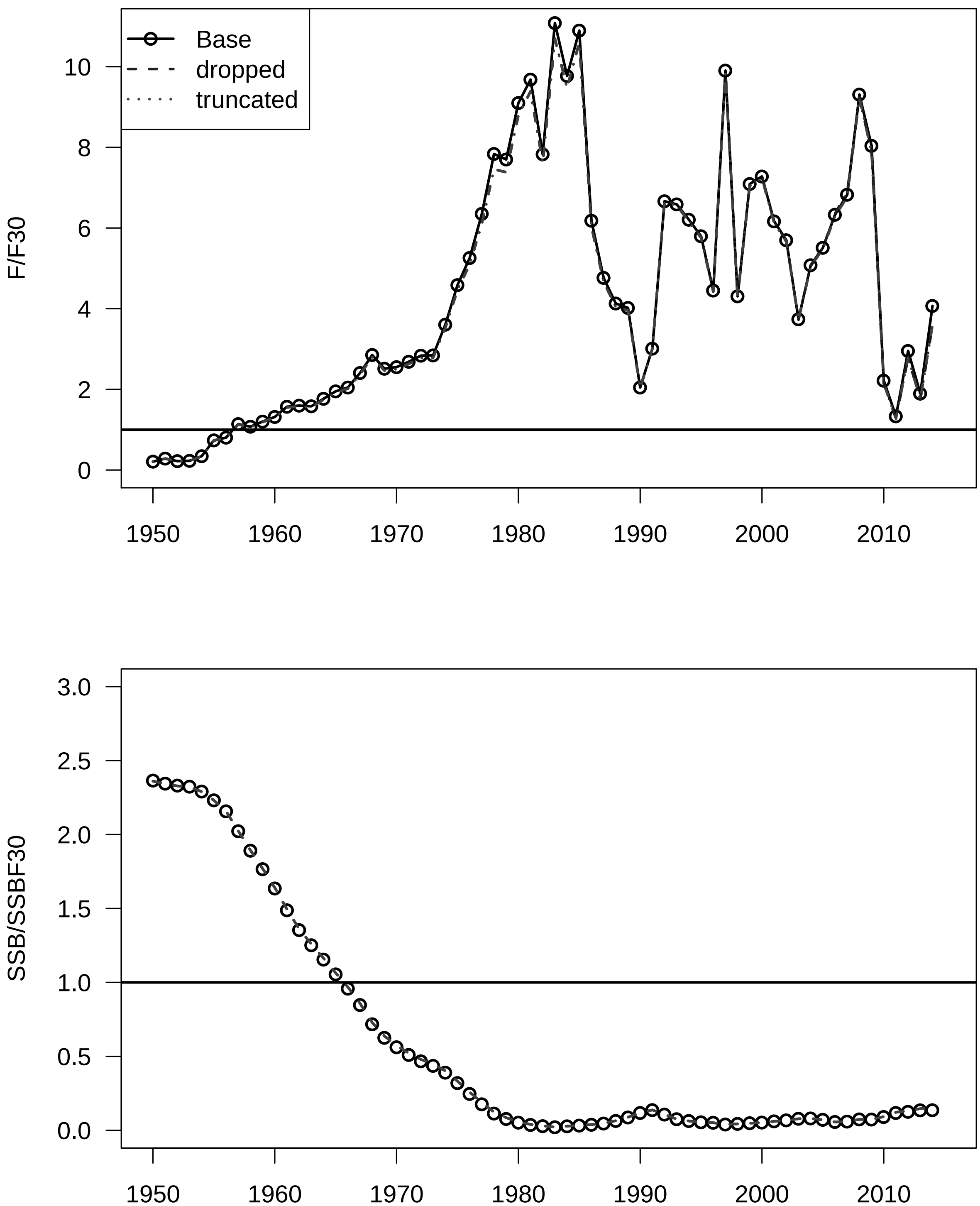


Figure 52. Sensitivity to higher or lower estimates of landings and discards (sensitivity runs S17–S20). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB to $SSB_{F30\%}$.

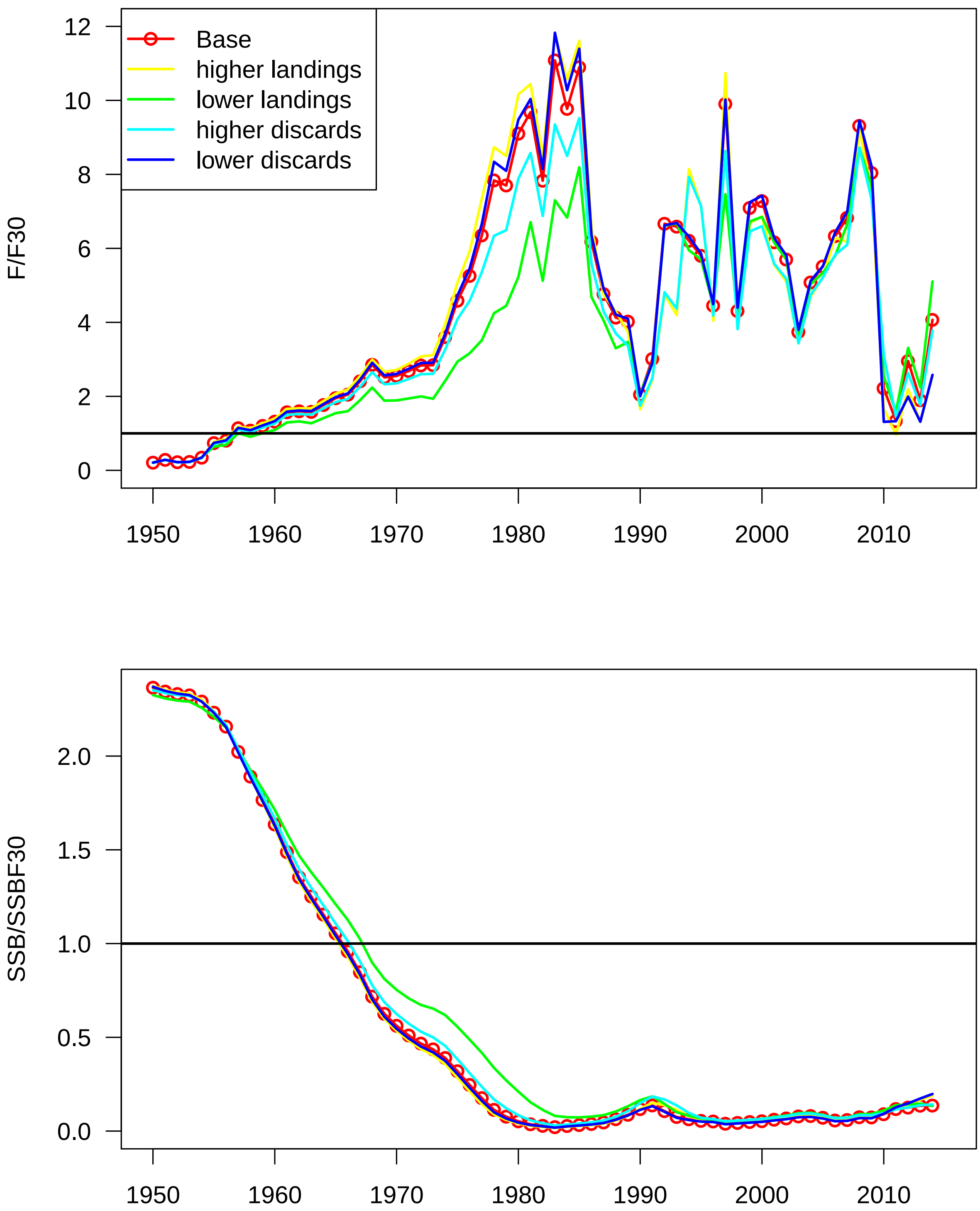
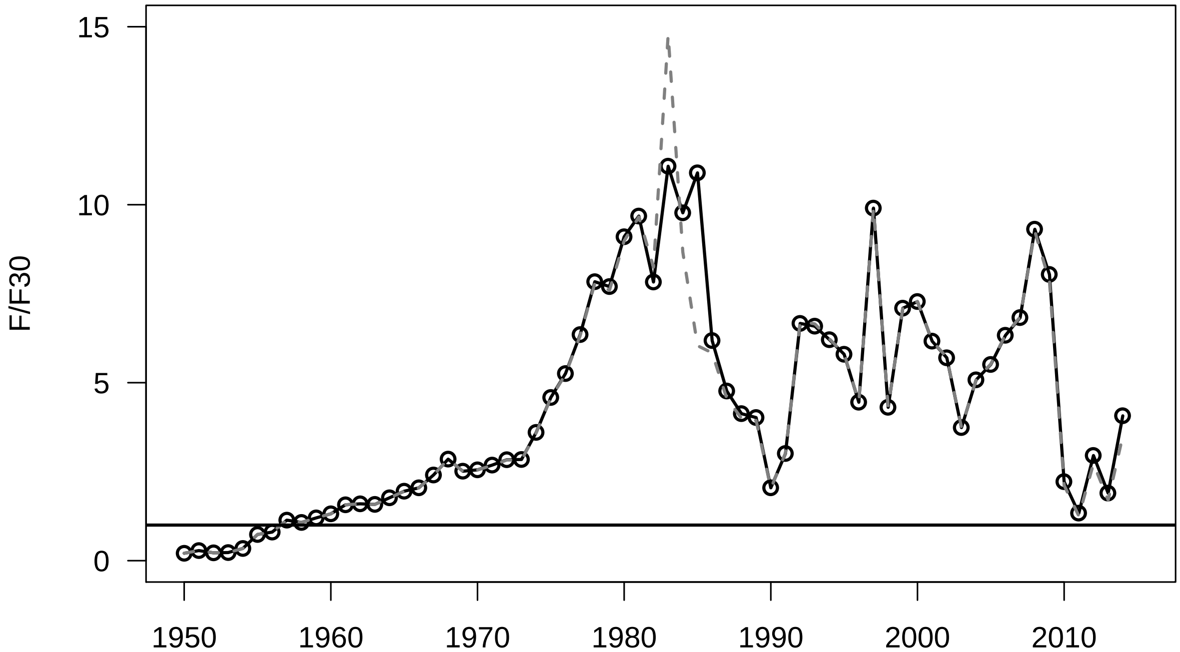


Figure 53. Sensitivity to smoothed 1984 and 1985 MRIP landings (sensitivity run S10). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.



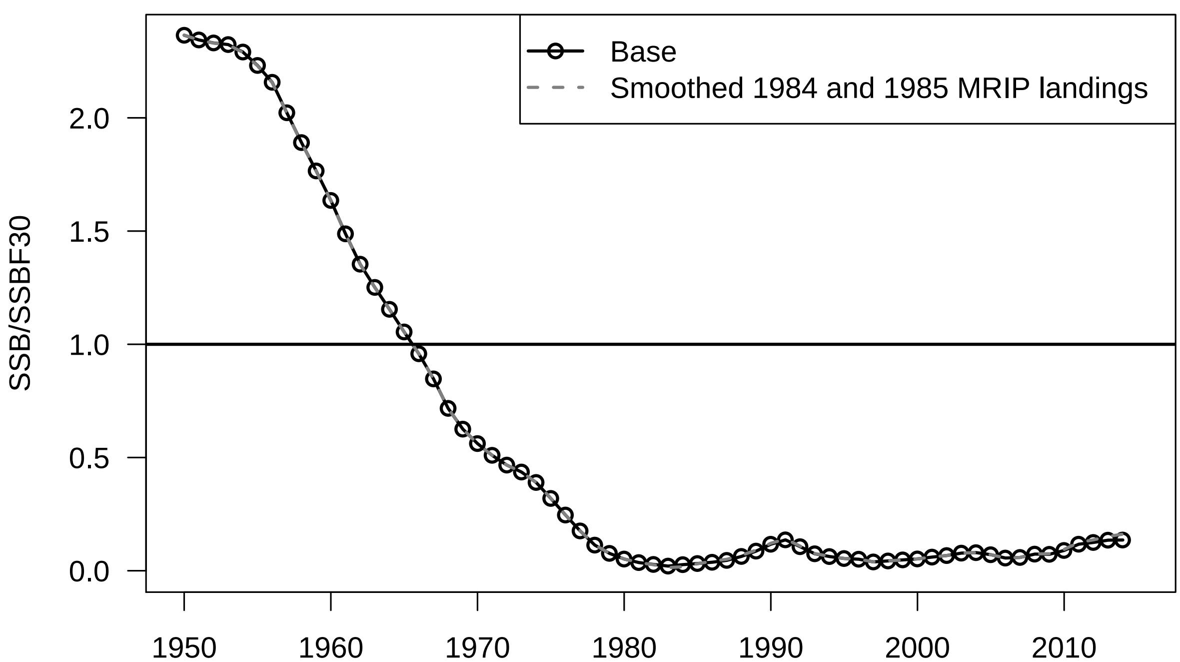


Figure 54. Sensitivity to continuity assumptions from SEDAR 24 (sensitivity run S24). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $SSB_{F30\%}$.

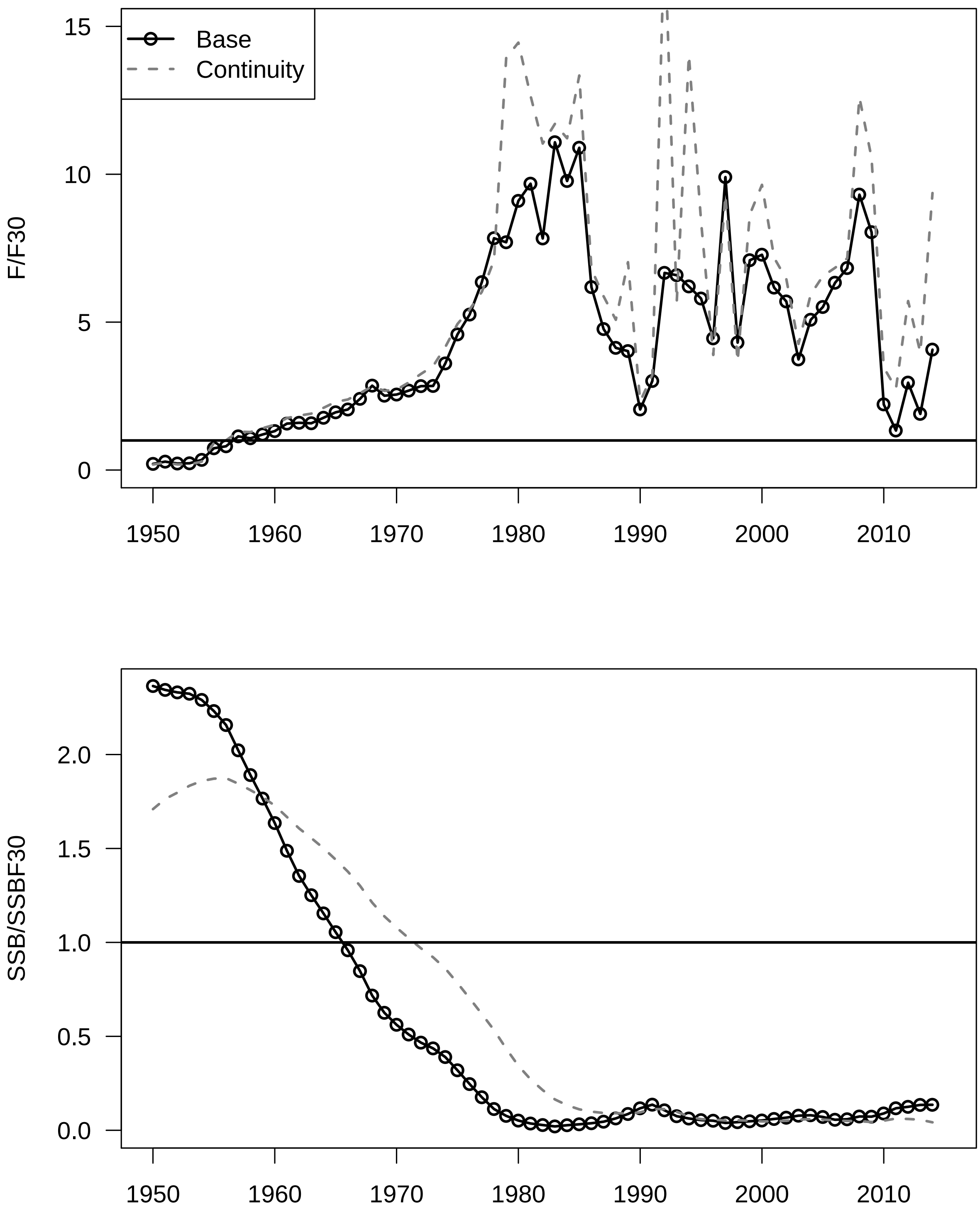


Figure 55. Phase plot of terminal status indicators from sensitivity runs of the Beaufort Assessment Model.

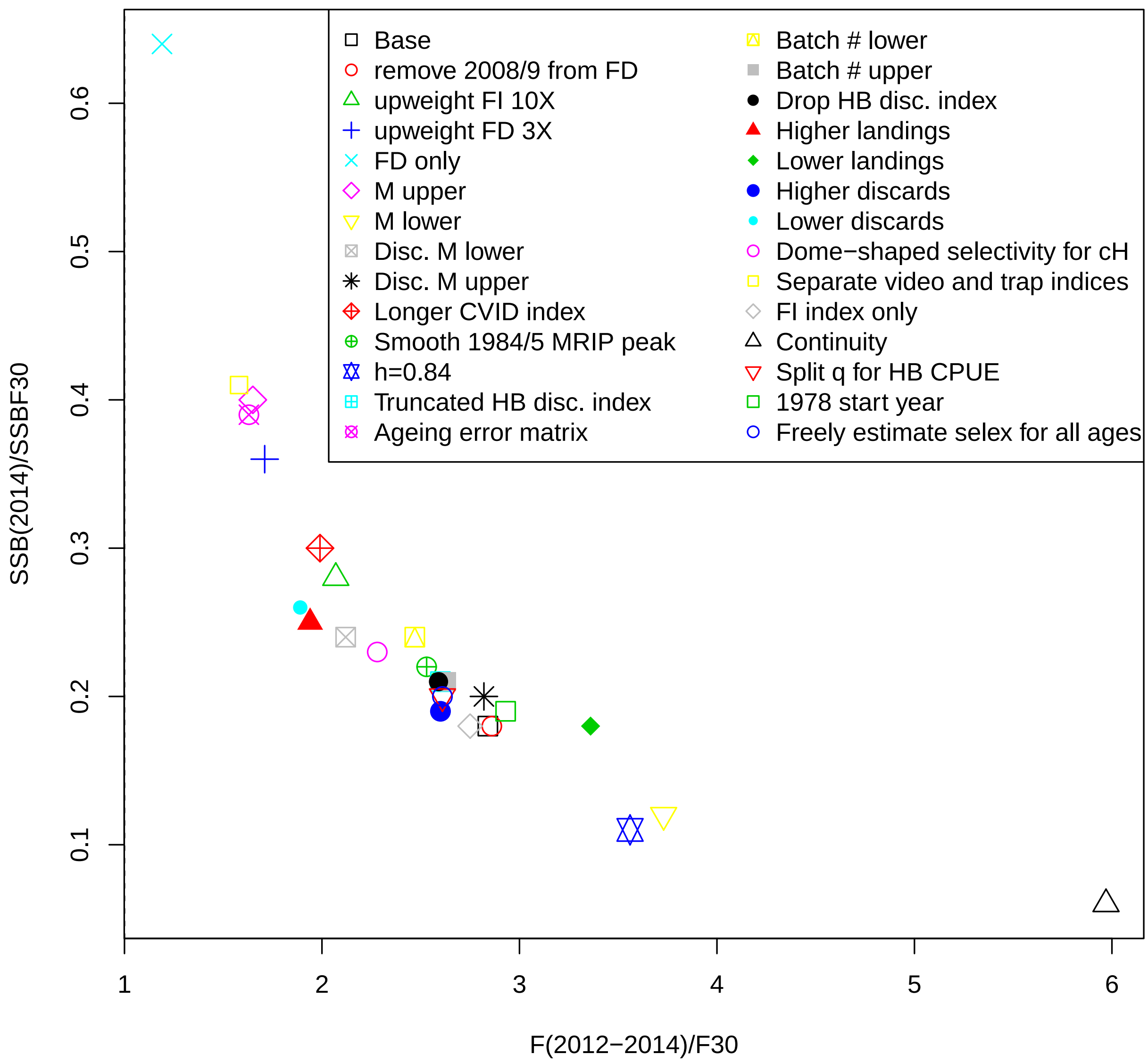


Figure 56. Retrospective analyses. Sensitivity to terminal year of data. Top panel: Fishing mortality rates. Middle panel: Recruits. Bottom panel: Spawning biomass. Closed circles show terminal-year estimates. Imperceptible lines overlap results of the base run.

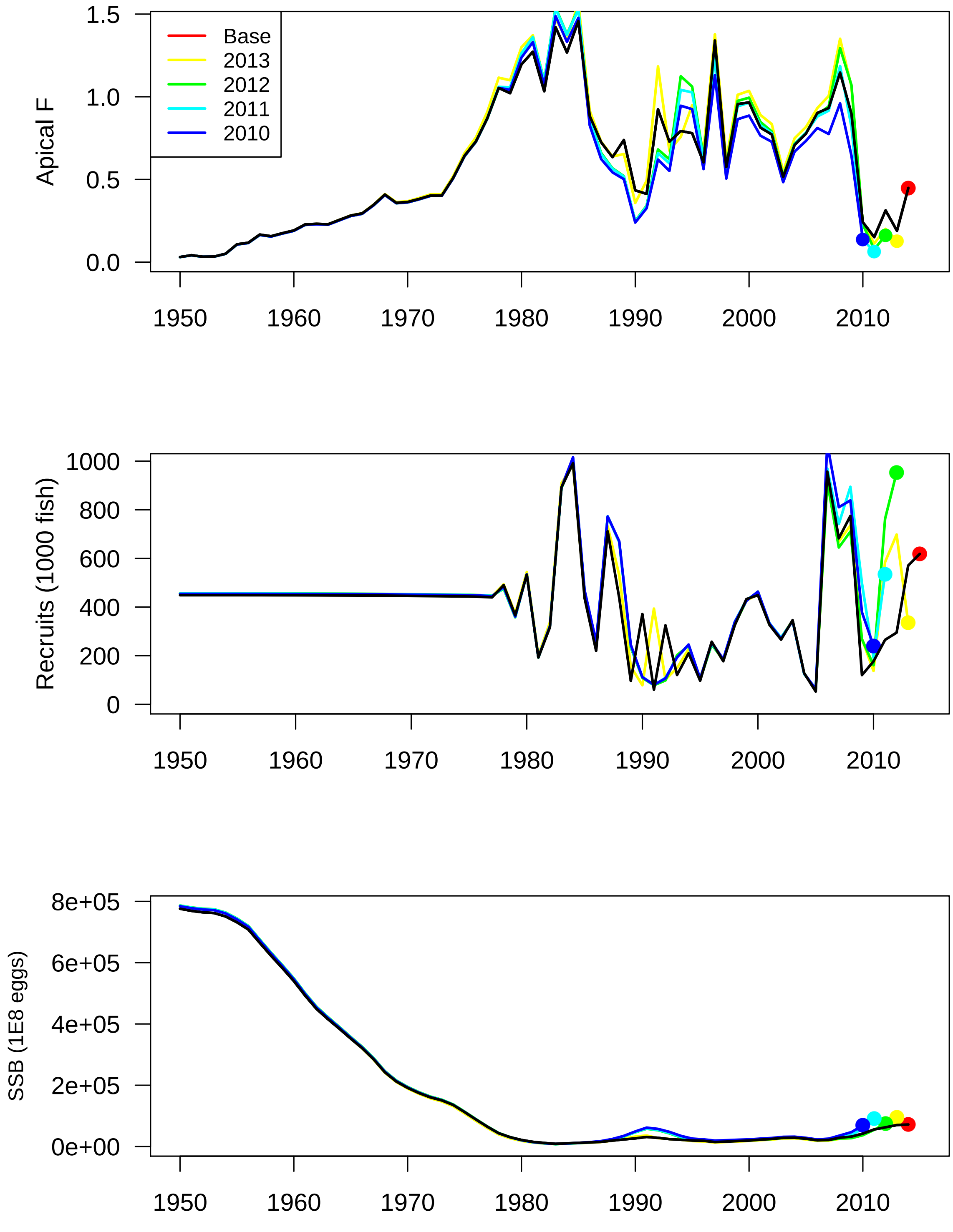


Figure 57. Projection results under scenario 1—fishing mortality rate at $F = 0$. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB_{F30\%}}$.

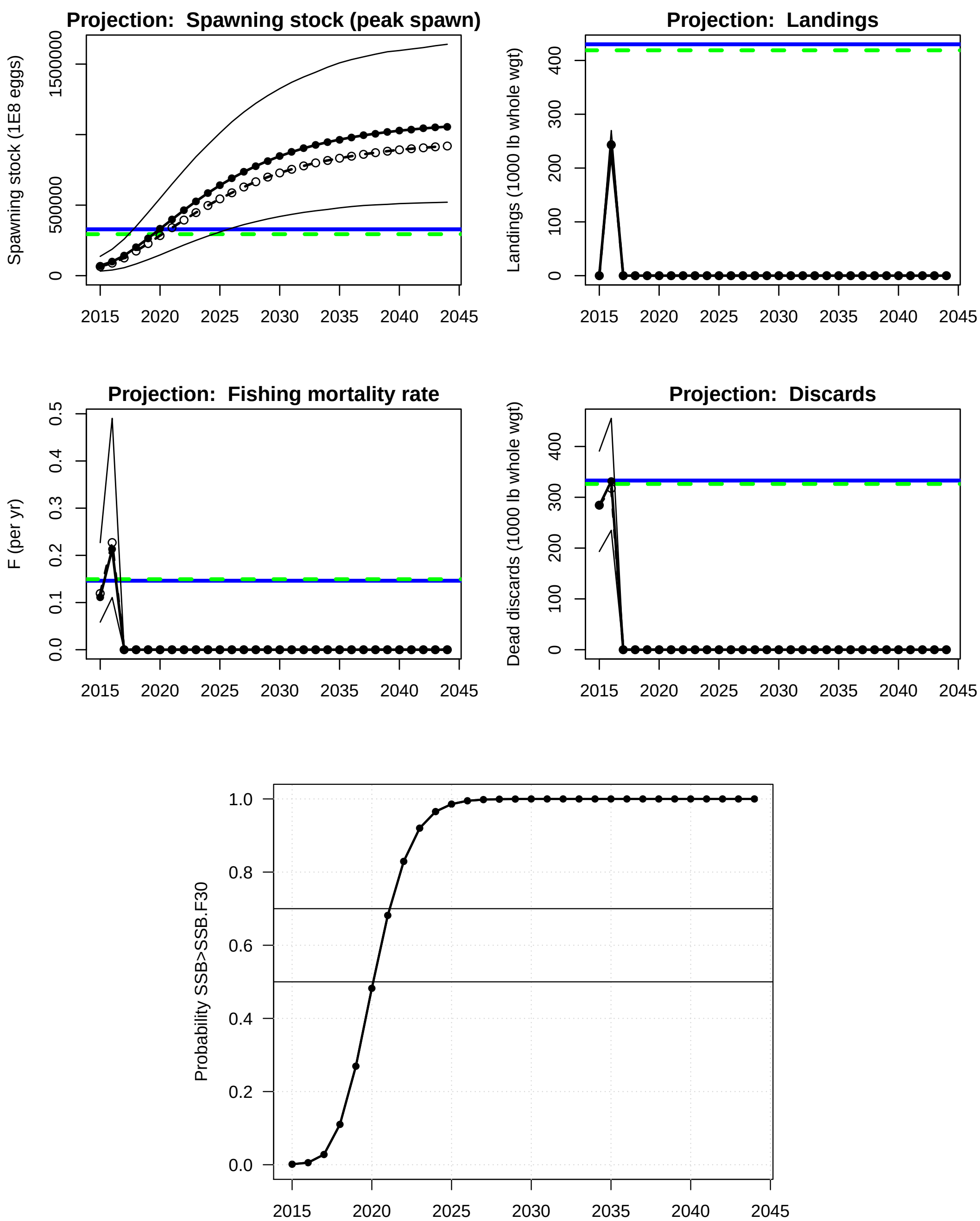


Figure 58. Projection results under scenario 2—fishing mortality rate at $F = F_{\text{current}}$. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\text{SSB}_{\text{F30\%}}$.

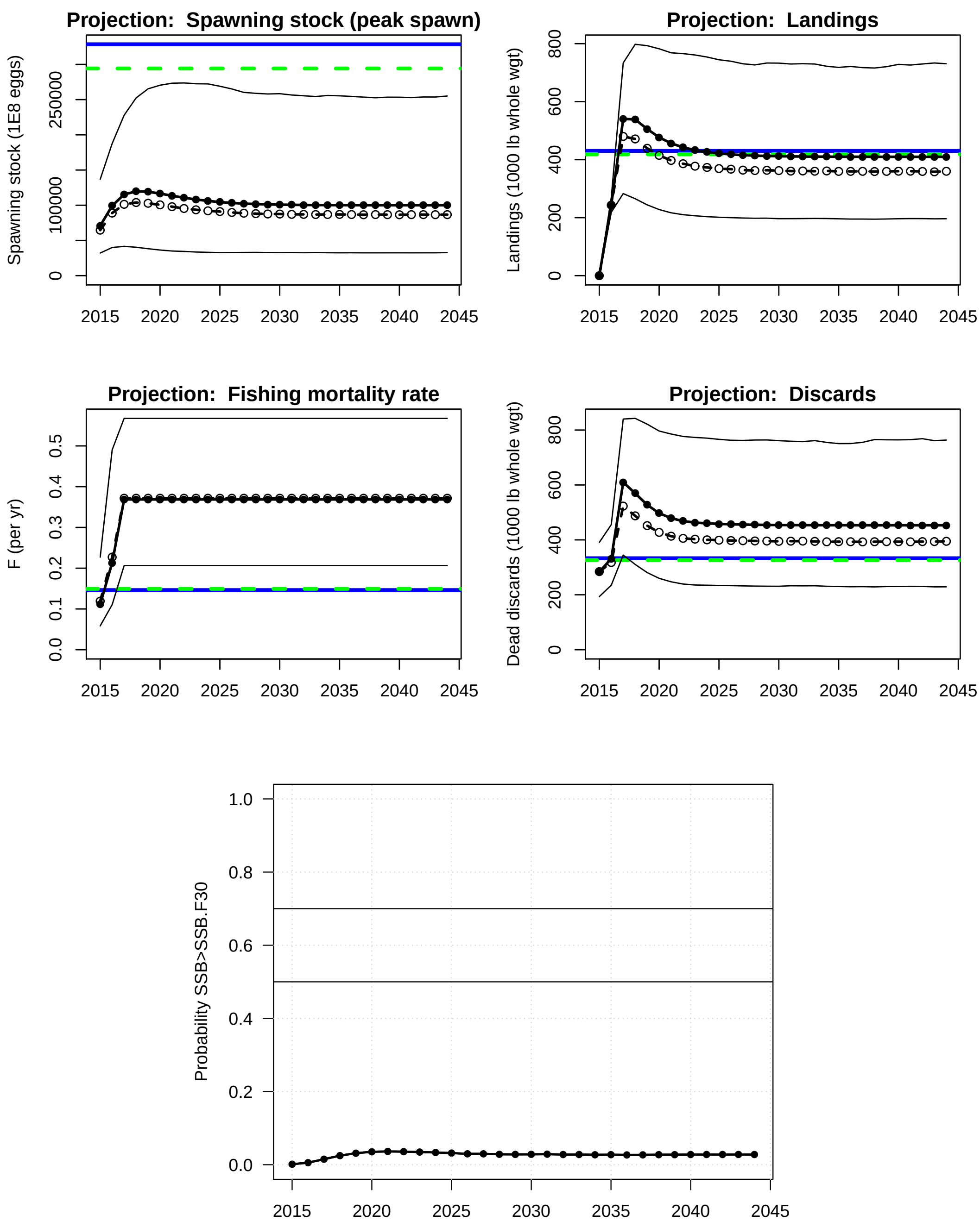


Figure 59. Projection results under scenario 3—fishing mortality rate at $F = F_{30\%}$. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB_{F30\%}}$.

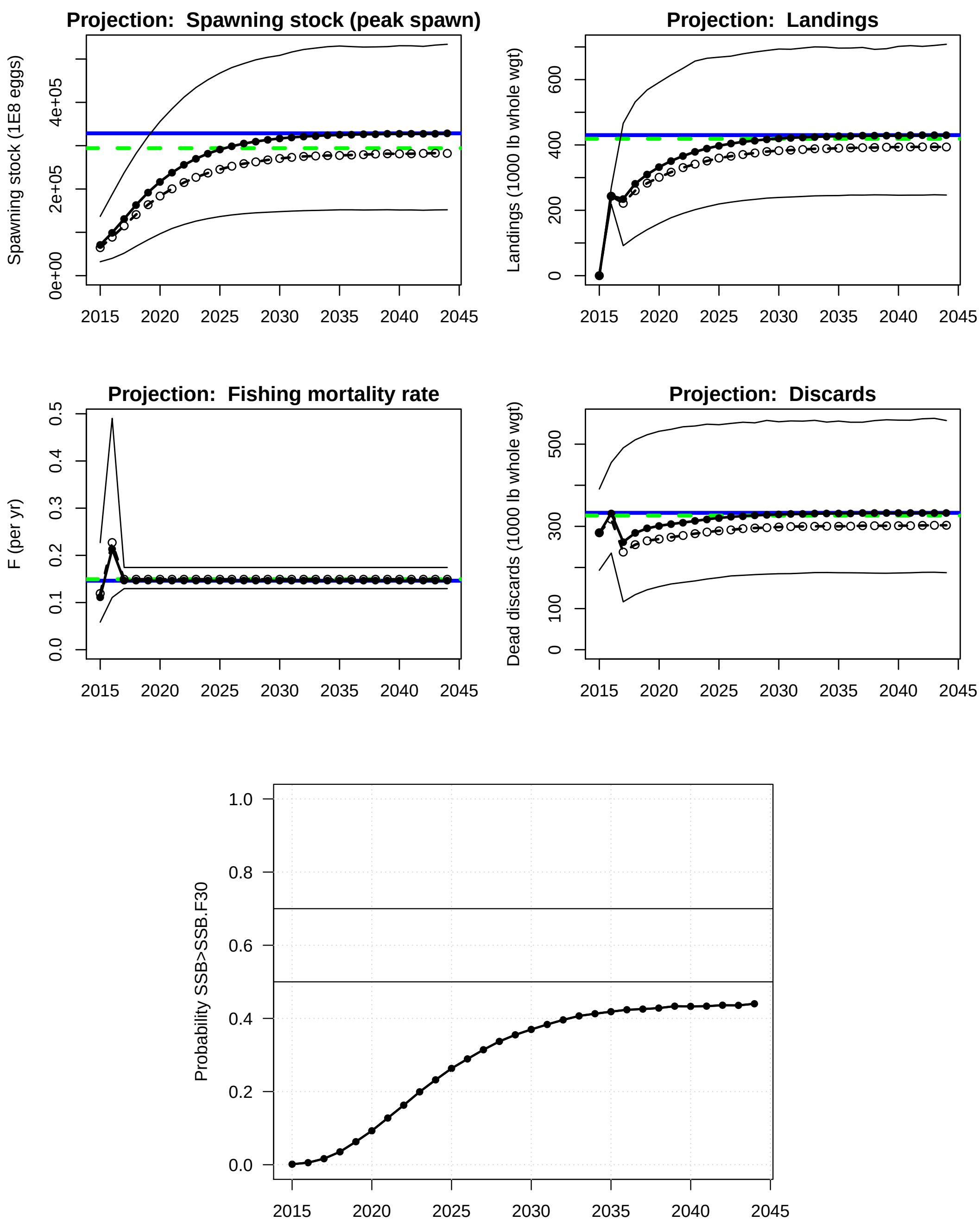


Figure 60. Projection results under scenario 4—fishing mortality rate at $F = 98\%F_{30\%}$. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F30\%}}$.

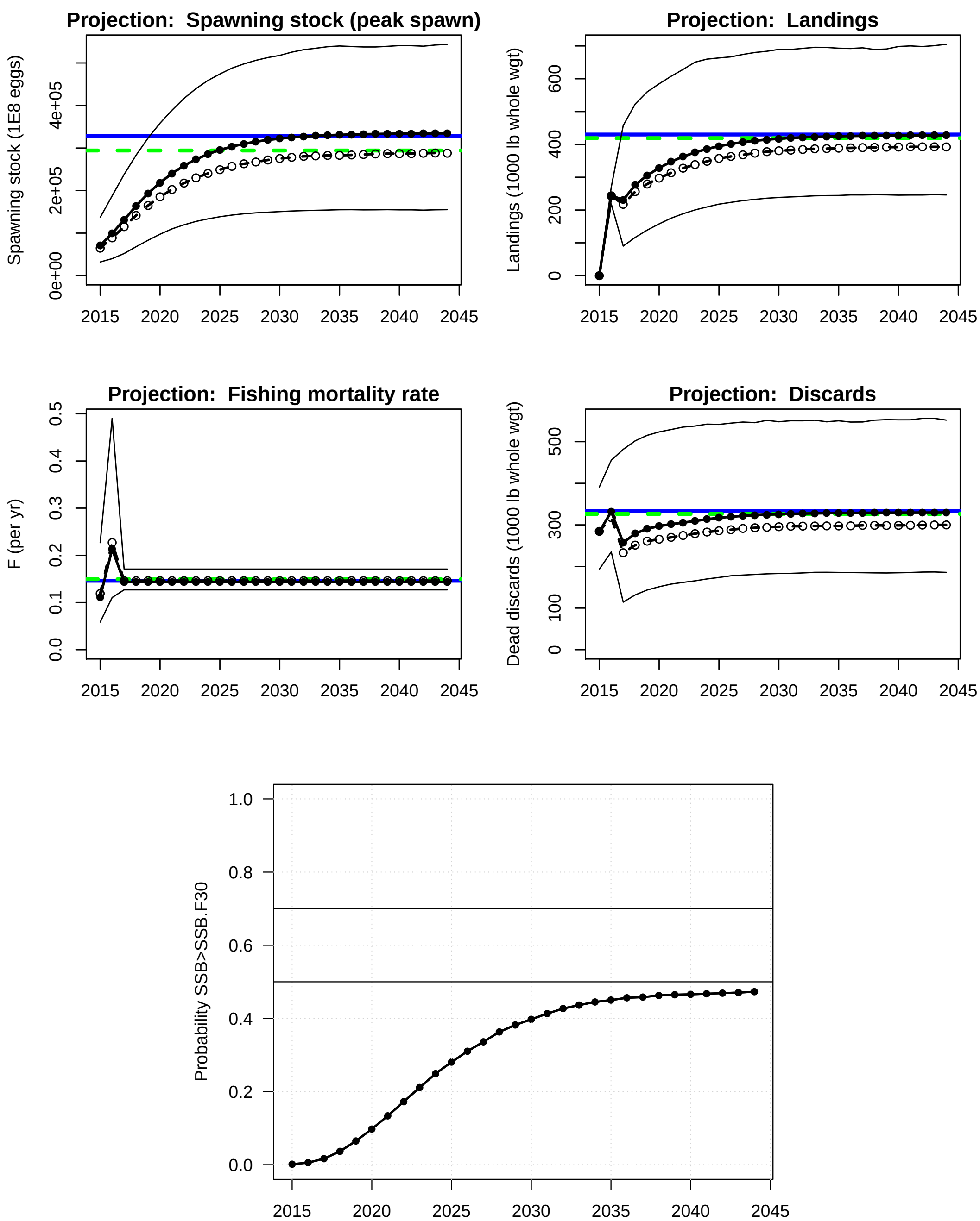


Figure 61. Projection results under scenario 5—fishing mortality rate at $F = F_{\text{rebuild}}$, with rebuilding probability of 0.5 in 2044. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\text{SSB}_{\text{F30\%}}$.

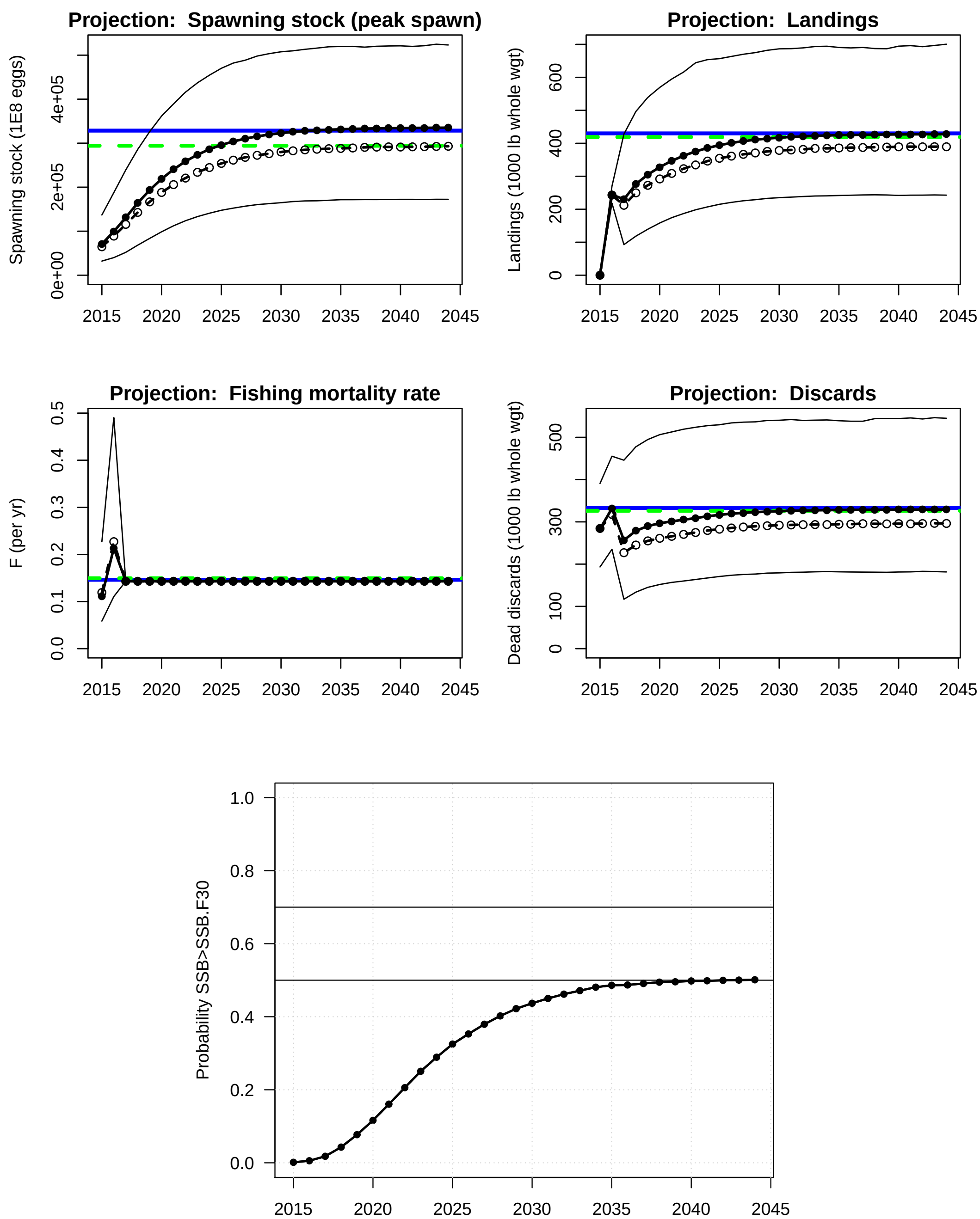


Figure 62. Projection results under scenario 6—fishing mortality rate set to average discard mortality rate only. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F30\%}}$.

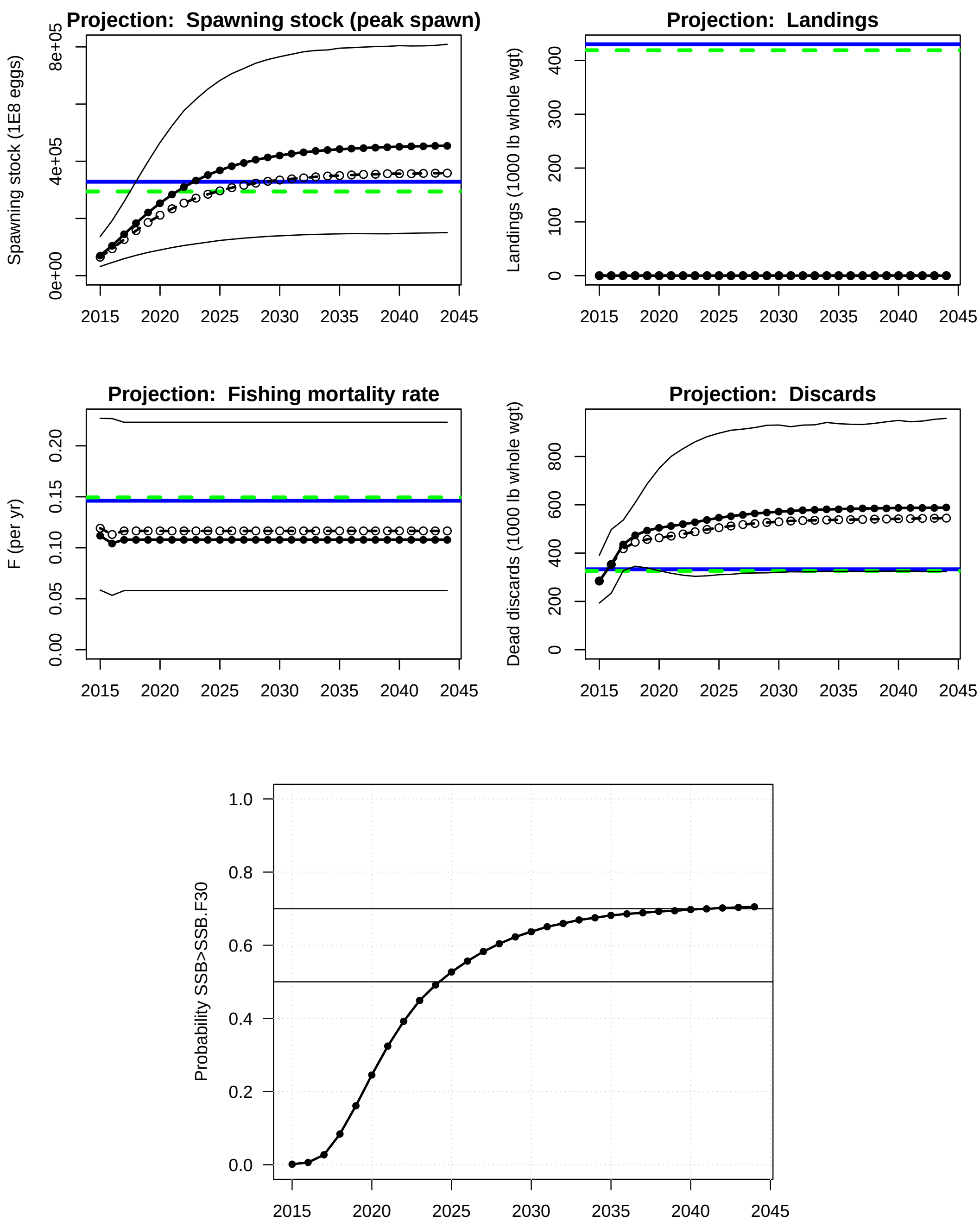


Figure 63. Abundance indices observed (obs.) and predicted (pred.) by the ASPIC surplus production model, and observed total removals (100,000 lbs) for South Atlantic red snapper. Comm = commercial, HB = headboat, HB.at.sea = headboat at sea discards, CVID = combined chevron trap-video index.

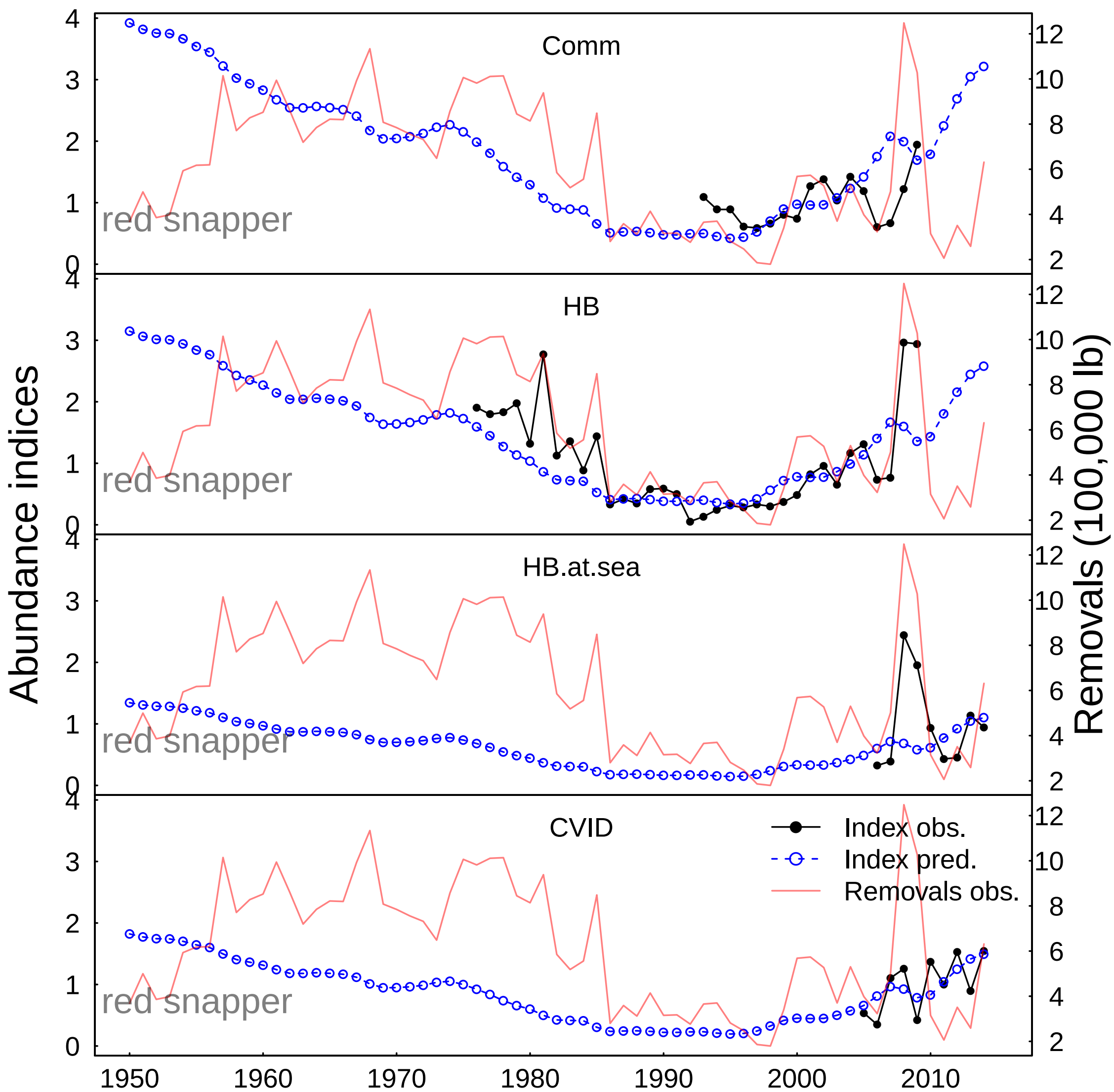


Figure 64. Prior distributions (blue shapes) and estimated parameter values (vertical black lines) for the South Atlantic red snapper ASPIC surplus production model.

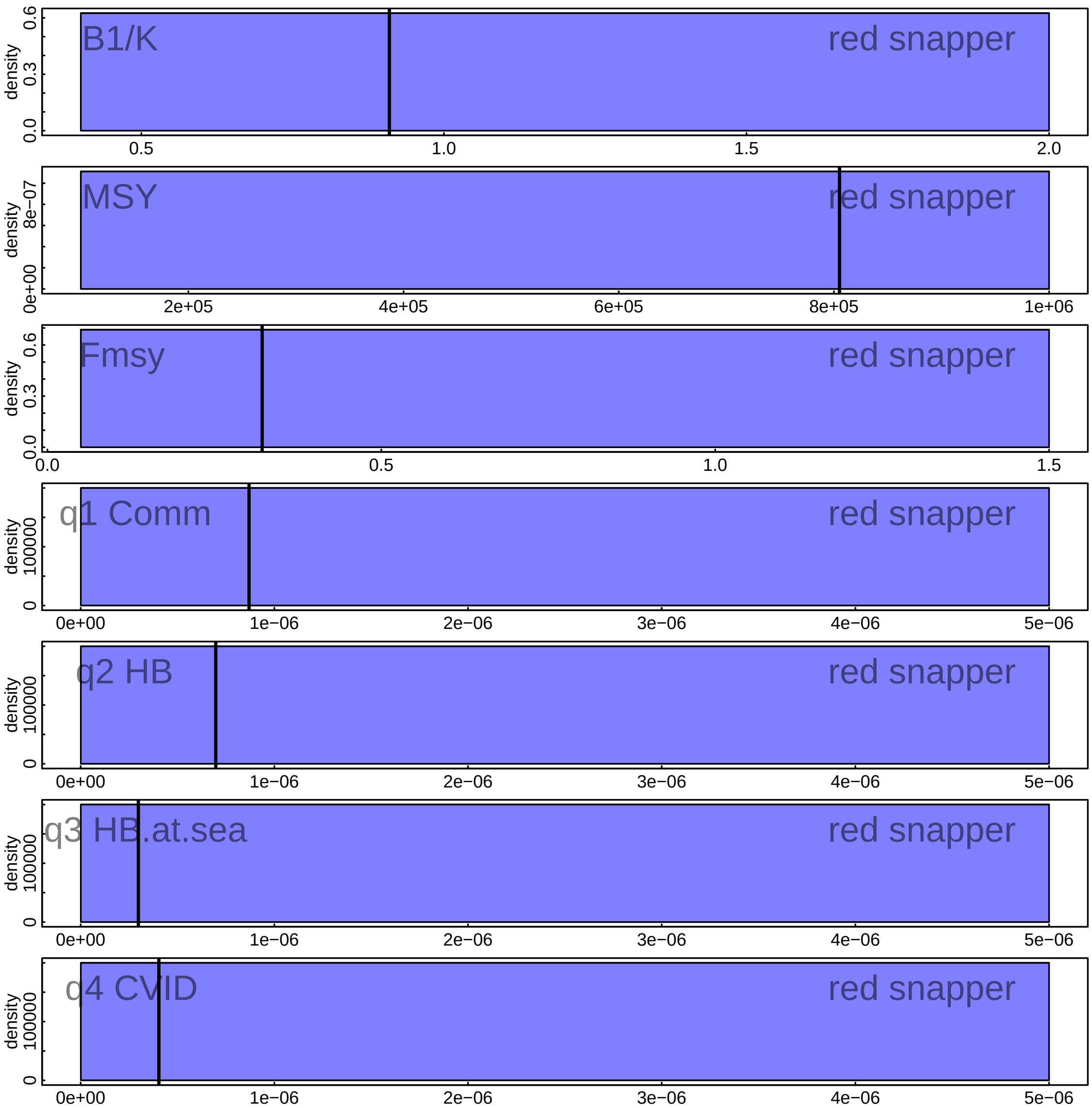


Figure 65. Bootstrap parameter values from ASPIC surplus production model run 320. Thick vertical lines represent ASPIC parameter estimates (solid) and 95% bootstrap percentile confidence intervals (dashed). Thin solid vertical lines are drawn at one in plots of F/F_{MSY} and B/B_{MSY} for reference.

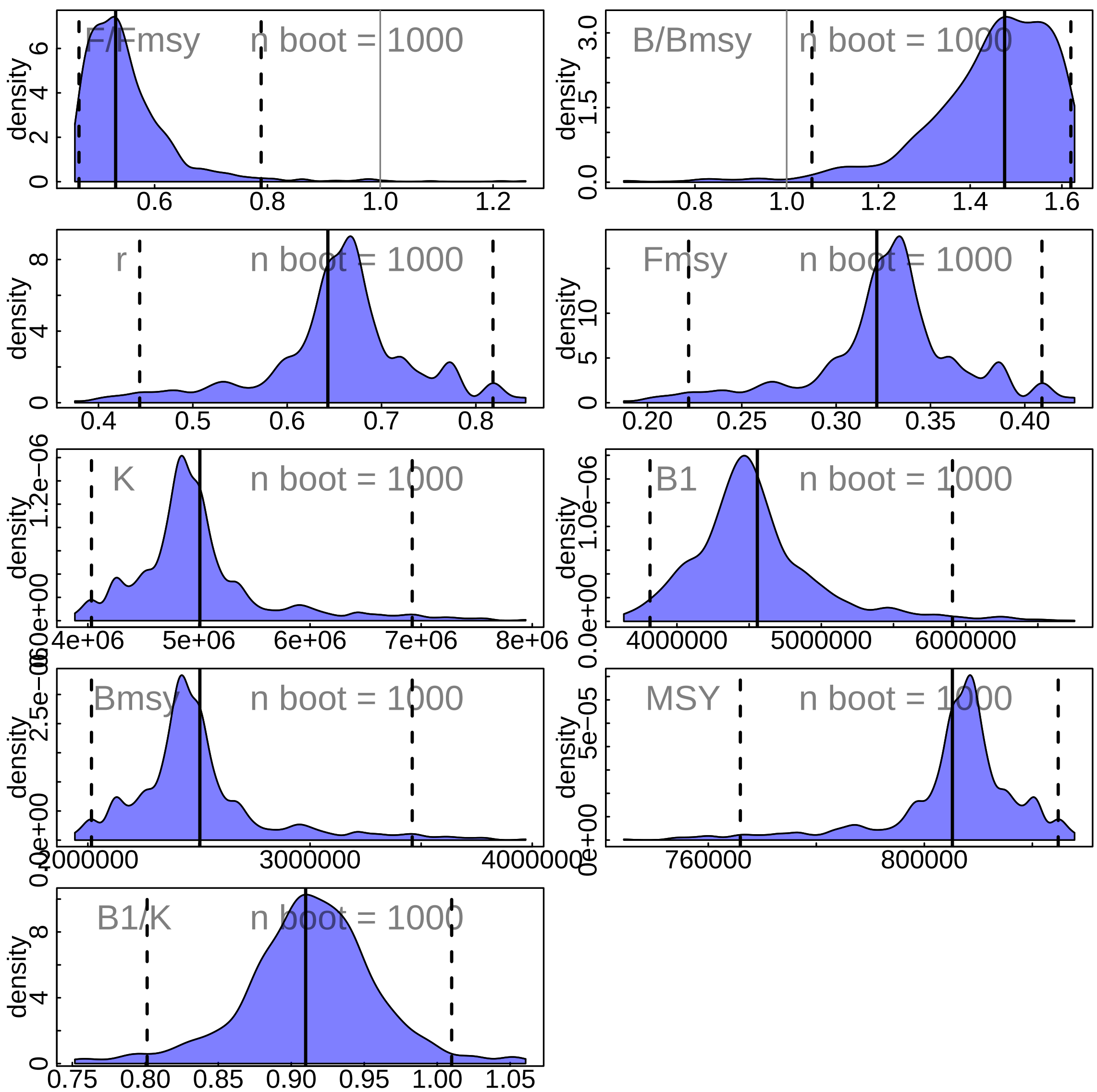
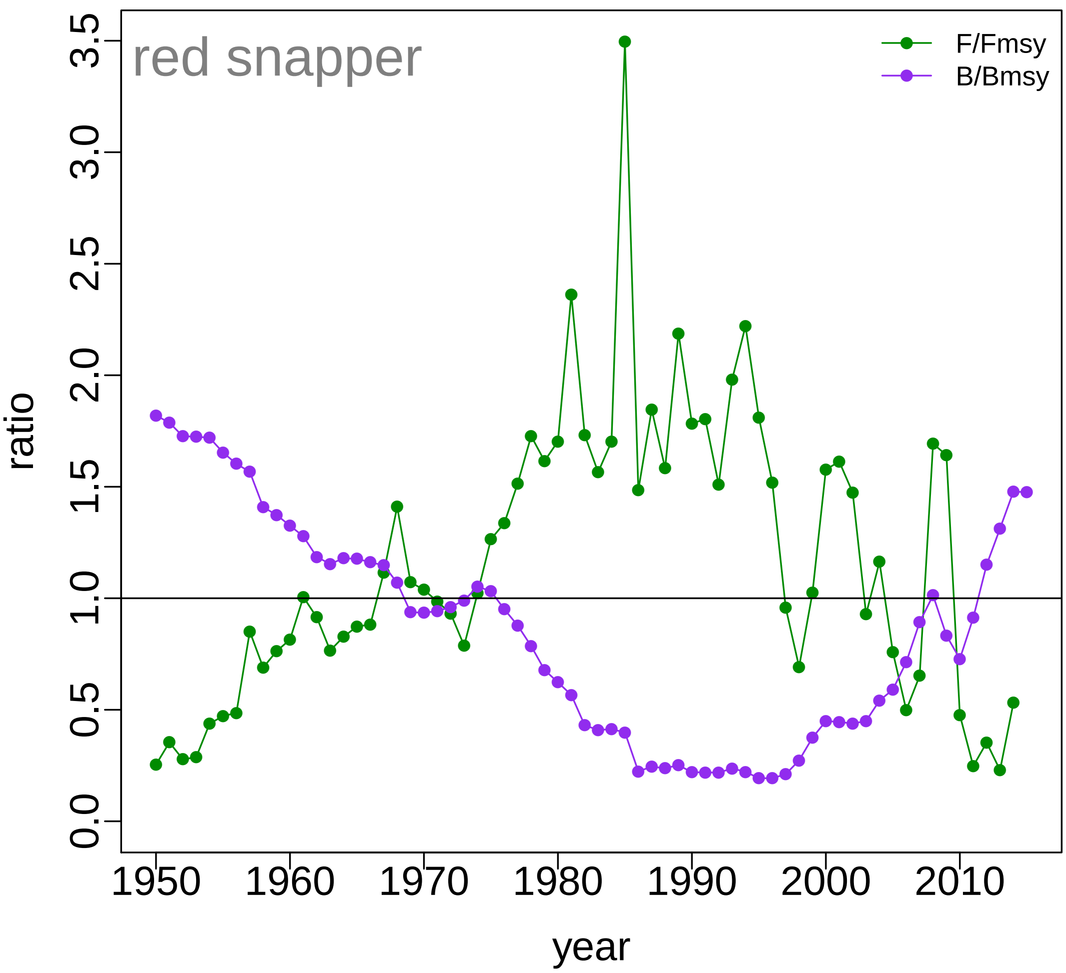


Figure 66. ASPIC surplus production model estimates of relative fishing rate (F/F_{MSY}) and biomass (B/B_{MSY}).



Appendix A Abbreviations and symbols

Table 33. Acronyms and abbreviations used in this report

Symbol	Meaning
ABC	Acceptable Biological Catch
AW	Assessment Workshop (here, for red snapper)
ASY	Average Sustainable Yield
B	Total biomass of stock, conventionally on January 1
BAM	Beaufort Assessment Model (a statistical catch-age formulation)
CPUE	Catch per unit effort; used after adjustment as an index of abundance
CV	Coefficient of variation
CVID	SERFS combined chevron trap and video survey
DW	Data Workshop (here, for red snapper)
F	Instantaneous rate of fishing mortality
$F_{30\%}$	Fishing mortality rate at which $F_{30\%}$ can be attained
F_{MSY}	Fishing mortality rate at which MSY can be attained
FL	State of Florida
FHWAR	The National Survey of Fishing, Hunting, and Wildlife-Associated Recreation Survey
GA	State of Georgia
GLM	Generalized linear model
K	Average size of stock when not exploited by man; carrying capacity
kg	Kilogram(s); 1 kg is about 2.2 lb.
klb	Thousand pounds; thousands of pounds
lb	Pound(s); 1 lb is about 0.454 kg
m	Meter(s); 1 m is about 3.28 feet.
M	Instantaneous rate of natural (non-fishing) mortality
MARMAP	Marine Resources Monitoring, Assessment, and Prediction Program, a fishery-independent data collection program of SCDNR
MCB	Monte Carlo/Bootstrap, an approach to quantifying uncertainty in model results
MFMT	Maximum fishing-mortality threshold; a limit reference point used in U.S. fishery management; often based on F_{MSY}
mm	Millimeter(s); 1 inch = 25.4 mm
MRFSS	Marine Recreational Fisheries Statistics Survey, a data-collection program of NMFS, predecessor of MRIP
MRIP	Marine Recreational Information Program, a data-collection program of NMFS, descended from MRFSS
MSST	Minimum stock-size threshold; a limit reference point used in U.S. fishery management. The SAFMC has defined MSST for red snapper as $(1 - M)\mathrm{SSB}_{\mathrm{MSY}} = 0.7\mathrm{SSB}_{\mathrm{MSY}}$.
MSY	Maximum sustainable yield (per year)
mt	Metric ton(s). One mt is 1000 kg, or about 2205 lb.
N	Number of fish in a stock, conventionally on January 1
NC	State of North Carolina
NMFS	National Marine Fisheries Service, same as "NOAA Fisheries Service"
NOAA	National Oceanic and Atmospheric Administration; parent agency of NMFS
OY	Optimum yield; SFA specifies that OY $\leq$ MSY.
PSE	Proportional standard error
R	Recruitment
SAFMC	South Atlantic Fishery Management Council (also, Council)
SC	State of South Carolina
SCDNR	Department of Natural Resources of SC
SDNR	Standard deviation of normalized residuals
SEDAR	SouthEast Data Assessment and Review process
SERFS	Southeast Regional Fishery-independent Sampling
SFA	Sustainable Fisheries Act; the Magnuson–Stevens Act, as amended
SL	Standard length (of a fish)
SRHS	Southeast Region Headboat Survey, conducted by NMFS-Beaufort laboratory
SPR	Spawning potential ratio
SSB	Spawning stock biomass; mature biomass of males and females
$\mathrm{SSB}_{\mathrm{MSY}}$	Level of SSB at which MSY can be attained
$\mathrm{SSB}_{\mathrm{F30\%}}$	Level of SSB at which $F_{30\%}$ can be attained
TIP	Trip Interview Program, a fishery-dependent biodata collection program of NMFS
TL	Total length (of a fish), as opposed to FL (fork length) or SL (standard length)
VPA	Virtual population analysis, an age-structured assessment
WW	Whole weight, as opposed to GW (gutted weight)
yr	Year(s)

Appendix B Parameter estimates from the Beaufort Assessment Model

```
# Number of parameters = 366  Objective function value = -1956.14  Maximum gradient component = 5.96937e-005
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# K:
0.240000000000
# t0:
-0.330000000000
# len_cv_val:
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# Linf_L:
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# K_L:
0.220000000000
# t0_L:
-0.660000000000
# len_cv_val_L:
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# Linf_20:
938.000000000
# K_20:
0.170000000000
# t0_20:
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# len_cv_val_20:
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# log_Nage_dev:
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 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
 0.00000000000 0.00000000000 0.00000000000
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# steep:
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# rec_sigma:
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 0.757318324702 0.784222329636 -0.400893545137 -1.30002703800 -0.143801874907 -0.205256786125 0.371955484101 1.28619711286
# selpar_A50_cH1:
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# selpar_slope_cH1:
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# selpar_A50_cH2:
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# selpar_slope_cH2:
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# selpar_A50_cH3:
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# selpar_slope_cH3:
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# selpar_slope_HB1:
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# selpar_A502_HB1:
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# selpar_slope2_HB1:
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# selpar_A50_HB2:
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# selpar_A502_HB2:
2.25027736370
# selpar_slope2_HB2:
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# selpar_A50_HB3:
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# selpar_slope_HB3:
3.35767716522
# selpar_A502_HB3:
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# selpar_slope2_HB3:
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# selpar_A50_GR2:
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# selpar_slope_GR2:
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# selpar_A502_GR2:
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# selpar_slope2_GR2:
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# selpar_A50_GR3:
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```

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# selpar_slope_HB2_D:
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# selpar_A502_HB2_D:
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# selpar_slope2_HB2_D:
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# selpar_A50_HB3_D:
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# selpar_slope_HB3_D:
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# selpar_slope2_HB3_D:
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# selpar_A502_cH2_D:
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# selpar_slope2_cH2_D:
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# selpar_A50_cH3_D:
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# selpar_slope_cH3_D:
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# selpar_A50_CVT:
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# selpar_slope_CVT:
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# log_q_HB_D:
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# log_q_CVT:
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 -0.492830411543 -0.383282298421 -0.313110376106 0.0486587829093 0.354139697066 -0.00766574024572 0.0139446490799
 -0.0387686996753 -0.0969873687998 -0.363586238903 0.190944332318 0.574817113965 0.733215705057 1.01835913030
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 0.676887588441 0.600817043938 0.172933692896 0.284213531392 0.0552230838463 -0.311689646371 -0.151579848805
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 0.500384533551 0.932614621671 0.716786005286 0.300996123848 0.524106797328 0.374376210489 0.275972078585
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# log_F_dev_HB:
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 -0.0748011913017 -0.0632384700369 0.0431176191044 0.149563624258 0.246508551309 0.368190750885 0.537236484677
 0.661712395070 0.791476042563 0.936442804895 0.991328649085 1.16873523320 0.981619425524 0.758050799224
 1.08759847472 0.433321436118 0.805994430928 0.0103147826406 0.565029945025 0.451350187065 -0.0956221833689
 0.0439287036212 0.0487781883903 0.00470594165115 0.961918734776 0.497089398881 0.731754552306 0.297891330481
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 0.423821917999 0.390563878751 0.519614539358 0.985941504161 0.644212206360 0.782283643821 -3.42347033019 -2.09076149162
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# log_F_dev_GR:
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 0.440545044930 0.569523398454 0.715623993134 0.771313514093 0.948535472682 1.06116075246 0.503257392687 1.01569096953
 1.48147444378 1.67974724108 0.937110843678 0.329739748713 0.370480455580 0.449522531037 -1.37817128845 0.0927475607962
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# log_F_dev_cH_D:
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 -1.95064679219 -1.28747200456 -1.32824320794 -0.567093445156 0.735814373727 1.61352129256 0.949591879322
 0.846759620716 0.903543604624
# log_avg_F_HB_D:
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# log_F_dev_HB_D:
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  0.0901217913932 0.770686051314 0.839774983440 1.32324787838 0.361352389058 0.442727954169 -0.124655874267
  -0.0370543321215 0.0780347286159 0.641015729367 0.901150739278 -0.0256535397639 2.51436057142 2.71597771725
   1.14292945111 2.51505782970 2.64689926556 3.13112075694 2.95417502377 2.59545904401 2.65113555734 2.31820752654
   1.62250552559
# log_avg_F_GR_D:
```

```
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# log_F_dev_GR_D:
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 -1.16994513942 -0.406879027687 0.123321112551 -0.584026154680 0.660802503276 0.592823729801 0.738070257363 -0.671535139188
 -0.840415497560 -0.730881501787 0.794714817227 1.12276860438 1.12756166661 0.818937371024 0.965919231288 1.79365010697
 1.63318630174 -0.00432480925527 0.817903500109 1.50061375511 1.47865474555 1.15184581026 -0.702657019111 0.682903492790
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# F_init:
0.0296007209743
```

SEDAR

Southeast Data, Assessment, and Review

SEDAR 41

South Atlantic Red Snapper

SECTION VII: Addenda 2

April 2017

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
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April 19, 2017

Memorandum To: Gregg Waugh, Executive Director, SAFMC

From: Bonnie J. Ponwith, Ph.D BRAINERD.THEOPHILUS.R.DR.1365819285 Digitally signed by BRAINERD.THEOPHILUS.R.DR.1365819285 Date: 2017.04.19 13:02:33 -04'00'
Science and Research Director

Subject: Red Snapper Assessment Errata

Southeast Fisheries Science Center Analysis discovered an error in the Red Snapper Assessment in the Headboat Discard Index input to the model. The input data were corrected and the model was rerun. The difference between the original run and corrected run is negligible. Monte Carlo Bootstrap uncertainty analysis shows almost no change. The attached report contains the corrected base run.

This information will be discussed at the upcoming SSC meeting.

Stock Assessment of Red Snapper off the Southeastern United States

SEDAR Benchmark Assessment

Southeast Fisheries Science Center

National Marine Fisheries Service

Last revision: April, 2017

Document History

February, 2016 Original release.

March, 2016 This release incorporates some of the corrections made during the Review Workshop, including corrected age composition data from the MARMAP program.

April, 2016 This release incorporates all of the corrections made during the Review Workshop, including corrected chevron trap age composition data. The corrections resulted in a new base run, for which iterative reweighting of the likelihood components and the starting value analysis were re-run. The new base run results, including updated uncertainty analyses and projections are included. The sensitivities and retrospectives, however, are unchanged. The Reviewers did not request that sensitivities or retrospectives be re-run because the base run changes were relatively small.

April, 2017 This release corrects the data used for the Headboat at-sea discard index. The correction resulted in a new base run, for which iterative reweighting of the likelihood components was conducted. The new base run results, including updated uncertainty analyses and projections are included. The sensitivities and retrospectives, however, are unchanged.

Contents

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2 Data Review and Update

The input data for this assessment are described below, with focus on modifications from the SEDAR41 DW.

2.1 Data Review

In this benchmark assessment, the Beaufort assessment model (BAM) was fitted to data sources developed during the SEDAR 41 DW with some modifications and additions.

Model input compiled during the DW

- Life history: Life history meristics, population growth, female maturity, proportion female, number of batches at age, size-dependent batch fecundity, and discard mortality
- Landings and discards: Commercial handline landings and discards, Headboat landings and discards, Recreational landings and discards
- Indices of abundance: Commercial handline, Headboat, Headboat discards, SERFS chevron trap, SERFS video

Model input modified or developed after the DW

- Life history: Fishery-dependent growth estimates, Growth estimates during the 20 inch size regulation, Age–specific natural mortality
- Landings and discards: changes to the recreational discards
- Indices of abundance: Fishery–independent indices combined (Chevron trap and Video)
- Length compositions: Commercial handline, Headboat, Recreational
- Age compositions: Commercial handline, Headboat, Recreational, Chevron trap

2.2 Data Update

2.2.1 Life History

Estimates of the von Bertalanffy growth parameters were provided by the DW for the population as a whole: (911.36mm, 0.24yr^{-1}, and -0.33yr). Two alternative von Bertalanffy curves were generated: one for all fisheries when no size limit was in place, and another to represent the fish captured by all fisheries under a 20 inch size limit regulation. Age-specific mortality was updated due to an error in the original calculation which forced the t_0 value to 0. Life-history information is summarized in Tables 1 and 2.

2.2.2 Landings and Discards

The fleet structure to be modeled was decided after the DW. The general recreational fleet comprises the charterboat and private boat fleets, while the headboat fleet stands alone. The decision was made to separate headboat from all other recreational fishing modes because length compositions diverge later in the time series. The general recreational fleet discards contained some zeros (years 1982, 1986, and 1990) that the panel considered unlikely to be accurate due to the magnitude of the surrounding years' values. The decision was made by the panel to fill in the zeros with the lowest observed discards in the regulatory time block of the zero value. Total removals as used in the assessment are in Table 3.

2.2.3 Indices of Abundance

The DW provided a SERFS chevron trap and video index separately. However, because the data are collected from the same sampling platforms (i.e. cameras mounted on the chevron traps), the two indices are not independent measures of abundance. Therefore, the panel decided to combine the two using the Conn (2010) method for combining indices. All indices and their corresponding CVs are shown in Table 4, and Figure 1 shows the indices as recommended by the data workshop plotted with the new CVID index for comparison. Fishery dependent indices of abundance were assumed to have CVs of 0.2, which is consistent with Francis (2003).

2.2.4 Length Compositions

Length compositions for all data sources were developed in 3-cm bins over the range 21–99 cm (labeled at bin center). All lengths below and above the minimum and maximum bins were pooled. The commercial handline, general recreational and headboat lengths were weighted by the region and landings (SEDAR41-AW05 2015). For inclusion, length compositions in any given year had to meet the sample size criteria of $nfish > 30$ and $ntrips \geq 10$ (Table 5). Furthermore, the AW panel decided to eliminate length comps where age comps were available. There were conflicts between the length compositions and age compositions, and the panel thought, given the relative ease of ageing this species and the fact the model is age-structured, the age compositions would provide more informative signals of year-class strength and better represent the catch in each fleet or survey.

2.2.5 Age Compositions

For age composition data, the upper range was pooled at 13 years old because a very small proportion of the data exist past age 13. The age compositions were weighted by the length compositions in attempt to address bias in selection of fish to be aged. For inclusion, age compositions in any given year had to meet the sample size criteria of $nfish > 10$ and $ntrips \geq 10$ (Table 5). Age composition was preferred over length composition when both were available from a given fleet in a given year. Age compositions were further corrected at the Review Workshop (SEDAR41-RW07 2016).

2.2.6 Additional Data Considerations

Size limits were in place beginning in 1983 (12 inch minimum size limit TL), and changed in 1992 (20 inch minimum size limit TL). A moratorium was put in place for Red Snapper in 2010, and three subsequent mini-seasons were allowed (2011-2014) with no size limit. The panel examined size composition data and determined that three time blocks should be used to account for size limits, or the lack thereof: 1950-1991, 1992-2009, and 2010-2014. Data available for this assessment are summarized in Tables 1–5.

3 Stock Assessment Methods

3.1 Overview

The primary model discussed during the Assessment Workshop (AW) was a statistical catch-age model implemented using the Beaufort Assessment Model (BAM) software (Williams and Shertzer 2015). BAM applies a statistical catch-age formulation, coded using AD Model Builder (Fournier et al. 2012). BAM is referred to as an integrated analysis because it uses all population dynamics-relevant data (e.g. removals, length and age compositions, and indices of abundance) in a single modeling framework. In contrast, production models (e.g. ASPIC or ASPM) or catch curve analyses only use subsets of the available data and often require simplifying assumptions. In essence, the catch-age model simulates a population forward in time while including fishing processes (Quinn and Deriso 1999; Shertzer et al. 2008). Quantities to be estimated are systematically varied until characteristics of the simulated population matches available data on the real population. The model is similar in structure to Stock Synthesis (Methot 1989; 2009). Versions of BAM have been used in previous SEDAR assessments of reef fishes in the U.S. South Atlantic, such as Red Porgy, Black Sea Bass, Tilefish, Blueline Tilefish, Gag, Greater Amberjack, Red Grouper, Snowy Grouper, and Vermilion Snapper, as well as in the previous SEDAR assessments of Red Snapper (SEDAR24 2010). In addition, a surplus production model implemented using ASPIC and a catch curve analysis (SEDAR41-AW08 2015) were used to provide supplementary information.

3.2 Data Sources

The catch-age model included data from three fleets that caught Red Snapper in southeastern U.S. waters: general recreational (charter and private boat), commercial handlines (hook-and-line), and recreational headboats. The model was fitted to data on annual landings (in numbers for the recreational fleets, in whole weight for commercial fleet); annual discards (in numbers for all fleets), annual length compositions of removals; annual age compositions of landings and surveys; three fishery dependent indices of abundance (commercial handlines, headboat, and headboat discards); and one fishery independent index of abundance (combined SERFS chevron trap and SERFS video index). Removals included landings and dead discards, assuming the mortality rates provided by the Data Workshop. Data used in the model are tabulated in §2 of this report.

3.3 Model Configuration

The assessment time period was 1950–2014. A general description of the assessment model follows.

3.4 Stock dynamics

In the assessment model, new biomass was acquired through growth and recruitment, while abundance of existing cohorts experienced exponential decay from fishing and natural mortality. The population was assumed closed to immigration and emigration. The model included age classes $1 - 20^+$, where the oldest age class 20^+ allowed for the accumulation of fish (i.e., plus group).

3.5 Initialization

Initial (1950) numbers at age assumed the stable age structure computed from expected recruitment and the initial, age-specific total mortality rate. That initial mortality was the sum of natural mortality and fishing mortality, where fishing mortality was the product of an initial fishing rate (F_{init}) and F-weighted average selectivity. The initial fishing rate was estimated using a prior centered around $F_{\text{init}} = 0.03$. The assumption matches what was used for SEDAR24 with the justification that the value should be small given the relatively low volume of landings prior to the assessment period. The initial recruitment in 1950 was assumed to be the expected value from the spawner-recruit curve. For the remainder of the initialization period (1950–1977), recruitment was assumed equal to expected values. Without sufficient age/length composition data prior to 1978, there is little information to estimate those historic recruitment deviations with accuracy.

3.6 Natural mortality rate

The natural mortality rate (M) was assumed constant over time, but decreasing with age. The form of M as a function of age was based on Charnov et al. (2013), a change from SEDAR24 which based natural mortality on the findings of Lorenzen (1996). The Charnov et al. (2013) approach inversely relates the natural mortality at age to somatic growth. As in previous SEDAR assessments, the age-dependent estimates of M_a were rescaled to provide the same fraction of fish surviving from age 4 through the oldest observed age (51 yr) as would occur with constant $M = 0.134$. This approach using cumulative mortality allows that fraction at the oldest age to be consistent with the findings of Then et al. (2014).

3.7 Growth

Mean size at age of the population, fishery removals under no size limit, and fishery removals under a 20 inch size limit (total length, TL) were modeled with the von Bertalanffy equation, and weight at age (whole weight, WW) was modeled as a function of total length (Figure 2, Table 2). Parameters of growth and conversions (TL-WW) were treated as input to the assessment model. For fitting length composition data, the distribution of size at age was assumed normal with a CV estimated by the assessment model for each growth curve.

3.8 Female maturity and sex ratio

Female maturity was modeled with a logistic function; parameters for this model and a vector of maturity at age were provided by the DW and treated as input to the assessment model (Table 2). The sex ratio was assumed to be 50:50, as recommended by the DW.

3.9 Spawning stock

Spawning biomass was modeled as population fecundity (number of eggs). For Red Snapper, peak spawning was considered to occur at the end of June. This included information on batch size as a function of age, as well as information on the number of annual batches as a function of age (SEDAR41-DW49 (2015) and Fitzhugh et al. (2012)).

3.10 Recruitment

Expected recruitment of age-1 fish was predicted from spawning biomass using the Beverton–Holt spawner-recruit model. Steepness, h, is a key parameter of this model, and unfortunately it is often difficult to estimate reliably (Conn et al. 2010). In this assessment, many initial attempts to estimate steepness resulted in a value near its upper bound of 1.0, indicating that the data were insufficient for estimation. Likelihood profiling showed that the value was likely above 0.92, and was unreliably estimated between 0.92 and 0.98. The AW Panel decided to assume an average annual recruitment while estimating lognormal deviations around that average. This was achieved by fixing steepness at $h = 0.99$.

3.11 Landings

Time series of landings from three fleets were modeled: commercial handline (1950–2014), general recreational (1955–2014), and headboat (1955–2014). Landings were modeled with the Baranov catch equation (Baranov 1918) and were fitted in either weight or numbers, depending on how the data were collected (1000 lb whole weight for commercial fleets, and 1000 fish for recreational). The DW provided observed landings back to the first assessment year (1950) for the commercial fleet and back to 1955 for the recreational fleets. However, sampling of headboats began in 1972 and other recreational sectors in 1981. Thus, historic landings of the recreational fleets were estimated indirectly by the DW using the FHWAR ratio method (SEDAR41-DW17). Historic landings were considered (and treated) in this assessment as a primary source of uncertainty.

3.12 Discards

As with landings, discard mortalities (in units of 1000 fish) were modeled with the Baranov catch equation (Baranov 1918), which required estimates of discard selectivities and release mortality probabilities. Discards were assumed to have fleet-specific, year-specific mortality probabilities, as suggested by the DW. Until 2007, the rate for commercial handlines was 0.48, and 0.38 thereafter. Until 2011, the general recreational and headboat rate was 0.37, with 0.285 thereafter. Annual discard mortalities, as fit by the model, were computed by multiplying total discards (tabulated in the DW report) by the fleet-specific and year-specific discard mortality rate. For general recreational and headboat fleets, discard time series were assumed to begin in 1981; for the commercial handlines fleet, discards were modeled starting in 1992 corresponding to the implementation of the 20-inch size limit.

3.13 Fishing

For each time series of removals (landings and discards), the assessment model estimated a separate full fishing mortality rate (F). Age-specific rates were then computed as the product of full F and selectivity at age. The across-fleet annual F was represented by apical F, computed as the maximum of F at age summed across fleets.

3.14 Selectivities

Selectivity curves applied to landings were estimated using a parametric approach. This approach applies plausible structure on the shape of the curves, and achieves greater parsimony than occurs with unique parameters for each age. Flat-topped selectivities were modeled as a two-parameter logistic function. Dome-shaped selectivities were modeled by combining two logistic functions: a two-parameter logistic function to describe the ascending limb of the curve, and a two-parameter logistic function to describe the descending limb. To model landings, the AW Panel recommended flat-topped selectivity for commercial handlines and dome-shaped selectivity for headboat and the general recreational fleets.

The assessment panel devoted substantial discussion and exploration to the pattern (flat-topped or dome-shaped) of selectivity at age. Several working papers and scientific literature (SEDAR24-AW05, SEDAR24-AW09, SEDAR24-AW12, SEDAR31-AW04, SEDAR31-AW12, SEDAR41-DW50, SEDAR41-DW08, Patterson et al. (2012), Wells et al. (2008), and Mitchell et al. (2014)) helped guide the panel's decisions by providing insight into selectivity based on length and age compositions, depth distributions of fishing effort, skill levels of fishermen, and how circumstances contrasted between the Atlantic and Gulf of Mexico. The choice of flat-topped selectivity for commercial handlines landings and dome-shaped for all others was based on several criteria. Two related considerations were the fleet-specific depths of fishing effort and the distribution of age at depth. In general, the commercial handlines fleet fish

in deeper water than other fleets, and although there was only weak correlation between depth and age of older fish (5^+), younger fish (1–5) were more readily caught in shallower depths (SEDAR24-AW05, and Mitchell et al. (2014)). It was also suggested that commercial gear and fishermen can better handle larger fish (SEDAR24-AW12). Catch curve data were consistent with the hypothesis that older fish are more vulnerable to the commercial handlines fleet than to recreational fleets (SEDAR41-AW08 2015).

Selectivity of each fleet was fixed within each block of size-limit regulations, but was permitted to vary among blocks where possible or reasonable. Fisheries experienced four blocks of size-limit regulations (no limit prior to 1983, 12-inch limit during 1983–1991, 20-inch limit during 1992–2009, and no size limit during the moratorium/miniseasons 2010–2014). However, the panel combined blocks one and two after seeing that the 12-inch size limit had a negligible effect on the selectivity pattern. Age and length composition data are critical for estimating selectivity parameters, and ideally, a model would have sufficient composition data from each fleet over time to estimate distinct selectivities in each period of regulations. That was not the case here, and thus additional assumptions were applied to define selectivities, as follows. Because the general recreational fleet had little age or length composition data prior to 1998, this fleet mirrored the headboat fleet until the final time block. All domed-shaped selectivities meant to characterize landings were configured so as not to allow a selectivity of 0 at older ages, which was considered implausible. Size and age composition data show larger, older fish are caught by all fleets. However, the selectivity functions would reach zero before the plus group age of 20. Therefore, the panel examined the age composition data and used the information they contained to create a plus group for the selectivities. Headboat selectivities were fixed as constant after age 10 at the value estimated for age 10. For the general recreational fleet, the constant age at which we fixed selectivity was 13. These plus groups were consistent with how the age composition data were fitted.

Selectivities of discards were estimated in a similar fashion to the landings in that the general recreational fleet discards mirrored the headboat fleet discards. Both the commercial handline discards and the headboat discards had sufficient length composition to estimate selectivities.

Selectivities of fishery dependent indices were the same as those of the relevant fleet. The fishery independent CVID index selectivity was assumed logistic and informed by the SERFS chevron trap age compositions.

3.15 Indices of abundance

The model was fit to three fishery dependent indices of relative abundance (headboat 1976–2009; headboat discards 2005–2014; and commercial handlines 1993–2009), and one fishery independent index of abundance (SERFS combined video and trap, CVID). Predicted indices were conditional on selectivity of the corresponding fleet or survey, and were computed from abundance at the midpoint of the year or, in the case of commercial handlines, biomass. The headboat discard index tracks small fish (less than 20 inches) and was included as a measure of recruitment strength.

3.16 Catchability

In the BAM, catchability scales indices of relative abundance to the estimated population at large. For the base model, the AW Panel recommended a time-invariant catchability.

A sensitivity run adopted a time-varying catchability for the headboat index. In this formulation, catchability was estimated in two stanzas, pre- and post-1992. Choice of the year 1992 was based on the implementation of a fishery management plan that may have changed fishing behavior.

3.17 Biological reference points

Biological reference points (benchmarks) were calculated based on the fishing rate that would allow a stock to attain 30% of the maximum spawning potential which would have been obtained in the absence of fishing mortality. Computed benchmarks included the MSY proxy, fishing mortality rate at $F_{30\%}$, total biomass at $F_{30\%}$, and spawning stock at $F_{30\%}$ (Gabriel and Mace 1999). In this assessment, spawning stock measures total eggs of the mature stock. These benchmarks are conditional on the estimated selectivity functions and the relative contributions of each fleet's fishing mortality. The selectivity pattern used here was the effort-weighted selectivities at age, with effort from each fleet estimated as the full F averaged over the last three years of the assessment.

3.18 Fitting criterion

The fitting criterion was a penalized likelihood approach in which observed removals (landings and discards) were fit closely, and observed composition data and abundance indices were fit to the degree that they were compatible. Removals and index data were fit using lognormal likelihoods. Length and age composition data were fit using robust multinomial likelihoods (Francis 2011), and only from years that met minimum sample size criteria ($nfish > 30$ and $ntrips \geq 10$) for length compositions and ($nfish > 10$ and $ntrips \geq 10$) for age compositions. Commercial and headboat discard length composition minimum sample size threshold was set lower ($nfish > 10$) due to the fact that the discard composition data were the only information available to estimate selectivity.

The model includes the capability for each component of the likelihood to be weighted by user-supplied values. For data components, these weights were applied by either adjusting CVs (lognormal components) or adjusting effective sample sizes (multinomial components). In this application to Red Snapper, CVs of landings and discards (in arithmetic space) were assumed equal to 0.05, to achieve a close fit to these time series yet allowing some imprecision. In practice, the small CVs are a matter of computational convenience, as they help achieve the desired result of close fits to the landings, while avoiding having to solve the Baranov equation iteratively (which is complex when there are multiple fisheries). Weights on other data components (indices, age/length compositions) were adjusted iteratively, starting from initial weights as follows. The CVs of indices were set equal to the values estimated by the GLMs used for standardization or at the fixed value of 0.2 for the headboat and commercial handline indices. Effective sample sizes of the multinomial components were assumed equal to the number of trips sampled annually, rather than the number of fish measured, reflecting the belief that the basic sampling unit occurs at the level of trip. These initial weights were then adjusted until standard deviations of normalized residuals were near 1.0 (Francis 2011). In sensitivity runs, weights on the fishery dependent indices were adjusted upward to explore their effects (not because up-weighted runs were considered equally plausible).

For parameters defining selectivities, CV of size at age, and σ_R, normal priors were applied to maintain parameter estimates near reasonable values, and to prevent the optimization routine from drifting into parameter space with negligible gradient in the likelihood. For σ_R, the prior mean (0.6) and standard deviation (0.25) were based on Beddington and Cooke (1983) and Mertz and Myers (1996).

3.19 Configuration of a base run

The base run was configured as described above. This configuration does not necessarily represent reality better than all other possible configurations, and thus this assessment attempted to portray uncertainty in point estimates through sensitivity analyses and through a Monte-Carlo/bootstrap approach (described below).

3.20 Sensitivity analyses

Sensitivity runs were chosen to investigate issues that arose specifically with this benchmark assessment. They were intended to demonstrate directionality of results with changes in inputs or simply to explore model behavior, and not all were considered equally plausible. These model runs vary from the base run as follows:

- S1: Remove the 2008 and 2009 years from the handline and headboat indices
- S2: Upweight fishery independent index further than was explored in the Assessment Workshop (10X likelihood weight after the iterative reweighting)
- S3: Upweight handline and headboat indices (3X likelihood weight after iterative reweighting)
- S4: Fishery dependent indices only
- S5: High value of M
- S6: Low value of M
- S7: Low discard mortality probabilities (commercial handlines rate set to 0.38 or 0.28, all recreational set to 0.27 or 0.20)
- S8: High discard mortality probabilities (commercial handlines rate set to 0.58 or 0.48, all recreational set 0.45 or 0.36)
- S9: Longer combined chevron trap and video (CVID) index (2005-2014)
- S10: Reduced general recreational landings in 1984 and 1985 by taking the geometric mean of surrounding years
- S11: Steepness $h = 0.84$
- S12: Headboat discard index excluded after 2009
- S13: Ageing error matrix included
- S14: Low value for age-specific number of batches
- S15: High value for age-specific number of batches
- S16: Headboat discard index dropped
- S17: High landings
- S18: Low landings
- S19: High discards
- S20: Low discards
- S21: Dome-shaped selectivity for commercial handline fleet
- S22: Separate video and trap index rather than a single CVID index
- S23: Fishery independent index only
- S24: Continuity run: changes include SEDAR24 values such as M, steepness, maturity, and SSB
- S25: Two time blocks for Headboat logbook index catchability (pre- and post-1992)
- S26: Retrospective - 1 year of data
- S27: Retrospective - 2 years of data
- S28: Retrospective - 3 years of data
- S29: Retrospective - 4 years of data

- S30: Use 1978 as the starting year, applied a loose prior to the estimation of F_{init} that corresponds to the geometric mean of the fishing mortality for 1950-1977
- S31: Estimate selectivities without fixing a plus group (for the selectivity estimation)

Sensitivities 5, 6, 14, 15, and 17-20 used the 10th and 90th quantiles (as the low and the high respectively) from the bootstraps of the observed data described in the uncertainty analysis methods (Section 3.24).

3.21 Parameters Estimated

The model estimated annual fishing mortality rates of each fleet, selectivity parameters, catchability coefficients associated with indices, parameters of the spawner-recruit model (except steepness), annual recruitment deviations, and CV of size at age for each age and growth relationship.

3.22 Per Recruit and Equilibrium Analyses

Yield per recruit and spawning potential ratio were computed as functions of F, as were equilibrium landings and spawning biomass. Equilibrium landings and discards were also computed as functions of biomass B, which itself is a function of F. As in the computation of benchmarks (described in §3.23), per recruit and equilibrium analyses applied the most recent selectivity patterns averaged across fleets, weighted by each fleet's F from the last three years of the assessment (2012–2014).

3.23 Benchmark/Reference Point Methods

In this assessment of Red Snapper, the quantities $F_{30\%}$, $\mathrm{SSB}_{\mathrm{F}30\%}$, $B_{\mathrm{F}30\%}$, and $L_{\mathrm{F}30\%}$ were estimated as proxies for MSY-based reference points. Steepness was not reliably estimable, so the stock-recruit relationship was not used to identify a maximum yield. Instead, steepness was fixed at 0.99 in order to assume an average level of recruitment while estimating deviations around the mean. $F_{30\%}$ was used in the rebuilding plan for Red Snapper, therefore, it was used here to generate fishing benchmarks. However, because the stock-recruitment relationship was not estimated, assumptions about recruitment are required to generate biomass benchmarks. Here, equilibrium recruitment was assumed equal to expected recruitment (arithmetic average). On average, expected recruitment is higher than that estimated directly from the spawner-recruit curve, because of lognormal deviation in recruitment. Thus, in this assessment, the method of benchmark estimation accounted for lognormal deviation by including a bias correction in equilibrium recruitment. The bias correction (ς) was computed from the variance (σ_R^2) of recruitment deviation in log space: $\varsigma = \exp(\sigma_R^2/2)$. Then, equilibrium recruitment (R_{eq}) associated with any F is,

$$R_{eq} = \frac{R_0 \left[\varsigma 0.8 h \Phi_F - 0.2(1-h)\right]}{(h-0.2)\Phi_F} \tag{1}$$

where R_0 is virgin recruitment, h is steepness which is fixed in this assessment, and $\Phi_F = \phi_F/\phi_0$ is spawning potential ratio given growth, maturity, and total mortality at age (including natural and fishing mortality rates). Because steepness is fixed at 0.99, R_{eq} as a function of F is approximately a straight line. The R_{eq} and mortality schedule imply an equilibrium age structure and an average sustainable yield (ASY). The estimate of $F_{30\%}$ is the F giving 30% of the SPR, and the estimate of $L_{\mathrm{F}30\%}$ is that ASY. The estimate of $\mathrm{SSB}_{\mathrm{F}30\%}$ follows from the corresponding equilibrium age structure, as does the estimate of discard mortalities $D_{F30\%\}}$, here separated from ASY (and consequently, $L_{\mathrm{F}30\%}$).

Estimates of $L_{\text{F30\%}}$ and related benchmarks are conditional on selectivity pattern. The selectivity pattern used here was an average of terminal-year selectivities from each fleet, where each fleet-specific selectivity was weighted in proportion to its corresponding estimate of F averaged over the last three years (2012–2014). If the selectivities or relative fishing mortalities among fleets were to change, so would the estimates of $L_{\text{F30\%}}$ and related benchmarks.

The maximum fishing mortality threshold (MFMT) is defined by the SAFMC as $F_{30\%}$, and the minimum stock size threshold (MSST) as 75%$\text{SSB}_{\text{F30\%}}$. Overfishing is defined as $F >$ MFMT and overfished as SSB < MSST. However, because this stock is currently under a rebuilding plan, increased emphasis is given to SSB relative to $\text{SSB}_{\text{F30\%}}$ (rather than MSST), as $\text{SSB}_{\text{F30\%}}$ is the rebuilding target. Current status of the stock is represented by SSB in the latest assessment year (2014), and current status of the fishery is represented by the geometric mean of F from the latest three years (2012–2014). Recent SEDAR assessments have considered the mean over the terminal three years to be a more robust metric.

3.24 Uncertainty and Measures of Precision

As in SEDAR24, this assessment used a mixed Monte Carlo and bootstrap (MCB) approach to characterize uncertainty in results of the base run. Monte Carlo and bootstrap methods (Efron and Tibshirani 1993; Manly 1997) are often used to characterize uncertainty in ecological studies, and the mixed approach has been applied successfully in stock assessment, including Restrepo et al. (1992), Legault et al. (2001), SEDAR4 (2004), and many South Atlantic SEDAR assessments since SEDAR19 (2009). The approach is among those recommended for use in SEDAR assessments (SEDAR Procedural Guidance 2010).

The approach translates uncertainty in model input into uncertainty in model output, by fitting the model many times with different values of "observed" data and key input parameters. A chief advantage of the approach is that the results describe a range of possible outcomes, so that uncertainty is characterized more thoroughly than it could be by any single fit or handful of sensitivity runs. A minor disadvantage of the approach is that computational demands are relatively high.

In this assessment, the BAM was successively re-fit in $n = 4000$ trials that differed from the original inputs by bootstrapping on data sources, and by Monte Carlo sampling of several key input parameters. The value of $n = 4000$ was chosen because a minimum of 3000 runs were desired, and it was anticipated that not all runs would converge or otherwise be valid. Of the 4000 trials, approximately 1.9% were discarded, because the model did not properly converge (in most cases, an estimated quantity was at its upper bound). This left $n = 3926$ MCB trials used to characterize uncertainty, which was sufficient for convergence of standard errors in management quantities.

The MCB analysis should be interpreted as providing an approximation to the uncertainty associated with each output. The results are approximate for two related reasons. First, not all combinations of Monte Carlo parameter inputs are equally likely, as biological parameters might be correlated. Second, all runs are given equal weight in the results, yet some might provide better fits to data than others.

3.24.1 Bootstrap of observed data

To include uncertainty in the indices of abundance, multiplicative lognormal errors were applied through a parametric bootstrap. To implement this approach in the MCB trials, random variables ($x_{s,y}$) were drawn for each year y of time series s from a normal distribution with mean 0 and variance $\sigma^2_{s,y}$ [that is, $x_{s,y} \sim N(0, \sigma^2_{s,y})$]. Annual observations were then perturbed from their original values ($\hat{O}_{s,y}$),

$$O_{s,y} = \hat{O}_{s,y}[\exp(x_{s,y} - \sigma^2_{s,y}/2)] \tag{2}$$

The term $\sigma^2_{s,y}/2$ is a bias correction that centers the multiplicative error on the value of 1.0. Standard deviations in log space were computed from CVs in arithmetic space, $\sigma_{s,y} = \sqrt{\log(1.0 + CV^2_{s,y})}$. As used for fitting the base run, CVs of indices of abundance were those provided by, or modified from, the data providers (tabulated in Table 4 of this assessment report).

Uncertainty was modeled for historical commercial landings similarly to the indices, and by the CVs provided by the commercial working group at the DW. No commercial discard CVs, headboat landings CVs, or headboat discard CVs by year were provided, therefore the panel had to make some assumptions. We assumed a value of $CV = 0.20$ for commercial discards and headboat discards. For headboat landings, we used information from the headboat program to assume a decreasing CV by time blocks (i.e. $CV = 0.15$ 1981-1995, $CV = 0.1$ for 1996-2007, and $CV = 0.05$ thereafter). General recreational landings and discards had complementary CVs, and those were used as provided except in a few instances. A CV greater than 1 was capped at 1, which was sufficiently large to represent high uncertainty but not so high that bootstrapped values caused implausible time series. The panel thought the resulting draws sufficiently represented uncertainty in spite of the dampening of a few years' CVs (Table 6).

Uncertainty in age and length compositions were included by drawing new distributions for each year of each data source, following a multinomial sampling process. Ages (or lengths) of individual fish were drawn at random with replacement using the cell probabilities of the original data. For each year of each data source, the number of fish sampled was the same as in the original data.

3.24.2 Monte Carlo sampling

In each successive fit of the model, several parameters were fixed (i.e., not estimated) at values drawn at random from distributions described below.

3.25 Natural mortality

A vector of age-specific natural mortality was provided by the Life History Working Group. They used the Charnov et al. (2013) estimator scaled to the Then et al. (2014) max age asymptotic M, and then used the uncertainty around the determination of maximum age to provide an upper and lower bound to the M vector. The Assessment Panel thought the upper ($M = 0.14$) and lower ($M = 0.12$) bound were too similar to the base vector to represent the true uncertainty around M. Instead, the AW Panel wanted to carry the uncertainty forward in both maximum age and the parameters of the Then et al. (2014) estimator of asymptotic M:

$$M = aT^b_{max} \tag{3}$$

To estimate uncertainty in a and b, we acquired the data of Then et al. (2014) and conducted a bootstrap of $n = 10,000$ iterations, drawing from the original data set with replacement. For each MCB iterations, one of the 10,000 fits was drawn at random, thus maintaining any correlation structure between a and b. We then drew T_{max} from a uniform distribution and calculated asymptotic M. For the age-dependent vector, we started with the Charnov age-dependent curve, and scaled it to the M estimate we calculated in the previous steps. A new M value was drawn and a new age-dependent vector was calculated for each MCB trial.

3.26 Discard mortality

The discard mortality working group provided an upper and lower bound for each time block (pre- and post-regulation) and fishery (commercial and recreational). Commercial rates before 2007 ranged from 38% to 58%, and 2007 to present ranged from 28% to 48%. Recreational rates before 2011 ranged from 27% to 45%, and 2011 on ranged from 20% to 36%. The rates decreased in response to the implementation of circle hooks, which are meant to cause fewer fatal bycatch events. We drew the rate for the earlier time period for each fleet from a truncated normal distribution with mean equal to the point estimate and a standard deviation devised to provide a 95% confidence interval similar to what the working group provided above. For the later time period for each fleet we also drew from a truncated normal distribution created similarly as in the previous step but with the upper bound fixed at the random draw from the earlier time period. The last step is meant to ensure that the second value is not larger than the first, so as to maintain the feature that discard mortality has decreased due to the circle hook regulation.

3.27 Batch Fecundity

Prior to the MCB analysis, a bootstrap procedure was run on the data set used to estimate batch fecundity at age for the base run. For each of 10000 bootstrap runs, the 69 paired observations of batch fecundity and fish length were sampled 69 times with replacement, the regression model refit, and the bootstrap parameters estimates saved to a data matrix. Once all bootstraps were run, the parameter matrix was trimmed by removing runs where either parameter value was outside of its 95% confidence interval. The parameters were found to be highly correlated, so during the MCB analysis, pairs of parameters were randomly drawn, with replacement, from the trimmed bootstrap parameter matrix. For each MCB run, predicted batch fecundity at age was calculated using a set of bootstrap parameters and a vector of length at age.

3.28 Batch number

Prior to the MCB analysis, a similar but separate bootstrap procedure was run on the data set used to estimate batch number at age for the base run. For each of 10000 bootstrap runs, the 1472 paired observations of spawning indicator presence, fish length, and day of the year were sampled 1472 times with replacement and the regression model refit. Predicted batch number at age was then calculated from the bootstrap parameter estimates and a vector of length at age, and the vectors saved to a data matrix. Once all bootstraps were run, the batch number at age matrix was trimmed by first summing batch number at age for each run, yielding lifetime batch number; runs where lifetime batch number was outside of the 95% confidence interval were trimmed. During the MCB analysis, a vector of batch number at age was randomly drawn, with replacement, from the trimmed bootstrap batch number at age matrix for each MCB run.

3.29 Projections

Projections were run to predict stock status in years after the assessment, 2015–2044. The year 2044 is the last year of the current rebuilding plan.

The structure of the projection model was the same as that of the assessment model, and parameter estimates were those from the assessment. Any time-varying quantities, such as recreational selectivity, were fixed to the most recent values of the assessment period. A single selectivity curve was applied to calculate removals, averaged across fleets using geometric mean Fs from the last three years of the assessment period, similar to computation of $L_{\mathrm{F30\%}}$ benchmarks (§3.23).

Expected values of SSB (time of peak spawning), F, recruits, and removals were represented by deterministic projections using parameter estimates from the base run. These projections were built on the spawner-recruit relationship with steepness fixed ($h = 0.99$) and with bias correction, and were thus consistent with estimated benchmarks in the sense that long-term fishing at $F_{30\%}$ would yield $L_{\text{F30\%}}$ from a stock size at $\text{SSB}_{\text{F30\%}}$. Uncertainty in future time series was quantified through stochastic projections that extended the Monte Carlo/Bootstrap (MCB) fits of the stock assessment model.

3.29.1 Initialization of projections

Initial age structure at the start of 2015 was computed by the assessment model.

Fishing rates that define the projections were assumed to start in 2017. Because the assessment period ended in 2014, the projections required an initialization period (2015–2016). For 2015, a moratorium year, the landings selectivity was set to 0 and the discard selectivity was rescaled to peak at 1. Then, an optimization routine solved for the F that matched the current dead discards (mean of 2012-2014) in numbers. In 2016, a similar routine soved for the F that matched current landings (mean of 2012-2014), assuming a mini-season would occur.

3.29.2 Uncertainty of projections

To characterize uncertainty in future stock dynamics, stochasticity was included in replicate projections, each an extension of a single MCB assessment model fit. Thus, projections carried forward uncertainties in natural mortality, reproduction, landings, discards, and discard mortalities, as well as in estimated quantities such as selectivity curves, and in initial (start of 2015) abundance at age.

Initial and subsequent recruitment values were generated with stochasticity using a Monte Carlo procedure, in which the estimated Beverton–Holt model (i.e. R_0, σ_R estimated, and $h = 0.99$) of each MCB fit was used to compute mean annual recruitment values ($\bar{R}_y$). Variability was added to the mean values by choosing multiplicative deviations at random from a lognormal distribution,

$$R_y = \bar{R}_y \exp(\epsilon_y). \tag{4}$$

Here ϵ_y was drawn from a normal distribution with mean 0 and standard deviation σ_R, where σ_R is the standard deviation from the relevant MCB fit.

The procedure generated 20,000 replicate projections of MCB model fits drawn at random (with replacement) from the MCB runs. In cases where the same MCB run was drawn, projections would still differ as a result of stochasticity in projected recruitment streams. Central tendencies were represented by the deterministic projections of the base run, as well as by medians of the stochastic projections. Precision of projections was represented graphically by the 10^{th} and 90^{th} percentiles of the replicate projections.

3.30 Rebuilding time frame

Based on results from the previous SEDAR24 benchmark assessment, Red Snapper is currently under a rebuilding plan. In this plan, the terminal year is 2044, and rebuilding is defined by the criterion that projection replicates achieve stock recovery (i.e., $\text{SSB}_{2044} \geq \text{SSB}_{\text{F30\%}}$) with probability of at least 50%. Here, the probability of stock recovery in each year of the rebuilding plan was computed as the proportion of stochastic projections where $\text{SSB} \geq \text{SSB}_{\text{F30\%}}$, with $\text{SSB}_{\text{F30\%}}$ taken to be iteration-specific (i.e., from that particular MCB run).

Projection scenarios Five projection scenarios were considered.

- Scenario 1: $F = 0$
- Scenario 2: $F = F_{\text{current}}$
- Scenario 3: $F = F_{30\%}$
- Scenario 4: $F_{target} = 98\% F_{30\%}$
- Scenario 5: $F = F_{\text{rebuild}}$, with rebuilding probability of 0.5 in 2044
- Scenario 6: Discards only

The F_{current} is represented by the geometric mean of fishing mortalities from 2012-2014. The F_{rebuild} is defined as the maximum F that achieves rebuilding in the allowable time frame. The discards only scenario treated the initialization year 2016 the same as 2015 (discards only), and then applied the mean F (from 2015-2016) forward starting in 2017.

3.31 Surplus Production Model

3.31.1 Overview

A logistic surplus production model, implemented in ASPIC (Version 7.03; Prager 2005), was used to estimate stock status of Red Snapper off the southeastern U.S. While primary assessment of the stock was performed using the age-structured BAM, the surplus production approach was intended as a complement, for additional comparison with the age-structured model's results. More specifically, this model focuses on the dynamics of the removals as they relate to the indices of abundance, while ignoring any age data or age-structure in the population.

3.31.2 Data Sources

Data sources supplied to a production model include a time series of removals (i.e. landings plus dead discards) and one or more indices of abundance (i.e. catch per unit of effort). These inputs should be in units of biomass (i.e. weight), therefore some of the data developed at the SEDAR41 DW required additional formatting. These changes are detailed below.

Removals

The available removals time series comprised commercial landings (1950-2014), recreational landings (1955-2014), commercial dead discards (1992-2014), and recreational dead discards (1981-2014), in pounds, summed by year.

Commercial Landings

The SEDAR41 DW reported commercial landings in pounds, thus these data did not need to be modified for the production model.

Recreational landings

During the SEDAR41 DW, recreational landings for the historical period (1955-1980) were estimated in numbers of individuals using the The National Survey of Fishing, Hunting, and Wildlife-Associated Recreation Survey (FHWAR) census method (see SEDAR41-DW17). For the contemporary period (1981-2014), the SEDAR-41 DW reported Southeast Region Headboat Survey (SRHS) and Marine Recreational Information Program (MRIP) recreational landings in numbers and weights. Recreational landings from this period did not need to be modified, but were used to convert historical landings to weight.

Following a similar approach used in SEDAR24, recreational landings in weight and numbers for all fleets were combined by year for the first three years of the contemporary period; dividing annual landings in weight by landings in numbers produced annual mean weight estimates. The average of these three mean weights (3.4 lb) was then multiplied by the historical landings in numbers to convert them to weight. The historical and combined contemporary recreational landings series were then joined to produce a single time series of recreational landings, in pounds.

Dead Discards

Discard estimates were generated in numbers at the SEDAR-41 DW. Since many discarded fish survive after release, discard mortality rates were applied to discards in numbers to calculate dead discards. For commercial discards, a discard mortality rate of 0.48 was applied prior to regulations in 2007, and a rate of 0.38 was applied from 2007 onward. For recreational discards, a discard mortality rate of 0.37 was applied prior to regulations in 2011, and a rate of 0.285 was applied from 2011 onward.

Mean weight of commercial discards was estimated by converting lengths of commercial discards to weights using data and a conversion equation supplied by the SEDAR-41 DW, and then calculating the average weight of these individuals. The data on lengths of commercial discards were divided into two time periods before (2007-2009) and after (2010-2013) the fishery was closed. The average estimated weights of commercial discards from each time period (before = 2.93 lb; after = 8.84 lb) were multiplied by discards in numbers, for years before and after the closure, respectively.

Mean weight of recreational discards was estimated by converting lengths of recreational headboat-at-sea observer discards to weights using data and a conversion equation supplied by the SEDAR-41 DW, and then calculating the average weight of these individuals. Year-specific mean weight estimates were multiplied by recreational discards in numbers for corresponding years when available (2005-2014). For years prior to 2005 where year-specific mean weights were not available, discards in numbers were multiplied by the average mean weight across the available years before the 2010 closure (1.96 lb).

Indices of Abundance

Five indices of abundance were produced by the SEDAR-41 DW for Red Snapper: commercial logbook handline index (hereafter commercial handline; units = lb kept per hook-hour), headboat (number of fish kept per angler), headboat-at-sea-observer (number of fish caught $<20''$ per angler), Southeast Reef Fish Survey (SERFS) chevron trap (number of fish caught per trap), and the SERFS video (number of fish observed per video). The commercial handline index was already in weight and did not need to be converted. The headboat index was converted to pounds by multiplying by year-specific mean weights, generated by dividing headboat landings in pounds by landings in numbers for each year. The headboat-at-sea-observer index was converted to pounds by multiplying by the same mean weights used to convert recreational discards to weight. The SERFS chevron trap and video indices were converted to weights by multiplying by year-specific mean weights calculated from combined recreational (headboat and MRIP) landings in weight divided by landings in numbers.

3.31.3 Model Configuration and Equations

Production modeling used the model formulation and ASPIC software (version 7.03) of Prager (1994; 2005). This is an observation-error estimator of the continuous-time form of the Schaefer (logistic) production model (Schaefer 1954; 1957). Estimation was conditioned on catch. The logistic model for population growth is the simplest form of a differential equation which satisfies a number of ecologically realistic constraints, such as a carrying capacity (a consequence of limited resources). When written in terms of stock biomass, this model specifies that

$$\frac{dB_t}{dt} = rB_t - \frac{r}{K}B_t^2 \quad (5)$$

where B_t is biomass in year t, r is the intrinsic rate of increase in absence of density dependence, and K is carrying capacity (Schaefer 1954; 1957). This equation may be rewritten to account for the effects of fishing by introducing an instantaneous fishing mortality term, F_t :

$$\frac{dB_t}{dt} = (r - F_t)B_t - \frac{r}{K}B_t^2 \quad (6)$$

By writing the term F_t as a function of catchability coefficients and effort expended by fishermen in different fisheries, Prager (1994) showed how to estimate model parameters from time series of yield and effort.

For Red Snapper, the model proved difficult to fit. It was configured using various combinations of removals, indices, starting dates, prior distributions and starting values, resulting in approximately 324 configurations. Many of these runs were completed during early model development but many others incorporated small changes to data inputs or model specifications suggested by AW panel members during the Assessment Workshop. As the BAM developed, most of these runs became obsolete and are not presented here. The run configured according to recommendations by the SEDAR41 AW panel is presented here. This model configuration (run 320) contained removals from 1950 to 2014 and the four indices used in the BAM (Comm, HB, HB-at-sea, CVID) from 1976 to 2014. Following the recommendations of the AW panel, the CVID index was upweighted by a factor of three (i.e. CVs divided by three), and the headboat-at-sea index was shifted forward by one year, since it indexes younger fish than the other indices.

Three other runs (318, 319, and 323) are also presented to relate the main run (320) to ASPIC results from the previous Red Snapper assessment (SEDAR 24). All three runs contain only the commercial and headboat indices, starting in 1993 and 1976 respectively, and removals starting in 1950. But in run 318 (the continuity run), the final year of removals and indices is 2009, as in SEDAR 24, while in run 319 (the updated continuity run) the final year of removals and indices is 2014, as in the BAM for the current assessment. Since both the commercial and headboat indices ended in 2009 the only difference between the continuity run and updated continuity run is the removals estimates from 2010-2014. Finally a run was completed (run 323; best configuration $\frac{B_1}{K}$ fixed) that is identical to the best configuration run, but with $\frac{B_1}{K}$ fixed at the estimate for the continuity run, for reasons described below.

To evaluate the uncertainty in the model fit and parameter estimates of the best configuration run, 1000 bootstrap runs were conducted. Percentile confidence intervals were also calculated for parameters.

4 Stock Assessment Results

4.1 Measures of Overall Model Fit

In general, the Beaufort assessment model (BAM) fit well to the available data. Predicted length compositions from the commercial handline and discards from the commercial and headboat fleets were reasonably close to observed data in most years, as were predicted age compositions (Figure 3). The model was configured to fit observed commercial and recreational removals closely (Figures 4–9). Fits to indices of abundance generally captured the observed trends but not all annual fluctuations (Figures 10–13).

4.2 Parameter Estimates

Estimates of all parameters from the catch-age model are shown in Appendix B. Estimates of management quantities and some key parameters are reported in sections below.

4.3 Stock Abundance and Recruitment

In general, estimated abundance at age showed truncation of the older ages through most of the assessment period, but with some signs of increase during the last decade (Figure 14; Table 7). Total estimated abundance was at its lowest value in the early 1990s, but near its highest levels at the end of the time series, comparable to those in the early 1970s, but with a more truncated age structure. The MCB results reflect the same patterns with their associated uncertainties for total abundance and abundance of age 2+ (Figure 18). Annual number of recruits is shown in Table 7 (age-1 column) and in Figure 15. The highest recruitment values were predicted to have occurred in the mid-1980s, 2006, and the terminal year of the model (2014).

4.4 Total and Spawning Biomass

Estimated biomass at age followed a similar pattern as abundance at age (Figure 16; Table 9). Total biomass and spawning biomass showed similar trends—general decline through to the early-1990s, and relatively stable or slowly increasing patterns since the mid-1990s (Figure 17; Table 10). Terminal year estimates are at levels not seen since the 1970s.

4.5 Selectivity

Selectivity of the SERFS index is shown in Figure 19, and selectivities of landings from commercial and recreational fleets are shown in Figures 20, 21, and 22. Selectivities of discards from commercial and recreational fleets are shown in Figures 23, 24, and 25. In the most recent years, full selection occurred near ages 2–4, depending on the fleet and time block.

Average selectivities of landings, dead discards, and the total weighted average of all selectivities were computed from F-weighted selectivities in the most recent three assessment years (Figure 26). This average selectivity was used in computation of point estimates of benchmarks, as well as in projections. All selectivities from each time block, including average selectivities, are tabulated in Tables 11, 12, and 13.

4.6 Fishing Mortality and Removals

Estimates of total F at age are shown in Table 15. In any given year, the maximum F at age (i.e., apical F) may be less than that year's sum of fully selected Fs across fleets. This inequality is due to the combination of two features of estimated selectivities: full selection occurs at different ages among gears and several sources of mortality have dome-shaped selectivity.

Estimated time series of landings and discards are shown in Tables 16, 17, 18, 19. Table 20 shows total landings at age in numbers, and Table 21 in weight. Table 22 shows total discards at age in numbers, and Table 23 in weight. Landings have been dominated by the general recreational and commercial handline fleet until recent years when the general recreational fleet became the dominant source of removals (Tables 16 and 17). Also since 2010, total landings remained below the level at $L_{\mathrm{F30\%}}$ (Figure 29).

Estimated discard mortalities occurred on a smaller scale than landings until the implementation of regulations and the use of mini-seasons, and have been above the $D_{F_{30\%}}$ level for most of the moratorium years (Tables 18 and 19, and Figure 30).

4.7 Spawner-Recruitment Parameters

The Beverton–Holt spawner-recruit curve is shown in Figure 31, along with the effect of density dependence on recruitment, depicted graphically by recruits per spawner as a function of spawning stock (1E8 Eggs). Values of recruitment-related parameters were as follows: steepness $h = 0.99$ (fixed), unfished age-1 recruitment $\widehat{R_0} = 320738$, and standard deviation of recruitment residuals in log space $\widehat{\sigma}_R = 0.81$ (which resulted in bias correction of $\varsigma = 1.40$). Uncertainty in these quantities was estimated through the MCB analysis (Figure 32).

4.8 Per Recruit and Equilibrium Analyses

Yield per recruit and spawning potential ratio were computed as functions of F. These computations applied the most recent selectivity patterns averaged across fleets, weighted by F from the last three years (2012–2014) (Figures 33 and 34).

As in per recruit analyses, equilibrium landings and spawning biomass were computed as functions of F (Figure 35). $F_{30\%}$ is used as a proxy for MSY, and the corresponding landings and spawning biomass are $L_{\mathrm{F30\%}}$ and $\mathrm{SSB}_{\mathrm{F30\%}}$.

4.9 Benchmarks / Reference Points

As described in §3.23, biological reference points (benchmarks) were derived analytically assuming equilibrium dynamics, corresponding to the spawner-recruit curve with fixed steepness $h = 0.99$ (Figure 31). Reference points estimated were $F_{30\%}$, $L_{\mathrm{F30\%}}$, $B_{\mathrm{F30\%}}$ and $\mathrm{SSB}_{\mathrm{F30\%}}$. Based on $F_{30\%}$, three possible values of F at optimum yield (OY) were considered—$F_{\mathrm{OY}} = 65\%F_{30\%}$, $F_{\mathrm{OY}} = 75\%F_{30\%}$, and $F_{\mathrm{OY}} = 85\%F_{30\%}$—and for each, the corresponding yield was computed. Standard errors of benchmarks were approximated as those from MCB analysis (§3.24).

Maximum likelihood estimates (base run) of benchmarks, as well as median values from MCB analysis, are summarized in Table 24. Point estimates of $L_{\mathrm{F30\%}}$-related quantities were $F_{30\%} = 0.15$ (y^{-1}), $L_{\mathrm{F30\%}} = 427.01$ (1000 lb), $B_{\mathrm{F30\%}} = 3637.2$ (mt), and $\mathrm{SSB}_{\mathrm{F30\%}} = 327705.9$ (1E8 Eggs). Median estimates were $F_{30\%} = 0.15$ (y^{-1}), $L_{\mathrm{F30\%}} = 415.17$ (1000 lb), $B_{\mathrm{F30\%}} = 3524.9$ (mt), and $\mathrm{SSB}_{\mathrm{F30\%}} = 293943.5$ (1E8 Eggs). Distributions of these benchmarks from the MCB analysis are shown in Figure 36.

4.10 Status of the Stock and Fishery

Estimated time series of stock status SSB/$SSB_{F30\%}$ showed general decline throughout the beginning of the assessment period, a leveling off, and then a modest increase since 2010 (Figure 37, Table 10). Base-run estimates of spawning biomass have remained below the threshold (MSST) since the early-1970s. Current stock status was estimated in the base run to be SSB/$SSB_{F30\%}$ = 0.15 (Table 24), indicating that the stock has not yet recovered to $SSB_{F30\%}$. Median values from the MCB analysis indicated similar results SSB/$SSB_{F30\%}$ =0.16. The uncertainty analysis suggested that the terminal estimate of stock status is robust (Figures 38, 39). Of the MCB runs, 100% indicated that the stock was below $SSB_{F30\%}$ in 2014. Age structure estimated by the base run showed fewer older fish in the last few decades than the (equilibrium) age structure expected at $L_{F30\%}$ (Figure 40). However, there is improvement in the terminal year(2014), particularly for ages younger than ten.

The estimated time series of $F/F_{30\%}$ suggests that overfishing has occurred throughout most of the assessment period (Table 10, Figure 37). Current fishery status in the terminal year, with current F represented by the geometric mean from 2012–2014, was estimated by the base run to be $F/F_{30\%}$ = 2.7 (Table 24). The fishery status was also robust (Figures 38, 39). Of the MCB runs, approximately 99.1% agreed with the base run that the stock is currently experiencing overfishing.

4.11 Sensitivity and Retrospective Analyses

Sensitivity runs, described in §3.3, were used for exploring data or model issues that arose during the assessment process, for evaluating implications of assumptions in the base assessment model, and for interpreting MCB results in terms of expected effects of input parameters. In some cases, sensitivity runs are simply a tool for better understanding model behavior, and therefore all runs are not considered equally plausible in the sense of alternative states of nature. Time series of $F/F_{30\%}$ and SSB/$SSB_{F30\%}$ are plotted to demonstrate sensitivity to the changing conditions in each run. The sensitivity of the base run to changes in natural mortality, steepness, dome-shaped selectivity for the commercial handline fleet, various index adjusts for both the fishery dependent indices and fishery independent index, the use of an ageing error matrix and high and low levels of landings and discards was explored (Figures 41–53). Sensitivity 24 is a version of a continuity run in that various assumptions made about parameters for SEDAR 24 were adopted for this sensitivity (e.g. higher discard mortalities, lower M, using gonad weight as a proxy for SSB, different female maturity and fecundity information, higher max age, lower steepness, different time of year for peak spawning, and fixed recruitment standard deviation). Time series of stock and fishery status estimated by this assessment are similar to those from the previous, SEDAR24 assessment (Figure 54). Trends in $F/F_{30\%}$ from the two assessments generally track each other, though the magnitude of the variations differ. Trends in SSB/$SSB_{F30\%}$ track each other, though there is divergence at the end of the time series where the current model estimates a more optimistic stock status.

None of the sensitivities show a recovered stock in 2014. A couple sensitivities suggest the stock is undergoing less overfishing than is estimated in the base. However, those runs eliminate the fishery independent index entirely, or upweight the fishery dependent indices to the point of swamping out any signal from the survey data. The vast majority of runs agree with the status indicated by the base run (Figure 55, Table 25). Results appeared to be most sensitive to natural mortality and steepness.

Retrospective analyses suggest a pattern of overestimating fishing mortality in the terminal year, however, the trend is less apparent for SSB (Figure 56).

4.12 Projections

Projections based on $F = 0$ allowed the spawning stock to grow such that the majority of replicate projections recovered to $\mathrm{SSB}_{\mathrm{F30\%}}$ by 2025 (Figure 57, Table 26), however the stock is already in a rebuilding plan so other projections were also requested in the TORs. This was not the case for projections based on $F = F_{\mathrm{current}}$ (Figure 58, Table 27), or if the fishing rate were reduced to $F_{30\%}$ (Figure 59, Table 28) or F_{target} (Figure 60, Table 29). By design, projections based on $F = F_{\mathrm{rebuild}}$ showed recovery with the desired probability in 2044 (Figure 61, Table 30). The projection with discard mortality only showed similar trajectories to the run assuming no other fishing mortality(Table 31 and Figure 62).

4.13 Surplus Production Model

4.13.1 Model Fit

For the best configuration run, model predictions underestimated observed values for the headboat index for the first ten years of the time series (1976-1985; Figure 63). They also underestimated the commercial index during the first five years of that series (1993-1997), while overestimating the headboat index for those same years. The model provided a very poor fit to the headboat-at-sea discard index (2006-2014) but produced a much better fit to the upweighted CVID index (2005-2014). The model did not fit high index values in 2008 and 2009 very closely, but predicted a slight decline from 2007-2009 followed by an increasing trend from 2010 to 2014.

4.13.2 Parameter Estimates and Uncertainty

The ASPIC model fits three main parameters ($\frac{B_1}{K}$, MSY, and F_{MSY}) as well as catchability coefficients (q_i) for each index i. Several other parameters can then be derived from these estimates: $r = 2F_{MSY}$, $K = \frac{2MSY}{F_{MSY}}$ and $B_{MSY} = \frac{K}{2}$. Recent status indicators $\frac{F}{F_{MSY}}$ and $\frac{B}{B_{MSY}}$ are calculated with the most recent estimates of F (2014) and B (2015). Estimates of the main parameters and recent status indicators for all four runs are presented in Table 32. Prior distributions and model estimates of the main parameters for the best configuration run are presented in Figure 64.

Across all runs, most of the main parameters varied very little (e.g. CV $MSY = 0.0027$; CV $F_{MSY} = 0.014$). By contrast $\frac{B_1}{K}$ varied widely (CV $\frac{B_1}{K} = 0.74$), due to variation in B_1 (CV $B_1 = 0.74$) rather than K (CV $K = 0.013$; Table 32). Among bootstrap runs based on the best configuration, distributions of $\frac{B_1}{K}$, MSY, and F_{MSY} were unimodal and relatively symmetrical (Figure 65).

4.13.3 Status of the Stock and Fishery

In the current best configuration run of the surplus production model, $\frac{B}{B_{MSY}}$ is greater than one, suggesting that the South Atlantic stock of Red Snapper is not overfished. The 95% bootstrap percentile confidence intervals for $\frac{B}{B_{MSY}}$ do not contain one (Figure 65). Since the surplus production model estimates that $\frac{F}{F_{MSY}}$ is less than one, the stock is considered to not be undergoing overfishing (Table 32; Figure 66). The 95% bootstrap percentile confidence intervals for $\frac{F}{F_{MSY}}$ do not contain one (Figure 65).

4.13.4 Interpretation

Status indicators in the continuity run (318), agree with the surplus production model from SEDAR 24 that South Atlantic Red Snapper were overfished and undergoing overfishing in 2009 (Table 32). However, in the updated continuity run (319), which is identical to the continuity run except for the 2010-2014 addition of landings data from 2010-2014, the surplus production model suggests that the stock is no longer overfished or undergoing overfishing. Despite several differences between the updated continuity run and the best configuration run (320), described above, most of the parameter estimates and status indicators are similar (Table 32). However the model estimate of $\frac{B_1}{K}$ is much lower in the best configuration run, driven by a lower estimate of B_1. After observing this difference, run 323 was configured by taking the best configuration run and fixing $\frac{B_1}{K}$ at the estimate from the continuity run to investigate potential influence. Fixing $\frac{B_1}{K}$ at this much lower value had little effect on status or most parameters, but caused the estimate of B_1 to go much lower.

As described above, the only data that go into a surplus production model are biomass of removals and abundance indices. Therefore such a model does not make use of many other sources of information such as sex, maturity, growth, fecundity, or population age and size structure. Because such data are available for Red Snapper, a model that uses them would be preferred for a detailed assessment on which to base management.

5 Discussion

5.1 Comments on the Assessment

Estimated benchmarks played a central role in this assessment. Values of $\mathrm{SSB}_{\mathrm{F30\%}}$ and $F_{30\%}$ were used to gauge the status of the stock and fishery to be consistent with established definitions of $MFMT$ and the existing rebuilding plan. The computation of the benchmarks was conditional on selectivity. If selectivity patterns change in the future, for example as a result of new size limits or different relative catch allocations among sectors, estimates of benchmarks would likely change as well.

The base run of the BAM indicated that the stock remains overfished $\mathrm{SSB}/\mathrm{SSB}_{\mathrm{F30\%}}=0.15$, and that overfishing is occurring $F/F_{30\%}=2.7$, though at a lower rate than in 2009 ($F/F_{\mathrm{MSY}}=4.12$ for SEDAR 24). Median values from the MCB analyses were in qualitative agreement with those results. This assessment estimates that, since 2010, the stock has been increasing at a modest rate and is now at levels not seen since the 1970s.

In addition to including the more recent years of data, this benchmark assessment contained several modifications to the previous data of SEDAR24, such as the use of APAIS-adjusted MRIP estimates instead of MRFSS, a new method for the reconstruction of historic recreational catch, the inclusion of a new fishery-independent survey, and the corresponding age composition data. Furthermore, life-history information was updated, including female maturity, sex ratio, growth, natural mortality, fecundity, and meristics. The assessment model itself was also modernized to the current version of BAM. The sum of these improvements should result in a more robust assessment.

In general, fishery dependent indices of abundance may not track actual abundance well, because of factors such as hyperdepletion or hyperstability. Furthermore, this issue can be exacerbated by management measures. In this assessment, the commercial handline and headboat indices generated from logbook data, were not extended beyond 2009 because of the moratorium on Red Snapper. In general, management measures in the southeast U.S. have made the continued utility of fishery dependent indices will be questionable. This situation amplifies the importance of fishery independent sampling and sampling programs conducted by the states.

Many assessed stocks in the southeast U.S. have shown histories of heavy exploitation. High rates of fishing mortality can lead to adaptive responses in life-history characteristics, such as growth and maturity schedules. Such adaptations can affect expected yield and stock recovery, and thus resource managers might wish to consider possible evolutionary effects of fishing in their management plans (Dunlop et al. 2009; Enberg et al. 2009). Indeed, Red Snapper have a very young age at maturity relative to their maximum lifespan, and some have hypothesized that this may be an adaptive response to exploitation.

Because steepness could not be estimated reliably in this assessment, its value in the base run was fixed at 0.99. Fixing steepness at its upper bound was not meant to imply that the stock has perfect compensation at any exploitation or stock level. Rather, it was a computational convenience to use the stock recruitment curve with $h = 0.99$ in order to treat recruitment as an average through time while estimating deviations around that average. Thus MSY-based management quantities are not appropriate, and the AW Panel provided the proxy of $F_{30\%}$ as was used for management subsequent to the last assessment.

The assessment start year was 1950, so as to include the period of largest landings. To initialize the model in 1950, the initial age structure was assumed to be in equilibrium, based on natural mortality at age and F_{init}. Average recruitment was assumed until the recruitment deviations could be estimated at the onset of the composition data (1978). These assumptions are common in assessment models, and they were tested with sensitivity runs where the start was 1978 and with different values of F_{init}. The end results were qualitatively similar, which indicates that the base run is not sensitive to these assumptions.

A complementary analysis was conducted using a surplus production model (ASPIC). ASPIC treats the stock as a pooled biomass and ignores the age structure in the population and the landings. It is unable to take into account that different ages are differentially vulnerable to fishing and therefore was not able to incorporate the (time-varying) selectivities used in the BAM. ASPIC is also not able to take into account that the reproductive contribution of this species increases with age or that there is variability in recruitment through time. ASPIC is useful in examining the relationship between removals and the indices. However, for a long-lived species with age-based data available, the catch-age model (BAM) provides the best illustration of the stock and is a better indicator of stock status, because it can account for the age structure of the population and landings and for year-class strength.

5.2 Comments on the Projections

Projections should be interpreted in light of the model assumptions and key aspects of the data. Some major considerations are the following:

- In general, projections of fish stocks are highly uncertain, particularly in the long term (e.g., beyond 5–10 years).
- Although projections included many major sources of uncertainty, they did not include structural (model) uncertainty. That is, projection results are conditional on one set of functional forms used to describe population dynamics, selectivity, recruitment, etc.
- Fisheries were assumed to continue fishing at their estimated current proportions of total effort, using the estimated current selectivity patterns. New management regulations that alter those proportions or selectivities would likely affect projection results.
- The first five scenarios of projections assumed no change in the selectivity applied to discards. As stock increase generally begins with the smallest size classes, management action may be needed to meet that assumption.
- The projections assumed that the assumed spawner-recruit relationship applies in the future and that past deviations represent future uncertainty in recruitment. If future recruitment is characterized by runs of large or small year classes, possibly due to environmental or ecological conditions, stock projections may be affected.

- Projections apply the Baranov catch equation to relate F and landings using a one-year time step, as in the assessment. The catch equation implicitly assumes that mortality occurs throughout the year. This assumption is violated when seasonal closures or small intensive fishing seasons are in effect, introducing additional and unquantified uncertainty into the projection results.

5.3 Research Recommendations

- Increased fishery independent information, particularly maintaining reliable indices of abundance and composition data streams
- Red Snapper were modeled in this assessment as a unit stock off the southeastern U.S. For any stock, variation in exploitation and life-history characteristics might be expected at finer geographic scales. Modeling such sub-stock structure would require more data, such as information on the movements and migrations of adults and juveniles, as well as spatial patterns of larval dispersal and recruitment. In addition, it is unclear whether a spatial model would improve the assessment.
- More research to describe the juvenile life history of Red Snapper is needed, including more work to identify the location of juveniles before they recruit to the fishery.
- The effects of environmental variation on the changes in recruitment or survivorship.
- The Florida sampling program, during the miniseason in particular, provided invaluable data to this assessment. Programs such as these would be useful in all South Atlantic states, particularly if the management regulations continue to make established methods of index development or composition sampling from fleets less regular or possible.

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7 Tables

Table 1. Life-history characteristics at age, including average body total length (TL) and weight (mid-year), proportion female, annual proportion females mature, and natural mortality at age. The CV of length was estimated by the assessment model; other values were treated as input.

Age	Avg. TL (mm)	Avg. TL (in)	CV length	Avg. Whole weight (kg)	Avg. Whole weight (lb)	Fem. maturity	Proportion Female	Nat. mortality
1	323.9	12.8	0.1	0.53	1.17	0.43	0.5	0.595
2	449.3	17.7	0.1	1.41	3.10	0.73	0.5	0.364
3	547.9	21.6	0.1	2.55	5.62	0.91	0.5	0.271
4	625.4	24.6	0.1	3.78	8.34	0.97	0.5	0.222
5	686.4	27.0	0.1	5.00	11.02	0.99	0.5	0.193
6	734.4	28.9	0.1	6.12	13.49	1.00	0.5	0.174
7	772.2	30.4	0.1	7.11	15.67	1.00	0.5	0.162
8	801.9	31.6	0.1	7.96	17.54	1.00	0.5	0.153
9	825.2	32.5	0.1	8.67	19.12	1.00	0.5	0.146
10	843.6	33.2	0.1	9.26	20.42	1.00	0.5	0.142
11	858.1	33.8	0.1	9.74	21.48	1.00	0.5	0.138
12	869.4	34.2	0.1	10.13	22.34	1.00	0.5	0.135
13	878.4	34.6	0.1	10.45	23.04	1.00	0.5	0.133
14	885.4	34.9	0.1	10.70	23.59	1.00	0.5	0.132
15	891.0	35.1	0.1	10.90	24.04	1.00	0.5	0.130
16	895.3	35.2	0.1	11.06	24.39	1.00	0.5	0.129
17	898.7	35.4	0.1	11.19	24.67	1.00	0.5	0.129
18	901.4	35.5	0.1	11.29	24.89	1.00	0.5	0.128
19	903.5	35.6	0.1	11.37	25.07	1.00	0.5	0.128
20	905.2	35.6	0.1	11.43	25.21	1.00	0.5	0.127

Table 2. Size (TL) in inches and weight in pounds (lb) at age as applied to the population (Pop), fishery–dependent portion of the population (FD), and fishery–dependent portion of the population during the 20 mm size limit (FD20). The CV of length was estimated by the assessment model; other values were treated as input through the von Bertalanffy growth parameters.

Age	Pop.TL	CV.Pop.TL	Pop.lb	FD.TL	CV.FD.TL	FD.lb	FD20.TL	CV.FD20.TL	FD20.lb
1	12.8	0.1	1.2	11.2	0.14	0.8	16.2	0.1	2.4
2	17.7	0.1	3.1	16.2	0.14	2.4	19.5	0.1	4.1
3	21.6	0.1	5.6	20.2	0.14	4.6	22.2	0.1	6.1
4	24.6	0.1	8.3	23.4	0.14	7.2	24.5	0.1	8.2
5	27.0	0.1	11.0	26.0	0.14	9.8	26.5	0.1	10.3
6	28.9	0.1	13.5	28.1	0.14	12.3	28.1	0.1	12.4
7	30.4	0.1	15.7	29.7	0.14	14.7	29.5	0.1	14.3
8	31.6	0.1	17.5	31.1	0.14	16.7	30.6	0.1	16.0
9	32.5	0.1	19.1	32.1	0.14	18.5	31.6	0.1	17.6
10	33.2	0.1	20.4	33.0	0.14	20.0	32.5	0.1	19.0
11	33.8	0.1	21.5	33.7	0.14	21.3	33.2	0.1	20.3
12	34.2	0.1	22.3	34.2	0.14	22.4	33.7	0.1	21.4
13	34.6	0.1	23.0	34.7	0.14	23.3	34.2	0.1	22.4
14	34.9	0.1	23.6	35.0	0.14	24.0	34.7	0.1	23.2
15	35.1	0.1	24.0	35.3	0.14	24.6	35.0	0.1	23.9
16	35.2	0.1	24.4	35.6	0.14	25.0	35.3	0.1	24.5
17	35.4	0.1	24.7	35.7	0.14	25.4	35.6	0.1	25.1
18	35.5	0.1	24.9	35.9	0.14	25.8	35.8	0.1	25.5
19	35.6	0.1	25.1	36.0	0.14	26.0	36.0	0.1	25.9
20	35.6	0.1	25.2	36.1	0.14	26.2	36.1	0.1	26.2

Table 3. Observed time series of landings(L) and discards(D) for commercial lines (cH), headboat (HB), and general recreational (GR). Commercial landings are in units of 1000 lb whole weight. Recreational landings and discards and commercial discards are in units of 1000 fish. Confidential data have been redacted.

Year	cH.L	HB.L	GR.L	cH.D	HB.D	GR.D
1950	368.657	.	.	.	.	.
1951	499.765	.	.	.	.	.
1952	385.930	.	.	.	.	.
1953	398.279	.	.	.	.	.
1954	593.207	.	.	.	.	.
1955	493.315	12.501	24.035	.	.	.
1956	483.907	13.652	26.248	.	.	.
1957	867.291	14.803	28.460	.	.	.
1958	612.508	15.953	30.673	.	.	.
1959	657.736	17.104	32.885	.	.	.
1960	671.075	18.255	35.098	.	.	.
1961	796.374	19.908	38.276	.	.	.
1962	645.983	21.561	41.454	.	.	.
1963	488.789	23.214	44.633	.	.	.
1964	537.589	24.867	47.811	.	.	.
1965	558.108	26.520	50.989	.	.	.
1966	554.506	26.676	51.288	.	.	.
1967	725.503	26.831	51.587	.	.	.
1968	865.520	26.986	51.885	.	.	.
1969	538.190	27.142	52.184	.	.	.
1970	513.023	27.297	52.483	.	.	.
1971	457.393	29.995	57.670	.	.	.
1972	406.641	32.693	62.857	.	.	.
1973	296.560	35.391	68.044	.	.	.
1974	478.352	38.088	73.231	.	.	.
1975	600.790	40.786	78.418	.	.	.
1976	571.504	41.246	79.303	.	.	.
1977	596.339	41.707	80.187	.	.	.
1978	594.356	42.167	81.072	.	.	.
1979	420.936	42.627	81.957	.	.	.
1980	385.485	43.087	82.842	.	.	.
1981	378.759	36.031	93.458	.	.	4.435
1982	308.445	19.553	36.294	.	.	4.435
1983	316.818	30.698	68.469	.	.	4.435
1984	253.431	31.146	212.547	.	0.069	61.825
1985	250.824	50.336	288.971	.	0.111	64.088
1986	219.440	16.625	100.736	.	0.037	64.088
1987	191.701	24.996	47.373	.	0.055	64.088
1988	173.689	36.527	80.821	.	0.08	50.274
1989	266.942	23.453	97.147	.	0.052	19.383
1990	226.542	20.919	12.092	.	0.046	19.383
1991	143.546	13.857	34.717	.	0.03	19.383
1992	104.374	5.301	51.908	19.603	2.51	27.994
1993	220.153	7.347	11.326	16.725	3.478	68.149
1994	195.319	8.225	18.313	21.134	3.894	66.54
1995	177.312	8.826	13.482	21.068	4.178	50.89
1996	138.671	5.543	9.342	20.727	2.624	20.445
1997	110.595	5.770	34.238	22.392	2.732	16.574
1998	89.602	4.741	13.015	16.171	2.244	26.789
1999	93.595	6.836	39.579	13.641	3.236	162.71
2000	104.165	8.437	45.347	14.552	3.994	248.597
2001	196.697	12.028	31.587	15.141	5.694	202.665
2002	187.967	12.931	35.062	29.848	6.122	123.362
2003	138.342	5.706	25.977	8.372	2.701	159.329
2004	172.083	10.842	28.914	2.425	18.79	199.638
2005	129.700	8.907	29.443	10.177	9.876	72.855
2006	86.382	5.945	26.769	4.817	17.233	119.735
2007	114.973	6.889	17.646	13.778	71.886	288.276
2008	252.146	18.943	81.638	12.553	73.609	511.984
2009	362.386	21.507	54.666	14.466	57.327	240.516
2010	6.448	0.477	0.062	17.438	38.443	138.478
2011	− − −	− − −	0.062	40.107	41.391	33.484
2012	8.142	2.127	15.628	19.214	46.782	142.961
2013	31.600	1.520	7.588	19.302	46.74	83.992
2014	65.443	5.904	28.186	27.008	46.612	285.962

Table 4. Observed indices of abundance and CVs from commercial line (cH), headboat (HB), combined chevon trap and video (CVID), and headboat discard (HB.D).

Year	cH	cH CV	HB	HB CV	CVID	CVID CV	HB.D	HB.D CV
1976	.	.	2.37	0.2	.	.	.	.
1977	.	.	2.16	0.2	.	.	.	.
1978	.	.	2.13	0.2	.	.	.	.
1979	.	.	2.23	0.2	.	.	.	.
1980	.	.	1.45	0.2	.	.	.	.
1981	.	.	2.95	0.2	.	.	.	.
1982	.	.	1.20	0.2	.	.	.	.
1983	.	.	1.64	0.2	.	.	.	.
1984	.	.	1.42	0.2	.	.	.	.
1985	.	.	2.07	0.2	.	.	.	.
1986	.	.	0.48	0.2	.	.	.	.
1987	.	.	0.58	0.2	.	.	.	.
1988	.	.	0.56	0.2	.	.	.	.
1989	.	.	0.90	0.2	.	.	.	.
1990	.	.	0.87	0.2	.	.	.	.
1991	.	.	0.69	0.2	.	.	.	.
1992	.	.	0.08	0.2	.	.	.	.
1993	1.09	0.2	0.16	0.2	.	.	.	.
1994	0.89	0.2	0.26	0.2	.	.	.	.
1995	0.89	0.2	0.28	0.2	.	.	.	.
1996	0.61	0.2	0.25	0.2	.	.	.	.
1997	0.59	0.2	0.27	0.2	.	.	.	.
1998	0.66	0.2	0.24	0.2	.	.	.	.
1999	0.80	0.2	0.29	0.2	.	.	.	.
2000	0.74	0.2	0.41	0.2	.	.	.	.
2001	1.27	0.2	0.76	0.2	.	.	.	.
2002	1.38	0.2	0.88	0.2	.	.	.	.
2003	1.04	0.2	0.52	0.2	.	.	.	.
2004	1.42	0.2	0.76	0.2	.	.	.	.
2005	1.19	0.2	0.76	0.2	.	.	0.33	0.34
2006	0.60	0.2	0.43	0.2	.	.	0.4	0.4
2007	0.67	0.2	0.44	0.2	.	.	2.49	0.19
2008	1.22	0.2	1.71	0.2	.	.	1.99	0.29
2009	1.94	0.2	1.81	0.2	.	.	0.95	0.26
2010	.	.	.	.	0.90	0.26	0.44	0.29
2011	.	.	.	.	0.66	0.23	0.46	0.34
2012	.	.	.	.	1.10	0.18	1.16	0.25
2013	.	.	.	.	0.87	0.20	0.96	0.27
2014	.	.	.	.	1.47	0.17	0.82	0.28

Table 5. Sample sizes (number of trips) of length compositions (len) or age compositions (age) by survey or fleet. Data sources are commercial lines (cH), headboat (HB), headboat discard (HB.D), general recreational (GR),and MARMAP chevron trap (CVT).

Year	len.cH	len.cH.D	len.HB.D	age.cH	age.HB	age.GR	age.CVT
1978	.	.	.	.	80	.	.
1979	.	.	.	.	31	.	.
1980	.	.	.	.	30	.	.
1981	.	.	.	.	141	.	.
1982	.	.	.	.	55	.	.
1983	.	.	.	.	167	.	.
1984	125	.	.	.	166	.	.
1985	139	.	.	.	160	.	.
1986	94	.	.	.	97	.	.
1987	89	.	.	.	60	.	.
1988	84	.	.	.	.	.	.
1989	88	.	.	.	.	.	.
1990	63	.	.	11	23	.	.
1991	106	.	.	.	13	.	.
1992	82	.	.	11	.	.	.
1993	.	.	.	.	.	.	.
1994	.	.	.	14	.	.	.
1995	.	.	.	.	.	.	.
1996	.	.	.	48	.	.	.
1997	.	.	.	45	.	.	.
1998	.	.	.	14	.	.	.
1999	.	.	.	15	.	.	.
2000	.	.	.	28	.	.	.
2001	.	.	.	23	.	15	.
2002	.	.	.	.	.	84	.
2003	.	.	.	10	.	91	.
2004	.	.	.	25	.	83	.
2005	.	.	37	53	22	78	.
2006	.	.	29	84	49	26	.
2007	.	.	64	132	34	.	.
2008	.	.	61	158	47	.	.
2009	.	13	56	263	241	58	.
2010	.	.	50	.	.	.	73
2011	.	.	48	.	.	.	70
2012	.	.	56	39	40	121	148
2013	.	13	60	109	35	139	139
2014	.	.	56	64	49	315	150

Table 6. Coefficients of variation used for the MCB bootstraps of landings and discards. Commercial handline landings (cv.L.cH), headboat landings (cv.L.HB), general recreational landings (cv.L.GR), commercial handline discards (cv.D.cH), headboat discards (cv.D.HB), and general recreational discards (cv.D.GR).

Year	CV.L.cH	CV.L.HB	CV.L.GR	CV.D.cH	CV.D.HB	CV.D.GR
1950	0.25	–	–	–	–	–
1951	0.25	–	–	–	–	–
1952	0.25	–	–	–	–	–
1953	0.25	–	–	–	–	–
1954	0.25	–	–	–	–	–
1955	0.25	0.59	0.59	–	–	–
1956	0.25	0.59	0.59	–	–	–
1957	0.25	0.59	0.59	–	–	–
1958	0.25	0.59	0.59	–	–	–
1959	0.25	0.59	0.59	–	–	–
1960	0.25	0.59	0.59	–	–	–
1961	0.25	0.59	0.59	–	–	–
1962	0.20	0.59	0.59	–	–	–
1963	0.20	0.59	0.59	–	–	–
1964	0.20	0.59	0.59	–	–	–
1965	0.20	0.59	0.59	–	–	–
1966	0.20	0.59	0.59	–	–	–
1967	0.20	0.59	0.59	–	–	–
1968	0.20	0.59	0.59	–	–	–
1969	0.20	0.59	0.59	–	–	–
1970	0.20	0.59	0.59	–	–	–
1971	0.20	0.59	0.59	–	–	–
1972	0.20	0.59	0.59	–	–	–
1973	0.20	0.59	0.59	–	–	–
1974	0.20	0.59	0.59	–	–	–
1975	0.20	0.59	0.59	–	–	–
1976	0.20	0.59	0.59	–	–	–
1977	0.20	0.59	0.59	–	–	–
1978	0.10	0.59	0.59	–	–	–
1979	0.10	0.59	0.59	–	–	–
1980	0.10	0.59	0.59	–	–	–
1981	0.10	0.15	0.27	–	–	1.00
1982	0.10	0.15	0.34	–	–	1.00
1983	0.10	0.15	0.18	–	–	1.00
1984	0.10	0.15	0.22	–	0.20	0.56
1985	0.10	0.15	0.20	–	0.20	1.34
1986	0.05	0.15	0.29	–	0.20	1.00
1987	0.05	0.15	0.20	–	0.20	1.00
1988	0.05	0.15	0.28	–	0.20	1.33
1989	0.05	0.15	0.21	–	0.20	1.18
1990	0.05	0.15	0.29	–	0.20	1.00
1991	0.05	0.15	0.31	–	0.20	1.00
1992	0.05	0.15	0.19	0.20	0.20	0.79
1993	0.05	0.15	0.22	0.20	0.20	0.68
1994	0.05	0.15	0.27	0.20	0.20	0.81
1995	0.05	0.15	0.29	0.20	0.20	0.53
1996	0.05	0.10	0.42	0.20	0.20	1.00
1997	0.05	0.10	0.52	0.20	0.20	0.54
1998	0.05	0.10	0.24	0.20	0.20	0.96
1999	0.05	0.10	0.23	0.20	0.20	0.47
2000	0.05	0.10	0.23	0.20	0.20	0.45
2001	0.05	0.10	0.18	0.20	0.20	0.42
2002	0.05	0.10	0.17	0.20	0.20	0.56
2003	0.05	0.10	0.20	0.20	0.20	0.47
2004	0.05	0.10	0.21	0.20	0.20	0.29
2005	0.05	0.10	0.24	0.20	0.20	0.23
2006	0.05	0.10	0.26	0.20	0.20	0.31
2007	0.05	0.10	0.24	0.20	0.20	0.26
2008	0.05	0.05	0.27	0.20	0.20	0.36
2009	0.05	0.05	0.25	0.20	0.20	0.38
2010	0.05	0.05	1.00	0.20	0.20	0.39
2011	0.05	0.05	1.00	0.20	0.20	0.34
2012	0.05	0.05	0.17	0.20	0.20	0.39
2013	0.05	0.05	0.18	0.20	0.20	0.31
2014	0.05	0.05	0.11	0.20	0.20	0.21

Table 7. Estimated total abundance at age (1000 fish) at start of year.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
1950	448.20	247.12	169.84	125.87	97.87	78.34	63.91	52.77	43.96	36.88	31.07	26.27	22.29	18.94	16.12	13.74	11.72	10.00	8.55	50.37	1573.85
1951	448.20	247.12	169.75	125.71	97.75	78.24	63.83	52.70	43.91	36.84	31.03	26.24	22.26	18.92	16.10	13.72	11.71	9.99	8.54	50.30	1572.86
1952	448.19	247.09	169.04	124.30	96.54	77.27	63.04	52.05	43.36	36.38	30.64	25.91	21.98	18.68	15.90	13.55	11.56	9.87	8.43	49.68	1563.45
1953	448.19	247.11	169.61	124.90	96.34	77.03	62.84	51.88	43.22	36.26	30.55	25.83	21.91	18.62	15.85	13.51	11.53	9.84	8.40	49.52	1562.94
1954	448.18	247.10	169.55	125.18	96.70	76.79	62.57	51.66	43.04	36.11	30.41	25.72	21.82	18.54	15.78	13.45	11.48	9.79	8.37	49.31	1561.56
1955	448.17	247.05	168.47	123.08	95.28	75.76	61.32	50.57	42.13	35.34	29.77	25.18	21.36	18.15	15.44	13.17	11.23	9.59	8.19	48.26	1547.50
1956	448.13	246.27	161.68	115.37	88.99	71.61	58.66	48.54	40.74	34.41	29.12	24.63	20.89	17.75	15.10	12.88	10.99	9.38	8.01	47.21	1510.35
1957	448.09	246.14	160.15	109.64	82.67	66.38	55.10	46.21	38.97	33.19	28.29	24.04	20.39	17.33	14.74	12.57	10.73	9.15	7.82	46.08	1477.69
1958	448.01	245.87	156.61	103.41	74.79	58.79	48.77	41.52	35.54	30.44	26.19	22.41	19.10	16.23	13.81	11.77	10.05	8.57	7.32	43.16	1422.36
1959	447.91	245.76	156.56	102.08	71.33	53.86	43.82	37.35	32.49	28.27	24.48	21.14	18.15	15.50	13.18	11.24	9.59	8.19	6.99	41.21	1389.12
1960	447.81	245.57	154.94	100.16	69.17	50.53	39.56	33.11	28.88	25.57	22.50	19.56	16.95	14.58	12.46	10.62	9.06	7.73	6.61	38.94	1354.30
1961	447.69	245.37	153.37	97.47	66.79	48.29	36.64	29.56	25.35	22.52	20.19	17.84	15.55	13.50	11.62	9.96	8.50	7.25	6.19	36.50	1320.15
1962	447.52	245.05	150.43	92.97	62.68	45.07	33.93	26.59	22.02	19.27	17.35	15.61	13.84	12.09	10.50	9.06	7.77	6.63	5.66	33.38	1277.43
1963	447.34	244.81	149.35	90.83	59.67	42.32	31.76	24.75	19.96	16.89	15.00	13.56	12.23	10.87	9.50	8.27	7.14	6.12	5.23	30.83	1246.44
1964	447.18	244.59	148.74	90.39	58.55	40.55	30.08	23.43	18.82	15.53	13.35	11.90	10.79	9.76	8.67	7.60	6.62	5.72	4.91	28.93	1226.11
1965	446.99	244.28	146.42	87.60	56.77	38.85	28.22	21.77	17.51	14.42	12.10	10.44	9.33	8.48	7.68	6.84	6.00	5.23	4.52	26.75	1200.20
1966	446.77	243.94	144.01	83.93	53.62	36.81	26.49	20.07	16.03	13.24	11.10	9.35	8.09	7.25	6.59	5.98	5.33	4.68	4.08	24.42	1171.76
1967	446.51	243.71	142.75	81.39	50.68	34.33	24.82	18.65	14.64	12.02	10.11	8.51	7.19	6.23	5.59	5.09	4.62	4.12	3.62	22.08	1146.66
1968	446.14	243.33	139.35	76.51	46.59	30.80	22.00	16.63	12.97	10.47	8.76	7.40	6.24	5.28	4.59	4.12	3.76	3.41	3.05	19.01	1110.41
1969	445.55	242.80	135.12	69.95	41.00	26.56	18.56	13.89	10.91	8.77	7.22	6.06	5.14	4.34	3.68	3.20	2.88	2.63	2.39	15.44	1066.07
1970	444.99	242.56	137.16	71.34	39.54	24.69	16.93	12.41	9.67	7.83	6.42	5.31	4.47	3.79	3.21	2.73	2.37	2.14	1.95	13.24	1052.74
1971	444.50	242.22	136.61	71.99	40.09	23.68	15.66	11.27	8.60	6.91	5.71	4.70	3.90	3.29	2.80	2.37	2.01	1.75	1.58	11.25	1040.89
1972	444.02	241.66	134.40	70.33	39.80	23.72	14.90	10.38	7.81	6.16	5.06	4.20	3.47	2.88	2.43	2.07	1.76	1.50	1.30	9.54	1027.37
1973	443.53	241.07	131.86	67.68	38.16	23.21	14.78	9.83	7.18	5.60	4.53	3.74	3.11	2.57	2.14	1.81	1.54	1.31	1.11	8.09	1012.86
1974	443.13	240.54	130.42	66.37	36.85	22.43	14.64	9.92	6.95	5.28	4.23	3.43	2.84	2.37	1.96	1.63	1.39	1.18	1.00	7.05	1003.62
1975	442.41	239.62	123.15	58.64	32.34	19.50	12.83	8.97	6.43	4.70	3.68	2.96	2.41	2.00	1.67	1.38	1.16	0.98	0.84	5.71	971.39
1976	440.88	238.23	113.91	47.92	24.83	15.02	9.89	7.04	5.26	3.96	3.00	2.36	1.90	1.55	1.29	1.08	0.89	0.75	0.63	4.23	924.61
1977	438.36	236.64	107.35	40.16	18.46	10.57	7.05	5.07	3.88	3.06	2.40	1.82	1.44	1.16	0.95	0.79	0.66	0.55	0.46	2.99	883.81
1978	490.78	234.27	98.35	32.15	13.18	6.76	4.31	3.17	2.47	2.01	1.66	1.30	0.99	0.78	0.63	0.52	0.43	0.36	0.30	1.89	896.34
1979	363.96	260.76	87.23	23.53	8.46	3.92	2.27	1.62	1.30	1.09	0.93	0.77	0.61	0.46	0.37	0.30	0.24	0.20	0.17	1.03	759.23
1980	539.19	193.18	96.76	21.20	6.32	2.58	1.36	0.88	0.69	0.60	0.53	0.45	0.38	0.30	0.23	0.18	0.15	0.12	0.10	0.59	865.79
1981	186.41	284.13	63.96	19.23	4.71	1.63	0.77	0.46	0.34	0.29	0.27	0.23	0.20	0.17	0.13	0.10	0.08	0.07	0.05	0.31	563.53
1982	307.89	97.40	88.82	11.21	3.77	1.07	0.43	0.23	0.16	0.13	0.11	0.11	0.09	0.08	0.07	0.05	0.04	0.03	0.03	0.15	511.87
1983	878.93	163.24	36.96	20.86	2.86	1.07	0.34	0.15	0.09	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.01	0.07	1104.92
1984	999.37	458.86	45.27	4.82	3.02	0.48	0.21	0.08	0.04	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	1512.31
1985	458.06	507.73	129.72	7.48	0.92	0.69	0.13	0.07	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	1104.93
1986	228.35	225.81	125.77	18.96	1.31	0.20	0.19	0.05	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	600.73
1987	784.38	112.09	87.32	37.54	6.38	0.50	0.09	0.09	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	1028.46
1988	576.82	406.58	50.66	32.13	15.16	2.84	0.24	0.05	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	1084.58
1989	215.42	301.94	194.02	20.83	14.48	7.51	1.54	0.14	0.03	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	755.97
1990	69.98	113.91	147.92	82.21	9.63	7.31	4.12	0.91	0.09	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	436.13
1991	63.82	36.48	66.17	84.38	50.19	6.19	4.90	2.86	0.65	0.07	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	315.75
1992	338.34	31.78	18.77	33.07	46.35	29.83	3.94	3.32	2.03	0.48	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	507.98
1993	118.87	172.64	19.71	8.50	10.74	16.91	13.01	2.04	1.98	1.34	0.34	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	366.14
1994	210.63	54.54	100.84	8.76	2.76	3.87	6.95	5.98	1.02	1.05	0.74	0.19	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	397.38
1995	97.19	97.24	31.92	46.52	2.99	1.03	1.63	3.26	3.05	0.55	0.59	0.43	0.11	0.01	0.00	0.00	0.00	0.00	0.00	0.00	286.55
1996	253.91	42.82	54.98	14.64	16.41	1.17	0.45	0.80	1.72	1.71	0.32	0.35	0.26	0.07	0.01	0.00	0.00	0.00	0.00	0.00	389.61
1997	172.65	129.31	27.19	29.34	6.28	7.54	0.58	0.25	0.46	1.03	1.05	0.20	0.22	0.16	0.04	0.00	0.00	0.00	0.00	0.00	376.30
1998	322.66	87.46	77.95	9.48	5.88	1.46	2.22	0.22	0.11	0.23	0.58	0.62	0.12	0.14	0.10	0.03	0.00	0.00	0.00	0.00	509.24
1999	436.64	167.71	56.50	42.70	4.21	2.80	0.76	1.26	0.13	0.07	0.15	0.38	0.42	0.08	0.09	0.07	0.02	0.00	0.00	0.00	714.00
2000	442.42	203.70	98.01	24.16	12.76	1.42	1.13	0.36	0.69	0.08	0.04	0.10	0.26	0.29	0.06	0.06	0.05	0.01	0.00	0.00	785.62
2001	323.07	192.88	113.53	41.23	7.21	4.30	0.57	0.53	0.20	0.41	0.05	0.03	0.07	0.18	0.20	0.04	0.05	0.03	0.01	0.00	684.60
2002	268.67	139.89	108.50	52.48	14.48	2.78	1.88	0.28	0.29	0.11	0.25	0.03	0.02	0.04	0.11	0.13	0.03	0.03	0.02	0.01	590.04
2003	346.83	119.88	79.98	51.09	19.20	5.86	1.28	0.97	0.16	0.17	0.07	0.16	0.02	0.01	0.03	0.08	0.08	0.02	0.02	0.02	625.93
2004	128.50	157.16	70.55	43.92	24.16	9.77	3.26	0.77	0.63	0.11	0.12	0.05	0.12	0.01	0.01	0.02	0.06	0.06	0.01	0.03	439.31
2005	52.34	44.17	75.58	32.50	17.10	10.48	4.79	1.78	0.46	0.40	0.07	0.08	0.03	0.08	0.01	0.01	0.01	0.04	0.04	0.03	240.01
2006	942.72	17.68	20.67	33.07	11.87	7.06	4.99	2.59	1.06	0.30	0.27	0.05	0.06	0.02	0.06	0.01	0.00	0.01	0.03	0.05	1042.56
2007	653.29	480.63	11.07	9.31	10.57	4.26	3.01	2.49	1.48	0.67	0.20	0.19	0.03	0.04	0.02	0.04	0.01	0.00	0.01	0.06	1177.37
2008	736.26	296.64	279.22	4.79	2.89	3.68	1.72	1.39	1.28	0.82	0.39	0.12	0.11	0.02	0.03	0.01	0.02	0.00	0.00	0.04	1329.44
2009	113.51	293.11	154.42	105.26	1.19	0.81	1.25	0.70	0.65	0.67	0.46	0.23	0.07	0.07	0.01	0.02	0.01	0.02	0.00	0.02	672.46
2010	144.25	39.53	140.62	62.97	32.07	0.41	0.32	0.56	0.35	0.35	0.37	0.26	0.13	0.04	0.04	0.01	0.01	0.00	0.01	0.02	422.31
2011	212.06	67.20	22.10	82.13	38.03	20.31	0.27	0.23	0.42	0.27	0.28	0.30	0.21	0.10	0.03	0.03	0.01	0.01	0.00	0.02	443.99
2012	227.48	110.51	42.57	14.38	54.64	26.14	14.42	0.20	0.17	0.32	0.21	0.21	0.23	0.16	0.08	0.03	0.02	0.00	0.01	0.02	491.78
2013	506.39	109.61	63.60	24.45	7.85	29.93	14.96	8.65	0.12	0.11	0.21	0.14	0.14	0.15	0.11	0.05	0.02	0.02	0.00	0.02	766.53
2014	859.61	262.50	69.29	41.06	15.43	5.01	19.69	10.12	6.00	0.09	0.08	0.15	0.10	0.10	0.11	0.08	0.04	0.01	0.01	0.01	1289.51
2015	431.84	430.16	156.09	38.69	19.63	7.06	2.36	9.65	5.14	3.13	0.05	0.04	0.08	0.05	0.06	0.06	0.04	0.02	0.01	0.01	1104.18

Table 8. Estimated biomass at age (mt) at start of year

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
1950	237.3	347.9	432.7	476.4	489.3	479.4	454.3	419.9	381.2	341.6	302.7	266.3	232.9	202.7	175.7	152.0	131.2	113.0	97.2	575.9	6309.5
1951	237.3	347.9	432.5	475.8	488.7	478.8	453.7	419.4	380.7	341.1	302.3	265.9	232.6	202.5	175.5	151.8	131.0	112.8	97.1	575.1	6302.5
1952	237.3	347.8	430.7	470.5	482.6	472.8	448.1	414.2	376.0	336.9	298.6	262.6	229.7	199.9	173.3	149.9	129.4	111.4	95.8	568.0	6235.5
1953	237.3	347.9	432.1	472.7	481.7	471.3	446.7	412.8	374.8	335.8	297.6	261.8	229.0	199.3	172.8	149.4	129.0	111.1	95.5	566.2	6224.8
1954	237.3	347.8	432.0	473.8	483.5	469.9	444.8	411.1	373.2	334.4	296.3	260.7	228.0	198.5	172.0	148.8	128.4	110.6	95.1	563.8	6209.9
1955	237.3	347.8	429.2	465.9	476.3	463.6	435.9	402.4	365.3	327.3	290.1	255.2	223.2	194.3	168.4	145.7	125.7	108.2	93.1	551.8	6106.4
1956	237.2	346.7	411.9	436.7	444.9	438.2	417.0	386.2	353.3	318.7	283.7	249.6	218.3	190.0	164.7	142.5	123.0	105.9	91.1	539.7	5899.1
1957	237.2	346.5	408.0	415.0	413.3	406.2	391.7	367.7	337.9	307.4	275.7	243.6	213.1	185.5	160.8	139.1	120.0	103.4	88.9	526.9	5687.7
1958	237.2	346.1	399.0	391.4	373.9	359.7	346.7	330.4	308.1	281.9	255.1	227.1	199.6	173.7	150.6	130.2	112.4	96.8	83.3	493.4	5296.7
1959	237.1	346.0	398.9	386.4	356.6	329.6	311.5	297.2	281.7	261.8	238.5	214.3	189.6	165.9	143.8	124.4	107.3	92.4	79.5	471.1	5033.6
1960	237.1	345.7	394.7	379.1	345.8	309.2	281.2	263.5	250.4	236.8	219.3	198.3	177.1	156.0	135.8	117.5	101.4	87.3	75.1	445.2	4756.4
1961	237.0	345.4	390.7	368.9	333.9	295.5	260.5	235.2	219.8	208.6	196.7	180.8	162.5	144.5	126.7	110.1	95.1	81.9	70.4	417.3	4481.6
1962	236.9	345.0	383.2	351.9	313.4	275.8	241.2	211.6	190.9	178.5	169.1	158.2	144.6	129.4	114.5	100.3	86.9	74.9	64.4	381.6	4152.2
1963	236.8	344.6	380.5	343.8	298.3	258.9	225.8	197.0	173.0	156.4	146.1	137.4	127.8	116.3	103.6	91.5	79.9	69.2	59.5	352.5	3899.1
1964	236.7	344.3	378.9	342.1	292.7	248.1	213.8	186.4	163.2	143.8	130.1	120.6	112.7	104.4	94.6	84.1	74.1	64.6	55.8	330.8	3722.0
1965	236.6	343.9	373.0	331.6	283.8	237.7	200.6	173.3	151.9	133.6	117.9	105.8	97.5	90.7	83.7	75.7	67.1	59.0	51.4	305.9	3520.6
1966	236.5	343.4	366.9	317.7	268.1	225.2	188.3	159.7	139.0	122.6	108.1	94.7	84.5	77.6	71.9	66.1	59.7	52.8	46.4	279.2	3308.4
1967	236.4	343.1	363.7	308.1	253.4	210.1	176.4	148.4	126.9	111.3	98.5	86.2	75.1	66.7	60.9	56.3	51.7	46.5	41.2	252.5	3113.3
1968	236.2	342.5	355.0	289.6	232.9	188.5	156.4	132.3	112.4	96.9	85.3	74.9	65.2	56.5	50.0	45.6	42.1	38.5	34.6	217.3	2853.1
1969	235.9	341.8	344.2	264.7	205.0	162.5	131.9	110.6	94.6	81.2	70.3	61.4	53.7	46.5	40.1	35.4	32.2	29.6	27.1	176.5	2545.4
1970	235.6	341.5	349.4	270.0	197.7	151.1	120.3	98.8	83.8	72.5	62.5	53.8	46.7	40.6	35.0	30.2	26.6	24.1	22.2	151.4	2413.7
1971	235.3	341.0	348.0	272.5	200.4	144.9	111.3	89.7	74.6	64.0	55.6	47.6	40.7	35.2	30.5	26.2	22.5	19.8	18.0	128.6	2306.5
1972	235.1	340.2	342.4	266.2	199.0	145.1	105.9	82.6	67.7	57.0	49.3	42.6	36.2	30.8	26.5	22.9	19.7	16.9	14.8	109.0	2209.9
1973	234.8	339.4	335.9	256.2	190.8	142.0	105.0	78.2	62.3	51.9	44.1	37.9	32.5	27.5	23.3	20.0	17.3	14.8	12.7	92.5	2119.0
1974	234.6	338.6	332.3	251.2	184.2	137.2	104.1	78.9	60.2	48.9	41.2	34.8	29.7	25.4	21.4	18.1	15.5	13.3	11.4	80.7	2061.7
1975	234.2	337.3	313.7	222.0	161.7	119.3	91.2	71.4	55.8	43.6	35.9	30.0	25.2	21.4	18.2	15.3	12.9	11.1	9.5	65.2	1894.9
1976	233.4	335.4	290.2	181.4	124.1	91.9	70.3	56.0	45.6	36.7	29.2	23.9	19.9	16.6	14.0	11.9	10.0	8.4	7.2	48.4	1654.6
1977	232.1	333.1	273.5	152.0	92.3	64.7	50.1	40.3	33.6	28.3	23.4	18.5	15.0	12.4	10.3	8.7	7.4	6.2	5.2	34.2	1441.3
1978	259.8	329.8	250.6	121.7	65.9	41.4	30.7	25.2	21.4	18.6	16.1	13.2	10.4	8.4	6.9	5.7	4.8	4.1	3.4	21.6	1259.9
1979	192.7	367.1	222.2	89.1	42.3	24.0	16.1	12.9	11.3	10.1	9.1	7.8	6.3	5.0	4.0	3.3	2.7	2.3	1.9	11.8	1041.9
1980	285.4	271.9	246.5	80.2	31.6	15.8	9.6	7.0	6.0	5.6	5.1	4.6	3.9	3.2	2.5	2.0	1.6	1.4	1.1	6.8	992.0
1981	98.7	400.0	163.0	72.8	23.5	9.9	5.5	3.7	2.9	2.7	2.6	2.4	2.1	1.8	1.4	1.1	0.9	0.7	0.6	3.5	799.8
1982	163.0	137.1	226.3	42.4	18.8	6.6	3.1	1.9	1.4	1.2	1.1	1.1	1.0	0.9	0.7	0.6	0.5	0.4	0.3	1.7	609.8
1983	465.3	229.8	94.2	79.0	14.3	6.5	2.4	1.2	0.8	0.6	0.5	0.5	0.5	0.4	0.4	0.3	0.2	0.2	0.2	0.8	897.9
1984	529.1	645.9	115.3	18.3	15.1	3.0	1.5	0.6	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	1330.7
1985	242.5	714.7	330.5	28.3	4.6	4.3	1.0	0.6	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.2	1327.6
1986	120.9	317.9	320.4	71.8	6.6	1.2	1.4	0.4	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	841.4
1987	415.2	157.8	222.5	142.1	31.9	3.1	0.6	0.7	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	974.6
1988	305.4	572.3	129.1	121.6	75.8	17.4	1.7	0.4	0.5	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1224.6
1989	114.0	425.0	494.3	78.8	72.4	45.9	10.9	1.1	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1243.5
1990	37.0	160.3	376.8	311.2	48.1	44.7	29.3	7.2	0.8	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1016.2
1991	33.8	51.4	168.6	319.4	250.9	37.9	34.8	22.7	5.6	0.6	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	926.2
1992	179.1	44.7	47.8	125.2	231.7	182.6	28.0	26.4	17.6	4.4	0.5	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	888.4
1993	62.9	243.0	50.2	32.2	53.7	103.5	92.4	16.2	17.1	12.4	3.3	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	687.7
1994	111.5	76.8	256.9	33.2	13.8	23.7	49.4	47.6	8.9	9.7	7.2	1.9	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	641.0
1995	51.5	136.9	81.3	176.1	14.9	6.3	11.6	25.9	26.5	5.1	5.8	4.3	1.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	547.6
1996	134.4	60.3	140.1	55.4	82.0	7.1	3.2	6.3	14.9	15.8	3.1	3.6	2.7	0.7	0.1	0.0	0.0	0.0	0.0	0.0	529.9
1997	91.4	182.0	69.3	111.1	31.4	46.1	4.2	2.0	4.0	9.5	10.2	2.0	2.3	1.7	0.5	0.1	0.0	0.0	0.0	0.0	567.7
1998	170.8	123.1	198.6	35.9	29.4	8.9	15.8	1.7	0.9	2.2	5.6	6.3	1.3	1.5	1.1	0.3	0.0	0.0	0.0	0.0	603.3
1999	231.2	236.1	143.9	161.6	21.1	17.1	5.4	10.0	1.1	0.6	1.5	3.9	4.4	0.9	1.0	0.8	0.2	0.0	0.0	0.0	840.8
2000	234.2	286.7	249.7	91.4	63.8	8.7	8.0	2.9	6.0	0.7	0.4	1.0	2.8	3.1	0.6	0.7	0.5	0.1	0.0	0.0	961.6
2001	171.0	271.5	289.2	156.1	36.1	26.3	4.1	4.3	1.7	3.8	0.5	0.3	0.7	2.0	2.2	0.4	0.5	0.4	0.1	0.0	971.2
2002	142.2	196.9	276.4	198.6	72.4	17.0	13.4	2.2	2.5	1.0	2.4	0.3	0.2	0.5	1.3	1.4	0.3	0.3	0.2	0.1	929.7
2003	183.6	168.8	203.8	193.4	96.0	35.8	9.1	7.7	1.4	1.6	0.7	1.6	0.2	0.1	0.3	0.8	0.9	0.2	0.2	0.2	906.6
2004	68.0	221.2	179.7	166.2	120.8	59.8	23.2	6.2	5.4	1.0	1.2	0.5	1.2	0.2	0.1	0.2	0.6	0.7	0.1	0.3	856.7
2005	27.7	62.2	192.6	123.0	85.5	64.1	34.1	14.2	4.0	3.7	0.7	0.8	0.4	0.8	0.1	0.1	0.2	0.4	0.5	0.3	615.3
2006	499.1	24.9	52.7	125.2	59.4	43.2	35.5	20.6	9.2	2.7	2.6	0.5	0.6	0.3	0.6	0.1	0.0	0.1	0.3	0.6	878.1
2007	345.8	676.6	28.2	35.3	52.8	26.1	21.4	19.9	12.8	6.2	1.9	1.9	0.4	0.4	0.2	0.4	0.1	0.0	0.1	0.6	1231.1
2008	389.8	417.6	711.4	18.1	14.5	22.5	12.3	11.1	11.1	7.6	3.8	1.2	1.2	0.2	0.3	0.1	0.3	0.0	0.0	0.4	1623.4
2009	60.1	412.6	393.4	398.4	5.9	5.0	8.9	5.6	5.7	6.2	4.4	2.3	0.7	0.7	0.1	0.2	0.1	0.2	0.0	0.3	1310.8
2010	76.4	55.6	358.3	238.3	160.3	2.5	2.3	4.5	3.0	3.2	3.6	2.6	1.4	0.4	0.4	0.1	0.1	0.0	0.1	0.2	913.4
2011	112.3	94.6	56.3	310.9	190.1	124.3	1.9	1.8	3.6	2.5	2.7	3.0	2.2	1.1	0.4	0.4	0.1	0.1	0.0	0.2	908.3
2012	120.4	155.6	108.4	54.4	273.2	160.0	102.5	1.6	1.5	2.9	2.0	2.2	2.4	1.7	0.9	0.3	0.3	0.1	0.1	0.2	990.5
2013	268.1	154.3	162.0	92.5	39.2	183.2	106.4	68.9	1.1	1.0	2.0	1.4	1.5	1.6	1.2	0.6	0.2	0.2	0.0	0.2	1085.6
2014	455.1	369.5	176.5	155.4	77.2	30.7	139.9	80.6	52.0	0.8	0.8	1.5	1.0	1.1	1.2	0.9	0.4	0.1	0.1	0.2	1545.1
2015	228.6	605.5	397.7	146.4	98.1	43.2	16.8	76.8	44.6	29.0	0.5	0.4	0.8	0.6	0.6	0.7	0.5	0.2	0.1	0.2	1691.2

Table 9. Estimated biomass at age (1000 lb) at start of year

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
1950	523.2	767.0	953.9	1050.3	1078.7	1056.9	1001.6	925.7	840.4	753.1	667.3	587.1	513.5	446.9	387.4	335.1	289.2	249.1	214.3	1269.6	13910.0
1951	523.2	767.0	953.5	1049.0	1077.4	1055.6	1000.2	924.6	839.3	752.0	666.5	586.2	512.8	446.4	386.9	334.7	288.8	248.7	214.1	1267.9	13894.6
1952	523.2	766.8	949.5	1037.3	1063.9	1042.3	987.9	913.2	828.9	742.7	658.3	578.9	506.4	440.7	382.1	330.5	285.3	245.6	211.2	1252.2	13746.9
1953	523.2	767.0	952.6	1042.1	1062.0	1039.0	984.8	910.1	826.3	740.3	656.1	577.2	504.9	439.4	381.0	329.4	284.4	244.9	210.5	1248.3	13723.3
1954	523.2	766.8	952.4	1044.5	1065.9	1036.0	980.6	906.3	822.8	737.2	653.2	574.7	502.7	437.6	379.2	328.0	283.1	243.8	209.7	1243.0	13690.5
1955	523.2	766.8	946.2	1027.1	1050.1	1022.1	961.0	887.1	805.3	721.6	639.6	562.6	492.1	428.4	371.3	321.2	277.1	238.5	205.3	1216.5	13462.3
1956	522.9	764.3	908.1	962.8	980.8	966.1	919.3	851.4	778.9	702.6	625.5	550.3	481.3	418.9	363.1	314.2	271.2	233.5	200.8	1189.8	13005.3
1957	522.9	763.9	899.5	914.9	911.2	895.5	863.5	810.6	744.9	677.7	607.8	537.0	469.8	409.0	354.5	306.7	264.6	228.0	196.0	1161.6	12539.2
1958	522.9	763.0	879.6	862.9	824.3	793.0	764.3	728.4	679.2	621.5	562.4	500.7	440.0	382.9	332.0	287.0	247.8	213.4	183.6	1087.8	11677.2
1959	522.7	762.8	879.4	851.9	786.2	726.6	686.7	655.2	621.0	577.2	525.8	472.5	418.0	365.7	317.0	274.3	236.6	203.7	175.3	1038.6	11097.2
1960	522.7	762.1	870.2	835.8	762.4	681.7	619.9	580.9	552.0	522.1	483.5	437.2	390.4	343.9	299.4	259.0	223.5	192.5	165.6	981.5	10486.1
1961	522.5	761.5	861.3	813.3	736.1	651.5	574.3	518.5	484.6	459.9	433.6	398.6	358.3	318.6	279.3	242.7	209.7	180.6	155.2	920.0	9880.2
1962	522.3	760.6	844.8	775.8	690.9	608.0	531.8	466.5	420.9	393.5	372.8	348.8	318.8	285.3	252.4	221.1	191.6	165.1	142.0	841.3	9154.0
1963	522.1	759.7	838.9	757.9	657.6	570.8	497.8	434.3	381.4	344.8	322.1	302.9	281.8	256.4	228.4	201.7	176.1	152.6	131.2	777.1	8596.0
1964	521.8	759.1	835.3	754.2	645.3	547.0	471.3	410.9	359.8	317.0	286.8	265.9	248.5	230.2	208.6	185.4	163.4	142.4	123.0	729.3	8205.6
1965	521.6	758.2	822.3	731.1	625.7	524.0	442.2	382.1	334.9	294.5	259.9	233.2	215.0	200.0	184.5	166.9	147.9	130.1	113.3	674.4	7761.6
1966	521.4	757.1	808.9	700.4	591.1	496.5	415.1	352.1	306.4	270.3	238.3	208.8	186.3	171.1	158.5	145.7	131.6	116.4	102.3	615.5	7293.8
1967	521.2	756.4	801.8	679.2	558.7	463.2	388.9	327.2	279.8	245.4	217.2	190.0	165.6	147.0	134.3	124.1	114.0	102.5	90.8	556.7	6863.6
1968	520.7	755.1	782.6	638.5	513.5	415.6	344.8	291.7	247.8	213.6	188.1	165.1	143.7	124.6	110.2	100.5	92.8	84.9	76.3	479.1	6290.0
1969	520.1	753.5	758.8	583.6	451.9	358.3	290.8	243.8	208.6	179.0	155.0	135.4	118.4	102.5	88.4	78.0	71.0	65.3	59.7	389.1	5611.6
1970	519.4	752.9	770.3	595.2	435.9	333.1	265.2	217.8	184.7	159.8	137.8	118.6	103.0	89.5	77.2	66.6	58.6	53.1	48.9	333.8	5321.3
1971	518.7	751.8	767.2	600.8	441.8	319.4	245.4	197.8	164.5	141.1	122.6	104.9	89.7	77.6	67.2	57.8	49.6	43.7	39.7	283.5	5085.0
1972	518.3	750.0	754.9	586.9	438.7	319.9	233.5	182.1	149.3	125.7	108.7	93.9	79.8	67.9	58.4	50.5	43.4	37.3	32.6	240.3	4872.0
1973	517.6	748.2	740.5	564.8	420.6	313.1	231.5	172.4	137.3	114.4	97.2	83.6	71.7	60.6	51.4	44.1	38.1	32.6	28.0	203.9	4671.6
1974	517.2	746.5	732.6	553.8	406.1	302.5	229.5	173.9	132.7	107.8	90.8	76.7	65.5	56.0	47.2	39.9	34.2	29.3	25.1	177.9	4545.3
1975	516.3	743.6	691.6	489.4	356.5	263.0	201.1	157.4	123.0	96.1	79.1	66.1	55.6	47.2	40.1	33.7	28.4	24.5	20.9	143.7	4177.5
1976	514.6	739.4	639.8	399.9	273.6	202.6	155.0	123.5	100.5	80.9	64.4	52.7	43.9	36.6	30.9	26.2	22.0	18.5	15.9	106.7	3647.8
1977	511.7	734.4	603.0	335.1	203.5	142.6	110.5	88.8	74.1	62.4	51.6	40.8	33.1	27.3	22.7	19.2	16.3	13.7	11.5	75.4	3177.5
1978	572.8	727.1	552.5	268.3	145.3	91.3	67.7	55.6	47.2	41.0	35.5	29.1	22.9	18.5	15.2	12.6	10.6	9.0	7.5	47.6	2777.6
1979	424.8	809.3	489.9	196.4	93.3	52.9	35.5	28.4	24.9	22.3	20.1	17.2	13.9	11.0	8.8	7.3	6.0	5.1	4.2	26.0	2297.0
1980	629.2	599.4	543.4	176.8	69.7	34.8	21.2	15.4	13.2	12.3	11.2	10.1	8.6	7.1	5.5	4.4	3.5	3.1	2.4	15.0	2187.0
1981	217.6	881.8	359.4	160.5	51.8	21.8	12.1	8.2	6.4	6.0	5.7	5.3	4.6	4.0	3.1	2.4	2.0	1.5	1.3	7.7	1763.3
1982	359.4	302.3	498.9	93.5	41.4	14.6	6.8	4.2	3.1	2.6	2.4	2.4	2.2	2.0	1.5	1.3	1.1	0.9	0.7	3.7	1344.4
1983	1025.8	506.6	207.7	174.2	31.5	14.3	5.3	2.6	1.8	1.3	1.1	1.1	1.1	0.9	0.9	0.7	0.4	0.4	0.4	1.8	1979.5
1984	1166.5	1424.0	254.2	40.3	33.3	6.6	3.3	1.3	0.7	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.7	2933.7
1985	534.6	1575.6	728.6	62.4	10.1	9.5	2.2	1.3	0.7	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.4	2926.9
1986	266.5	700.8	706.4	158.3	14.6	2.6	3.1	0.9	0.4	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1855.0
1987	915.4	347.9	490.5	313.3	70.3	6.8	1.3	1.5	0.4	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2148.6
1988	673.3	1261.7	284.6	268.1	167.1	38.4	3.7	0.9	1.1	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2699.8
1989	251.3	937.0	1089.7	173.7	159.6	101.2	24.0	2.4	0.7	0.7	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2741.4
1990	81.6	353.4	830.7	686.1	106.0	98.5	64.6	15.9	1.8	0.4	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2240.3
1991	74.5	113.3	371.7	704.2	553.1	83.6	76.7	50.0	12.3	1.3	0.2	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2041.9
1992	394.8	98.5	105.4	276.0	510.8	402.6	61.7	58.2	38.8	9.7	1.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1958.6
1993	138.7	535.7	110.7	71.0	118.4	228.2	203.7	35.7	37.7	27.3	7.3	0.9	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1516.1
1994	245.8	169.3	566.4	73.2	30.4	52.2	108.9	104.9	19.6	21.4	15.9	4.2	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	1413.2
1995	113.5	301.8	179.2	388.2	32.8	13.9	25.6	57.1	58.4	11.2	12.8	9.5	2.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1207.2
1996	296.3	132.9	308.9	122.1	180.8	15.7	7.1	13.9	32.8	34.8	6.8	7.9	6.0	1.5	0.2	0.0	0.0	0.0	0.0	0.0	1168.2
1997	201.5	401.2	152.8	244.9	69.2	101.6	9.3	4.4	8.8	20.9	22.5	4.4	5.1	3.7	1.1	0.2	0.0	0.0	0.0	0.0	1251.6
1998	376.5	271.4	437.8	79.1	64.8	19.6	34.8	3.7	2.0	4.9	12.3	13.9	2.9	3.3	2.4	0.7	0.0	0.0	0.0	0.0	1330.0
1999	509.7	520.5	317.2	356.3	46.5	37.7	11.9	22.0	2.4	1.3	3.3	8.6	9.7	2.0	2.2	1.8	0.4	0.0	0.0	0.0	1853.6
2000	516.3	632.1	550.5	201.5	140.7	19.2	17.6	6.4	13.2	1.5	0.9	2.2	6.2	6.8	1.3	1.5	1.1	0.2	0.0	0.0	2120.0
2001	377.0	598.6	637.6	344.1	79.6	58.0	9.0	9.5	3.7	8.4	1.1	0.7	1.5	4.4	4.9	0.9	1.1	0.9	0.2	0.0	2141.1
2002	313.5	434.1	609.4	437.8	159.6	37.5	29.5	4.9	5.5	2.2	5.3	0.7	0.4	1.1	2.9	3.1	0.7	0.7	0.4	0.2	2049.6
2003	404.8	372.1	449.3	426.4	211.6	78.9	20.1	17.0	3.1	3.5	1.5	3.5	0.4	0.2	0.7	1.8	2.0	0.4	0.4	0.4	1998.7
2004	149.9	487.7	396.2	366.4	266.3	131.8	51.1	13.7	11.9	2.2	2.6	1.1	2.6	0.4	0.2	0.4	1.3	1.5	0.2	0.7	1888.7
2005	61.1	137.1	424.6	271.2	188.5	141.3	75.2	31.3	8.8	8.2	1.5	1.8	0.9	1.8	0.2	0.2	0.4	0.9	1.1	0.7	1356.5
2006	1100.3	54.9	116.2	276.0	131.0	95.2	78.3	45.4	20.3	6.0	5.7	1.1	1.3	0.7	1.3	0.2	0.0	0.2	0.7	1.3	1935.9
2007	762.4	1491.6	62.2	77.8	116.4	57.5	47.2	43.9	28.2	13.7	4.2	4.2	0.9	0.9	0.4	0.9	0.2	0.0	0.2	1.3	2714.1
2008	859.4	920.6	1568.4	39.9	32.0	49.6	27.1	24.5	24.5	16.8	8.4	2.6	2.6	0.4	0.7	0.2	0.7	0.0	0.0	0.9	3579.0
2009	132.5	909.6	867.3	878.3	13.0	11.0	19.6	12.3	12.6	13.7	9.7	5.1	1.5	1.5	0.2	0.4	0.2	0.4	0.0	0.7	2889.8
2010	168.4	122.6	789.9	525.4	353.4	5.5	5.1	9.9	6.6	7.1	7.9	5.7	3.1	0.9	0.9	0.2	0.2	0.0	0.2	0.4	2013.7
2011	247.6	208.6	124.1	685.4	419.1	274.0	4.2	4.0	7.9	5.5	6.0	6.6	4.9	2.4	0.9	0.9	0.2	0.2	0.0	0.4	2002.5
2012	265.4	343.0	239.0	119.9	602.3	352.7	226.0	3.5	3.3	6.4	4.4	4.9	5.3	3.7	2.0	0.7	0.7	0.2	0.2	0.4	2183.7
2013	591.1	340.2	357.1	203.9	86.4	403.9	234.6	151.9	2.4	2.2	4.4	3.1	3.3	3.5	2.6	1.3	0.4	0.4	0.0	0.4	2393.3
2014	1003.3	814.6	389.1	342.6	170.2	67.7	308.4	177.7	114.6	1.8	1.8	3.3	2.2	2.4	2.6	2.0	0.9	0.2	0.2	0.4	3406.4
2015	504.0	1334.9	876.8	322.8	216.3	95.2	37.0	169.3	98.3	63.9	1.1	0.9	1.8	1.3	1.3	1.5	1.1	0.4	0.2	0.4	3728.5

Table 10. Estimated time series of status indicators, fishing mortality, and biomass. Fishing mortality rate is apical F. Total biomass (B, mt) is at the start of the year, and spawning biomass (SSB, 1E8 eggs) at the time of peak spawning (mid-year). The $MSST_{F30}$ is defined by $\mathrm{MSST} = (1 - M)SSB_{F30}$*, with constant* $M = 0.134$.

Year	F	F/F_{30}	B	$B/B_{unfished}$	SSB	$SSB/SSBB_{F30}$	$SSB/MSST_{F30}$
1950	0.031	0.211	6309	0.789	778399	2.375	3.167
1951	0.042	0.288	6303	0.788	771030	2.353	3.137
1952	0.033	0.224	6235	0.780	766363	2.339	3.118
1953	0.034	0.232	6225	0.779	763741	2.331	3.107
1954	0.051	0.349	6210	0.777	752534	2.296	3.062
1955	0.108	0.736	6106	0.764	732688	2.236	2.981
1956	0.117	0.803	5899	0.738	707974	2.160	2.881
1957	0.166	1.139	5688	0.711	663309	2.024	2.699
1958	0.157	1.074	5297	0.663	619670	1.891	2.521
1959	0.176	1.201	5034	0.630	578307	1.765	2.353
1960	0.192	1.317	4756	0.595	535242	1.633	2.178
1961	0.230	1.570	4482	0.561	486562	1.485	1.980
1962	0.233	1.597	4152	0.519	442383	1.350	1.800
1963	0.231	1.581	3899	0.488	408720	1.247	1.663
1964	0.258	1.768	3722	0.466	376971	1.150	1.534
1965	0.286	1.953	3521	0.440	344137	1.050	1.400
1966	0.300	2.049	3308	0.414	312478	0.954	1.271
1967	0.353	2.412	3113	0.389	275954	0.842	1.123
1968	0.418	2.861	2853	0.357	232992	0.711	0.948
1969	0.368	2.515	2545	0.318	202988	0.619	0.826
1970	0.374	2.556	2414	0.302	182221	0.556	0.741
1971	0.393	2.688	2307	0.289	165389	0.505	0.673
1972	0.415	2.839	2210	0.276	151460	0.462	0.616
1973	0.416	2.843	2119	0.265	141616	0.432	0.576
1974	0.528	3.614	2062	0.258	126555	0.386	0.515
1975	0.673	4.602	1895	0.237	103334	0.315	0.420
1976	0.772	5.277	1655	0.207	79258	0.242	0.322
1977	0.935	6.393	1441	0.180	56261	0.172	0.229
1978	1.159	7.929	1260	0.158	35804	0.109	0.146
1979	1.144	7.821	1042	0.130	24108	0.074	0.098
1980	1.345	9.200	992	0.124	16265	0.050	0.066
1981	1.470	10.056	800	0.100	11267	0.034	0.046
1982	1.178	8.055	610	0.076	8746	0.027	0.036
1983	1.765	12.074	898	0.112	6173	0.019	0.025
1984	1.530	10.462	1331	0.166	8305	0.025	0.034
1985	1.652	11.299	1328	0.166	9969	0.030	0.041
1986	0.938	6.416	841	0.105	11769	0.036	0.048
1987	0.729	4.986	975	0.122	14235	0.043	0.058
1988	0.618	4.227	1225	0.153	19963	0.061	0.081
1989	0.588	4.020	1244	0.156	28089	0.086	0.114
1990	0.290	1.985	1016	0.127	38849	0.119	0.158
1991	0.423	2.891	926	0.116	46176	0.141	0.188
1992	0.903	6.173	888	0.111	37334	0.114	0.152
1993	0.902	6.172	688	0.086	27160	0.083	0.111
1994	0.854	5.844	641	0.080	22693	0.069	0.092
1995	0.820	5.611	548	0.068	19406	0.059	0.079
1996	0.625	4.278	530	0.066	18083	0.055	0.074
1997	1.386	9.482	568	0.071	14062	0.043	0.057
1998	0.589	4.027	603	0.075	15399	0.047	0.063
1999	0.986	6.741	841	0.105	16923	0.052	0.069
2000	0.987	6.751	962	0.120	18635	0.057	0.076
2001	0.825	5.641	971	0.121	21573	0.066	0.088
2002	0.783	5.358	930	0.116	23781	0.073	0.097
2003	0.527	3.605	907	0.113	27137	0.083	0.110
2004	0.721	4.934	857	0.107	27692	0.085	0.113
2005	0.785	5.369	615	0.077	24579	0.075	0.100
2006	0.919	6.284	878	0.110	19523	0.060	0.079
2007	0.948	6.483	1231	0.154	20795	0.063	0.085
2008	1.171	8.010	1623	0.203	27476	0.084	0.112
2009	0.967	6.612	1311	0.164	29515	0.090	0.120
2010	0.282	1.932	913	0.114	36650	0.112	0.149
2011	0.186	1.269	908	0.114	46989	0.143	0.191
2012	0.409	2.796	990	0.124	49264	0.150	0.200
2013	0.256	1.750	1086	0.136	51560	0.157	0.210
2014	0.589	4.028	1545	0.193	48993	0.150	0.199
2015	.	.	1691	0.212	.	.	.

Table 11. Selectivity at age for combined chevon trap and video (CVID), commercial handlines (cH), headboat (HB), and general recreational (GR) landings (L) and discards (D). For time-varying selectivities, values shown are from selectivity block 1 (1950–1991).

Age	CVID	cH.L	HB.L	GR.L	cH.D	HB.D	GR.D
1	0.065	0.012	0.049	0.049	1.000	1.000	1.000
2	0.637	0.374	0.667	0.667	0.956	0.709	0.709
3	0.978	0.967	1.000	1.000	0.663	0.275	0.275
4	0.999	0.999	0.897	0.897	0.331	0.073	0.073
5	1.000	1.000	0.749	0.749	0.133	0.017	0.017
6	1.000	1.000	0.586	0.586	0.048	0.004	0.004
7	1.000	1.000	0.429	0.429	0.017	0.001	0.001
8	1.000	1.000	0.297	0.297	0.006	0.000	0.000
9	1.000	1.000	0.196	0.196	0.002	0.000	0.000
10	1.000	1.000	0.125	0.125	0.001	0.000	0.000
11	1.000	1.000	0.125	0.125	0.000	0.000	0.000
12	1.000	1.000	0.125	0.125	0.000	0.000	0.000
13	1.000	1.000	0.125	0.125	0.000	0.000	0.000
14	1.000	1.000	0.125	0.125	0.000	0.000	0.000
15	1.000	1.000	0.125	0.125	0.000	0.000	0.000
16	1.000	1.000	0.125	0.125	0.000	0.000	0.000
17	1.000	1.000	0.125	0.125	0.000	0.000	0.000
18	1.000	1.000	0.125	0.125	0.000	0.000	0.000
19	1.000	1.000	0.125	0.125	0.000	0.000	0.000
20	1.000	1.000	0.125	0.125	0.000	0.000	0.000

Table 12. Selectivity at age for combined chevon trap and video (CVID), commercial handlines (cH), headboat (HB), and general recreational (GR) landings (L) and discards (D). For time-varying selectivities, values shown are from selectivity block 2 (1992–2009).

Age	CVID	cH.L	HB.L	GR.L	cH.D	HB.D	GR.D
1	0.065	0.001	0.001	0.005	1.000	1.000	1.000
2	0.637	0.026	0.030	0.068	0.956	0.709	0.709
3	0.978	0.425	0.697	0.547	0.663	0.275	0.275
4	0.999	0.954	1.000	1.000	0.331	0.073	0.073
5	1.000	0.998	0.763	0.909	0.133	0.017	0.017
6	1.000	1.000	0.518	0.716	0.048	0.004	0.004
7	1.000	1.000	0.320	0.515	0.017	0.001	0.001
8	1.000	1.000	0.185	0.342	0.006	0.000	0.000
9	1.000	1.000	0.102	0.213	0.002	0.000	0.000
10	1.000	1.000	0.055	0.127	0.001	0.000	0.000
11	1.000	1.000	0.055	0.074	0.000	0.000	0.000
12	1.000	1.000	0.055	0.042	0.000	0.000	0.000
13	1.000	1.000	0.055	0.024	0.000	0.000	0.000
14	1.000	1.000	0.055	0.024	0.000	0.000	0.000
15	1.000	1.000	0.055	0.024	0.000	0.000	0.000
16	1.000	1.000	0.055	0.024	0.000	0.000	0.000
17	1.000	1.000	0.055	0.024	0.000	0.000	0.000
18	1.000	1.000	0.055	0.024	0.000	0.000	0.000
19	1.000	1.000	0.055	0.024	0.000	0.000	0.000
20	1.000	1.000	0.055	0.024	0.000	0.000	0.000

Table 13. Selectivity at age for combined chevon trap and video (CVID), commercial handlines (cH), headboat (HB), and general recreational (GR) landings (L) and discards (D). For time-varying selectivities, values shown are from selectivity block 3 (2010–2014).

Age	CVID	cH.L	HB.L	GR.L	cH.D	HB.D	GR.D
1	0.065	0.006	0.017	0.005	0.032	0.714	0.714
2	0.637	0.067	0.336	0.036	0.219	0.883	0.883
3	0.978	0.446	1.000	0.232	0.704	0.990	0.990
4	0.999	0.901	0.916	0.710	0.953	1.000	1.000
5	1.000	0.990	0.738	0.952	0.994	0.911	0.911
6	1.000	0.999	0.566	0.994	0.999	0.753	0.753
7	1.000	1.000	0.416	0.999	1.000	0.570	0.570
8	1.000	1.000	0.295	1.000	1.000	0.401	0.401
9	1.000	1.000	0.203	1.000	1.000	0.267	0.267
10	1.000	1.000	0.137	1.000	1.000	0.171	0.171
11	1.000	1.000	0.137	1.000	1.000	0.171	0.171
12	1.000	1.000	0.137	1.000	1.000	0.171	0.171
13	1.000	1.000	0.137	1.000	1.000	0.171	0.171
14	1.000	1.000	0.137	1.000	1.000	0.171	0.171
15	1.000	1.000	0.137	1.000	1.000	0.171	0.171
16	1.000	1.000	0.137	1.000	1.000	0.171	0.171
17	1.000	1.000	0.137	1.000	1.000	0.171	0.171
18	1.000	1.000	0.137	1.000	1.000	0.171	0.171
19	1.000	1.000	0.137	1.000	1.000	0.171	0.171
20	1.000	1.000	0.137	1.000	1.000	0.171	0.171

Table 14. Estimated time series of fully selected fishing mortality rates for commercial handlines (F.cH.L), headboat (F.HB.L), recreational (F.GR.L) landings (L) and discards (D). Also shown is Full F, the maximum F at age summed across fleets, which may not equal the sum of fully selected F's because of dome-shaped selectivities.

Year	F.cH.L	F.HB.L	F.GR.L	F.cH.D	F.HB.D	F.GR.D	Full F
1950	0.031	0.000	0.000	0.000	0.000	0.000	0.031
1951	0.042	0.000	0.000	0.000	0.000	0.000	0.042
1952	0.033	0.000	0.000	0.000	0.000	0.000	0.033
1953	0.034	0.000	0.000	0.000	0.000	0.000	0.034
1954	0.051	0.000	0.000	0.000	0.000	0.000	0.051
1955	0.044	0.022	0.043	0.000	0.000	0.000	0.108
1956	0.044	0.025	0.049	0.000	0.000	0.000	0.117
1957	0.085	0.029	0.056	0.000	0.000	0.000	0.166
1958	0.064	0.033	0.063	0.000	0.000	0.000	0.157
1959	0.073	0.036	0.069	0.000	0.000	0.000	0.176
1960	0.080	0.039	0.076	0.000	0.000	0.000	0.192
1961	0.103	0.045	0.086	0.000	0.000	0.000	0.230
1962	0.091	0.050	0.096	0.000	0.000	0.000	0.233
1963	0.073	0.055	0.105	0.000	0.000	0.000	0.231
1964	0.086	0.060	0.115	0.000	0.000	0.000	0.258
1965	0.096	0.066	0.127	0.000	0.000	0.000	0.286
1966	0.103	0.068	0.131	0.000	0.000	0.000	0.300
1967	0.148	0.072	0.138	0.000	0.000	0.000	0.353
1968	0.202	0.076	0.147	0.000	0.000	0.000	0.418
1969	0.141	0.079	0.152	0.000	0.000	0.000	0.368
1970	0.144	0.080	0.154	0.000	0.000	0.000	0.374
1971	0.137	0.089	0.171	0.000	0.000	0.000	0.393
1972	0.129	0.099	0.191	0.000	0.000	0.000	0.415
1973	0.099	0.109	0.210	0.000	0.000	0.000	0.416
1974	0.173	0.124	0.238	0.000	0.000	0.000	0.528
1975	0.255	0.146	0.280	0.000	0.000	0.000	0.673
1976	0.301	0.165	0.316	0.000	0.000	0.000	0.772
1977	0.404	0.187	0.358	0.000	0.000	0.000	0.935
1978	0.551	0.214	0.412	0.000	0.000	0.000	1.159
1979	0.500	0.226	0.435	0.000	0.000	0.000	1.144
1980	0.575	0.270	0.519	0.000	0.000	0.000	1.345
1981	0.683	0.225	0.584	0.000	0.000	0.006	1.470
1982	0.678	0.182	0.339	0.000	0.000	0.006	1.178
1983	0.960	0.259	0.578	0.000	0.000	0.002	1.765
1984	0.494	0.133	0.912	0.000	0.000	0.025	1.530
1985	0.345	0.194	1.113	0.000	0.000	0.044	1.652
1986	0.306	0.088	0.532	0.000	0.000	0.082	0.938
1987	0.278	0.156	0.295	0.000	0.000	0.037	0.729
1988	0.191	0.133	0.293	0.000	0.000	0.029	0.618
1989	0.196	0.076	0.316	0.000	0.000	0.021	0.588
1990	0.147	0.086	0.050	0.000	0.000	0.048	0.290
1991	0.098	0.087	0.217	0.000	0.000	0.086	0.423
1992	0.110	0.083	0.701	0.032	0.003	0.038	0.903
1993	0.403	0.223	0.272	0.036	0.007	0.139	0.902
1994	0.380	0.135	0.333	0.043	0.007	0.125	0.854
1995	0.360	0.178	0.266	0.063	0.012	0.148	0.820
1996	0.314	0.113	0.197	0.040	0.004	0.034	0.625
1997	0.317	0.167	0.899	0.045	0.005	0.030	1.386
1998	0.242	0.088	0.260	0.022	0.003	0.033	0.589
1999	0.205	0.116	0.658	0.014	0.003	0.147	0.986
2000	0.212	0.118	0.646	0.014	0.003	0.214	0.987
2001	0.320	0.133	0.365	0.017	0.006	0.216	0.825
2002	0.263	0.132	0.375	0.041	0.008	0.161	0.783
2003	0.178	0.061	0.279	0.011	0.003	0.181	0.527
2004	0.225	0.130	0.341	0.005	0.040	0.426	0.721
2005	0.194	0.125	0.427	0.047	0.052	0.389	0.785
2006	0.176	0.148	0.596	0.003	0.009	0.063	0.919
2007	0.340	0.231	0.376	0.006	0.037	0.149	0.948
2008	0.350	0.139	0.674	0.006	0.040	0.277	1.171
2009	0.381	0.154	0.412	0.015	0.085	0.357	0.967
2010	0.006	0.003	0.001	0.041	0.051	0.184	0.282
2011	0.000	0.010	0.001	0.106	0.041	0.033	0.186
2012	0.007	0.018	0.172	0.056	0.046	0.140	0.409
2013	0.030	0.012	0.093	0.053	0.030	0.054	0.256
2014	0.064	0.033	0.339	0.060	0.018	0.112	0.589

Table 15. Estimated instantaneous fishing mortality rate (per yr) at age.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.000	0.012	0.030	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
1951	0.001	0.016	0.041	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
1952	0.000	0.012	0.032	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
1953	0.000	0.013	0.033	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
1954	0.001	0.019	0.049	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051
1955	0.004	0.060	0.108	0.102	0.093	0.082	0.072	0.063	0.056	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
1956	0.004	0.066	0.117	0.111	0.100	0.088	0.076	0.067	0.059	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
1957	0.005	0.088	0.166	0.161	0.148	0.134	0.121	0.110	0.101	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095
1958	0.005	0.087	0.157	0.149	0.135	0.120	0.105	0.092	0.083	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076
1959	0.006	0.097	0.176	0.167	0.152	0.135	0.118	0.104	0.094	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
1960	0.007	0.107	0.192	0.183	0.166	0.147	0.129	0.114	0.102	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
1961	0.008	0.125	0.230	0.220	0.200	0.179	0.159	0.141	0.128	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119
1962	0.008	0.131	0.233	0.221	0.200	0.176	0.153	0.134	0.119	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109
1963	0.009	0.134	0.231	0.217	0.193	0.167	0.142	0.121	0.105	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093
1964	0.010	0.149	0.258	0.243	0.217	0.189	0.161	0.138	0.120	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108
1965	0.011	0.164	0.286	0.269	0.240	0.209	0.179	0.153	0.134	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120
1966	0.011	0.172	0.300	0.282	0.253	0.220	0.189	0.162	0.142	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128
1967	0.012	0.195	0.353	0.336	0.305	0.271	0.238	0.210	0.189	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174
1968	0.013	0.224	0.418	0.402	0.369	0.333	0.298	0.268	0.246	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230
1969	0.013	0.207	0.368	0.349	0.314	0.277	0.240	0.210	0.186	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170
1970	0.013	0.210	0.374	0.354	0.320	0.281	0.245	0.214	0.190	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173
1971	0.014	0.225	0.393	0.371	0.332	0.290	0.249	0.214	0.188	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169
1972	0.016	0.242	0.415	0.389	0.346	0.299	0.254	0.215	0.186	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165
1973	0.017	0.250	0.416	0.386	0.338	0.286	0.236	0.194	0.162	0.139	0.139	0.139	0.139	0.139	0.139	0.139	0.139	0.139	0.139	0.139
1974	0.020	0.306	0.528	0.497	0.443	0.384	0.328	0.280	0.244	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218
1975	0.024	0.380	0.673	0.637	0.574	0.505	0.438	0.382	0.338	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308
1976	0.027	0.433	0.772	0.732	0.661	0.582	0.507	0.443	0.395	0.361	0.361	0.361	0.361	0.361	0.361	0.361	0.361	0.361	0.361	0.361
1977	0.032	0.514	0.935	0.892	0.811	0.723	0.637	0.565	0.510	0.472	0.472	0.472	0.472	0.472	0.472	0.472	0.472	0.472	0.472	0.472
1978	0.037	0.624	1.159	1.113	1.020	0.918	0.820	0.737	0.674	0.629	0.629	0.629	0.629	0.629	0.629	0.629	0.629	0.629	0.629	0.629
1979	0.038	0.627	1.144	1.092	0.994	0.886	0.783	0.696	0.629	0.582	0.582	0.582	0.582	0.582	0.582	0.582	0.582	0.582	0.582	0.582
1980	0.046	0.741	1.345	1.283	1.166	1.037	0.914	0.809	0.730	0.674	0.674	0.674	0.674	0.674	0.674	0.674	0.674	0.674	0.674	0.674
1981	0.054	0.799	1.470	1.408	1.288	1.157	1.030	0.923	0.841	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784
1982	0.040	0.605	1.178	1.145	1.068	0.983	0.901	0.832	0.780	0.743	0.743	0.743	0.743	0.743	0.743	0.743	0.743	0.743	0.743	0.743
1983	0.055	0.919	1.765	1.710	1.586	1.450	1.319	1.208	1.124	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064
1984	0.082	0.899	1.530	1.433	1.277	1.106	0.943	0.805	0.699	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625
1985	0.112	1.032	1.652	1.520	1.324	1.110	0.906	0.733	0.601	0.508	0.508	0.508	0.508	0.508	0.508	0.508	0.508	0.508	0.508	0.508
1986	0.117	0.586	0.938	0.868	0.771	0.669	0.572	0.490	0.427	0.383	0.383	0.383	0.383	0.383	0.383	0.383	0.383	0.383	0.383	0.383
1987	0.062	0.430	0.729	0.684	0.616	0.542	0.471	0.412	0.366	0.334	0.334	0.334	0.334	0.334	0.334	0.334	0.334	0.334	0.334	0.334
1988	0.052	0.376	0.618	0.575	0.510	0.440	0.374	0.317	0.274	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244
1989	0.042	0.350	0.588	0.550	0.490	0.426	0.365	0.313	0.273	0.245	0.245	0.245	0.245	0.245	0.245	0.245	0.245	0.245	0.245	0.245
1990	0.056	0.179	0.290	0.271	0.249	0.226	0.205	0.187	0.173	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163	0.163
1991	0.102	0.301	0.423	0.377	0.327	0.276	0.229	0.188	0.157	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136
1992	0.078	0.113	0.521	0.903	0.815	0.656	0.498	0.365	0.268	0.204	0.166	0.144	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131
1993	0.184	0.174	0.540	0.902	0.827	0.716	0.615	0.538	0.484	0.450	0.436	0.427	0.422	0.422	0.422	0.422	0.422	0.422	0.422	0.422
1994	0.178	0.172	0.503	0.854	0.793	0.691	0.596	0.519	0.465	0.430	0.412	0.401	0.395	0.395	0.395	0.395	0.395	0.395	0.395	0.395
1995	0.225	0.206	0.508	0.820	0.748	0.646	0.555	0.484	0.435	0.404	0.389	0.381	0.376	0.376	0.376	0.376	0.376	0.376	0.376	0.376
1996	0.080	0.090	0.357	0.625	0.585	0.515	0.452	0.402	0.367	0.345	0.334	0.328	0.324	0.324	0.324	0.324	0.324	0.324	0.324	0.324
1997	0.085	0.142	0.782	1.386	1.268	1.049	0.834	0.656	0.526	0.440	0.392	0.364	0.347	0.347	0.347	0.347	0.347	0.347	0.347	0.347
1998	0.059	0.073	0.331	0.589	0.549	0.475	0.405	0.347	0.307	0.280	0.266	0.258	0.253	0.253	0.253	0.253	0.253	0.253	0.253	0.253
1999	0.167	0.173	0.579	0.986	0.896	0.737	0.581	0.452	0.357	0.295	0.260	0.239	0.227	0.227	0.227	0.227	0.227	0.227	0.227	0.227
2000	0.235	0.221	0.595	0.987	0.895	0.737	0.583	0.455	0.362	0.301	0.266	0.246	0.234	0.234	0.234	0.234	0.234	0.234	0.234	0.234
2001	0.242	0.211	0.501	0.825	0.758	0.651	0.551	0.470	0.411	0.374	0.354	0.343	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336
2002	0.212	0.195	0.482	0.783	0.712	0.602	0.499	0.416	0.356	0.318	0.298	0.286	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279
2003	0.197	0.166	0.328	0.527	0.483	0.411	0.342	0.285	0.244	0.217	0.202	0.193	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188
2004	0.473	0.368	0.504	0.721	0.642	0.538	0.443	0.366	0.311	0.275	0.257	0.246	0.240	0.240	0.240	0.240	0.240	0.240	0.240	0.240
2005	0.490	0.395	0.555	0.785	0.691	0.568	0.455	0.363	0.298	0.255	0.232	0.219	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211
2006	0.079	0.104	0.526	0.919	0.833	0.680	0.531	0.408	0.319	0.260	0.228	0.209	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198
2007	0.195	0.179	0.567	0.948	0.862	0.730	0.608	0.512	0.444	0.401	0.381	0.369	0.362	0.362	0.362	0.362	0.362	0.362	0.362	0.362
2008	0.326	0.289	0.705	1.171	1.073	0.905	0.741	0.606	0.507	0.443	0.407	0.385	0.373	0.373	0.373	0.373	0.373	0.373	0.373	0.373
2009	0.460	0.370	0.626	0.967	0.882	0.758	0.643	0.551	0.485	0.442	0.420	0.407	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399
2010	0.169	0.218	0.267	0.282	0.264	0.226	0.183	0.143	0.111	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089
2011	0.057	0.092	0.159	0.186	0.182	0.169	0.154	0.140	0.129	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121
2012	0.135	0.188	0.284	0.384	0.409	0.384	0.348	0.315	0.289	0.270	0.270	0.270	0.270	0.270	0.270	0.270	0.270	0.270	0.270	0.270
2013	0.062	0.095	0.167	0.238	0.256	0.245	0.229	0.213	0.201	0.192	0.192	0.192	0.192	0.192	0.192	0.192	0.192	0.192	0.192	0.192
2014	0.097	0.156	0.312	0.516	0.589	0.578	0.551	0.525	0.505	0.490	0.490	0.490	0.490	0.490	0.490	0.490	0.490	0.490	0.490	0.490

Table 16. Estimated time series of landings in number (1000 fish) for commercial handlines (L.cH), headboat (L.HB), and recreational (L.GR).

Year	L.cH	L.HB	L.GR	Total
1950	26.72	0.00	0.00	26.72
1951	36.24	0.00	0.00	36.24
1952	28.03	0.00	0.00	28.03
1953	28.96	0.00	0.00	28.96
1954	43.21	0.00	0.00	43.21
1955	35.86	12.50	24.03	72.40
1956	35.07	13.65	26.24	74.96
1957	63.01	14.80	28.46	106.27
1958	44.96	15.95	30.67	91.58
1959	48.92	17.10	32.88	98.90
1960	50.72	18.25	35.09	104.06
1961	61.33	19.91	38.27	119.50
1962	50.87	21.56	41.44	113.87
1963	39.36	23.21	44.62	107.18
1964	44.17	24.86	47.79	116.83
1965	46.83	26.51	50.96	124.30
1966	47.63	26.67	51.26	125.56
1967	64.06	26.82	51.56	142.44
1968	79.27	26.98	51.85	158.10
1969	51.58	27.13	52.15	130.87
1970	51.08	27.29	52.44	130.81
1971	46.95	29.98	57.62	134.55
1972	42.73	32.68	62.79	138.19
1973	31.74	35.37	67.96	135.07
1974	52.01	38.06	73.12	163.19
1975	67.36	40.74	78.26	186.37
1976	67.80	41.21	79.16	188.17
1977	76.47	41.63	79.89	197.98
1978	84.98	42.15	81.02	208.15
1979	69.21	42.66	82.06	193.94
1980	66.23	43.10	82.90	192.24
1981	74.29	36.05	93.58	203.92
1982	55.18	19.58	36.38	111.13
1983	66.37	30.70	68.48	165.55
1984	64.77	31.16	213.19	309.12
1985	57.44	50.35	289.40	397.20
1986	42.79	16.62	100.67	160.09
1987	33.05	24.98	47.32	105.35
1988	34.45	36.50	80.66	151.61
1989	47.25	23.44	96.85	167.54
1990	33.10	20.91	12.09	66.10
1991	16.78	13.85	34.68	65.31
1992	9.05	5.30	51.69	66.04
1993	18.28	7.35	11.33	36.96
1994	19.78	8.23	18.34	46.35
1995	17.56	8.83	13.49	39.89
1996	13.95	5.54	9.34	28.83
1997	10.90	5.77	34.06	50.73
1998	10.12	4.74	13.02	27.87
1999	10.34	6.84	39.64	56.81
2000	12.00	8.44	45.33	65.77
2001	22.84	12.03	31.58	66.44
2002	21.23	12.95	35.21	69.39
2003	14.86	5.71	26.00	46.57
2004	17.62	10.84	28.85	57.30
2005	12.98	8.91	29.45	51.34
2006	7.97	5.94	26.71	40.62
2007	11.46	6.89	17.64	35.99
2008	32.29	18.97	81.94	133.19
2009	42.58	21.56	55.04	119.18
2010	0.80	0.48	0.06	1.34
2011	0.06	1.36	0.06	1.48
2012	0.76	2.13	15.63	18.52
2013	3.01	1.52	7.58	12.11
2014	6.86	5.90	28.19	40.96

Table 17. Estimated time series of landings in whole weight (1000 lb) for commercial handlines (L.cH), headboat (L.HB), and recreational (L.GR).

Year	L.cH	L.HB	L.GR	Total
1950	368.62	0.00	0.00	368.62
1951	499.70	0.00	0.00	499.70
1952	385.89	0.00	0.00	385.89
1953	398.23	0.00	0.00	398.23
1954	593.08	0.00	0.00	593.08
1955	493.22	105.75	203.31	802.28
1956	483.80	114.78	220.66	819.24
1957	866.92	122.74	235.97	1225.63
1958	612.30	129.58	249.12	991.00
1959	657.47	136.40	262.22	1056.09
1960	670.77	143.03	274.96	1088.76
1961	795.90	153.17	294.44	1243.51
1962	645.64	162.58	312.54	1120.76
1963	488.57	172.14	330.92	991.63
1964	537.30	181.95	349.75	1068.99
1965	557.76	191.13	367.39	1116.28
1966	554.13	188.87	363.02	1106.02
1967	724.79	186.03	357.57	1268.39
1968	864.41	181.64	349.13	1395.18
1969	537.72	177.02	340.23	1054.96
1970	512.55	175.05	336.44	1024.04
1971	456.98	190.36	365.84	1013.18
1972	406.28	205.65	395.20	1007.13
1973	296.34	220.73	424.13	941.21
1974	477.72	234.66	450.83	1163.20
1975	599.63	242.92	466.60	1309.14
1976	570.47	232.73	447.08	1250.28
1977	594.82	220.92	423.98	1239.72
1978	593.46	206.52	396.94	1196.93
1979	421.56	195.11	375.36	992.03
1980	385.97	194.12	373.36	953.44
1981	379.07	152.91	396.94	928.92
1982	309.64	92.64	172.14	574.42
1983	317.08	113.40	252.95	683.43
1984	253.59	107.39	734.77	1095.75
1985	250.90	197.92	1137.61	1586.42
1986	219.44	76.40	462.69	758.53
1987	191.49	119.79	226.91	538.19
1988	173.48	154.01	340.42	667.91
1989	266.36	116.12	479.86	862.34
1990	226.27	128.96	74.56	429.79
1991	143.44	107.22	268.45	519.11
1992	104.28	55.54	552.83	712.65
1993	219.96	72.37	111.99	404.32
1994	195.68	65.04	151.15	411.87
1995	177.58	76.82	117.98	372.38
1996	138.61	46.80	80.59	265.99
1997	110.34	50.02	290.38	450.75
1998	89.59	36.77	100.84	227.20
1999	93.62	56.24	318.87	468.74
2000	104.14	66.54	352.23	522.91
2001	196.53	95.73	249.85	542.11
2002	188.45	106.61	291.45	586.52
2003	138.42	48.99	225.26	412.67
2004	171.75	95.44	258.03	525.22
2005	129.65	78.12	269.04	476.81
2006	86.18	56.31	251.10	393.59
2007	114.51	55.91	129.07	299.49
2008	251.87	137.40	583.25	972.53
2009	363.67	173.98	441.18	978.83
2010	6.45	3.30	0.54	10.28
2011	0.57	11.10	0.62	12.29
2012	8.14	16.71	177.71	202.56
2013	31.60	10.73	87.37	129.70
2014	65.44	34.94	300.40	400.78

Table 18. Estimated time series of discard mortalities in numbers (1000 fish) for commercial handlines (D.cH), headboat (D.HB), and recreational (D.GR).

Year	D.cH	D.HB	D.GR	Total
1981	.	.	1.64	.
1982	.	.	1.64	.
1983	.	.	1.64	.
1984	.	0.03	22.88	.
1985	.	0.04	23.71	.
1986	.	0.01	23.71	.
1987	.	0.02	23.71	.
1988	.	0.03	18.60	.
1989	.	0.02	7.17	.
1990	.	0.02	7.17	.
1991	.	0.01	7.18	.
1992	9.41	0.93	10.36	20.70
1993	8.03	1.29	25.24	34.56
1994	10.15	1.44	24.64	36.23
1995	10.12	1.55	18.85	30.52
1996	9.95	0.97	7.57	18.49
1997	10.75	1.01	6.13	17.90
1998	7.76	0.83	9.91	18.51
1999	6.55	1.20	60.22	67.96
2000	6.98	1.48	91.96	100.42
2001	7.27	2.11	75.03	84.41
2002	14.33	2.27	45.68	62.27
2003	4.02	1.00	58.97	63.98
2004	1.16	6.95	74.05	82.16
2005	4.89	3.66	27.12	35.66
2006	2.31	6.38	44.31	53.00
2007	5.24	26.60	106.67	138.51
2008	4.77	27.24	189.47	221.48
2009	5.50	21.22	89.22	115.94
2010	6.63	14.24	51.45	72.32
2011	15.29	11.80	9.55	36.64
2012	7.30	13.34	40.83	61.48
2013	7.34	13.33	23.98	44.65
2014	10.26	13.29	81.59	105.14

Table 19. Estimated time series of discard mortalities in whole weight (1000 lb) for commercial handlines (D.cH), headboat (D.HB), and recreational (D.GR).

Year	D.cH	D.HB	D.GR	Total
1981	.	.	3.60	.
1982	.	.	2.76	.
1983	.	.	2.26	.
1984	.	0.04	36.31	.
1985	.	0.08	47.41	.
1986	.	0.03	52.04	.
1987	.	0.03	34.54	.
1988	.	0.06	34.77	.
1989	.	0.05	17.92	.
1990	.	0.05	22.49	.
1991	.	0.03	20.02	.
1992	16.93	1.31	14.66	32.90
1993	20.82	2.95	57.87	81.64
1994	24.91	2.76	47.22	74.88
1995	29.00	3.56	43.42	75.98
1996	20.52	1.59	12.40	34.51
1997	25.11	2.02	12.24	39.37
1998	16.37	1.44	17.22	35.03
1999	13.52	2.09	105.29	120.90
2000	15.50	2.76	171.76	190.03
2001	18.39	4.36	155.23	177.98
2002	37.87	4.71	95.05	137.64
2003	9.49	1.85	109.24	120.58
2004	3.61	17.36	184.84	205.81
2005	18.73	10.48	77.71	106.92
2006	3.11	7.88	54.79	65.79
2007	10.82	50.42	202.22	263.47
2008	11.11	52.43	364.70	428.24
2009	19.25	62.33	262.02	343.60
2010	48.30	74.13	267.83	390.25
2011	134.28	59.46	48.10	241.84
2012	67.40	62.09	190.03	319.52
2013	62.72	44.02	79.16	185.90
2014	73.25	35.67	219.04	327.97

Table 20. Estimated landings at age in numbers (1000 fish)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.13	2.38	4.37	3.43	2.71	2.19	1.79	1.49	1.24	1.05	0.88	0.75	0.63	0.54	0.46	0.39	0.33	0.29	0.24	1.44
1951	0.17	3.24	5.94	4.65	3.67	2.96	2.43	2.02	1.69	1.42	1.20	1.01	0.86	0.73	0.62	0.53	0.45	0.39	0.33	1.95
1952	0.13	2.52	4.62	3.59	2.83	2.29	1.88	1.56	1.30	1.09	0.92	0.78	0.66	0.56	0.48	0.41	0.35	0.30	0.25	1.50
1953	0.14	2.61	4.79	3.73	2.92	2.36	1.93	1.60	1.34	1.13	0.95	0.81	0.68	0.58	0.50	0.42	0.36	0.31	0.26	1.55
1954	0.21	3.91	7.15	5.58	4.38	3.51	2.87	2.38	1.99	1.67	1.41	1.20	1.02	0.86	0.74	0.63	0.54	0.46	0.39	2.30
1955	1.26	12.07	15.09	10.75	7.67	5.48	3.92	2.87	2.15	1.66	1.40	1.19	1.01	0.86	0.73	0.62	0.53	0.45	0.39	2.29
1956	1.41	13.27	15.74	10.92	7.73	5.55	3.99	2.90	2.17	1.68	1.42	1.21	1.02	0.87	0.74	0.63	0.54	0.46	0.39	2.32
1957	1.75	17.45	21.59	14.62	10.37	7.66	5.80	4.46	3.49	2.81	2.40	2.04	1.73	1.47	1.26	1.07	0.91	0.78	0.67	3.93
1958	1.83	17.29	20.01	12.90	8.62	6.10	4.49	3.40	2.63	2.08	1.79	1.53	1.31	1.11	0.95	0.81	0.69	0.59	0.50	2.96
1959	2.03	19.16	22.18	14.14	9.15	6.24	4.52	3.44	2.71	2.18	1.89	1.64	1.41	1.20	1.02	0.87	0.74	0.64	0.54	3.20
1960	2.23	20.91	23.87	15.09	9.66	6.37	4.44	3.32	2.62	2.15	1.89	1.65	1.43	1.23	1.05	0.90	0.77	0.65	0.56	3.29
1961	2.57	24.31	27.70	17.30	11.06	7.28	4.97	3.62	2.84	2.36	2.12	1.87	1.64	1.42	1.22	1.05	0.90	0.76	0.65	3.85
1962	2.77	25.35	27.58	16.63	10.36	6.70	4.46	3.10	2.31	1.85	1.67	1.51	1.34	1.17	1.02	0.88	0.75	0.64	0.55	3.24
1963	2.94	25.89	27.14	15.96	9.57	5.99	3.89	2.62	1.85	1.40	1.25	1.13	1.02	0.91	0.79	0.69	0.60	0.51	0.44	2.58
1964	3.23	28.52	29.84	17.58	10.43	6.42	4.14	2.81	1.99	1.48	1.28	1.14	1.03	0.94	0.83	0.73	0.64	0.55	0.47	2.78
1965	3.56	31.20	32.06	18.61	11.07	6.74	4.27	2.87	2.04	1.52	1.28	1.11	0.99	0.90	0.82	0.73	0.64	0.56	0.48	2.85
1966	3.70	32.45	32.87	18.61	10.93	6.70	4.22	2.80	1.98	1.49	1.25	1.05	0.91	0.82	0.74	0.67	0.60	0.53	0.46	2.76
1967	4.03	36.40	37.45	20.96	12.17	7.51	4.87	3.29	2.35	1.80	1.51	1.28	1.08	0.94	0.84	0.77	0.70	0.62	0.54	3.33
1968	4.47	41.25	42.12	22.88	13.15	8.04	5.25	3.64	2.64	2.01	1.68	1.42	1.20	1.02	0.89	0.80	0.73	0.66	0.59	3.67
1969	4.36	38.30	36.72	18.58	10.10	5.91	3.67	2.44	1.73	1.28	1.05	0.89	0.75	0.64	0.54	0.47	0.42	0.39	0.35	2.27
1970	4.41	38.78	37.78	19.21	9.89	5.58	3.40	2.22	1.56	1.16	0.96	0.79	0.67	0.57	0.48	0.41	0.36	0.32	0.29	1.98
1971	4.80	41.19	39.23	20.13	10.36	5.49	3.19	2.02	1.37	1.01	0.83	0.69	0.57	0.48	0.41	0.35	0.30	0.26	0.23	1.65
1972	5.24	43.82	40.36	20.49	10.66	5.65	3.09	1.87	1.24	0.88	0.72	0.60	0.50	0.41	0.35	0.30	0.25	0.21	0.19	1.37
1973	5.60	45.09	39.65	19.57	10.02	5.33	2.88	1.61	1.00	0.68	0.55	0.45	0.38	0.31	0.26	0.22	0.19	0.16	0.14	0.99
1974	6.55	53.57	47.44	23.52	12.09	6.61	3.80	2.26	1.40	0.97	0.78	0.63	0.52	0.44	0.36	0.30	0.26	0.22	0.18	1.30
1975	7.91	64.19	53.63	25.08	12.97	7.15	4.23	2.65	1.73	1.17	0.92	0.74	0.60	0.50	0.42	0.35	0.29	0.24	0.21	1.43
1976	8.93	71.11	54.58	22.60	11.03	6.13	3.66	2.35	1.60	1.12	0.85	0.67	0.54	0.44	0.37	0.31	0.26	0.21	0.18	1.21
1977	10.29	80.96	58.30	21.60	9.45	5.05	3.09	2.04	1.45	1.08	0.85	0.64	0.51	0.41	0.34	0.28	0.23	0.19	0.16	1.06
1978	13.60	92.86	60.64	19.75	7.79	3.78	2.25	1.55	1.14	0.88	0.73	0.57	0.44	0.35	0.28	0.23	0.19	0.16	0.13	0.84
1979	10.36	103.78	53.38	14.30	4.92	2.14	1.15	0.76	0.57	0.45	0.39	0.32	0.25	0.19	0.15	0.12	0.10	0.08	0.07	0.43
1980	18.18	86.66	64.53	14.06	4.03	1.55	0.76	0.46	0.34	0.28	0.24	0.21	0.17	0.14	0.11	0.08	0.07	0.06	0.05	0.27
1981	6.57	133.43	44.49	13.35	3.16	1.04	0.46	0.26	0.18	0.15	0.14	0.12	0.10	0.09	0.07	0.05	0.04	0.03	0.03	0.16
1982	7.70	37.48	55.17	7.00	2.29	0.62	0.24	0.12	0.08	0.06	0.06	0.05	0.05	0.04	0.03	0.03	0.02	0.02	0.01	0.07
1983	34.04	84.34	27.85	15.79	2.12	0.77	0.23	0.10	0.06	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.04
1984	41.53	229.69	31.96	3.38	2.02	0.30	0.12	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01
1985	22.39	273.77	94.45	5.37	0.63	0.43	0.07	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1986	5.57	76.91	66.80	9.95	0.65	0.09	0.08	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	14.62	31.26	39.68	16.83	2.69	0.19	0.03	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	9.84	102.03	20.47	12.68	5.55	0.93	0.07	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	3.44	72.31	75.79	7.96	5.14	2.41	0.44	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.43	12.75	31.36	17.39	1.93	1.36	0.71	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.74	6.38	19.04	23.54	12.74	1.38	0.93	0.46	0.09	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.89	1.33	6.32	17.65	23.66	13.27	1.44	0.94	0.45	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.15	4.74	6.42	4.49	5.52	7.99	5.56	0.79	0.71	0.46	0.11	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.30	1.54	30.73	4.46	1.38	1.78	2.90	2.26	0.36	0.34	0.24	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	0.12	2.42	9.37	22.76	1.43	0.45	0.64	1.17	1.01	0.17	0.18	0.13	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.25	0.85	13.06	6.02	6.60	0.43	0.15	0.25	0.49	0.47	0.09	0.09	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00
1997	0.61	7.52	12.49	19.97	4.16	4.55	0.31	0.11	0.17	0.34	0.32	0.06	0.06	0.04	0.01	0.00	0.00	0.00	0.00	0.00
1998	0.37	1.88	17.94	3.76	2.26	0.51	0.68	0.06	0.03	0.05	0.13	0.13	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00
1999	1.07	6.92	20.10	24.05	2.29	1.35	0.31	0.43	0.04	0.02	0.03	0.08	0.08	0.02	0.02	0.01	0.00	0.00	0.00	0.00
2000	1.04	8.14	34.48	13.54	6.92	0.68	0.46	0.12	0.20	0.02	0.01	0.02	0.05	0.06	0.01	0.01	0.01	0.00	0.00	0.00
2001	0.48	5.41	33.86	20.52	3.50	1.90	0.22	0.19	0.06	0.12	0.01	0.01	0.02	0.05	0.05	0.01	0.01	0.01	0.00	0.00
2002	0.40	3.87	31.14	25.07	6.70	1.16	0.69	0.09	0.08	0.03	0.06	0.01	0.00	0.01	0.03	0.03	0.01	0.01	0.00	0.00
2003	0.38	2.36	16.29	18.34	6.68	1.82	0.34	0.22	0.03	0.03	0.01	0.03	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
2004	0.16	3.65	18.30	19.49	10.38	3.75	1.08	0.22	0.16	0.02	0.03	0.01	0.02	0.00	0.00	0.00	0.01	0.01	0.00	0.01
2005	0.08	1.17	20.74	15.10	7.69	4.17	1.62	0.51	0.11	0.08	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00
2006	2.19	0.70	7.18	18.00	6.17	3.23	1.91	0.81	0.27	0.06	0.05	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01
2007	1.04	15.27	3.84	5.12	5.60	2.04	1.27	0.93	0.50	0.21	0.06	0.05	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.02
2008	1.80	12.81	109.43	2.96	1.75	2.03	0.84	0.59	0.48	0.27	0.12	0.04	0.03	0.01	0.01	0.00	0.01	0.00	0.00	0.01
2009	0.17	8.78	50.40	57.22	0.64	0.40	0.55	0.28	0.23	0.22	0.15	0.07	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.01
2010	0.01	0.04	0.61	0.43	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.03	0.19	0.19	0.68	0.27	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.18	1.07	1.99	1.57	7.57	3.78	2.11	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00
2013	0.30	0.81	2.40	2.03	0.80	3.15	1.58	0.92	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00
2014	1.57	5.66	7.38	9.54	4.39	1.48	5.86	3.03	1.81	0.03	0.02	0.05	0.03	0.03	0.03	0.02	0.01	0.00	0.00	0.00

Table 21. Estimated landings at age in whole weight (1000 lb)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.19	8.14	25.65	29.12	30.02	29.57	28.20	26.25	23.99	21.63	19.29	17.06	14.99	13.10	11.40	9.89	8.56	7.39	6.37	37.82
1951	0.26	11.09	34.80	39.47	40.69	40.08	38.22	35.57	32.52	29.31	26.14	23.12	20.31	17.75	15.45	13.41	11.60	10.01	8.63	51.25
1952	0.20	8.64	27.07	30.49	31.39	30.93	29.49	27.45	25.09	22.62	20.17	17.84	15.67	13.70	11.92	10.35	8.95	7.73	6.66	39.54
1953	0.21	8.94	28.08	31.68	32.39	31.88	30.40	28.29	25.86	23.31	20.79	18.38	16.16	14.12	12.29	10.66	9.23	7.96	6.86	40.76
1954	0.31	13.41	41.93	47.41	48.55	47.44	45.19	42.05	38.44	34.65	30.90	27.33	24.02	20.99	18.27	15.85	13.71	11.84	10.20	60.59
1955	1.86	41.38	88.47	91.31	85.13	74.09	61.63	50.56	41.50	34.40	30.67	27.13	23.84	20.83	18.13	15.73	13.61	11.75	10.13	60.14
1956	2.09	45.48	92.26	92.69	85.74	75.06	62.71	51.17	41.95	34.74	31.12	27.52	24.19	21.14	18.40	15.96	13.81	11.92	10.28	61.02
1957	2.58	59.81	126.59	124.17	114.99	103.69	91.24	78.66	67.37	58.15	52.46	46.62	40.97	35.80	31.16	27.04	23.39	20.20	17.40	103.35
1958	2.71	59.26	117.29	109.54	95.64	82.52	70.59	59.94	50.66	42.95	39.11	35.00	30.90	27.01	23.50	20.40	17.65	15.23	13.13	77.96
1959	3.00	65.68	130.04	120.10	101.55	84.41	71.04	60.61	52.24	45.12	41.35	37.35	33.21	29.16	25.38	22.02	19.05	16.45	14.18	84.17
1960	3.29	71.65	139.93	128.15	107.12	86.19	69.81	58.51	50.55	44.42	41.39	37.63	33.77	29.86	26.11	22.66	19.60	16.92	14.58	86.60
1961	3.79	83.32	162.40	146.90	122.67	98.56	78.20	63.89	54.86	48.81	46.30	42.80	38.65	34.50	30.38	26.49	22.92	19.78	17.05	101.25
1962	4.10	86.89	161.71	141.21	114.90	90.59	70.13	54.63	44.49	38.38	36.58	34.42	31.61	28.39	25.24	22.16	19.26	16.63	14.33	85.10
1963	4.34	88.74	159.12	135.51	106.14	81.11	61.21	46.20	35.67	29.07	27.32	25.83	24.15	22.05	19.73	17.48	15.31	13.28	11.44	67.94
1964	4.78	97.76	174.97	149.28	115.73	86.80	65.16	49.50	38.35	30.66	27.89	26.00	24.42	22.71	20.65	18.42	16.28	14.22	12.31	73.11
1965	5.26	106.95	187.99	158.06	122.80	91.22	67.21	50.71	39.43	31.52	27.98	25.26	23.39	21.85	20.23	18.35	16.32	14.38	12.54	74.84
1966	5.47	111.24	192.74	158.06	121.30	90.61	66.37	49.34	38.23	30.75	27.28	24.03	21.54	19.84	18.46	17.04	15.41	13.67	12.03	72.60
1967	5.97	124.77	219.57	177.96	135.05	101.57	76.59	58.07	45.43	37.18	33.11	29.14	25.50	22.74	20.85	19.34	17.81	16.06	14.23	87.47
1968	6.62	141.40	246.94	194.29	145.87	108.74	82.57	64.22	50.85	41.56	36.80	32.50	28.42	24.73	21.96	20.09	18.58	17.06	15.37	96.61
1969	6.44	131.28	215.27	157.76	112.09	80.00	57.74	43.11	33.38	26.46	23.06	20.26	17.78	15.46	13.40	11.86	10.82	9.98	9.15	59.65
1970	6.52	132.92	221.47	163.13	109.66	75.50	53.53	39.19	30.12	24.10	20.91	18.08	15.77	13.77	11.92	10.30	9.10	8.28	7.62	52.18
1971	7.10	141.16	230.00	170.96	114.88	74.24	50.23	35.66	26.52	20.81	18.21	15.67	13.47	11.69	10.16	8.77	7.56	6.66	6.05	43.38
1972	7.75	150.18	236.63	173.98	118.21	76.47	48.64	33.01	23.85	18.16	15.79	13.70	11.72	10.01	8.65	7.50	6.46	5.55	4.88	35.99
1973	8.28	154.53	232.44	166.22	111.14	72.07	45.30	28.43	19.29	14.04	12.02	10.37	8.94	7.60	6.47	5.58	4.82	4.14	3.55	25.97
1974	9.69	183.62	278.16	199.71	134.07	89.38	59.71	39.80	27.05	20.00	16.95	14.40	12.34	10.58	8.96	7.60	6.53	5.63	4.83	34.20
1975	11.70	219.99	314.42	212.94	143.83	96.68	66.45	46.79	33.30	24.16	20.02	16.83	14.20	12.10	10.34	8.73	7.38	6.33	5.45	37.50
1976	13.21	243.73	319.98	191.94	122.39	83.00	57.52	41.49	30.93	23.24	18.62	15.31	12.79	10.73	9.11	7.76	6.53	5.51	4.72	31.77
1977	15.21	277.49	341.79	183.42	104.82	68.26	48.64	36.05	27.99	22.32	18.50	14.70	12.01	9.98	8.34	7.06	5.99	5.03	4.24	27.88
1978	20.12	318.26	355.52	167.71	86.42	51.10	35.42	27.29	21.92	18.25	15.91	13.09	10.33	8.39	6.94	5.79	4.88	4.14	3.47	21.98
1979	15.33	355.70	312.97	121.44	54.63	28.98	18.08	13.37	10.99	9.33	8.44	7.30	5.96	4.68	3.79	3.12	2.60	2.19	1.85	11.29
1980	26.88	297.02	378.36	119.39	44.73	21.01	11.95	8.09	6.49	5.71	5.32	4.78	4.10	3.34	2.61	2.10	1.73	1.43	1.21	7.20
1981	9.71	457.32	260.84	113.36	35.10	14.06	7.28	4.62	3.48	3.05	2.97	2.74	2.45	2.09	1.69	1.32	1.06	0.87	0.72	4.19
1982	11.38	128.45	323.47	59.41	25.35	8.44	3.75	2.18	1.55	1.28	1.23	1.19	1.09	0.97	0.83	0.67	0.52	0.42	0.34	1.91
1983	50.34	289.06	163.29	134.07	23.49	10.35	3.64	1.73	1.07	0.80	0.70	0.67	0.64	0.59	0.52	0.44	0.35	0.27	0.22	1.18
1984	61.41	787.25	187.39	28.66	22.42	4.07	1.89	0.70	0.35	0.22	0.18	0.16	0.15	0.14	0.13	0.11	0.10	0.08	0.06	0.30
1985	33.11	938.32	553.74	45.61	6.96	5.88	1.17	0.60	0.24	0.13	0.09	0.07	0.06	0.06	0.06	0.05	0.05	0.04	0.03	0.15
1986	8.23	263.59	391.65	84.52	7.18	1.24	1.23	0.29	0.18	0.09	0.06	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.07
1987	21.62	107.14	232.65	142.89	29.83	2.61	0.48	0.51	0.13	0.09	0.05	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.05
1988	14.55	349.71	120.03	107.67	61.55	12.64	1.11	0.21	0.23	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.03
1989	5.09	247.82	444.36	67.56	57.04	32.55	6.85	0.63	0.12	0.15	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.02
1990	0.64	43.71	183.88	147.65	21.40	18.42	11.10	2.54	0.26	0.06	0.07	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.01
1991	1.09	21.88	111.62	199.91	141.39	18.61	14.58	8.03	1.69	0.16	0.04	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01
1992	2.88	6.82	45.36	163.90	268.90	177.03	21.81	15.93	8.17	1.62	0.15	0.03	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.01
1993	0.49	24.22	46.06	41.71	62.74	106.60	84.36	13.33	13.02	8.97	2.34	0.26	0.06	0.08	0.02	0.02	0.01	0.01	0.00	0.02
1994	0.98	7.85	220.37	41.39	15.67	23.80	43.97	38.06	6.52	6.78	4.91	1.29	0.15	0.03	0.04	0.01	0.01	0.00	0.00	0.01
1995	0.38	12.37	67.22	211.42	16.22	6.03	9.79	19.64	18.48	3.40	3.75	2.79	0.75	0.09	0.02	0.03	0.01	0.01	0.00	0.01
1996	0.79	4.36	93.65	55.89	74.99	5.77	2.32	4.14	9.08	9.18	1.79	2.01	1.52	0.41	0.05	0.01	0.01	0.00	0.00	0.01
1997	1.96	38.42	89.55	185.51	47.30	60.77	4.68	1.86	3.21	6.78	6.67	1.26	1.39	1.05	0.28	0.03	0.01	0.01	0.00	0.01
1998	1.19	9.59	128.65	34.91	25.71	6.77	10.39	0.99	0.49	1.05	2.63	2.88	0.58	0.68	0.51	0.14	0.02	0.00	0.00	0.00
1999	3.46	35.38	144.18	223.34	26.02	18.04	4.73	7.19	0.67	0.33	0.68	1.68	1.81	0.37	0.43	0.32	0.09	0.01	0.00	0.01
2000	3.36	41.59	247.26	125.80	78.63	9.13	7.02	2.08	3.58	0.38	0.21	0.46	1.18	1.34	0.27	0.32	0.24	0.06	0.01	0.01
2001	1.54	27.67	242.83	190.58	39.78	25.39	3.41	3.15	1.14	2.38	0.30	0.18	0.43	1.16	1.31	0.27	0.31	0.23	0.06	0.01
2002	1.29	19.78	223.36	232.87	76.19	15.49	10.43	1.49	1.47	0.57	1.24	0.16	0.10	0.24	0.64	0.72	0.15	0.17	0.13	0.04
2003	1.22	12.04	116.81	170.33	75.87	24.23	5.22	3.79	0.59	0.62	0.25	0.58	0.07	0.05	0.11	0.30	0.34	0.07	0.08	0.08
2004	0.50	18.67	131.22	181.04	117.96	50.01	16.43	3.72	2.88	0.48	0.54	0.23	0.53	0.07	0.04	0.11	0.28	0.32	0.06	0.14
2005	0.24	5.96	148.72	140.23	87.38	55.70	24.64	8.52	2.03	1.65	0.29	0.33	0.14	0.33	0.04	0.03	0.07	0.18	0.20	0.13
2006	7.08	3.56	51.50	167.17	70.13	43.08	29.00	13.60	4.97	1.25	1.07	0.19	0.22	0.10	0.23	0.03	0.02	0.05	0.12	0.22
2007	3.37	78.06	27.51	47.53	63.69	27.26	19.35	15.72	9.09	4.07	1.23	1.18	0.22	0.28	0.12	0.29	0.04	0.02	0.06	0.42
2008	5.81	65.47	784.82	27.51	19.89	27.14	12.77	9.96	8.78	5.40	2.54	0.77	0.75	0.15	0.18	0.08	0.18	0.02	0.01	0.30
2009	0.56	44.90	361.43	531.43	7.23	5.34	8.38	4.65	4.30	4.40	3.06	1.55	0.49	0.49	0.10	0.12	0.05	0.12	0.02	0.20
2010	0.01	0.14	3.58	3.63	2.55	0.04	0.04	0.07	0.05	0.05	0.05	0.04	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
2011	0.04	0.64	1.10	5.81	3.00	1.58	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.27	3.68	11.68	13.29	83.95	51.12	33.18	0.52	0.49	0.98	0.67	0.73	0.81	0.59	0.30	0.10	0.10	0.02	0.02	0.07
2013	0.45	2.79	14.07	17.24	8.89	42.63	24.86	16.15	0.25	0.24	0.49	0.33	0.36	0.40	0.29	0.15	0.05	0.05	0.01	0.04
2014	2.32	19.42	43.26	80.99	48.74	19.98	92.12	53.50	34.84	0.55	0.52	1.04	0.71	0.75	0.84	0.60	0.31	0.10	0.10	0.11

Table 22. Estimated discards at age in numbers (1000 fish)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1951	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1952	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1953	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1954	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1955	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1956	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1957	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1958	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1959	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1960	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1966	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1967	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.85	0.74	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	1.31	0.25	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	1.48	0.15	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	18.14	4.62	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	14.48	8.56	0.70	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	13.47	8.53	1.65	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	21.09	2.01	0.56	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	12.37	5.94	0.27	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	3.28	3.15	0.74	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	2.47	2.99	1.49	0.23	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	3.97	1.63	1.13	0.40	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	18.28	1.53	0.43	0.27	0.15	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	15.05	18.45	0.87	0.12	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	25.79	5.71	4.57	0.13	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	14.79	12.87	1.90	0.94	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	14.49	2.25	1.51	0.16	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	10.04	6.90	0.66	0.26	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	13.69	3.30	1.44	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	50.09	15.54	1.92	0.39	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	69.66	25.89	4.53	0.29	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	52.49	25.58	5.75	0.56	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	38.69	17.03	5.61	0.86	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	46.72	13.11	3.47	0.61	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	37.18	37.36	6.45	1.02	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	15.59	11.07	7.83	0.98	0.16	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	51.78	0.77	0.31	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2007	86.83	51.15	0.41	0.09	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	155.08	50.12	16.20	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	32.07	68.13	13.42	2.31	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	17.03	6.48	28.41	13.54	6.56	0.07	0.05	0.07	0.03	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	8.82	4.80	2.66	11.83	5.49	2.79	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
2012	21.63	14.93	7.28	2.57	9.21	3.91	1.82	0.02	0.01	0.02	0.01	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
2013	22.73	7.50	6.19	2.63	0.82	2.84	1.25	0.63	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
2014	58.80	26.23	8.99	5.45	1.91	0.56	1.89	0.83	0.42	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00

Table 23. Estimated discards at age in whole weight (1000 lb)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1950	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1951	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1952	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1953	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1954	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1955	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1956	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1957	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1958	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1959	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1960	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1966	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1967	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.99	2.29	0.29	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	1.53	0.79	0.42	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	1.73	0.46	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	21.17	14.33	0.81	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	16.90	26.57	3.92	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	15.73	26.46	9.29	0.58	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	24.62	6.25	3.13	0.55	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	14.44	18.42	1.51	0.39	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	3.83	9.78	4.14	0.18	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	2.88	9.29	8.39	1.90	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	4.63	5.06	6.36	3.35	0.63	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	21.34	4.76	2.40	2.28	1.62	0.47	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	17.56	57.26	4.86	0.96	0.54	0.35	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	30.10	17.74	25.64	1.07	0.15	0.09	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	17.26	39.93	10.66	7.82	0.24	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	16.91	7.00	8.50	1.32	0.75	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	11.72	21.41	3.73	2.13	0.24	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	15.97	10.23	8.09	0.54	0.16	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	58.46	48.24	10.81	3.24	0.13	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	81.30	80.35	25.46	2.41	0.48	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	61.26	79.38	32.27	4.70	0.31	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	45.15	52.86	31.50	7.16	0.87	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	54.53	40.69	19.48	5.10	0.70	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	43.40	115.94	36.22	8.49	1.55	0.19	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	18.19	34.36	44.01	8.17	1.72	0.39	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	60.43	2.38	1.76	1.05	0.14	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2007	101.34	158.74	2.33	0.72	0.29	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	180.99	155.54	91.00	0.54	0.11	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	37.43	211.44	75.38	19.25	0.08	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	19.87	20.12	159.56	112.98	72.27	0.98	0.74	1.15	0.60	0.51	0.58	0.42	0.22	0.07	0.07	0.01	0.02	0.01	0.02	0.03
2011	10.29	14.91	14.96	98.75	60.56	37.58	0.54	0.47	0.87	0.57	0.62	0.69	0.50	0.26	0.08	0.08	0.02	0.02	0.01	0.05
2012	25.24	46.33	40.86	21.46	101.54	52.81	28.58	0.36	0.28	0.46	0.32	0.34	0.38	0.28	0.14	0.05	0.04	0.01	0.01	0.03
2013	26.52	23.29	34.75	21.96	9.00	38.33	19.60	11.05	0.15	0.13	0.26	0.18	0.19	0.21	0.15	0.08	0.02	0.02	0.00	0.02
2014	68.63	81.41	50.52	45.46	21.08	7.52	29.69	14.52	8.02	0.11	0.10	0.21	0.14	0.15	0.16	0.12	0.06	0.02	0.02	0.02

Table 24. Estimated status indicators, benchmarks, and related quantities from the base run of the Beaufort catch-age model, conditional on estimated current selectivities averaged across fleets. Also presented are median values and measures of precision (standard errors, SE) from the Monte Carlo/Bootstrap analysis. Rate estimates (F) are in units of y^{-1}*; status indicators are dimensionless; and biomass estimates are in units of metric tons or pounds, as indicated. Spawning stock biomass (SSB) is measured as population fecundity (number of eggs)*

Quantity	Units	Estimate	Median	SE
$F_{30\%}$	y^{-1}	0.15	0.15	0.01
$85\%F_{30\%}$	y^{-1}	0.12	0.13	0.01
$75\%F_{30\%}$	y^{-1}	0.11	0.11	0.01
$65\%F_{30\%}$	y^{-1}	0.10	0.10	0.01
$F_{30\%}$	y^{-1}	0.15	0.15	0.01
$F_{40\%}$	y^{-1}	0.11	0.11	0.01
$B_{\mathrm{F30\%}}$	metric tons	3637	3525	6052
$\mathrm{SSB}_{\mathrm{F30\%}}$	Eggs (1E8)	327706	293944	91136
MSST	Eggs (1E8)	245779	220458	68352
$L_{\mathrm{F30\%}}$	1000 lb whole	427	415	77
$R_{\mathrm{F30\%}}$	number fish	446642	455926	110006
$L_{85\%\mathrm{F30\%}}$	1000 lb whole	411	399	74
$L_{75\%\mathrm{F30\%}}$	1000 lb whole	395	384	71
$L_{65\%\mathrm{F30\%}}$	1000 lb whole	375	365	67
$F_{2012-2014}/F_{30\%}$	—	2.70	2.66	0.90
$\mathrm{SSB}_{2014}/\mathrm{MSST}$	—	0.20	0.21	0.12
$\mathrm{SSB}_{2014}/\mathrm{SSB}_{\mathrm{F30\%}}$	—	0.15	0.16	0.09

Table 25. Results from sensitivity runs of the Beaufort catch-age model. Current F represented by geometric mean of last three assessment years. Runs should not all be considered equally plausible.

Run	Description	$F_{30\%}$	$SSB_{F30\%}$ (1E8 Eggs)	$L_{F30\%}$ (1000 lb)	$F_{current}/F_{30\%}$	$SSB_{end}/SSB_{F30\%}$	R0(1000)	sigmaR	Finit
Base	—	0.147	329948	459	2.84	0.18	331	0.79	0.03
S1	remove 2008/9 from FD	0.147	329929	468	2.86	0.18	330	0.79	0.03
S2	upweight FI 10X	0.146	332402	438	2.07	0.28	325	0.82	0.03
S3	upweight FD 3X	0.146	344879	448	1.71	0.36	338	0.82	0.03
S4	FD only	0.145	332259	325	1.19	0.64	347	0.74	0.03
S5	M upper	0.169	246562	424	1.65	0.4	430	0.82	0.03
S6	M lower	0.133	406658	470	3.73	0.12	285	0.75	0.03
S7	Disc. M lower	0.147	328444	520	2.12	0.24	317	0.83	0.03
S8	Disc. M upper	0.146	335957	424	2.82	0.2	354	0.72	0.03
S9	Longer CVID index	0.147	334145	470	1.99	0.3	344	0.76	0.03
S10	Smooth 1984/5 MRIP peak	0.147	328483	462	2.53	0.22	327	0.8	0.03
S11	h=0.84	0.146	396289	525	3.56	0.11	497	0.6	0.03
S12	Truncated HB disc. index	0.147	331524	470	2.6	0.21	334	0.78	0.03
S13	Ageing error matrix	0.144	334881	409	1.63	0.39	319	0.85	0.03
S14	Batch number lower	0.154	220597	468	2.47	0.24	330	0.79	0.03
S15	Batch number upper	0.146	362022	465	2.63	0.21	333	0.78	0.03
S16	Drop HB disc. index	0.147	331560	470	2.59	0.21	334	0.78	0.03
S17	Higher landings	0.147	441258	654	1.94	0.25	406	0.89	0.03
S18	Lower landings	0.146	232011	298	3.36	0.18	258	0.64	0.03
S19	Higher discards	0.146	338021	500	2.6	0.19	362	0.7	0.03
S20	Lower discards	0.147	327352	561	1.89	0.26	306	0.87	0.03
S21	Dome-shaped selectivity for cH	0.15	355593	490	2.28	0.23	333	0.87	0.03
S22	Separate video and trap indices	0.143	331956	391	1.58	0.41	341	0.76	0.03
S23	FI index only	0.146	330170	436	2.75	0.18	342	0.75	0.03
S24	Continuity	0.102	817833	501	5.97	0.06	114	1.18	0.04
S25	Split q for HB CPUE	0.147	331168	466	2.61	0.2	333	0.79	0.03
S26	1978 start year	0.147	299224	418	2.93	0.19	320	0.7	0.2
S27	Estimate selex for all ages	0.148	328522	465	2.61	0.2	332	0.78	0.03

Table 26. Projection results with fishing mortality rate fixed at $F = 0$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), pr.reb = proportion of stochastic projection replicates with $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F}30\%}$. The extension b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	432	310	0.12	0.13	63370	58040	0	0	0	0	70	69	279	281	0.001
2016	436	308	0.24	0.26	87803	78457	28	28	244	243	71	66	343	329	0.004
2017	439	314	0.00	0.00	126462	111544	0	0	0	0	0	0	0	0	0.015
2018	442	314	0.00	0.00	180342	157052	0	0	0	0	0	0	0	0	0.067
2019	444	318	0.00	0.00	241177	207405	0	0	0	0	0	0	0	0	0.192
2020	446	316	0.00	0.00	305554	261097	0	0	0	0	0	0	0	0	0.390
2021	446	325	0.00	0.00	371340	315588	0	0	0	0	0	0	0	0	0.605
2022	447	319	0.00	0.00	436842	369565	0	0	0	0	0	0	0	0	0.776
2023	447	320	0.00	0.00	499775	422387	0	0	0	0	0	0	0	0	0.892
2024	448	318	0.00	0.00	559749	473142	0	0	0	0	0	0	0	0	0.953
2025	448	325	0.00	0.00	615542	521524	0	0	0	0	0	0	0	0	0.983
2026	448	322	0.00	0.00	666967	565810	0	0	0	0	0	0	0	0	0.993
2027	448	327	0.00	0.00	714392	606683	0	0	0	0	0	0	0	0	0.997
2028	448	321	0.00	0.00	757163	644437	0	0	0	0	0	0	0	0	0.999
2029	448	324	0.00	0.00	795659	680658	0	0	0	0	0	0	0	0	1.000
2030	448	321	0.00	0.00	830549	711124	0	0	0	0	0	0	0	0	1.000
2031	448	322	0.00	0.00	861736	739593	0	0	0	0	0	0	0	0	1.000
2032	448	320	0.00	0.00	889361	764257	0	0	0	0	0	0	0	0	1.000
2033	448	320	0.00	0.00	913872	786749	0	0	0	0	0	0	0	0	1.000
2034	448	319	0.00	0.00	935454	806215	0	0	0	0	0	0	0	0	1.000
2035	448	321	0.00	0.00	954544	824197	0	0	0	0	0	0	0	0	1.000
2036	448	323	0.00	0.00	971405	839359	0	0	0	0	0	0	0	0	1.000
2037	448	322	0.00	0.00	986280	853107	0	0	0	0	0	0	0	0	1.000
2038	448	319	0.00	0.00	999400	865349	0	0	0	0	0	0	0	0	1.000
2039	448	319	0.00	0.00	1010969	876882	0	0	0	0	0	0	0	0	1.000
2040	448	322	0.00	0.00	1021170	885872	0	0	0	0	0	0	0	0	1.000
2041	448	320	0.00	0.00	1030164	891838	0	0	0	0	0	0	0	0	1.000
2042	448	322	0.00	0.00	1038093	899554	0	0	0	0	0	0	0	0	1.000
2043	448	320	0.00	0.00	1045082	903786	0	0	0	0	0	0	0	0	1.000
2044	448	321	0.00	0.00	1051243	910470	0	0	0	0	0	0	0	0	1.000

Table 27. Projection results with fishing mortality rate fixed at $F = F_{\text{current}}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\text{SSB} \geq \text{SSB}_{\text{F30\%}}$. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	432	310	0.12	0.13	63370	58040	0	0	0	0	70	69	279	281	0.001
2016	436	308	0.24	0.26	87803	78457	28	28	244	243	71	66	343	329	0.004
2017	439	314	0.39	0.40	101048	88970	54	47	506	447	111	94	596	507	0.009
2018	441	313	0.39	0.40	104221	90788	50	43	504	438	103	87	559	475	0.014
2019	441	314	0.39	0.40	103601	89616	45	39	475	411	98	84	522	447	0.018
2020	441	311	0.39	0.40	101372	87427	43	37	451	390	96	82	496	426	0.021
2021	441	319	0.39	0.40	98928	85355	41	35	433	376	95	82	481	414	0.023
2022	441	313	0.39	0.40	96768	83444	40	35	422	367	94	81	472	410	0.024
2023	440	313	0.39	0.40	94914	82528	40	35	415	362	94	81	468	405	0.024
2024	440	311	0.39	0.40	93436	81291	40	34	409	358	94	81	466	404	0.025
2025	440	318	0.39	0.40	92263	80530	39	34	406	355	94	81	464	405	0.023
2026	440	314	0.39	0.40	91381	79593	39	34	403	354	94	81	463	404	0.023
2027	440	319	0.39	0.40	90750	79116	39	34	401	352	94	81	462	404	0.023
2028	440	313	0.39	0.40	90288	78840	39	34	400	352	93	81	462	402	0.022
2029	440	316	0.39	0.40	89959	78457	39	34	399	351	93	81	461	400	0.022
2030	440	313	0.39	0.40	89733	78412	39	34	398	349	93	81	461	402	0.022
2031	440	314	0.39	0.40	89574	78504	39	34	398	348	93	81	461	403	0.021
2032	440	312	0.39	0.40	89461	78546	39	34	398	349	93	81	461	402	0.021
2033	440	312	0.39	0.40	89383	78488	39	34	398	349	93	80	461	400	0.019
2034	440	311	0.39	0.40	89328	78699	39	34	397	348	93	80	460	400	0.019
2035	440	312	0.39	0.40	89290	78393	39	34	397	347	93	80	460	400	0.018
2036	440	315	0.39	0.40	89263	78314	39	34	397	348	93	80	460	398	0.018
2037	440	314	0.39	0.40	89245	77966	39	34	397	348	93	80	460	398	0.017
2038	440	311	0.39	0.40	89232	77935	39	34	397	348	93	80	460	399	0.017
2039	440	310	0.39	0.40	89224	78213	39	34	397	348	93	80	460	399	0.018
2040	440	314	0.39	0.40	89217	78131	39	34	397	348	93	80	460	399	0.019
2041	440	312	0.39	0.40	89213	78267	39	34	397	348	93	81	460	399	0.020
2042	440	313	0.39	0.40	89210	78063	39	34	397	348	93	81	460	400	0.020
2043	440	312	0.39	0.40	89208	78081	39	34	397	346	93	81	460	401	0.019
2044	440	313	0.39	0.40	89207	78117	39	34	397	348	93	80	460	401	0.020

Table 28. Projection results with fishing mortality rate fixed at $F = F_{30\%}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), pr.reb = proportion of stochastic projection replicates with $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F30\%}}$. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	432	310	0.12	0.13	63370	58040	0	0	0	0	70	69	279	281	0.001
2016	436	308	0.24	0.26	87803	78457	28	28	244	243	71	66	343	329	0.004
2017	439	314	0.15	0.15	116361	102522	22	20	207	195	44	39	241	218	0.009
2018	442	314	0.15	0.15	146966	127331	24	22	253	233	45	40	266	239	0.021
2019	443	317	0.15	0.15	175465	149920	26	23	285	258	46	41	281	252	0.040
2020	444	315	0.15	0.15	200733	169768	27	24	310	279	46	41	291	261	0.064
2021	445	323	0.15	0.15	222841	187374	28	25	332	298	47	42	299	267	0.096
2022	445	318	0.15	0.15	241979	202838	29	26	350	313	47	42	304	273	0.133
2023	446	319	0.15	0.15	257965	216120	29	27	365	327	47	42	310	279	0.167
2024	446	317	0.15	0.15	271354	227528	30	27	377	339	47	43	315	284	0.203
2025	446	324	0.15	0.15	282261	237107	30	27	387	349	48	43	319	288	0.234
2026	446	320	0.15	0.15	291141	244945	31	28	395	357	48	43	322	292	0.265
2027	446	325	0.15	0.15	298461	252233	31	28	401	364	48	43	324	295	0.293
2028	446	320	0.15	0.15	304304	258346	31	28	407	370	48	43	326	297	0.319
2029	446	323	0.15	0.15	308994	262872	31	29	411	375	48	44	328	298	0.340
2030	446	320	0.15	0.15	312828	266655	31	29	414	378	48	44	329	300	0.357
2031	447	320	0.15	0.15	315895	269863	31	29	417	380	48	44	330	301	0.373
2032	447	318	0.15	0.15	318319	271942	32	29	419	382	48	44	331	303	0.387
2033	447	319	0.15	0.15	320248	273385	32	29	421	384	48	44	332	302	0.398
2034	447	317	0.15	0.15	321769	275170	32	29	422	385	48	44	332	302	0.406
2035	447	319	0.15	0.15	322982	276801	32	29	423	386	48	44	332	303	0.413
2036	447	322	0.15	0.15	323949	277909	32	29	424	387	48	43	333	302	0.420
2037	447	321	0.15	0.15	324719	278086	32	29	424	387	48	44	333	303	0.422
2038	447	318	0.15	0.15	325331	278898	32	29	425	387	48	44	333	303	0.426
2039	447	317	0.15	0.15	325818	279526	32	29	425	389	48	44	333	304	0.429
2040	447	321	0.15	0.15	326206	279292	32	29	426	388	48	43	334	303	0.431
2041	447	318	0.15	0.15	326513	279646	32	29	426	388	48	44	334	304	0.433
2042	447	320	0.15	0.15	326758	280069	32	29	426	389	48	44	334	303	0.434
2043	447	319	0.15	0.15	326953	280511	32	29	426	389	48	44	334	304	0.436
2044	447	320	0.15	0.15	327107	281317	32	29	426	389	48	44	334	305	0.438

Table 29. Projection results with fishing mortality rate fixed at $F = 98\%F_{30\%}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F30\%}}$*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	432	310	0.12	0.13	63370	58040	0	0	0	0	70	69	279	281	0.001
2016	436	308	0.24	0.26	87803	78457	28	28	244	243	71	66	343	329	0.004
2017	439	314	0.14	0.15	116554	102701	22	20	204	191	43	39	236	214	0.009
2018	442	314	0.14	0.15	147566	127869	24	22	249	229	44	40	261	235	0.021
2019	443	317	0.14	0.15	176574	150930	25	23	280	255	45	40	277	248	0.041
2020	444	315	0.14	0.15	202402	171207	27	24	306	276	45	40	287	257	0.068
2021	445	323	0.14	0.15	225080	189241	28	25	328	294	46	41	295	263	0.101
2022	445	318	0.14	0.15	244772	205267	28	26	346	310	46	41	301	270	0.140
2023	446	319	0.14	0.15	261274	218931	29	26	362	324	46	42	306	276	0.177
2024	446	317	0.14	0.15	275135	230819	30	27	374	336	47	42	311	281	0.216
2025	446	324	0.14	0.15	286462	240644	30	27	384	346	47	42	315	285	0.250
2026	446	320	0.14	0.15	295709	248731	30	28	392	354	47	43	318	289	0.283
2027	446	325	0.14	0.15	303348	256468	31	28	399	362	47	43	321	292	0.314
2028	446	320	0.14	0.15	309463	262888	31	28	404	367	47	43	323	294	0.340
2029	446	323	0.14	0.15	314383	267501	31	28	408	373	47	43	324	295	0.366
2030	447	320	0.14	0.15	318413	271419	31	28	412	376	47	43	326	297	0.384
2031	447	320	0.14	0.15	321643	274734	31	28	415	378	47	43	327	298	0.401
2032	447	318	0.14	0.15	324202	277080	31	29	417	380	47	43	328	300	0.419
2033	447	319	0.14	0.15	326244	278482	31	29	418	382	47	43	328	299	0.429
2034	447	317	0.14	0.15	327857	280438	31	29	420	383	47	43	329	299	0.437
2035	447	319	0.14	0.15	329147	282062	31	29	421	385	47	43	329	300	0.445
2036	447	322	0.14	0.15	330176	283369	31	29	422	386	47	43	330	300	0.451
2037	447	321	0.14	0.15	330997	283572	32	29	423	385	47	43	330	300	0.454
2038	447	318	0.14	0.15	331652	284239	32	29	423	386	47	43	330	300	0.457
2039	447	318	0.14	0.15	332173	284986	32	29	424	387	47	43	330	301	0.461
2040	447	321	0.14	0.15	332589	284754	32	29	424	387	47	43	330	300	0.463
2041	447	318	0.14	0.15	332920	285289	32	29	424	387	47	43	330	301	0.466
2042	447	320	0.14	0.15	333184	285527	32	29	424	387	47	43	331	300	0.468
2043	447	319	0.14	0.15	333393	286147	32	29	425	387	47	43	331	301	0.469
2044	447	320	0.14	0.15	333561	286879	32	29	425	388	47	43	331	302	0.473

Table 30. Projection results with fishing mortality rate fixed at $F = F_{\text{rebuild}}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\text{SSB} \geq \text{SSB}_{\text{F30\%}}$*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	432	310	0.12	0.13	63370	58040	0	0	0	0	70	69	279	281	0.001
2016	436	308	0.24	0.26	87803	78457	28	28	244	243	71	66	343	329	0.004
2017	439	314	0.14	0.14	116573	102855	21	20	203	186	43	38	236	209	0.010
2018	442	314	0.14	0.14	147623	128689	24	21	249	224	44	39	261	230	0.025
2019	443	317	0.14	0.14	176680	152227	25	22	280	250	45	39	277	244	0.049
2020	444	315	0.14	0.14	202560	173676	26	23	306	272	45	40	287	253	0.083
2021	445	323	0.14	0.14	225292	192272	28	24	328	291	46	40	294	259	0.124
2022	445	318	0.14	0.14	245038	208432	28	25	346	306	46	41	300	266	0.168
2023	446	319	0.14	0.14	261589	222291	29	26	361	321	46	41	306	273	0.210
2024	446	317	0.14	0.14	275495	235178	30	27	374	334	47	41	311	278	0.251
2025	446	324	0.14	0.14	286862	245047	30	27	384	344	47	42	315	282	0.288
2026	446	320	0.14	0.14	296144	253406	30	27	392	352	47	42	318	285	0.323
2027	446	325	0.14	0.14	303815	260726	31	28	399	360	47	42	320	288	0.355
2028	446	320	0.14	0.14	309955	266702	31	28	404	366	47	42	322	290	0.380
2029	446	323	0.14	0.14	314897	271842	31	28	408	371	47	42	324	292	0.403
2030	447	320	0.14	0.14	318946	276078	31	28	412	374	47	42	325	293	0.421
2031	447	320	0.14	0.14	322193	278737	31	28	414	376	47	42	326	295	0.436
2032	447	318	0.14	0.14	324765	281639	31	28	417	378	47	42	327	296	0.452
2033	447	319	0.14	0.14	326817	283858	31	28	418	380	47	43	328	296	0.462
2034	447	317	0.14	0.14	328439	285560	31	28	420	382	47	42	328	296	0.471
2035	447	319	0.14	0.14	329736	286369	31	29	421	382	47	42	329	297	0.477
2036	447	322	0.14	0.14	330772	287263	31	29	422	383	47	42	329	296	0.482
2037	447	321	0.14	0.14	331598	288575	32	29	422	383	47	42	329	296	0.485
2038	447	318	0.14	0.14	332257	289369	32	29	423	383	47	42	330	297	0.490
2039	447	317	0.14	0.14	332782	290043	32	29	423	384	47	42	330	298	0.495
2040	447	321	0.14	0.14	333200	290214	32	29	424	384	47	42	330	297	0.497
2041	447	319	0.14	0.14	333533	290371	32	29	424	385	47	42	330	297	0.496
2042	447	320	0.14	0.14	333799	290884	32	29	424	385	47	43	330	297	0.496
2043	447	319	0.14	0.14	334010	291259	32	29	424	386	47	43	330	298	0.495
2044	447	320	0.14	0.14	334179	291227	32	29	425	385	47	43	330	298	0.496

Table 31. Projection results with fishing mortality rate applied only to discards. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (1E8 eggs), L = landings expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F30\%}}$*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(1E8)	S.med(1E8)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2015	432	306	0.12	0.13	63370	58033	0	0	0	0	70	69	279	282	0.001
2016	436	311	0.11	0.12	93943	84171	0	0	0	0	70	69	346	345	0.004
2017	440	312	0.12	0.13	129264	113133	0	0	0	0	76	71	430	414	0.016
2018	443	316	0.12	0.13	165018	141286	0	0	0	0	77	71	472	443	0.052
2019	444	314	0.12	0.13	199126	167365	0	0	0	0	77	72	496	459	0.110
2020	445	322	0.12	0.13	230244	191136	0	0	0	0	77	73	511	470	0.181
2021	446	317	0.12	0.13	258437	212321	0	0	0	0	78	73	522	480	0.251
2022	446	318	0.12	0.13	283795	231043	0	0	0	0	78	74	531	489	0.313
2023	446	319	0.12	0.13	305879	246463	0	0	0	0	79	74	541	498	0.366
2024	446	324	0.12	0.13	325137	260140	0	0	0	0	79	75	552	509	0.414
2025	447	320	0.12	0.13	341463	272140	0	0	0	0	79	76	561	517	0.452
2026	447	325	0.12	0.13	355334	282256	0	0	0	0	80	76	569	527	0.484
2027	447	319	0.12	0.13	367293	291101	0	0	0	0	80	76	575	533	0.512
2028	447	323	0.12	0.13	377276	298167	0	0	0	0	80	77	581	539	0.535
2029	447	320	0.12	0.13	385681	304830	0	0	0	0	80	77	585	543	0.554
2030	447	320	0.12	0.13	392908	310205	0	0	0	0	81	77	589	547	0.567
2031	447	320	0.12	0.13	398981	315115	0	0	0	0	81	77	592	549	0.581
2032	447	320	0.12	0.13	404020	319257	0	0	0	0	81	77	595	552	0.592
2033	447	319	0.12	0.13	408235	322070	0	0	0	0	81	77	597	552	0.601
2034	447	319	0.12	0.13	411727	324568	0	0	0	0	81	77	599	554	0.609
2035	447	323	0.12	0.13	414665	326003	0	0	0	0	81	77	601	554	0.614
2036	447	321	0.12	0.13	417136	327593	0	0	0	0	81	77	602	556	0.620
2037	447	318	0.12	0.13	419213	328401	0	0	0	0	81	77	603	557	0.625
2038	447	318	0.12	0.13	420958	330168	0	0	0	0	81	78	604	558	0.628
2039	447	323	0.12	0.13	422424	331400	0	0	0	0	81	77	605	559	0.631
2040	447	318	0.12	0.13	423655	332671	0	0	0	0	81	78	606	559	0.632
2041	447	320	0.12	0.13	424689	332754	0	0	0	0	81	78	606	560	0.634
2042	447	321	0.12	0.13	425557	333040	0	0	0	0	81	78	607	563	0.638
2043	447	321	0.12	0.13	426286	333165	0	0	0	0	81	78	607	562	0.639
2044	447	320	0.12	0.13	426898	334378	0	0	0	0	81	78	607	562	0.640

Table 32. Parameter estimates from selected ASPIC surplus production model runs 318 (continuity), 319 (updated continuity), 320 (best configuration), and 323 (best configuration with B_1/K fixed) All parameter values are rounded to 3 significant digits. MSY, B_1, and K are in units of 1000 pounds. Catchability parameters correspond to the commercial (q_1), headboat (q_2), headboat-at-sea (q_3), and CVID (q_4) indices.

Run	F/F_{MSY}	B/B_{MSY}	B_1/K	MSY	F_{MSY}	q_1	q_2	q_3	q_4	B_1	K
318	2.15	0.53	0.467	805	0.313	9.35e-07	7.14e-07			2400	5140
319	0.614	1.3	1.94	802	0.314	9.42e-07	7.14e-07			9930	5110
320	0.531	1.48	0.91	805	0.322	8.69e-07	6.98e-07	2.98e-07	4.04e-07	4560	5010
323	0.53	1.47	0.467	807	0.321	8.74e-07	7e-07	2.99e-07	4.02e-07	2350	5030

8 Figures

Figure 1. Indices of abundance used in fitting the assessment model. HB indicates the headboat logbook index; Handline indicated the the commercial handline logbook index; HB Disc indicated the headboat discard observer index, CVT indicates the SERFS chevron trap index; VID indicates the SERFS video index, and CVID indicates the combined chevron trap and video index. The CVT and VID indices were only used during sensitivity runs.

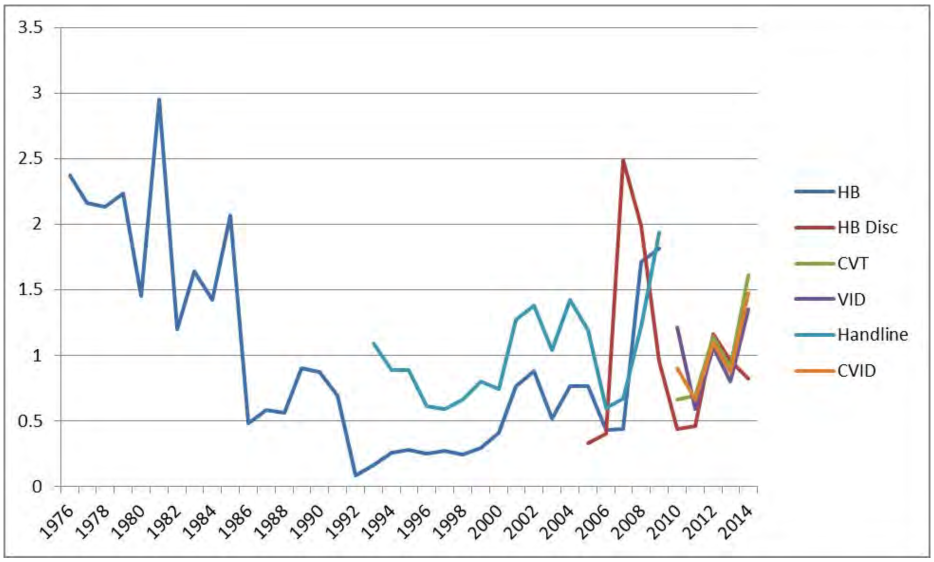


Figure 2. Mean total length at age (mm) and estimated upper and lower 95% confidence intervals of the population.

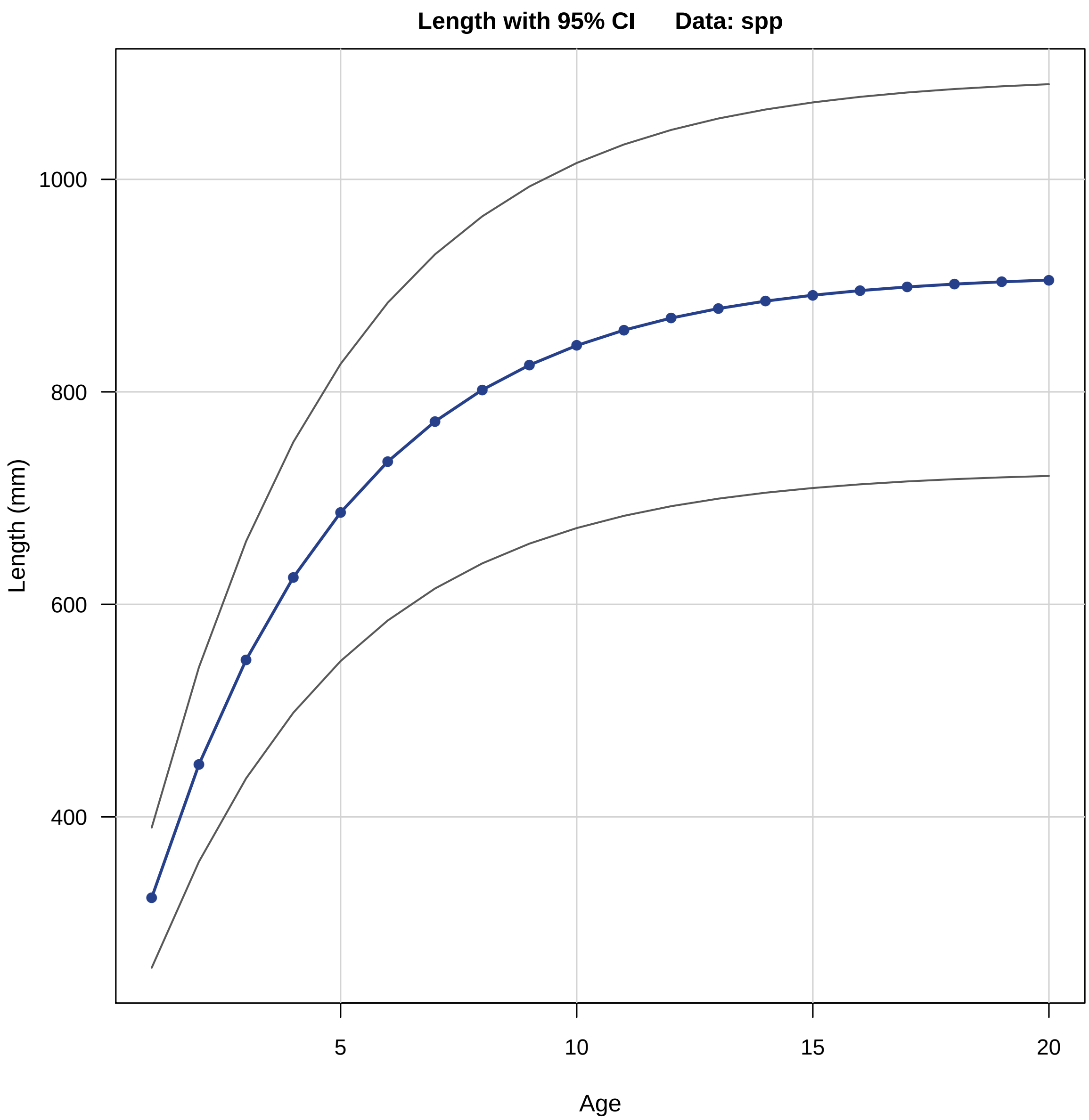


Figure 3. Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, CVT to MARMAP chevron trap, cH to commercial handline, HB to headboat and GR to general recreational.

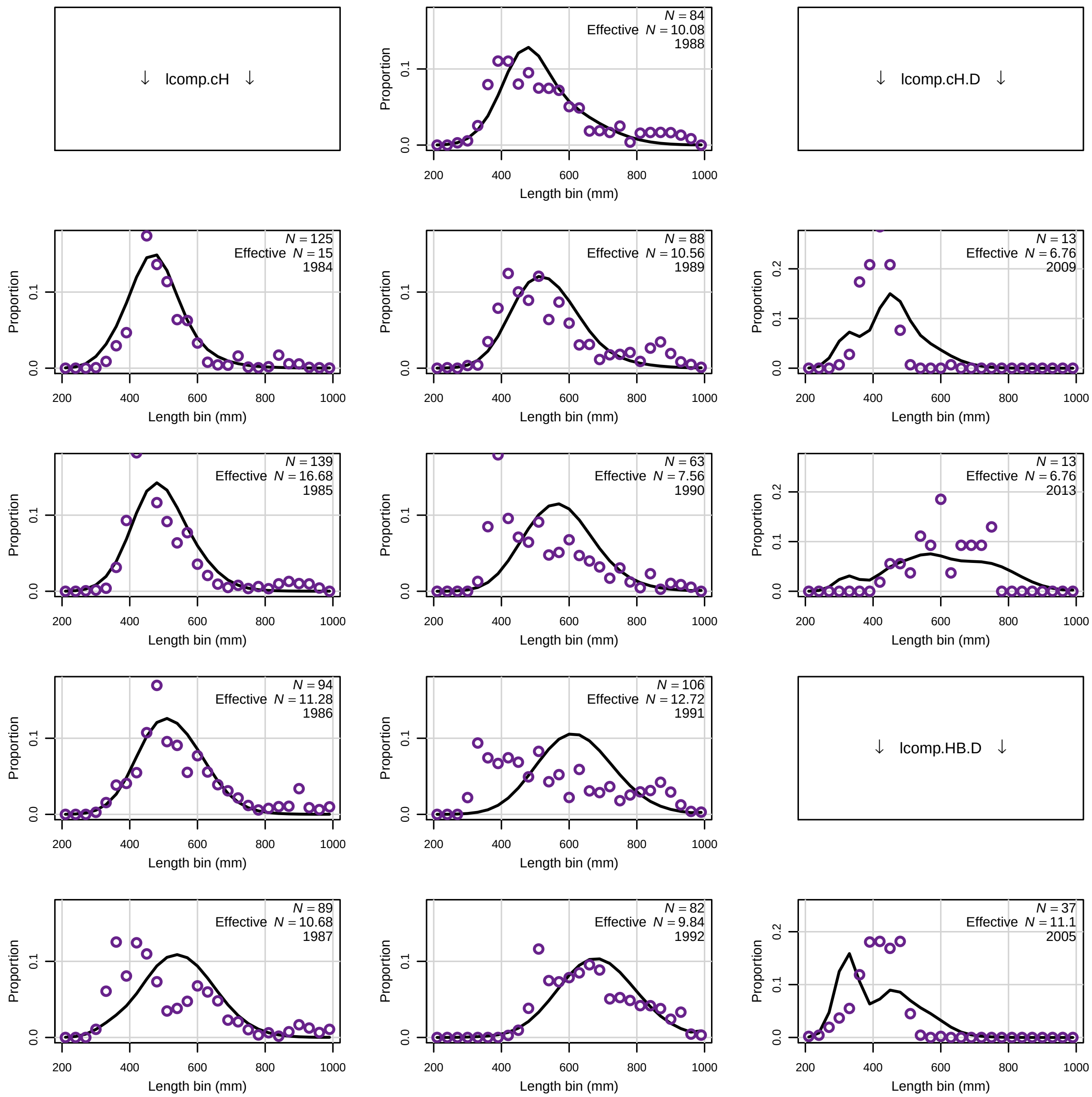


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

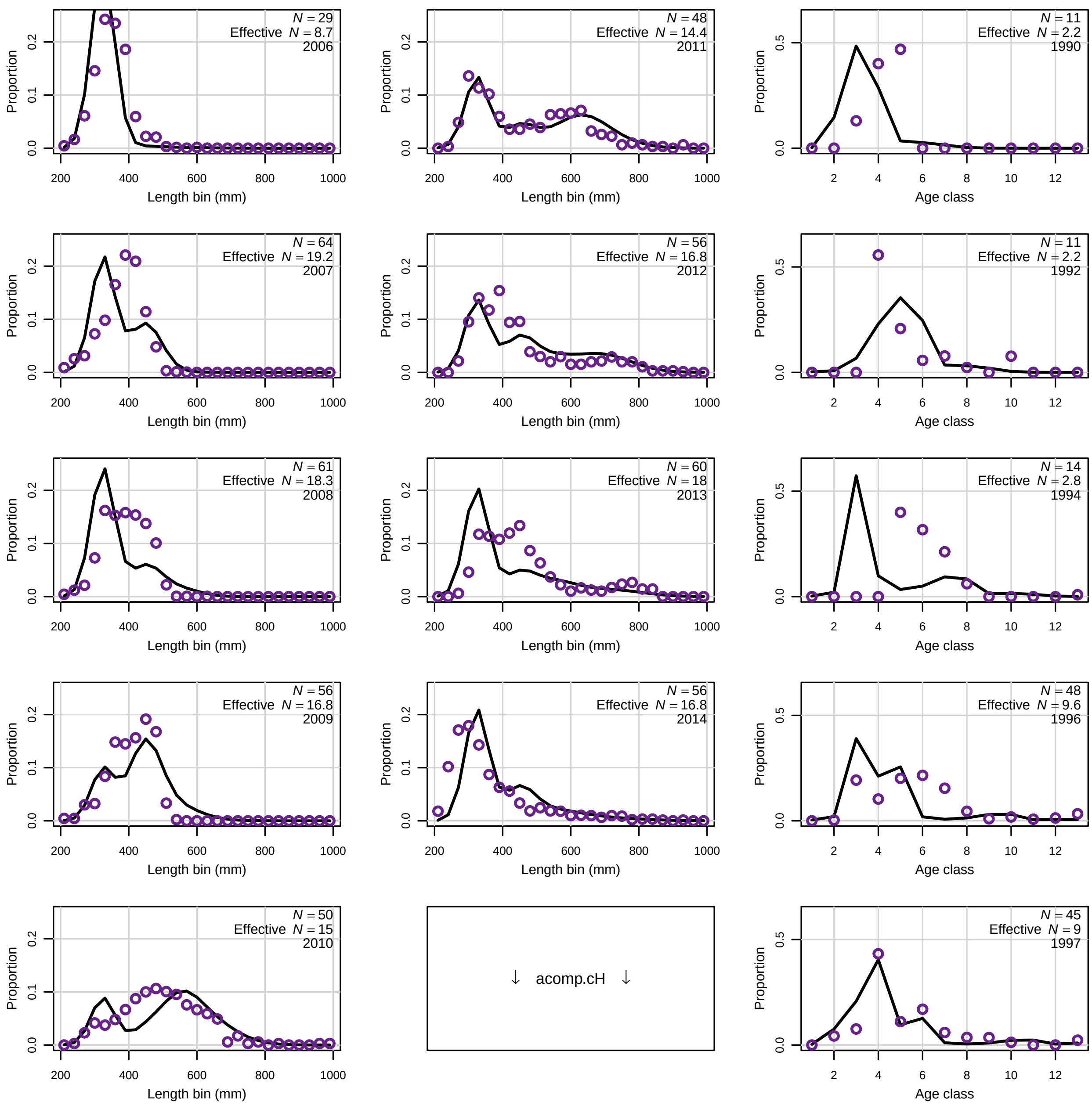


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

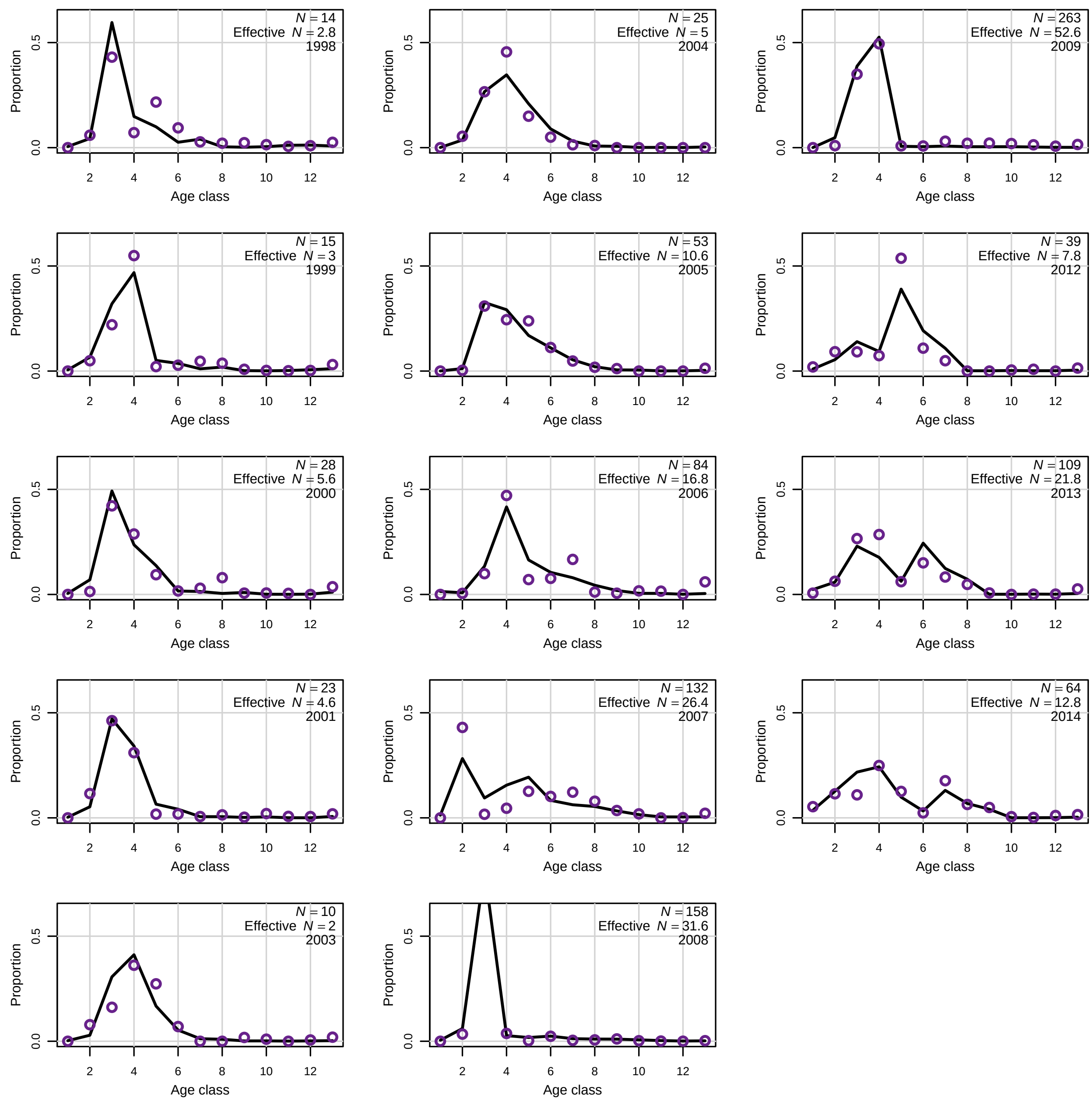


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

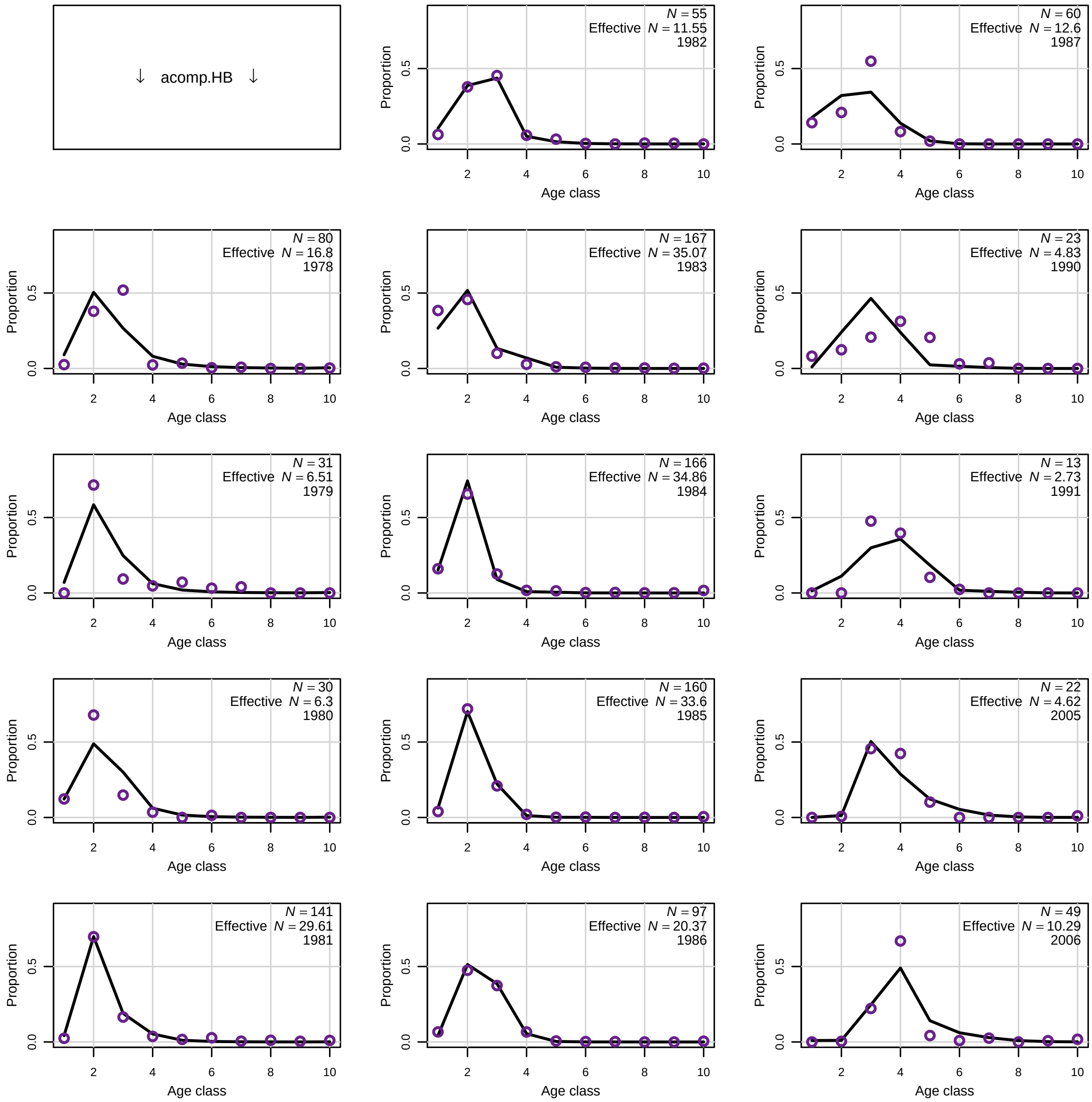


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

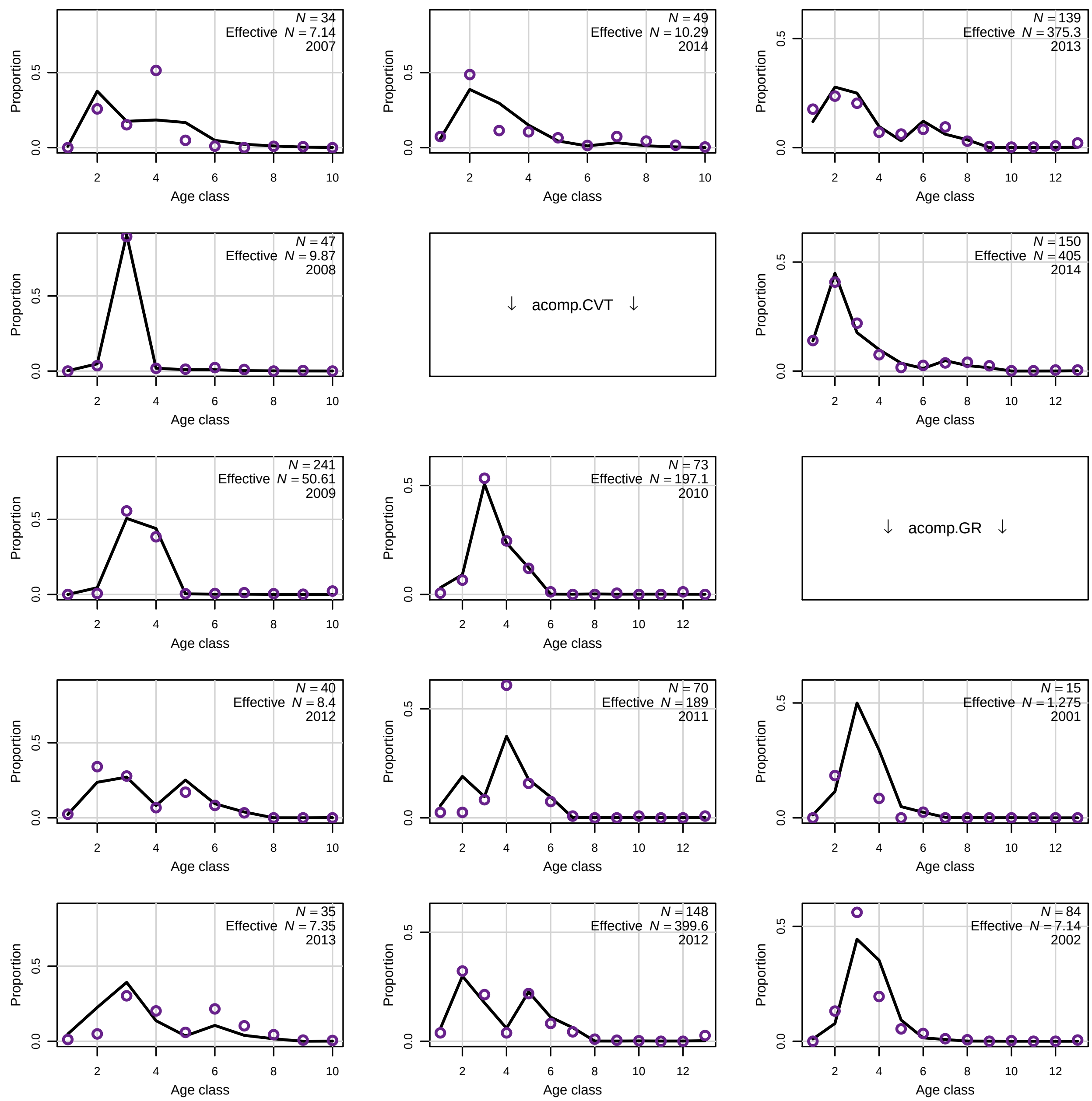


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

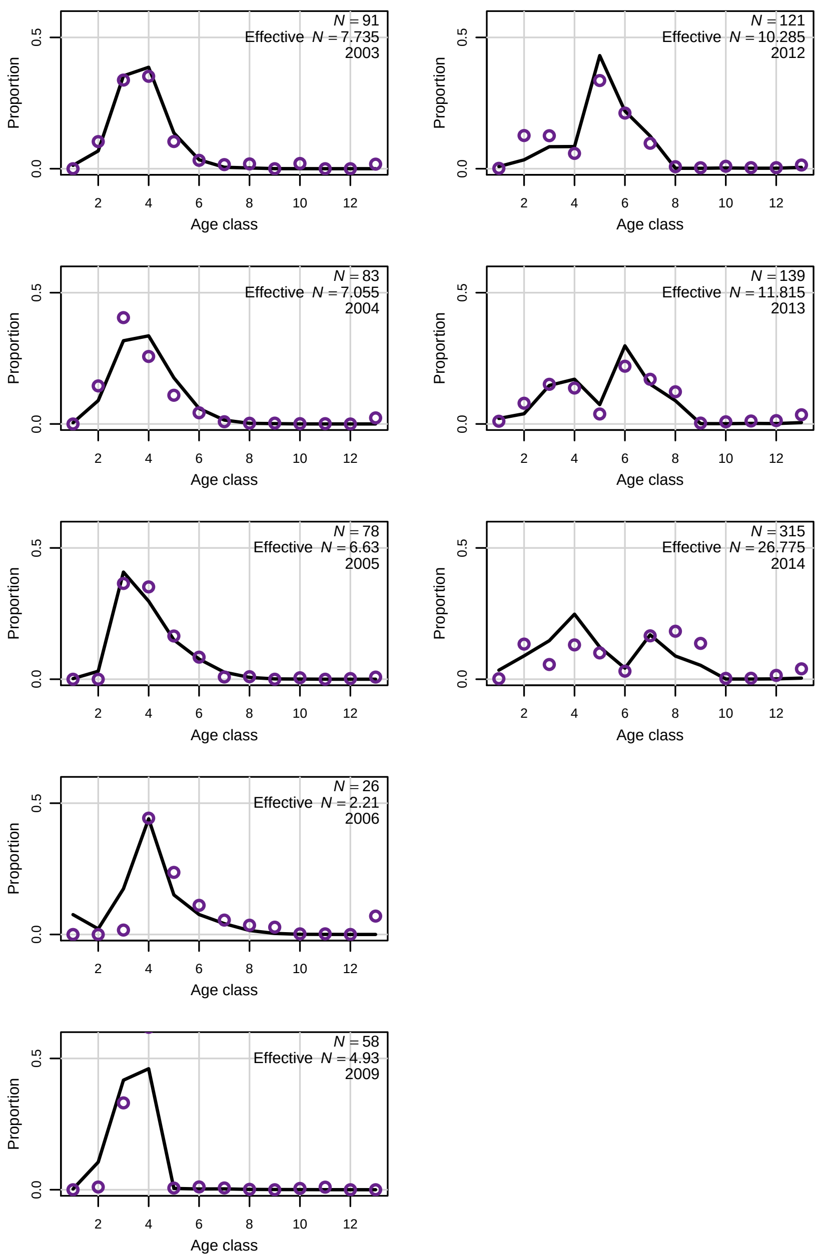


Figure 4. Observed (open circles) and estimated (solid line, circles) commercial handline landings in 1000 lb whole weight.

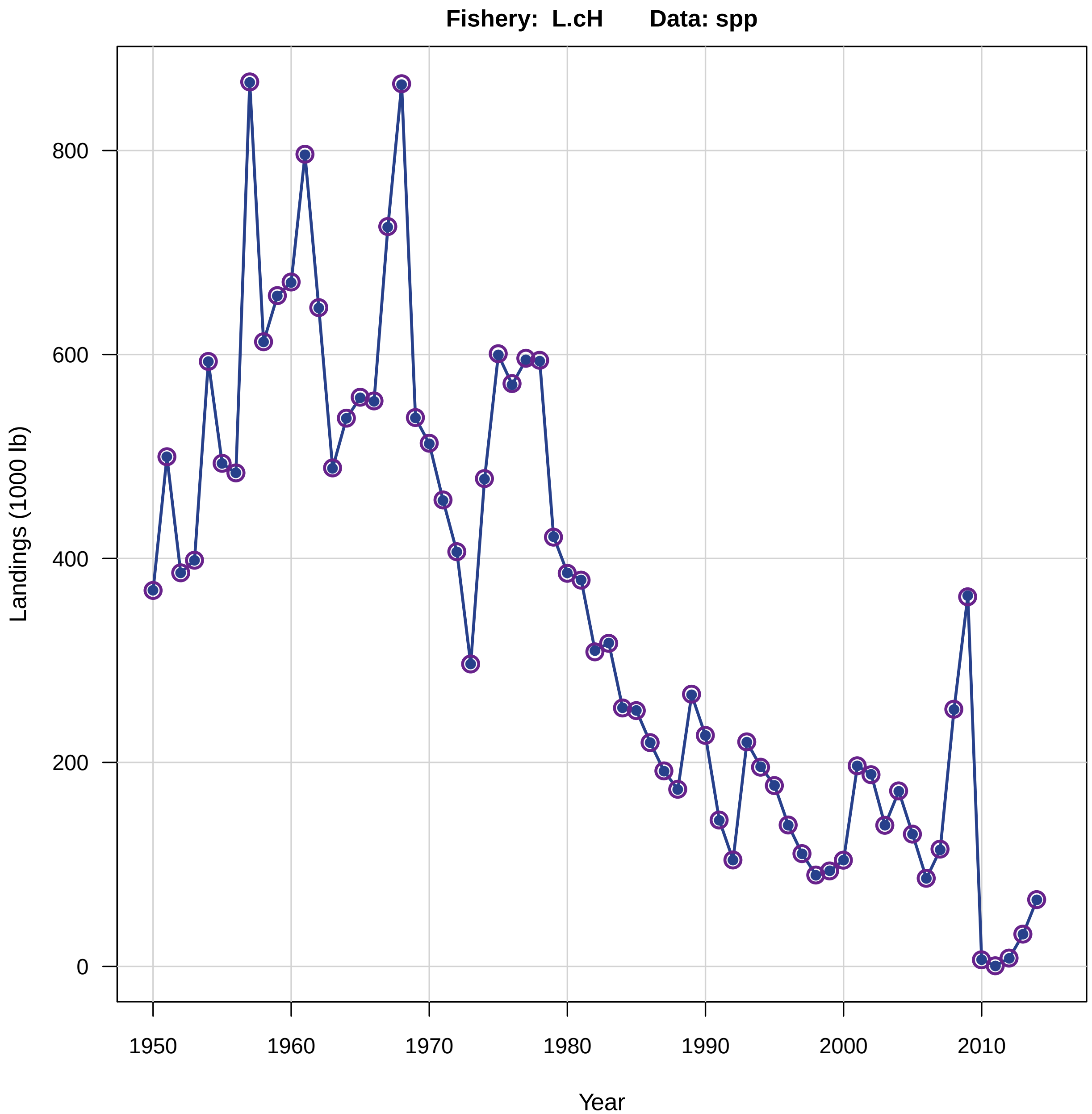


Figure 5. Observed (open circles) and estimated (solid line, circles) headboat landings in 1000s of fish.

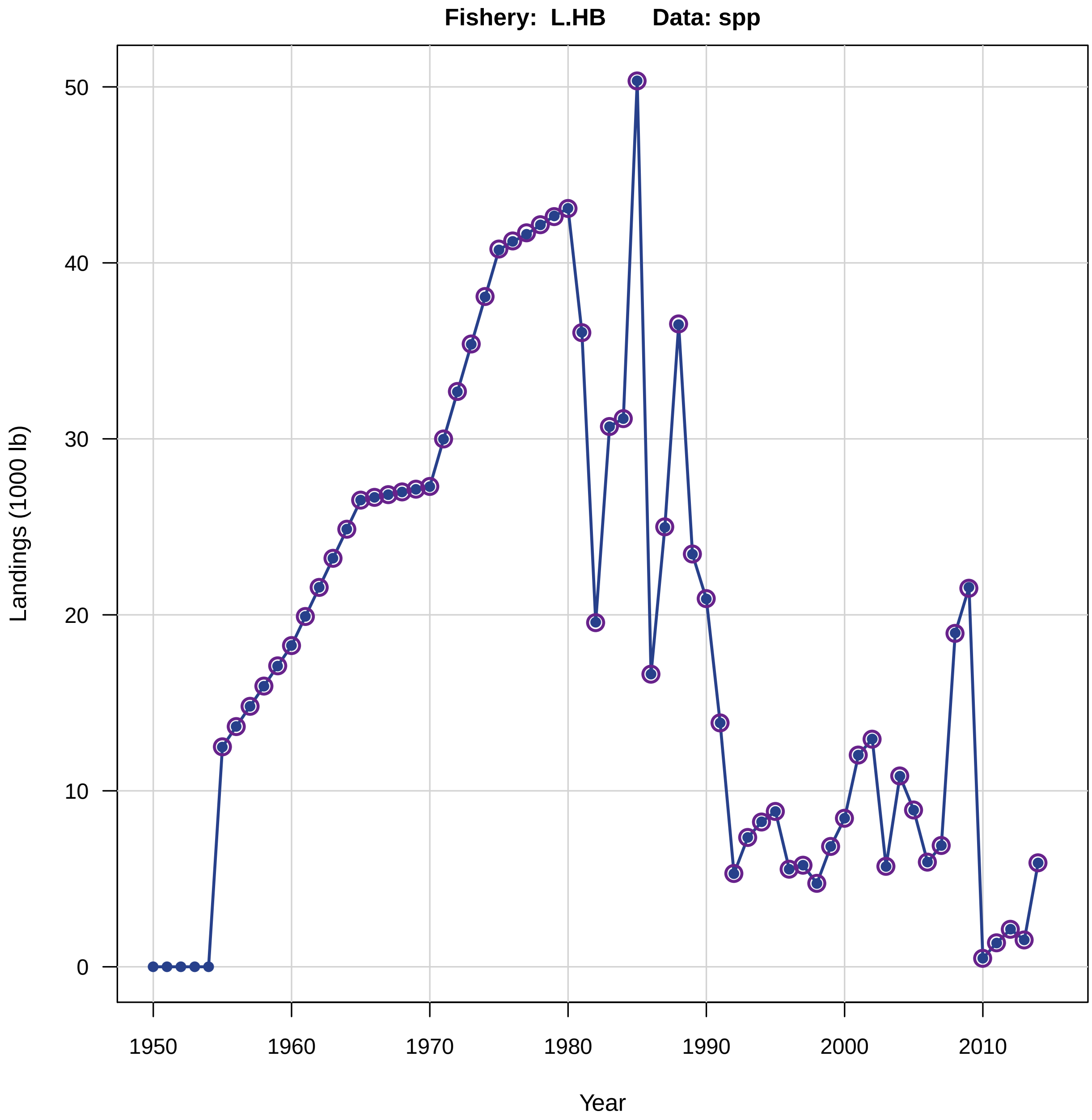


Figure 6. Observed (open circles) and estimated (solid line, circles) general recreational landings in 1000s of fish.

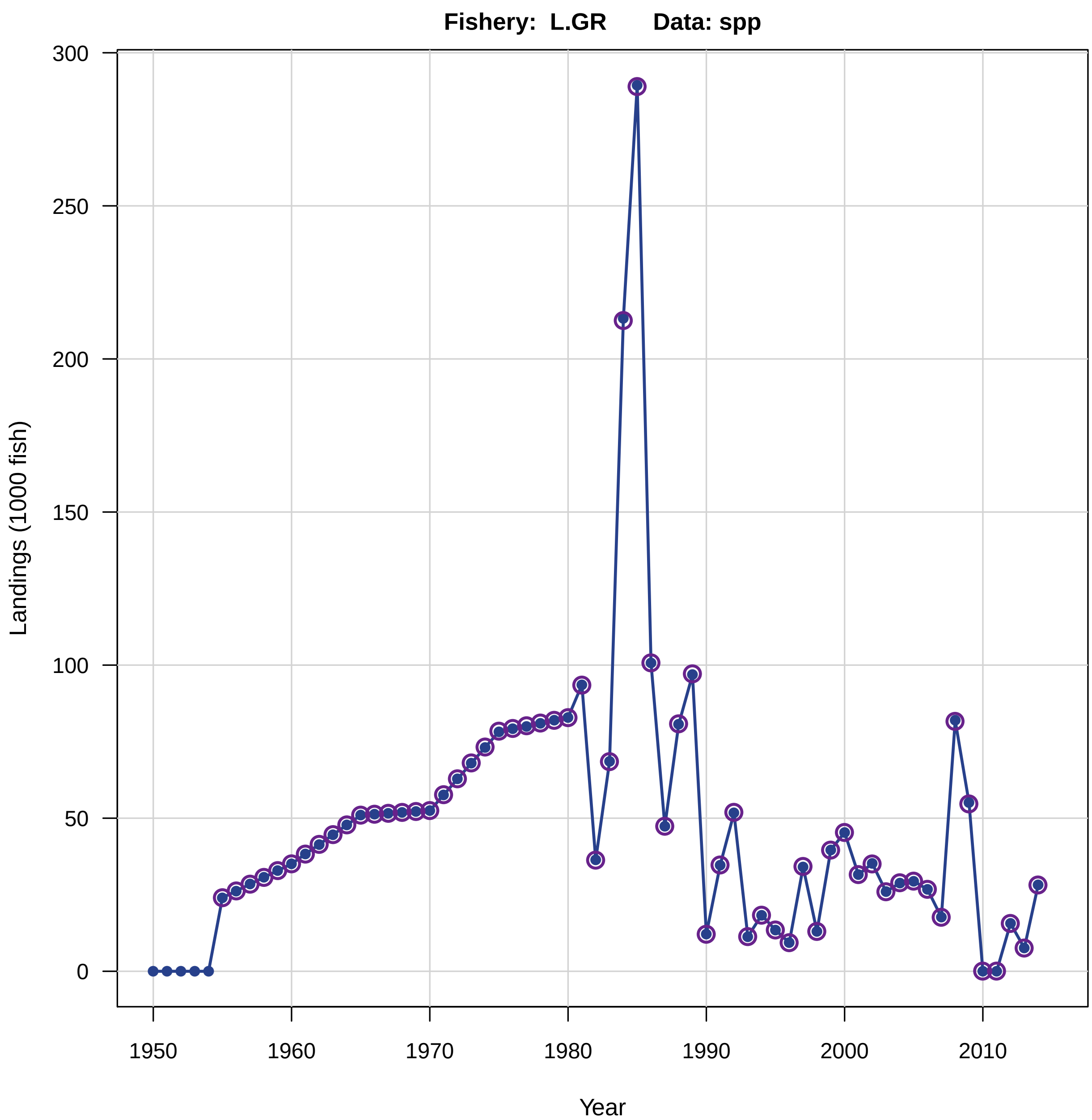


Figure 7. Observed (open circles) and estimated (solid line, circles) commercial handline discard mortalities.

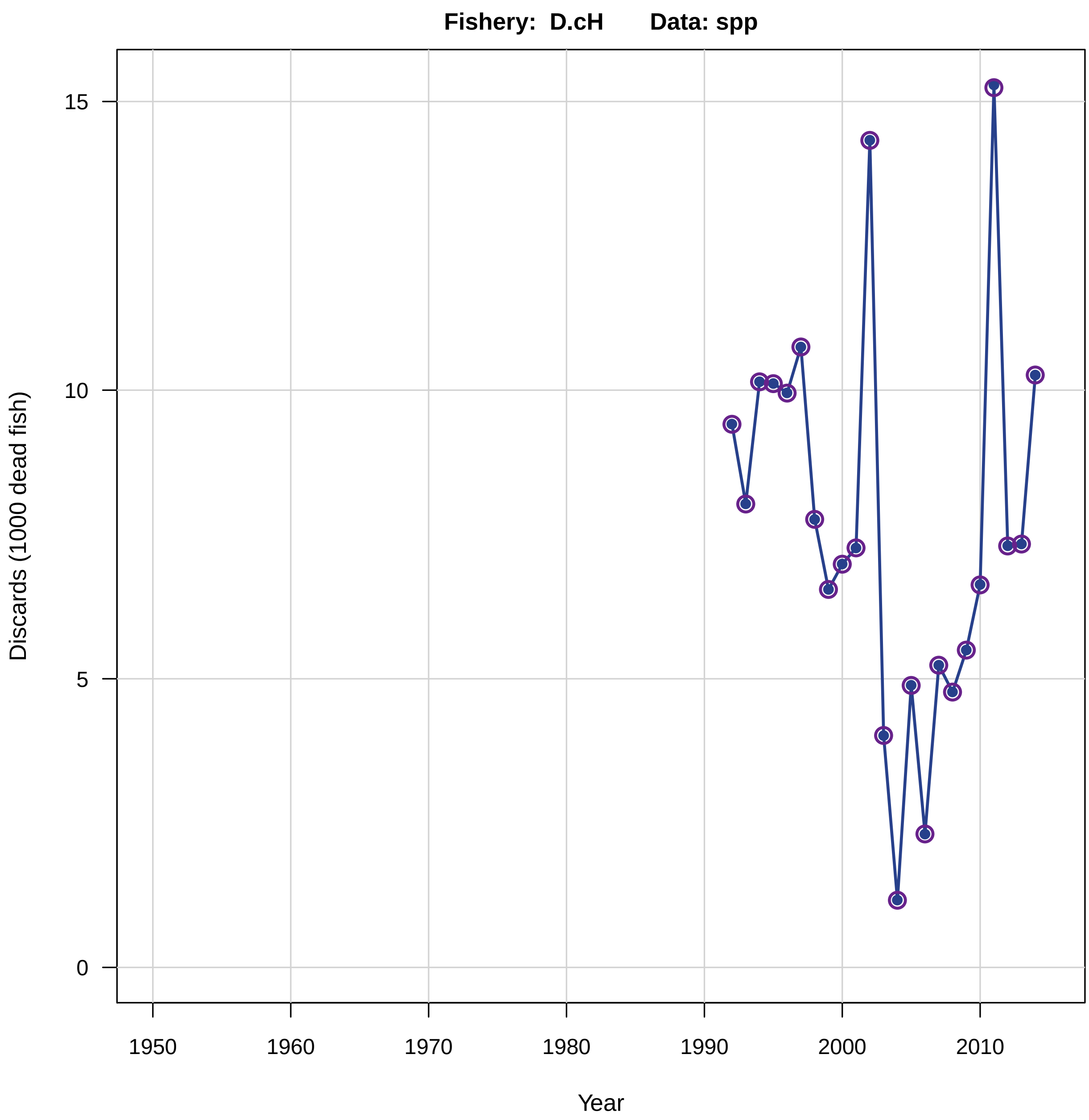


Figure 8. Observed (open circles) and estimated (solid line, circles) headboat discard mortalities.

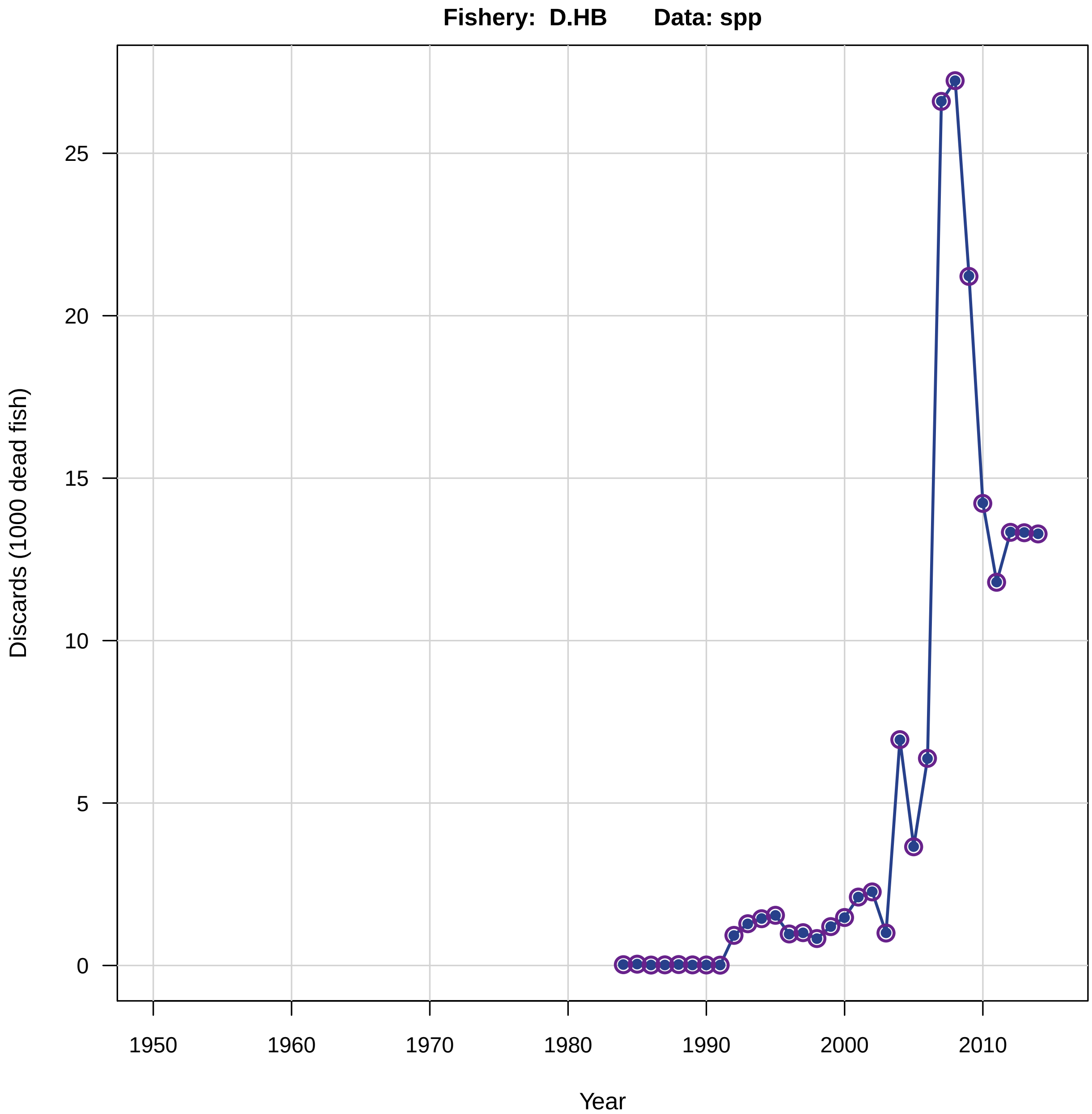


Figure 9. Observed (open circles) and estimated (solid line, circles) general recreational discard mortalities.

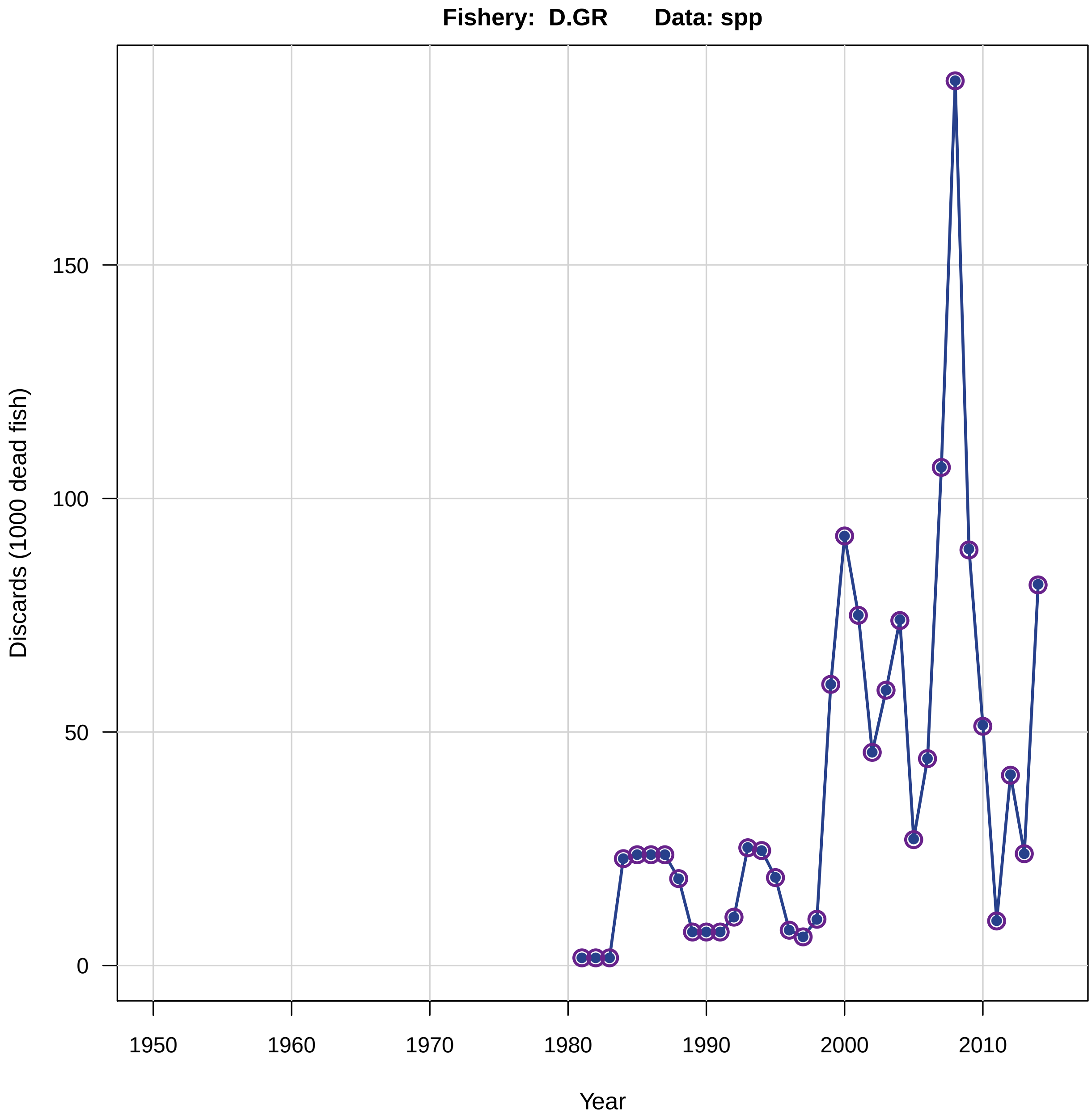


Figure 10. Observed (open circles) and estimated (solid line, circles) index of abundance from the SERFS combined trap and video index. The error bars represent the annual CV provided by the GLM standardization divided by the likelihood weight on the index.

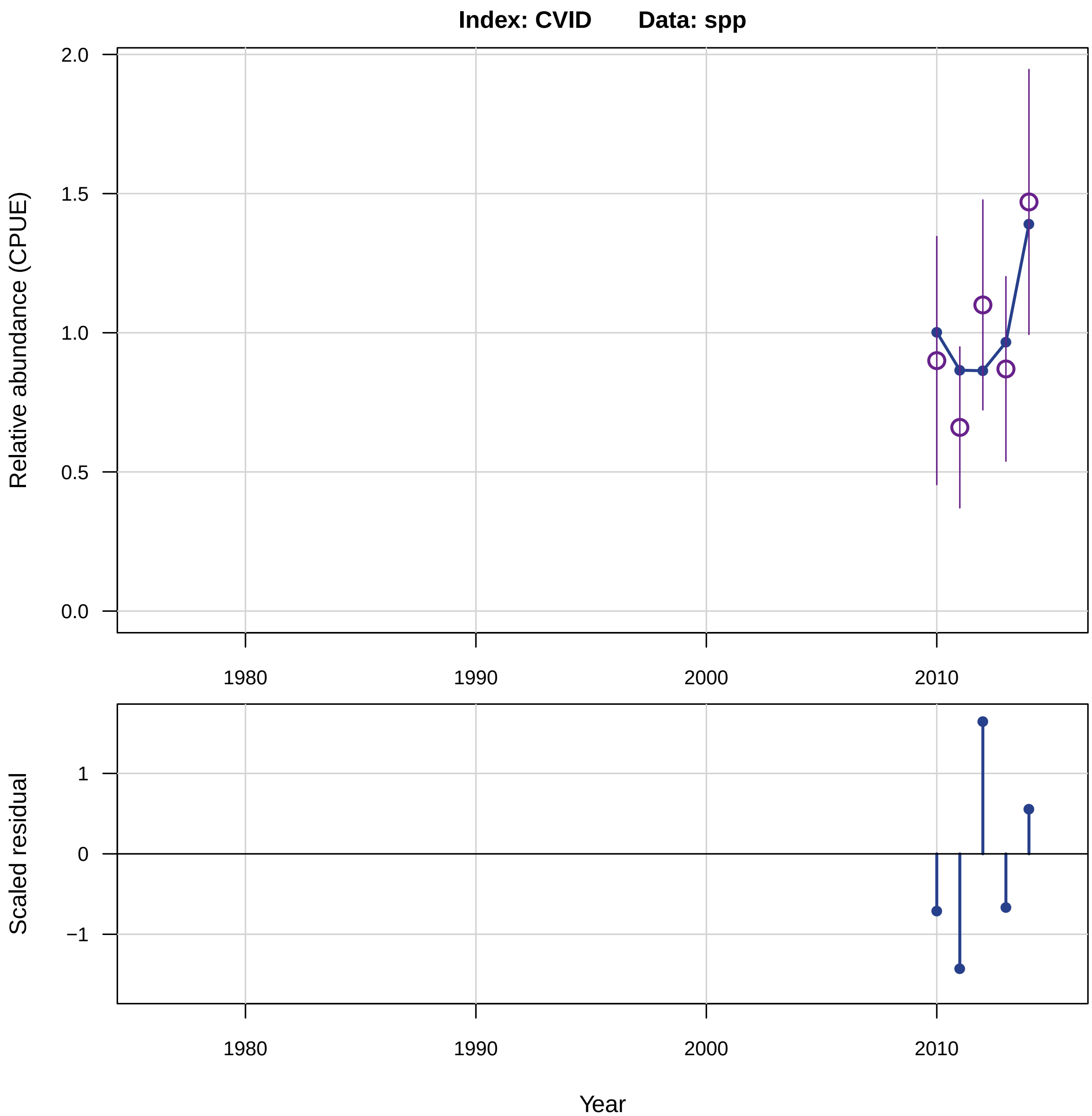


Figure 11. Observed (open circles) and estimated (solid line, circles) index of abundance from the commercial handline fleet. The error bars represent the annual CV of the index (0.2) divided by the likelihood weight on the index.

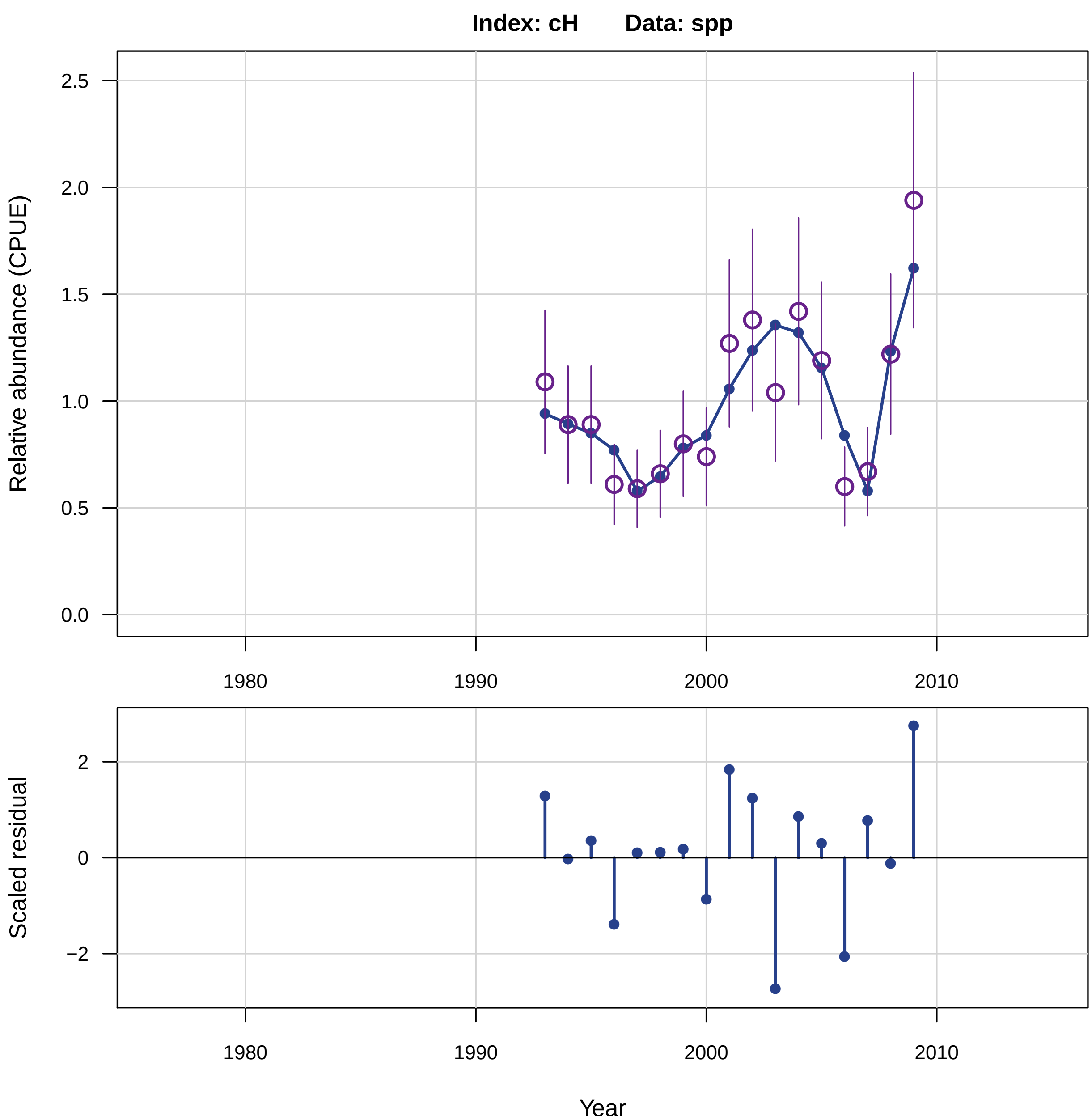


Figure 12. Observed (open circles) and estimated (solid line, circles) abundance from the headboat fleet. The error bars represent the annual CV of the index (0.2) divided by the likelihood weight on the index.

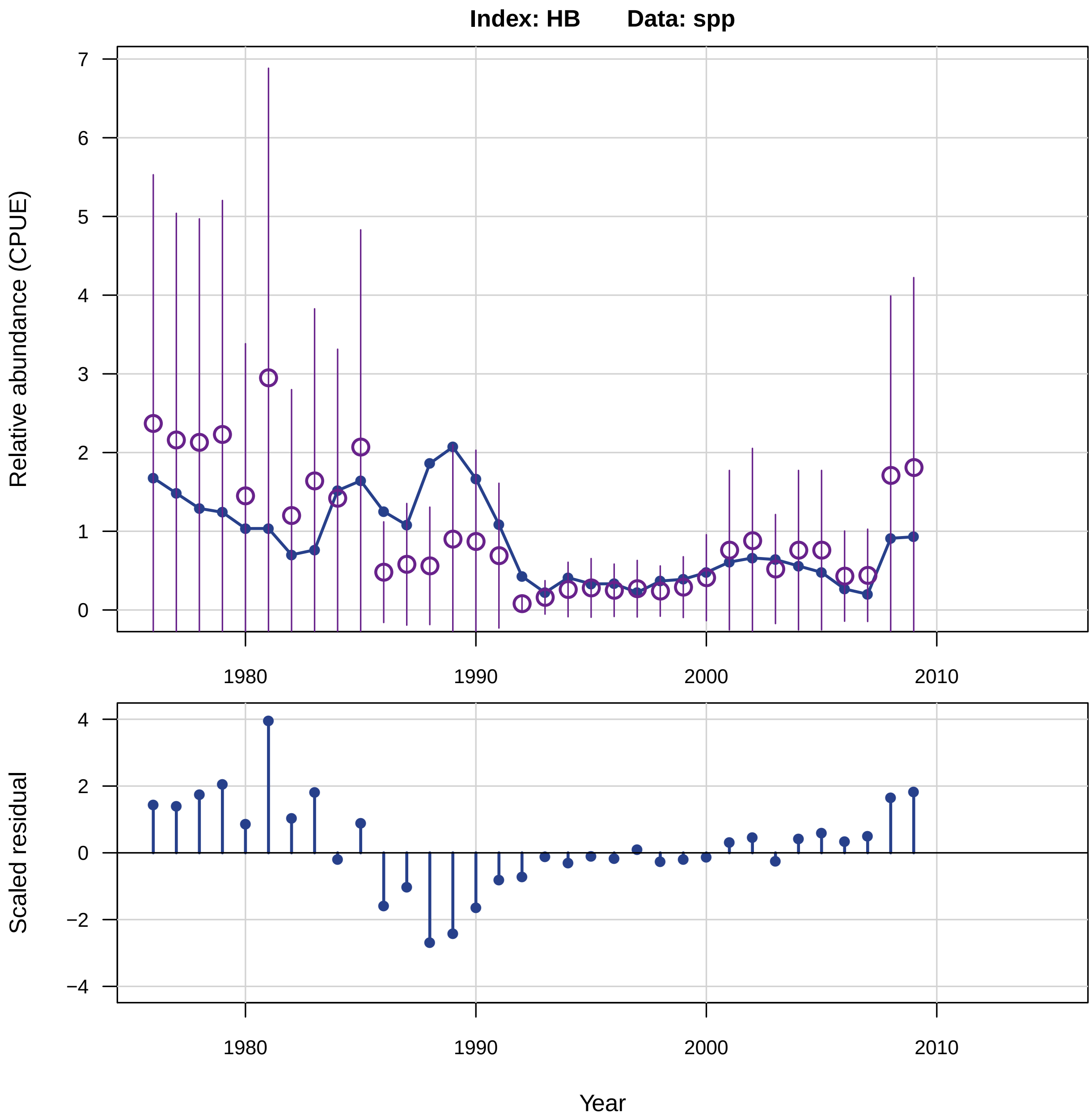


Figure 13. Observed (open circles) and estimated (solid line, circles) abundance from the headboat fleet (discards). The error bars represent the annual CV provided by the GLM standardization divided by the likelihood weight on the index.

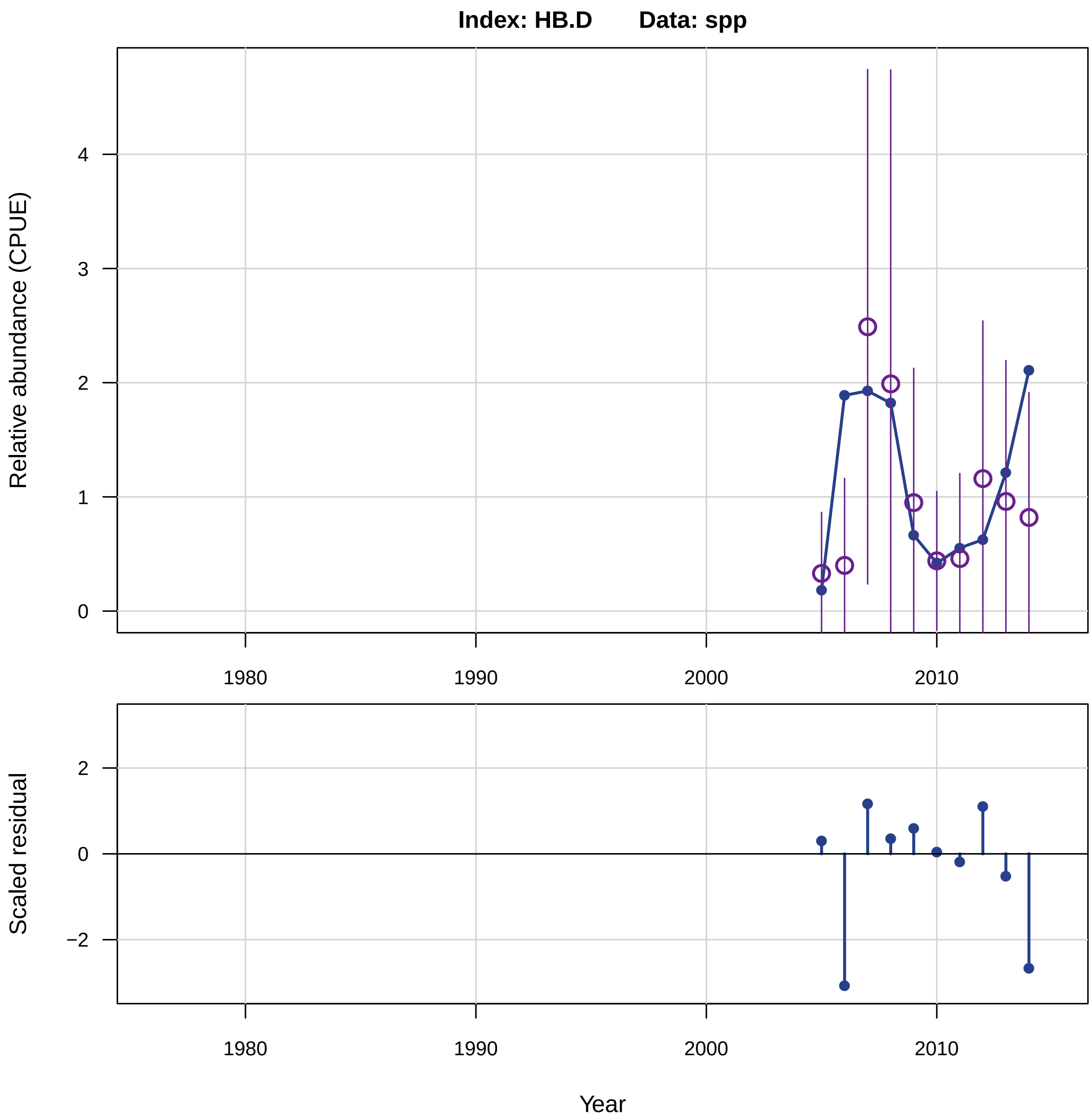


Figure 14. Estimated abundance at age at start of year.

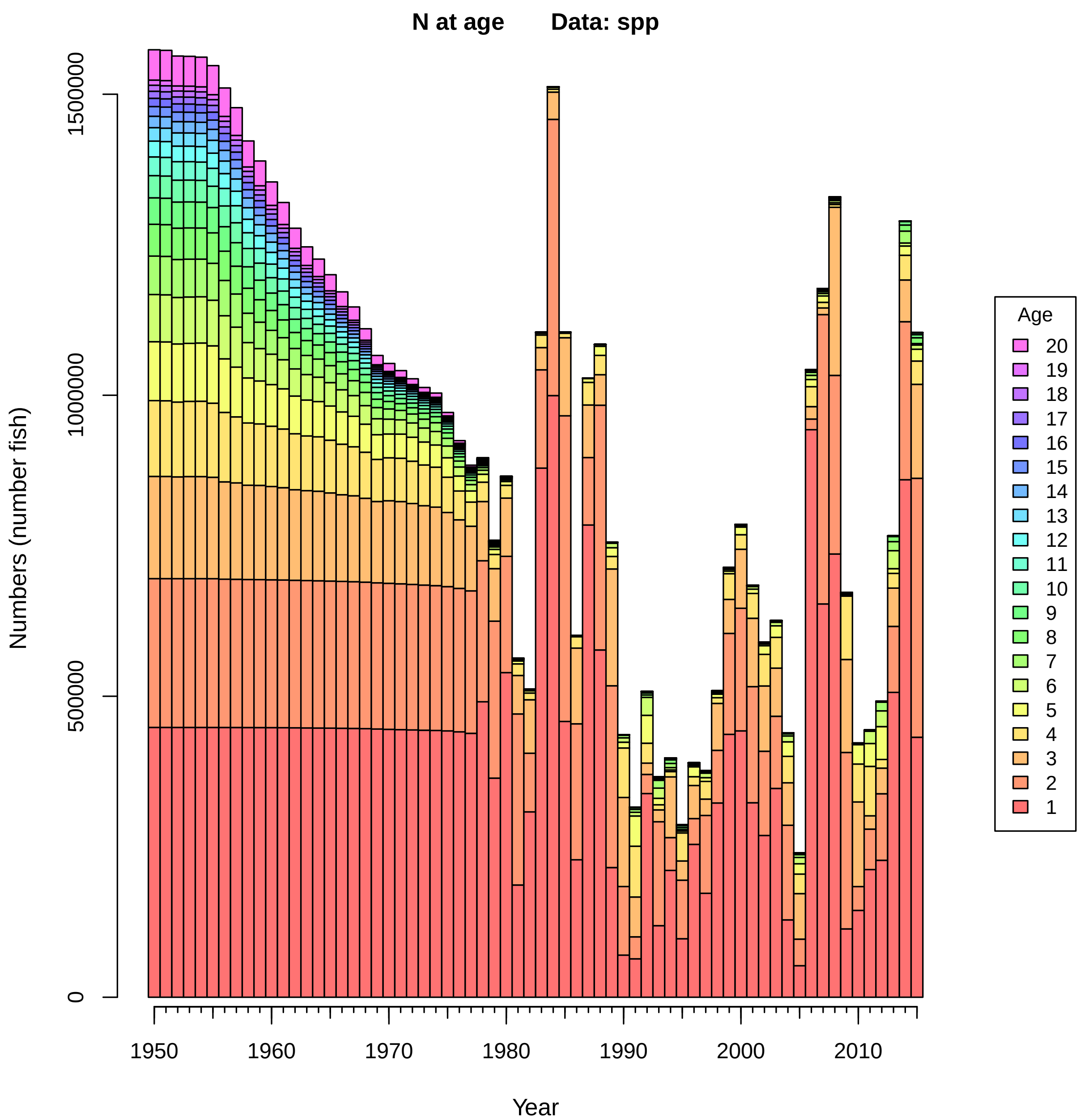


Figure 15. Top panel: Estimated recruitment of age-1 fish. Horizontal dashed line indicates $R_{F30\%}$. Bottom panel: log recruitment residuals.

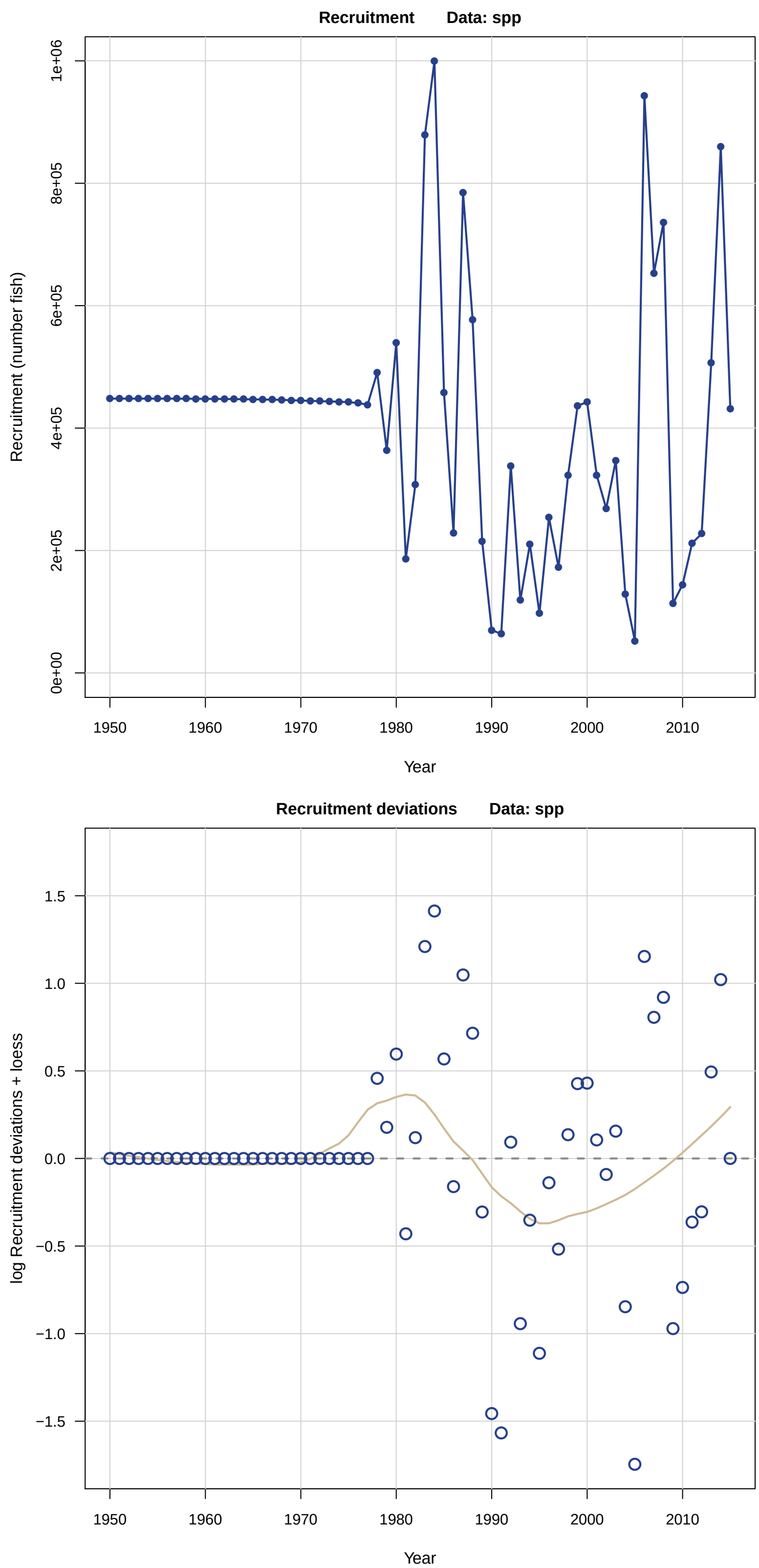


Figure 16. Estimated biomass at age at start of year.

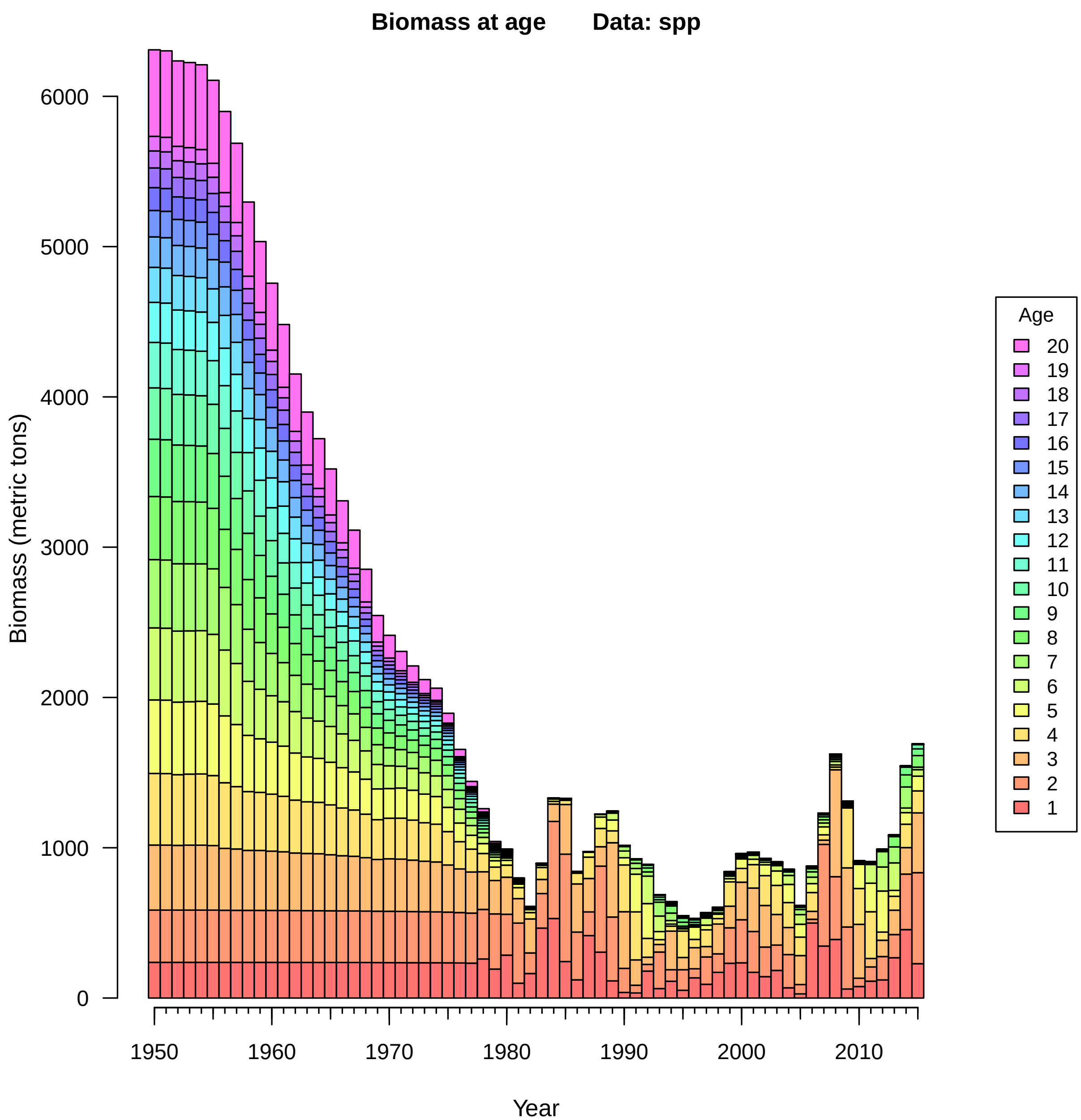
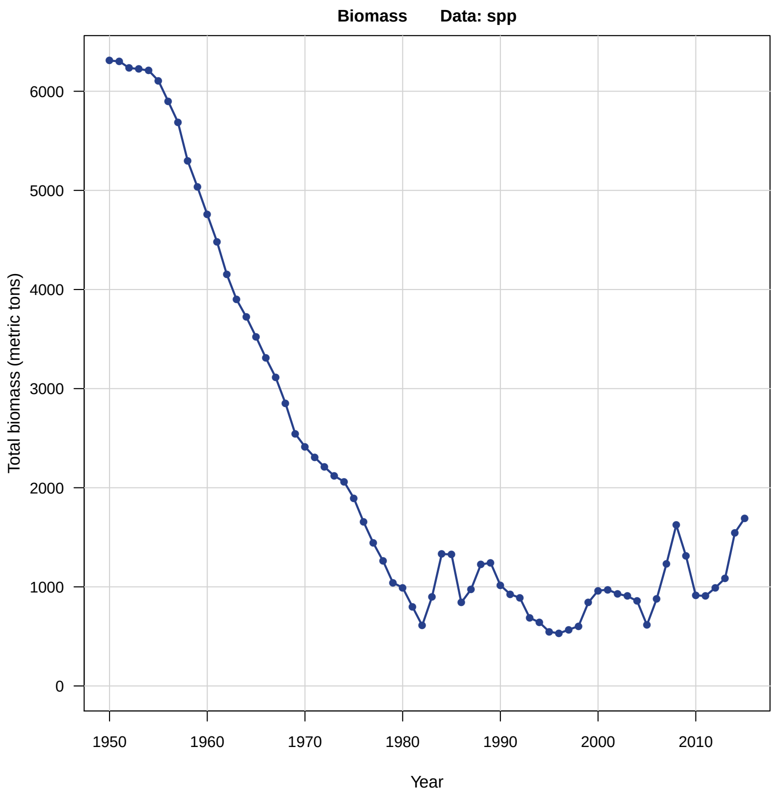


Figure 17. Top panel: Estimated total biomass (metric tons) at start of year. Horizontal dashed line indicates $B_{F30\%}$. Bottom panel: Estimated spawning stock (population fecundity) at time of peak spawning.



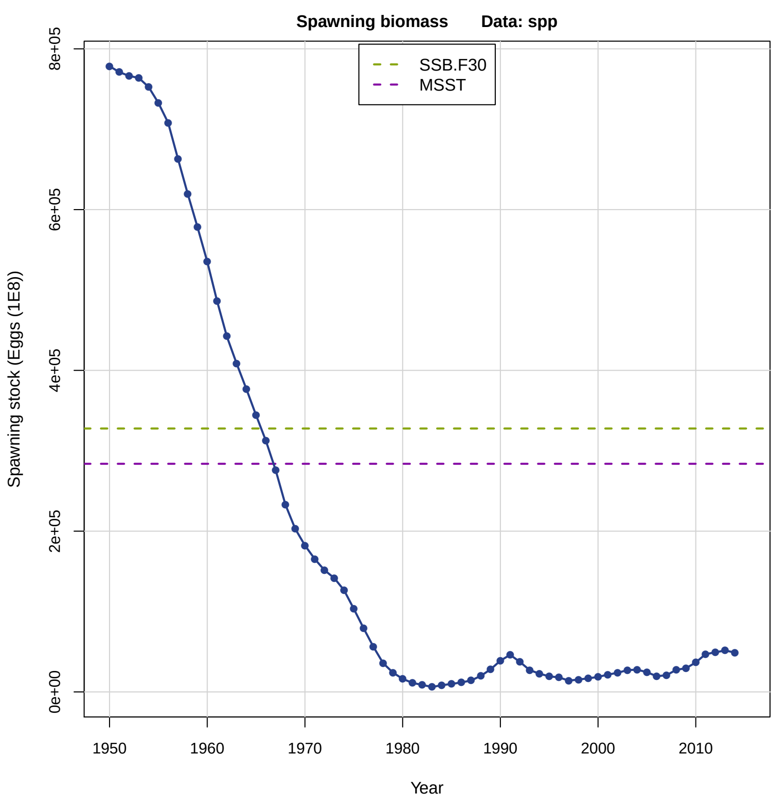


Figure 18. Monte Carlo Bootstrap estimates of population abundance. Top panel is all ages, and the bottom panel represents age 2+.

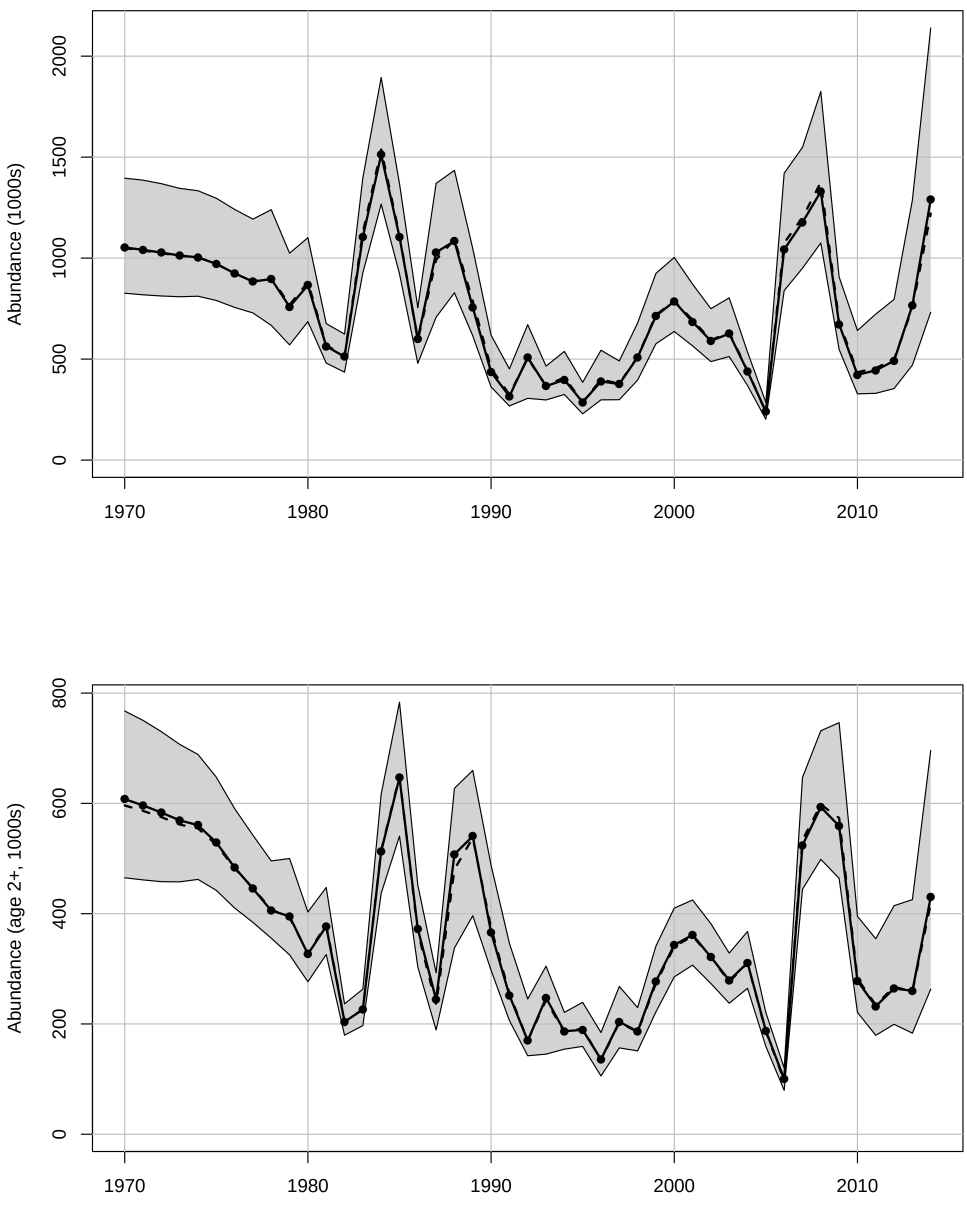


Figure 19. Selectivity of SERFS index.

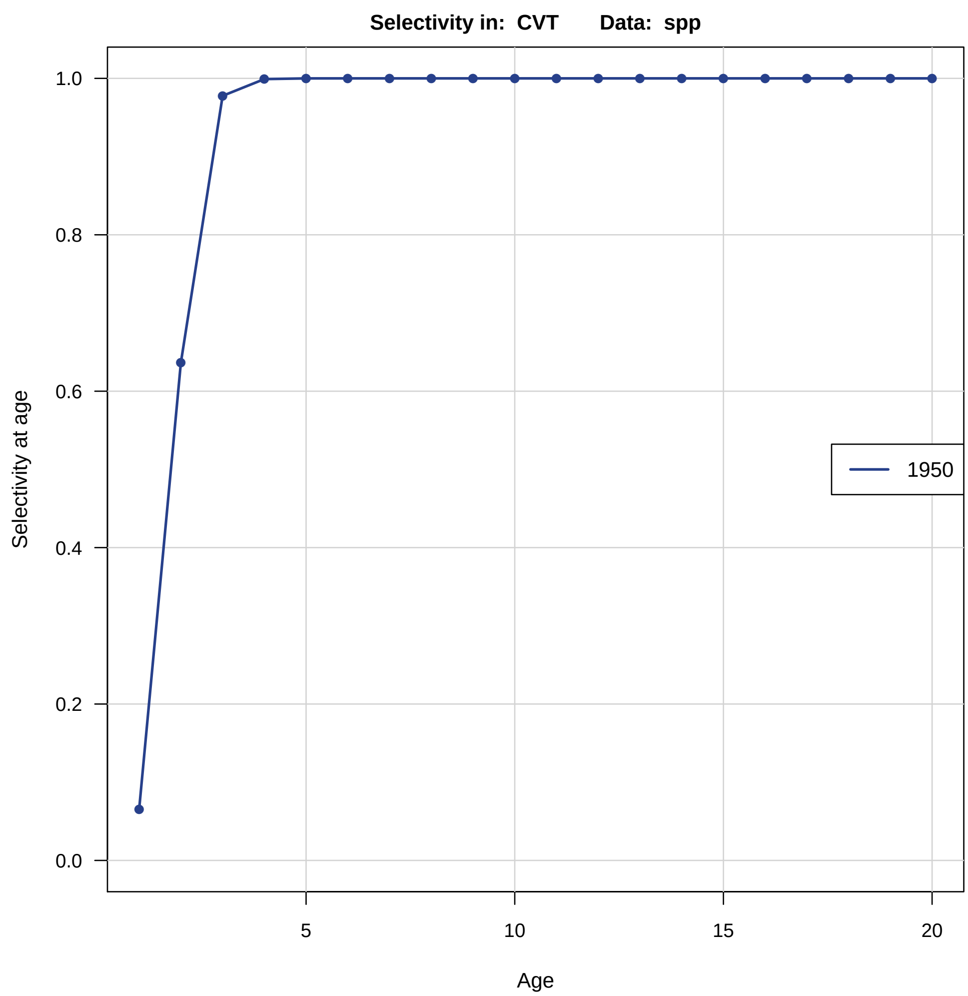


Figure 20. Selectivities of commercial handline landings. The legend indicates the first year each selectivity curve applies to the fleet.

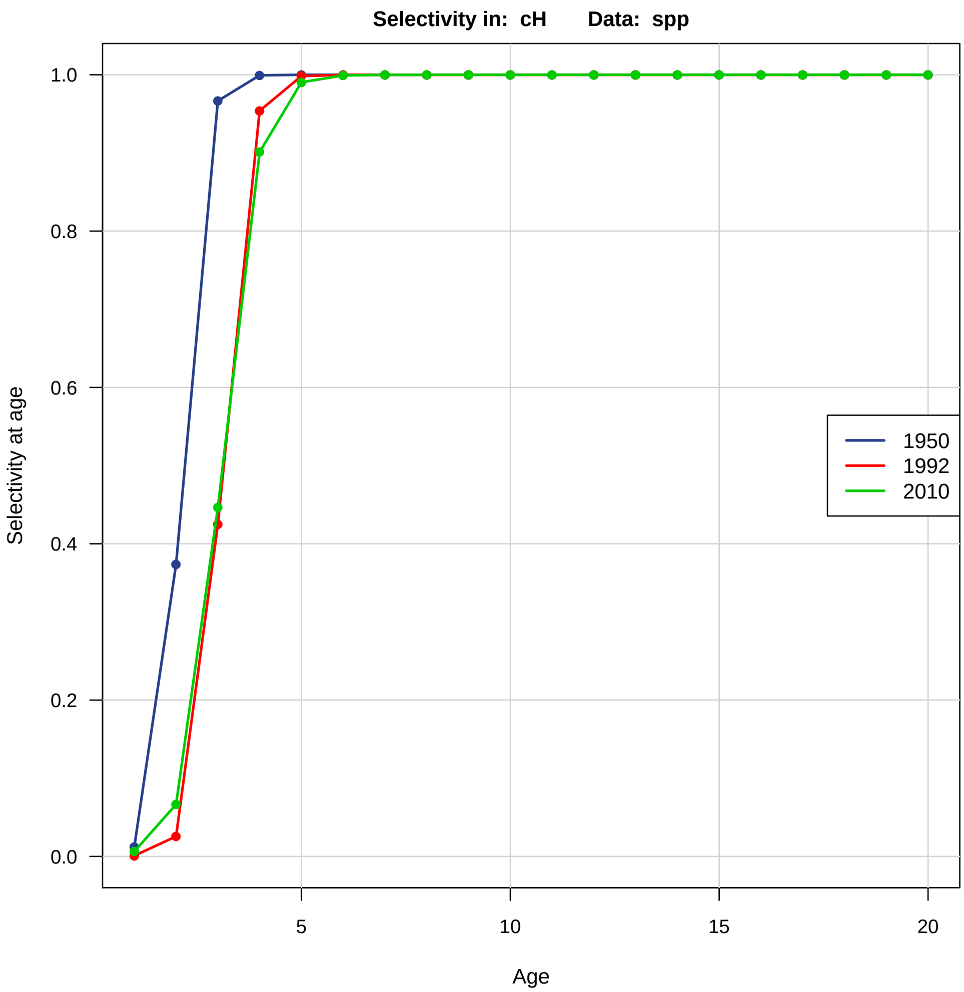


Figure 21. Selectivities of headboat landings. The legend indicates the first year each selectivity curve applies to the fleet.

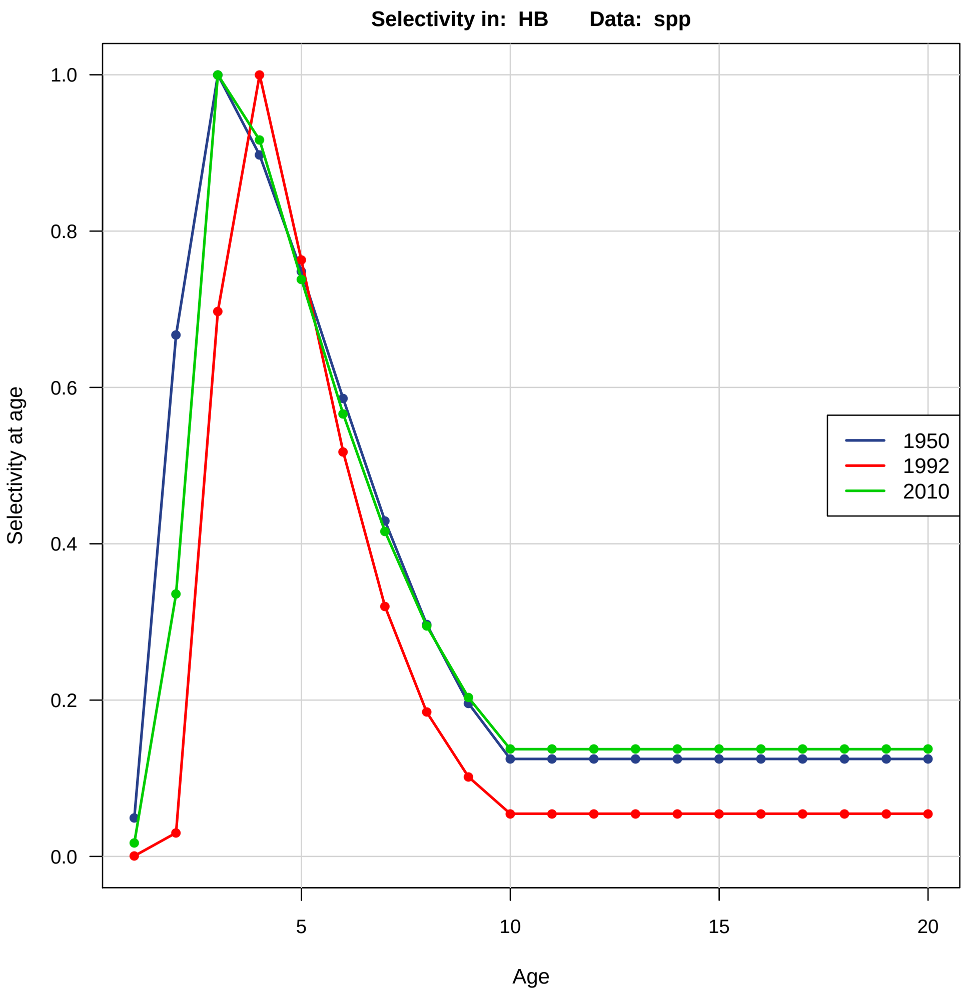


Figure 22. Selectivities of general recreational landings. The legend indicates the first year each selectivity curve applies to the fleet.

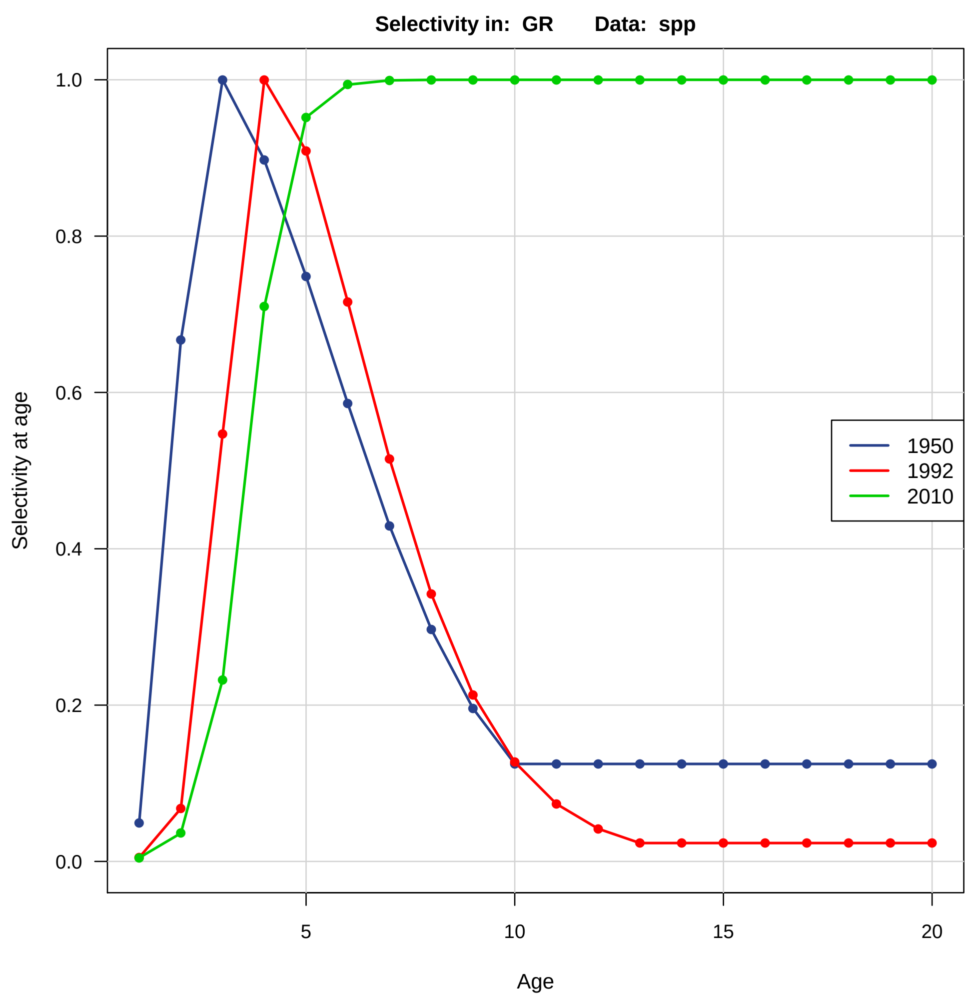


Figure 23. Selectivities of commercial handline discards. The legend indicates the first year each selectivity curve applies to the fleet.

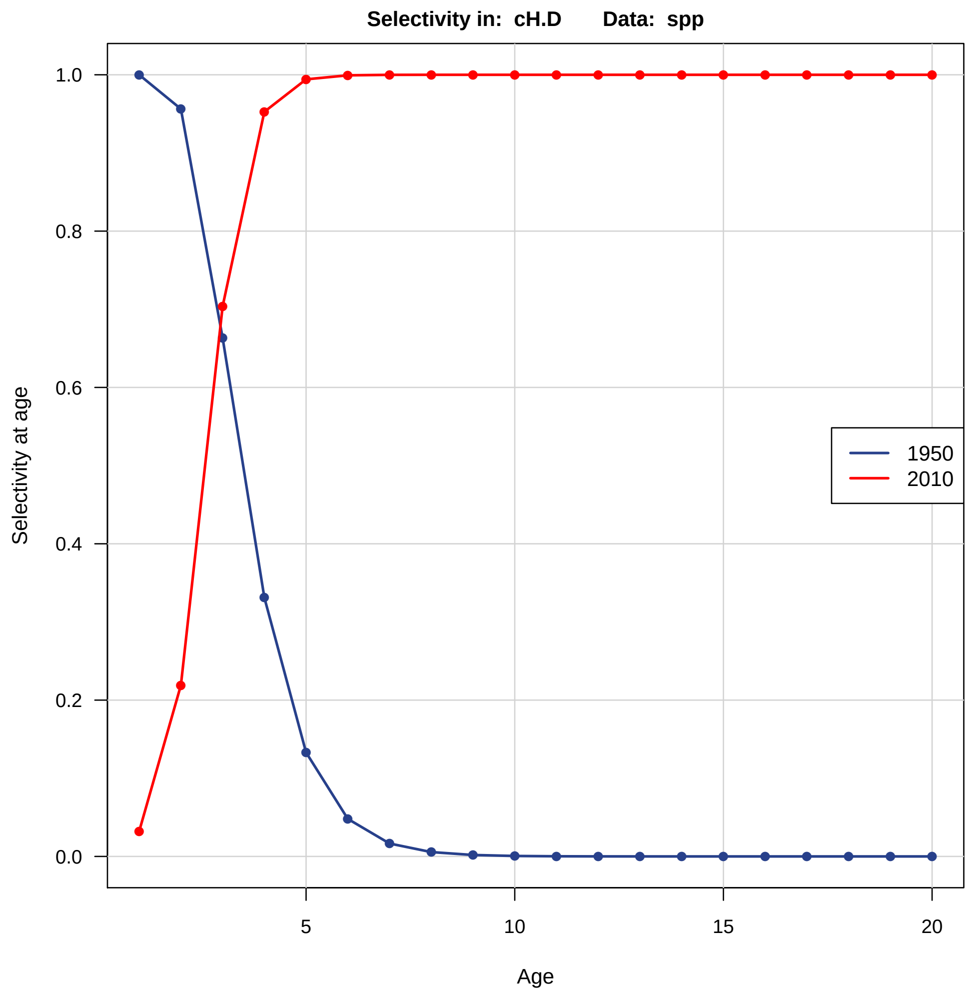


Figure 24. Selectivities of headboat discards. The legend indicates the first year each selectivity curve applies to the fleet.

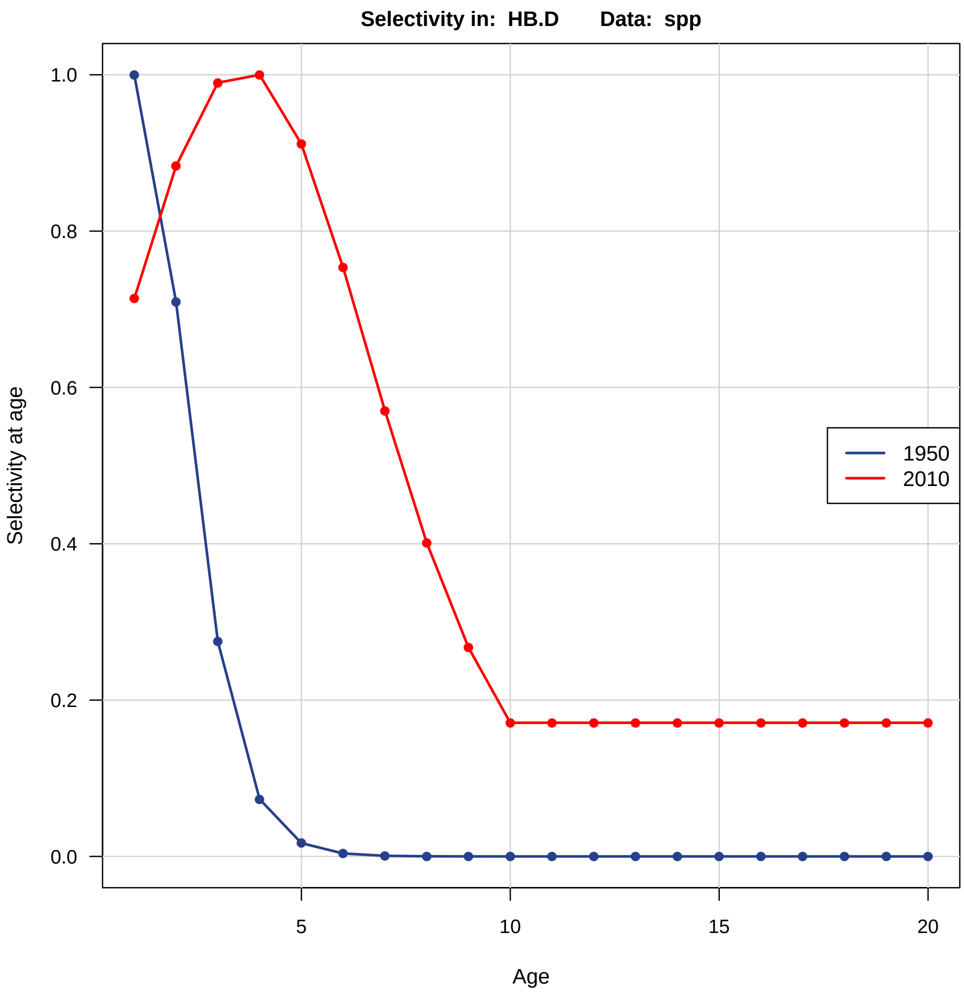


Figure 25. Selectivities of general recreational discards. The legend indicates the first year each selectivity curve applies to the fleet.

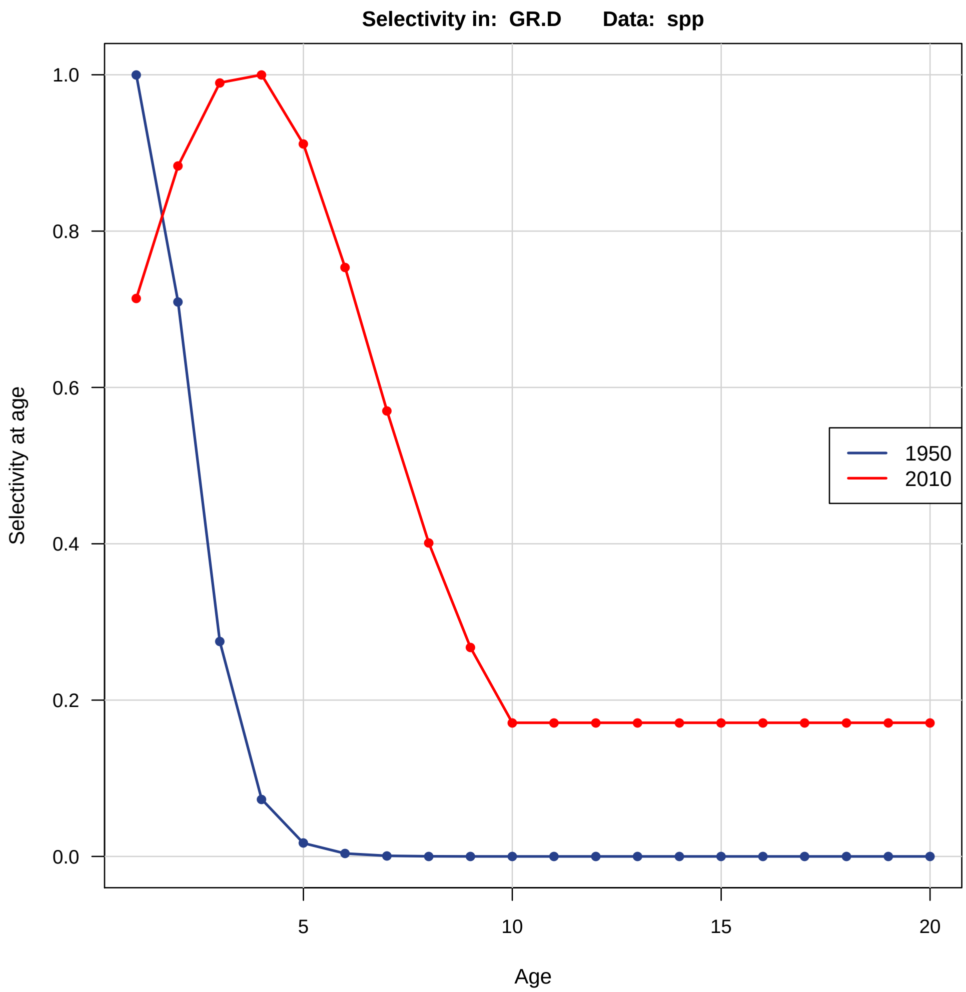


Figure 26. Average selectivity of discards(top left), landings (top right), and total weighted average (bottom) from the terminal assessment years, weighted by geometric mean F's from the last three assessment years, and used in computation of benchmarks and projections.

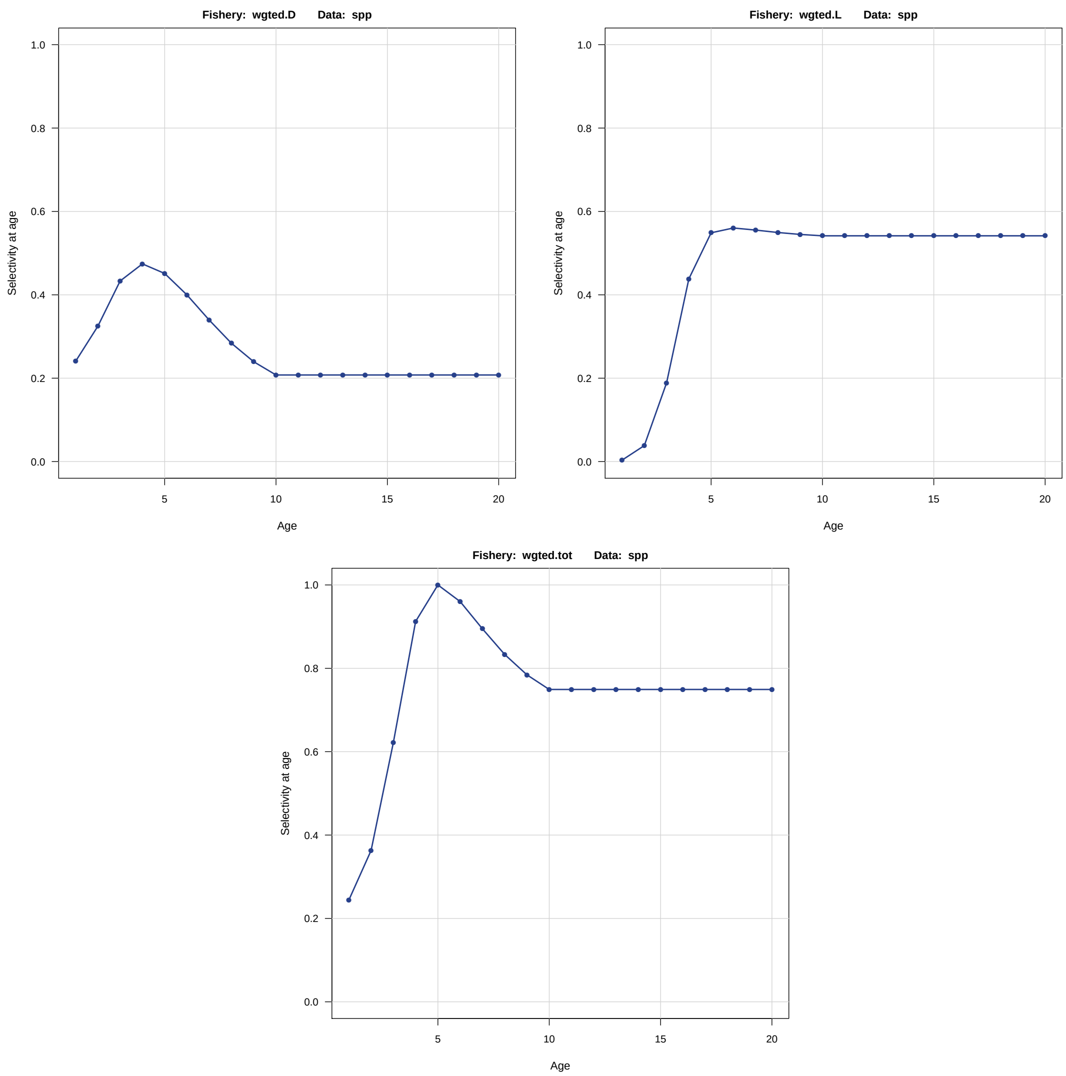


Figure 27. Estimated fully selected fishing mortality rate (per year) by fleet. cH refers to commercial handlines, HB to headboat, GR to general recreational, and D refers to discard mortality.

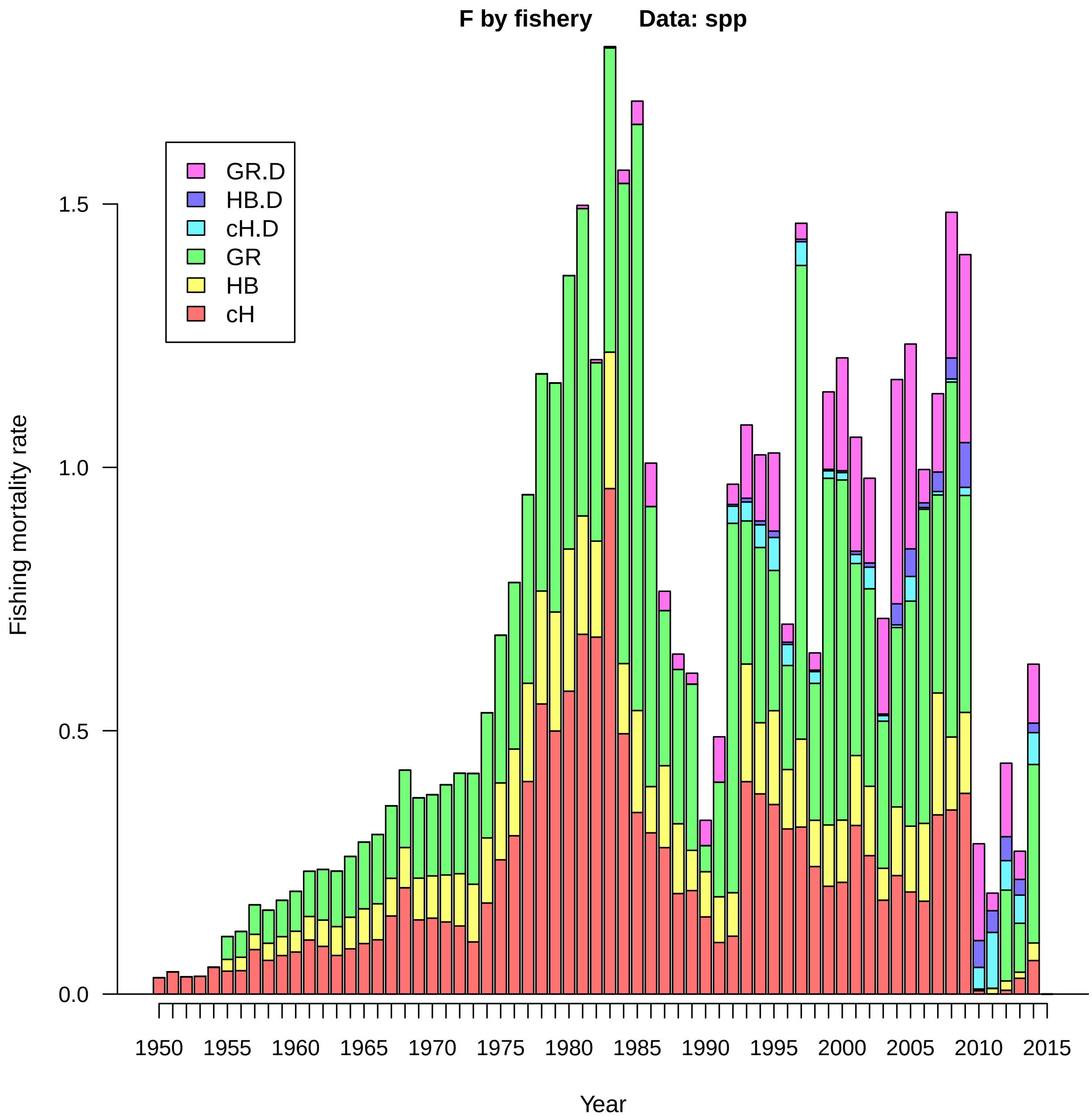


Figure 28. Estimated landings in numbers by fleet from the catch-age model. cH refers to commercial handlines, HB to headboat, and GR to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of $L_{F30\%}$ in numbers.

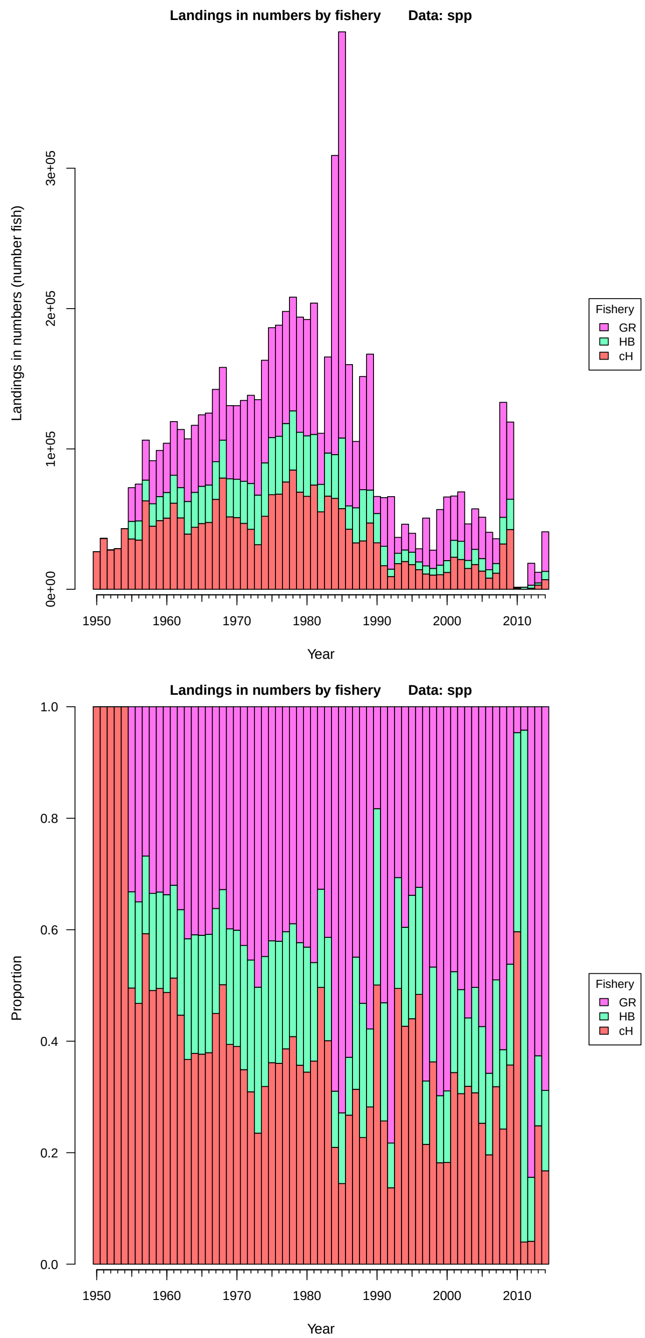


Figure 29. Estimated landings in whole weight by fleet from the catch-age model. cH refers to commercial handlines, HB to headboat, and GR to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of $L_{F30\%}$ in weight.

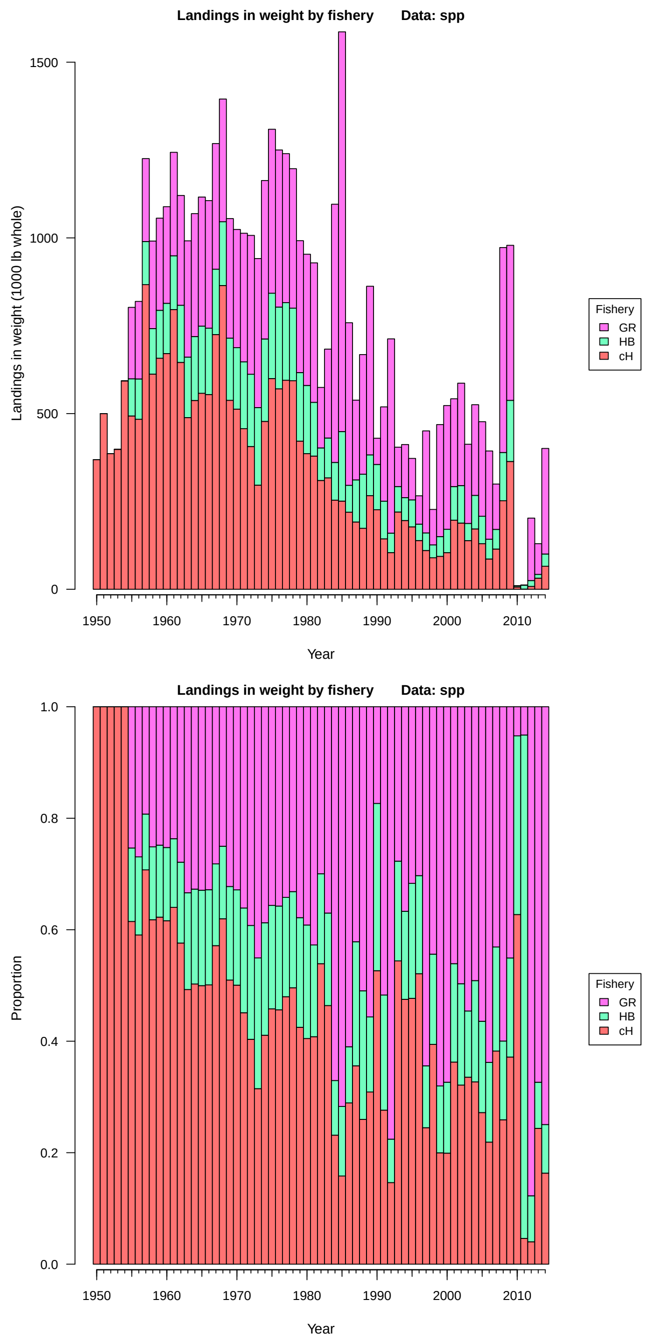


Figure 30. Estimated discard mortalities by fleet from the catch-age model. cH refers to commercial lines, hb to headboat, rec to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of $D_{F_{30\%}}$ *in numbers.*

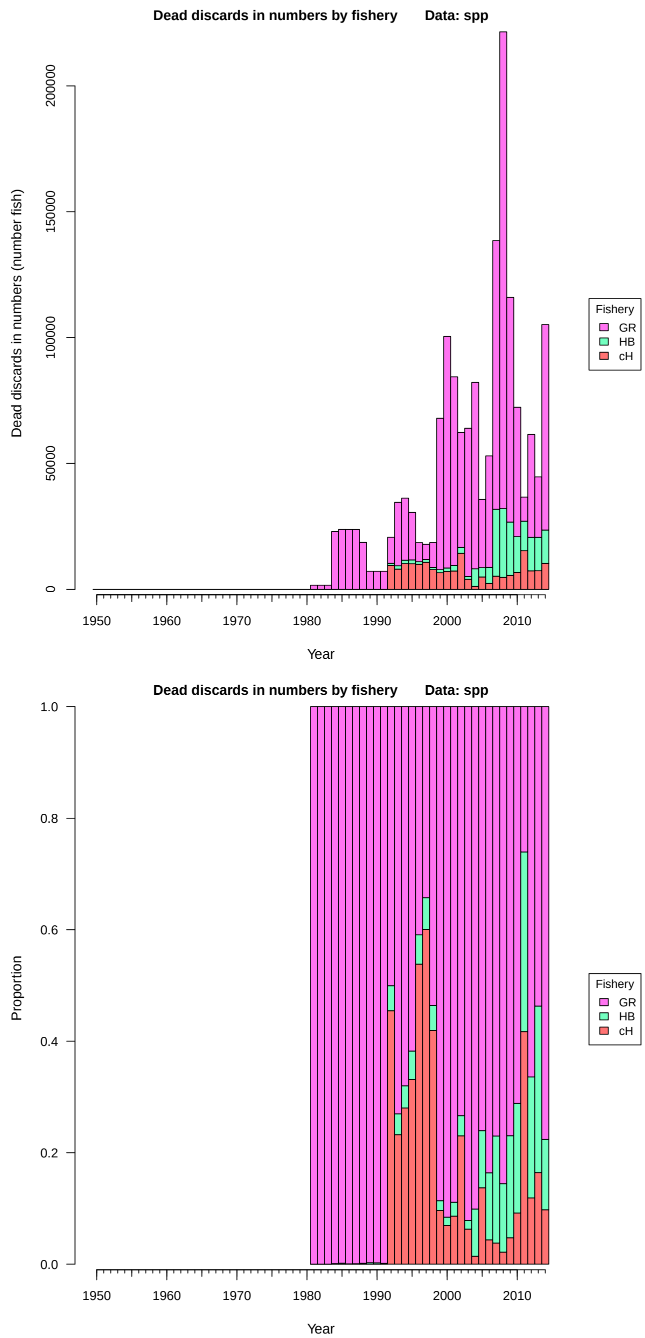


Figure 31. Top panel: Beverton–Holt spawner-recruit curves, with and without lognormal bias correction. The expected (upper) curve was used for computing management benchmarks. Bottom panel: log of recruits (number age-1 fish) per spawner as a function of spawners.

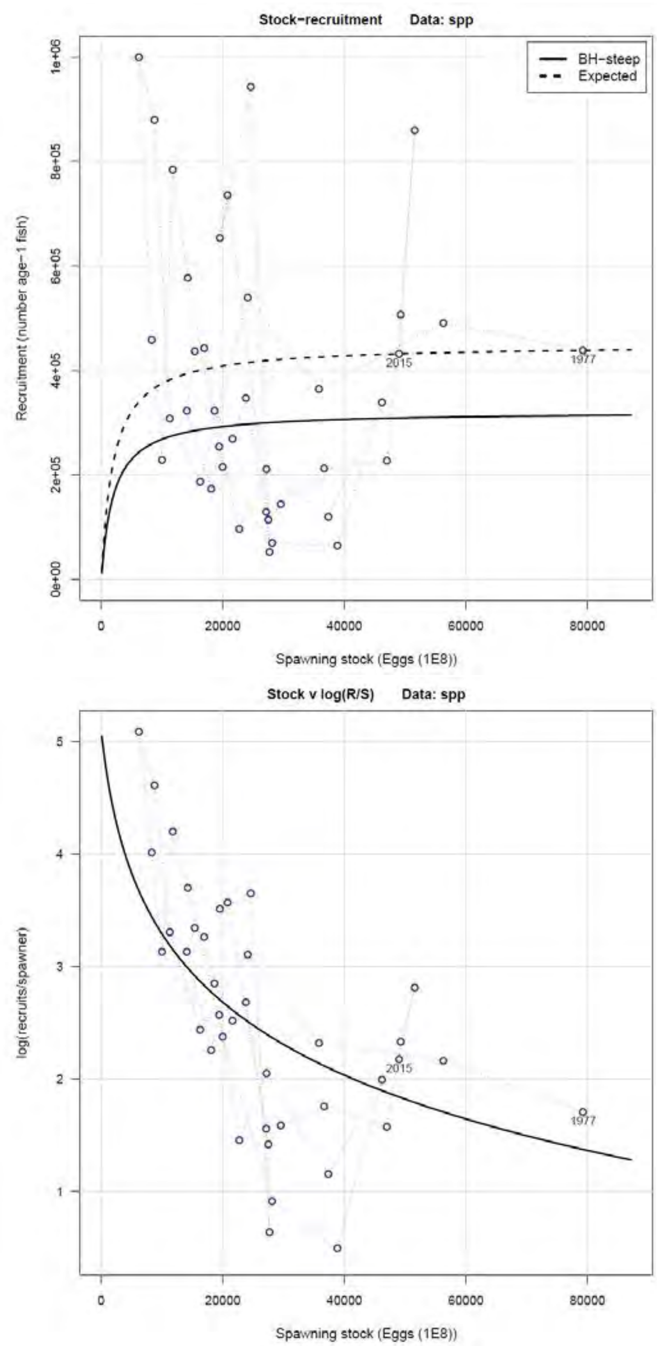


Figure 32. Probability densities of spawner-recruit quantities R0 (unfished recruitment of age-1 fish), steepness (fixed at 0.99), unfished spawners per recruit, and standard deviation of recruitment residuals in log space. Solid vertical lines represent point estimates or values from the base run of the Beaufort Assessment Model; dashed vertical lines represent medians from the MCB runs.

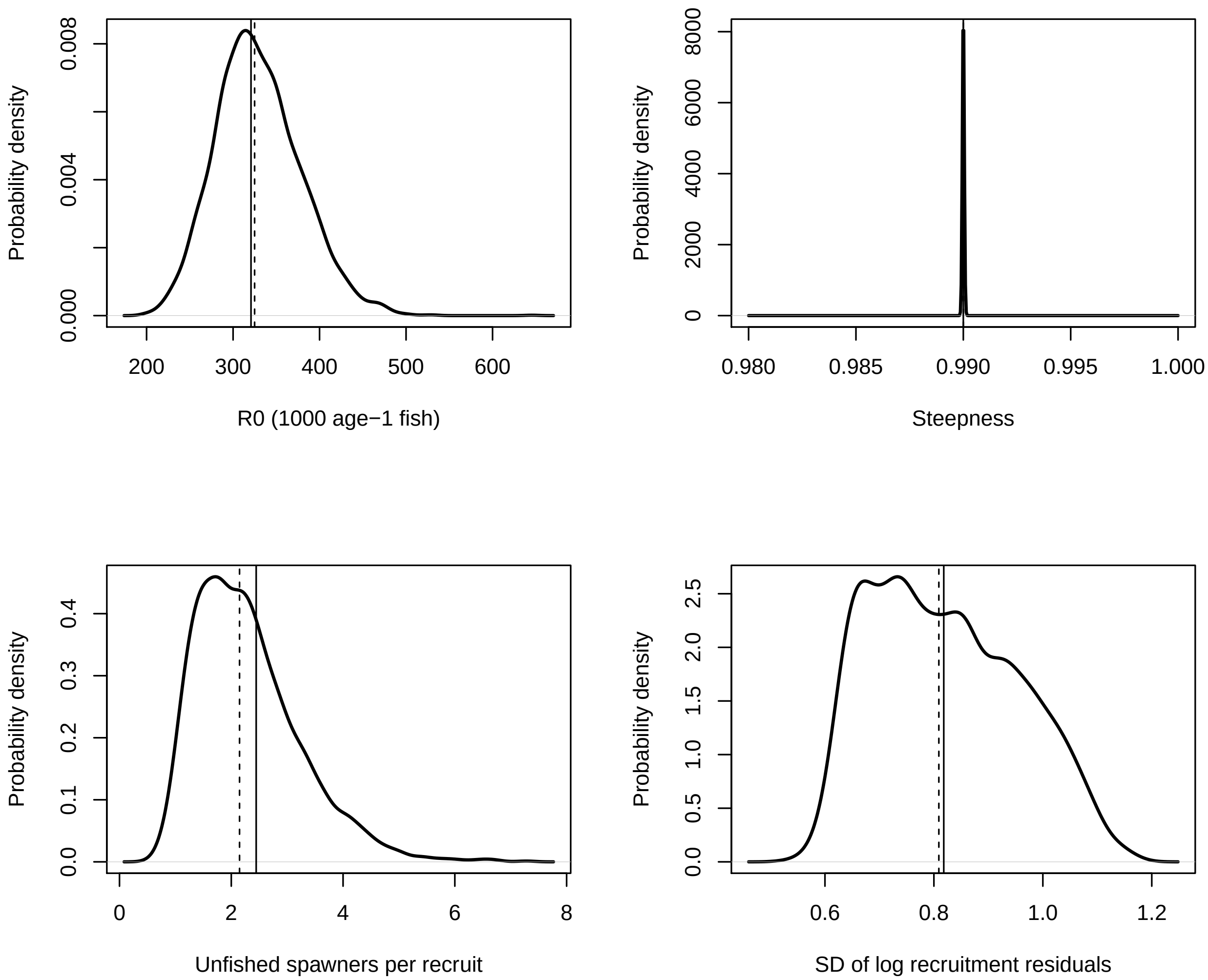


Figure 33. Yield per recruit based on average selectivity from the end of the assessment period.

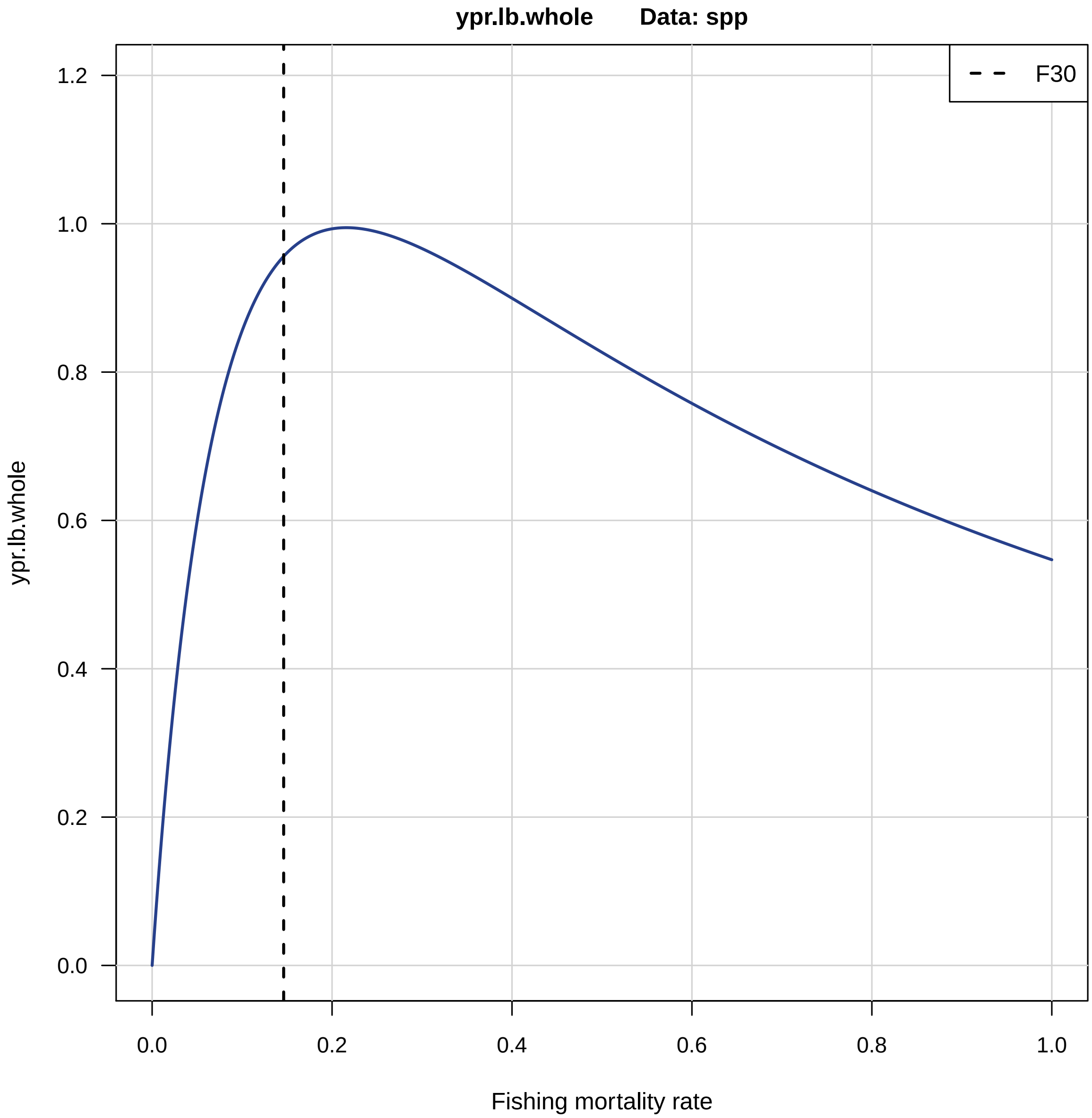


Figure 34. Spawning potential ratio (spawning biomass per recruit relative to that at the unfished level), from which the X% level of SPR provides $F_{X\%}$. SPR is based on average selectivity from the end of the assessment period.

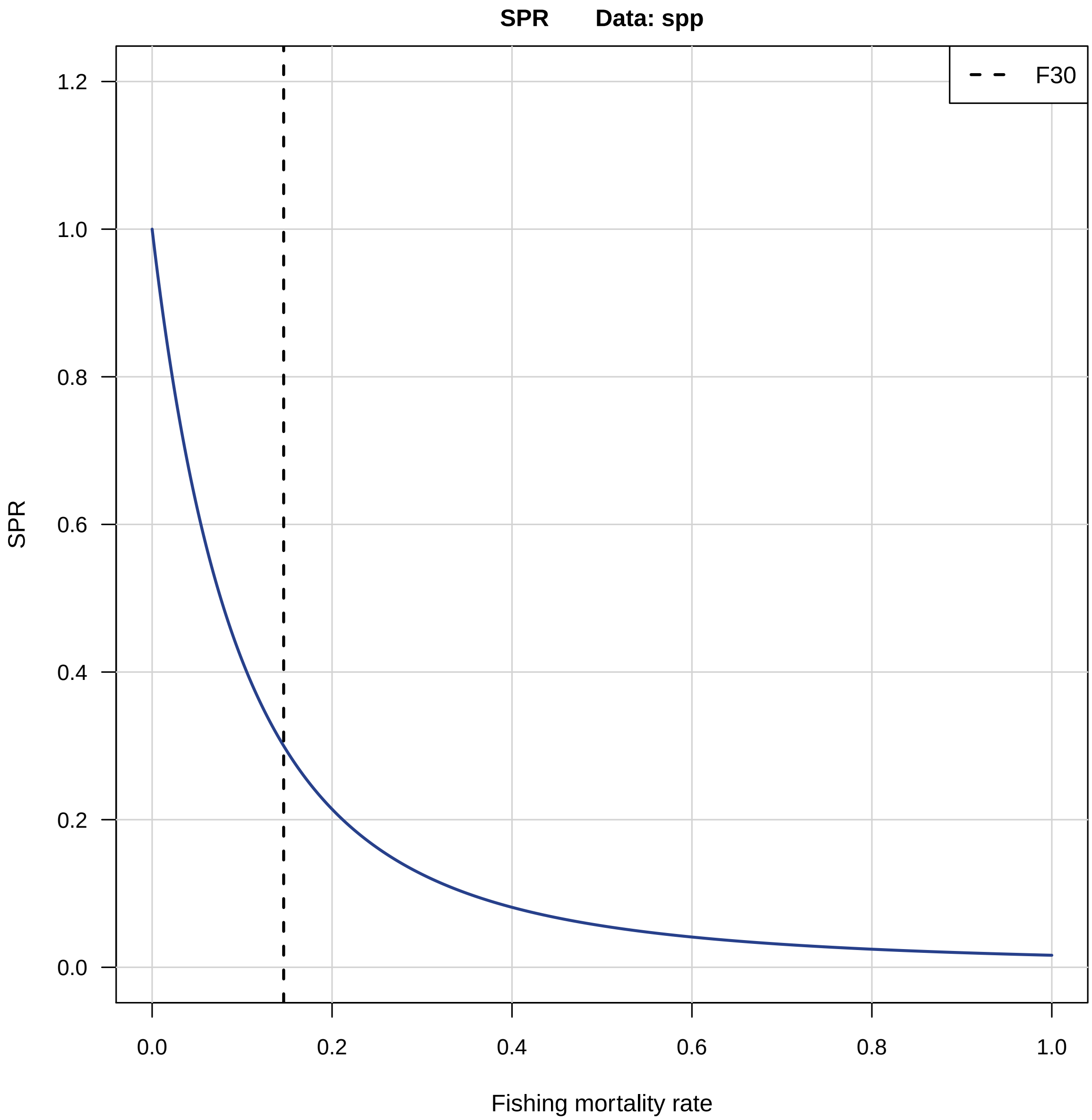


Figure 35. Equilibrium spawning biomass based on average selectivity from the end of the assessment period.

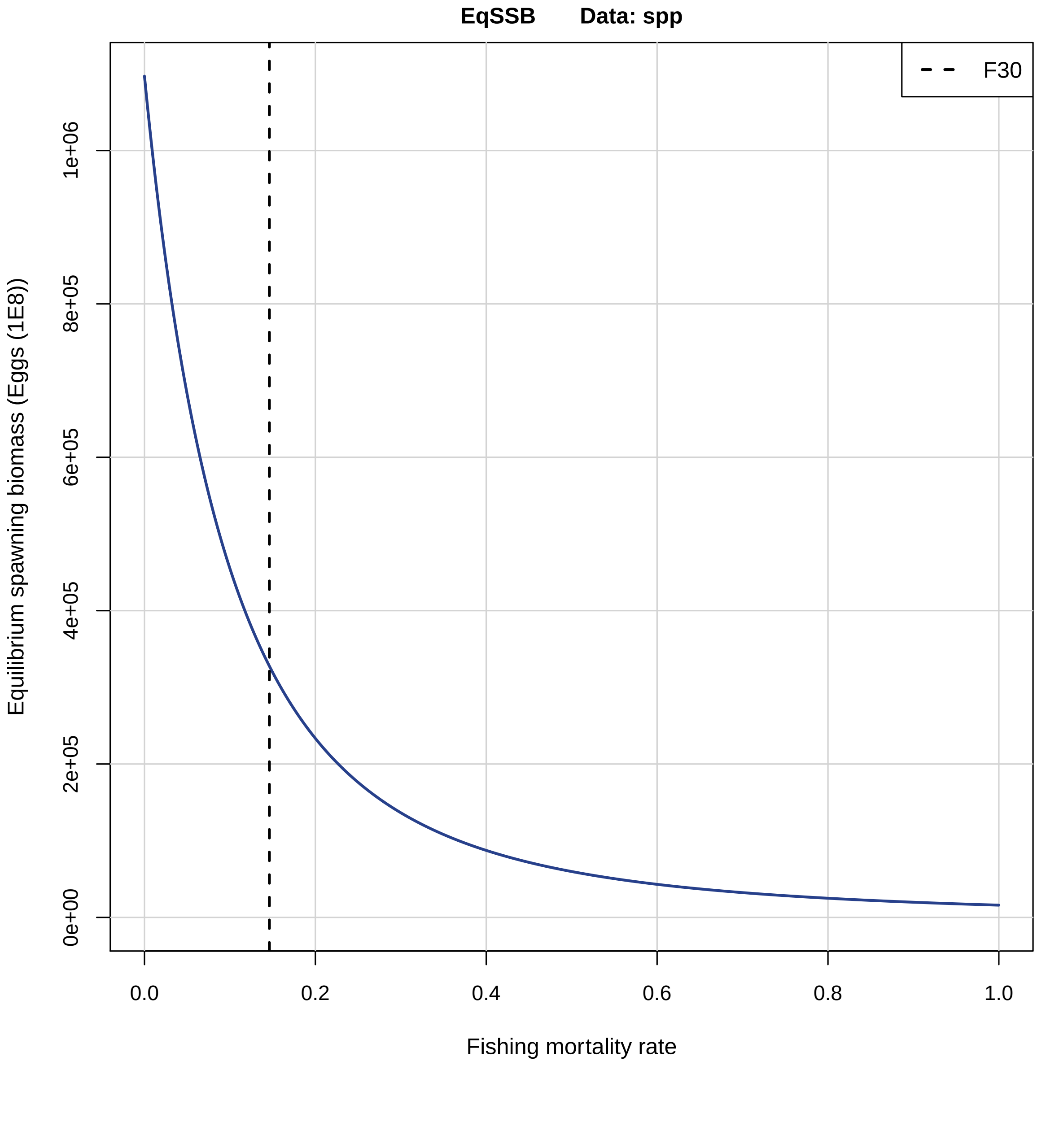


Figure 36. Probability densities of $F_{30\%}$-related benchmarks from MCB analysis of the Beaufort Assessment Model. Solid vertical lines represent point estimates from the base run; dashed vertical lines represent median values.

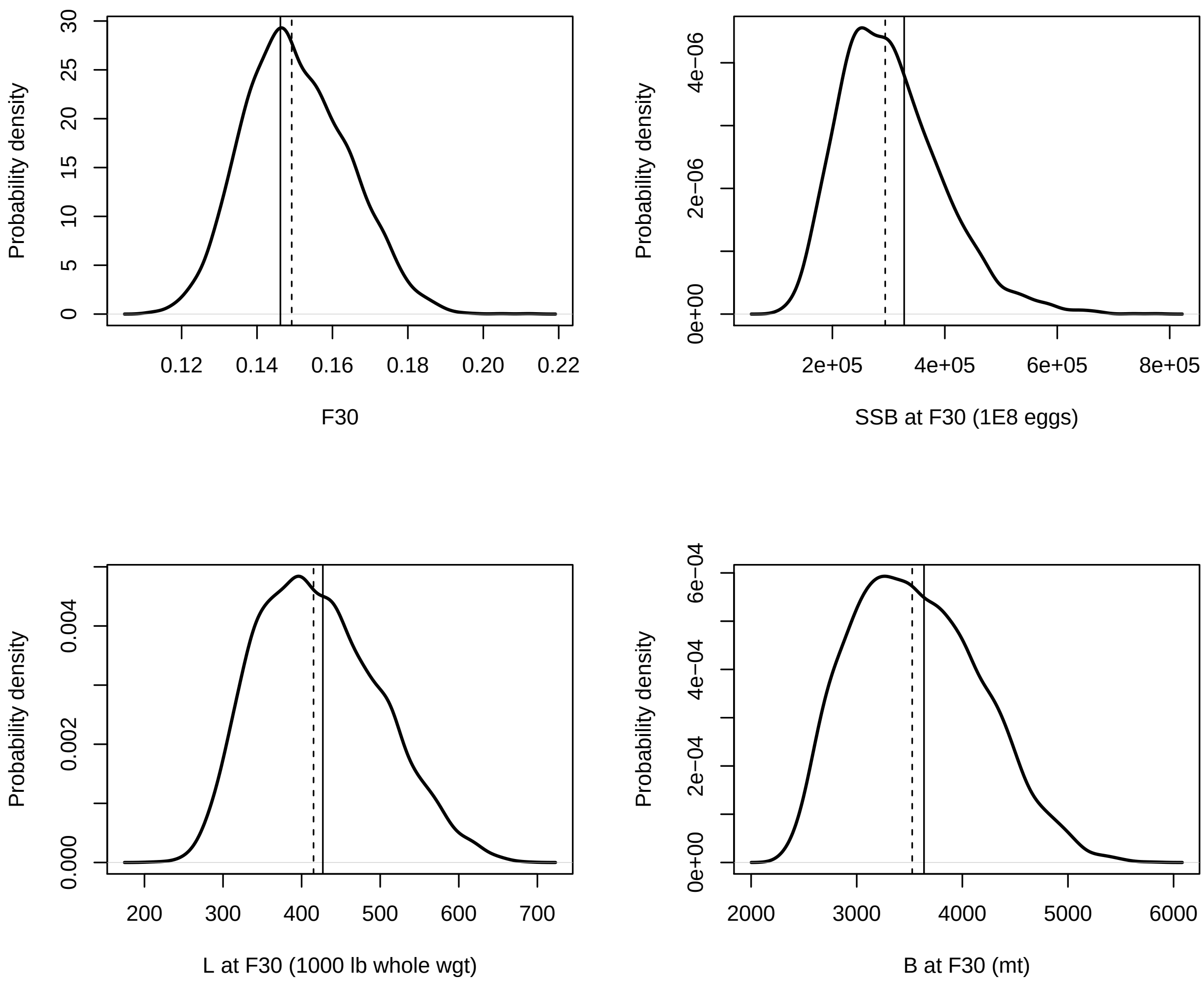
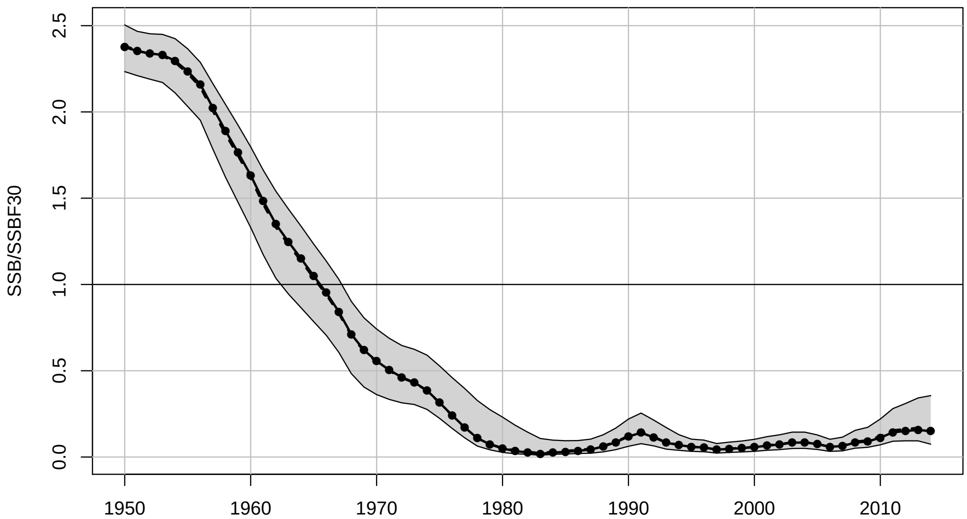


Figure 37. Estimated time series relative to benchmarks. Solid line indicates estimates from base run of the Beaufort Assessment Model; dashed lines represent median values; gray error bands indicate 5^{th} and 95^{th} percentiles of the MCB trials. Top panel: spawning biomass relative to $\mathrm{SSB}_{\mathrm{F30\%}}$. Bottom panel: F relative to $F_{30\%}$.



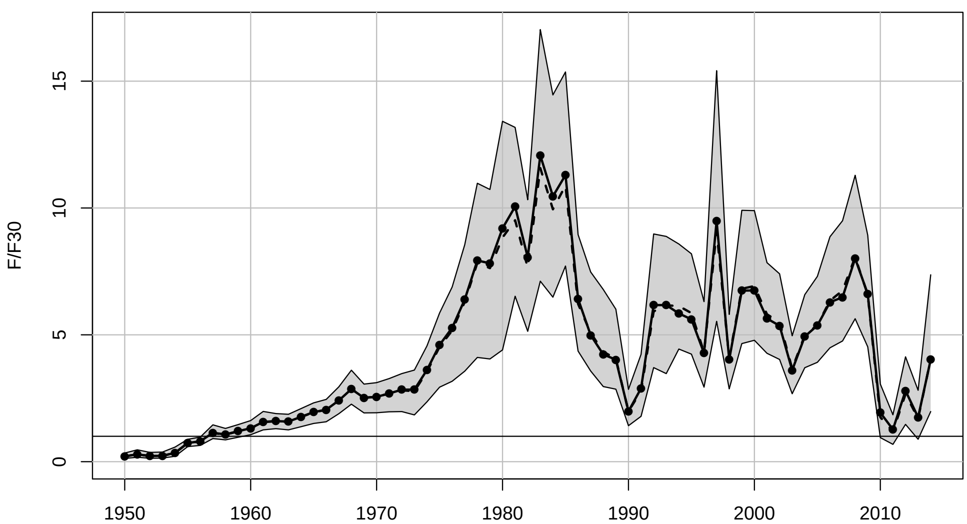


Figure 38. Probability densities of terminal status estimates from MCB analysis of the Beaufort Assessment Model. Solid vertical lines represent point estimates from the base run; dashed vertical lines represent median values.

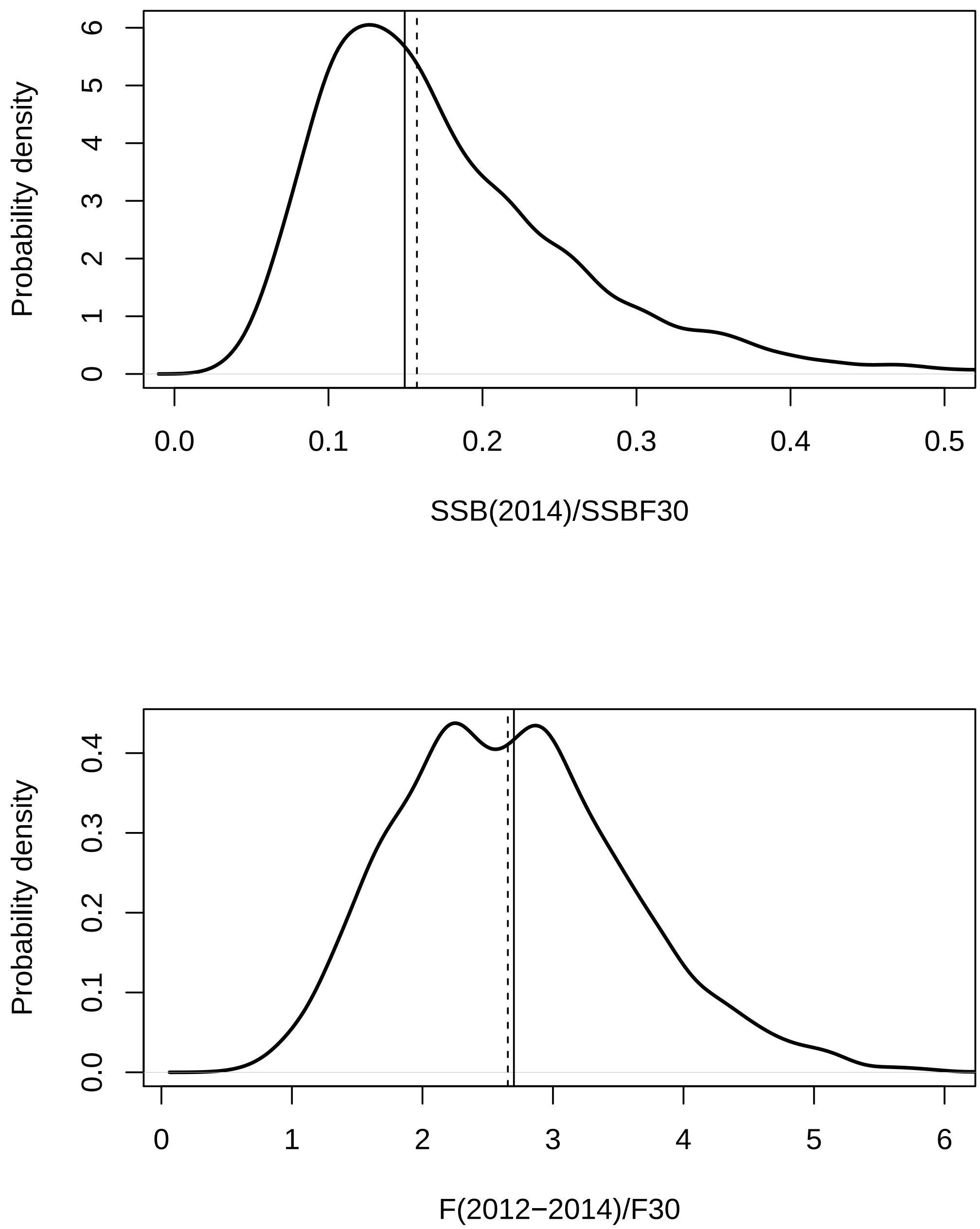


Figure 39. Phase plots of terminal status estimates from MCB analysis of the Beaufort Assessment Model. The intersection of crosshairs indicates estimates from the base run; lengths of crosshairs defined by 5^{th} and 95^{th} percentiles. Proportion of runs falling in each quadrant indicated.

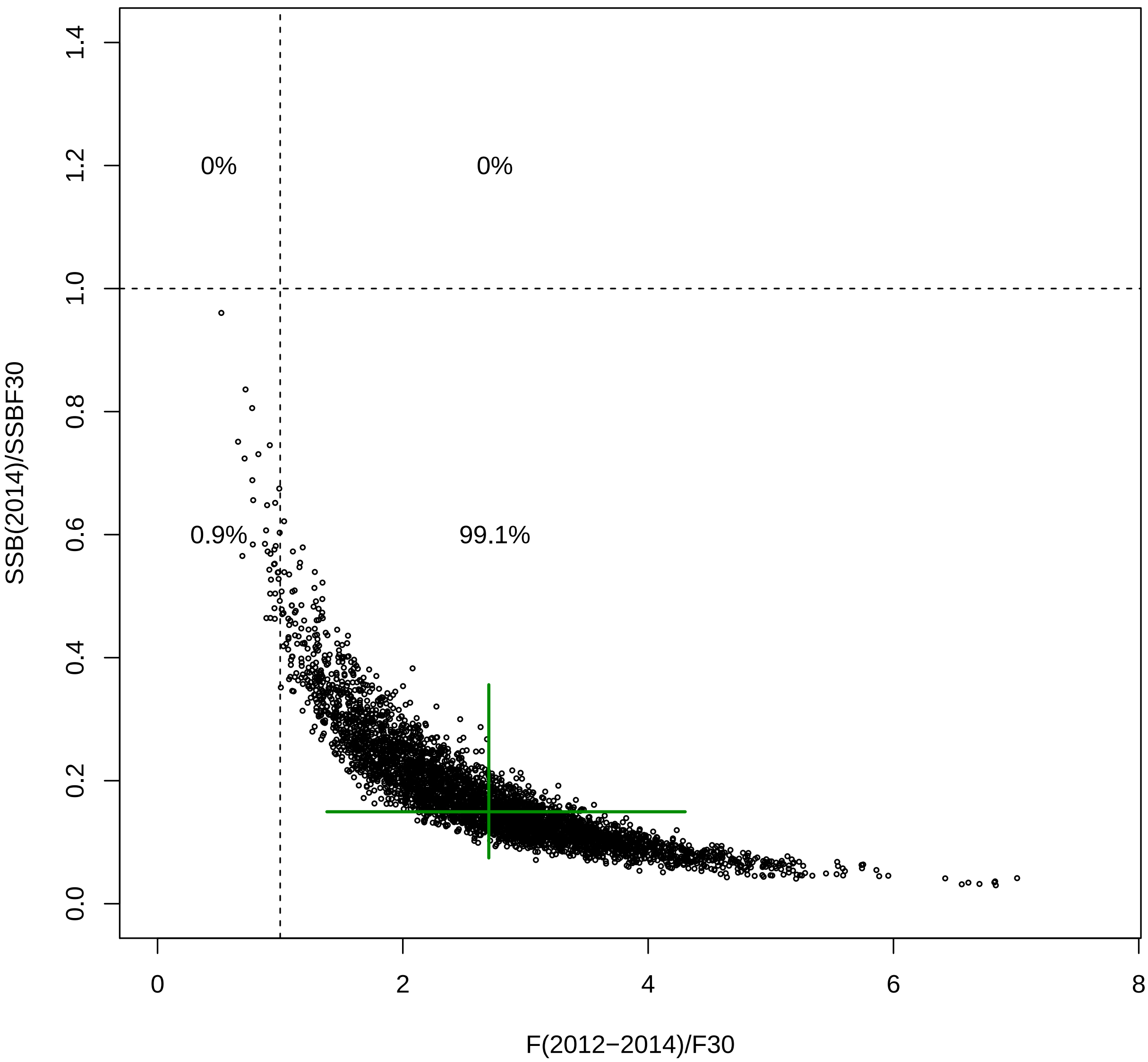


Figure 40. Age structure relative to the equilibrium expected at $F_{30\%}$.

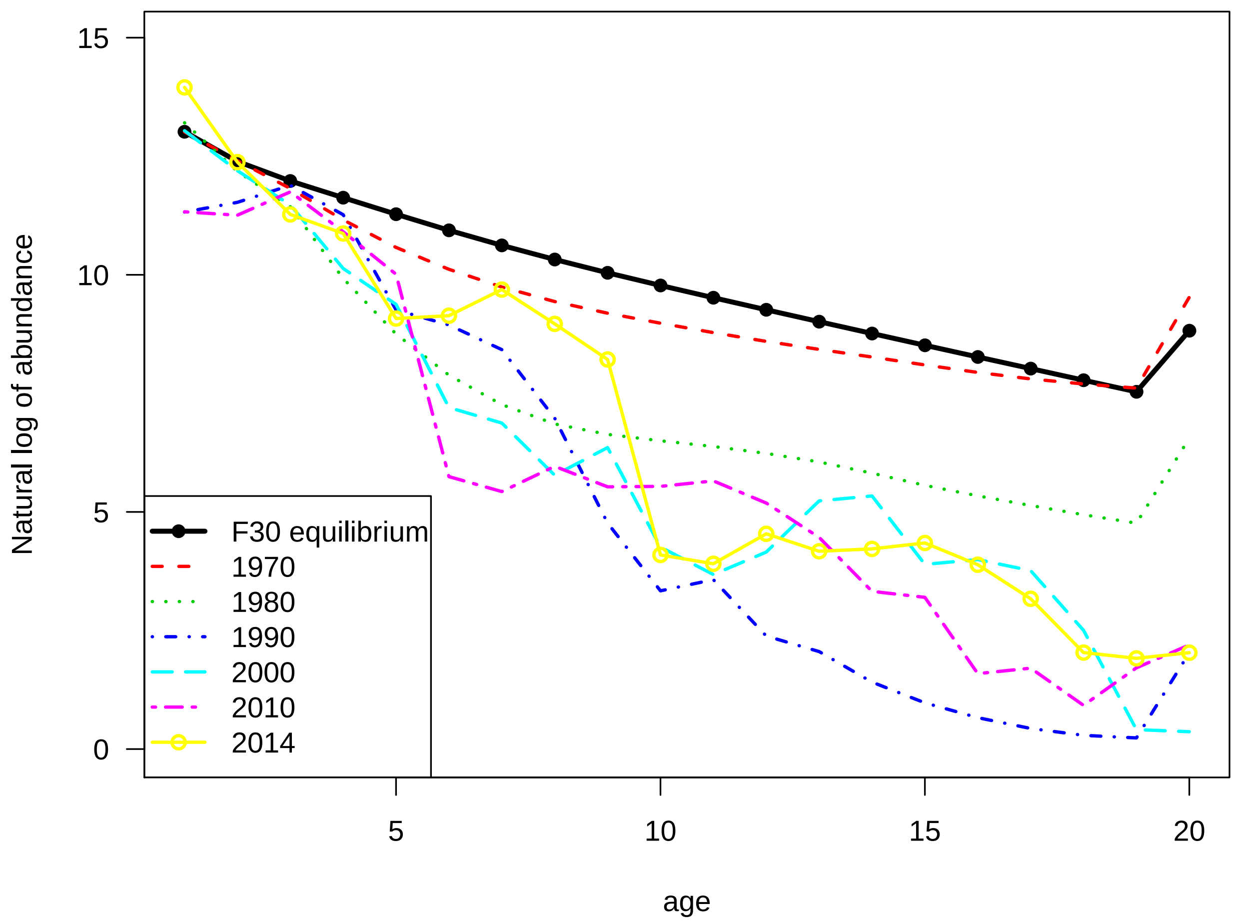


Figure 41. Sensitivity to changes in natural mortality (sensitivity runs S5 and S6). Top panel: Ratio of F to $F_{30\%}$*. Bottom panel: Ratio of* SSB *to* $SSB_{F30\%}$.

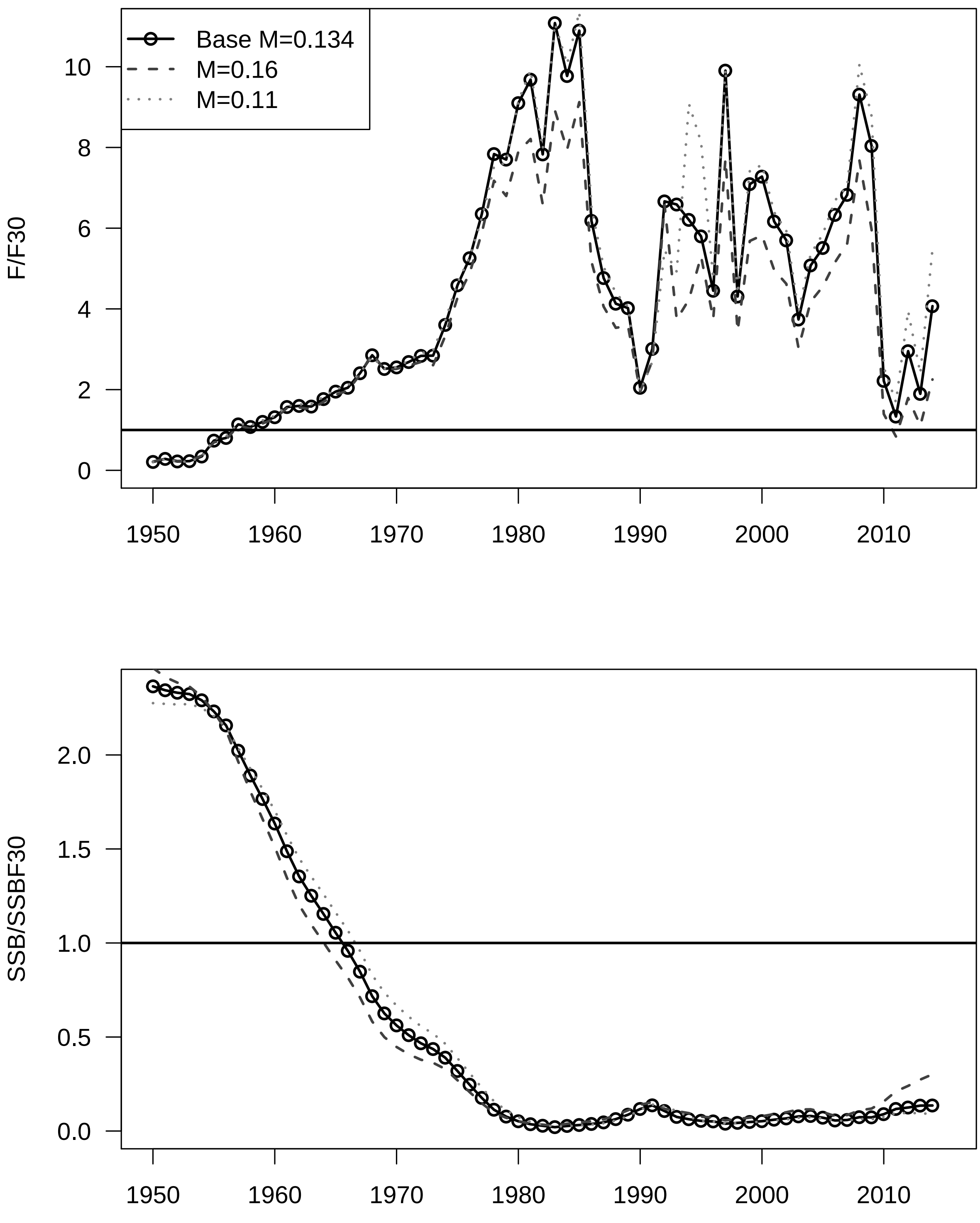


Figure 42. Sensitivity to steepness (sensitivity run S11). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

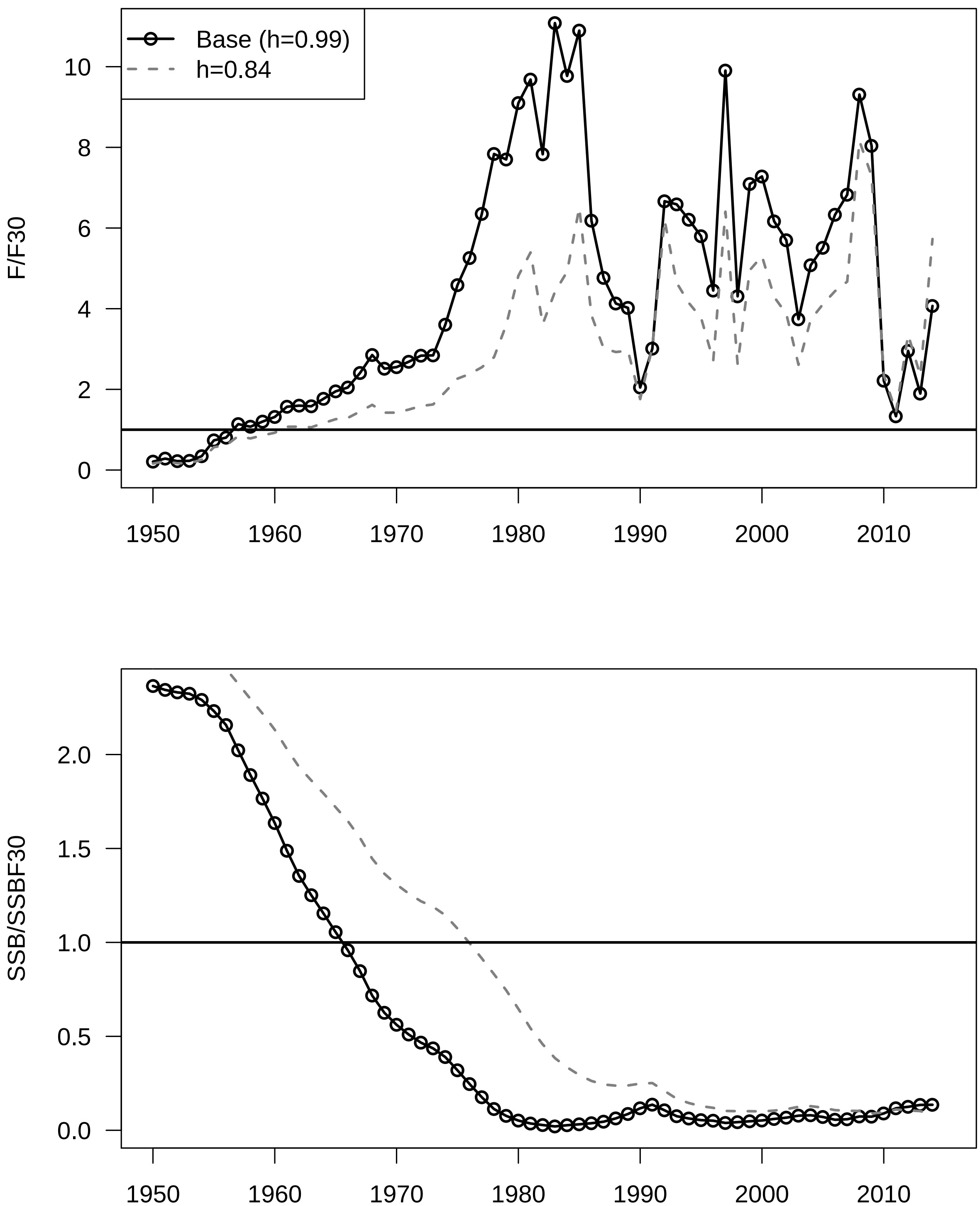


Figure 43. Sensitivity to start year (1978 compared to 1950) (sensitivity run S26). Top panel: Ratio of F to $F_{30\%}$. *Bottom panel: Ratio of* SSB *to* $SSB_{F30\%}$.

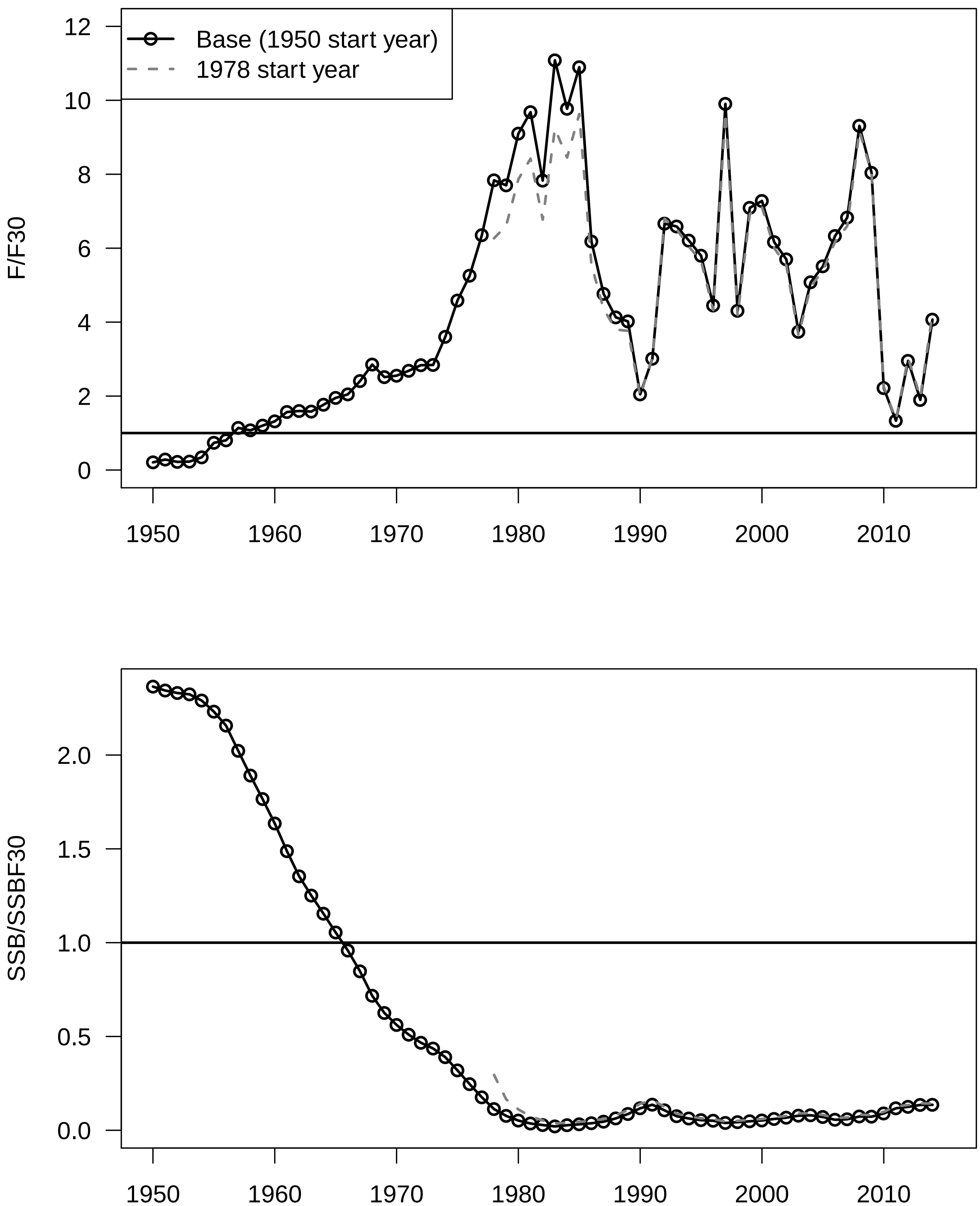


Figure 44. Sensitivity to aging error matrix (sensitivity run S13). Top panel: Ratio of F to $F_{30\%}$. *Bottom panel: Ratio of* SSB *to* $SSB_{F30\%}$.

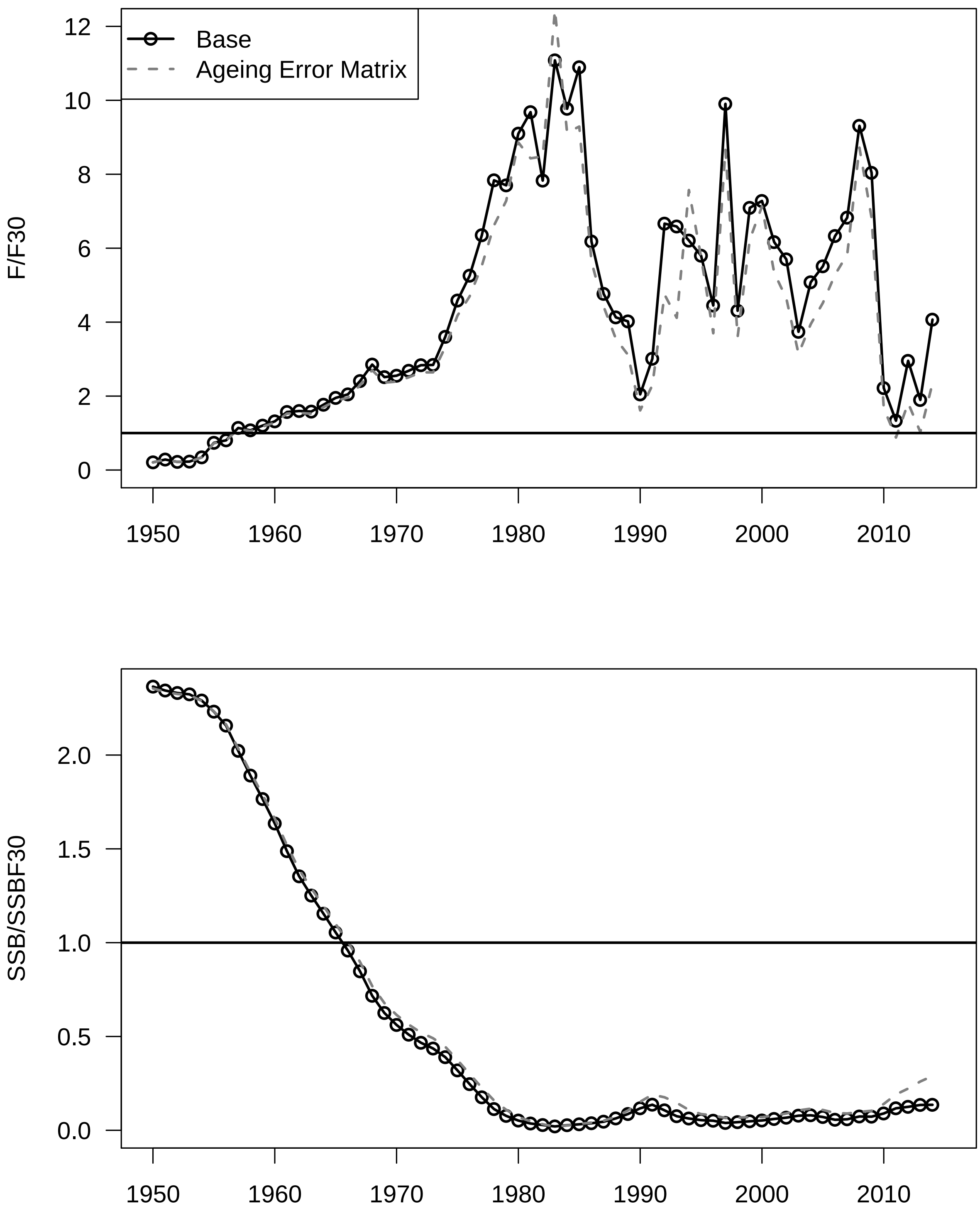


Figure 45. Sensitivity to batch number (sensitivity runs S14 and S15). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

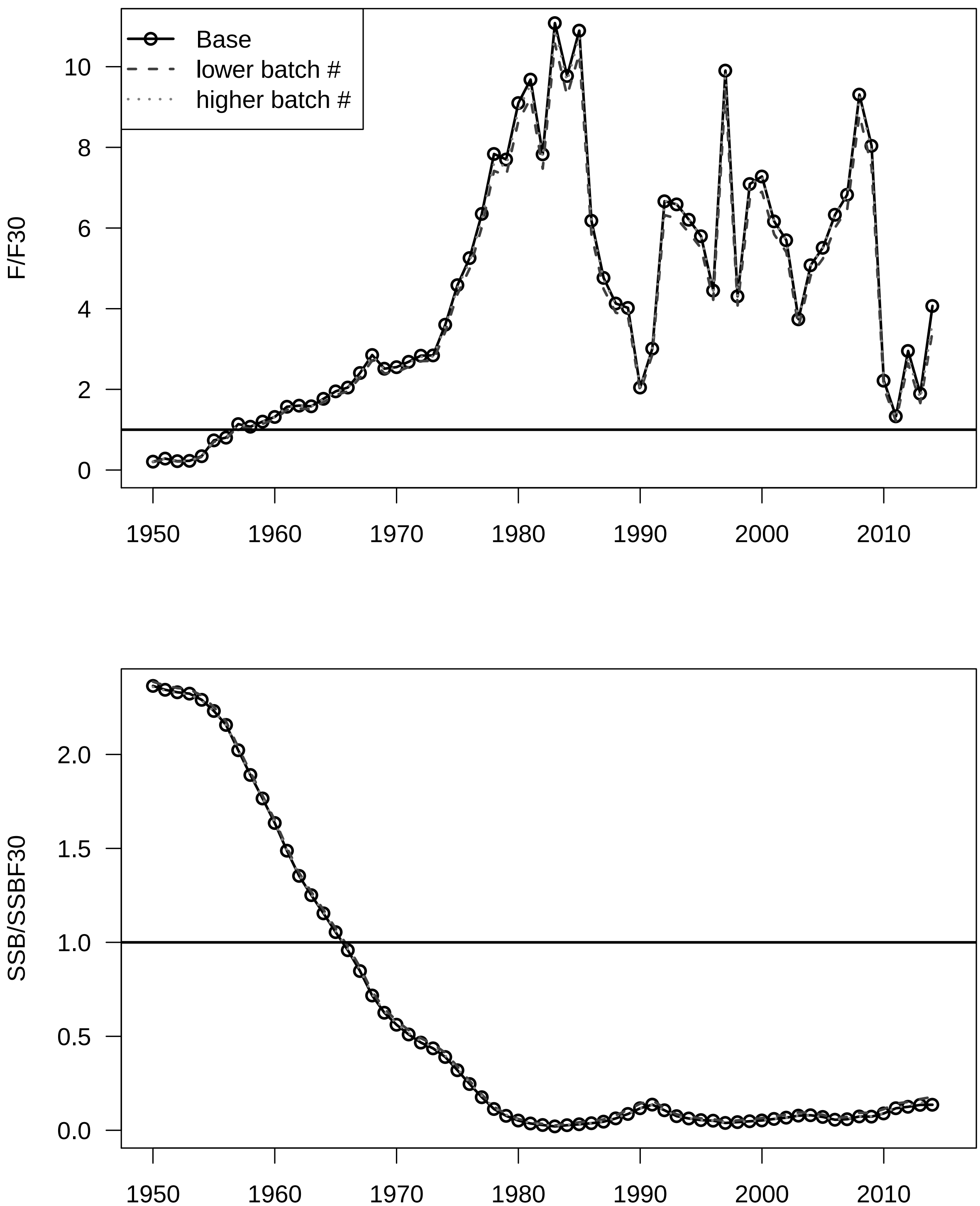
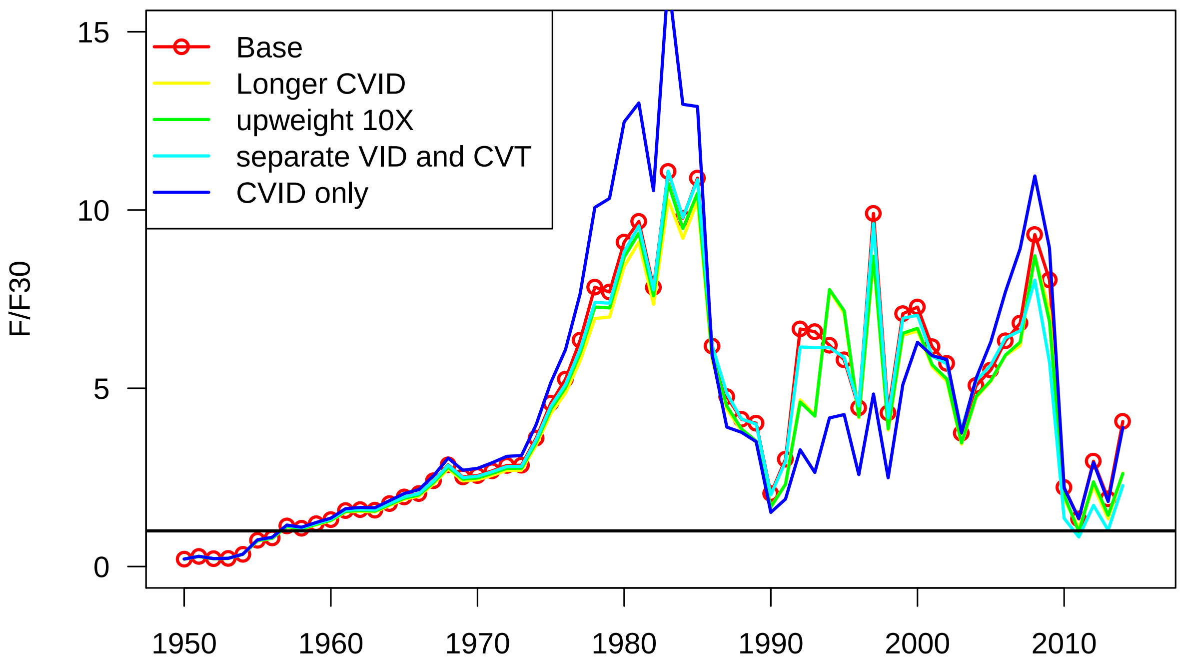


Figure 46. Sensitivity to various changes to SERFS video and trap indices (sensitivity runs S2, S9, S22 and S23). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB to $SSB_{F30\%}$.



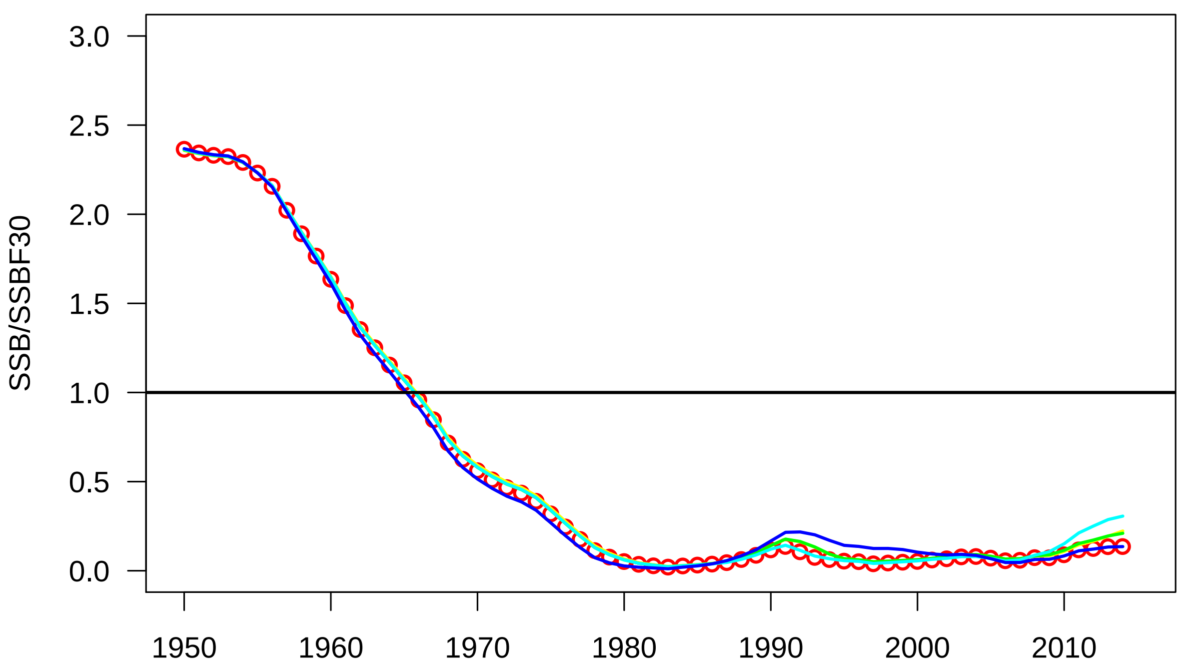


Figure 47. Sensitivity to discard mortality (sensitivity run S7 and S8). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $SSB_{F30\%}$.

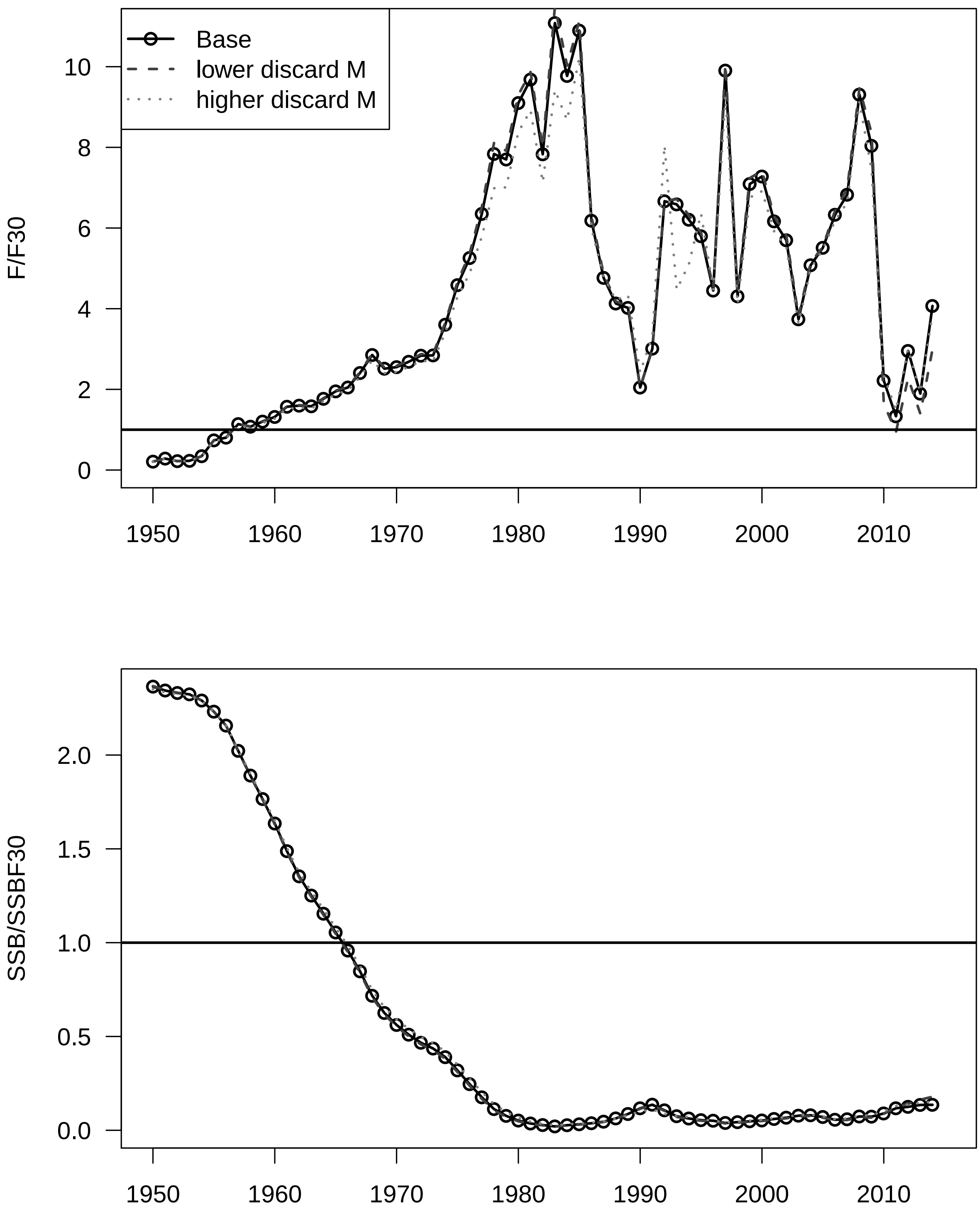


Figure 48. Sensitivity to dome-shaped selectivity for commercial handline (sensitivity run S21). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

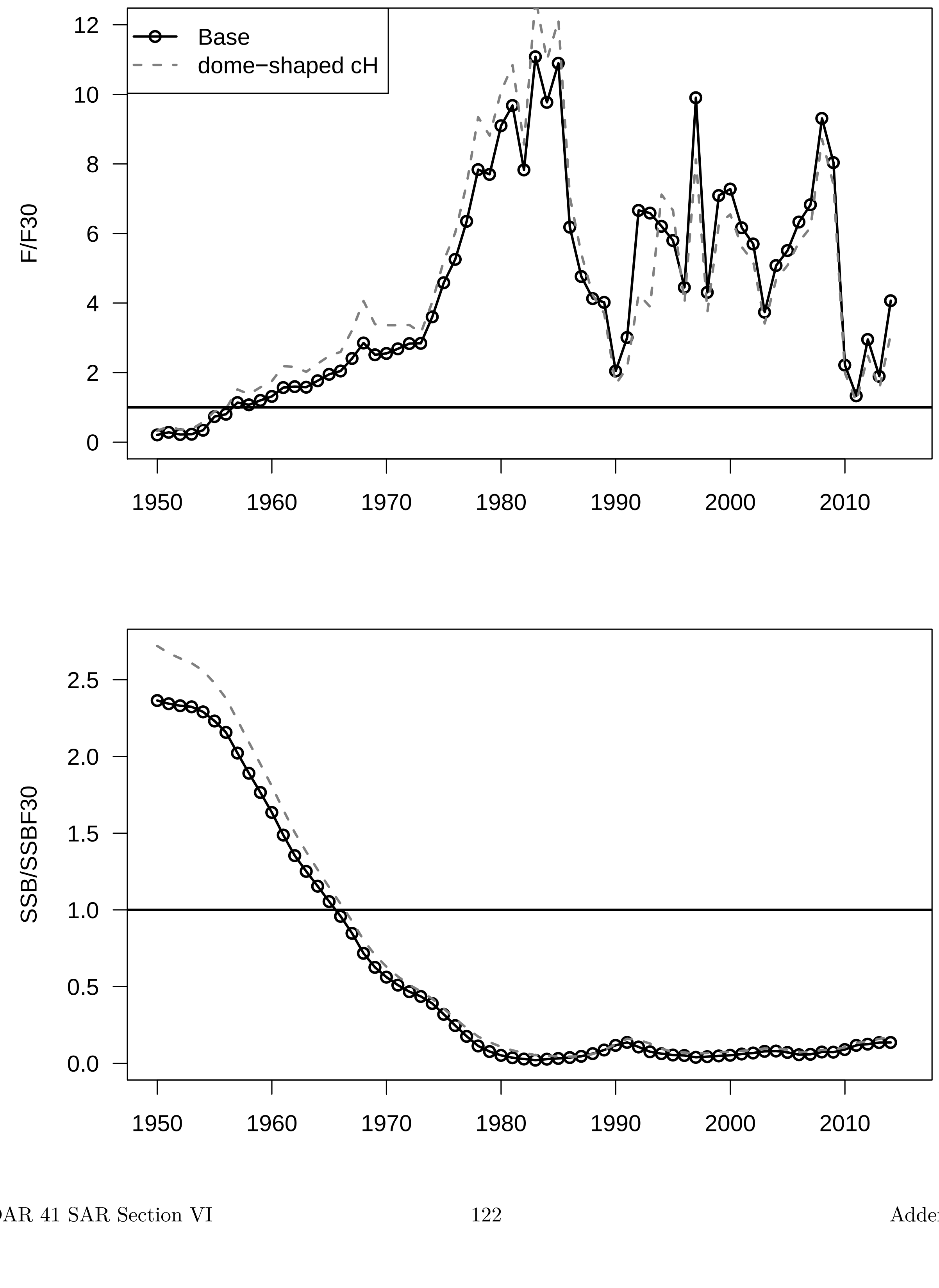


Figure 49. Sensitivity to various changes to fishery dependent indices (sensitivity runs S1, S3, S4, and S25). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\text{SSB}_{\text{F30\%}}$.

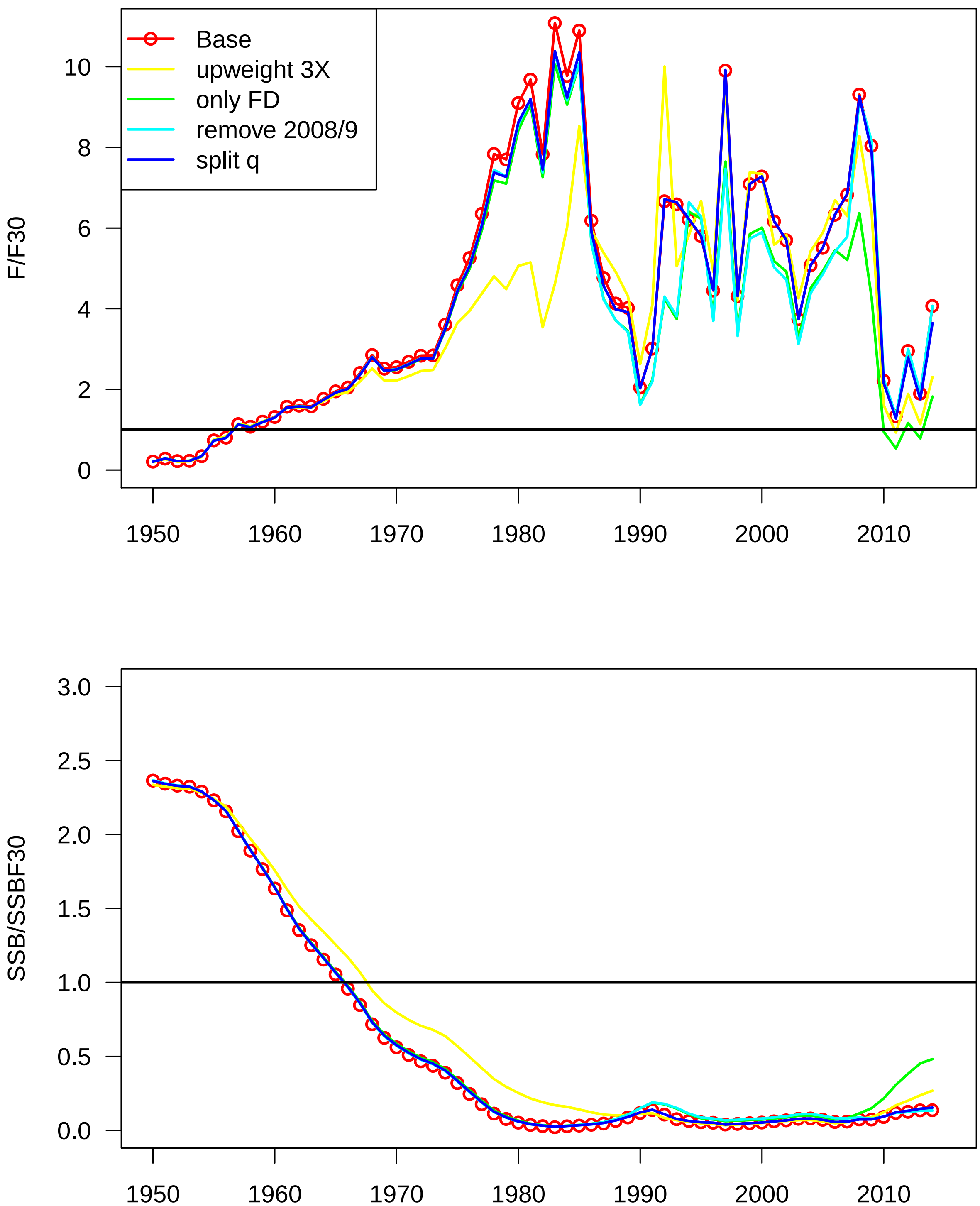


Figure 50. Sensitivity to not fixing selectivities (sensitivity run S27). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{F30\%}$.

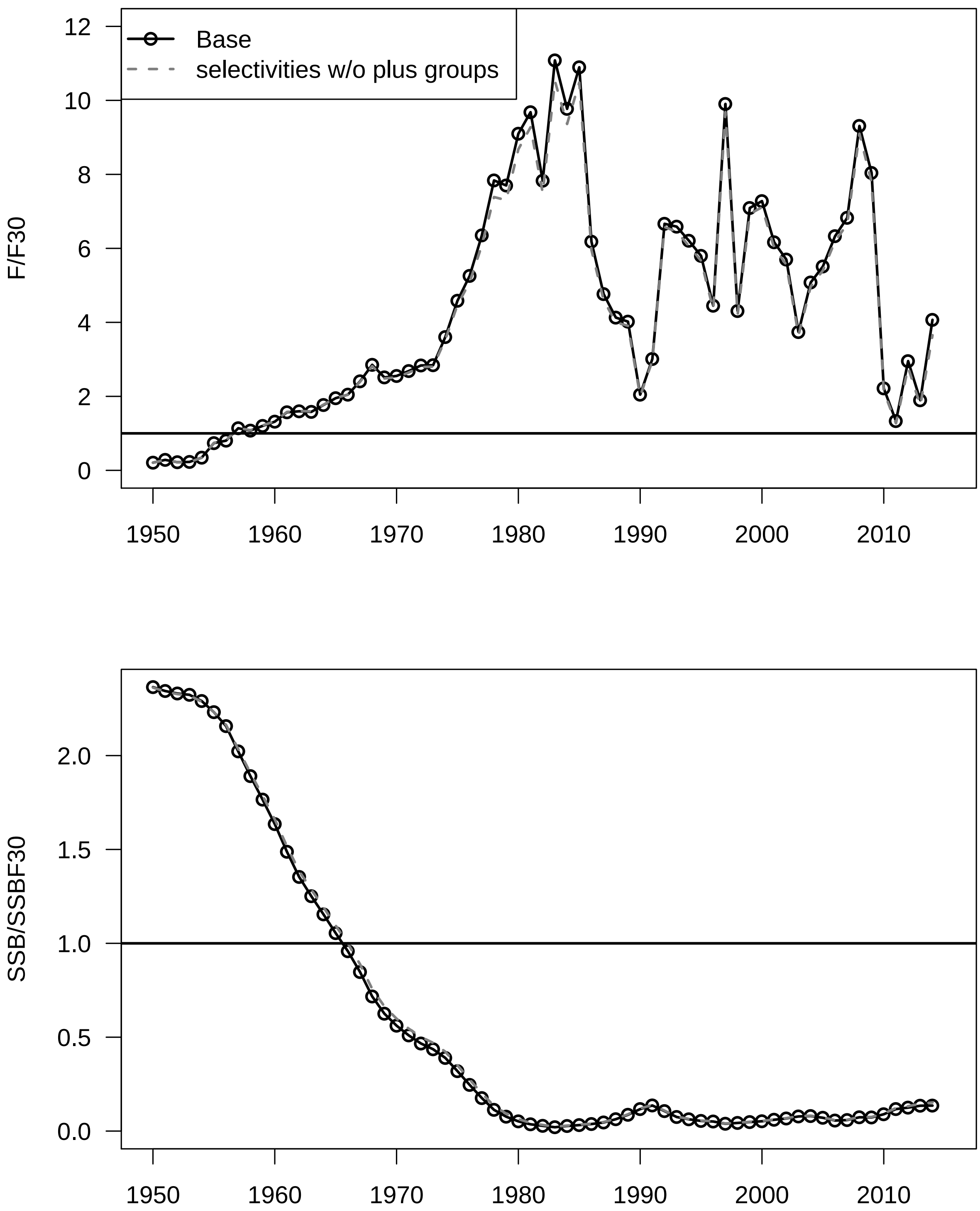


Figure 51. Sensitivity to dropping or truncating headboat discard index (sensitivity runs S12 and S16). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

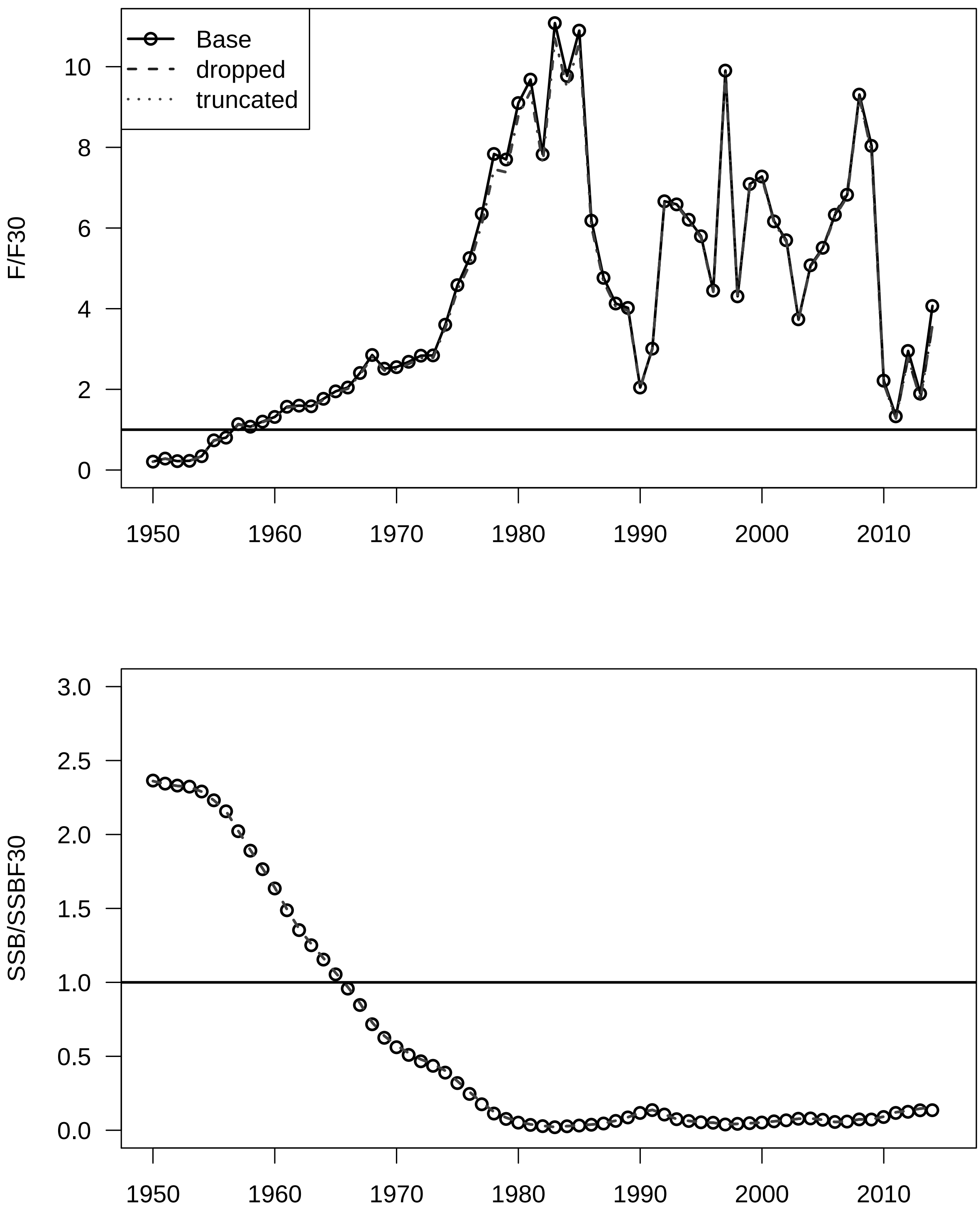


Figure 52. Sensitivity to higher or lower estimates of landings and discards (sensitivity runs S17–S20). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

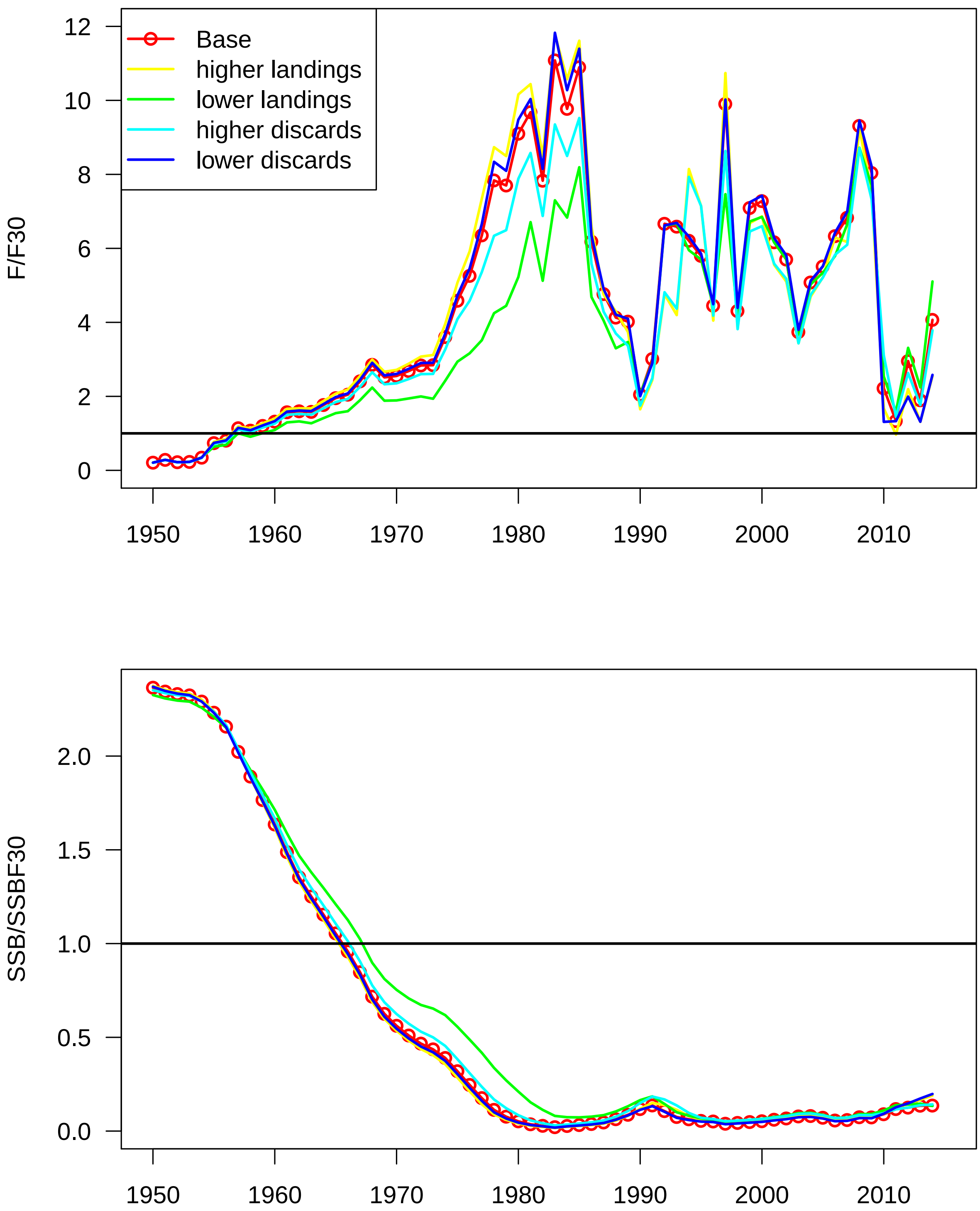


Figure 53. Sensitivity to smoothed 1984 and 1985 MRIP landings (sensitivity run S10). Top panel: Ratio of F to $F_{30\%}$*. Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$*.*

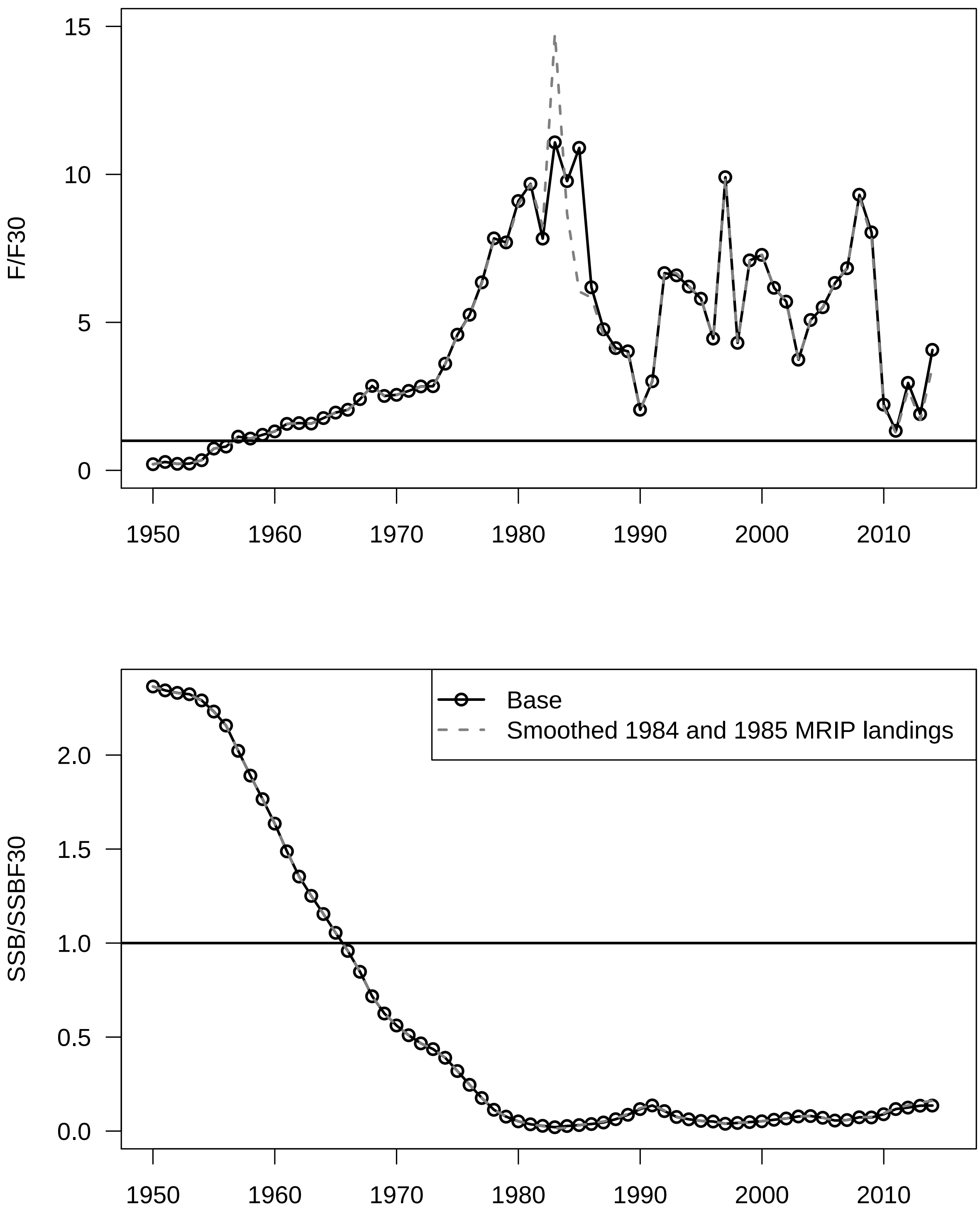


Figure 54. Sensitivity to continuity assumptions from SEDAR 24 (sensitivity run S24). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{F30\%}}$.

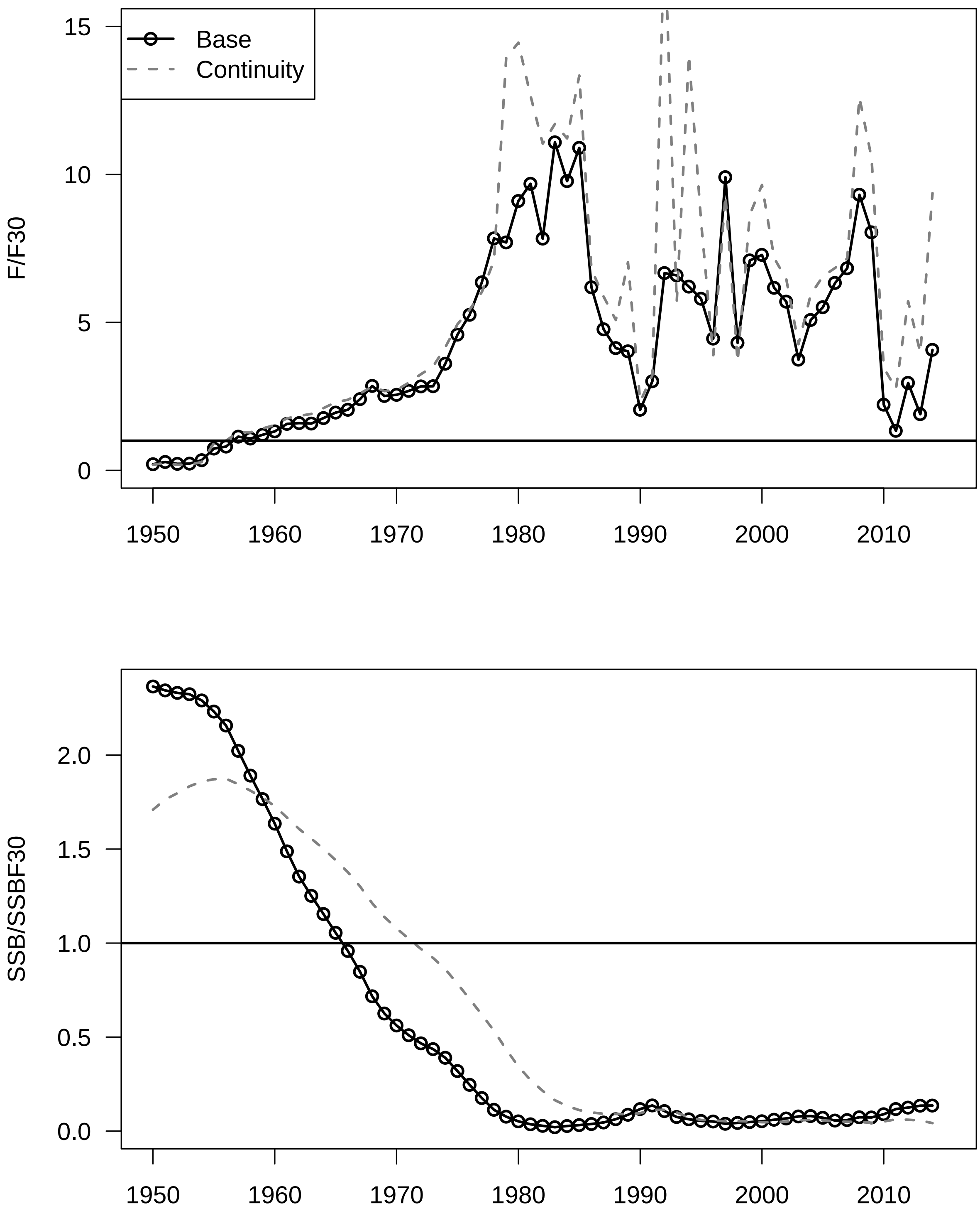


Figure 55. Phase plot of terminal status indicators from sensitivity runs of the Beaufort Assessment Model.

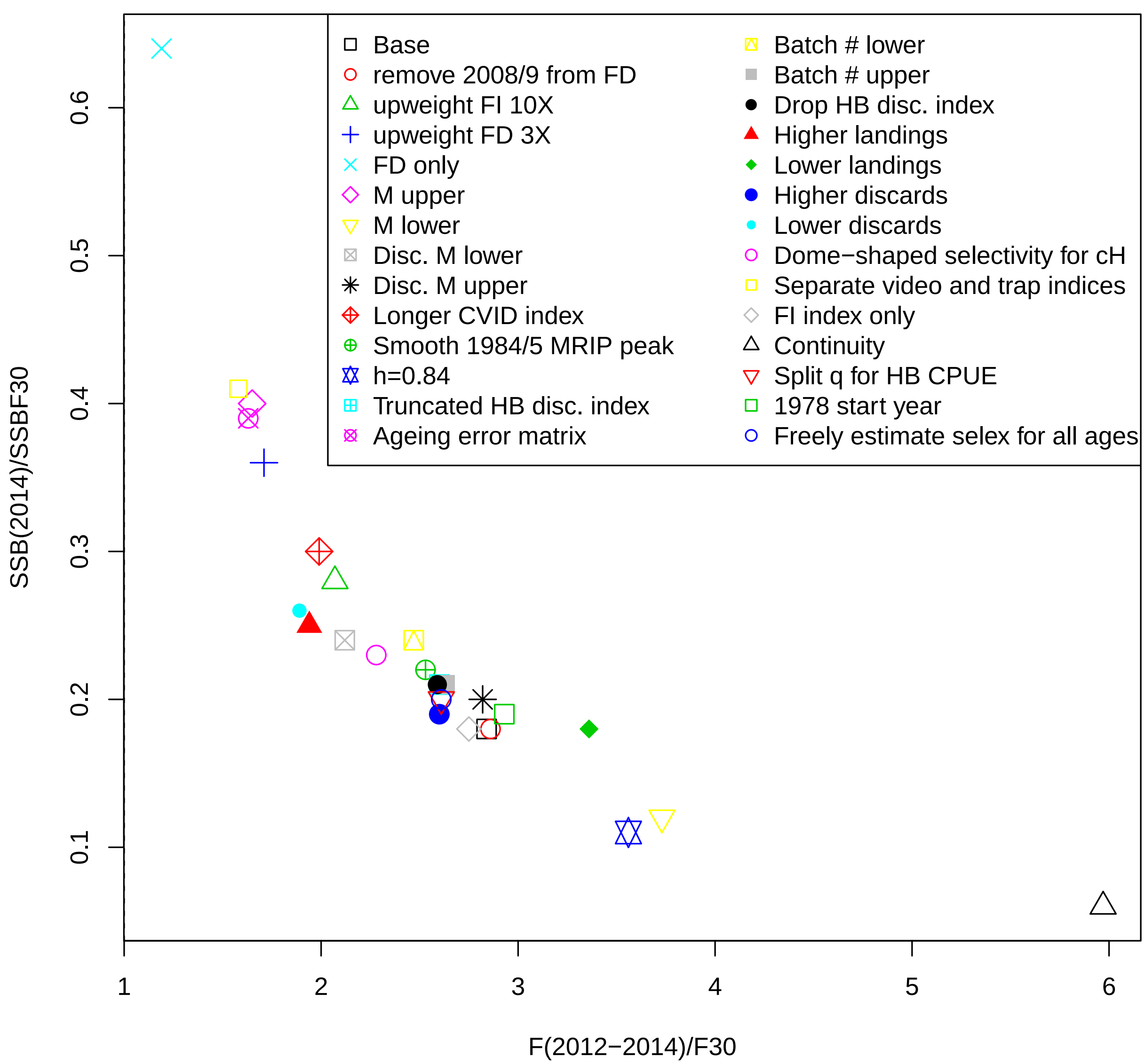


Figure 56. Retrospective analyses. Sensitivity to terminal year of data. Top panel: Fishing mortality rates. Middle panel: Recruits. Bottom panel: Spawning biomass. Closed circles show terminal-year estimates. Imperceptible lines overlap results of the base run.

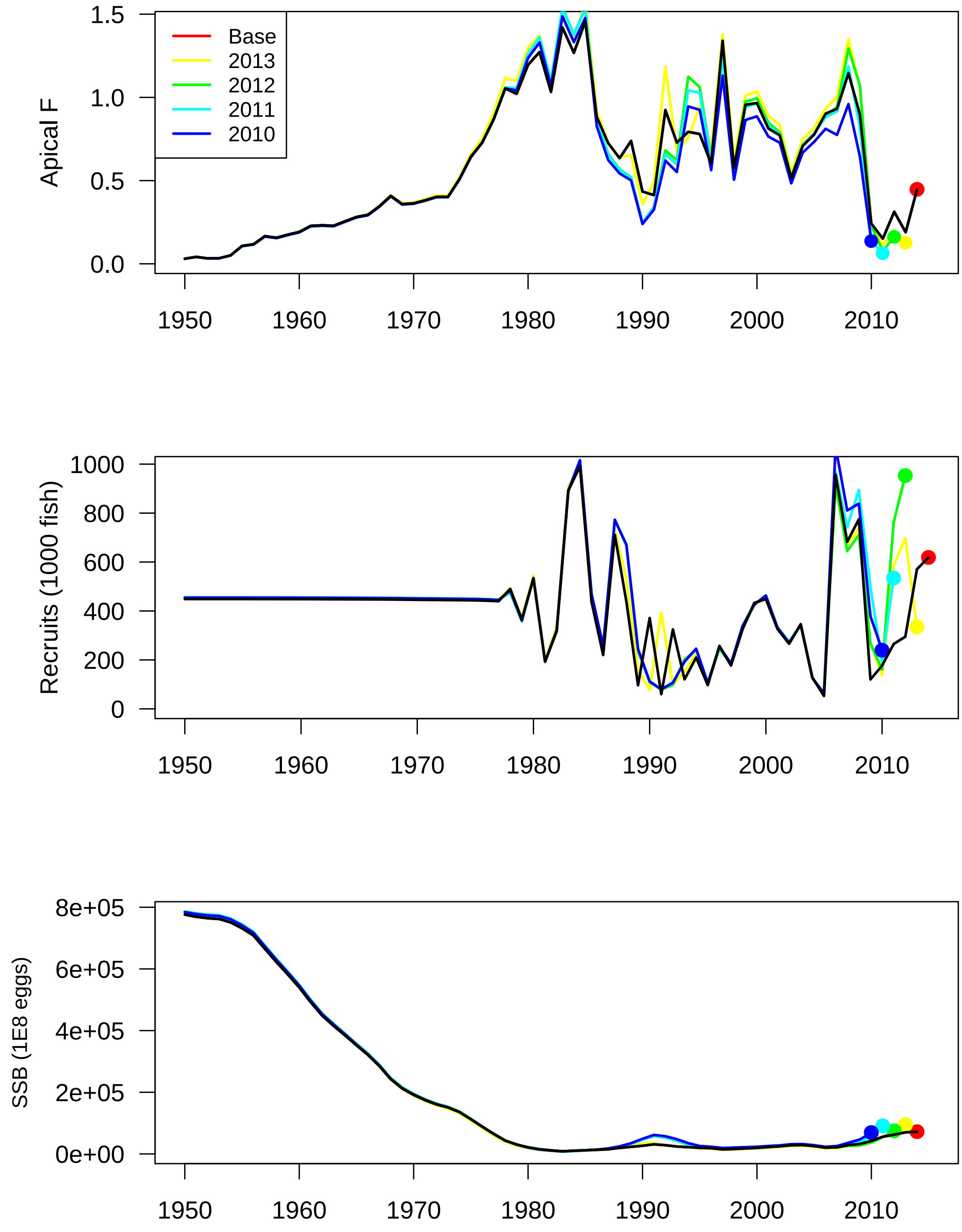


Figure 57. Projection results under scenario 1—fishing mortality rate at $F = 0$. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F30\%}}$.

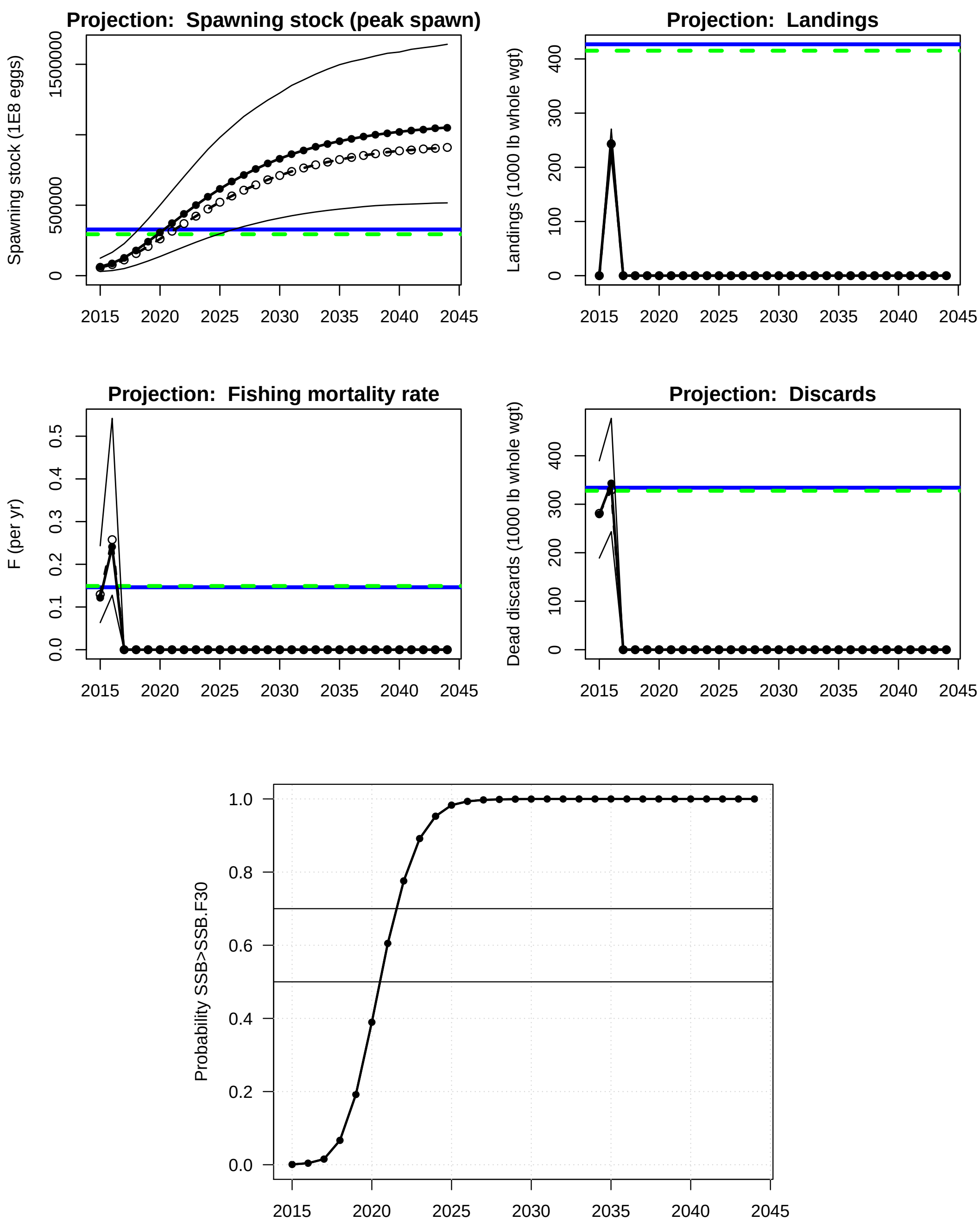


Figure 58. Projection results under scenario 2—fishing mortality rate at $F = F_{\mathrm{current}}$*. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to* 5^{th} *and* 95^{th} *percentiles of replicate projections. Solid horizontal lines mark* $F_{30\%}$*-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific* $\mathrm{SSB}_{\mathrm{F30\%}}$*.*

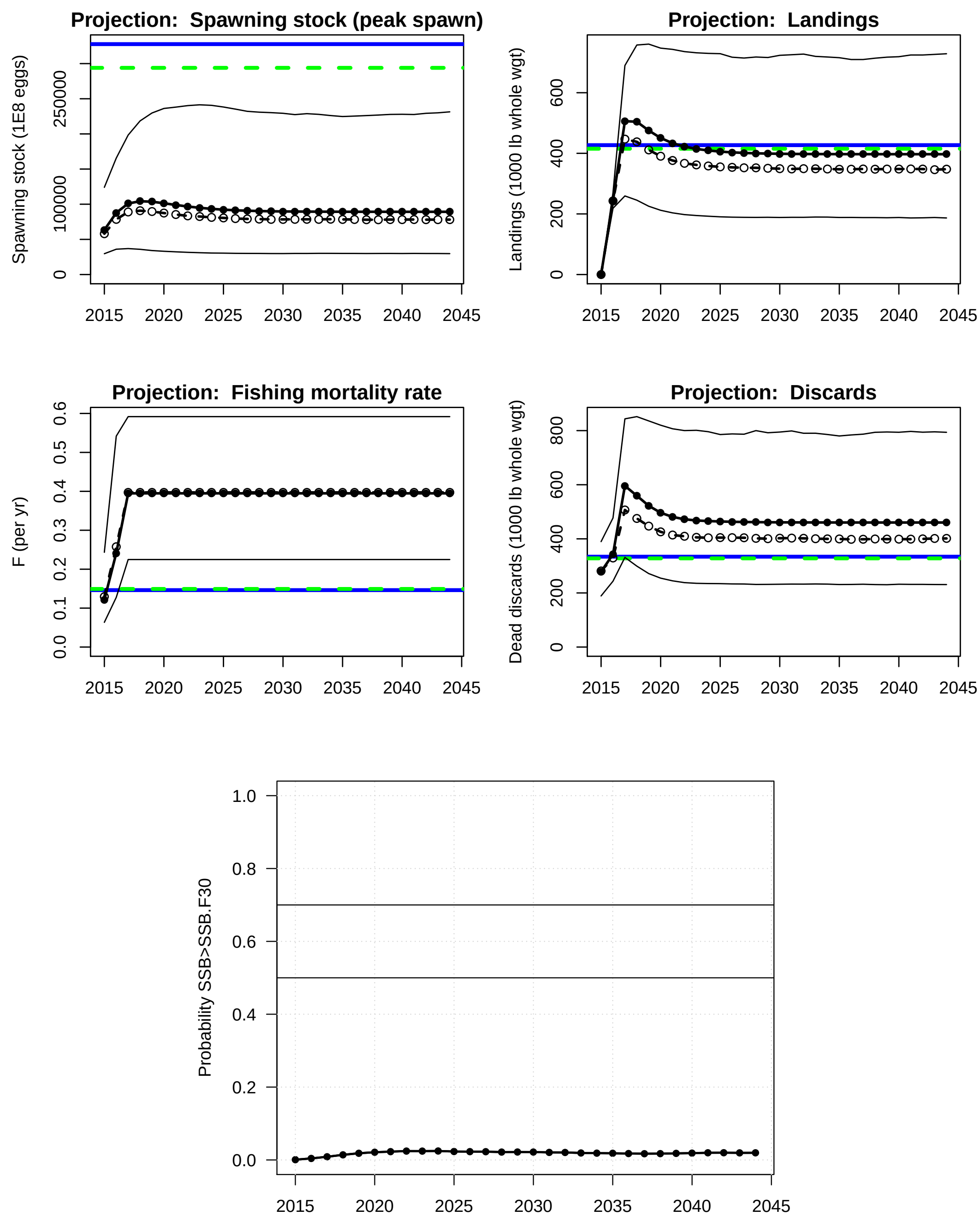


Figure 59. Projection results under scenario 3—fishing mortality rate at $F = F_{30\%}$. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB_{F30\%}}$.

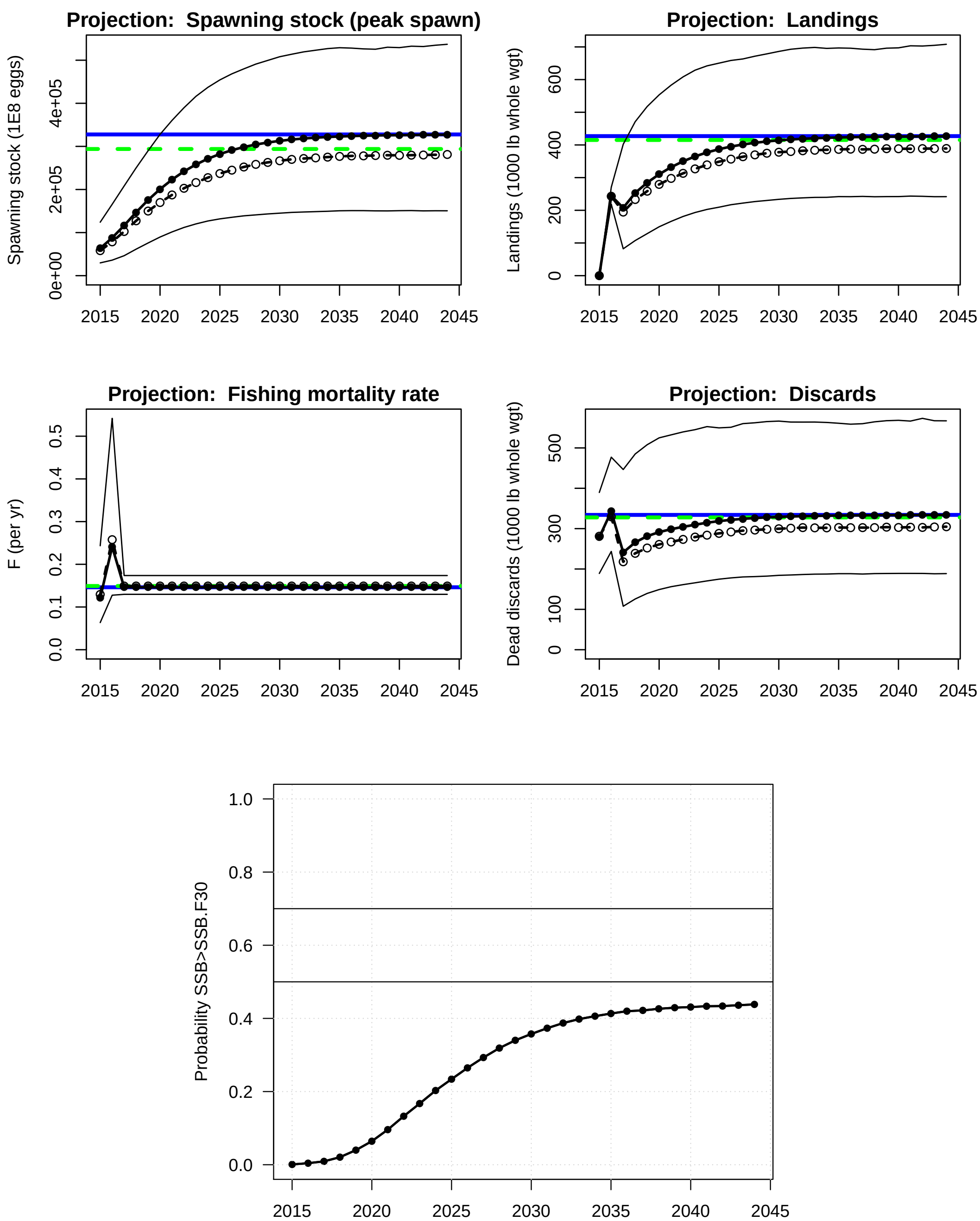


Figure 60. Projection results under scenario 4—fishing mortality rate at $F = 98\% F_{30\%}$. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F30\%}}$.

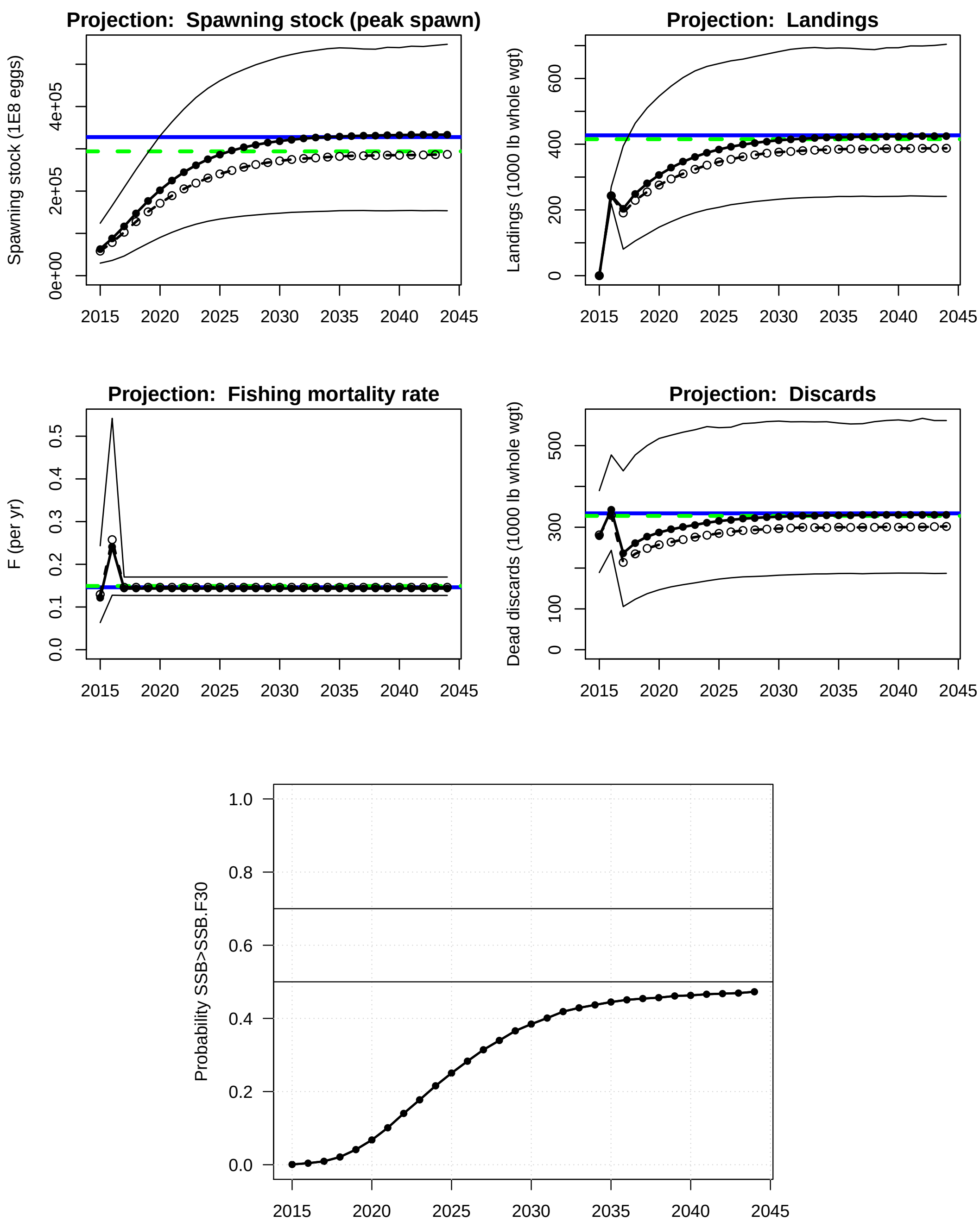


Figure 61. Projection results under scenario 5—fishing mortality rate at $F = F_{\text{rebuild}}$, with rebuilding probability of 0.5 in 2044. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\text{SSB}_{\text{F30\%}}$.

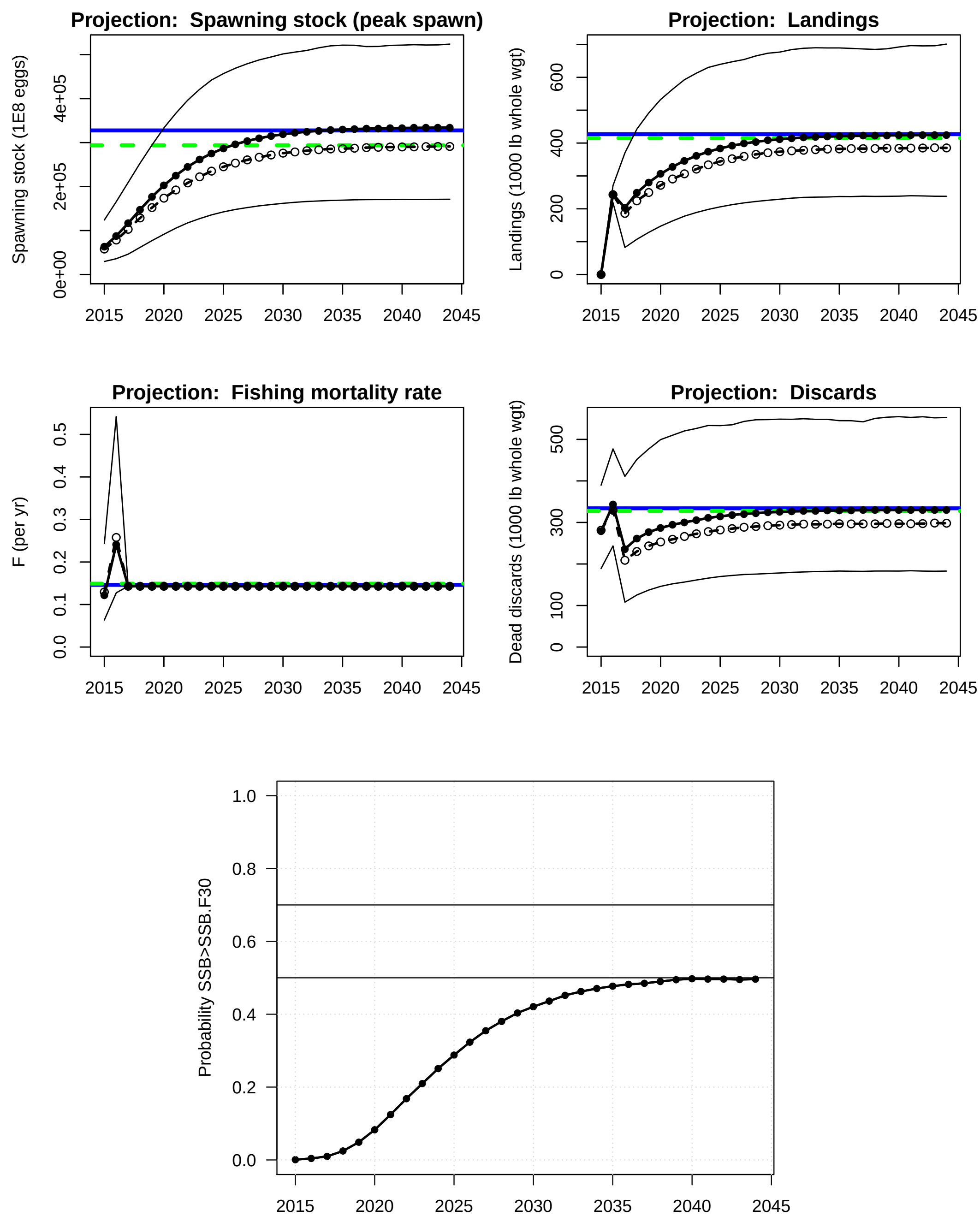


Figure 62. Projection results under scenario 6—fishing mortality rate set to average discard mortality rate only. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F30\%}}$.

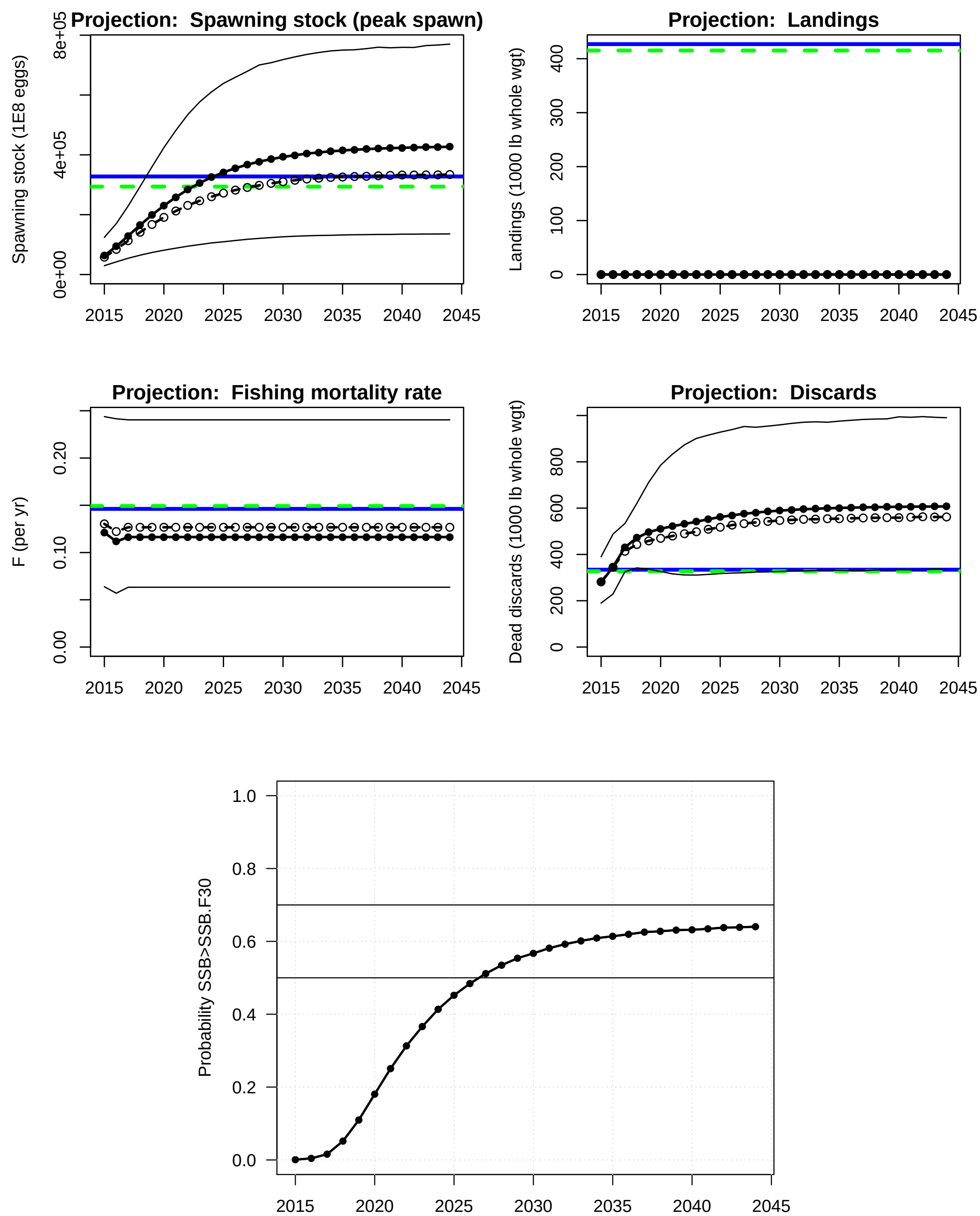


Figure 63. Abundance indices observed (obs.) and predicted (pred.) by the ASPIC surplus production model, and observed total removals (100,000 lbs) for South Atlantic red snapper. Comm = commercial, HB = headboat, HB.at.sea = headboat at sea discards, CVID = combined chevron trap-video index.

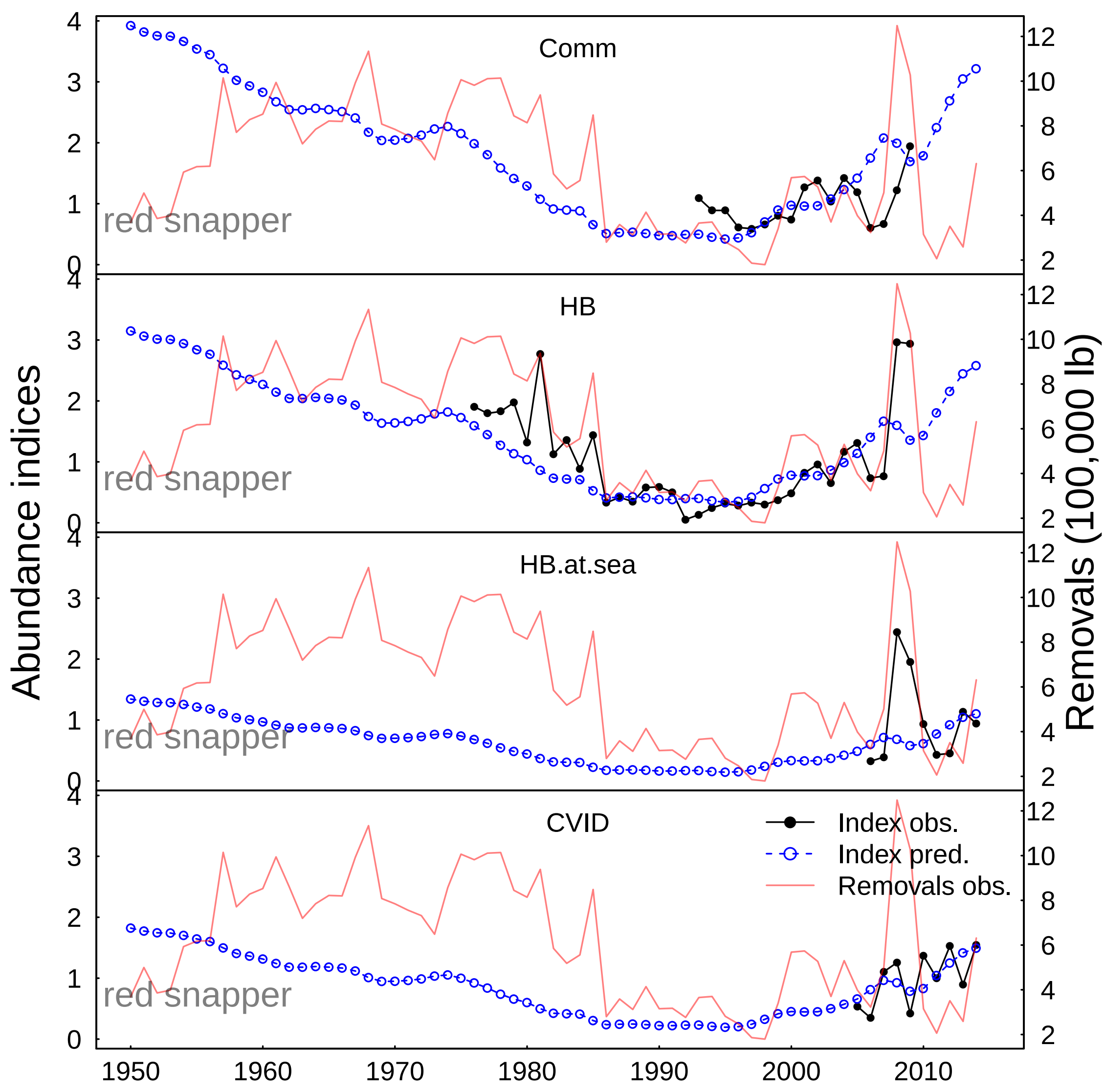


Figure 64. Prior distributions (blue shapes) and estimated parameter values (vertical black lines) for the South Atlantic red snapper ASPIC surplus production model.

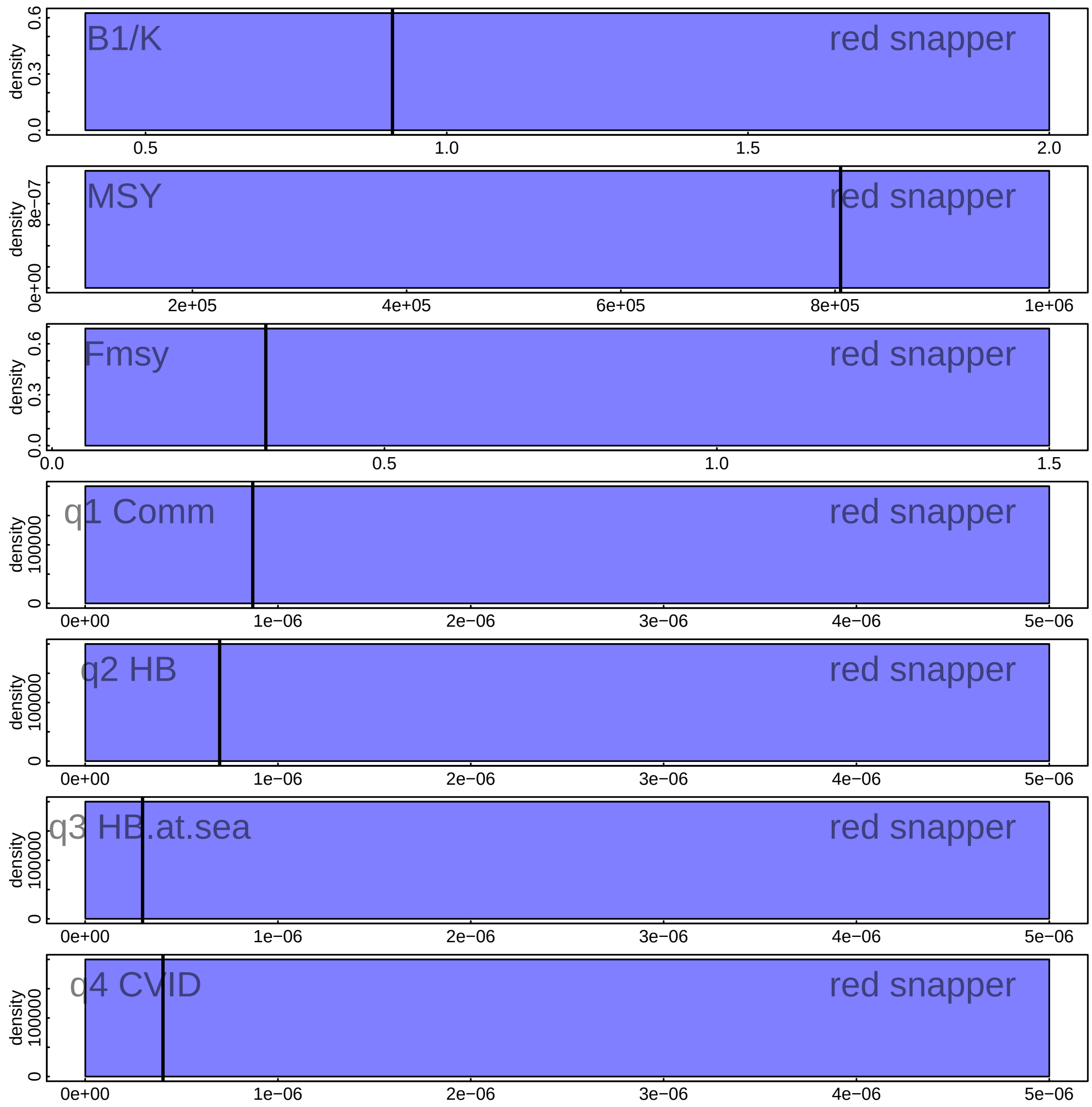


Figure 65. Bootstrap parameter values from ASPIC surplus production model run 320. Thick vertical lines represent ASPIC parameter estimates (solid) and 95% bootstrap percentile confidence intervals (dashed). Thin solid vertical lines are drawn at one in plots of F/F_{MSY} and B/B_{MSY} for reference.

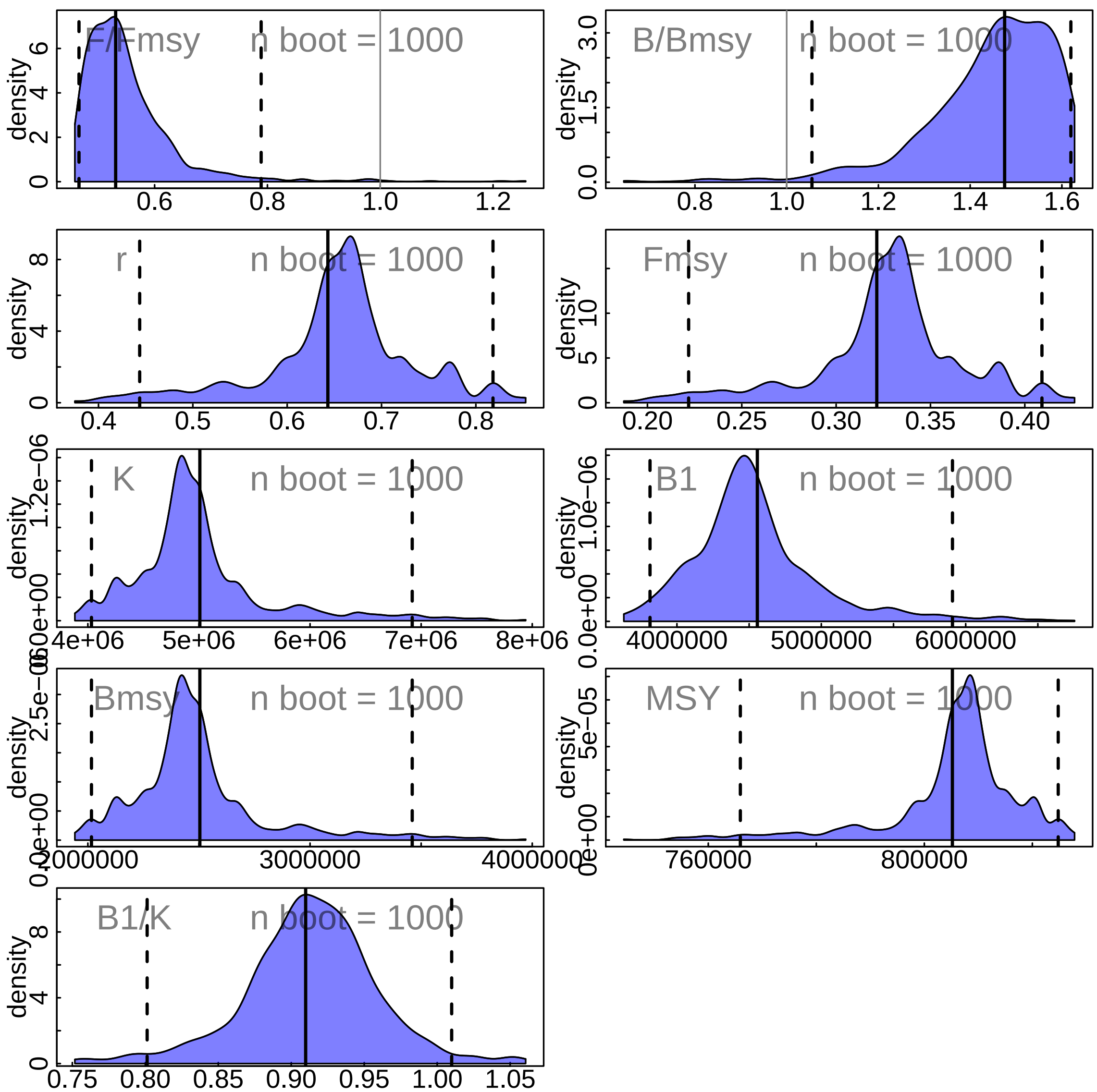
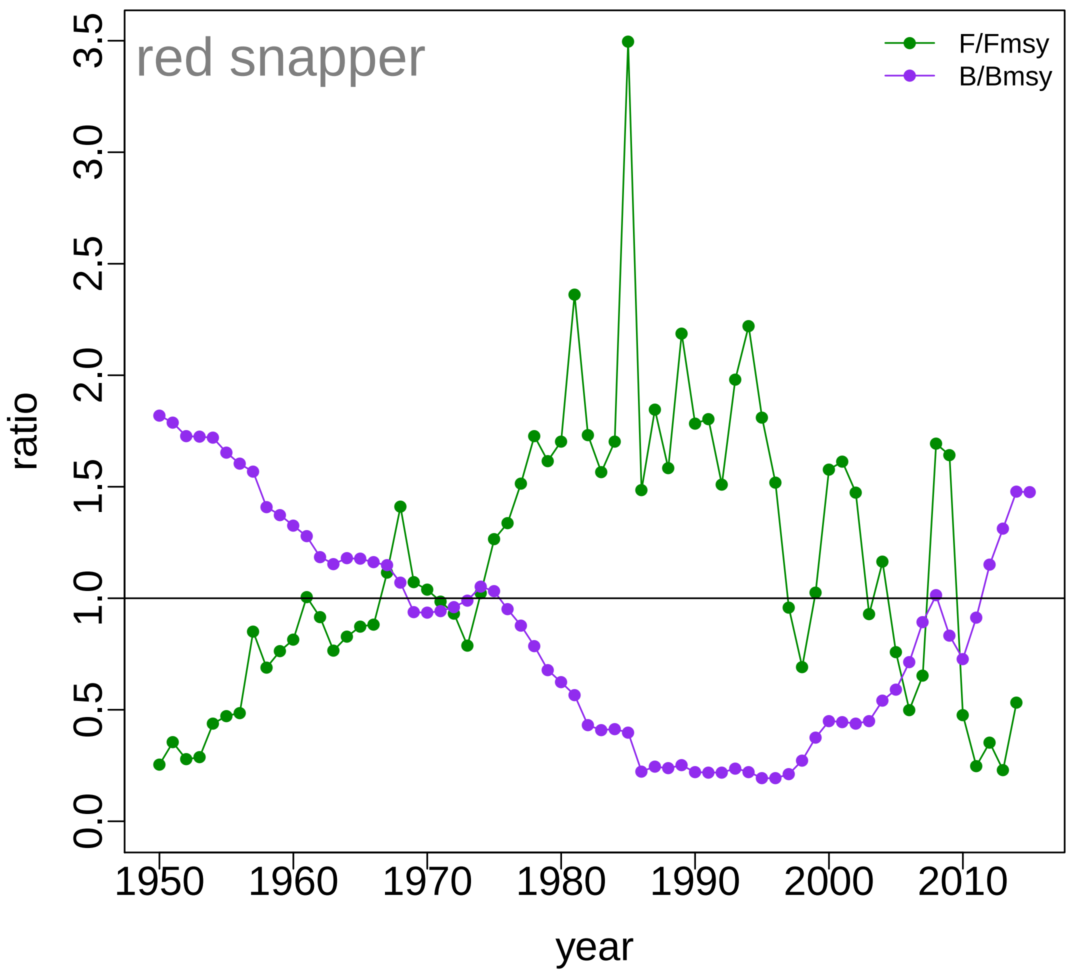


Figure 66. ASPIC surplus production model estimates of relative fishing rate (F/F_{MSY}) and biomass (B/B_{MSY}).



Appendix A Abbreviations and symbols

Table 33. Acronyms and abbreviations used in this report

Symbol	Meaning
ABC	Acceptable Biological Catch
AW	Assessment Workshop (here, for red snapper)
ASY	Average Sustainable Yield
B	Total biomass of stock, conventionally on January 1
BAM	Beaufort Assessment Model (a statistical catch-age formulation)
CPUE	Catch per unit effort; used after adjustment as an index of abundance
CV	Coefficient of variation
CVID	SERFS combined chevron trap and video survey
DW	Data Workshop (here, for red snapper)
F	Instantaneous rate of fishing mortality
$F_{30\%}$	Fishing mortality rate at which $F_{30\%}$ can be attained
F_{MSY}	Fishing mortality rate at which MSY can be attained
FL	State of Florida
FHWAR	The National Survey of Fishing, Hunting, and Wildlife-Associated Recreation Survey
GA	State of Georgia
GLM	Generalized linear model
K	Average size of stock when not exploited by man; carrying capacity
kg	Kilogram(s); 1 kg is about 2.2 lb.
klb	Thousand pounds; thousands of pounds
lb	Pound(s); 1 lb is about 0.454 kg
m	Meter(s); 1 m is about 3.28 feet.
M	Instantaneous rate of natural (non-fishing) mortality
MARMAP	Marine Resources Monitoring, Assessment, and Prediction Program, a fishery-independent data collection program of SCDNR
MCB	Monte Carlo/Bootstrap, an approach to quantifying uncertainty in model results
MFMT	Maximum fishing-mortality threshold; a limit reference point used in U.S. fishery management; often based on F_{MSY}
mm	Millimeter(s); 1 inch = 25.4 mm
MRFSS	Marine Recreational Fisheries Statistics Survey, a data-collection program of NMFS, predecessor of MRIP
MRIP	Marine Recreational Information Program, a data-collection program of NMFS, descended from MRFSS
MSST	Minimum stock-size threshold; a limit reference point used in U.S. fishery management. The SAFMC has defined MSST for red snapper as $(1-M)\mathrm{SSB}_{\mathrm{MSY}} = 0.7\mathrm{SSB}_{\mathrm{MSY}}$.
MSY	Maximum sustainable yield (per year)
mt	Metric ton(s). One mt is 1000 kg, or about 2205 lb.
N	Number of fish in a stock, conventionally on January 1
NC	State of North Carolina
NMFS	National Marine Fisheries Service, same as “NOAA Fisheries Service”
NOAA	National Oceanic and Atmospheric Administration; parent agency of NMFS
OY	Optimum yield; SFA specifies that OY $\leq$ MSY.
PSE	Proportional standard error
R	Recruitment
SAFMC	South Atlantic Fishery Management Council (also, Council)
SC	State of South Carolina
SCDNR	Department of Natural Resources of SC
SDNR	Standard deviation of normalized residuals
SEDAR	SouthEast Data Assessment and Review process
SERFS	Southeast Regional Fishery-independent Sampling
SFA	Sustainable Fisheries Act; the Magnuson–Stevens Act, as amended
SL	Standard length (of a fish)
SRHS	Southeast Region Headboat Survey, conducted by NMFS-Beaufort laboratory
SPR	Spawning potential ratio
SSB	Spawning stock biomass; mature biomass of males and females
$\mathrm{SSB}_{\mathrm{MSY}}$	Level of SSB at which MSY can be attained
$\mathrm{SSB}_{\mathrm{F30\%}}$	Level of SSB at which $F_{30\%}$ can be attained
TIP	Trip Interview Program, a fishery-dependent biodata collection program of NMFS
TL	Total length (of a fish), as opposed to FL (fork length) or SL (standard length)
VPA	Virtual population analysis, an age-structured assessment
WW	Whole weight, as opposed to GW (gutted weight)
yr	Year(s)

Appendix B Parameter estimates from the Beaufort Assessment Model

```
# Number of parameters = 366  Objective function value = -1951.20  Maximum gradient component = 3.74112e-005
# Linf:
911.360000000
# K:
0.240000000000
# t0:
-0.330000000000
# len_cv_val:
0.103911613704
# Linf_L:
927.000000000
# K_L:
0.220000000000
# t0_L:
-0.660000000000
# len_cv_val_L:
0.139090983676
# Linf_20:
938.000000000
# K_20:
0.170000000000
# t0_20:
-2.41000000000
# len_cv_val_20:
0.100000029668
# log_Nage_dev:
 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
# log_R0:
12.6783793044
# steep:
0.990000000000
# rec_sigma:
0.818102531385
# R_autocorr:
0.00000000000
# log_rec_dev:
 0.457537558478 0.177887516656 0.596081349239 -0.430026388392 0.118926982008 1.21016744625 1.41291313014 0.568249030814 -0.160622680087 1.04766572397 0.714977120708 -0.305747974534 -1.45660939739 -1.56722307051
# selpar_A50_cH1:
2.13297154796
# selpar_slope_cH1:
3.88062143991
# selpar_A50_cH2:
3.09105863848
# selpar_slope_cH2:
3.33473916537
# selpar_A50_cH3:
3.08891050864
# selpar_slope_cH3:
2.42510949883
# selpar_A50_HB1:
1.88378267082
# selpar_slope_HB1:
3.54246021238
# selpar_A502_HB1:
3.79838916550
# selpar_slope2_HB1:
0.514619758261
# selpar_A50_HB2:
2.92961195540
# selpar_slope_HB2:
4.07669904945
# selpar_A502_HB2:
1.98351604776
# selpar_slope2_HB2:
0.653233646931
# selpar_A50_HB3:
2.29407884707
# selpar_slope_HB3:
3.37817174161
# selpar_A502_HB3:
2.19260024802
# selpar_slope2_HB3:
0.436836800807
# selpar_A50_GR2:
3.06592361767
# selpar_slope_GR2:
2.70676736368
# selpar_A502_GR2:
3.02073139942
# selpar_slope2_GR2:
0.588080290001
# selpar_A50_GR3:
3.57180467300
# selpar_slope_GR3:
2.08907291585
# selpar_A50_HB2_D:
0.766113358942
# selpar_slope_HB2_D:
0.484983160191
```

```
# selpar_A502_HB2_D:
1.15344665739
# selpar_slope2_HB2_D:
1.55677128989
# selpar_A50_HB3_D:
1.55070623873
# selpar_slope_HB3_D:
0.529401014875
# selpar_A502_HB3_D:
4.08062361079
# selpar_slope2_HB3_D:
0.516121290879
# selpar_A50_cH2_D:
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# selpar_slope_cH2_D:
0.488972548711
# selpar_A502_cH2_D:
1.70477627954
# selpar_slope2_cH2_D:
1.11106174907
# selpar_A50_cH3_D:
2.59513853167
# selpar_slope_cH3_D:
2.13645024460
# selpar_A50_CVT:
1.82586340241
# selpar_slope_CVT:
3.21899177029
# log_q_cH:
-6.33120989517
# log_q_HB:
-11.8810905835
# log_q_HB_D:
-12.8060356742
# log_q_CVT:
-12.2394582969
# M_constant:
0.134000000000
# log_avg_F_cH:
-1.98147518192
# log_F_dev_cH:
 -1.49687584191 -1.18611810279 -1.43746548361 -1.40355079721 -0.994476899346 -1.15200499920 -1.13248446861 -0.489280249664 -0.767142009048 -0.633713965540 -0.545597710092 -0.294220576158 -0.419521117751 -0.63101
# log_avg_F_HB:
-2.47173956726
# log_F_dev_HB:
 -1.32661816356 -1.19747207806 -1.06867014027 -0.953120143952 -0.855016377799 -0.761175117217 -0.638778346766 -0.525604485812 -0.431669732036 -0.341505724094 -0.246872928729 -0.210585614455 -0.164994735575 -0.10
# log_avg_F_GR:
-1.61803667431
# log_F_dev_GR:
 -1.52666935698 -1.39753187965 -1.26877505002 -1.15317139303 -1.05511310010 -0.961286518369 -0.838914340222 -0.725767285047 -0.631839134719 -0.541707815486 -0.447109690682 -0.410859004909 -0.365267028399 -0.3009
# log_avg_F_cH_D:
-3.72256331837
# log_F_dev_cH_D:
 0.292811823207 0.400833551825 0.576381470652 0.950509229335 0.500771663677 0.621339569425 -0.0750482116686 -0.537094562241 -0.542953545333 -0.336159205679 0.527801866279 -0.833215659609 -1.56395787905 0.6616494
# log_avg_F_HB_D:
-5.75855003085
# log_F_dev_HB_D:
 -4.73020931752 -3.72289661565 -4.19441528381 -4.60824727639 -4.22209722560 -4.04857749218 -3.32397085361 -3.16474888643 0.0869964083602 0.809321470525 0.843678532847 1.34886481821 0.329935038360 0.456159709437
# log_avg_F_GR_D:
-2.67216775093
# log_F_dev_GR_D:
 -2.41347222131 -2.48708991382 -3.40703651572 -1.01858950327 -0.450826242458 0.176279486394 -0.634044616253 -0.865374339250 -1.21402434434 -0.366618049618 0.220573093966 -0.587460476786 0.699171684388 0.59639720
# F_init:
0.0295838913167
```

SEDAR 41 Red Snapper: Projection Supplement for SSC's ABC Working Group

Prepared by NMFS Southeast Fisheries Science Center

Draft date: February 27, 2018

The SAFMC's SSC requested additional projections of the Red Snapper stock, based on the SEDAR 41 assessment model, for consideration by the SSC's ABC working group.

Using the most recent estimates of actual landings and discard estimates for all fleets in 2015 and 2016, this document describes the following two scenarios:

Scenario 1 – Yield based on fishing the stock at the Fmsy proxy (30% SPR) with management taking effect in 2017.

Scenario 2 – Yield based on fishing the stock at $F_{rebuild}$ with management taking effect in 2017.

The most complete data available for 2015 and 2016 landings and discards are shown in Table 1. These data were provided by the SEFSC for each fleet (commercial, headboat, and general recreational from MRIP). The commercial data are electronically reported and have not yet gone through the quality control process in each state.

In the Assessment Workshop projections, average selectivities were used to characterize the fish taken for landings and discards from all fleets throughout the projection time period. Here, fleet-specific selectivities were used for landings and discards to calculate fishing mortality by fleet during the interim period (i.e. the period before new management takes effect). Projection results are shown in Figures 1–4, and tabulated in Tables 2–5.

Table 1. Estimates of landings and discards for Red Snapper in the South Atlantic by fleet in 2015.

	Commercial		Headboat		MRIP	
	Landings	Discards	Landings	Discards	Landings	Discards
2015	4,762 lb	31,565 fish	750 fish	54,405 fish	1,111 fish	508,196 fish
2016	4,151 lb	34,568 fish	331 fish	66,511 fish	72 fish	788,460 fish

Table 2. Projection results with fishing mortality rate fixed at F = $F_{30\%}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), B = biomass (mt), S = spawning stock (1E8 eggs), L = landings expressed in numbers (1000s) or whole weight (1000 lb), and D = dead discards expressed in numbers (1000s) or whole weight (1000 lb), pr.rebuild = proportion of stochastic projection replicates with SSB greater than or equal to $SSB_{F30\%}$. The extension .base indicates expected values (deterministic) from the base run; the extension .med indicates median values from the stochastic projections. Highlighted values are those analogous to the fields the SSC has used to set OFL.

year	R.base(1000)	R.med(1000)	F.base	F.med	B.base(mt)	B.med(mt)	S.base(1E8)	S.med(1E8)	L.base(1000)	L.med(1000)	L.base(1000 lb)	L.med(1000 lb)	D.base(1000)	D.med(1000)	D.base(1000 lb)	D.med(1000 lb)	pr.rebuild
2015	432	311	0.3	0.32	1691	1592	58160	53036	2	2	20	15	172	170	644	658	0
2016	435	313	0.46	0.53	1824	1670	69086	59429	1	1	7	7	257	253	1117	1119	0
2017	437	312	0.15	0.15	1657	1454	84145	70062	15	13	144	126	34	30	170	147	0
2018	439	306	0.15	0.15	1936	1696	105898	87154	17	15	177	153	38	33	198	171	0
2019	441	315	0.15	0.15	2200	1941	129158	105405	20	17	207	181	41	36	223	196	0.001
2020	443	314	0.15	0.15	2440	2161	153011	125626	22	20	241	211	43	38	247	219	0.002
2021	444	317	0.15	0.15	2651	2363	176587	145854	24	22	273	240	44	40	266	237	0.009
2022	444	314	0.15	0.15	2830	2537	199019	165155	26	23	300	266	45	41	280	251	0.027
2023	445	314	0.15	0.15	2980	2665	219379	182332	27	25	323	288	46	41	292	262	0.058
2024	445	313	0.15	0.15	3104	2776	237520	197494	28	25	343	306	47	42	301	270	0.099
2025	446	315	0.15	0.15	3206	2868	253248	211409	29	26	359	322	47	42	308	276	0.136
2026	446	319	0.15	0.15	3290	2955	266664	223484	30	27	372	333	47	42	313	282	0.183
2027	446	314	0.15	0.15	3358	3018	278050	233790	30	27	383	343	47	43	317	286	0.225
2028	446	317	0.15	0.15	3414	3082	287470	241562	30	27	391	351	48	43	320	289	0.262
2029	446	316	0.15	0.15	3458	3124	295221	249426	31	28	398	358	48	43	323	292	0.301
2030	446	318	0.15	0.15	3494	3152	301621	255471	31	28	404	364	48	43	325	293	0.33
2031	446	318	0.15	0.15	3523	3176	306819	259335	31	28	409	368	48	43	327	295	0.344
2032	446	320	0.15	0.15	3546	3205	311000	264020	31	28	412	372	48	43	329	297	0.368
2033	446	317	0.15	0.15	3565	3229	314375	267522	31	28	415	375	48	43	330	298	0.383
2034	447	319	0.15	0.15	3580	3258	317080	270558	32	29	418	378	48	44	331	300	0.396
2035	447	319	0.15	0.15	3591	3276	319247	273033	32	29	420	381	48	44	331	301	0.403
2036	447	317	0.15	0.15	3601	3288	320979	276065	32	29	421	383	48	44	332	303	0.416
2037	447	319	0.15	0.15	3608	3303	322356	278529	32	29	422	385	48	44	332	302	0.426
2038	447	320	0.15	0.15	3614	3314	323453	279138	32	29	423	387	48	44	333	302	0.428
2039	447	317	0.15	0.15	3619	3317	324325	279758	32	29	424	388	48	43	333	303	0.431
2040	447	314	0.15	0.15	3623	3316	325018	280540	32	29	425	389	48	43	333	303	0.435
2041	447	318	0.15	0.15	3626	3319	325569	281107	32	29	425	390	48	43	333	303	0.437
2042	447	318	0.15	0.15	3628	3331	326008	282300	32	29	426	389	48	44	333	303	0.441
2043	447	316	0.15	0.15	3630	3323	326356	282074	32	29	426	390	48	44	334	303	0.44
2044	447	316	0.15	0.15	3631	3325	326633	281476	32	29	426	389	48	44	334	303	0.438

Table 3. Projection results with fishing mortality rate fixed at $F = F_{rebuild}$ starting in 2017. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), B = biomass (mt), S = spawning stock (1E8 eggs), L = landings expressed in numbers (1000s) or whole weight (1000 lb), and D = dead discards expressed in numbers (1000s) or whole weight (1000 lb), pr.rebuild = proportion of stochastic projection replicates with SSB greater than or equal to $SSB_{F30\%}$. The extension .base indicates expected values (deterministic) from the base run; the extension .med indicates median values from the stochastic projections. Highlighted values are those analogous to the fields the SSC has used to set ABC.

year	R.base(1000)	R.med(1000)	F.base	F.med	B.base(mt)	B.med(mt)	S.base(1E8)	S.med(1E8)	L.base(1000)	L.med(1000)	L.base(1000 lb)	L.med(1000 lb)	D.base(1000)	D.med(1000)	D.base(1000 lb)	D.med(1000 lb)	pr.rebuild
2015	432	311	0.3	0.32	1691	1592	58160	53036	2	2	20	15	172	170	644	658	0
2016	435	313	0.46	0.53	1824	1670	69086	59429	1	1	7	7	257	253	1117	1119	0
2017	437	312	0.14	0.14	1657	1454	84429	70448	14	12	139	119	33	28	164	138	0
2018	439	306	0.14	0.14	1943	1703	106769	88233	17	14	171	146	36	31	191	162	0
2019	441	315	0.14	0.14	2213	1959	130783	107879	19	16	201	172	39	34	216	186	0.001
2020	443	314	0.14	0.14	2462	2191	155516	128933	21	19	234	202	41	36	239	209	0.003
2021	444	317	0.14	0.14	2679	2410	180062	150545	24	21	266	231	43	38	258	227	0.011
2022	444	314	0.14	0.14	2866	2585	203515	171370	25	22	294	258	44	39	273	241	0.04
2023	445	314	0.14	0.14	3022	2724	224896	190096	27	24	317	280	45	40	284	252	0.078
2024	445	313	0.14	0.14	3153	2851	244027	206555	28	25	336	298	45	40	293	261	0.122
2025	446	315	0.14	0.14	3261	2936	260684	221223	28	25	353	313	45	40	300	266	0.172
2026	446	318	0.14	0.14	3350	3025	274953	234208	29	26	366	325	46	41	305	272	0.226
2027	446	314	0.14	0.14	3422	3097	287111	244764	29	26	377	335	46	41	310	277	0.28
2028	446	317	0.14	0.14	3481	3163	297212	253878	30	27	386	345	46	41	313	280	0.325
2029	446	316	0.14	0.14	3529	3206	305557	261926	30	27	393	351	46	41	316	282	0.355
2030	446	318	0.14	0.14	3568	3237	312476	268501	30	27	399	357	46	41	318	284	0.387
2031	447	318	0.14	0.14	3599	3270	318118	274049	31	27	404	362	46	41	320	285	0.408
2032	447	320	0.14	0.14	3624	3300	322676	278199	31	28	408	366	46	41	322	288	0.425
2033	447	317	0.14	0.14	3644	3321	326369	281477	31	28	411	369	47	42	323	289	0.438
2034	447	319	0.14	0.14	3660	3351	329342	284833	31	28	413	373	47	42	324	291	0.453
2035	447	319	0.14	0.14	3673	3366	331733	287730	31	28	415	375	47	42	324	292	0.468
2036	447	317	0.14	0.14	3684	3382	333651	290349	31	28	417	377	47	42	325	294	0.476
2037	447	320	0.14	0.14	3692	3395	335183	292558	31	28	418	379	47	42	325	294	0.488
2038	447	320	0.14	0.14	3698	3398	336407	294572	31	28	419	382	47	42	326	294	0.496
2039	447	317	0.14	0.14	3704	3400	337385	295413	31	28	420	382	47	42	326	295	0.502
2040	447	314	0.14	0.14	3708	3412	338166	295843	31	28	421	384	47	42	326	295	0.505
2041	447	319	0.14	0.14	3711	3417	338789	296341	31	28	421	385	47	42	327	294	0.507
2042	447	318	0.14	0.14	3714	3418	339286	296755	31	28	422	384	47	42	327	295	0.51
2043	447	316	0.14	0.14	3716	3419	339683	297088	31	28	422	385	47	42	327	294	0.511
2044	447	316	0.14	0.14	3718	3423	340000	297058	31	28	422	384	47	42	327	295	0.511

Figure 1. Projection results under scenario 1—fishing mortality rate at $F = F_{30\%}$ starting in 2017. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $SSB_{F30\%}$.

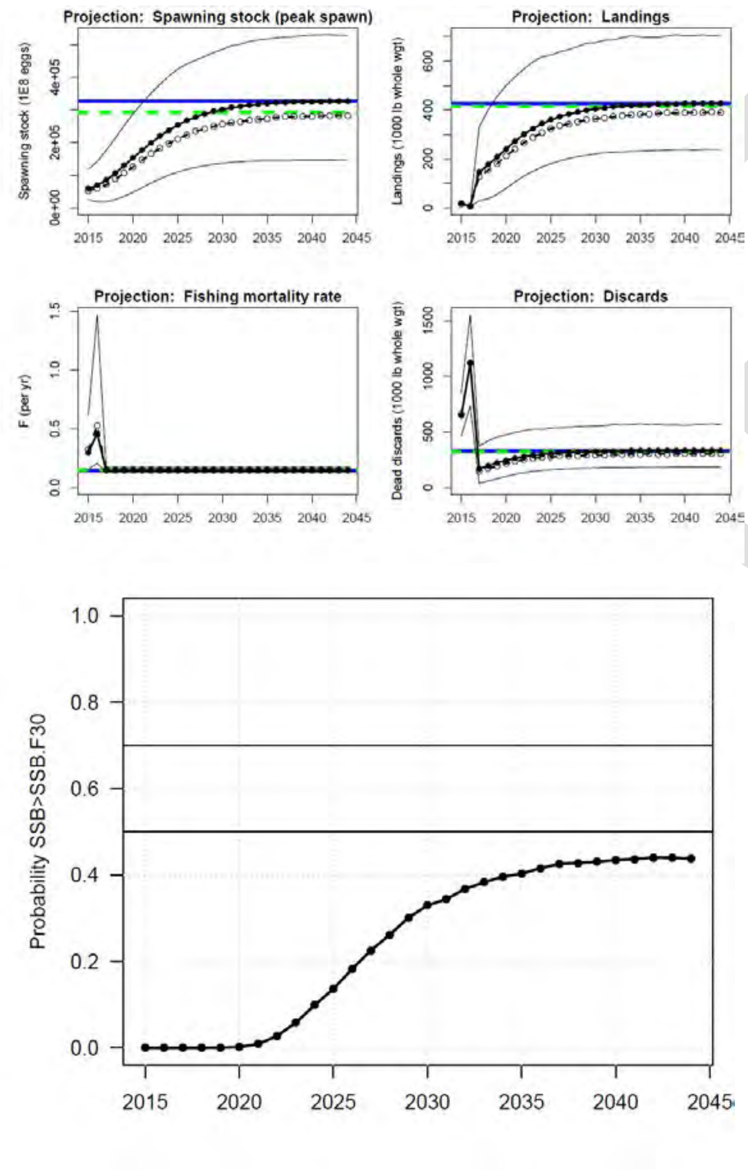
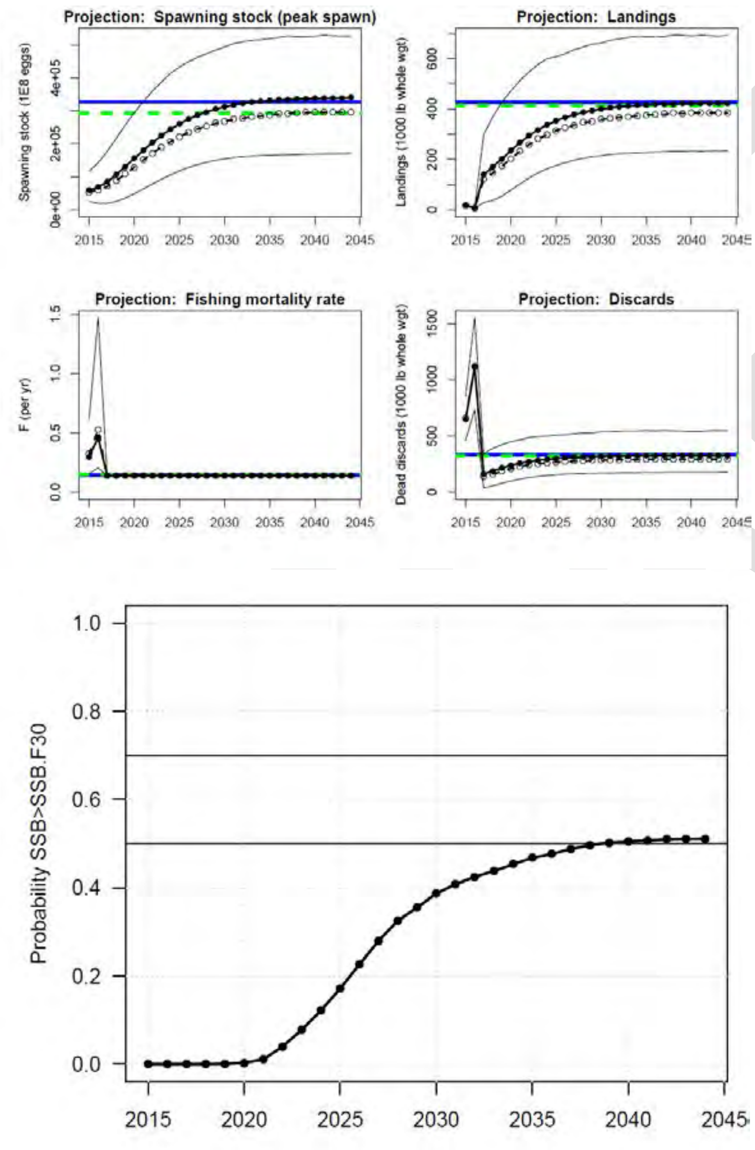


Figure 2. Projection results under scenario 2—fishing mortality rate at $F = F_{rebuild}$ starting in 2017, with rebuilding probability of 0.5 in 2044. In top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{30\%}$-related quantities; dashed horizontal lines represent corresponding medians. Spawning stock (SSB) is at time of peak spawning. In bottom panel, the curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $SSB_{F30\%}$.



Summary of Red Snapper Indices for ABC Subcommittee

ACTION: Assessment of the appropriateness of the indices available for red snapper; do any indices cross MSY or B_{MSY}, have catch at MSY, AND evidence that catch was not negatively impacting stock. Provide a table. - *Genny and Amy*.

Notes:

- No reliable estimate of MSY available. Proxies for MSY and B_{MSY} are landings at $F_{30\%}$ ($L_{F30\%}$) and $B_{F30\%}$, respectively, as in SEDAR 41. MSY proxy= 427 (1,000 lb), B_{MSY} proxy=3,637 mt (SEDAR 41 pdf p. 722)
- Four indices used in final base run (Table 1, Figure 1). Several additional indices considered at data workshop are shown below as well (Table 1).
- Potential time frames for defining reference period of relatively low red snapper exploitation:
    - 1950-1953 when L largely $<L_{F30\%}$ (Figure 2)
    - 1950-1965 when $B>B_{F30\%}$ (Figure 3)
    - 1950-1965, if SSB relative to $SSB_{30\%}$ (327,706 eggs) is also considered as a metric of low impact (Figure 3)
    - 1950-1976 if h=0.84 and SSB relative to $SSB_{30\%}$ is also considered as a metric of low impact (Figure 4). This was also a period of expanded age structure as indicated by headboat landings weight vs. number and estimated biomass at age (Figure 5).
- Conclusion: No individual index covers both an obvious period of low exploitation and recent years. If the mid-70s can be considered a period of light exploitation with relatively low negative impact on stock, generation of a long-term composite index could be explored for use in setting an ABC. However, issues regarding differing selectivities among long-term and recent surveys (e.g. headboat vs. CVID) would need to be resolved.
- Recommendation: No index sufficiently addresses the questions posed above.

Table 1. Summary of available indices. RS=red snapper.

Index	FI or FD	Start Year	Last year with reliable RS catch	Covers period of low exploitation/impact	Used in base run
Headboat[1]	FD	1976	2009	Maybe?	Yes
Headboat discards[1]	FD	2005	present	No	Yes
Handline[1]	FD	1993	2009	No	Yes
CVID[1]	FI	2010	present	No	Yes
SERFS CVT[2]	FI	1990 (2010+ used in assmt. due to expansion of survey)	present	No	No
SERFS VID[2]	FI	2010	present	No	No
Headboat at sea observer[4]	FD	2005/2010	2009/2013	No	No
SC logbook[4]	FD	1993	2013	No	No
MRFSS/MRIP[4]	FD	1982	Present	No	No
Headboat logbook[4]	FD	1995	2009	No	No

1. SEDAR41_SA_RS_SAR_REVISION1_Final_4.24.2017
2. SEDAR41_DW06_Ballenger_etal._RSChevronTrapIndicesWithAddendum_8.19.2014
3. SEDAR41_DW04_Purcell_etal._RSVideoIndex_7.31.2014
4. SEDAR 41. 2014. SEDAR 41 Indices of Abundance Report Cards. SEDAR41-DW39. SEDAR, North Charleston, SC. 75 pp.

Figure 1. From AW Report Addendum II Figure 1 (SEDAR 41 pdf p. 732)

Figure 1. Indices of abundance used in fitting the assessment model. HB indicates the headboat logbook index; Handline indicated the the commercial handline logbook index; HB Disc indicated the headboat discard observer index, CVT indicates the SERFS chevron trap index; VID indicates the SERFS video index, and CVID indicates the combined chevron trap and video index. The CVT and VID indices were only used during sensitivity runs.

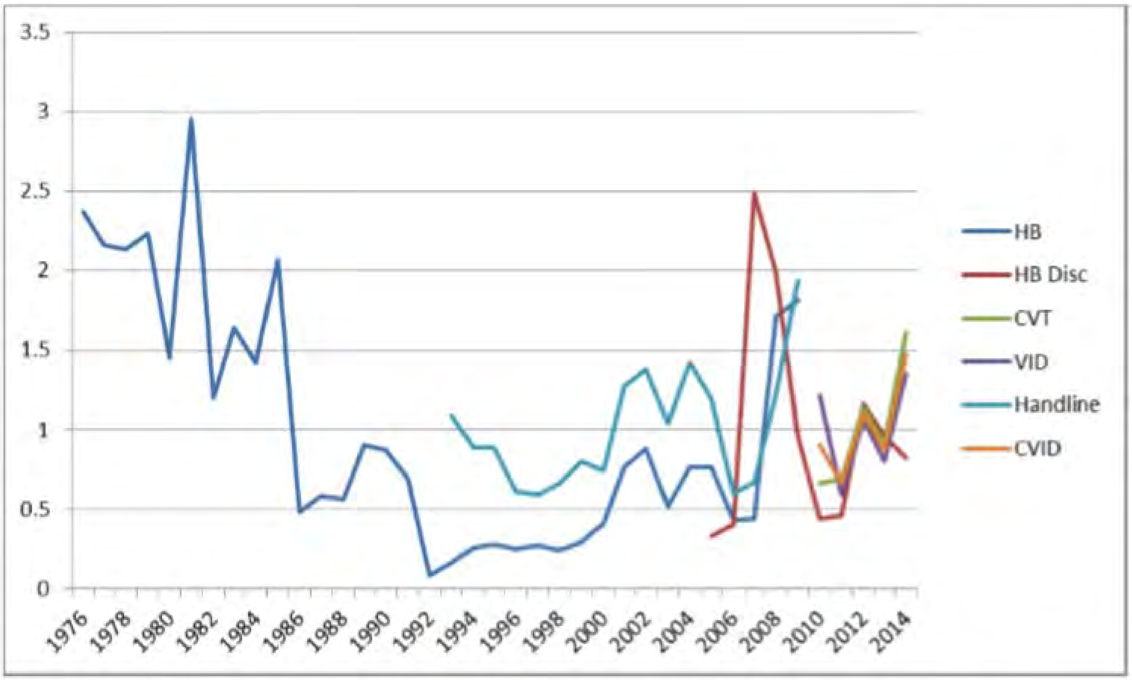


Figure 2. From AW Report Addendum II Figure 28 (SEDAR pdf p. 764)

Figure 28. Estimated landings in numbers by fleet from the catch-age model. cH refers to commercial handlines, HB to headboat, and GR to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of $L_{F30\%}$ in numbers.

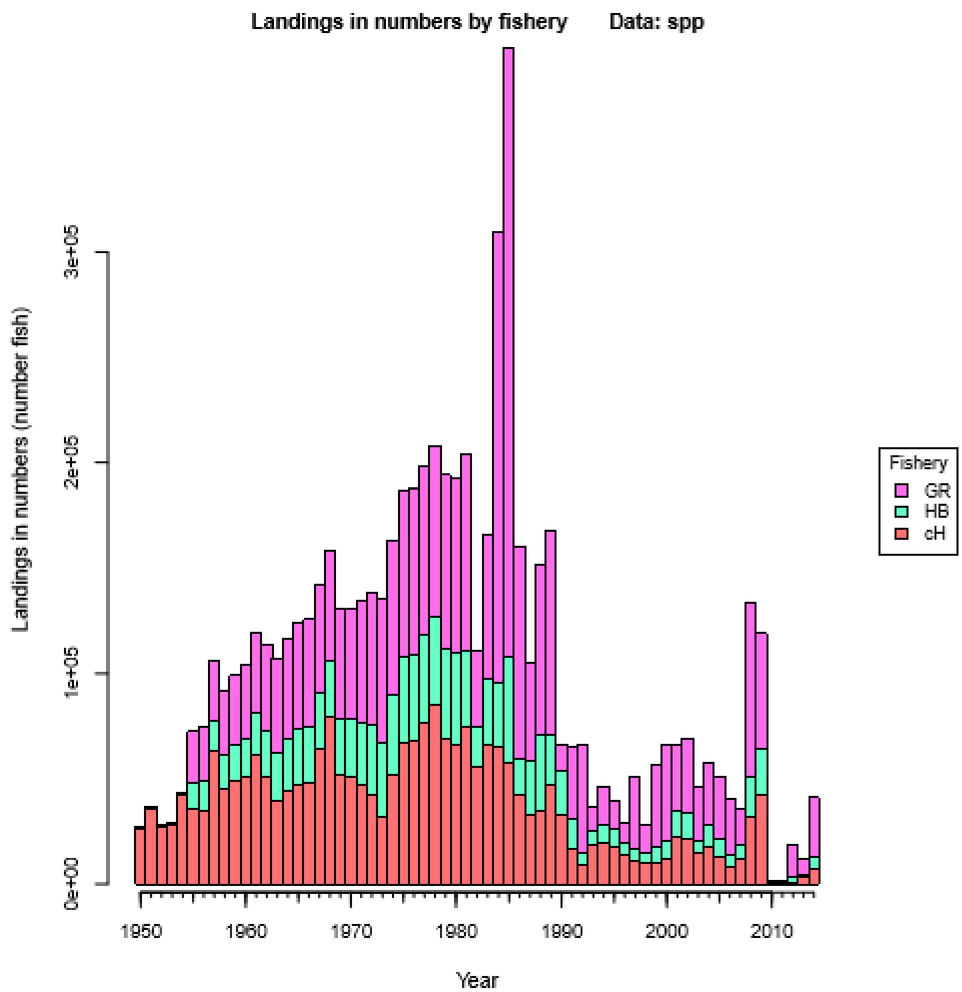


Figure 3. From AW Report Addendum II Figure 17 (SEDAR 41 pdf p. 753)

Figure 17. Top panel: Estimated total biomass (metric tons) at start of year. Horizontal dashed line indicates $B_{F30\%}$. Bottom panel: Estimated spawning stock (population fecundity) at time of peak spawning.

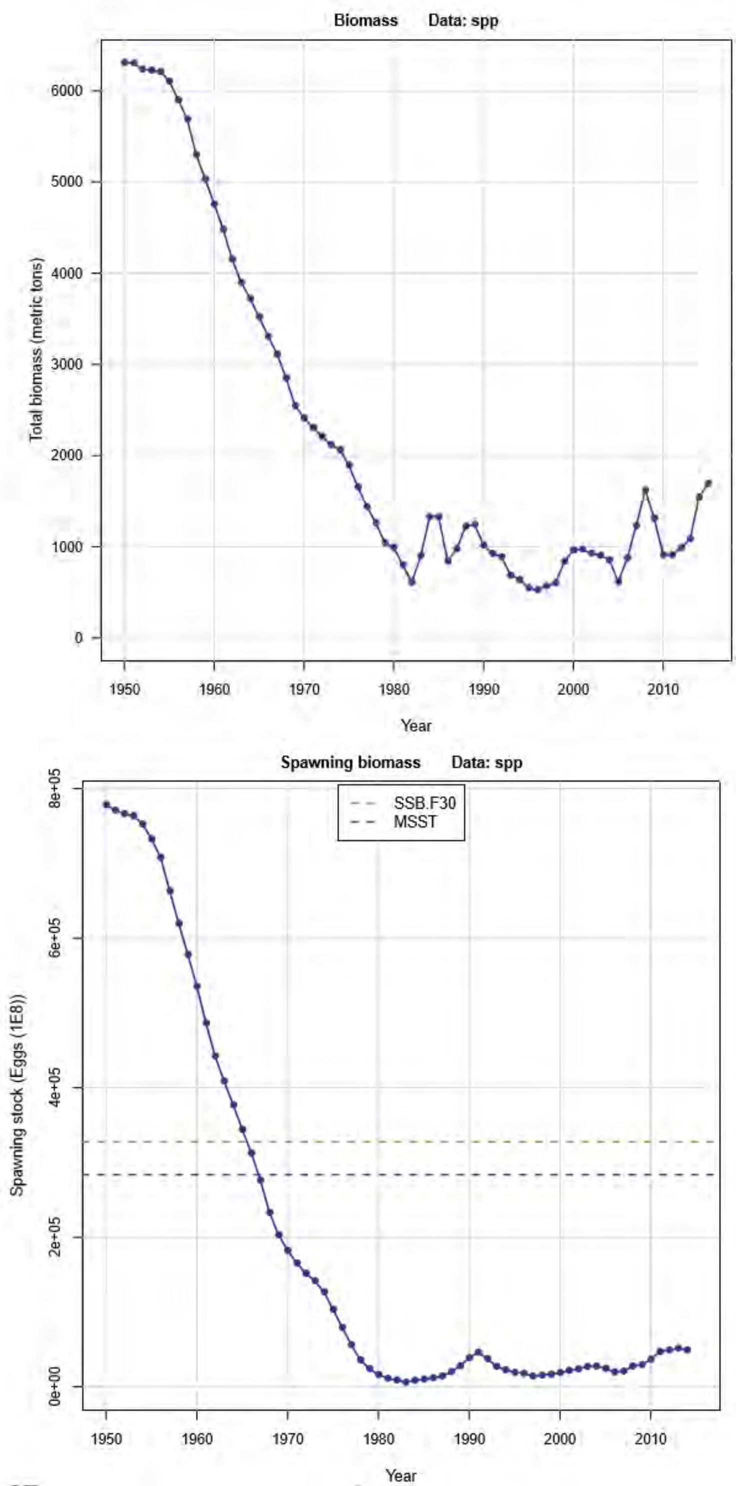


Figure 4. Bottom panel from AW Report Figure 42 (SEDAR pdf p. 778)

Figure 42. Sensitivity to steepness (sensitivity run S11). Top panel: Ratio of F to $F_{30\%}$. Bottom panel: Ratio of SSB *to* $SSB_{F30\%}$.

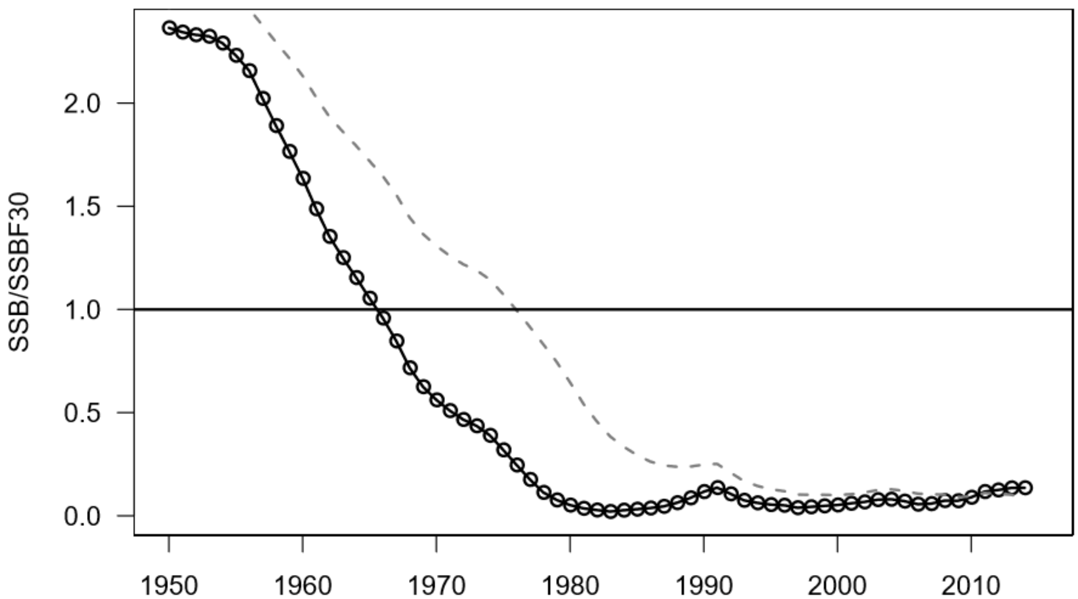


Figure 5. Top panel from DW Report Figure 4.11.3 (SEDAR 41 pdf p. 255); bottom panel from AW Report Addendum II Figure 16 (SEDAR 41 pdf p. 751).

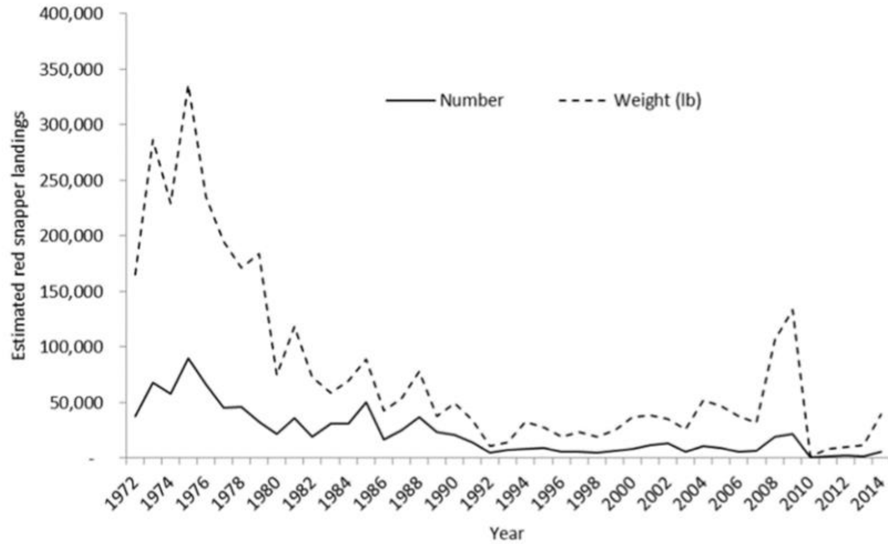
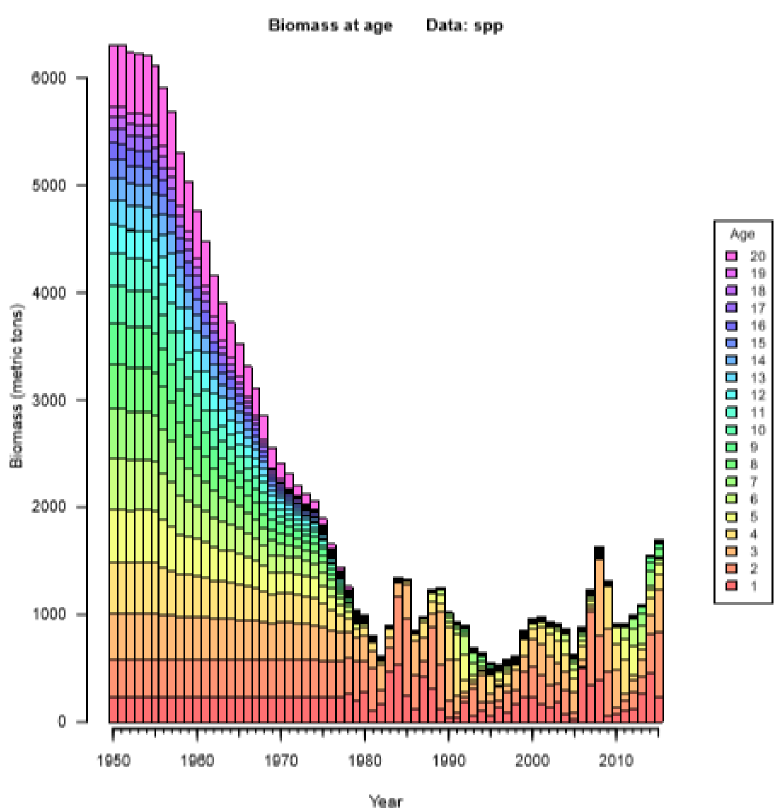


Figure 4.11.3. South Atlantic estimated red snapper landings (number and pounds) for the headboat fishery, 1972-2014.

Figure 16. Estimated biomass at age at start of year.



Standardized video counts of Southeast U.S. Atlantic red snapper (*Lutajanus campechanus*) from the Southeast Reef Fish Survey

Kevin Purcell, Nathan Bacheler, and Lewis Coggins

SEDAR41-DW04

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Standardized video counts of Southeast U.S. Atlantic red snapper (*Lutjanus campechanus*) from the Southeast Reef Fish Survey

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Abstract

Standardized video counts of red snapper were generated from video cameras deployed by the Southeast Reef Fish Survey for 2010 – 2013. Samples between Cape Hatteras, North Carolina, and St. Lucie Inlet, Florida, were included in the analyses. The index is meant to describe population trends for red snapper in the region. A zero-inflated negative binomial model was used to standardize video count data by a variety of predictor variables that could influence abundance and video counts, and a camera calibration study was used to calibrate counts of red snapper between the two cameras used during monitoring.

Background

The Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program has conducted most of the historical fishery-independent sampling in the U.S. South Atlantic (North Carolina to Florida). MARMAP has used a variety of gears over time, but chevron traps are one of the primary gears used to monitor reef fish species and have been deployed since the late 1980s. In 2009, MARMAP began receiving additional funding to monitor reef fish from the SEAMAP-SA program. In 2010, the SouthEast Fishery-Independent Survey (SEFIS) was initiated by NMFS to work collaboratively with MARMAP/SEAMAP-SA using identical methods to collect additional fishery-independent samples in the region. Together, these three programs are now called the Southeast Reef Fish Survey (SERFS). In 2010, video cameras were attached to some traps deployed by SERFS, and beginning in 2011 all traps included video cameras (Figure 1).

The SERFS survey currently samples between Cape Hatteras, North Carolina, and St. Lucie Inlet, Florida. This survey targets hardbottom habitats between approximately 15 and 100 meters deep. SERFS began affixing high-definition video cameras to chevron traps on a limited basis in 2010 (Georgia and Florida only), but since 2011 has attached cameras to all chevron traps as part of their normal monitoring efforts. All four years of data are included here, as recommended by Bacheler and Carmichael (2014; SEDAR41-RD23).

Hard-bottom sampling stations were selected for sampling in one of three ways. First, most sites were randomly selected from the SERFS sampling frame that consisted of approximately 3,000 sampling stations on or very near hard bottom habitat. Second, some stations in the sampling frame were sampled opportunistically even though they were not randomly selected for sampling in a given year. Third, new hard-bottom stations were added during the study period through the use of information from various sources including fishermen, charts, and historical surveys. These new locations were investigated using a vessel echosounder or drop cameras and sampled if hard bottom was detected. Only those new stations landing on hardbottom habitat were included in the analyses. All sampling for this study occurred during daylight hours between April and October on the R/V *Savannah*, R/V *Palmetto*, NOAA Ship

Nancy Foster, or the NOAA Ship *Pisces* using identical methodologies as described below. Samples were intentionally spread out spatially on each cruise (see Figure 2 in Bacheler and Carmichael 2014).

Chevron fish traps with attached video cameras were deployed at each station sampled in our study (Figure 1). Chevron traps were constructed from plastic-coated, galvanized 2-mm diameter wire (mesh size = 3.4 cm2) and measured 1.7 m × 1.5 m × 0.6 m, with a total volume of 0.91 m3. Trap mouth openings were shaped like a teardrop and measured approximately 18 cm wide and 45 cm high. Each trap was baited with 24 menhaden (*Brevoortia* spp.). Traps were typically deployed in groups of six, and each trap in a set was deployed at least 200 m from all other traps to provide some measure of independence between traps. A soak time of 90 minutes was targeted for each trap deployed.

GoPro Hero (2010) or Canon Vixia HFS-200 high-definition video cameras in Gates underwater housings (2011 – 2013) were attached to chevron traps. A second high-definition GoPro Hero video or Nikon Coolpix S210/S220 still camera was attached over the nose of most traps in an underwater housing, and was used to quantify microhabitat features in the opposite direction. Cameras were turned on and set to record before traps were deployed, and were turned off after trap retrieval. Trap-video samples were excluded from our analysis if videos were unreadable for any reason (e.g., too dark, camera out of focus, files corrupt) or the traps did not fish properly (e.g., bouncing or dragging due to waves or current, trap mouth was obstructed).

Relative abundance of reef fish on video was estimated using the MeanCount approach (Conn 2011; Schobernd et al. 2014). MeanCount was calculated as the mean number of individuals of each species over a number of video frames in the video sample. Video reading time was limited to an interval of 20 total minutes, commencing 10 minutes after the trap landed on the bottom to allow time for the trap to settle. One-second snapshots are read every 30 seconds for the 20-minute time interval, totaling 41 snapshots read for each video. The mean number of individuals for each target species in the 41 snapshots is the MeanCount for that species in each video sample. Zero-inflated modeling approaches used below require count data instead of continuous data like MeanCount. Therefore, these analyses used a response variable called SumCount that was simply the sum of all individuals seen across all video frames. SumCount and MeanCount track exactly linearly with one another when the same numbers of video frames are used in their calculation. Therefore, SumCount values were only used from videos where 41 frames were read (~99% of all samples).

SERFS employs video readers to count fish on videos. There was an extensive training period for each video reader, and all videos from new readers are re-read by fish video reading experts until they are very high quality. After that point, 10% or 15 videos (whichever is larger) are re-read annually by fish video reading experts. Video readers also quantify microhabitat features (i.e., percent of bottom that is hardbottom, maximum substrate relief, substrate size, coverage of attached biota, predominant biotic type, and maximum biotic height), in order to standardize for habitat types sampled over time. Water clarity was also scored for each sample as poor, fair, or good. If bottom substrate could not be seen, then water clarity was considered poor, and if bottom habitat could be seen but the horizon was not visible, water clarity was considered fair. If the horizon could be seen in the distance, water clarity was considered to be good. Including water clarity in index models allowed for a standardization of fish counts based on variable water clarities over time and across the study area. A CTD cast was also taken for each simultaneously deployed group of traps, within 2 m of the bottom, and water temperature from these CTD casts was available for standardization models.

Camera calibration

GoPro cameras were used for fish counts in 2010, while Canon cameras were used in 2011 – 2013. To calibrate fish count between these two cameras, side-by-side Canon-GoPro videos were taken during the summer of 2013 and read for red snapper. Additionally, a lab experiment was conducted to quantify differences in field of view between the two cameras. Results indicated the Canon cameras saw 51% of the field of video of GoPro cameras, but the quality of GoPro videos was perhaps slightly lower than that of Canon videos. A total of 15 calibration videos were read that included red snapper. Based on a regression analysis applied to the calibration video results, there were 53% (1 minus the regression slope parameter) fewer red snapper seen on Canon cameras compared to GoPro cameras, which is almost exactly what one would predict based on the reduction of field of view on Canon cameras compared to GoPro cameras (see Figures 7-9 in Bacheler and Carmichael 2014). Therefore, it was recommended that the 2010 relative abundance data point be reduced by 53% to account for differences in viewing areas among the cameras.

Data and Treatment

Data subsetting

Overall, there were 3987 survey videos with red snapper present during the examined 4 year sampling period (2010-2013). We removed any data points in which the survey video was considered unreadable by an analyst, or if the survey point was located in water greater than 100 meters, due to very limited samples in waters deeper than 100 m). Additionally, any survey video for which less than 41 video frames were read was removed from the full data set. Standardizing the number or readable frames for any data point was essential due to our use of SumCount as a response variable (see above). We also identified any video sample in which corresponding predictor variables were missing and removed them from the final data set.

Of the total 3987 video samples considered for inclusion in our modeling analysis, 885 were removed based on the data subsetting approach described above, leaving 3102 samples in the red snapper analyses for 2010 – 2013 (Figure 2).

Standardization

Response Variable

For the video index of red snapper we modeled the SumCount, or total number of red snapper observed across 41 video frames. There were a number of viable candidate response variables applicable for the estimation of abundance from video surveys, the relative merits of which were discussed at length during the video index development workshop (Bacheler and Carmichael 2014). The panel accepted the rational for using MeanCount, or the average number of individuals observed during a video reading, and recommended the use of SumCount as a response variable suitable for a zero-inflated modeling approach. The use of SumCount requires that an equal number of video frames (*n* = 41) be considered for each data point considered in the model estimation.

Explanatory Variables

We considered 9 explanatory variables in our model analysis: year, depth, latitude, water temperature, turbidity, and current direction, all of which were recommended during the video index development workshop (Bacheler and Carmichael 2014). The workshop panel also suggested including habitat variables, for which we included biotic density and substrate composition.

YEAR (*y*) – Year was include because standardized catch rates by year are the objective of this analysis. We modeled data from 2010-2013, noting that data from 2010 was spatially limited due to reduced video deployment during this initial year. Due to the high spatial overlap between the sampled region and the spatial occupancy of red snapper, data from 2010 were included in this analysis. This decision was supported by recommendations from the video index development panel (Bacheler Carmicheal 2014). Annual summaries of data points considered are outlined in Table 2.

SEASON (*t*) – A temporal parameter based on the Julian day the sample was collected (Figure 3). The season parameter is treated as an octile factor based on the recommendations of the video index development workshop.

DEPTH (*d*) – Water depth is a key component affecting the distribution of red snapper, so we considered all data points in waters shallower than 100m. Data points were excluded from deeper waters generally due to limited samples and rare occurrence (Figure 3). Annual depth distribution for survey data are outlined in Table 2.

LATITUDE (*lat*) – The latitudes of video samples were included as a spatial parameter in the model (Figure 3). Based on recommendations made by the video index development workshop, latitude was treated as a factor in the model and divided into 8 levels based on octiles.

TEMPERATURE (*temp*) – bottom water temperature was collected from each station and incorporated as a predictor variable. Bottom water temperature ranged from 12 – 29 degrees Celsius (Figure 3). For the standardization, model temperature was treated as a factor with 4 levels based on quantiles.

TURBIDITY (*wc*) – Due to the effect of turbidity on both species distributions and on the ability of an analyst to process video survey samples, we included water clarity (*wc*) in our standardization model. Turbidity information was recorded during video analysis based on the ability of an analyst to perceive the horizon and surrounding habitat and was scored at 3 levels (0 – Horizon visible, 1 – Habitat but not horizon visible, 2 – Habitat not visible).

CURRENT DIRECTION (*cd*) – A categorical variable estimating current direction based on the video point of view. Current direction data was included to better account for variability in detection due to the current moving fish away or towards the camera. This variable was collected during video processing and scored as a 4-level categorical variable (Towards, Away, Sideways, Unknown) and was incorporated into the model as such.

BIOTIC DENSITY (*bd*) – An estimation of the percent cover of attached biota visible during any video. The estimation is made based on percentage cover and ranged from 0 – 98%. For our analysis *bd* was treated as a categorical variable with 4 levels: none (0%), low (1-9%), moderate (10-39%) and high (>40%).

SUBSTRATE COMPOSITION (sc) – An estimate of the amount of hardbottom in the video viewing area. This variable was treated as a categorical variable with 4 levels: none (0%), low (1-9%), moderate (10-39%) and high (>40%).

Zero-Inflated Model

The recommendation of the video index workshop was to apply a zero-inflated modeling approach to the development of fishery-independent video index for red snapper in the South Atlantic. Zero-inflated models are valuable tools for modeling distributions that do not fit standard error distribution due to excessive number of zeroes. These data distributions are often referred to as "zero-inflated" and are a common condition of count-based ecological data. Zero inflation is considered a special case of over dispersion that is not readily addressed using traditional transformation procedures (Hall 2000). Due to the high proportion of zero counts found in our data set (Figure 4), we used a zero inflated mixed model approach which models the occurrence of zero values using two different processes, a binomial and a count processes (Zuur et al. 2009). The benefit and utility of this approach was discussed at length during the video index workshop (Bacheler and Carmichael 2014) and their use was the final recommendation of the panel.

Initially, a null model (1) was considered employing both a zero-inflated Poisson (ZIP) and a zero-inflated negative binomial (ZINB) formulation.

(1) $$SumCount = y + wc + cd + sc + bd + d + t + lat + temp \mid y + wc + cd + sc + bd + d + t + lat + temp$$

We compared the variance structure of each model formulation using a likelihood ratio test (Zuur et al. 2009) to determine the most appropriate model formulation for the development of a video index for red snapper. The likelihood ratio test (Table 1) showed strong support for application of a ZINB formulation that, in addition to a comparison of model fits for both the ZIP and ZINP formulations (Figure 5), resulted in decision to use a ZINB approach. The results concurred with expectations based on the level of zero-inflation and over dispersion within the original red snapper data and with the recommendations of the video index development panel (Bacheler and Carmichael 2014).

A backwards step-wise model selection procedure was used to exclude unnecessary model parameters from the null model (1) formulation. The optimum red snapper model formulation (2) was determined using a combination of AIC and likelihood ratio tests (Zuur et al. 2009) and excluded water clarity (*wc*) and temperature (*temp*) from the binomial component of the model and excluded both water clarity (*wc*) and season (*t*) from the negative binomial component of the model (Table 3).

(2) $$SumCount = y + cd + sc + bd + d + t + lat \mid y + cd + sc + bd + d + lat + temp$$

Model diagnostics showed no discernable pattern of association between Pearson's residuals and fitted values or the fitted values and the original data (Figure 6). An examination of model residuals for the spatio-temporal (Figure 7) and environmental model parameters (Figure 8) showed no clear patterns of association, indicating correspondence to underlying model assumptions (Zuur et al. 2009). Finally, a comparison of predicted values against the original data distribution (Figure 9) visualizes how our model fits the original data.

All data manipulation and analysis was conducted using R version 3.0.2 (R Core Team 2014). Modeling was executed using the **zeroinfl** function in the **pscl** package (Jackman 2008), available from the Comprehensive R Archive Network (CRAN).

Results

Annual standardized index values for red snapper including coefficient of variation estimates are presented in Table 4. The relative nominal video counts for red snapper differed considerably in comparison to the standardized index with only the 2011 relative nominal value falling within the 2.5% and 97.5% confidence intervals of the standardized index (Figure 10). The nominal value for 2010 (2.30) was considerably higher than the standardized index value for 2010 (1.42), which was expected due to the integration of a camera calibration to the standardized index. Additionally, the standardization index procedure increased estimates of abundance for both the 2012 and 2013 survey years with the relative nominal value falling below and outside of the index confidence intervals. Due to the short temporal extent of this index (4 years), limited inferences can be discerned concerning patterns of red snapper abundance, however the index does indicate an increase in relative video counts since the 2011 survey year and relative stability for the 2012-2013 survey years.

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Table 1: Preliminary model formulation comparison

	df	Likelihood	df	χ^2	*p*-value
ZIP	70	-8513			
ZINB	71	-3753	1	9521.5	<0.001

Table 2: Annual total number of video samples included in the analysis

Year	Number of video samples	Depth range (m)	Latitude range	Date range
2010	218	16-64	28.71-31.74	209-300
2011	624	15-93	27.22-34.54	139-298
2012	1059	15-98	27.22-35.01	115-284
2013	1201	15-92	27.33-35.01	114-277

Table 3: Model selection results for Zero-Inflated Negative Binomial model for red snapper observed during SERFS video surveys, 2010-2013

	Removed Term						
Step	**Binomial Process**	**Count Process**	***df***	**AIC**	**$\chi 2$**	***df***	***p-value***
null	<none>	<none>	71	7647.17			
1	*temp*	<none>	68	7643.01	1.84	3	0.606
2	*temp, wc*	<none>	66	7641.71	2.69	2	0.259
3	*temp, wc*	*wc*	64	7640.60	2.89	2	0.235
4	*temp, wc*	*wc, t*	57	7638.46	11.85	7	0.105

Table 2: The relative nominal SumCount, number of stations sampled, proportion positive, standardized index, and CV for the SERFS red snapper video index

Year	Relative nominal SumCount	N	Proportion positive	Standardized index	CV
2010	2.30	218	0.267	1.42	0.17
2011	0.42	624	0.155	0.57	0.17
2012	0.59	1059	0.206	1.00	0.15
2013	0.66	1201	0.233	0.96	0.11

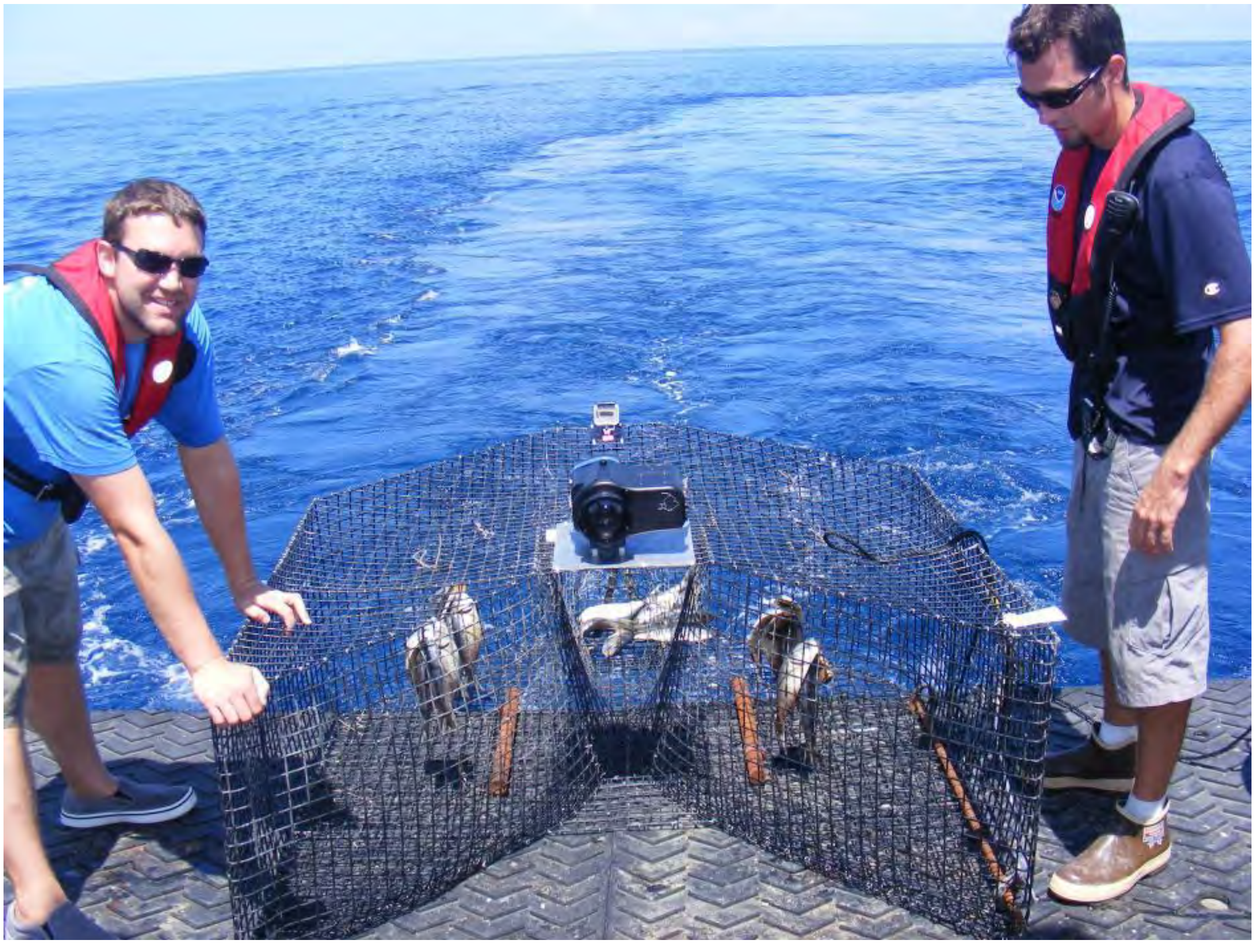

Figure 1: Chevron trap used by SERFS showing the attached underwater video cameras.

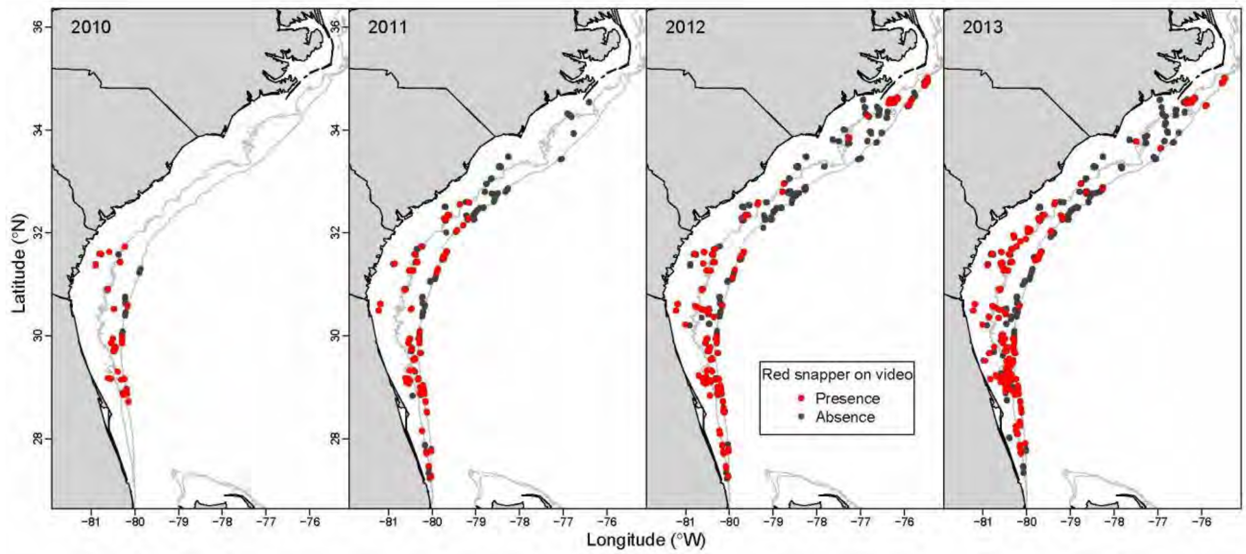

Figure 2: Annual spatial distribution of underwater video samples collected by SERFS in 2010 – 2013. Dark gray points indicate no red snapper were seen on video and red points indicate red snapper were seen on video. Note that red points were overlaid on top of gray points, and points may overlap.

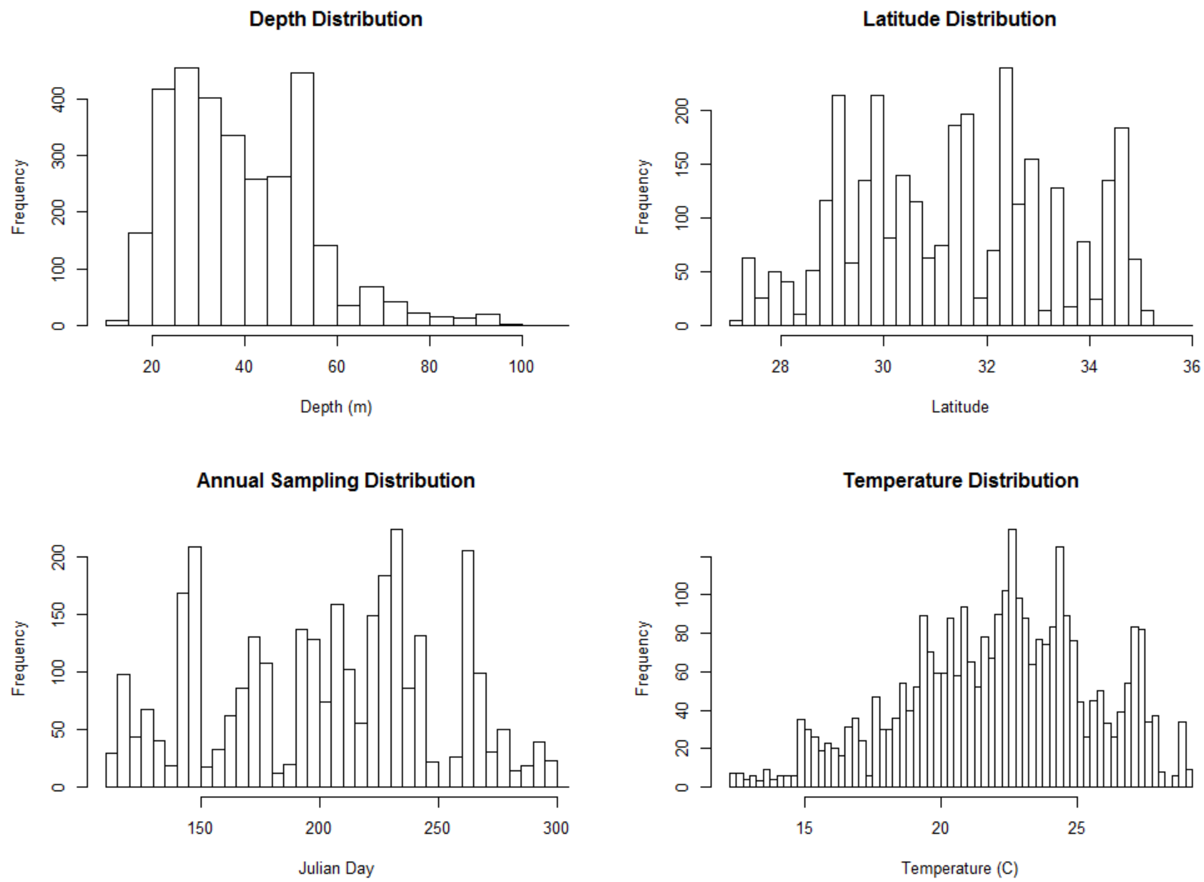

Figure 3: Sample distribution for the original data continuous variables.

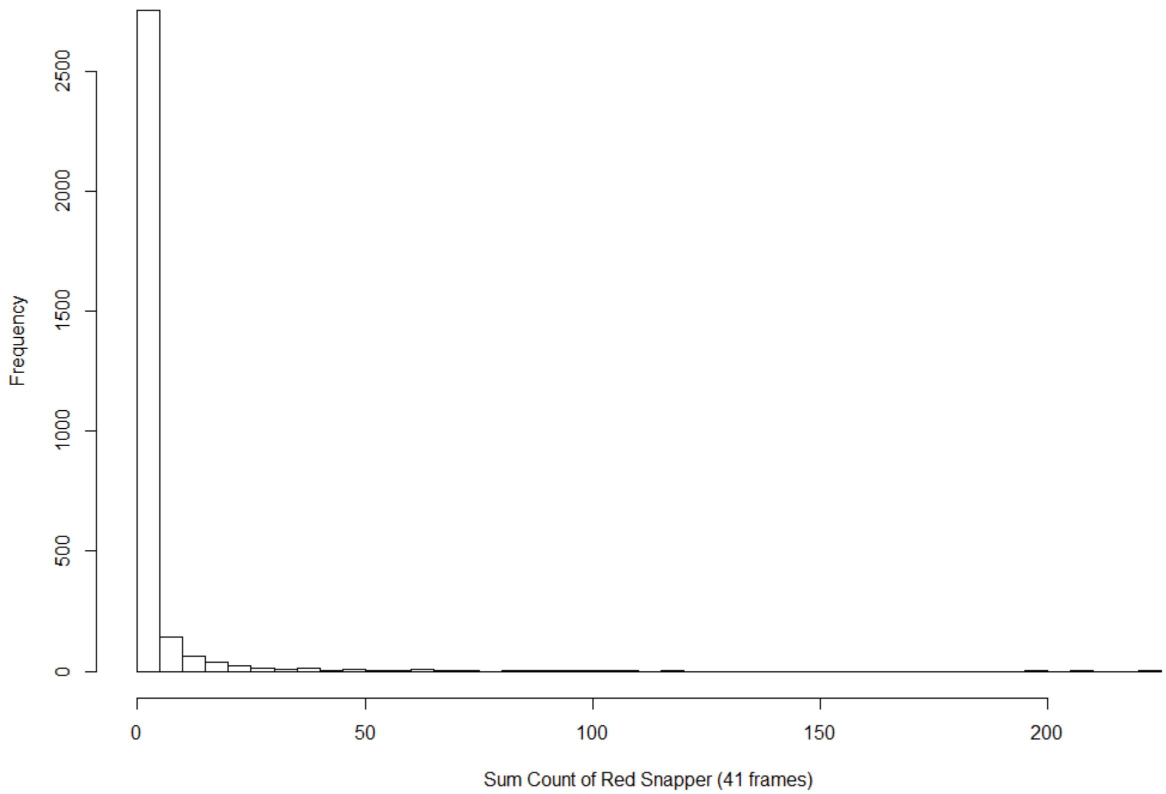

Figure 4: SumCount distribution for red snapper video observations in the South Atlantic.

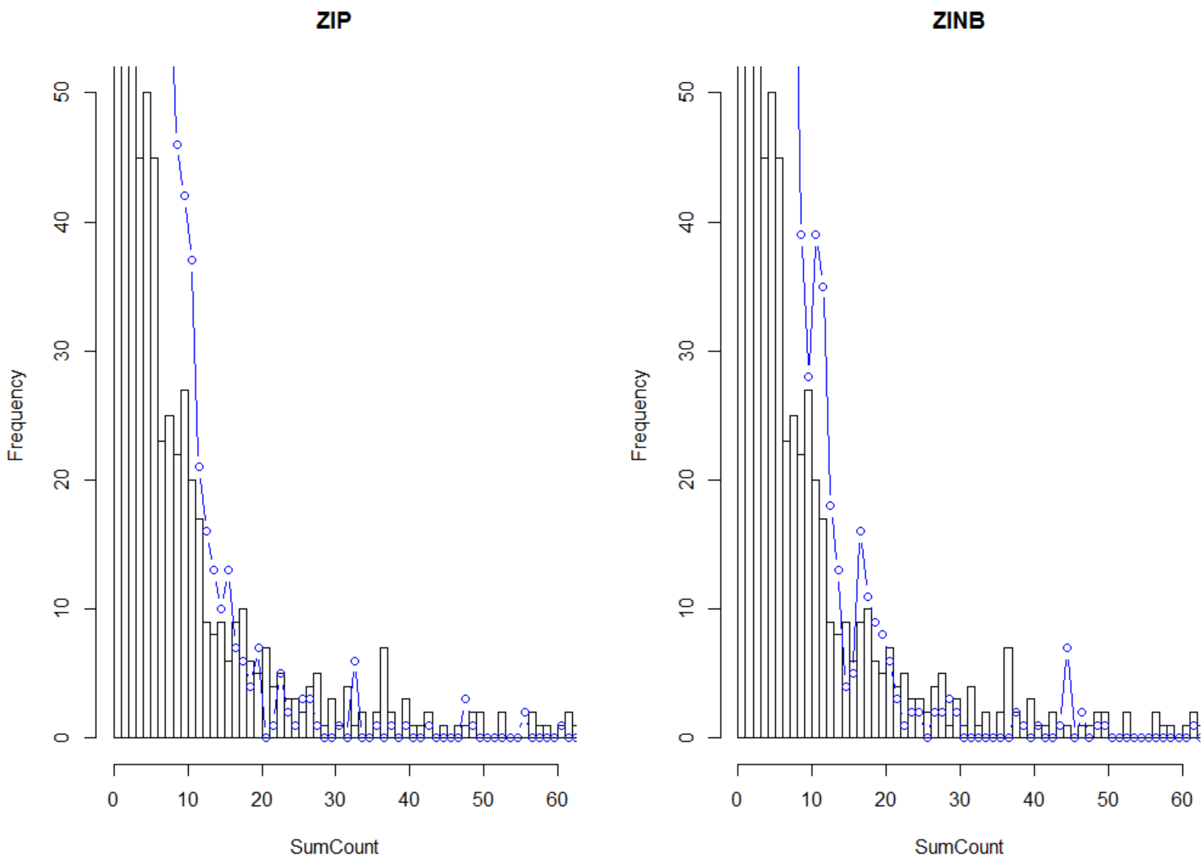

Figure 3: Model formulation comparison, with ZIP (left) and ZINB (right) fitted values plotted against the original data distribution

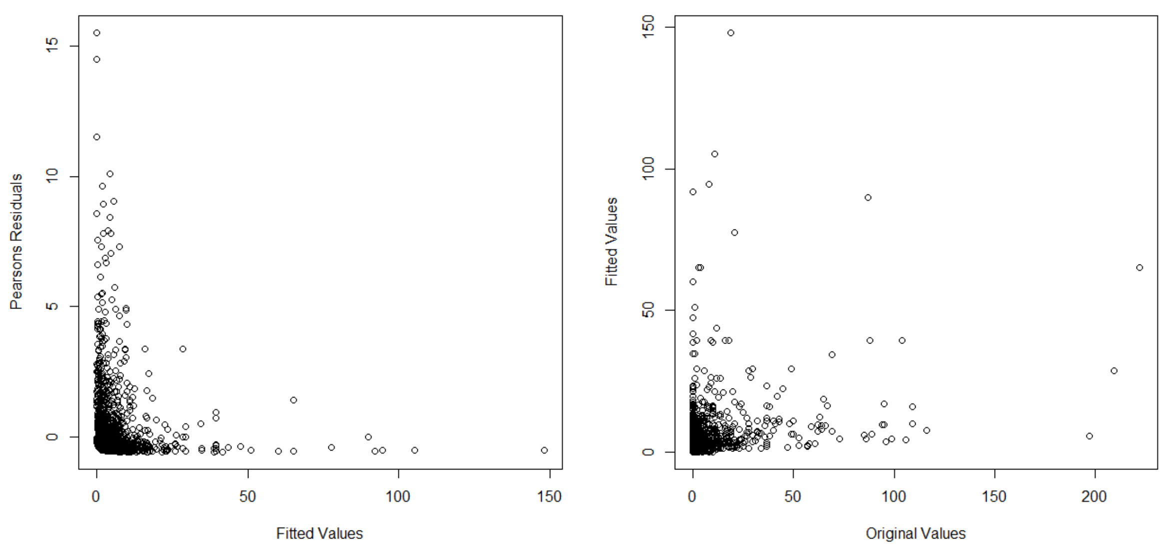

Figure 4: Model diagnostic plots showing fitted model values against Pearson's residuals (left) and fitted values plotted against original data values (right)

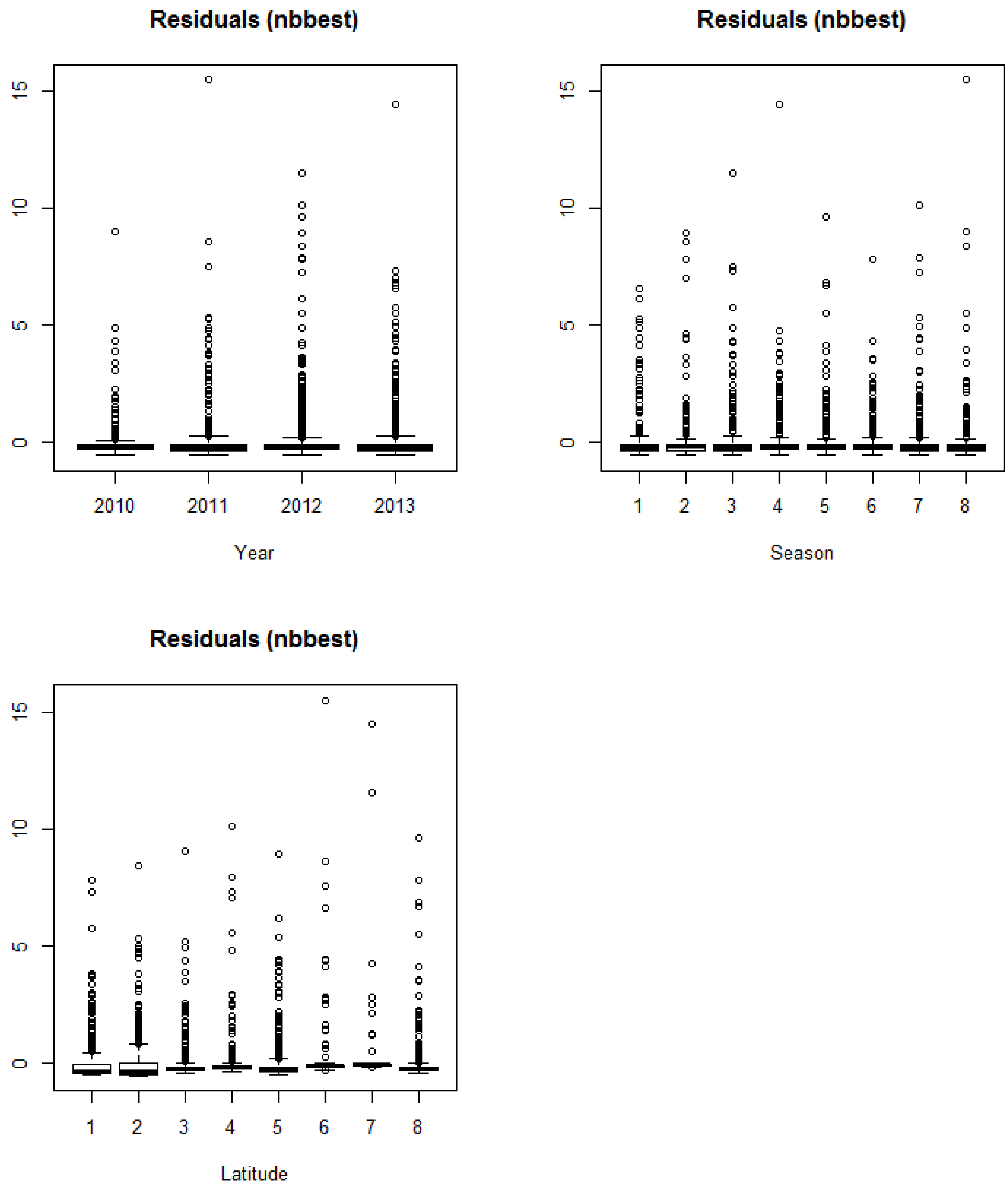

Figure 5: Model diagnostic plots showing Pearson's residuals from the final model plotted against both the temporal and spatial model variables

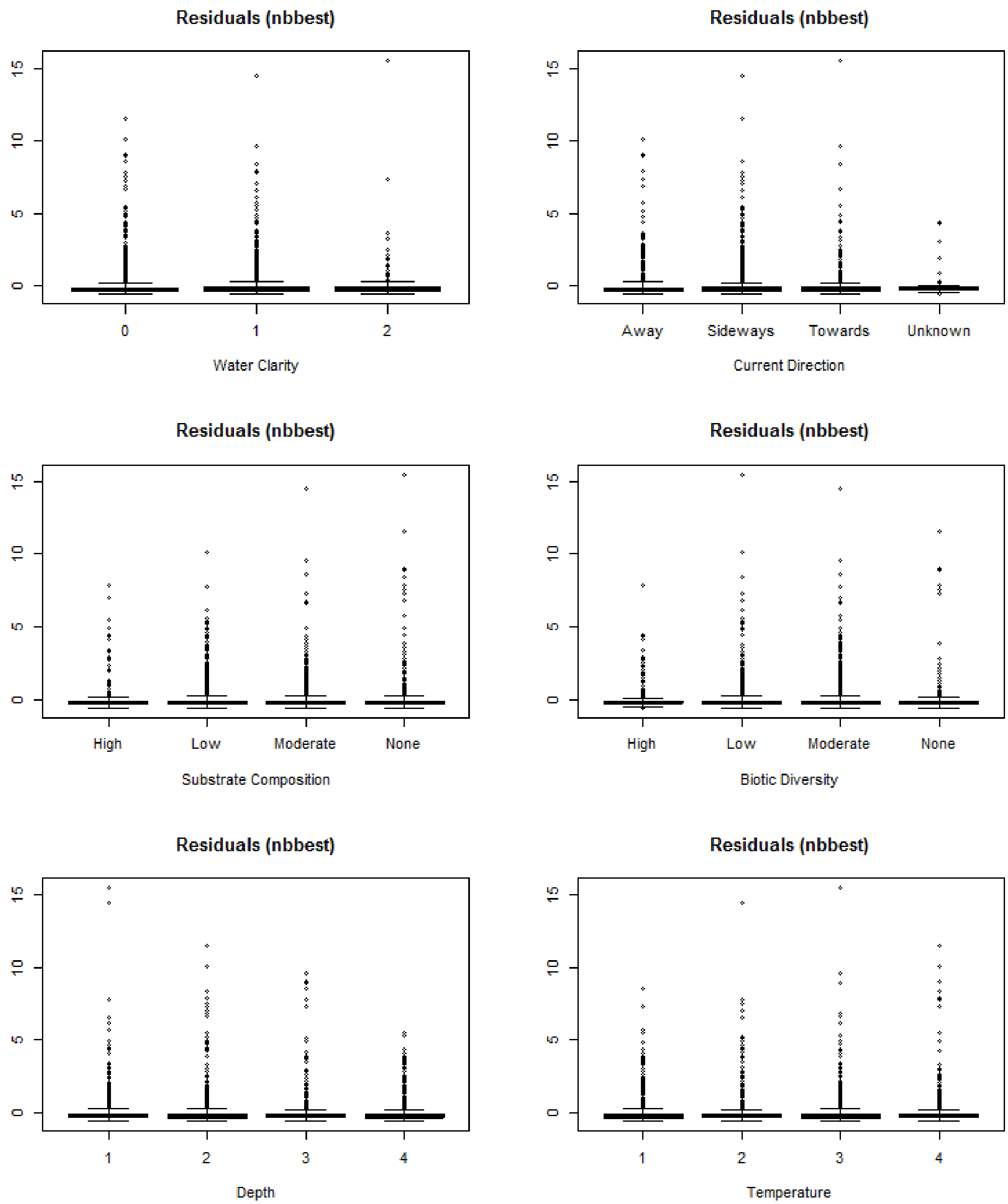

Figure 6: Model diagnostic plots showing Pearson's residuals for the final model plotted against environmental model parameters

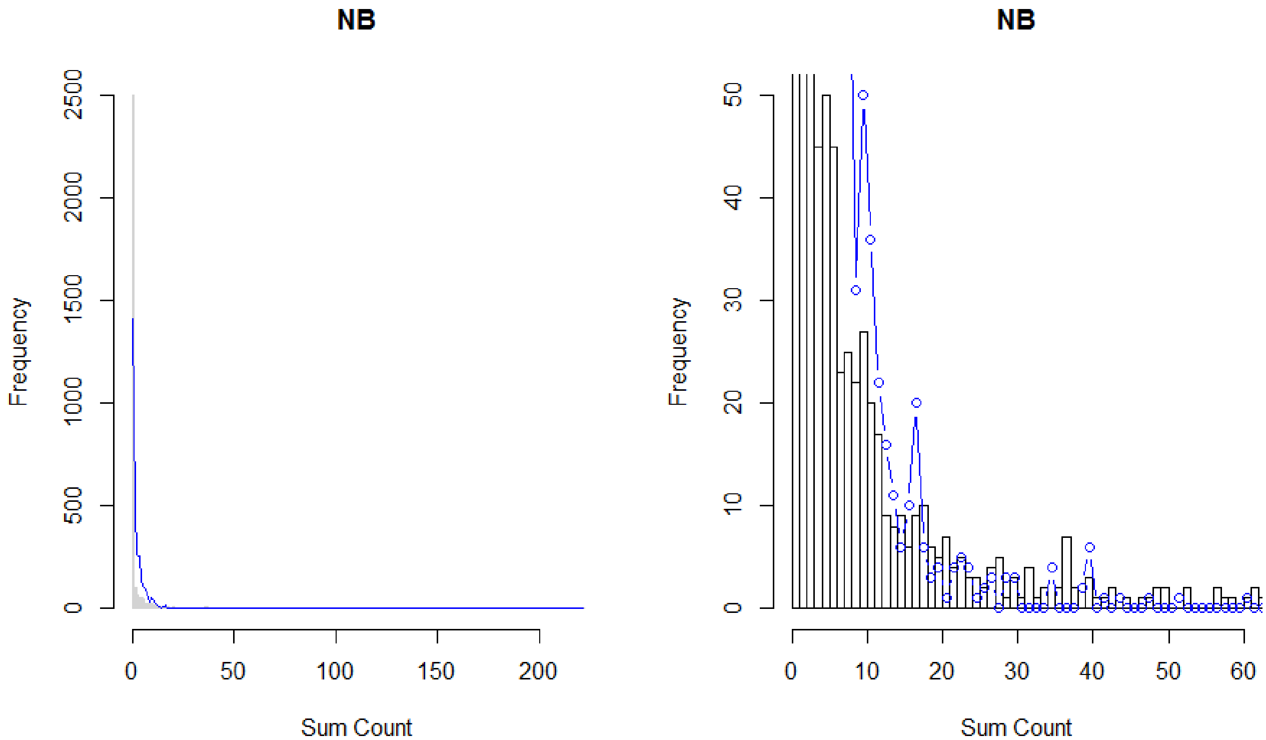

Figure 7: Model diagnostic plots of fitted model values (blue line) against the original data distribution. Full distribution view (left) and limited x-axis view (right)

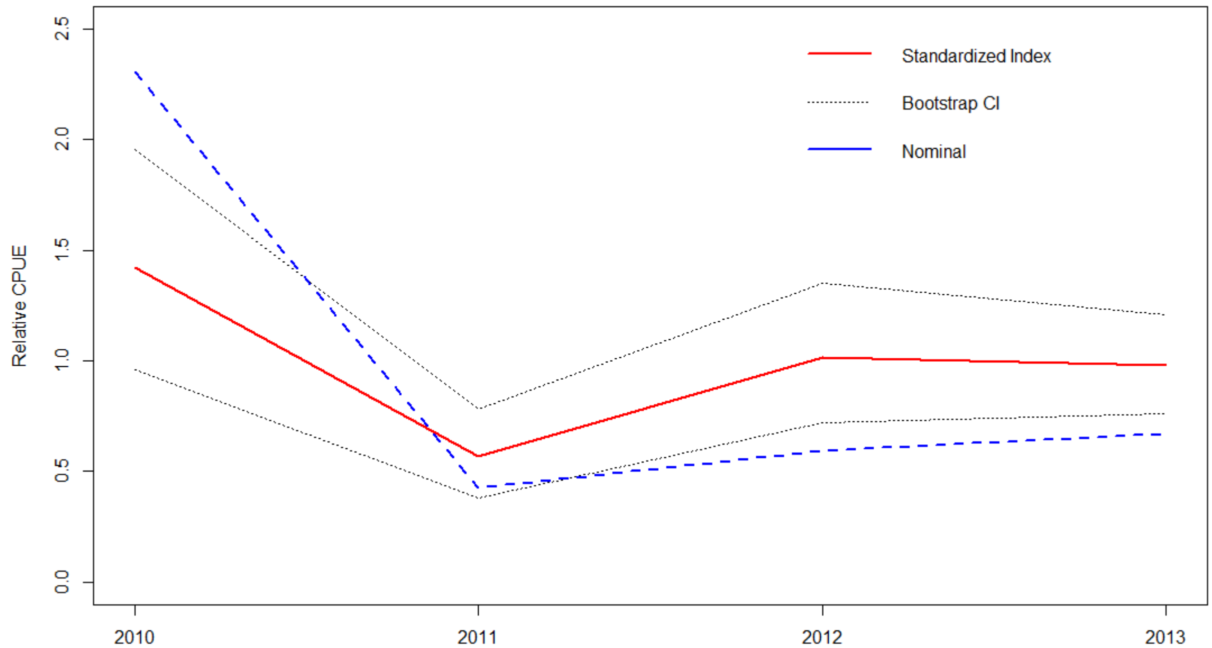

Figure 8: Relative standardized index (solid line) with 2.5% and 97.5% confidence intervals (dashed lines) and the relative nominal index (blue) for red snapper CPUE in the SERFS video survey

Red Snapper Fishery-Independent Indices of Abundance in US South Atlantic Waters Based on a Chevron Trap Survey

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***Addendum added to reflect changes made during Data Workshop.**
Final index is found in the addendum.

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Abstract

Fishery-independent measures of catch and effort with standard gear types and deployment strategies are valuable for monitoring the status of stocks, interpreting fisheries landings data, performing stock assessments, and developing regulations for managing fish resources. This report presents a summary of the fishery-independent monitoring of Red Snapper in the US South Atlantic region and includes data from the three monitoring programs (MARMAP, SEAMAP-SA, and SEFIS, known collectively as SERFS). Specifically, it presents annual nominal catch per unit effort (CPUE) of Red Snapper in chevron traps from 1990 to 2013. Also included are annual CPUE estimates for chevron trap catches from 1990 to 2013 standardized by a delta-generalized linear model (dGLM) and a zero-inflated negative binomial model (ZINB). The standardized models account for the effects of potential covariates that may affect sampling or abundance, other than year of capture, on annual CPUE estimates. We also include length and age compositions for the chevron trap survey to describe selectivity. The ZINB model fit best to observed catches of Red Snapper. Standardized annual CPUE estimates normalized to the series' average indicated that CPUE was highly variable with little trend through the early 2000s, before declining to series' lows in the mid 2000s. Since approximately 2006, CPUE in the region has been increasing generally.

Introduction

Fishery-independent measures of catch and effort with standard gear types and deployment strategies are valuable for monitoring the status of stocks, interpreting fisheries landings data, performing stock assessments, and developing regulations for managing fish resources. Inevitably, tighter management regulations result in fishery-dependent catches reflecting the demographics of a restricted subset of the population, affecting the utility of fishery-dependent data when assessing the current status of the stock. When fisheries are highly regulated, fishery-independent surveys are often the only method available to adequately characterize population size, age and length compositions, and reproductive parameter distributions, all of which are needed to assess the status of stocks. The Marine Resources Monitoring, Assessment and Prediction (MARMAP) program has conducted fishery-independent research on the continental shelf and shelf edge between Cape Hatteras, North Carolina, and St. Lucie, Florida, for over 40 years to provide information for reliable stock assessments and evaluation of management plans. Housed at the Marine Resources Research Institute (MRRI) at the South Carolina Department of Natural Resources (SCDNR), the overall mission of the MARMAP program has been to determine the distributions, relative abundances, and critical habitats of economically and ecologically important fishes of the SAB, and to relate these features to environmental factors and exploitation activities.

Although the MARMAP program has used various gear types and methods of deployment since its inception, the program has strived to use consistent gears and sampling methodologies throughout extended time periods to allow for analyses of long-term changes in relative abundance, age compositions, length frequencies, and other information. As such, the MARMAP program primarily has used a standard sampling methodology with chevron traps for monitoring purposes on known live-bottom habitats since 1990. The focus of this report is on developing an annual catch per unit effort

(CPUE) or abundance index for Red Snapper (*Lutjanus campechanus*) based on chevron trap catches from 1990 to 2013.

Until recently, the MARMAP program was the only long-term fishery-independent program that collected the data necessary to develop indices of relative abundance for species in the South Atlantic Fisheries Management Council's (SAFMC) snapper-grouper species complex. In 2008, with a first field season occurring in 2009, the Southeast Area Monitoring and Assessment Program's South Atlantic component (SEAMAP-SA) provided funding to complement MARMAP efforts. A particular goal of the SEAMAP-SA Reef Fish complement is to assist with the expansion of the geographical sampling coverage of the current fishery-independent surveys, focusing on either shallow or deep potential live-bottom areas. In addition, the SEAMAP-SA complement funding allowed for expanded sampling in marine protected areas (MPAs).

Beginning in 2010, NOAA Fisheries made funding available to create the Southeast Fisheries Independent Survey (SEFIS) program housed at the Southeast Fisheries Science Center (SEFSC) laboratory in Beaufort, NC. This fishery-independent survey was designed to further complement the historical MARMAP/SEAMAP-SA reef fish monitoring efforts, again aimed at extending the geographical range of the surveys. SEFIS activities were coordinated closely with MARMAP/SEAMAP-SA staff, which trained SEFIS personnel and have participated in SEFIS monitoring cruises. SEFIS uses gear and methodologies identical to MARMAP/SEAMAP-SA to maintain the integrity of the long-term data set. In 2011, for logistical and cost savings reasons and since all programs were using identical sampling methods, it was decided that SEFIS vessels would concentrate sampling efforts in waters off Georgia and Florida, while MARMAP/SEAMAP-SA vessels would concentrate efforts off South Carolina and North Carolina. Given the close coordination and consistent sampling methodology used by each of the fishery-independent sampling programs, it is possible to combine catch, effort, and length data collected by each program for chevron traps for the analyses presented in this report (see **Error! Reference source not found.** for gear deployment summary). The combined efforts of MARMAP, SEAMAP-SA Reef Fish Complement, and SEFIS to conduct fishery-independent reef fish monitoring in the US South Atlantic region are now referred to as the Southeast Reef Fish Survey (SERFS).

Objective

This report presents a summary of the fishery-independent monitoring of Red Snapper in the US South Atlantic region and includes data from the three monitoring programs (MARMAP, SEAMAP-SA, and SEFIS, known collectively as SERFS). Specifically, it presents annual nominal catch per unit effort (CPUE) of Red Snapper in chevron traps from 1990 to 2013. Also included are annual CPUE estimates for chevron trap catches from 1990 to 2013 standardized by a delta-generalized linear model (dGLM) and a zero-inflated negative binomial model (ZINB). The standardized models account for the effects of potential covariates that may affect sampling or abundance, other than year of capture, on annual CPUE estimates. Data presented in this report are based on the combined SERFS database accessed in January, 2014 for the dGLM analysis and on July 14, 2014 for the nominal and ZINB analyses, and include data collected through the 2013 sampling season.

Methods

Survey Design and Gear

The standard SERFS sampling area includes waters of the continental shelf and shelf edge between Cape Hatteras, NC, and St. Lucie Inlet, FL, although over the years the majority of sampling has occurred south of Cape Lookout, NC (Figure 1). Throughout this range, we sample stations established on confirmed live bottom (monitoring) from May through September each year, though cruises have occurred prior to and after these months in some years. Traps deployed on suspected live bottom in a given year (reconnaissance) are evaluated based on catch and video or photographic evidence of bottom type for inclusion in the sampling frame the next year.

MARMAP began using chevron traps in 1988 after a commercial fisherman introduced the use of this trap design in the US South Atlantic region (Collins 1990). Subsequently, in 1988 and 1989, chevron traps were used simultaneously with blackfish and Florida Antillean traps to compare the efficiency of the three different trap designs at capturing reef fishes on live-/hard-bottom habitats (Collins 1990). Results indicated that the chevron trap was most effective overall for species of commercial and recreational interest in terms of both total weight and numbers of individuals captured (Collins 1990). Based on these results, the MARMAP program has used chevron traps for reef fish monitoring purposes in the US South Atlantic since 1990, using this single gear to replace both blackfish and Florida Antillean traps. Currently, all three fishery-independent monitoring programs composing SERFS continue to utilize the chevron trap as their primary monitoring gear.

Each year, stations are selected randomly from known live-/hard-bottom stations identified for monitoring via fish traps (low to moderate relief) in that year (currently ~ 3,500 stations are available). Stations are selected randomly in a manner such that no station selected in a given year is closer than 200 m to any other selected station, though the minimum difference typically is closer to 400 m. Chevron traps have been deployed at depths ranging from 13 to 218 m, although the depth of usage generally is less than 100 m. The vast majority of the deeper deployments occurred in 1997.

The chevron trap time series has been continuous from 1990 to present, although the distribution and extent of sampling has changed over time. The spatial coverage of the survey has expanded over the time series as we have added stations and sampling effort in the northern and southern ends of the survey. Figure 1 shows the extent of the survey for all sampling years included in this report and the locations of Red Snapper catches and Table 1 shows changes in the survey with regards to some environmental variables over all years included in this report.

Chevron traps are arrowhead shaped, with a total interior volume of 0.91 m^3 (Figure 2, Collins 1990). Each trap is constructed of 35 x 35 mm square mesh plastic-coated wire (MARMAP 2009). Each trap possesses a single entrance funnel ("horse neck") and release panel to remove the catch (Collins 1990; MARMAP 2009). Prior to deployment each chevron trap is baited with a combination of whole or cut clupeids (*Brevoortia* or *Alosa* spp., family Clupeidae), with *Brevoortia* spp. most often used. Four whole clupeids on each of four stringers are suspended within the trap and approximately 8 clupeids, with their abdomen sliced open, are placed loose in the trap (Collins 1990; MARMAP 2009). An individual trap is attached to an appropriate length of 8 mm (5/16 in) polypropylene line buoyed to the surface using a polyball buoy. We attach a 10 m trailer line to this polyball buoy, with the end of the trailer line clipped to a Hi-Flyer buoy or another polyball. Generally traps are deployed in sets of six when a sufficient number of stations are available in a given area (MARMAP 2009). Traps are retrieved in chronological order of deployment, using a hydraulic pot hauler, after an approximately 90-minute soak time.

Oceanographic Data

While traps are soaking, oceanographic variables (mainly temperature and salinity) are determined using a CTD. Bottom temperature (°C) as used in this report is defined as the temperature of the deepest recording within 5 m of the bottom.

Data and Treatment

Data and Nominal CPUE Estimation

Data available for use in CPUE estimation for each trap (deployment) included a unique collection number, date of deployment, soak time, latitude, longitude, bottom depth, catch code, number of Red Snapper captured, aggregate weight of Red Snapper captured, and bottom temperature, among other variables. We used numbers, instead of weight, of Red Snapper for all analyses. Estimates of CPUE, or relative abundance, are given as the number of Red Snapper caught per trap per hour soak time (dGLM CPUE) or number per trap (nominal CPUE and ZINB CPUE).

Prior to modeling, a subset of the available SERFS trap data was selected for CPUE estimation based on several criteria:

1) Deployments made via SERFS with a project ID of P05 (MARMAP fishery-independent samples), T59 (SEAMAP-SA Reef Fish Complement fishery-independent samples), and T60 (SEFIS fishery-independent samples)
2) Deployments with catch codes of 0 (no catch), 1 (catch with finfish), 2 (catch without finfish), 9 (recon trap deployment), 90 (recon trap deployment with no catch), 91 (recon trap deployment with finfish), and 92 (recon trap deployment without finfish catch)
    a. For development of the dGLM standardized index (i.e. index presented in the 2013 trends report), all 9, 90, 91, and 92 catch codes were removed from analysis
3) Deployments with station codes of “Random” (randomly-selected live-bottom station), “NonRandom” (non-randomly sampled live-bottom station (a.k.a. haphazard sample)), “ReconConv” (reconnaissance deployments that were subsequently converted into live-bottom stations), and “Is Null” (traps for which there is no station code value – the use of station codes is fairly new since 2010. Historically we used only the catch ID to indicate randomly-selected stations)
4) Deployments with Gear ID equal to 324 (chevron traps)
5) Deployments with Data Source not equal to “Tag-MARMAP”
    a. “Tag-MARMAP” represents special historic MARMAP cruises that were used to tag various species of fish. Because standard sampling procedures were not used (e.g.

not all fish were measured for length frequency) these samples are excluded from CPUE development

6) Deployments at depths between 15 and 74 m
    a. Represents the depth range at which 100% of Red Snapper were collected by any gear used in the SERFS (Ballenger et al. 2012b)
    b. Given previous constraints, this removes 248 traps deployed at <15 m or >74 m of depth and 2 traps for which we are missing depth data
7) Soak times outside of a window between 45 and 150 minutes, which generally indicates deviations from standard protocols
    a. Note, SERFS targets a soak time of 90 minutes for all chevron trap deployments
    b. Removes an additional 192 traps with unusually long or short soak times
8) Deployments made since 1990
    a. Removes an additional 178 traps sampled in 1988 and 1989

Delta-Generalized Linear Model (dGLM) CPUE Standardization

In the MARMAP annual trends report, Red Snapper annual CPUE is calculated using a dGLM method. In this method, CPUE is standardized among years using the "delta-GLM" technique described in Lo et al. (1992). Briefly, the standardized CPUE is the product of fitted values from two generalized linear models (GLMs). The first model examines the effects of factors or "covariates" on the presence or absence of a species using the binomial error distribution. As we assume each gear deployment is independent and identical to all other gear deployments, each gear deployment in effect represents a binomial trial with a sample size of one (n=1). In such cases, we refer to the distribution as a Bernoulli distribution, thus our reference to the Bernoulli sub-model or Bernoulli GLM of the delta-GLM in the remainder of this report. By modeling this presence/absence data using the Bernoulli distribution, we assume that the presence/absence data conform to the Bernoulli distribution density function

$$f(y;\pi) = \binom{1}{y} * \pi^y * (1-\pi)^{1-y}.$$

The mean and variance of the Bernoulli distribution are given by

$$E(Y) = \pi \qquad\qquad \mathrm{var}(Y) = \pi * (1-\pi).$$

The second model examines the effects of covariates on the CPUE of positive observations using a second assumed error distribution (e.g. gamma distribution, Gaussian distribution, lognormal distribution, etc.). This model is referred to as the positive GLM or the error distribution identified as "best" modeling the positive data (e.g. gamma sub-model and lognormal sub-model).

In the current report, only the use of the gamma and lognormal distributions were investigated to model the positive data in the dGLM. The gamma distribution is appropriate for use with a continuous response variable *Y* that has positive values (*Y* > 0), and is represented by the probability density function

$$f(y;\mu,\nu) = \frac{1}{\Gamma(\nu)} * \left(\frac{\nu}{\mu}\right)^{\nu} * y^{\nu-1} * e^{\frac{y*\nu}{\mu}} \qquad y > 0 \text{ (Zuur et al. 2009).}$$

Under the gamma distribution, the mean and variance of *Y* are

$$E(Y) = \mu \qquad \mathrm{var}(Y) = \frac{\mu^2}{\nu}.$$

The lognormal distribution is a continuous probability distribution of a response variable *Y* whose logarithm is normally distributed, and is represented by the probability density function

$$f(y;\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} * e^{-\frac{(\ln y-\mu)^2}{2\sigma^2}} \qquad y > 0.$$

Under the lognormal distribution, the mean and variance of *Y* are

$$E(Y) = e^{\mu+\frac{1}{2}\sigma^2} \qquad \mathrm{var}(Y) = \left(e^{\sigma^2} - 1\right) * e^{2\mu+\sigma^2}.$$

Covariates in the initial development of the dGLM CPUE estimates include latitude, depth, bottom temperature, and season. Covariates were defined as categorical variables for this analysis based on the 50% quartiles for distribution of sampling efforts, creating 2 bins for each covariate (Bubley et al. 2014). Selection of the covariates included in the final model (both Bernoulli GLM and positive GLM) was done based on Akaike's information criteria (AIC; Akaike 1973). Year was included as a covariate in both models regardless of the selection outcome based on AIC. Further, we allowed the possibility that different covariates may appear in the Bernoulli GLM and positive GLM. The final dGLM standardized CPUE index is the product of the year effects and any selected covariates from the two models. Coefficients of variation, standard error, and standard deviations were determined by a jackknifing approach.

Zero-Inflated Model CPUE Standardization

CPUE was standardized among years using a zero-inflated count model (ZINB). Given the biological knowledge of Red Snapper and the sampling design of the SERFS chevron trap survey, we compared model fits with the ZINB method to those of the nominal CPUE estimation and dGLM method based on conclusions and recommendations drawn during SEDARs 32 and 36. Investigation of this technique to model CPUE data also was suggested during the Fishery-Independent Survey Independent Review for the South Atlantic (SEFSC 2012). As is the case with many ecological count data sets (Zuur et al. 2009), the observed CPUE data appeared to be zero-inflated based on preliminary analyses (Figure 3), suggesting the appropriateness of zero-inflated count data models.

Briefly, we provide some background information regarding zero-inflated count data models. For a more complete discussion, see Chapter 11 in Zuur et al. (2009). Zeileis et al. (2008) provides a nice overview and comparison of Poisson, negative binomial, and zero-inflated models in R. Some textbooks devoting sections to the discussion of zero-inflated models include Cameron and Trivedi (1998), Hardin and Hilbe (2007), or Hilbe (2007).

The concept of zero inflation derives from the observation that in many ecological, economic, and social studies there are far more zeros in count data than what would be expected for a Poisson or negative binomial distribution. As such, zero inflation means that we have far more zeros than we would expect. Ignoring zero inflation when it exists can have two major consequences, namely the estimated parameters and standard errors may be biased and the excessive number of zeros can cause overdispersion (Zuur et al. 2009).

Zeros due to design and observer errors are called false zeros or false negatives while structural and "animal" zeros are known as positive zeros, true zeros, or true negatives (Zuur et al. 2009). To address these different sources of zeros, two distinctive classes of zero-inflated models have been developed, two-part (hurdle) and mixture models, with the difference between the two classes arising due to differences in how they deal with zeros. Two-part models do not discriminate between the four different types of zeros and simply treat a zero as a zero whereas mixture models account for the type of zero.

Mixture models (zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB)) treat zeros via two different processes: the binomial process and the count process (Zuur et al. 2009). A binomial generalized linear model is used to model the probability of measuring a zero while the count process is modeled by a Poisson or negative binomial GLM. As such, the fundamental difference between hurdle and mixture models is that the count process can produce zeros in mixture models but not in hurdle models (Zuur et al. 2009). In such a setup, the zeros resulting from the count process model represent true zeros, while the binomial GLM models the probability of measuring a false zero versus all other types of data (counts and true zeros; Zuur et al. 2009). In short, the probability functions of a ZINB are:

$$f(y_i = 0) = \pi_i + (1 - \pi_i) * \left(\frac{k}{\mu_i + k}\right)^k$$

$$f(Y_i = y_i | y_i > 0) = (1 - \pi_i) * \frac{\Gamma(y_i + k)}{\Gamma(k) * \Gamma(y_i + 1)} * \left(\frac{k}{\mu_i + k}\right)^k * \left(1 - \frac{k}{\mu_i + k}\right)^k$$

for the binomial component and the non-zero component, respectively. In ZINB, the expected mean and variance are slightly different due to the definition of the probability functions. The mean and variance of a ZINB are:

$$\mathrm{E}(Y_i) = \mu_i * (1 - \pi_i)$$

$$\mathrm{var}(Y_i) = (1 - \pi_i) * \left(\mu_i + \frac{\mu_i^2}{k}\right) + \mu_i^2 * (\pi_i^2 + \pi_i).$$

If the probability of false zeros is 0, the mean and variance of the negative binomial GLM are equal.

In the development of the ZINB CPUE model for Red Snapper, we modeled CPUE as catch per trap, compared to the traditional method of calculating catch per trap per hour. We included soak time as an offset term instead of creating a catch rate by dividing the catch per trap by the soak time or sample duration. By defining this offset variable we adjust for the amount of opportunity for the gear to capture a fish (e.g. a deployment with a soak time of 120 minutes has twice the opportunity than a deployment with a soak time of 60 minutes).

Similar to dGLM, ZINB models can account for effects of different covariates on observed counts. The same or different covariates can be included in the binomial sub-model and catch sub-model. In initial investigations we considered the following covariates in addition to year:

- Depth – continuous variable
- Bottom temperature – continuous variable
- Longitude – continuous variable
- Latitude – continuous variable
- Day of Year (DOY) – continuous variable

Other covariates in the data set that could have been considered included bottom salinity, month, season, dissolved oxygen concentration, chlorophyll-A concentration, nitrite (NO_2) concentration, nitrate (NO_3) concentration, and phosphate (PO_4) concentration. We didn't consider bottom salinity as a potential covariate due to its general lack of variability in oceanic waters and preliminary investigations suggesting there was little relationship between Red Snapper CPUE and bottom salinity. We didn't consider month or season as a covariate as each is correlated to a high degree with our included covariate DOY. Given DOY gives more temporal resolution, the assumption was made that it would provide greater power in standardizing Red Snapper CPUE with regards to within year day of sampling differences. Finally, we didn't consider the last five potential covariates due to missing values on a large number of trap sets data for these variables, primarily due to the lack of equipment to collect these variables historically.

Prior to inclusion of the considered covariates in the full model, we used preliminary analyses to investigate the possibility of collinearity between any of the variables. A pairs plot of continuous covariates revealed high correlation between latitude and longitude (due to the shape of the survey region), and moderate correlation between bottom temperature and depth and bottom temperature and DOY (Figure 4). Variance inflation factor (VIF) estimates for all considered covariates were all <2, though there was some concern regarding the higher VIF for bottom temperature (Table 2). When bottom temperature is excluded, all VIFs fall to <1.2. Given the weak ecological relationships expected between CPUE and the considered covariates, that bottom temperature was moderately correlated with both latitude and depth, and that we are missing bottom temperature data on numerous stations throughout the history of the SERFS due to CTD failure, we removed bottom temperature from consideration as a potential covariate.

Box plots of the remaining covariates (depth, latitude, and DOY) among years showed no obvious strong collinearity (Figure 5). With regards to sampling depth, sampling throughout the entire period appeared fairly homogenous, with the possible exception of 1992. With regards to latitude, it appears there has been a general expansion at two points during the survey, 1996, and 2010 (Figure 1). Most notable is the expansion in 2010, which corresponds to the first sampling season including SEFIS. Since 2010 the median latitude of sampling has shifted south with an overall broader range of sampling.

1999 was slightly anomalous in that the latitude distribution is restricted compared to surrounding years, with it being more similar to the early years of the survey. Finally, for DOY there does seem to be more year to year variability in days sampled. This is to be expected given the nature of the survey and weather constraints. Most notably, sampling appeared to occur earlier than average in 1990 and 1992 and later than average in 1991 and 2010. Also, sampling in 1999 was restricted temporally compared to other years.

Due to the desire to include continuous variables in the zero-inflated standardization model, we used generalized additive models (GAM) to investigate the relationship of continuous covariates with CPUE. We investigated two sets of GAMs, one looking at the relationship of continuous covariates to the presence/absence of Red Snapper and one looking at the relationship of continuous covariates to Red Snapper catch.

For the presence/absence GAMs, each of the covariates had a non-linear effect on the presence of Red Snapper (Figure 6 and Table 3). Probability of presence of Red Snapper peaked at depths of 25-70 m, declining at shallower and deeper depths. The decline in presence at depths between 40 and 55 m may be explained by a lack of stations in this depth zone at latitudes where red snapper are commonly found relative to other depths. Probability of presence shows two distinct peaks at latitudes of 28-30^{o}N and >34.5^{o}N, with a smaller peak around 32^{o}N. In general, latitude has a greater effect on probability of capture than the other covariates. Finally, the relationship between DOY and probability of presence is either flat or parabolic with highest probabilities of presence occurring at the beginning and end of the sampling season. These peaks could be driven by low sample sizes near the beginning and end of the sampling seasons.

For the catch GAMs, each of the covariates had a non-linear effect on the catch of Red Snapper (Figure 7 and Table 3). Highest catches of Red Snapper occurred at the shallowest depths, generally declining as depth increases. Highest catches of Red Snapper showed a trimodal peak compared to latitude, with similar peaks at around 28.5°N, 31°N, and 33°N. Finally, Red Snapper catch compared to DOY was fairly flat, except for a slight peak around 275 days.

Based on these GAM analyses, in addition to year, we included the continuous covariates depth, latitude and DOY as polynomials in the full ZI model to allow for non-linear effects of these covariates on Red Snapper CPUE. To determine the order of the polynomials, we rounded the GAM effective degrees of freedom (Table 3) to the nearest whole number, letting this number represent the highest polynomial order. Prior to model development, these continuous variables were centered and scaled to improve statistical convergence.

Selection of the covariates included in the final model (both zero-inflation and count sub-models) was done based on Bayesian information criterion (BIC; Schwarz 1978). We allowed the possibility that different covariates may appear in each of the sub-models. All analyses were performed in R (Version 3.1.0; R Development Core Team 2014). The zero-inflated models in R were developed using the function zeroinfl available in the package *pscl* (Jackman 2011; Zeileis et al. 2008).

Chevron Trap Length and Age Composition

Red Snapper lengths were measured following retrieval of each chevron trap set to the nearest centimeter prior to 2010 and to the nearest millimeter from 2010 to 2013. Lengths were measured either as fork length or maximum (pinched) total length at the time of capture. Here, we report length in maximum (pinched) total length and any fork lengths were converted to such based on conversions developed by Ballenger et al. (2012b) from over 1,700 fish. All measurements done in mm were rounded to the nearest whole cm prior to analysis. Length percent compositions were calculated for each year using 1-cm length bins centered on the integer. Although the resolution of the majority of the time series and all analyses were done in cm, length compositions are presented in mm to be consistent with other reports, including life history. Following length measurements, sagittal otoliths were removed from all Red Snapper to serve as the aging structure for Red Snapper. Ages presented here are calendar age based on increment counts, estimated increment formation on July 1st, and edge type (White et al. 2010, SEDAR 24-DW14).

Results

Sampling Summary

A data set for analysis was obtained from a query of the SERFS database on July 14, 2014. Given the constraints mentioned above and removing any collections we are missing covariate data (1 station removed because of missing latitude data), from 1990 to 2013 we made 10,664 chevron trap monitoring deployments (Table 1), averaging 444 collections per year (range: 219-1,331), following standard monitoring station sampling protocol. The average depth for these collections was 37 m, with annual averages ranging from 33 to 41 m. The average latitude was 32.10°N, with annual averages ranging from 31.25°N to 32.79°N. The average DOY was 194, with annual averages ranging from 151 to 222 days.

Nominal CPUE

Nominal catch per trap averaged 0.136 for the entire time series, with annual averages ranging from a low of 0.016 in 1996 to a high of 0.367 in 2012 (Table 4 and Figure 8).

Delta-GLM CPUE

Results of the dGLM standardization reported here were initially reported in an annual report of trends in catch of snapper-grouper species (Bubley et al. 2014) and were not updated for this report. These results are presented here purely for comparative purposes, as the authors felt that a newer approach such as the zero-inflated methods would be more appropriate for the Red Snapper data set.

DGLM-standardized CPUE estimates were variable (range: 0.01 – 0.9; Table 4) with no clear directional trend throughout the time series until the last 4 years (Figure 8). Since 2010, the trend was upward, reaching historically high levels in 2013, topping previous series' high levels in 2011 and 2012. The standardization method reduced variability due to sampling differences among years and reduced the extent of recent years' increase in relative abundance compared to the nominal estimates, suggesting that some of the increase in abundance was due to changes in sampling.

Zero-Inflated CPUE

Preliminary model analyses clearly suggested that a zero-inflated negative binomial model (ZINB) was superior to a Poisson GLM, a negative binomial GLM, or zero-inflated Poisson model (ZIP). Both the best-fit Poisson GLM and best-fit negative binomial GLM, with overdispersions of 3.404 and 1.445, respectively, suggested overdispersion remained given these model structures (Table 5). Continued overdispersion despite these model structures suggests the catch data is zero-inflated and likely should be modeled using a zero-inflated model structure. While the overdispersion for the best-fit negative binomial GLM was mild, this model had a hard time converging and was unstable statistically. Comparing the ZIP and ZINB full models, BIC clearly suggested that a negative binomial error structure for the count model was superior to a Poisson error structure (Table 5), likely due to its ability to better account for the dispersion parameter by estimating theta directly in the model.

Step-wise selection using BIC starting with the full model removed a number of covariate polynomials from both the zero-inflation and count sub-models (Table 5). The only constraint on this selection was that the variable "Year" must be retained in the count sub-model of ZINB model. The resulting final model had the following form:

Zero-Inflation Sub-Model

$$\text{Abund}^* = offset(\ln(\text{soak time})) + \text{Depth}^2 + \text{Depth}^7 + \text{Latitude} + \text{Latitude}^2 + \text{Latitude}^3 + \text{Latitude}^4 + \text{Latitude}^6 + \text{Latitude}^8 + \text{DOY} + \text{DOY}^2$$

Count Sub-Model

$$\text{Abund} = offset(\ln(\text{soak time})) + \text{Year} + \text{Depth}^2 + \text{Depth}^3 + \text{Depth}^4 + \text{Depth}^5 + \text{Depth}^6 + \text{Depth}^7 + \text{Depth}^9 + \text{Latitude}^2 + \text{DOY}^3$$

where Abund* represents the catch data transformed to presence/absence data and Abund represents the observed catch data.

Standardized annual CPUE estimates normalized to the series average indicates that CPUE was highly variable with little trend through the early 2000s, before declining to series' lows in the mid 2000s (Figure 9). Since approximately 2006, CPUE in the region has been increasing generally (Figure 9). This is similar to the pattern observed for CPUE estimates based upon the dGLM (Figure 8; Bubley et al. 2014).

Plots of annual variance and coefficient of variation (CV) estimates indicate that 10,000 bootstraps were sufficient for these measures to stabilize (Figure 11). Standardization using the ZINB resulted in annual CV estimates of approximately 45%. Individual year CV estimates ranged from a low of 20% to a high of 138% in 2011 and 2003, respectively (Table 4). Though not directly comparable due to different measures of CPUE used and the different criteria used to include collections in the dGLM, it appears that annual CVs estimated using the ZINB are similar to those estimated using the dGLM standardization (Table 4).

A plot of the observed and predicted number of Red Snapper caught suggests that the ZINB was moderately successful at capturing the observed catch pattern (Figure 11). While the ZINB does a fair job predicting the number of traps that had 0 catch, it does a poor job predicting the number of Red Snapper captured given a trap is positive for Red Snapper. In this case it predicts many more traps would catch only a single Red Snapper than observed. Further, it predicts at most only 3 Red Snapper would be caught in any given trap, though we have observed as many as 28 Red Snapper in an individual trap.

Residual diagnostics suggest that there were some outlier observations in the dataset represented by large Pearson residuals (in excess of 30; Figure 12), though overall there is no strong indication of a pattern in the residuals or heteroscedascity when the residuals are plotted against included covariates (Figures 13 and 14). When Pearson residuals are compared to several potential covariates excluded from the final model (Chlorophyll-A concentration, dissolved oxygen concentration, Event (all traps included in a given trap set), longitude, month, salinity, season, and bottom temperature), first glance suggests there is no strong indication of a pattern to the residuals or heteroscedascity, which indicates that no excluded covariates are critical to the model (Figures 15 and 16). The mean Pearson residuals versus dissolved oxygen and bottom temperature show patterns to the residuals that cause some concern (Figure 16). For dissolved oxygen the long string of mainly negative residuals at higher dissolved oxygen concentrations (Figure 16) suggests that Red Snapper catch may be related to dissolved oxygen concentrations. However, we are missing dissolved oxygen measurements from a large number of stations, particularly in earlier years, making the use of this variable as a covariate difficult. For bottom temperature the mean of the residuals indicate a long string of negative residuals at either end (low temperatures (particularly) and high temperatures; Figure 16) that causes some concern. Finally, looking at the spatial distribution of positive and negative Pearson residuals suggests no obvious spatial patterning of the residuals (Figure 17). The one concern may be the group of negative residuals (blue dots) occurring near the northern end of our sampling range north of about 34^{o}N latitude. This lack of spatial structure to the residuals also is supported by the sample variogram, which doesn't show any indication of spatial correlation in trap catches closer than 10 km to each other (Figure 18).

The final ZINB model suggests highly non-linear relationships among Red Snapper catch and included covariates (depth, latitude, and day of year; Figure 19). For depth, as originally suggested, Red Snapper catch peaks at depths between 35 and 40 m, with smaller peaks around 23 and 55 m. For latitude, we see a generally bimodal distribution with catch peaking at around 28-29^{o}N and then again north of approximately 34.5^{o}N. There is a much smaller peak at around 31.5^{o}N. Finally, DOY tends to have little effect on Red Snapper catch until late in the season, after approximately day 250 when Red Snapper catch tends to increase.

Addendum 1

A Zero-Inflated Model of CPUE of Red Snapper in US South Atlantic Waters Based on Fishery-Independent Chevron Trap Surveys

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This work represents partial fulfillment of the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program contract (NA11NMF4540174) sponsored by the National Marine Fisheries Service (Southeast Fisheries Science Center) and the South Carolina Department of Natural Resources.

Objective

This report presents a summary of the fishery-independent monitoring of gray triggerfish in the US South Atlantic region and includes data from the three monitoring programs (MARMAP, SEAMAP-SA, and SEFIS, known collectively as the Southeast Reef Fish Survey (SERFS)). Specifically, it presents annual catch per unit effort (CPUE) of gray triggerfish from chevron traps. Included here are annual CPUE estimates for chevron trap catches standardized by a zero-inflated statistical model for the years 1990-2013. The zero-inflated model accounts for the effects of potential covariates, other than year of capture, on annual CPUE estimates. Data presented in this report are based on the combined SERFS database accessed on July 14, 2012, and include data collected through the 2013 sampling season. The original report above presents a nominal index, a delta-GLM standardized index, and a zero-inflated standardized index based on the same chevron trap catches. The difference between the two zero-inflated indices presented (original in above report and current model reported here) is how the covariates are treated in the model with the former treating the covariates as continuous variables that are modeled using polynomials in the model and the latter treating the covariates as categorical variables.

Methods

Survey Design and Gear

See the original report above for a description of the sample collection methods

Oceanographic Data

See the original report above for details regarding the collection of oceanographic data via a CTD.

Data and Treatment

Data and Nominal CPUE Estimation

Data available for use in CPUE estimation for each trap (deployment) included a unique collection number, date of deployment, soak time, latitude, longitude, bottom depth, catch code, number of Red Snapper captured, aggregate weight of Red Snapper captured, and bottom temperature, among other variables. We used numbers, instead of weight, of Red Snapper for all analyses. Estimates of CPUE, or relative abundance, are given as the number of Red Snapper caught per trap.

Prior to modeling, a subset of the available SERFS trap data was selected for CPUE estimation based on several criteria:

9) Deployments made via SERFS with a project ID of P05 (MARMAP fishery-independent samples), T59 (SEAMAP-SA Reef Fish Complement fishery-independent samples), and T60 (SEFIS fishery-independent samples)
10) Deployments with catch codes of 0 (no catch), 1 (catch with finfish), 2 (catch without finfish), 9 (recon trap deployment), 90 (recon trap deployment with no catch), 91 (recon trap deployment with finfish), and 92 (recon trap deployment without finfish catch)

    a. For development of the dGLM standardized index (i.e. index presented in the 2013 trends report), all 9, 90, 91, and 92 catch codes were removed from analysis

11) Deployments with station codes of “Random” (randomly-selected live-bottom station), “NonRandom” (non-randomly sampled live-bottom station (a.k.a. haphazard sample)), “ReconConv” (reconnaissance deployments that were subsequently converted into live-bottom stations), and “Is Null” (traps for which there is no station code value – the use of station codes is fairly new since 2010. Historically we used only the catch ID to indicate randomly-selected stations)
12) Deployments with Gear ID equal to 324 (chevron traps)
13) Deployments with Data Source not equal to “Tag-MARMAP”
    a. “Tag-MARMAP” represents special historic MARMAP cruises that were used to tag various species of fish. Because standard sampling procedures were not used (e.g. not all fish were measured for length frequency) these samples are excluded from CPUE development
14) Deployments at depths between 15 and 74 m
    a. Represents the depth range at which 100% of Red Snapper were collected by any gear used in the SERFS (Ballenger et al. 2012b)
    b. Given previous constraints, this removes 248 traps deployed at <15 m or >74 m of depth and 2 traps for which we are missing depth data
15) Soak times outside of a window between 45 and 150 minutes, which generally indicates deviations from standard protocols
    a. Note, SERFS targets a soak time of 90 minutes for all chevron trap deployments
    b. Removes an additional 192 traps with unusually long or short soak times
16) Deployments made since 2010
    a. Removes an additional 6754 traps sampled in 1988-2009 – prior to this period sampling was somewhat limited in the heart of Red Snapper habitat off northern Florida and southern Georgia. Only since has the percent positive samples for Red Snapper in chevron traps exceeded 5%.
    b. Exclusion of early years was made via consensus within the SEDAR 41 Index Working Group and during a SEDAR 41 Data Workshop plenary session.

Zero-Inflated Model CPUE Standardization

CPUE was standardized among years using a zero-inflated count model (ZINB). Given the biological knowledge of Red Snapper and the sampling design of the SERFS chevron trap survey, we compared model fits with the ZINB method to those of the nominal CPUE estimation and dGLM method based on conclusions and recommendations drawn during SEDARs 32 and 36. Investigation of this technique to model CPUE data also was suggested during the Fishery-Independent Survey Independent Review for the South Atlantic (SEFSC 2012). As is the case with many ecological count data sets (Zuur et al. 2009), the observed CPUE data appeared to be zero-inflated based on preliminary analyses (Figure 3), suggesting the appropriateness of zero-inflated count data models.

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Mixture models (zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB)) treat zeros via two different processes: the binomial process and the count process (Zuur et al. 2009). A binomial generalized linear model is used to model the probability of measuring a zero while the count process is modeled by a Poisson or negative binomial GLM. As such, the fundamental difference between hurdle and mixture models is that the count process can produce zeros in mixture models but not in hurdle models (Zuur et al. 2009). In such a setup, the zeros resulting from the count process model represent true zeros, while the binomial GLM models the probability of measuring a false zero versus all other types of data (counts and true zeros; Zuur et al. 2009). In short, the probability functions of a ZINB are:

$$f(y_i = 0) = \pi_i + (1 - \pi_i) * \left(\frac{k}{\mu_i + k}\right)^k$$

$$f(Y_i = y_i | y_i > 0) = (1 - \pi_i) * \frac{\Gamma(y_i + k)}{\Gamma(k) * \Gamma(y_i + 1)} * \left(\frac{k}{\mu_i + k}\right)^k * \left(1 - \frac{k}{\mu_i + k}\right)^k$$

for the binomial component and the non-zero component, respectively. In ZINB, the expected mean and variance are slightly different due to the definition of the probability functions. The mean and variance of a ZINB are:

$$\mathrm{E}(Y_i) = \mu_i * (1 - \pi_i)$$

$$\mathrm{var}(Y_i) = (1-\pi_i) * \left(\mu_i + \frac{\mu_i^2}{k}\right) + \mu_i^2 * \left(\pi_i^2 + \pi_i\right).$$

If the probability of false zeros is 0, the mean and variance of the negative binomial GLM are equal.

In the development of the ZINB CPUE model for Red Snapper, we modeled CPUE as catch per trap, compared to the traditional method of calculating catch per trap per hour. We included soak time as an offset term instead of creating a catch rate by dividing the catch per trap by the soak time or sample duration. By defining this offset variable we adjust for the amount of opportunity for the gear to capture a fish (e.g. a deployment with a soak time of 120 minutes has twice the opportunity than a deployment with a soak time of 60 minutes).

Similar to dGLM, ZINB models can account for effects of different covariates on observed counts. The same or different covariates can be included in the binomial sub-model and catch sub-model. In initial investigations we considered the following covariates in addition to year:

- Depth – categorical variable
- Bottom temperature – categorical variable
- Longitude – categorical variable
- Latitude – categorical variable
- Day of Year (DOY) – categorical variable

Other covariates in the data set that could have been considered included bottom salinity, month, season, dissolved oxygen concentration, chlorophyll-A concentration, nitrite (NO_2) concentration, nitrate (NO_3) concentration, and phosphate (PO_4) concentration. We didn't consider bottom salinity as a potential covariate due to its general lack of variability in oceanic waters and preliminary investigations suggesting there was little relationship between Red Snapper CPUE and bottom salinity. We didn't consider month or season as a covariate as each is correlated to a high degree with our included covariate DOY. Given DOY gives more temporal resolution, the assumption was made that it would provide greater power in standardizing Red Snapper CPUE with regards to within year day of sampling differences. Finally, we didn't consider the last five potential covariates due to missing values on a large number of trap sets data for these variables, primarily due to the lack of equipment to collect these variables historically.

Prior to inclusion of the considered covariates in the full model, we used preliminary analyses to investigate the possibility of collinearity between any of the variables. A pairs plot of continuous covariates revealed high correlation between latitude and longitude (due to the shape of the survey region), and moderate correlation between bottom temperature and depth and bottom temperature and DOY (Figure 4). Variance inflation factor (VIF) estimates for all considered covariates were all <2 (Table 2).

Box plots of the covariates (depth, latitude, bottom temperature, and DOY) among years showed no obvious strong collinearity (Figure 20). With regards to sampling depth, sampling throughout the entire period appeared fairly homogenous. With regards to latitude, it appears that the sampling distribution has been fairly homogenous, though there is a slight indication of more northern sampling in 2012. For bottom temperature, sampling throughout the entire period appeared fairly homogenous. Finally, for DOY while the overall range of DOY sampled annually was similar, there is some indication that the median DOY sampled in 2010 was later than in the other three years.

Due to the desire to inform the binning structure of covariates in the zero-inflated standardization model, we used generalized additive models (GAM) to investigate the relationship of each covariate with CPUE. We investigated two sets of GAMs, one looking at the relationship of continuous covariates to the presence/absence of Red Snapper and one looking at the relationship of continuous covariates to Red Snapper catch.

For the presence/absence GAMs, all covariates except bottom temperature had a non-linear effect on the presence of Red Snapper (Figure 20 and Table 8). Probability of presence of Red Snapper peaked at depths of 25-70 m, declining at shallower and deeper depths. The decline in presence at depths between 40 and 55 m may be explained by a lack of stations in this depth zone at latitudes where red snapper are commonly found relative to other depths. Probability of presence shows two distinct peaks at latitudes of 28-30^{o}N and >34.5^{o}N, with a smaller peak around 32^{o}N. In general, latitude has a greater effect on probability of capture than the other covariates. Probability of presence shows no discernible trend with respect to bottom temperature. Finally, the relationship between DOY and probability of presence is either flat or parabolic with highest probabilities of presence occurring at the beginning and end of the sampling season. These peaks could be driven by low sample sizes near the beginning and end of the sampling seasons.

For the catch GAMs, each of the covariates had a non-linear effect on the catch of Red Snapper (Figure 21 and Table 8). Catch of red snapper shows three distinct peaks at depths of 20-25 m, 35-40 m, and 50-60 m, though some of this high frequency variability is likely driven by station distribution. There is a marked decrease in the catch of red snapper at depths shallower than 20 m and deeper than 60 m. Highest catches of Red Snapper occurred at the shallowest depths, generally declining as depth increases. Catches of Red Snapper clearly peaked at around 29^{o}N, with smaller peaks occurring at 32^{o}N and >34^{o}N. With regards to bottom temperature, catch of Red Snapper generally increased as temperature increased through approximately 27^{o}C. At higher temperatures, catch of Red Snapper appeared to rapidly decline though sample size at these high temperatures is small. Finally, Red Snapper catch compared to DOY showed the same trend as the presence/absence data, with highest catches occurring at the beginning and end of the sampling seasons.

Based on these GAM analyses, in addition to year, we decided to include the categorical covariates depth, latitude, bottom temperature and DOY in the full ZI model (Table 8). To inform the bin structure, we used the GAM analyses relating catch of Red Snapper to each covariate (Figures 21 and 22) to identify periods or relatively homogenous catch of Red Snapper with respect to the covariate. This resulted in 4, 5, 3, and 4 bins for the covariates depth, latitude, bottom temperature, and DOY, respectively (Table 8). Members of the SEDAR 41 Index Working Group provided guidance on the number of bins and potential bin break points during the SEDAR 41 data workshop.

Selection of the covariates included in the final model (both zero-inflation and count sub-models) was done based on Akaike's information criterion (AIC; Akaike 1973). We allowed the possibility that different covariates may appear in each of the sub-models. All analyses were performed in R (Version 3.1.0; R Development Core Team 2014). The zero-inflated models in R were developed using the function zeroinfl available in the package *pscl* (Jackman 2011; Zeileis et al. 2008).

Results

Sampling Summary

A data set for analysis was obtained from a query of the SERFS database on July 14, 2014. Given the constraints mentioned above and removing any collections we are missing covariate data (410 stations removed because of missing bottom temperature data), from 2010 to 2013 we made 3,679 chevron trap monitoring deployments (Table 9), averaging 920 collections per year (range: 610-1,304), following standard monitoring station sampling protocol. The average depth for these collections was 38 m, with annual averages ranging from 37 to 40 m. The average latitude was 31.39°N, with annual averages ranging from 30.84°N to 31.80°N. The average bottom temperature was 21.9°C, with annual averages ranging from 21.1 to 22.2°C. The average DOY was 200, with annual averages ranging from 194 to 222 days. Please note that due to missing bottom temperature data and the desire of SEDAR 41 index working group panelists to include bottom temperature as a covariate, we removed greater than 10% of available collections for the years 2010 and 2011 (Table 10).

Zero-Inflated CPUE

Step-wise forward selection using AIC add the covariates depth, latitude, and bottom temperature to both the zero-inflation and count sub-models (Table 11). In addition, the covariate year was added to the zero-inflation sub-model. The covariate DOY was not added to either sub-model. The only constraint on this selection was that the variable "Year" must be retained in the count sub-model of ZINB model. The resulting final model had the following form:

Zero-Inflation and Count Sub-Model

$$\text{Abund} = offset(\ln(\text{soak time})) + \text{Year} + \text{Depth} + \text{Latitude} + \text{Temperature}$$

where Abund represents the catch data transformed to presence/absence data in the zero-inflation model and the observed catch data in the count model.

Standardized annual CPUE estimates normalized to the series average indicates that CPUE was below average in 2010 and 2011 and above average in 2012 and 2013 (Figure 23).

In the bootstrap to estimate variability in the annual relative abundance index we observed a convergence rate of 57.6%, resulting in 2880 individual bootstraps being used in variability estimation. For each of these bootstraps we calculated an observed relative index based on the bootstrap sampling (Figure 24), with those giving the same overall pattern of relative abundance observed in the base model. Plots of annual variance and coefficient of variation (CV) estimates indicate that 2,880 bootstraps were sufficient for these measures to stabilize (Figure 25). Standardization using the ZINB resulted in annual CV estimates of approximately 18%. Individual year CV estimates ranged from a low of 11% to a high of 23% in 2012 and 2010, respectively (Table 12).

A plot of the observed and predicted number of Red Snapper caught suggests that the ZINB was moderately successful at capturing the observed catch pattern (Figure 26). While the ZINB does a fair job predicting the number of traps that had 0 catch, it does a poor job predicting the number of Red Snapper captured given a trap is positive for Red Snapper. In this case it predicts many more traps would catch only a single Red Snapper than observed. Further, it predicts at most only 3 Red Snapper would be caught in any given trap, though we have observed as many as 28 Red Snapper in an individual trap.

Residual diagnostics suggest that there were some outlier observations in the dataset represented by large Pearson residuals (in excess of 20; Figure 27), though overall there is no strong indication of a pattern in the residuals or heteroscedascity when the residuals are plotted against included covariates (Figures 28 and 29). When Pearson residuals are compared to several potential covariates excluded from the final model (Chlorophyll-A concentration, dissolved oxygen concentration, Event (all traps included in a given trap set), longitude, month, salinity, season, and bottom temperature), first glance suggests there is no strong indication of a pattern to the residuals or heteroscedascity, which indicates that no excluded covariates are critical to the model (Figures 30 and 31). Finally, looking at the spatial distribution of positive and negative Pearson residuals suggests no obvious spatial patterning of the residuals (Figure 32). This lack of spatial structure to the residuals also is supported by the sample variogram, which doesn't show any indication of spatial correlation in trap catches closer than 10 km to each other (Figure 33).

The final ZINB model suggests non-linear relationships among Red Snapper catch and depth and latitude, a linear relationship between Red Snapper catch and bottom temperature, and no effect of DOY on Red Snapper catch (Figure 34). For depth, as originally suggested, Red Snapper catch peaks in bin 2, which corresponds to depths between at depths between 30 and 44 m. For latitude, we see a generally bimodal distribution with catch peaking in bins 2 (28-29.99^{o}N) and 5 (>=34^{o}N). For bottom temperature, the catch of Red Snapper increases as bottom temperature increases. Finally, because DOY is excluded from the final ZINB model, there is no predicted effect of DOY on the catch of Red Snapper.

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Tables

Table 1: Number of chevron trap deployments on live/hard-bottom areas and information associated with chevron trap deployments included in nominal and standardized catch per unit effort (CPUE) calculations for Red Snapper.

		Depth (m)				Latitude (°N)				Day of Year			
			Range				Range				Range		
Year	**Collections**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**
1990	345	33	17	62	0.55	32.55	30.42	33.86	0.0347	151	114	222	1.51
1991	296	34	17	57	0.63	32.62	30.42	34.61	0.0481	216	163	268	2.02
1992	315	34	17	62	0.57	32.79	30.42	34.32	0.0393	155	92	227	2.47
1993	406	35	16	60	0.61	32.39	30.43	34.32	0.0387	176	131	226	1.46
1994	429	36	16	64	0.61	32.27	30.74	33.82	0.0310	185	130	300	2.35
1995	386	33	16	60	0.70	32.09	29.94	33.75	0.0406	203	124	299	2.73
1996	375	38	15	74	0.65	32.23	27.92	34.33	0.0600	190	121	261	2.25
1997	420	38	15	74	0.65	31.98	27.87	34.59	0.0757	196	126	273	1.51
1998	463	41	15	74	0.70	32.04	27.44	34.59	0.0687	182	126	231	1.78
1999	236	36	15	71	0.83	31.94	27.27	34.59	0.1188	199	153	272	1.82
2000	295	36	15	73	0.71	32.37	28.95	34.28	0.0652	196	138	294	2.40
2001	255	37	15	67	0.82	32.32	27.87	34.28	0.0693	206	144	298	2.27
2002	238	37	15	70	0.84	31.87	27.86	33.95	0.0874	207	169	268	1.94
2003	219	38	16	62	0.79	32.07	27.43	34.33	0.1113	202	155	266	2.15
2004	280	39	15	74	0.88	32.27	29.00	33.97	0.0636	177	127	303	2.16
2005	303	38	15	69	0.74	32.08	27.33	34.32	0.0842	191	124	273	2.84
2006	292	37	15	69	0.76	32.30	27.27	34.39	0.0874	203	158	272	1.97
2007	330	37	15	73	0.75	32.18	27.33	34.33	0.0795	200	142	268	2.08
2008	297	37	15	70	0.70	32.16	27.27	34.59	0.0858	193	127	274	2.57
2009	395	35	15	70	0.68	32.23	27.27	34.60	0.0824	202	127	282	2.41
2010	760	38	15	71	0.49	31.37	27.34	34.59	0.0596	222	125	301	1.95
2011	849	38	15	73	0.46	31.25	27.23	34.54	0.0645	202	124	299	1.63
2012	1149	39	15	74	0.41	31.84	27.23	35.02	0.0629	191	116	285	1.35
2013	1331	37	15	73	0.35	31.26	27.23	35.01	0.0544	197	115	278	1.27

Table 2. Variance inflation factor (VIF) estimates and degrees of freedom (df) for all considered covariates.

	Including Temp.		Excluding Temp.	
Variable	**VIF**	**df**	**VIF**	**df**
Year	1.470	23	1.234	23
Depth	1.295	1	1.048	1
Bottom Temperature	1.920	1		
Latitude	1.220	1	1.106	1
Day of Year	1.467	1	1.126	1

Table 3. Generalized Additive Model (GAM) results and full model polynomial order for the zero inflation sub-model (ZI) and count sub-model (Count) for the zero-inflated index model. EDF = effective degrees of freedom of smoothed spline.

	Presence/Absence GAM		Catch GAM					
			Including 0 Catches		Excluding 0 Catches		Polynomials	
Variable	**EDF**	**p-value**	**EDF**	**p-value**	**EDF**	**p-value**	**ZI**	**Count**
Depth	8.7	<0.0001	8.62	<0.0001	8.42	<0.0001	9	9
Latitude	8.33	<0.0001	8.89	<0.0001	8.21	<0.0001	8	9
Day of Year	2.76	0.0001	8.12	<0.0001	7.87	<0.0001	3	8

Table 4. Red Snapper nominal catch per unit effort (CPUE), delta-GLM (dGLM) standardized CPUE*, and zero-inflated negative binomial (ZINB) standardized CPUE for chevron traps. N = number of included traps, positive = proportion of included collections positive for Red Snapper, fish = number of individuals captured, CV = coefficient of variation, and normalized = annual index value normalized to its long-term mean to give relative abundance over time. *From Bubley et al. (2014) – note the number of stations used annually (and thus # positive and % positive) for this model is different due to the exclusion of all "ReconConv" stations from this analysis and earlier database access date.

				Nominal			dGLM Standardized*			ZINB Standardized		
Year	**n**	**Positive**	**% Positive**	**CPUE**	**CV**	**Normalized**	**CPUE**	**CV**	**Normalized**	**CPUE**	**CV**	**Normalized**
1990	345	8	2.32	0.070	0.61	0.78	0.037	0.50	0.82	0.180	0.58	0.74
1991	296	6	2.03	0.057	0.55	0.64	0.062	0.52	1.4	0.288	0.39	1.19
1992	315	9	2.86	0.067	0.40	0.75	0.064	0.44	1.45	0.294	0.49	1.21
1993	406	12	2.96	0.076	0.38	0.85	0.06	0.37	1.36	0.481	0.32	1.98
1994	429	19	4.43	0.105	0.43	1.17	0.053	0.31	1.19	0.340	0.32	1.40
1995	386	7	1.81	0.034	0.43	0.38	0.027	0.44	0.6	0.168	0.44	0.69
1996	375	6	1.60	0.016	0.41	0.18	0.01	0.48	0.23	0.048	0.40	0.20
1997	420	6	1.43	0.057	0.58	0.64	0.021	0.57	0.46	0.145	0.67	0.60
1998	463	8	1.73	0.054	0.57	0.60	0.025	0.47	0.56	0.163	0.49	0.67
1999	236	4	1.69	0.093	0.57	1.04	–	–	–	0.496	0.54	2.04
2000	295	8	2.71	0.058	0.41	0.64	0.045	0.42	1.02	0.253	0.33	1.04
2001	255	7	2.75	0.035	0.40	0.39	0.047	0.42	1.06	0.245	0.40	1.01
2002	238	13	5.46	0.139	0.35	1.55	0.071	0.40	1.6	0.571	0.45	2.35
2003	219	1	0.46	0.032	1.00	0.36	–	–	–	0.114	1.38	0.47
2004	280	4	1.43	0.018	0.53	0.20	0.02	0.61	0.46	0.103	0.52	0.43
2005	303	7	2.31	0.040	0.44	0.44	0.031	0.43	0.7	0.108	0.43	0.45
2006	292	4	1.37	0.017	0.53	0.19	0.014	0.53	0.32	0.073	0.39	0.30
2007	330	8	2.42	0.088	0.70	0.98	0.041	0.48	0.93	0.288	0.54	1.19
2008	297	7	2.36	0.064	0.53	0.72	0.043	0.46	0.97	0.18	0.43	0.77
2009	395	8	2.03	0.025	0.37	0.28	0.021	0.38	0.48	0.097	0.33	0.40
2010	760	69	9.08	0.216	0.18	2.41	0.049	0.31	1.11	0.246	0.22	1.01
2011	849	69	8.13	0.141	0.14	1.58	0.072	0.21	1.63	0.231	0.20	0.95
2012	1149	150	13.05	0.366	0.14	4.10	0.073	0.18	1.65	0.426	0.23	1.76
2013	1331	142	10.67	0.277	0.14	3.10	0.088	0.19	2.00	0.278	0.23	1.14

Table 5. Results of Bayesian information criterion (BIC) selection, including some best-fit preliminary models (RSPoissonSel, RSNBSel, RSZIPAll,RSZINBVisual) based on different model structures from the initial full model mentioned in the report.

Step	Model	Variable	Sub-Model	BIC	Difference
	RSPoissonSel			8824.0	-3055.93
	RSNBSel			5905.0	-136.93
	RSZIPAll			6704.1	-936.04
	RSZINBVisual			6012.8	-244.76
1	ZINB1ab	-Year	Zero Inflation	5951.1	-183.06
2	ZINb2i	-Depth^{8}	Count	5941.8	-173.78
3	ZINB3z	-DOY^{7}	Count	5932.6	-164.51
4	ZINB4ak	-Depth^{9}	Zero Inflation	5923.3	-155.25
5	ZINB5m	-Latitude^{3}	Count	5914.1	-146.07
6	ZINB6d	-Depth^{3}	Count	5905.1	-137.00
7	ZINB7r	-Latitude^{8}	Count	5896.4	-128.36
8	ZINB8p	-Latitude^{6}	Count	5887.3	-119.28
9	ZINB9av	-DOY^{3}	Zero Inflation	5878.9	-110.81
10	ZINB10aj	-Depth^{8}	Zero Inflation	5871.3	-103.25
11	ZINB11s	-Latitude^{9}	Count	5863.8	-95.77
12	ZINB12k	-Latitude	Count	5856.9	-88.81
13	ZINB13aa	-DOY^{8}	Count	5850.1	-82.07
14	ZINB14u	-DOY^{2}	Count	5842.6	-74.57
15	ZINB15y	-DOY^{6}	Count	5834.6	-66.53
16	ZINB16ag	-Depth^{5}	Zero Inflation	5828.3	-60.24
17	ZINB17ae	-Depth^{3}	Zero Inflation	5820.0	-51.89
18	ZINB18w	-DOY^{4}	Count	5814.5	-46.44
19	ZINB19q	-Latitude^{7}	Count	5808.5	-40.46
20	ZINB20o	-Latitude^{5}	Count	5802.0	-33.94
21	ZINB21n	-Latitude^{4}	Count	5801.8	-33.73
22	ZINB22ac	-Depth	Zero Inflation	5794.9	-26.84
23	ZINB23af	-Depth^{4}	Zero Inflation	5794.0	-25.97
24	ZINB24ah	-Depth^{6}	Zero Inflation	5785.3	-17.28

25	ZINB25ap	$-Latitude^5$	Zero Inflation	5785.2	-17.18
26	ZINB26ar	$-Latitude^7$	Zero Inflation	5777.1	-9.03
27	ZINB27b	-Depth	Count	5775.7	-7.63
28	ZINB28bb	$+Depth^3$	Count	5773.9	-5.83
29	ZINB29t	-DOY	Count	5773.9	-5.86
30	ZINB30x	$-DOY^5$	Count	5768.1	0.00

Table 6. Length composition of Red Snapper collected by chevron trap during the Southeast Reef Fish Survey from 1990 to 2013. Lengths are maximum (pinched) total length in mm (measured or rounded to the nearest 1-cm bin) and composition is in percent of fish in each 1-cm bin of the total for each year.

Length (mm)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
190	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
220	0.0	5.9	0.0	3.2	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	14.3	0.0	0.0	16.7	0.0	3.4	0.0	0.0	0.8	0.5	0.3
230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
240	0.0	11.8	0.0	0.0	2.2	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.6	0.8	0.7	0.8
250	0.0	23.5	0.0	0.0	0.0	0.0	0.0	7.7	0.0	4.5	0.0	0.0	7.5	14.3	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.8	1.4	1.6
260	0.0	5.9	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	2.5	14.3	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	3.7	0.8
270	0.0	5.9	0.0	0.0	0.0	0.0	20.0	11.5	0.0	4.5	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.8
280	0.0	5.9	0.0	0.0	0.0	0.0	10.0	15.4	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	2.6	1.3
290	0.0	29.4	4.8	0.0	0.0	0.0	0.0	3.8	0.0	9.1	0.0	0.0	5.0	14.3	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.8	2.3	1.6
300	0.0	0.0	14.3	3.2	0.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	3.4	9.1	0.0	0.8	1.4	1.9
310	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.6	0.0	0.7	1.6
320	0.0	5.9	0.0	0.0	0.0	0.0	0.0	3.8	0.0	22.7	0.0	0.0	5.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.8	1.4	2.1
330	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	8.0	9.1	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	3.5
340	0.0	5.9	0.0	0.0	0.0	0.0	0.0	3.8	4.0	4.5	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	1.2	0.0	0.9	4.0
350	8.3	0.0	9.5	0.0	2.2	0.0	0.0	0.0	8.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.9	0.0	0.0	0.0	1.9	5.3
360	0.0	0.0	9.5	3.2	6.7	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	6.9	0.0	0.6	0.8	3.3	4.3
370	12.5	0.0	4.8	0.0	0.0	0.0	0.0	7.7	4.0	13.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	0.0	0.0	1.2	0.0	3.5	3.5
380	0.0	0.0	0.0	0.0	4.4	0.0	0.0	3.8	8.0	4.5	0.0	11.1	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	2.4
390	8.3	0.0	4.8	0.0	4.4	0.0	0.0	3.8	4.0	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	17.2	9.1	0.0	0.0	4.7	1.3
400	20.8	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0	11.8	0.0	0.0	0.0	0.0	0.0	0.0	19.4	0.0	0.0	0.6	0.0	4.4	1.9
410	12.5	0.0	4.8	0.0	4.4	0.0	0.0	0.0	8.0	4.5	5.9	11.1	5.0	0.0	0.0	8.3	0.0	22.6	6.9	0.0	2.9	0.8	3.3	4.0
420	20.8	0.0	0.0	0.0	0.0	0.0	0.0	3.8	12.0	0.0	5.9	11.1	2.5	0.0	0.0	0.0	0.0	9.7	0.0	0.0	1.7	0.0	1.9	1.9
430	4.2	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	11.8	22.2	7.5	0.0	16.7	0.0	0.0	6.5	10.3	0.0	6.4	0.0	2.1	1.6
440	0.0	0.0	0.0	6.5	2.2	7.7	10.0	0.0	0.0	0.0	17.6	11.1	2.5	0.0	0.0	0.0	0.0	3.2	0.0	0.0	5.2	1.7	3.0	0.8
450	0.0	0.0	0.0	3.2	0.0	7.7	0.0	3.8	0.0	0.0	17.6	0.0	0.0	0.0	0.0	0.0	0.0	3.2	10.3	0.0	4.6	4.1	1.6	2.1

460	0.0	0.0	0.0	6.5	2.2	0.0	0.0	0.0	0.0	0.0	5.9	11.1	5.0	0.0	0.0	0.0	0.0	3.2	0.0	9.1	5.8	0.0	0.9	1.6
470	4.2	0.0	0.0	9.7	4.4	0.0	10.0	0.0	0.0	0.0	5.9	0.0	2.5	0.0	0.0	8.3	0.0	0.0	0.0	0.0	2.3	4.1	1.2	1.6
480	0.0	0.0	4.8	6.5	0.0	7.7	0.0	0.0	4.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	3.2	6.9	0.0	3.5	2.5	0.7	2.1
490	4.2	0.0	0.0	19.4	4.4	15.4	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	4.1	0.2	2.1
500	4.2	0.0	4.8	12.9	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	8.3	0.0	0.0	3.4	27.3	6.4	3.3	0.5	1.6
510	0.0	0.0	0.0	3.2	4.4	0.0	0.0	0.0	4.0	0.0	0.0	0.0	2.5	0.0	0.0	8.3	16.7	0.0	10.3	0.0	6.4	1.7	0.2	2.1
520	0.0	0.0	0.0	3.2	2.2	7.7	0.0	0.0	4.0	0.0	0.0	0.0	5.0	0.0	0.0	16.7	0.0	0.0	0.0	9.1	6.4	4.1	0.0	0.8
530	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	4.0	0.0	5.9	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
540	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	4.0	0.0	0.0	11.1	7.5	0.0	0.0	0.0	0.0	0.0	3.4	0.0	5.2	6.6	0.2	0.5
550	0.0	0.0	4.8	3.2	4.4	7.7	0.0	0.0	4.0	0.0	0.0	0.0	5.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	1.7	4.1	0.7	1.3
560	0.0	0.0	4.8	3.2	2.2	7.7	0.0	0.0	0.0	0.0	0.0	11.1	0.0	0.0	16.7	0.0	0.0	0.0	3.4	0.0	2.9	3.3	0.7	0.3
570	0.0	0.0	0.0	6.5	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	6.6	0.5	0.3
580	0.0	0.0	0.0	3.2	6.7	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	5.8	0.0	0.5
590	0.0	0.0	14.3	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	2.9	2.5	0.9	0.5
600	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	2.3	5.8	0.5	0.3
610	0.0	0.0	0.0	0.0	4.4	7.7	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	4.1	1.6	1.1
620	0.0	0.0	9.5	0.0	6.7	23.1	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	2.5	2.3	0.8
630	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.4	0.5
640	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	2.5	2.1	1.9
650	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	1.7	2.5	1.6	0.3
660	0.0	0.0	0.0	0.0	2.2	7.7	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.7	1.4	0.3
670	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	2.5	1.4	0.0
680	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.7	0.3
690	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	1.6
700	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	9.1	1.2	3.3	3.5	0.5
710	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	18.2	0.6	0.8	1.9	2.4
720	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.8	1.2	1.1
730	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	1.2	0.8	2.8	2.7
740	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.5	1.3
750	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	8.3	0.0	0.0	0.0	0.0	0.6	0.8	1.4	1.9
760	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.8	1.9	3.2
770	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.9	2.7

780	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	1.9	1.3
790	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.7	2.1
800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.6
810	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.9	0.5
820	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.7	1.9
830	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.3
840	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
850	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
860	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.7	0.8
870	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.8
880	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.8
890	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5
900	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
910	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.3
920	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
940	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
950	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
960	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
980	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Fish	24	17	21	31	45	13	10	26	25	22	17	9	40	7	6	12	6	31	29	11	173	121	430	376
Traps	8	6	9	12	19	7	8	7	8	4	8	7	16	1	5	7	5	9	11	9	74	70	155	143

Table 7. Age composition of Red Snapper collected by chevron trap during the Southeast Reef Fish Survey from 1990 to 2013. Ages are calendar age and composition is in percent of fish in each 1-year bin of the total for each year.

Age	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	57.9	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	57.1	0.0	0.0	66.7	0.0	3.4	0.0	0.6	2.5	3.8	17.7
2	16.7	26.3	10.0	6.9	4.8	0.0	20.0	16.7	36.0	31.6	20.0	42.9	34.2	42.9	40.0	0.0	0.0	96.6	41.4	18.2	6.6	2.5	32.2	23.6
3	41.7	15.8	55.0	20.7	21.4	3.6	10.0	50.0	44.0	36.8	53.3	57.1	52.6	0.0	20.0	33.3	16.7	3.4	51.7	36.4	53.3	8.3	21.4	20.4
4	37.5	0.0	20.0	44.8	42.9	39.3	30.0	20.8	8.0	31.6	20.0	0.0	10.5	0.0	20.0	33.3	16.7	0.0	3.4	36.4	24.6	60.8	3.8	7.1
5	4.2	0.0	5.0	17.2	23.8	28.6	20.0	12.5	4.0	0.0	6.7	0.0	2.6	0.0	20.0	8.3	0.0	0.0	0.0	0.0	12.0	15.8	21.9	6.3
6	0.0	0.0	10.0	3.4	4.8	28.6	20.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	1.2	7.5	8.2	8.4
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.8	4.3	9.5
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	0.0	0.0	1.0	3.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.5	0.5
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.2	0.3
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
12	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.8
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.3
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.2	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Fish	24	19	20	29	42	28	10	24	25	19	15	7	38	7	5	12	6	29	29	11	167	120	416	368
Traps	8	8	9	12	19	14	8	6	8	4	8	6	15	1	4	7	5	8	11	9	73	70	148	139

Addendum Tables

Table 8. Generalized Additive Model (GAM) results and full model polynomial order for the zero inflation sub-model (ZI) and count sub-model (Count) for the zero-inflated index model. EDF = effective degrees of freedom of smoothed spline.

	Presence/Absence GAM		Catch GAM		Bins				
Variable	**EDF**	**p-value**	**EDF**	**p-value**	**1**	**2**	**3**	**4**	**5**
Depth (m)	8.60	<0.0001	8.30	<0.0001	<30	30-44	45-59	>=60	
Latitude (^{o}N)	8.76	<0.0001	8.98	<0.0001	<28	28-29.99	30-32.49	32.5-33.99	>=34
Bottom Temperature (^{o}C)	2.46	0.2800	8.79	<0.0001	<15	15-26.99	>=27		
Day of Year	6.92	0.0025	8.51	<0.0001	<150	150-199	200-249	>=250	

Table 9: Number of chevron trap deployments on live/hard-bottom areas and information associated with chevron trap deployments included in standardized catch per unit effort (CPUE) calculations for Red Snapper.

		Depth (m)				Latitude (^{o}N)				Bottom Temperature (^{o}C)				Day of Year			
			Range				Range				Range				Range		
Year	**Collections**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**
2010	610	39	15	71	0.54	31.61	27.34	34.59	0.0675	21.1	12.3	29.4	0.155	210	125	301	2.07
2011	671	40	15	73	0.53	30.84	27.23	34.54	0.0708	21.7	14.8	28.8	0.149	209	140	299	1.74
2012	1094	39	15	74	0.42	31.80	27.23	35.02	0.0654	22.2	12.9	27.8	0.104	194	116	285	1.35
2013	1304	37	15	73	0.36	31.23	27.23	35.01	0.0550	22.1	12.4	28.1	0.085	197	115	278	1.28

Table 10. Annual and total exclusion of chevron trap monitoring station collections from ZINB analysis due to missing bottom temperature data. Excluding and including refers to excluding bottom temperature as a covariate during model construction or including bottom temperature as a covariate during model construction, respectively.

	Sample Size		
Year	**Excluding Temperature**	**Including Temperature**	**% Change**
2010	760	610	19.74%
2011	849	671	20.97%
2012	1149	1094	4.79%
2013	1331	1304	2.03%
Total	**4089**	**3679**	**10.03%**

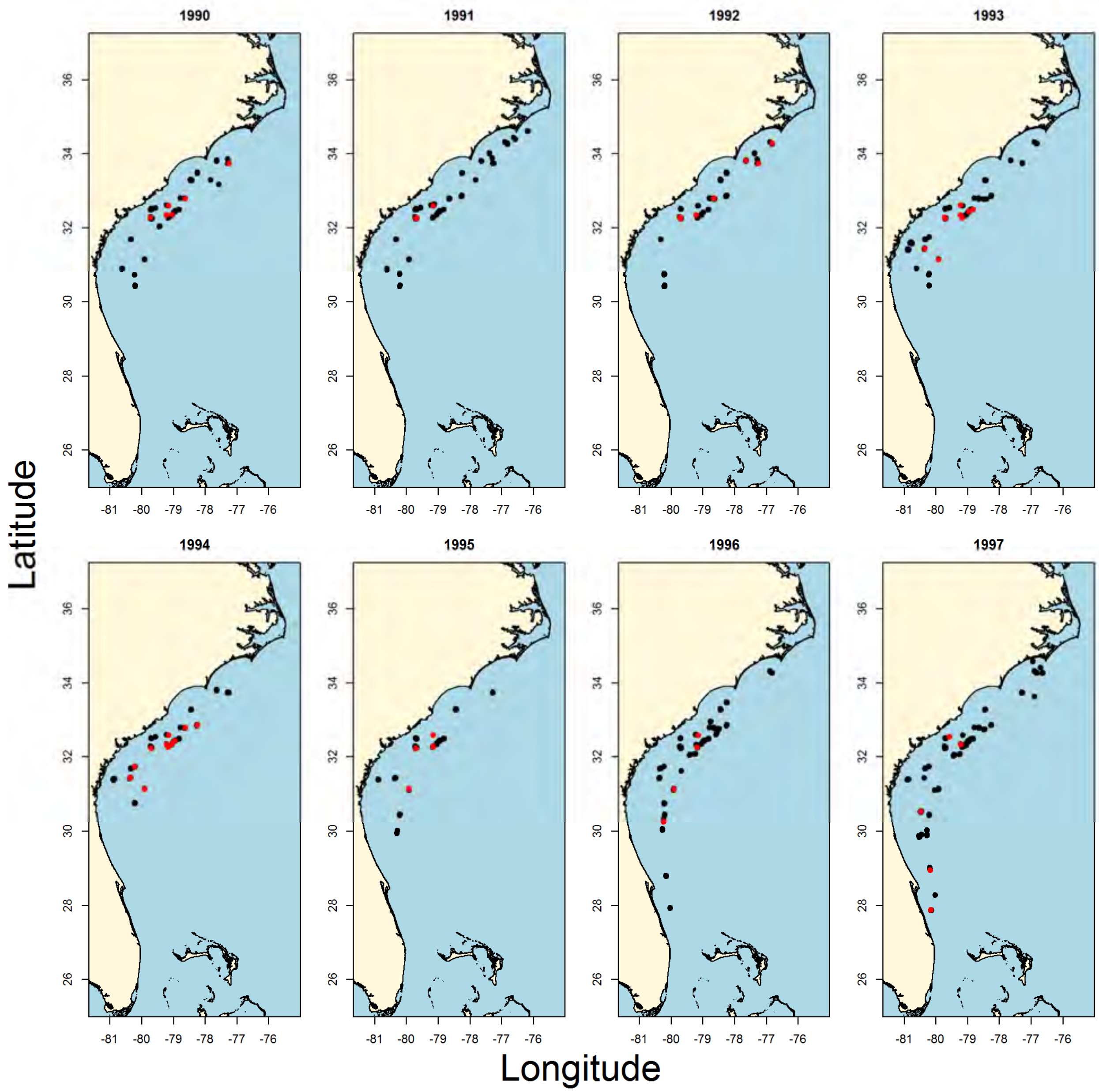
Table 11. Results of AIC selection using forward selection.

Step	Model	Variable	Sub-Model	AIC	Difference
	RSZINB			3707	-337.355
1	ZINB1ZIAdd3	+Latitude	Zero-inflation	3453	-83.544
2	ZINB2ZIAdd2	+Depth	Zero-inflation	3425	-55.439
3	ZINB3CountAdd2	+Latitude	Count	3400	-30.405
4	ZINB4CountAdd2	+Temperature	Count	3393	-23.704
5	ZINB5CountAdd1	+Depth	Count	3378	-9.096
6	ZINB6ZIAdd2	+Temperature	Zero-inflation	3374	-4.534
7	ZINB7ZIAdd1	+Year	Zero-inflation	3369	0.000

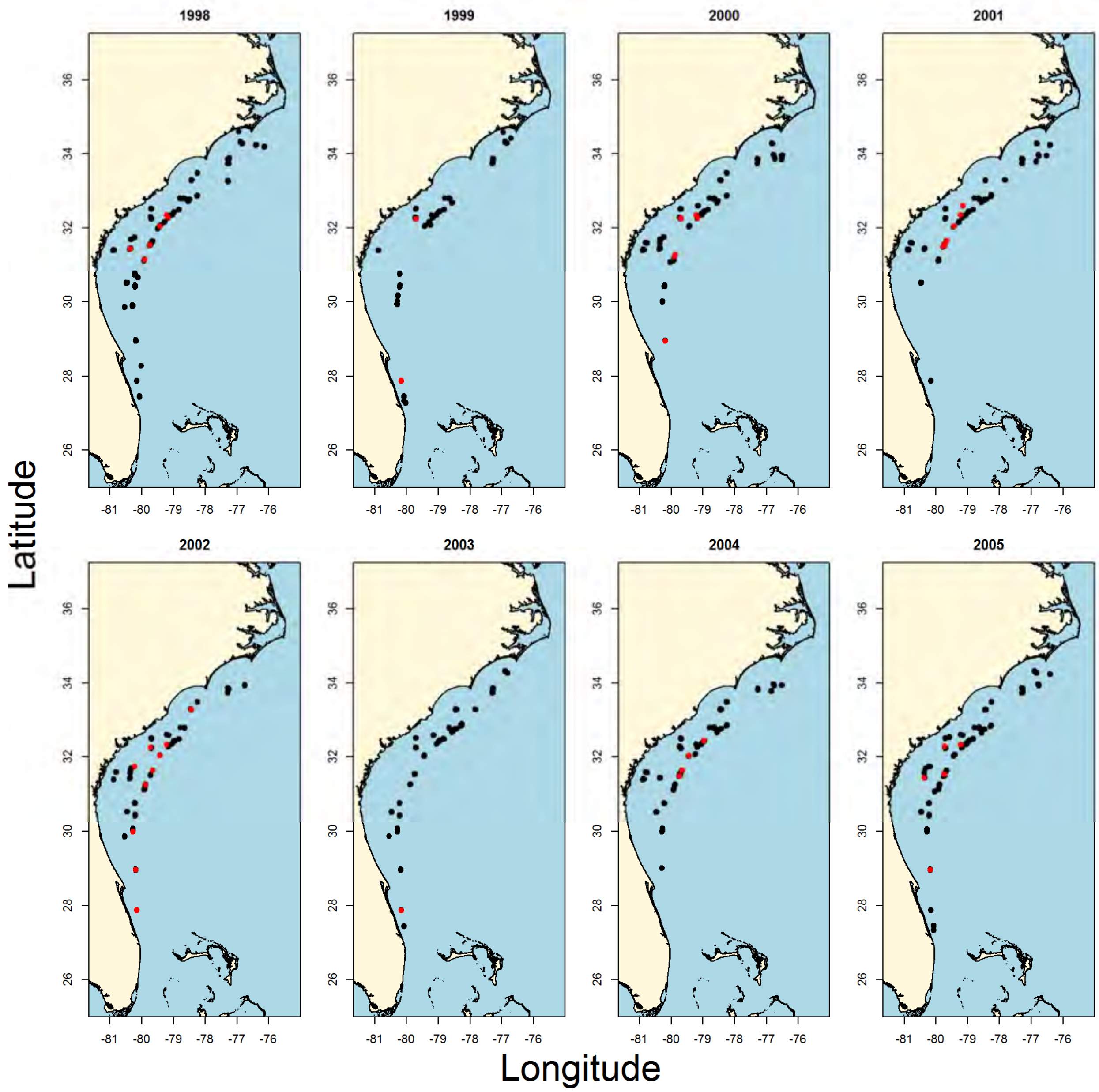
Table 12. Red Snapper nominal catch per unit effort (CPUE) and zero-inflated negative binomial (ZINB) standardized CPUE for chevron traps. N = number of included traps, positive = proportion of included collections positive for Red Snapper, CV = coefficient of variation, and normalized = annual index value normalized to its long-term mean to give relative abundance over time.

		Nominal			ZINB Standardized		
Year	**n**	**CPUE**	**CV**	**Normalized**	**CPUE**	**CV**	**Normalized**
2010	610	0.166	0.24	0.673	0.193	0.23	0.707
2011	671	0.173	0.15	0.703	0.147	0.27	0.536
2012	1094	0.364	0.15	1.479	0.449	0.11	1.642
2013	1304	0.281	0.14	1.144	0.305	0.12	1.115

Figures



1990
1991
1992
1993
1994
1995
1996
1997
36
34
32
30
28
26
-81
-80
-79
-78
-77
-76
Latitude
Longitude


1998
1999
2000
2001
2002
2003
2004
2005
Latitude
Longitude
-81 -80 -79 -78 -77 -76
26 28 30 32 34 36

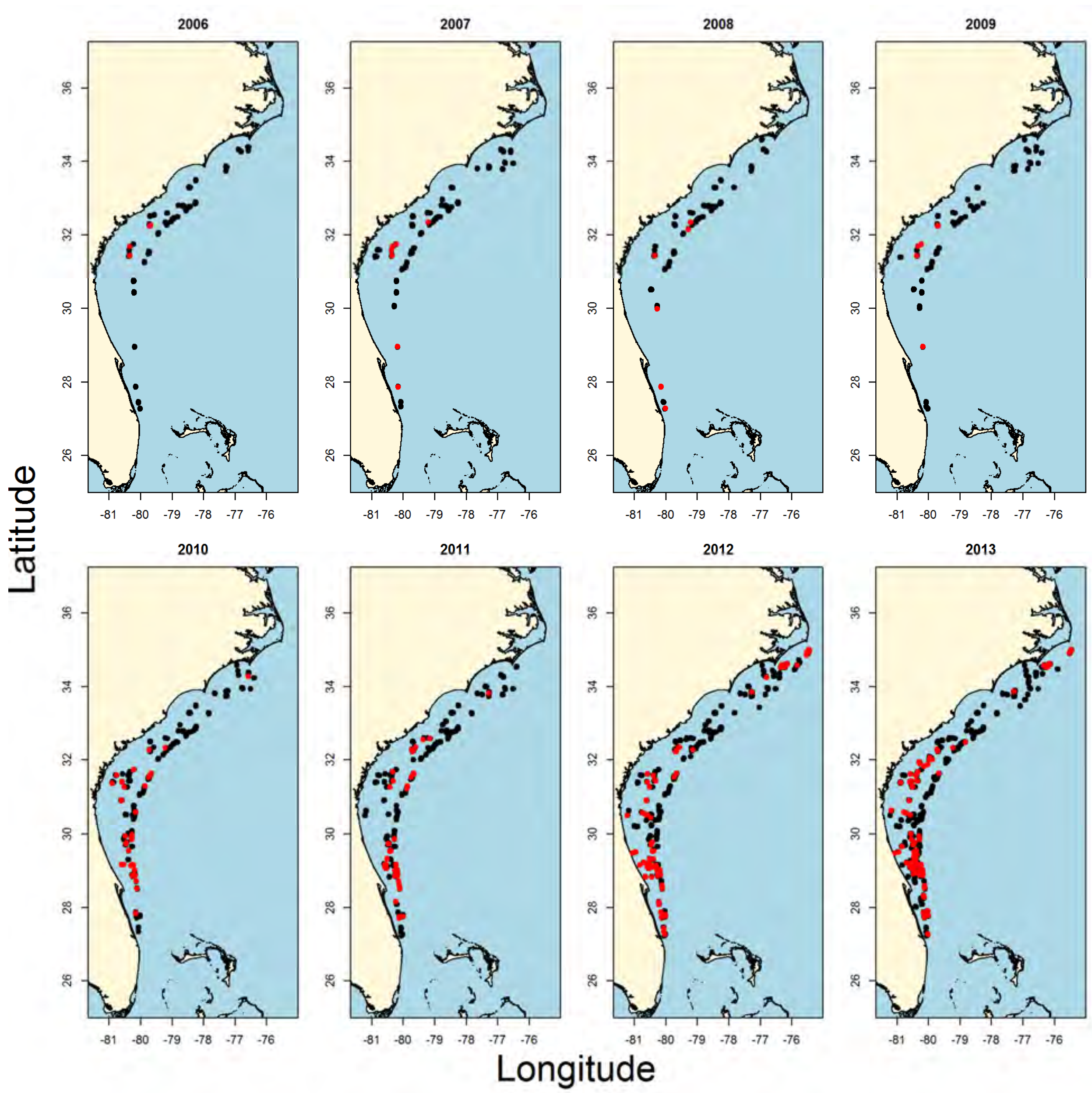


Figure 1: Progression of the spatial coverage of monitoring chevron trap deployments by the Southeast Reef Fish Survey since the initial year using chevron traps to monitor fish on live/hard bottom. Red indicates stations at which Red Snapper were collected in a given year. Note that each symbol may represent multiple sampling events. CTDs were deployed with each trap set, but not pictured here.

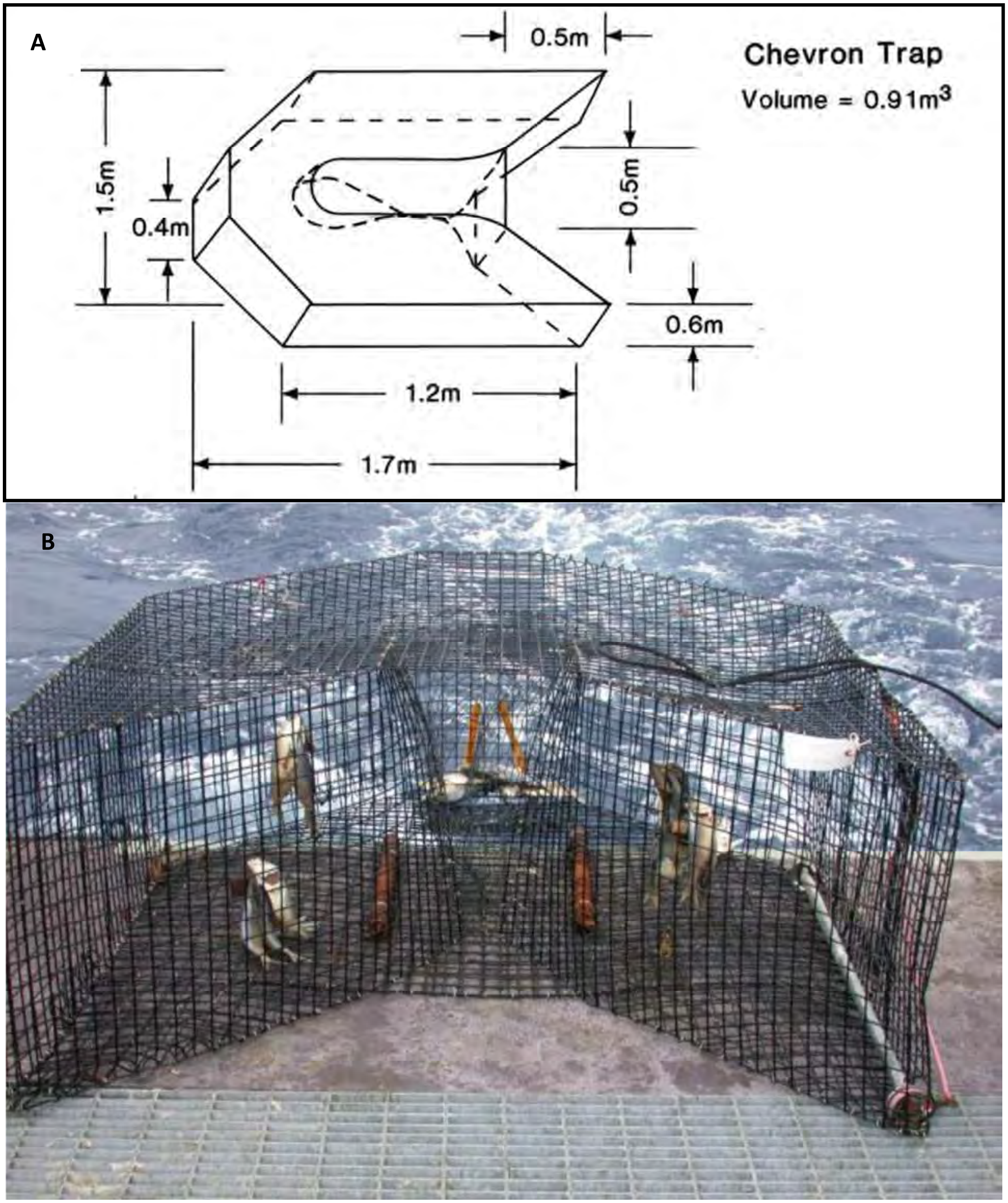


Figure 2. Chevron traps used by SERFS for monitoring reef fish. A. Diagram with dimensions. B. Chevron trap ready for deployment baited with clupeids. Iron sashes attached to the bottom weigh the trap down and help maintain the proper orientation of the trap on the bottom.

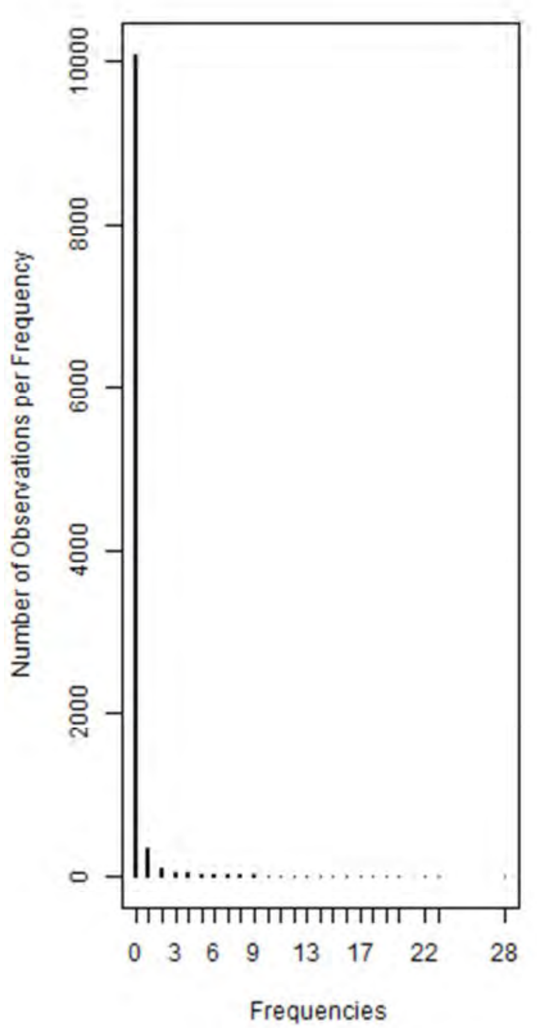


Figure 3. Frequency of occurrence of chevron traps with a given catch of Red Snapper.

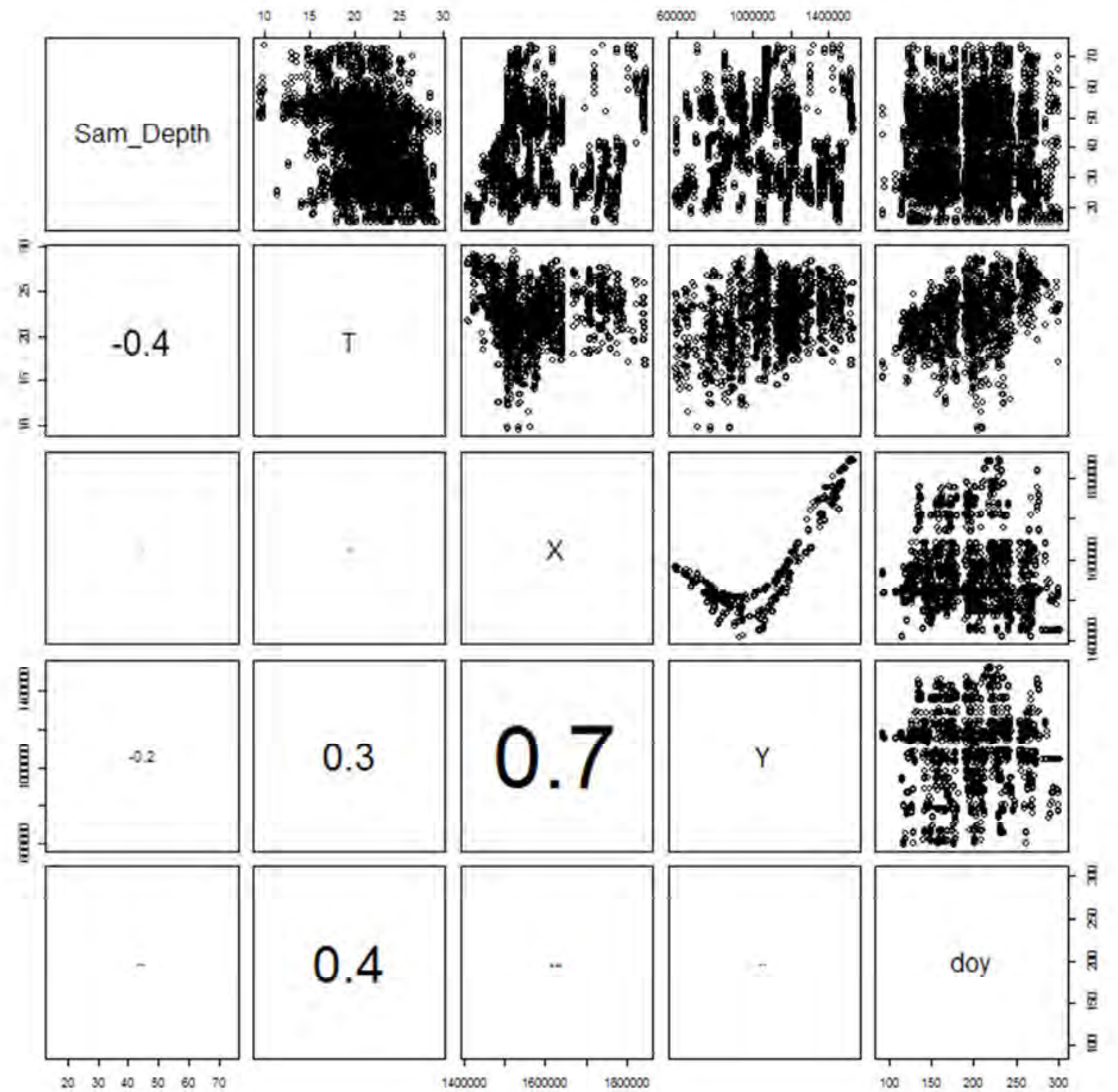


Figure 4. Pairs plot of correlation between considered continuous covariates. Diagonal provides the variable name, lower triangle provides the correlation coefficient estimates, and upper triangle provides scatter plots of the raw data. Sam_Depth=depth in meters; T=bottom temperature in ^{o}C; X=longitude in m, Y=latitude in m; and doy=day of year.

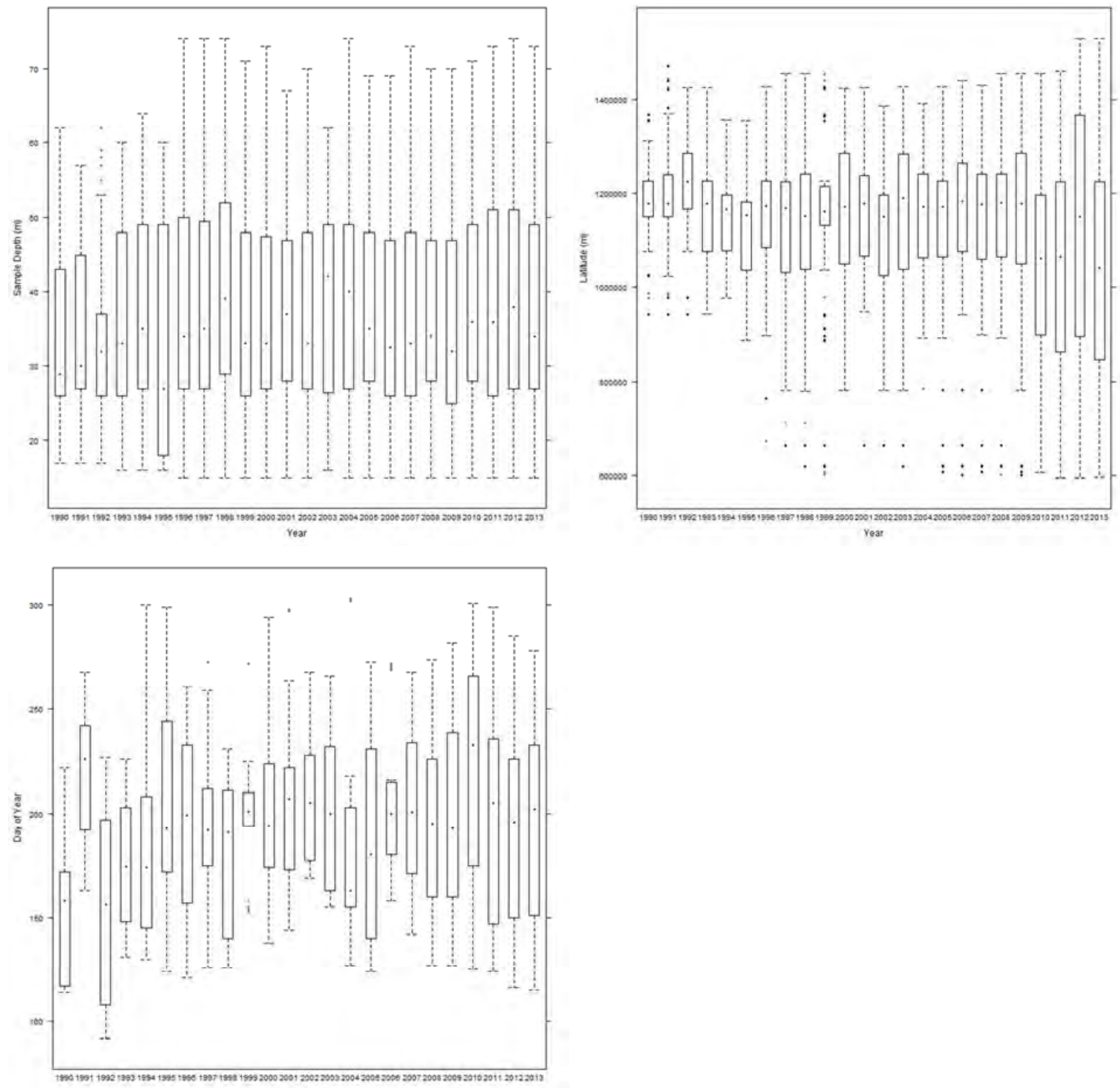


Figure 5. Box plots of depth (top left), latitude (top right), and day of year (bottom left) as a function of year.

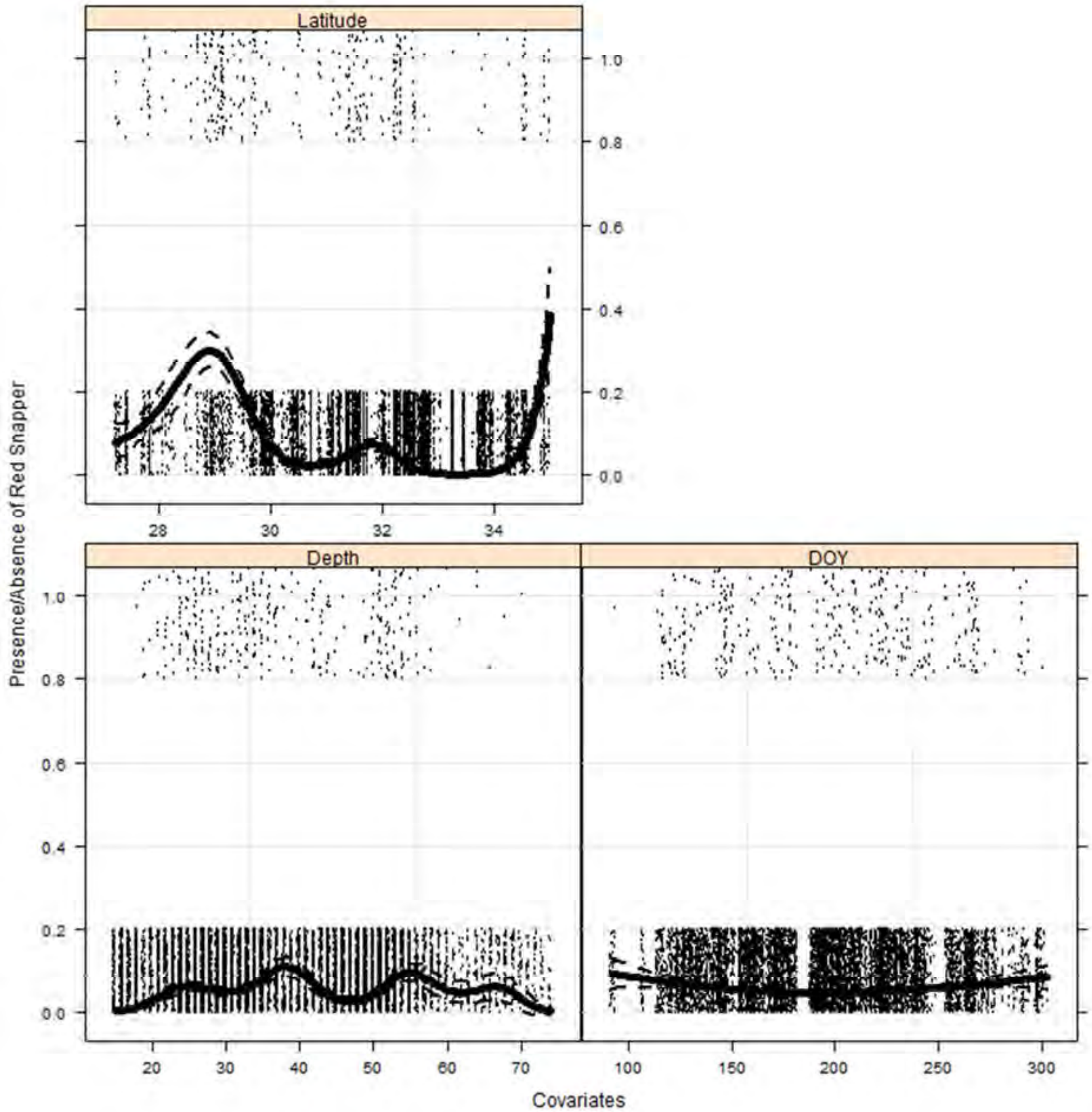


Figure 6. Presence (1) and absence (0) of Red Snapper with respect to the considered covariates, latitude (°N), depth (m), and day of year (DOY). The raw presence/absence data has been jittered in the figure. The solid black line represents a fitted GAM to the presence/absence data with respect to a given covariate. Dashed black lines represent 95% confidence intervals around the GAM fit.

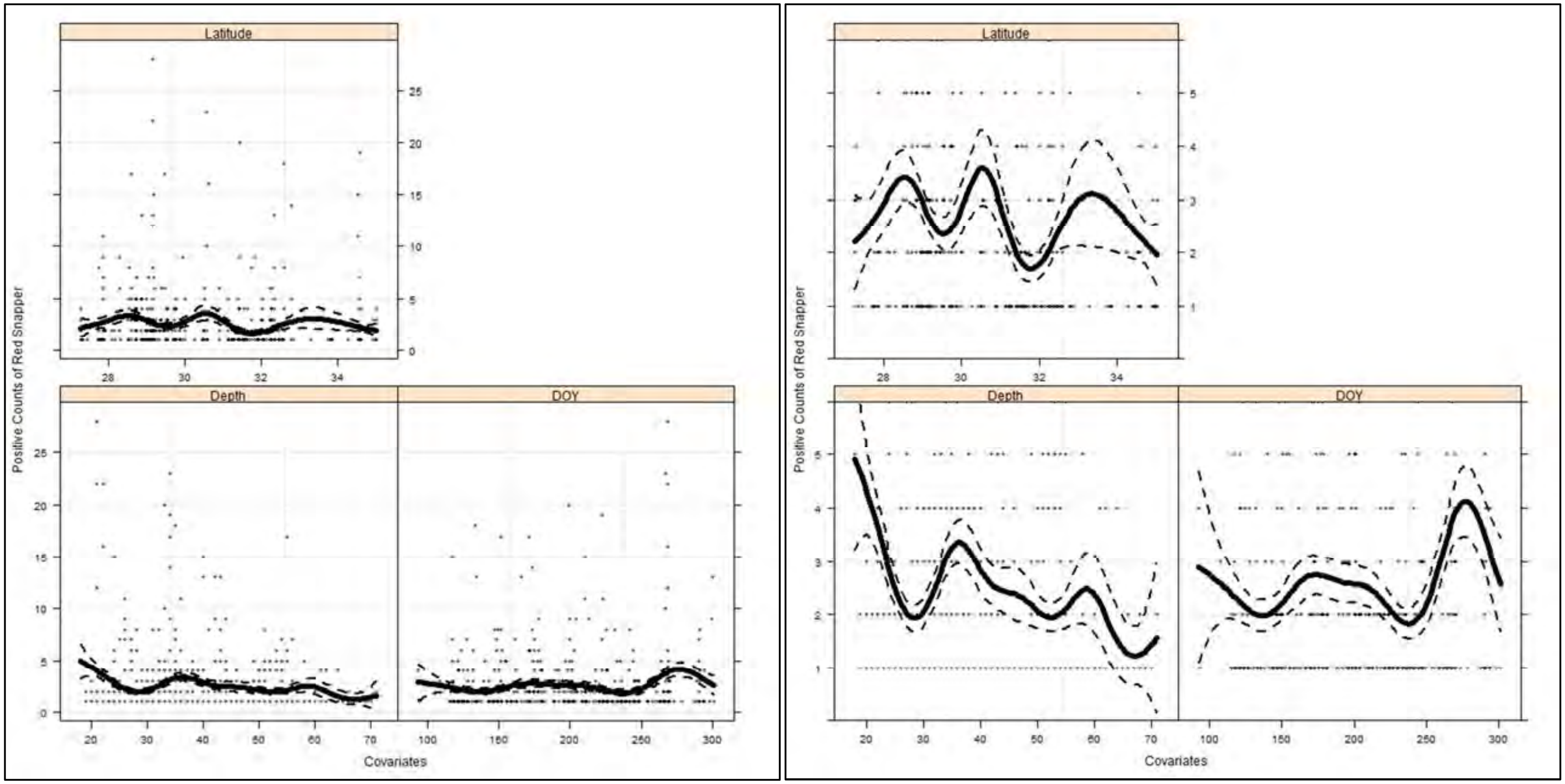


Figure 7. Catch of Red Snapper with respect to the considered covariates, latitude (°N), depth (m), and day of year (DOY). The left panel has an unrestricted y-axis that shows the full catch distribution of Red Snapper. The right panel restricts the y-axis to the range of the GAM model fits to show better detail of the GAM fits. Sold black line represents a fitted GAM to the catch data with respect to a given covariate. Dashed black lines represent 95% confidence intervals about the GAM fit. Only traps that caught Red Snapper were considered for the GAM fits.

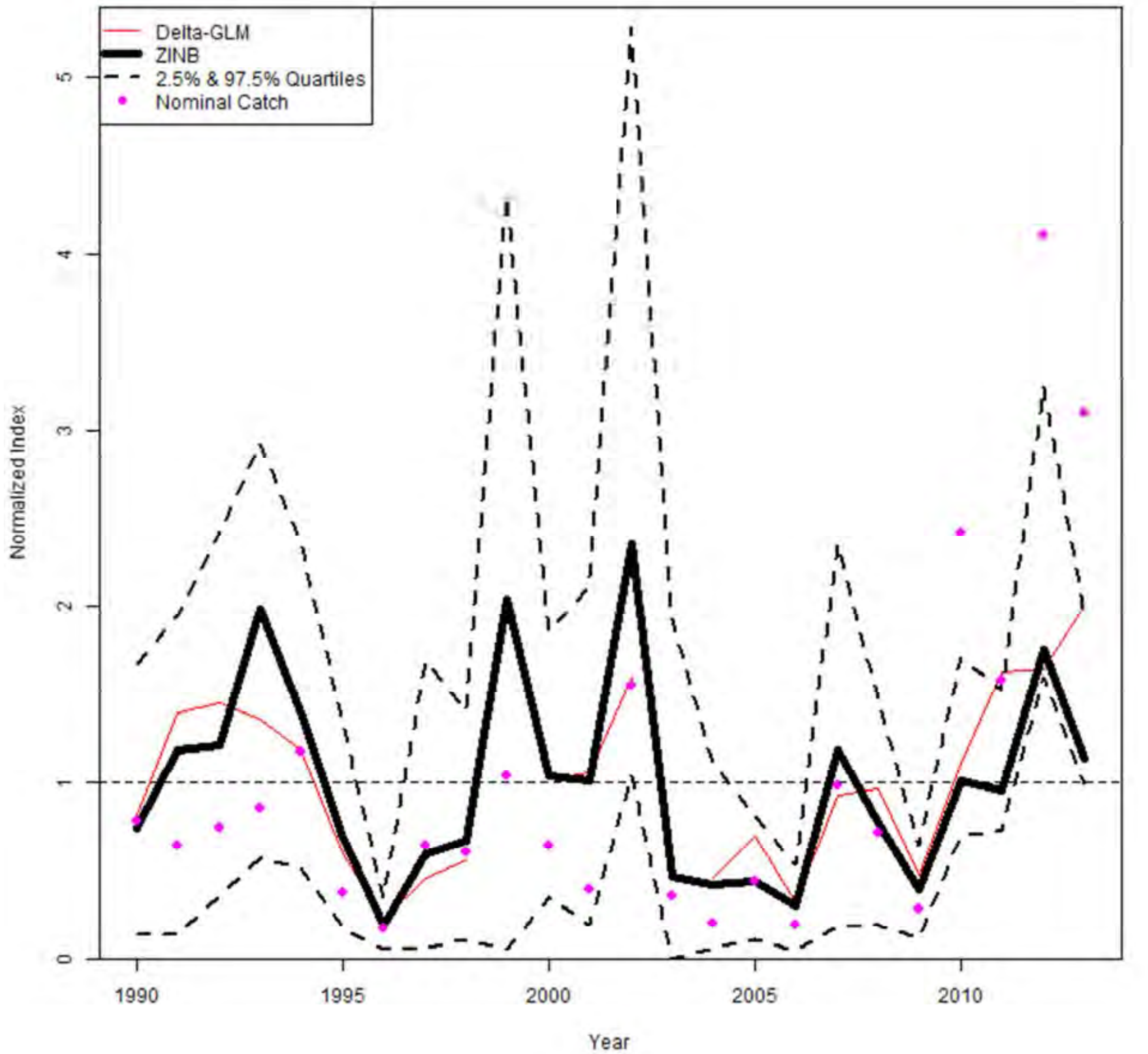


Figure 8. Red Snapper indices of relative abundance for chevron traps. Nominal catch, Delta-GLM standardized CPUE*, and Zero-inflated negative binomial (ZINB) standardized catch normalized to each index's long-term mean to provide relative abundance. *From Bubley et al. (2014).

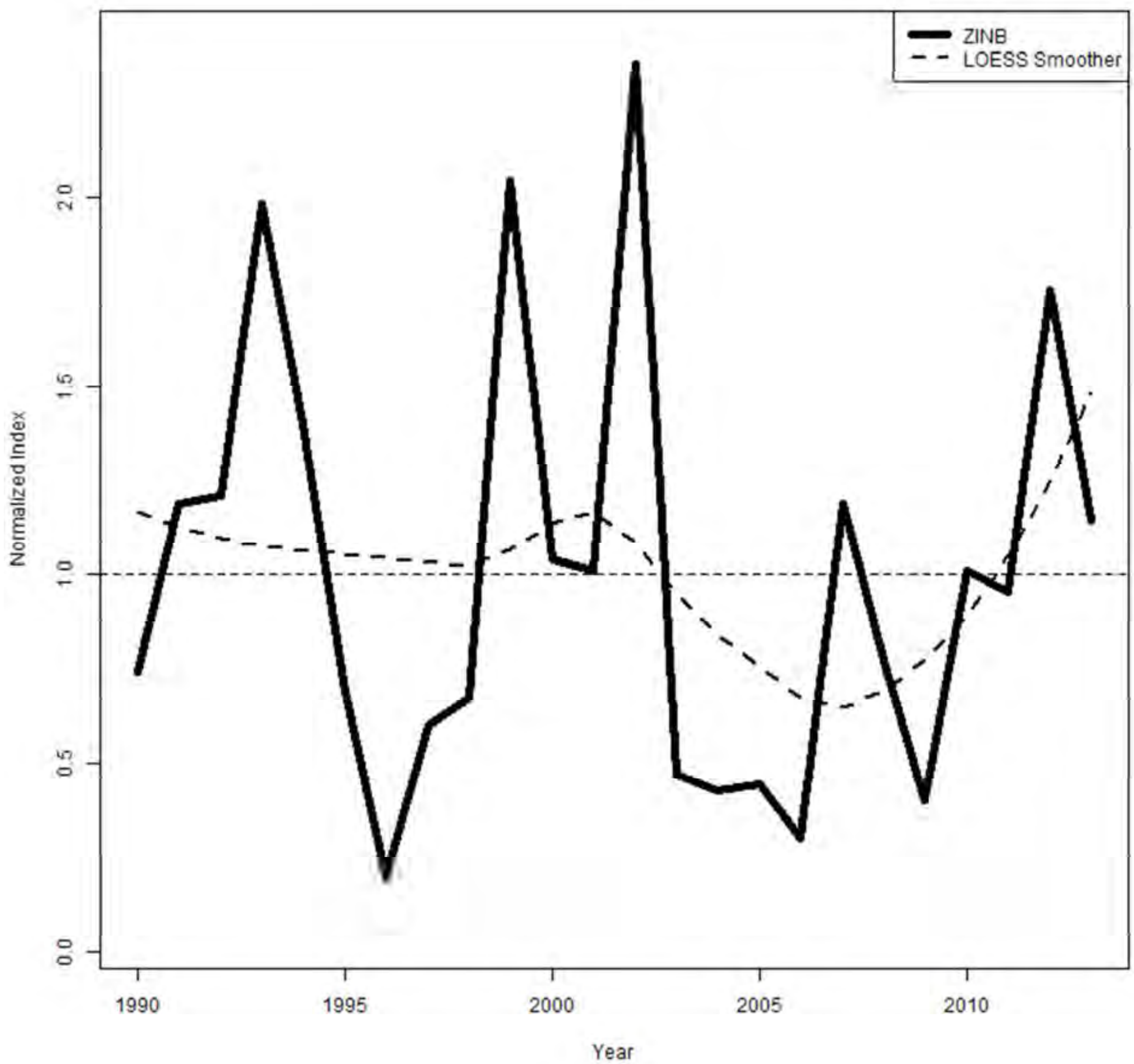


Figure 9. ZINB index of relative abundance for Red Snapper based on the best fit ZINB selected by the Bayesian information criterion (BIC). Heavy dashed-line represents locally-weight scatterplot smoothing (LOESS smoother) that has been added to the plot to aid visual interpretation of the abundance trends. All index values were normalized to the series' mean prior to plotting.

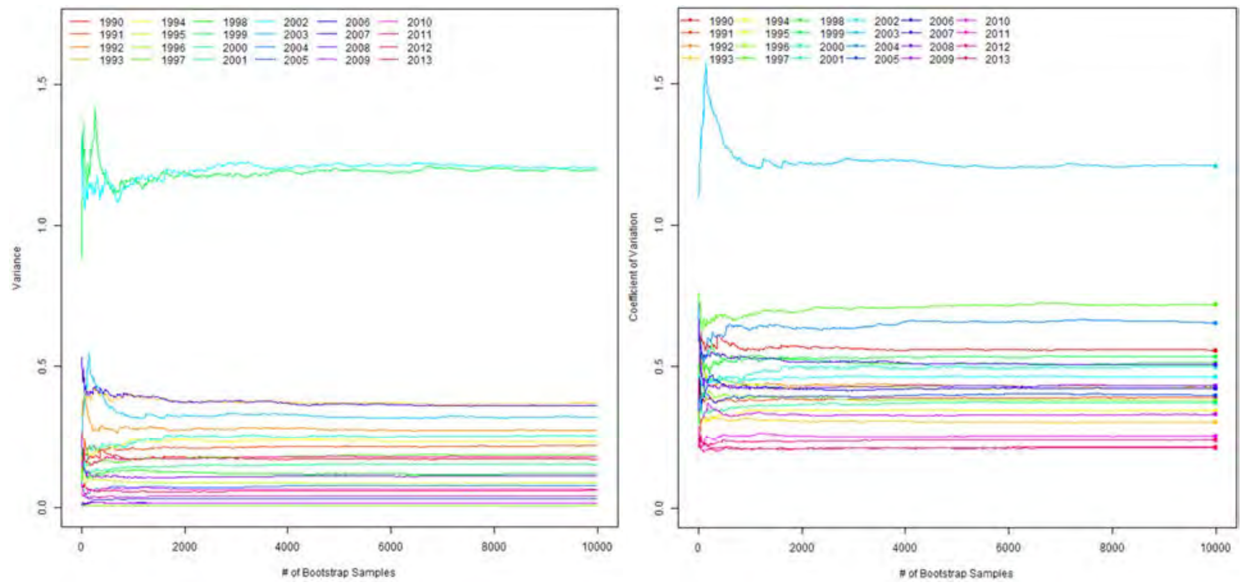


Figure 10. Bootstrap diagnostic plots used to determine if variance (left) and coefficient of variation (CV; right) estimates stabilized over the number of bootstrap iterations run.

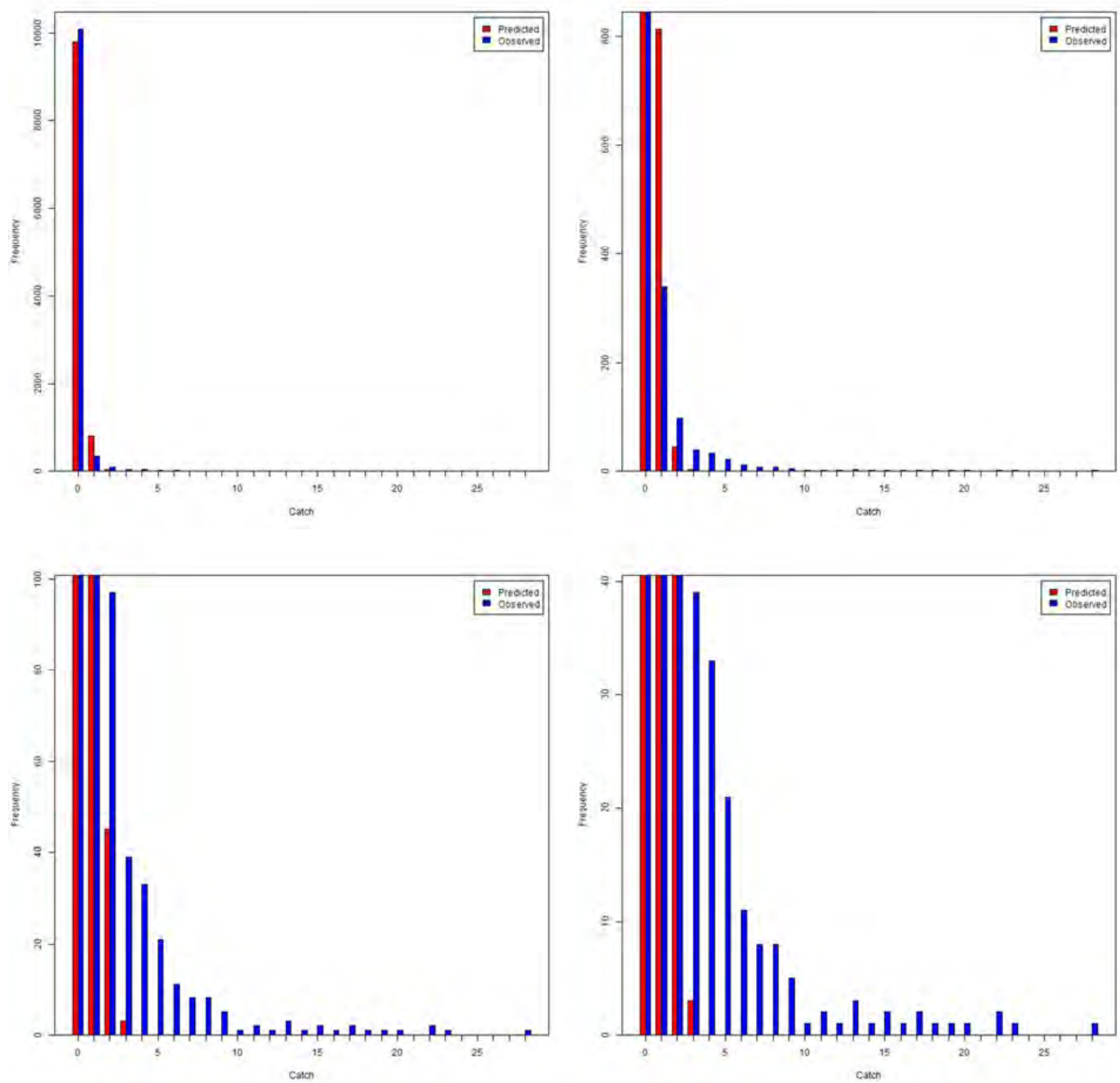


Figure 11. Frequency of traps observed (Observed) with a given catch of Red Snapper or predicted by the ZINB (Predicted). Plots represent the same data, with the y-axis truncated to better resolve low frequencies as one moves clockwise through the plots starting with the top left plot.

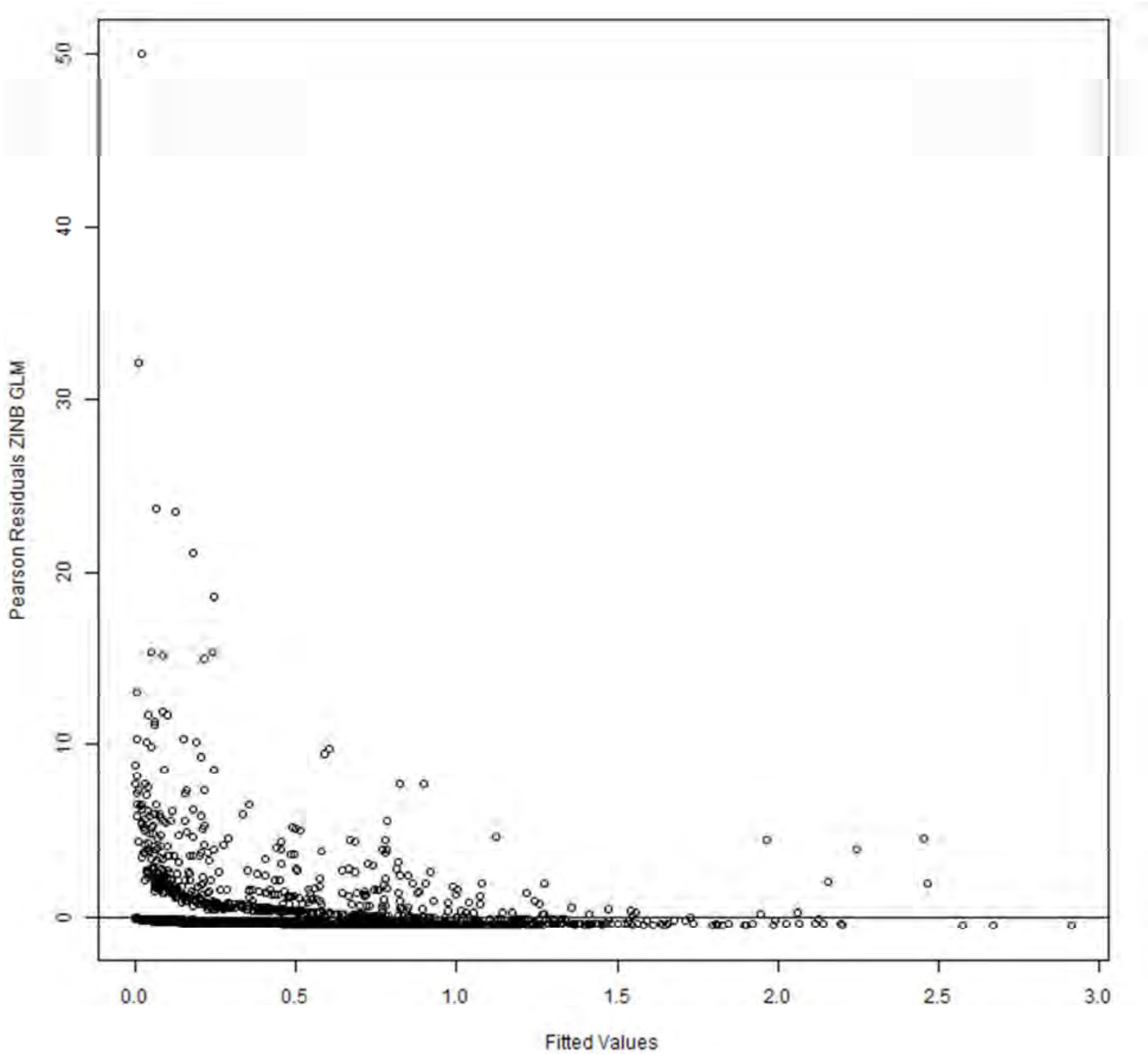


Figure 12. Pearson residuals versus fitted values for the final ZINB model.

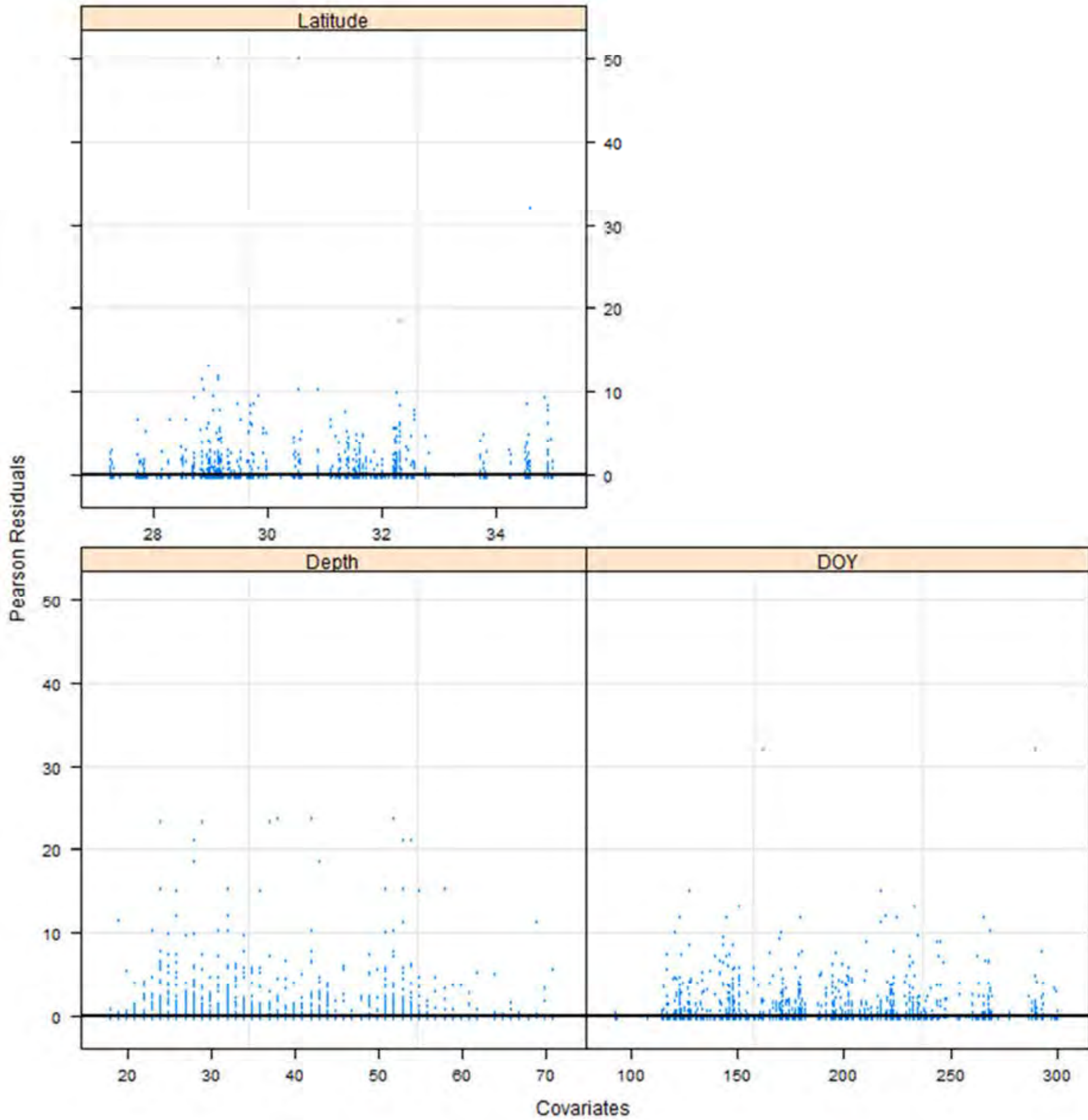


Figure 13. Pearson residuals versus covariates included in the final ZINB model.

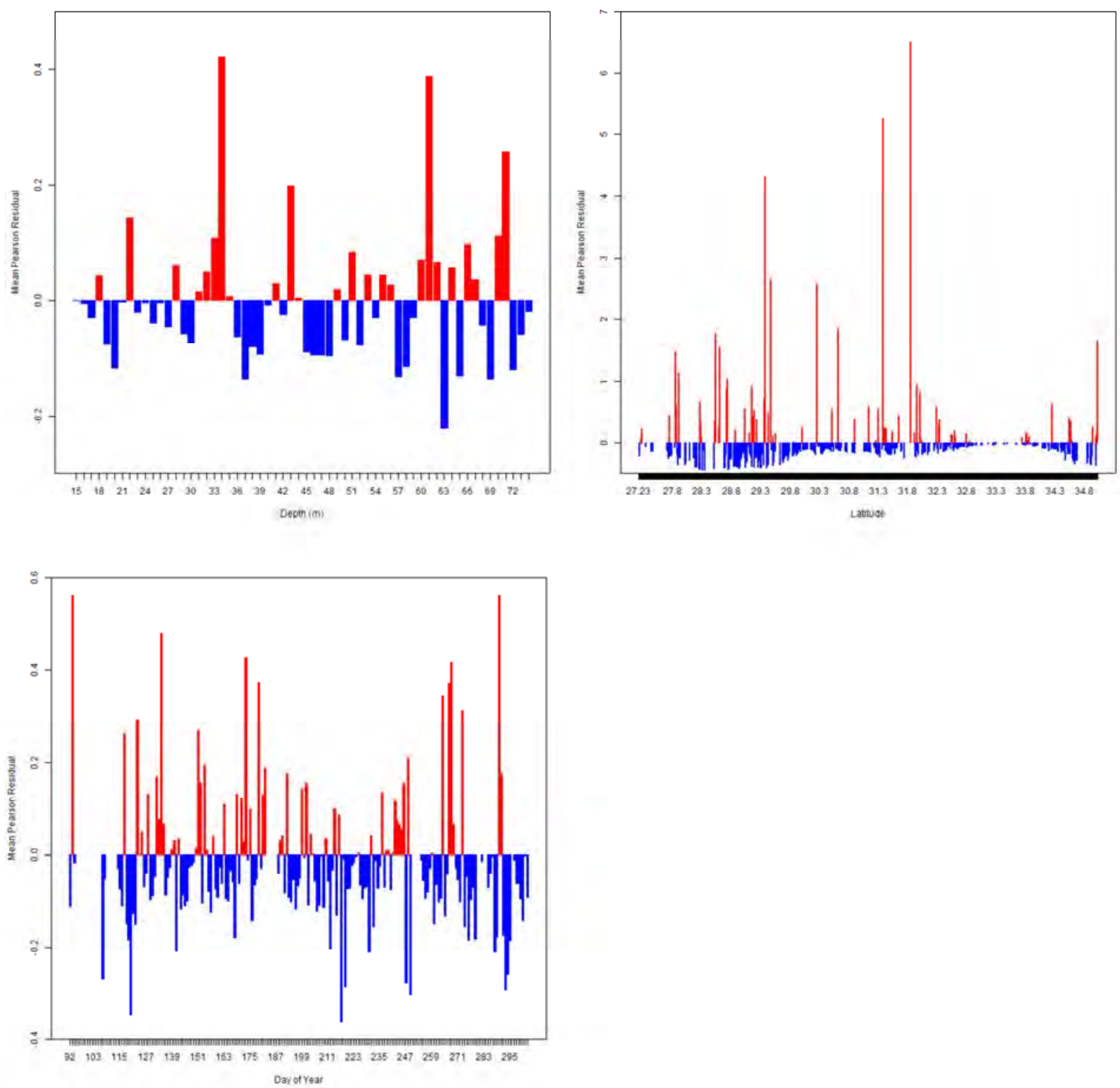


Figure 14. Mean Pearson residual versus included covariates for the final ZINB model.

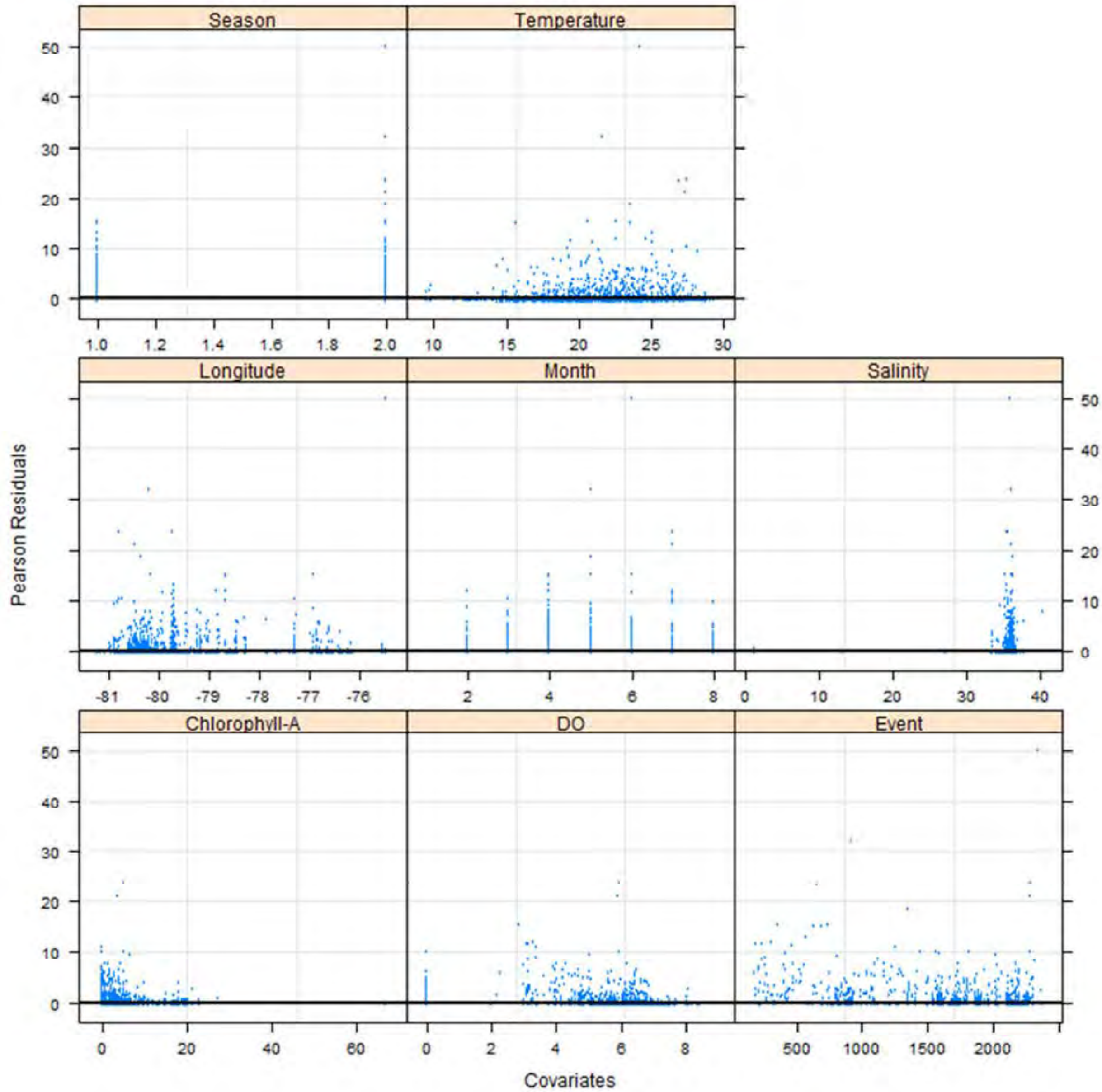


Figure 15. Pearson residuals versus covariates excluded from the final ZINB model.

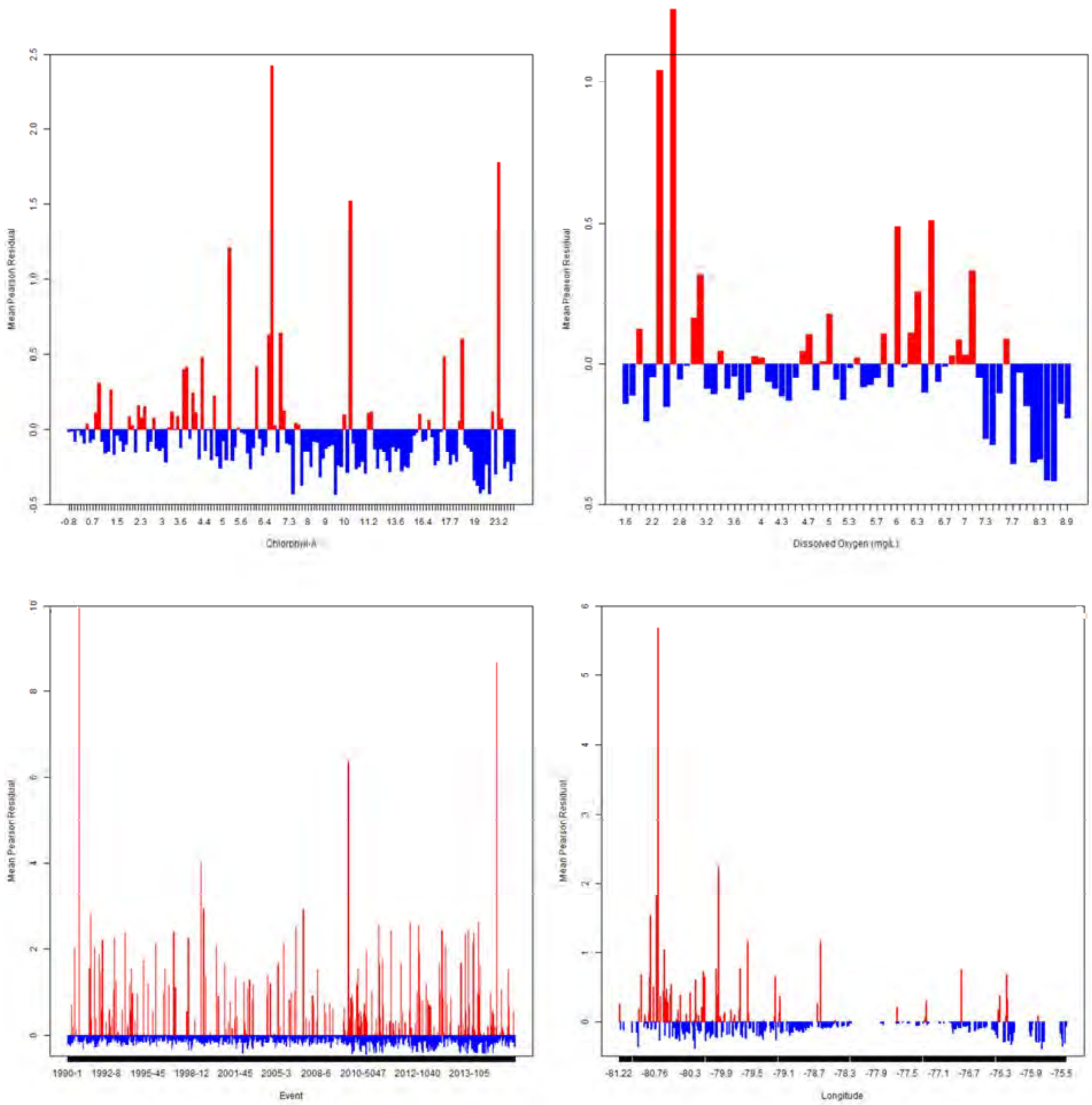


Figure 16. Mean Pearson residuals versus covariates excluded from the final ZINB model.

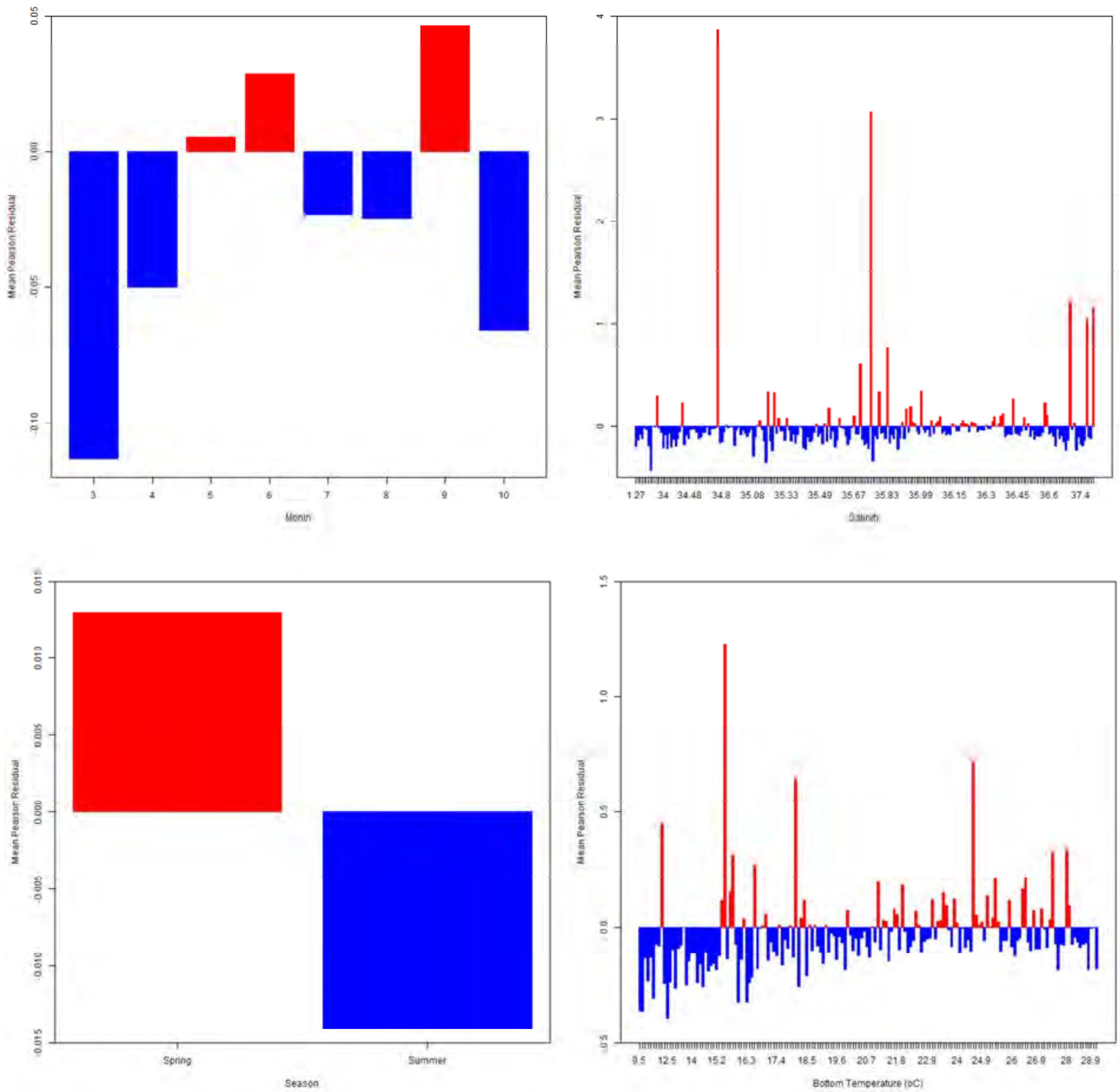


Figure 16 (cont). Mean Pearson residuals versus covariates excluded from the final ZINB model.

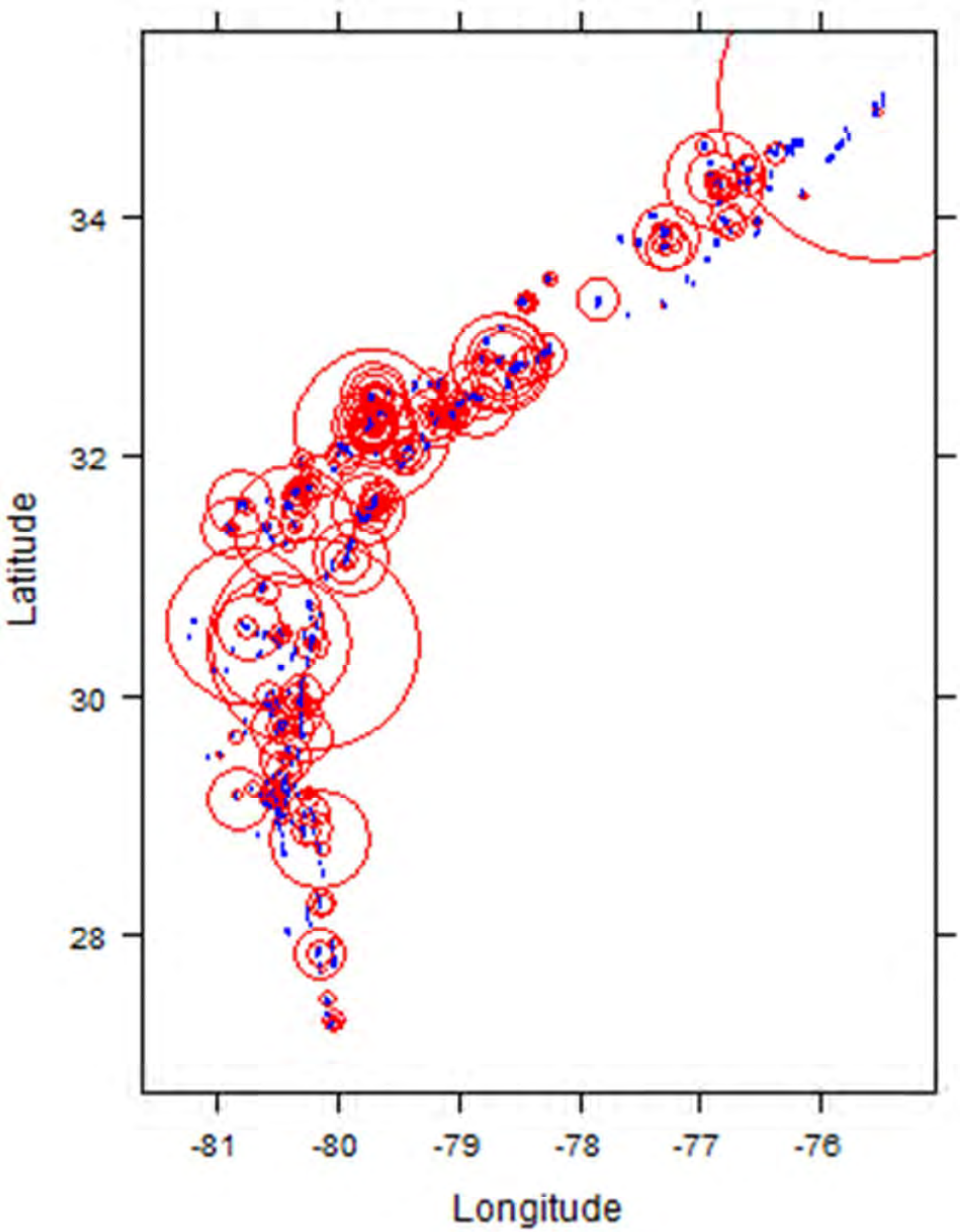


Figure 17. Spatial distribution of Pearson residuals. Red circles indicate positive Pearson residuals and blue circles represent negative Pearson residuals. Size of the circle is indicative of the magnitude of the residual with larger circles corresponding to larger Pearson residual values.

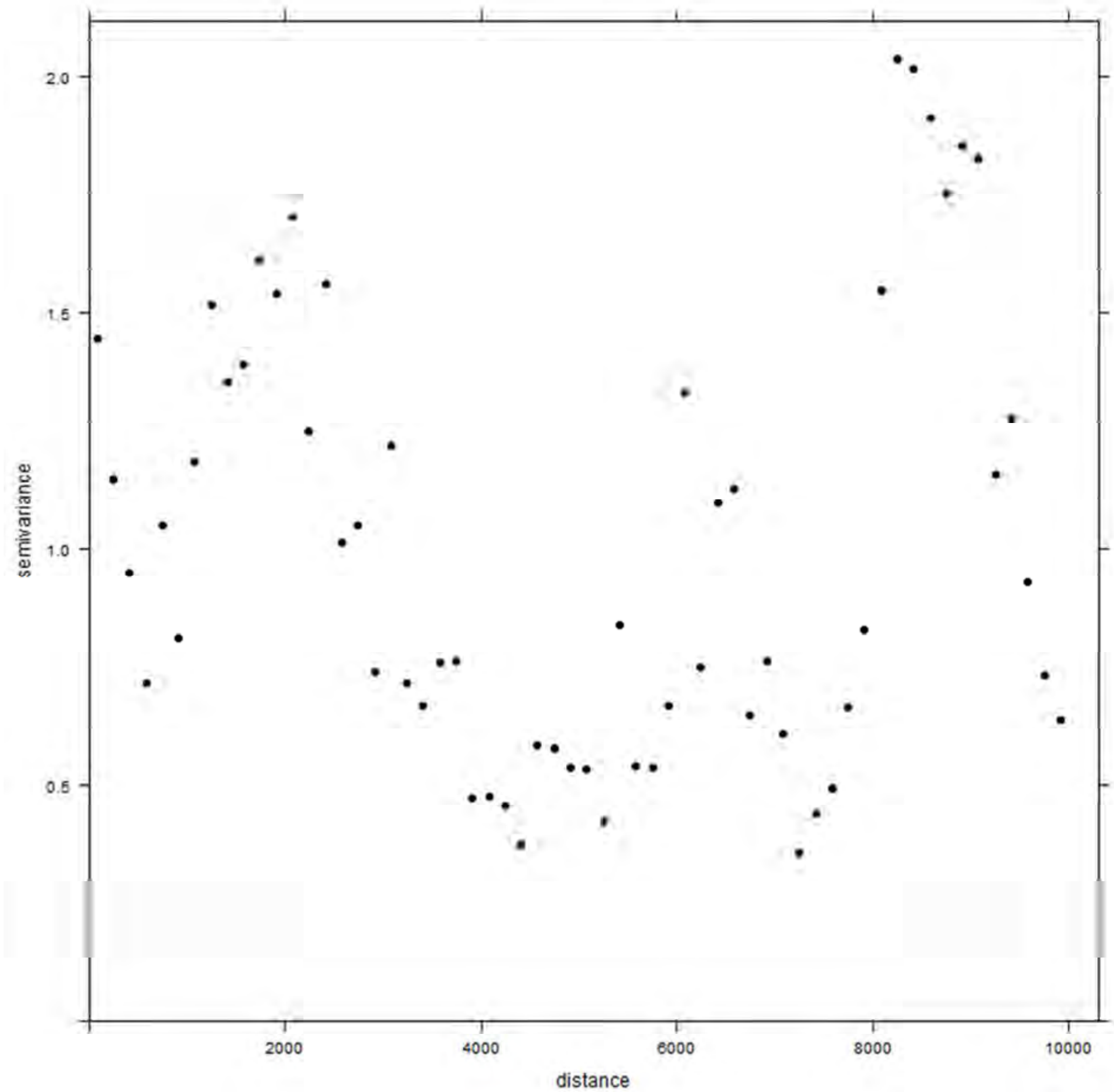


Figure 18. Sample variogram of Pearson residuals. The sample variogram is limited to 10,000 m (10 km).

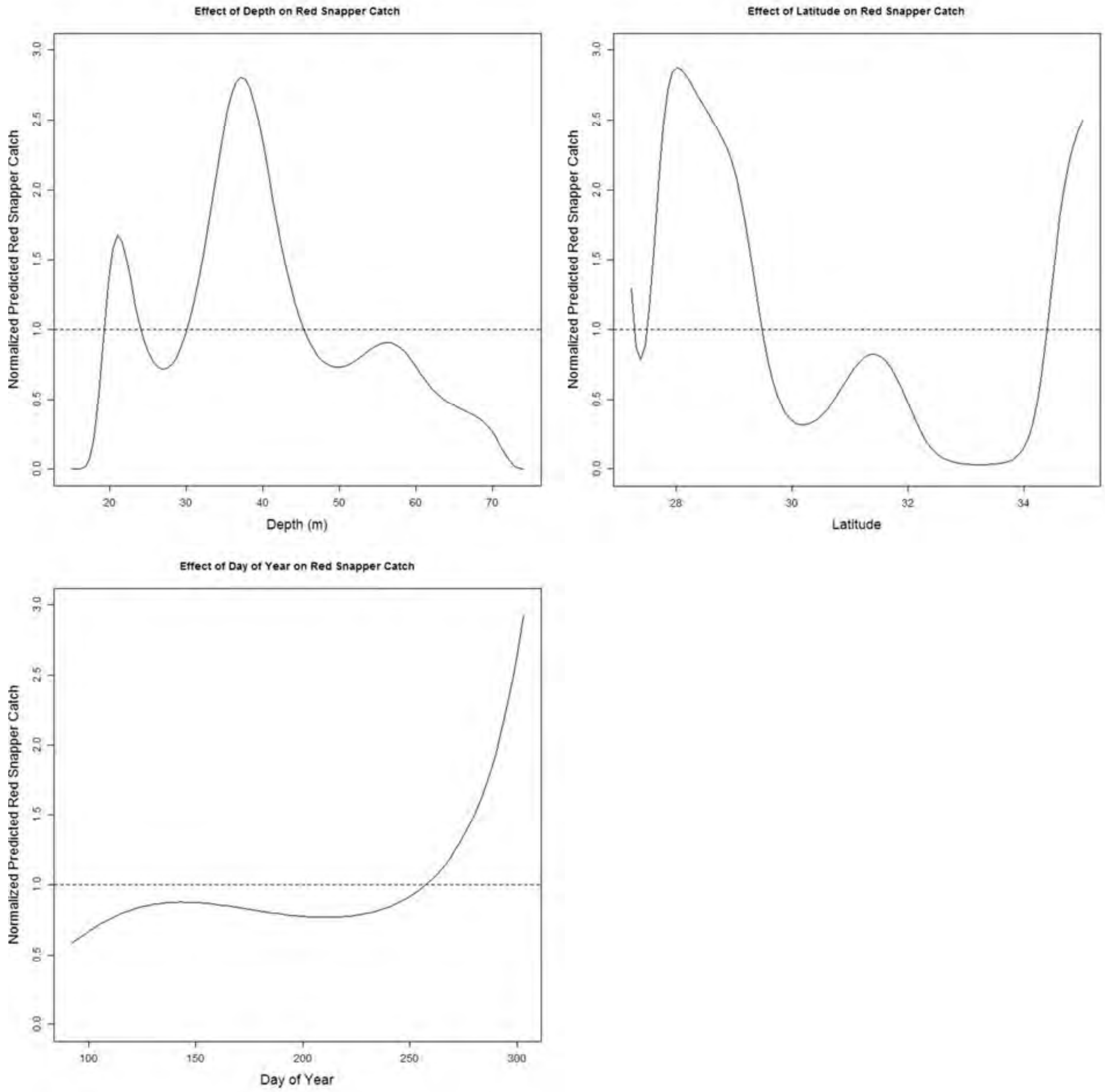


Figure 19. Covariate effects on predicted red snapper catch.

Addendum Figures

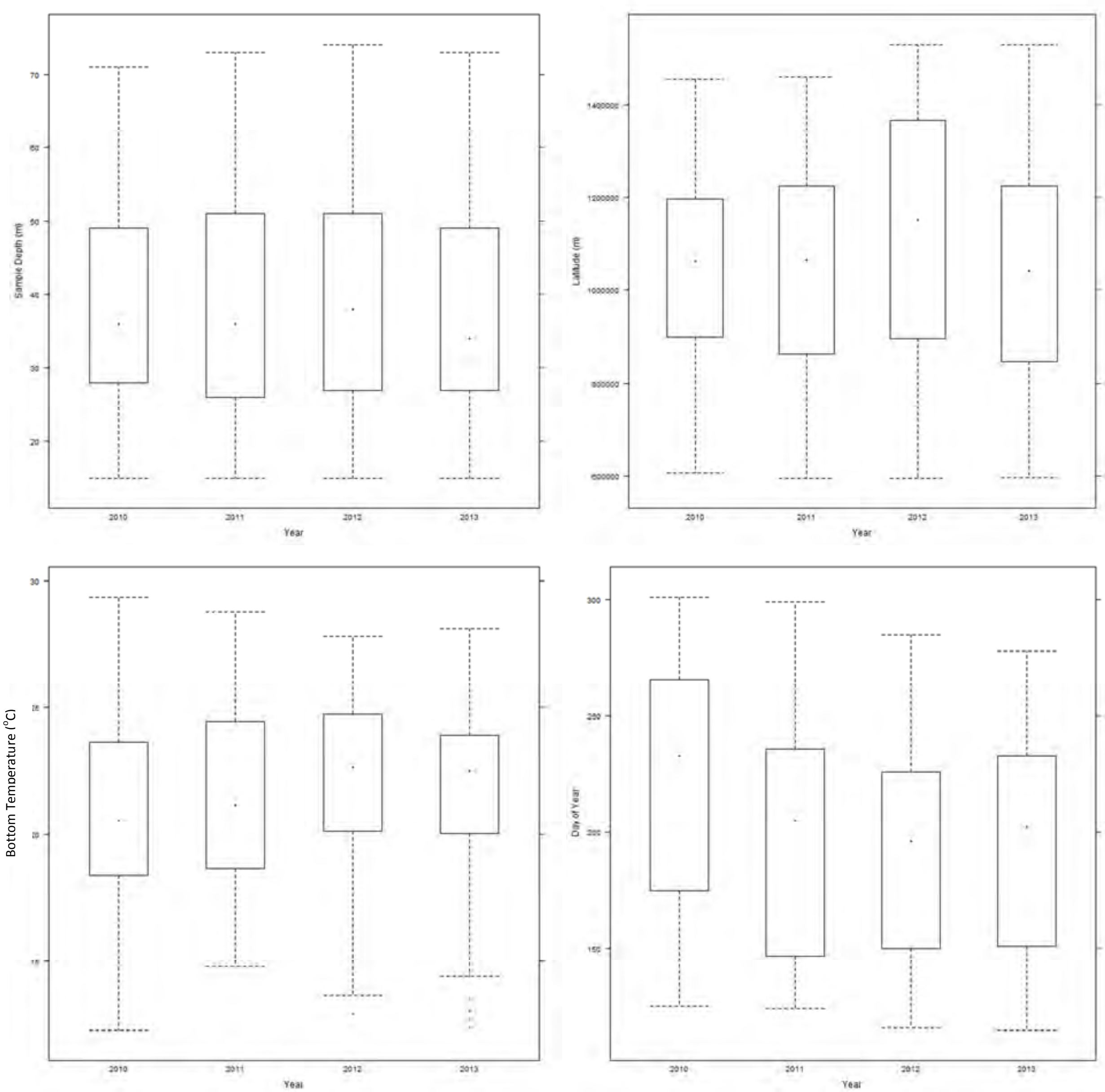


Figure 20. Box plots of depth (top left), latitude (top right), bottom temperature (bottom left), and day of year (bottom right) as a function of year.

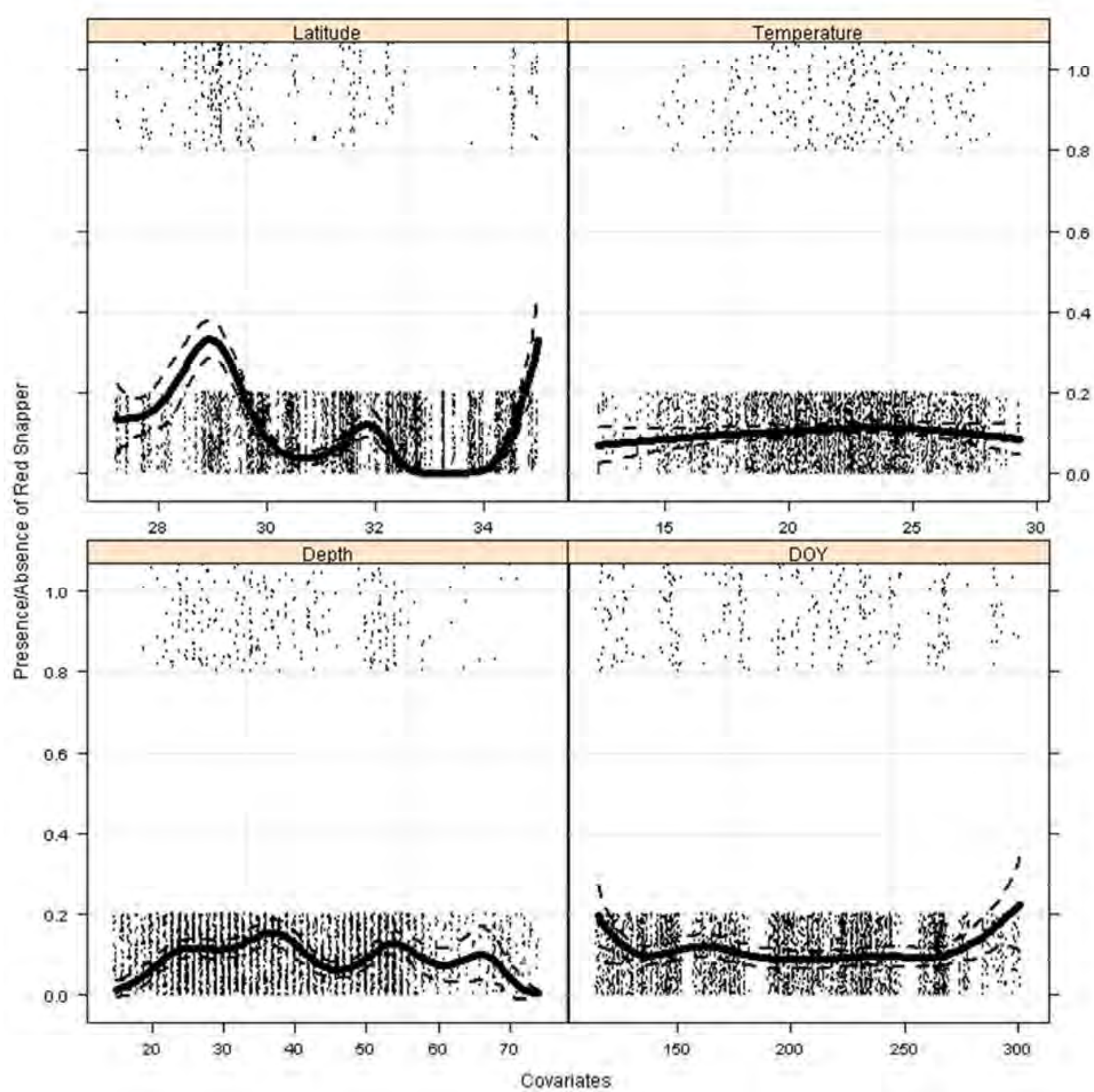


Figure 21. Presence (1) and absence (0) of Red Snapper with respect to the considered covariates, latitude (°N), depth (m), bottom temperature (^{o}C), and day of year (DOY). The raw presence/absence data has been jittered in the figure. The solid black line represents a fitted GAM to the presence/absence data with respect to a given covariate. Dashed black lines represent 95% confidence intervals around the GAM fit.

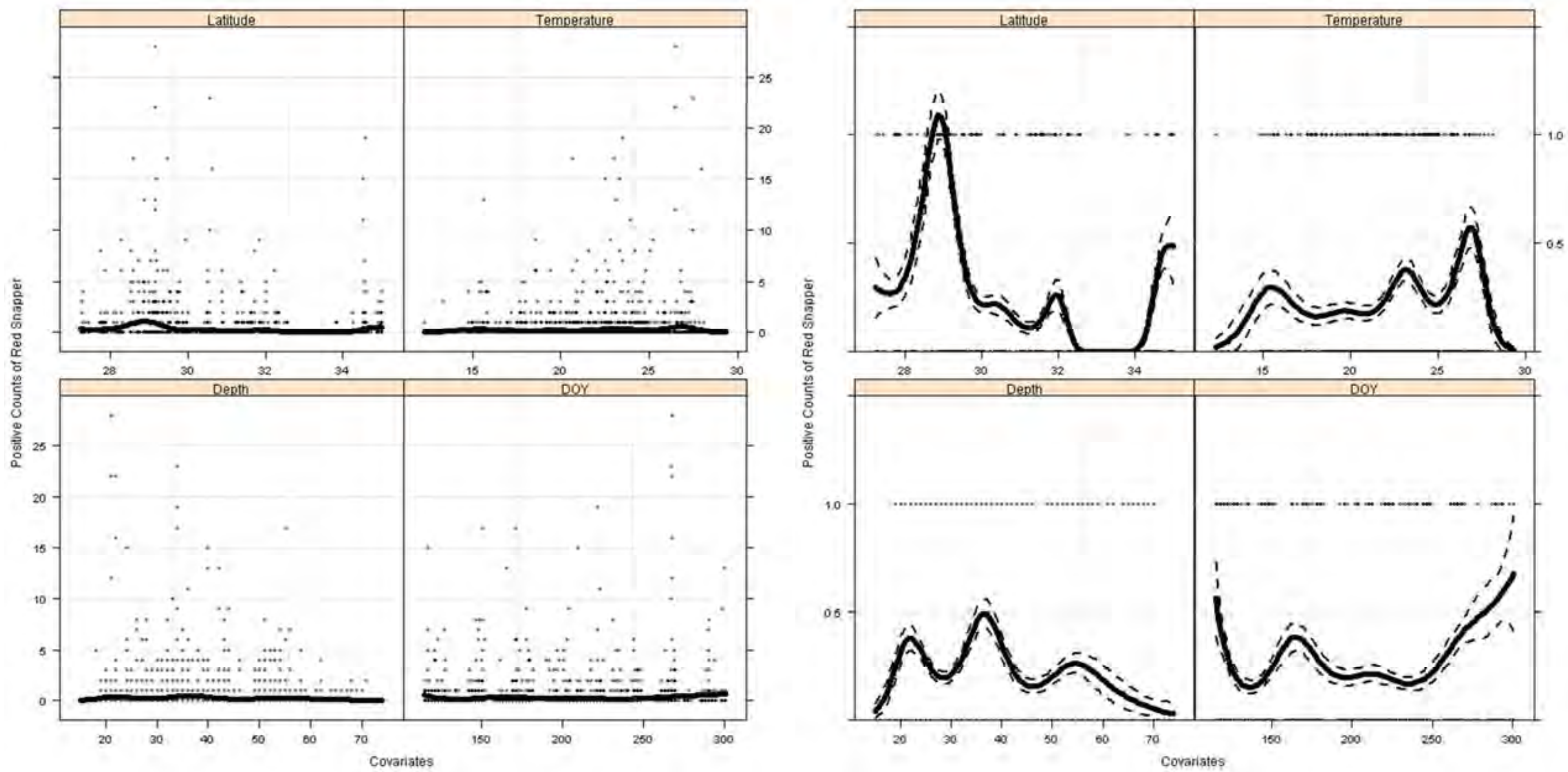


Figure 22. Catch of Red Snapper with respect to the considered covariates, latitude (°N), depth (m), and day of year (DOY). The left panel has an unrestricted y-axis that shows the full catch distribution of Red Snapper. The right panel restricts the y-axis to the range of the GAM model fits to show better detail of the GAM fits. Sold black line represents a fitted GAM to the catch data with respect to a given covariate. Dashed black lines represent 95% confidence intervals about the GAM fit. Only traps that caught Red Snapper were considered for the GAM fits.

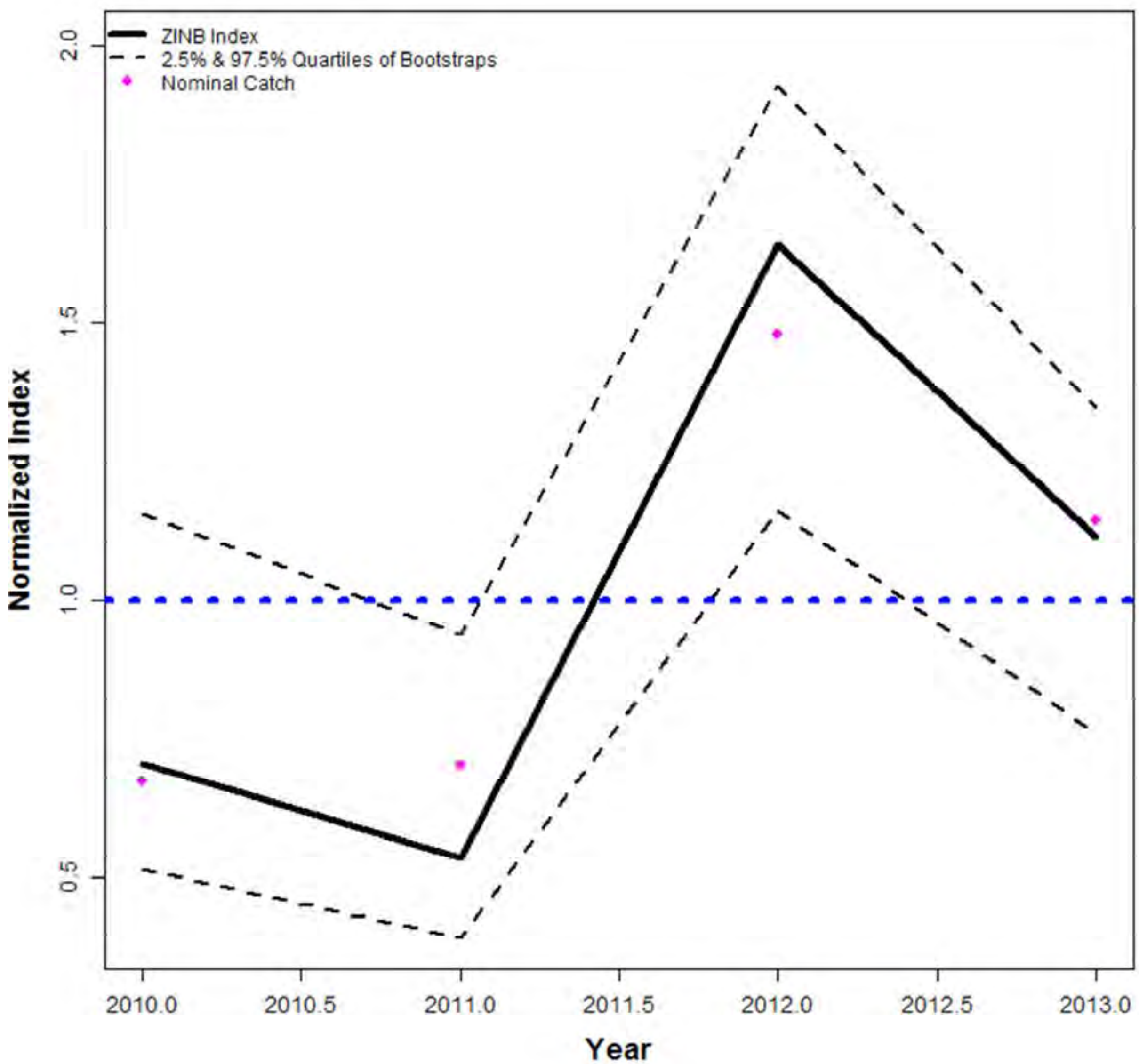


Figure 23. Red Snapper index of relative abundance for chevron traps. Nominal catch and Zero-inflated negative binomial (ZINB) standardized catch normalized to each index's long-term mean to provide relative abundance.

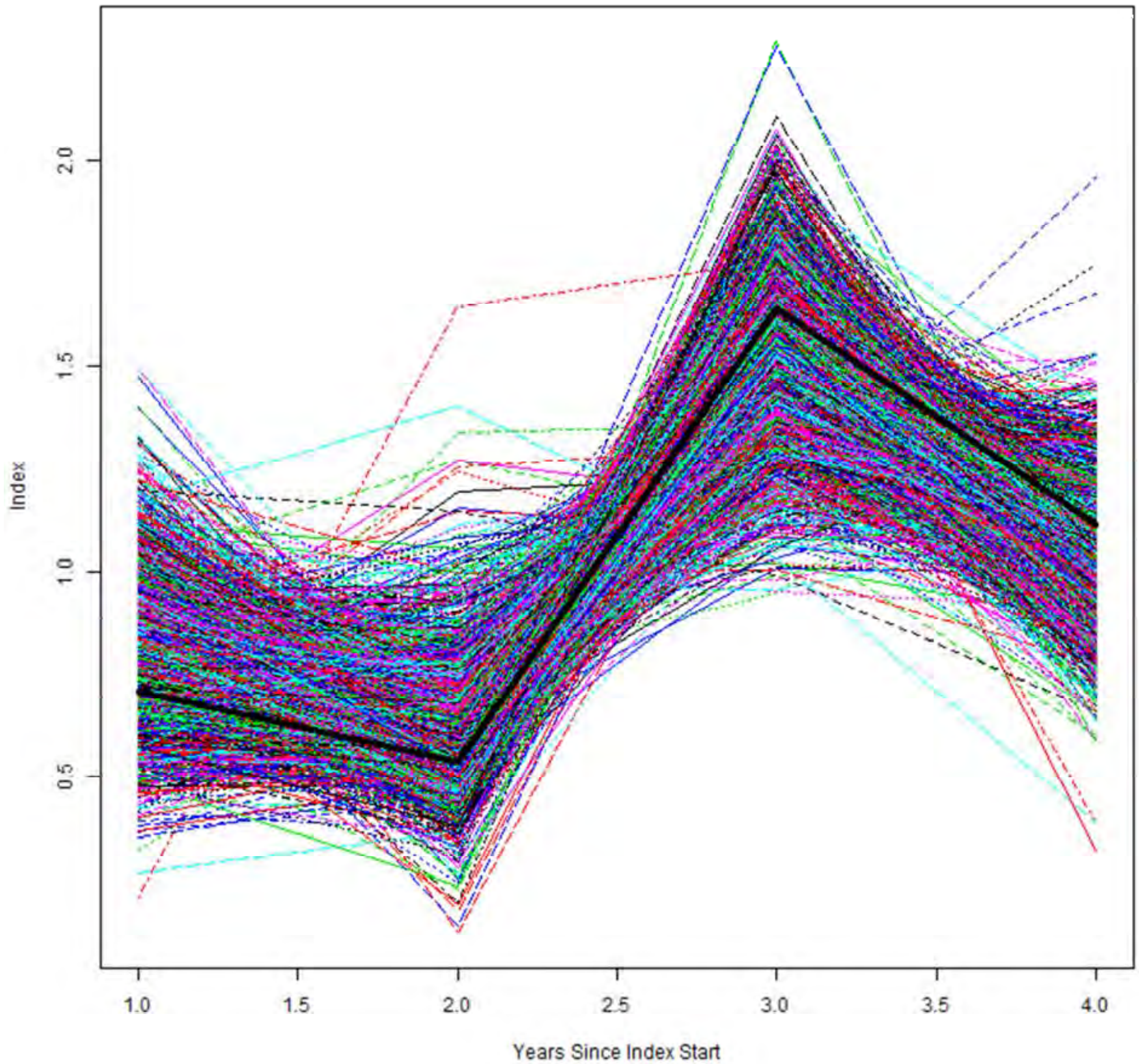


Figure 24. Plot of all individual bootstrap runs normalized annual relative abundance index. Superimposed (black line) is the predicted annual relative abundance index based on the observed catch data.

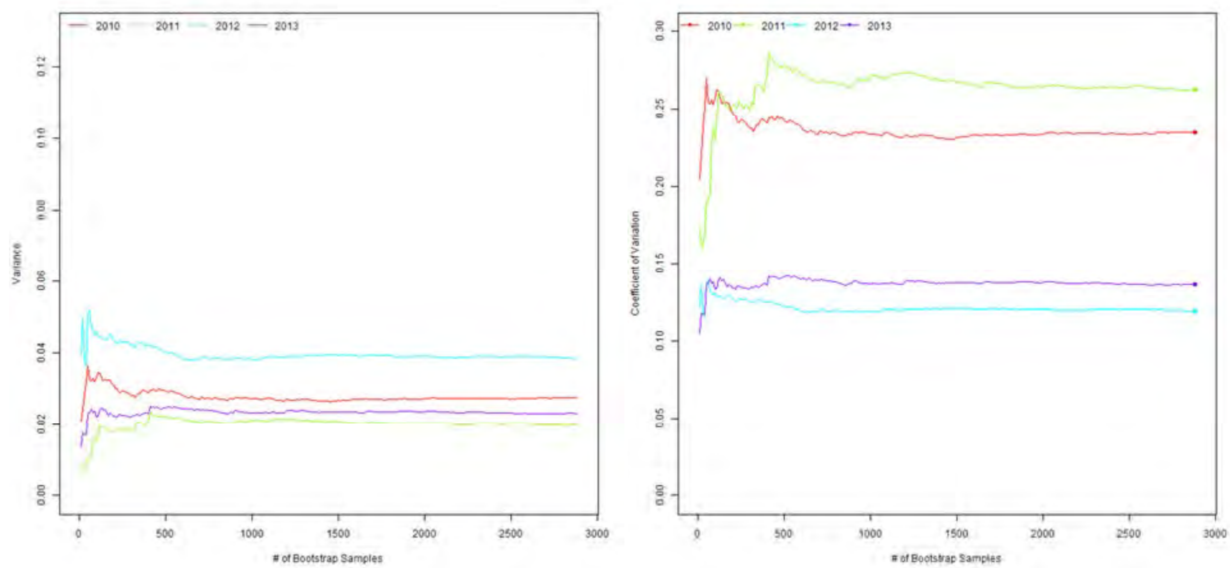


Figure 25. Bootstrap diagnostic plots used to determine if variance (left) and coefficient of variation (CV; right) estimates stabilized over the number of bootstrap iterations run.

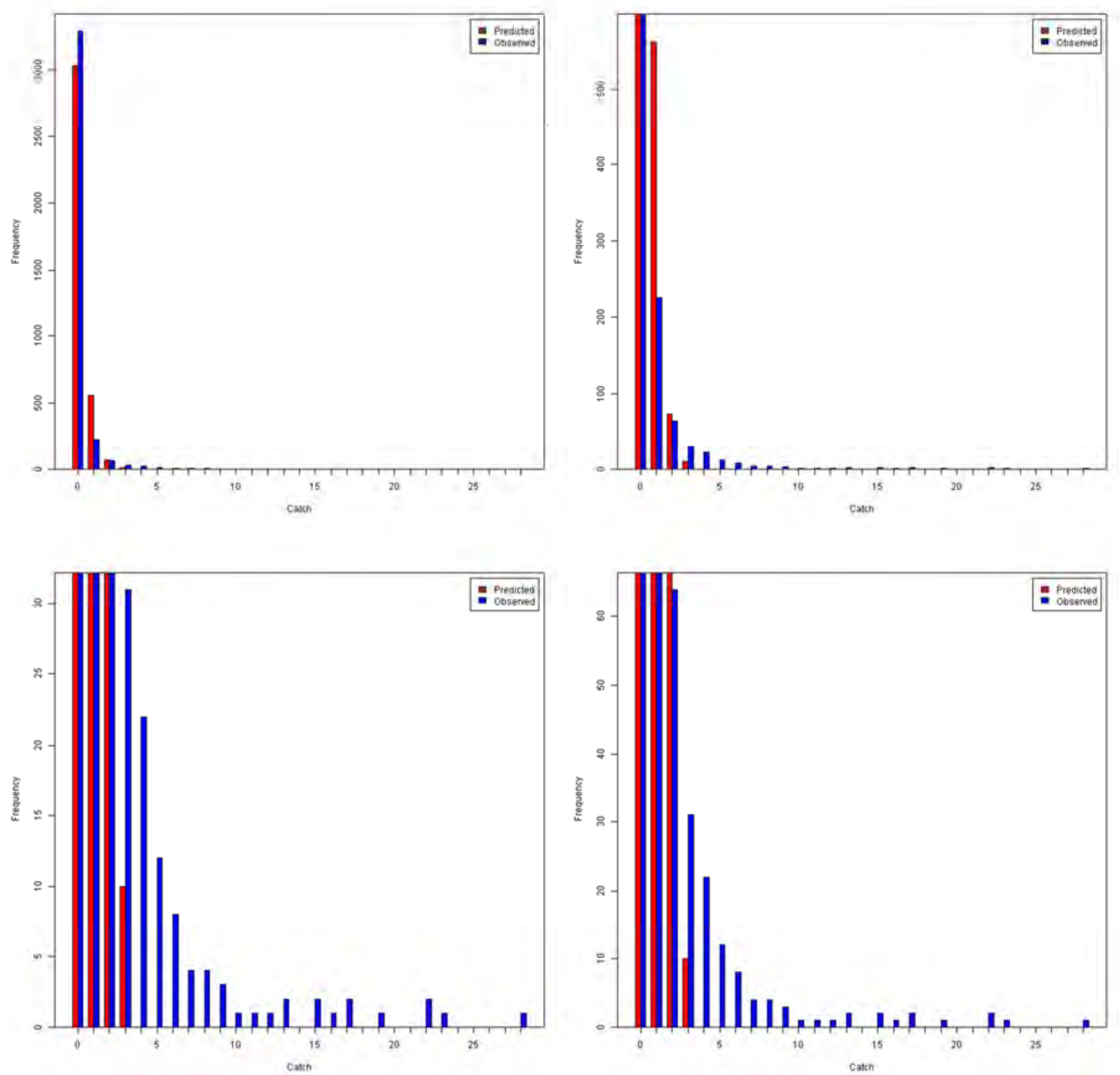


Figure 26. Frequency of traps observed (Observed) with a given catch of Red Snapper or predicted by the ZINB (Predicted). Plots represent the same data, with the y-axis truncated to better resolve low frequencies as one moves clockwise through the plots starting with the top left plot.

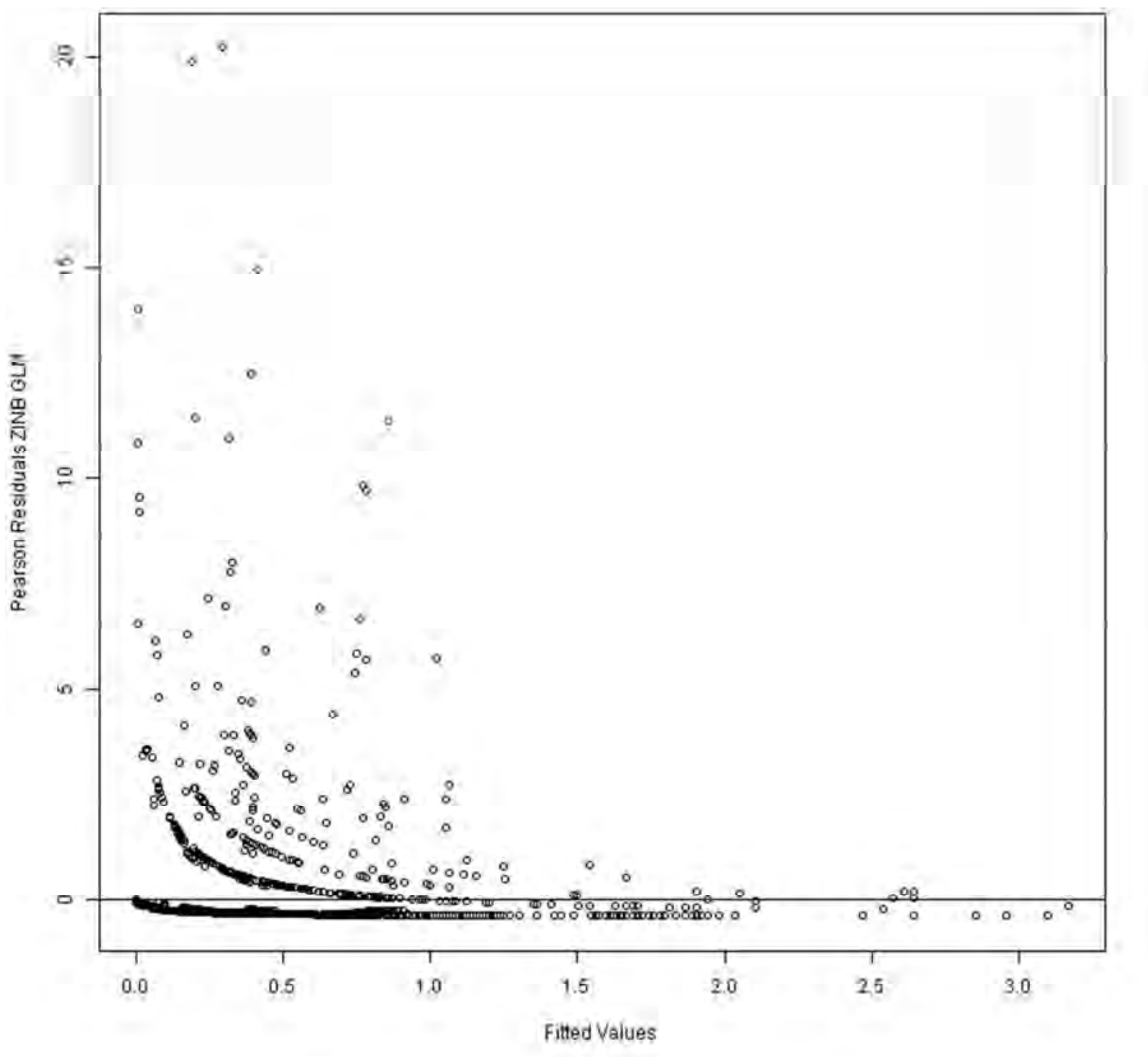


Figure 27. Pearson residuals versus fitted values for the final ZINB model.

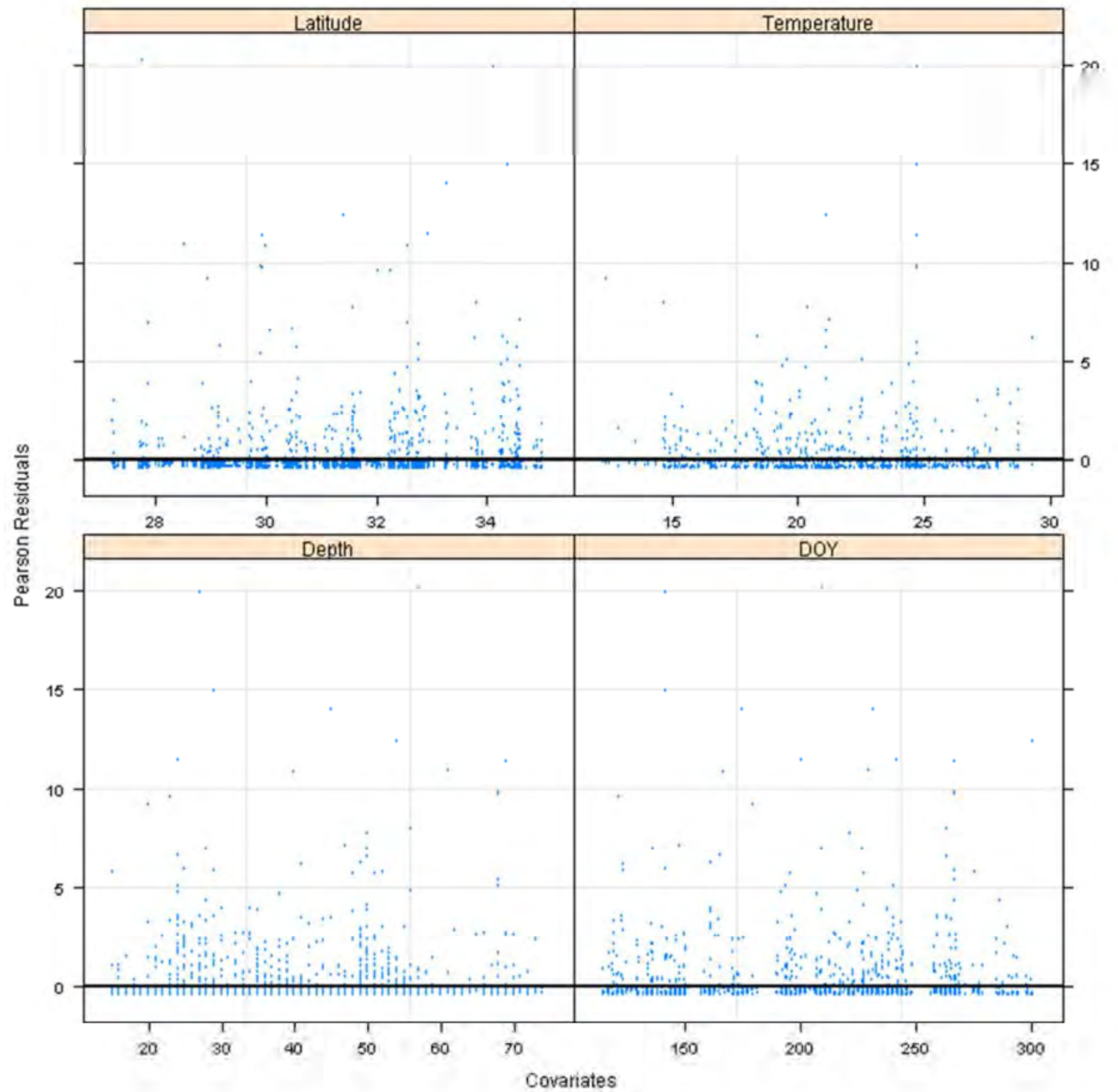


Figure 27. Pearson residuals versus covariates included in the final ZINB model.

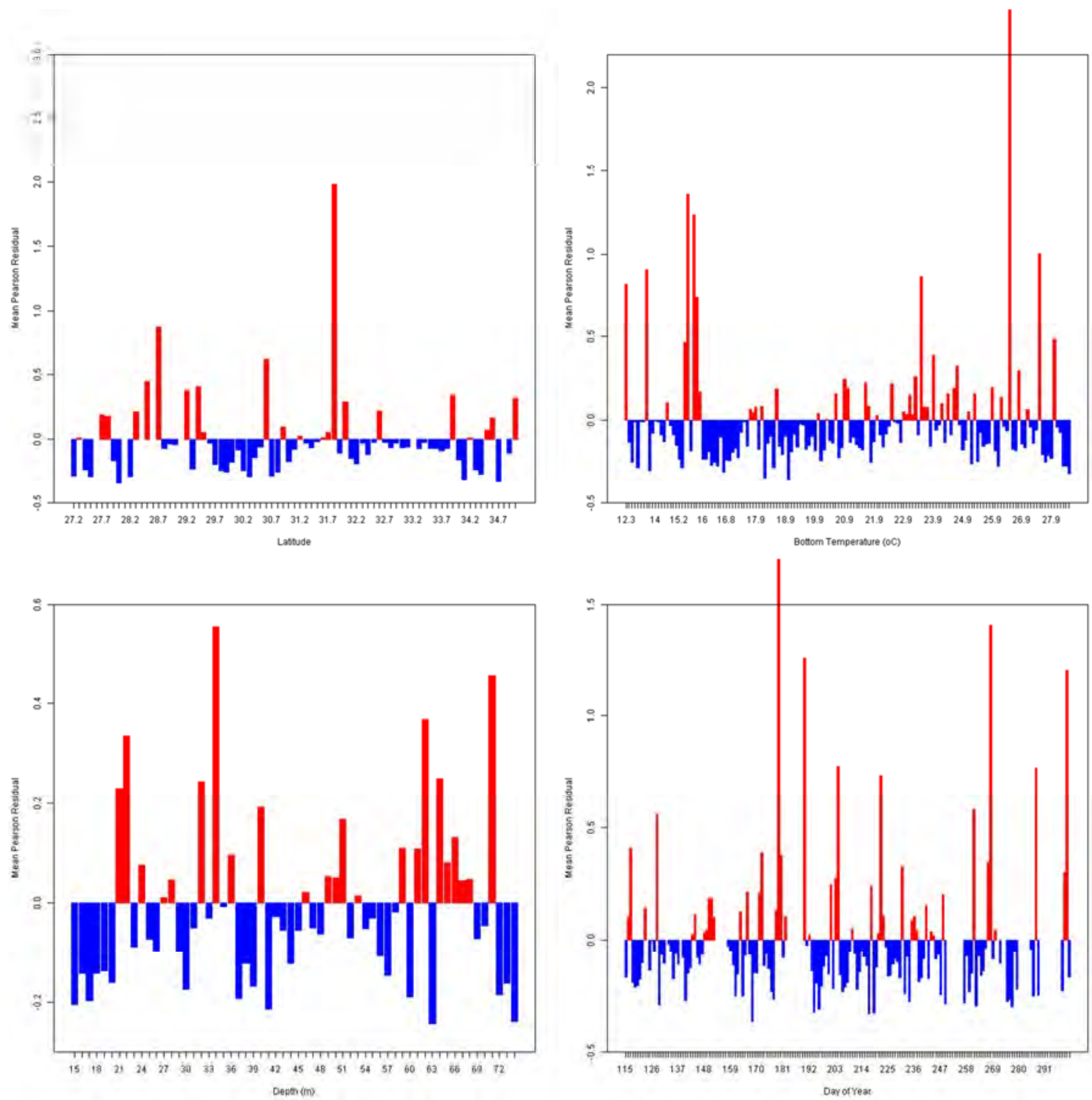


Figure 29. Mean Pearson residual versus included covariates for the final ZINB model.

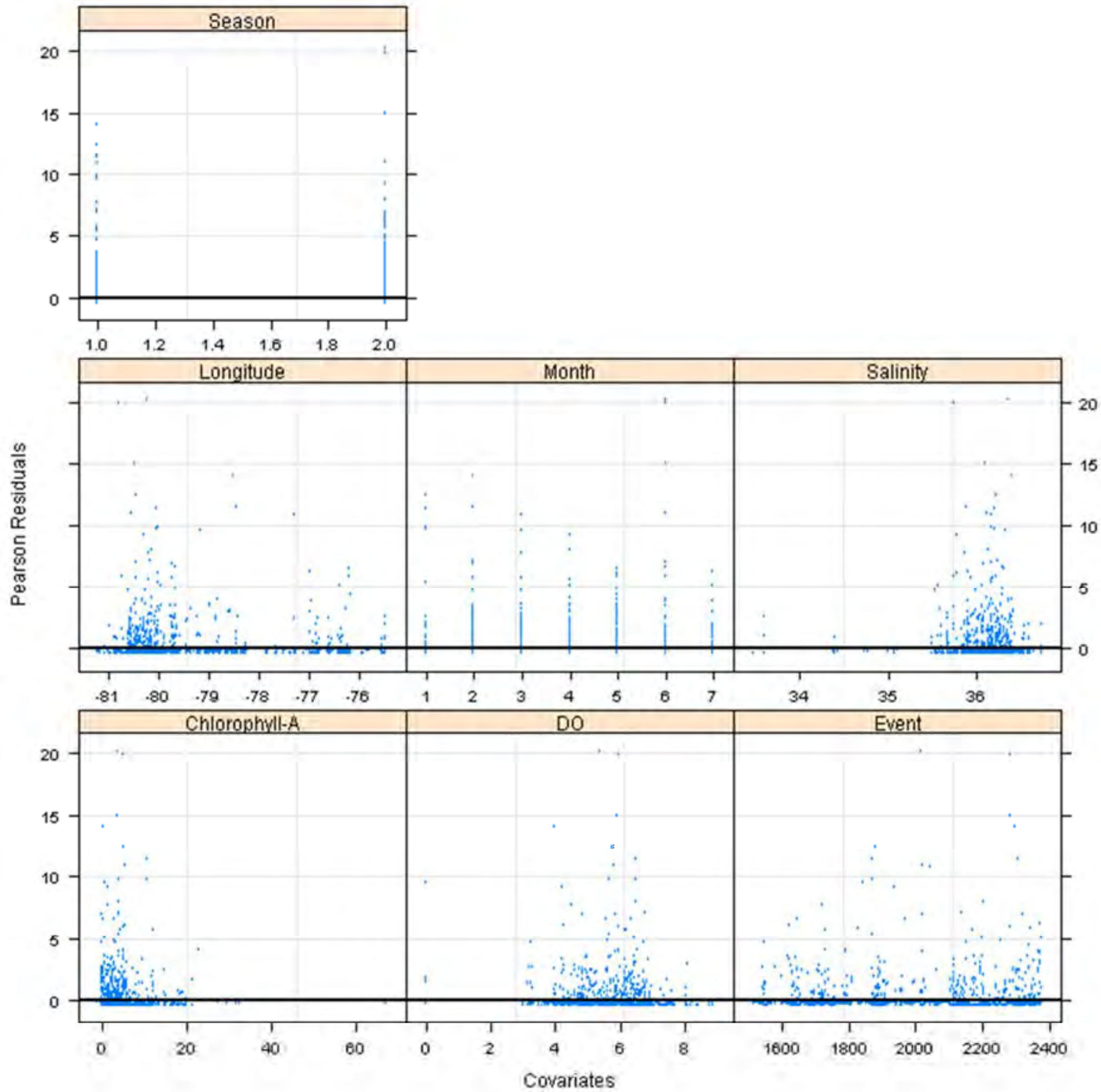


Figure 30. Pearson residuals versus covariates excluded from the final ZINB model.

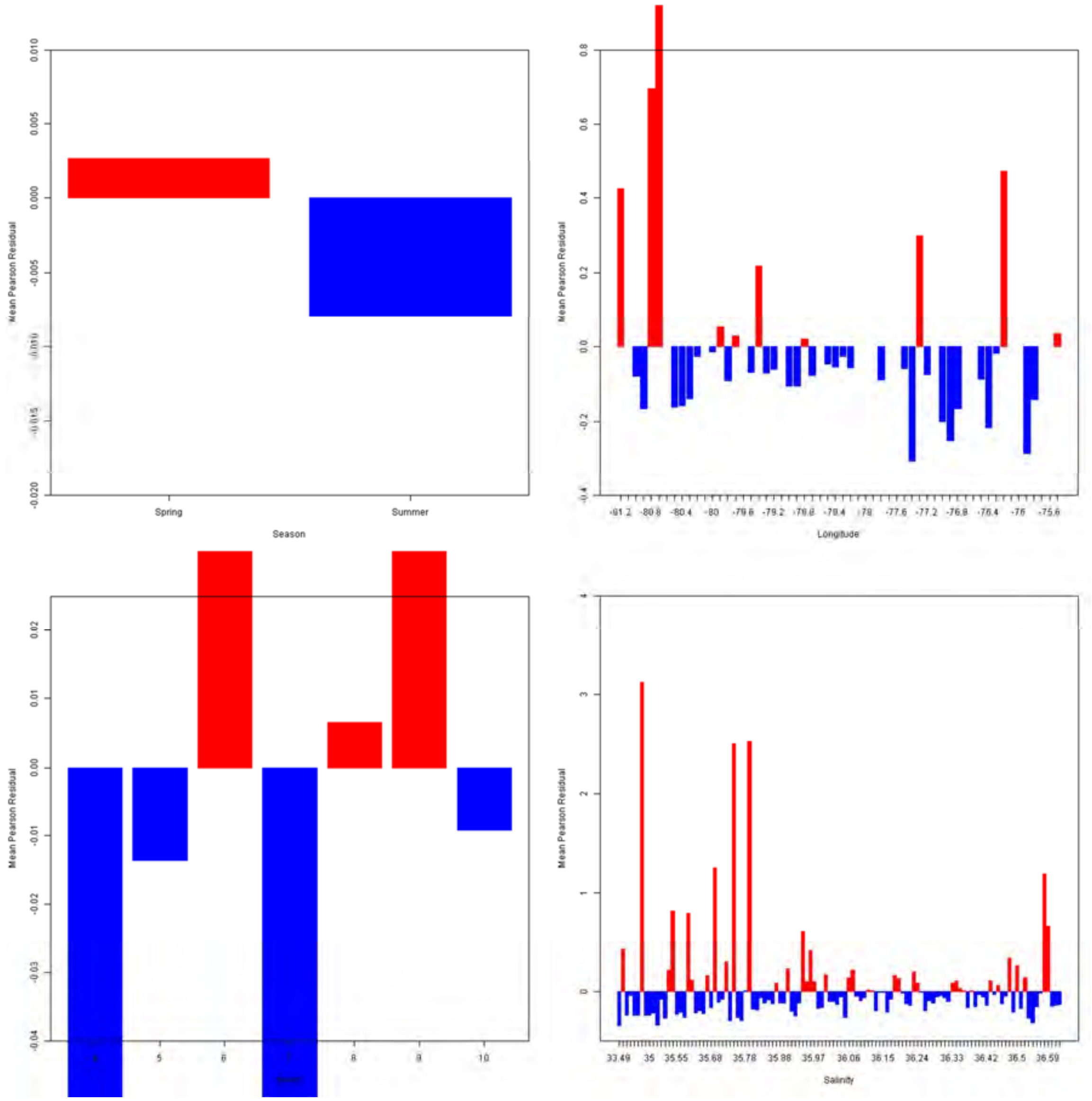


Figure 31. Mean Pearson residuals versus covariates excluded from the final ZINB model.

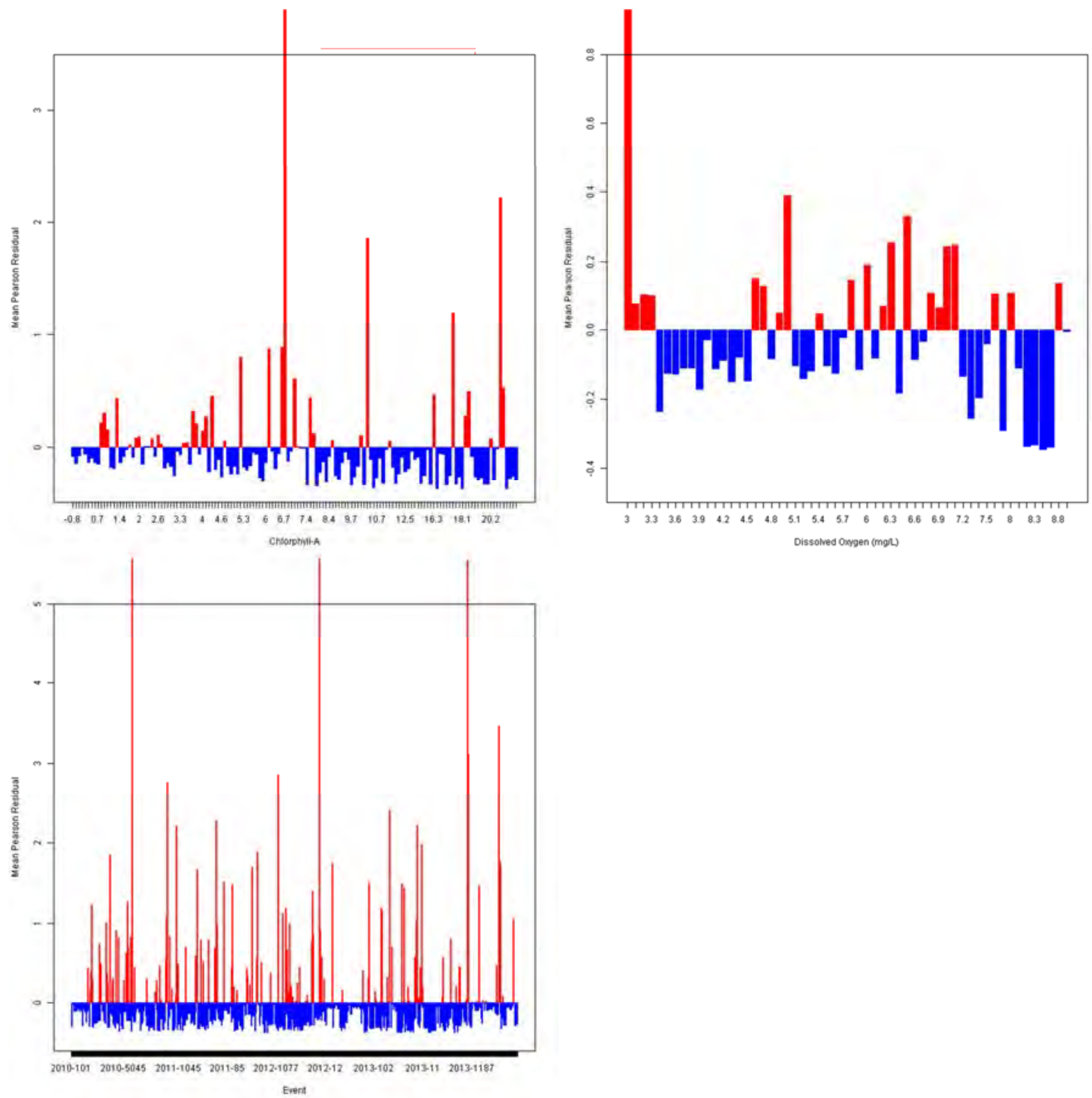


Figure 31 (cont). Mean Pearson residuals versus covariates excluded from the final ZINB model.

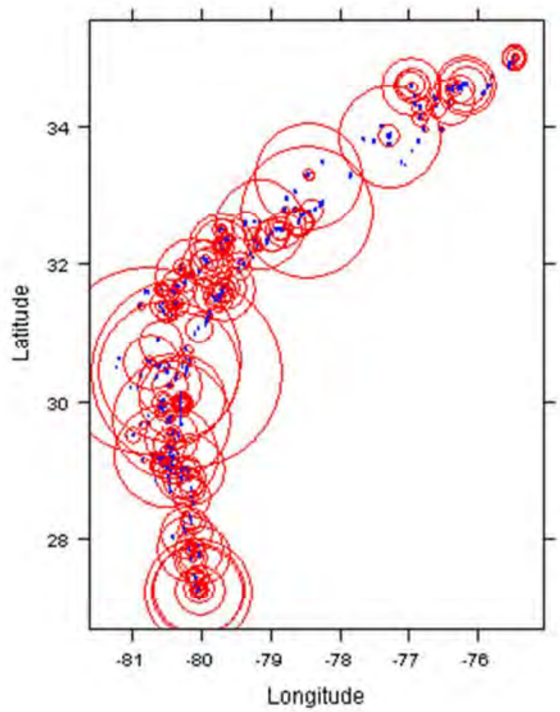


Figure 32. Spatial distribution of Pearson residuals. Red circles indicate positive Pearson residuals and blue circles represent negative Pearson residuals. Size of the circle is indicative of the magnitude of the residual with larger circles corresponding to larger Pearson residual values.

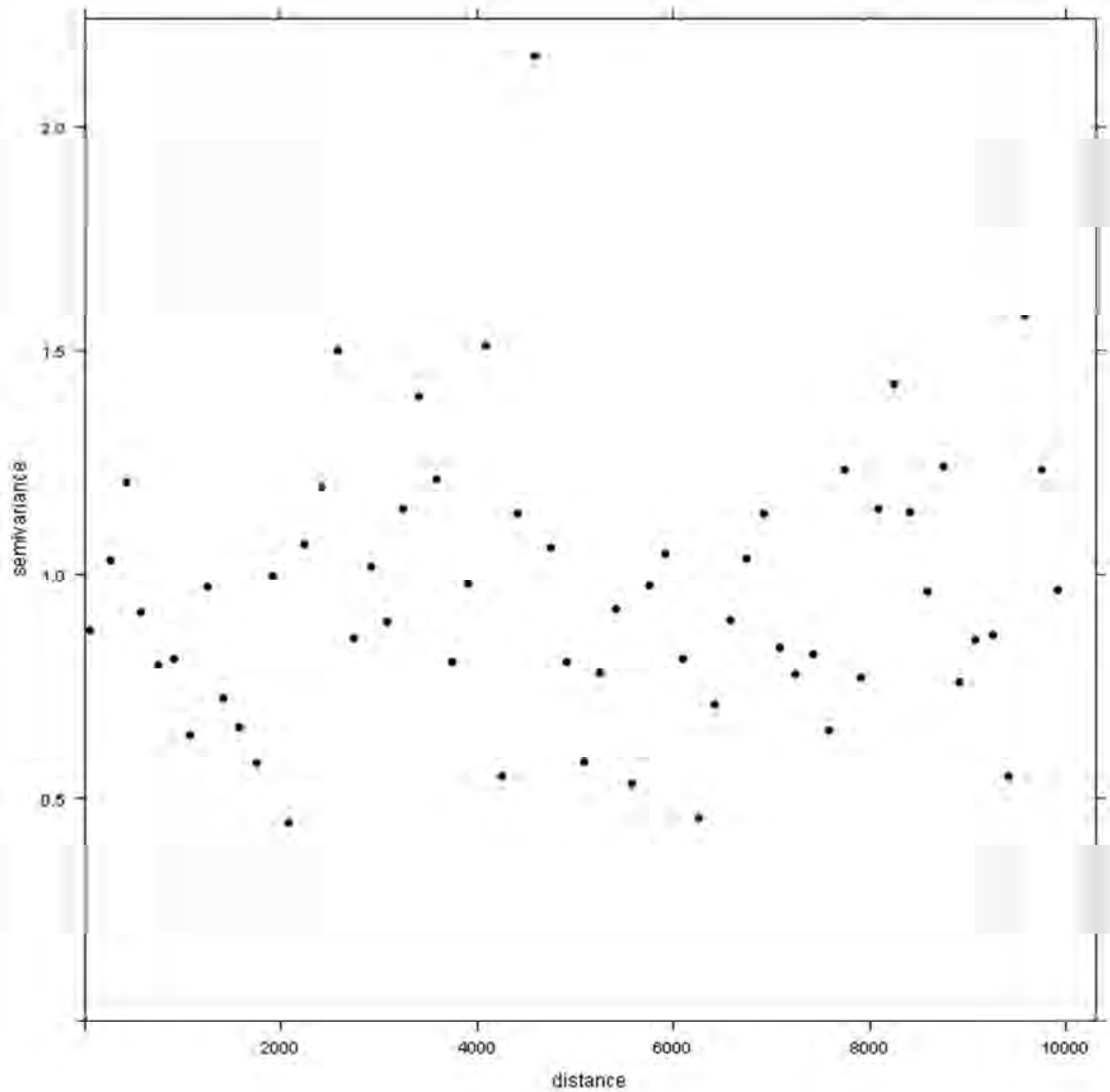


Figure 33. Sample variogram of Pearson residuals. The sample variogram is limited to 10,000 m (10 km).

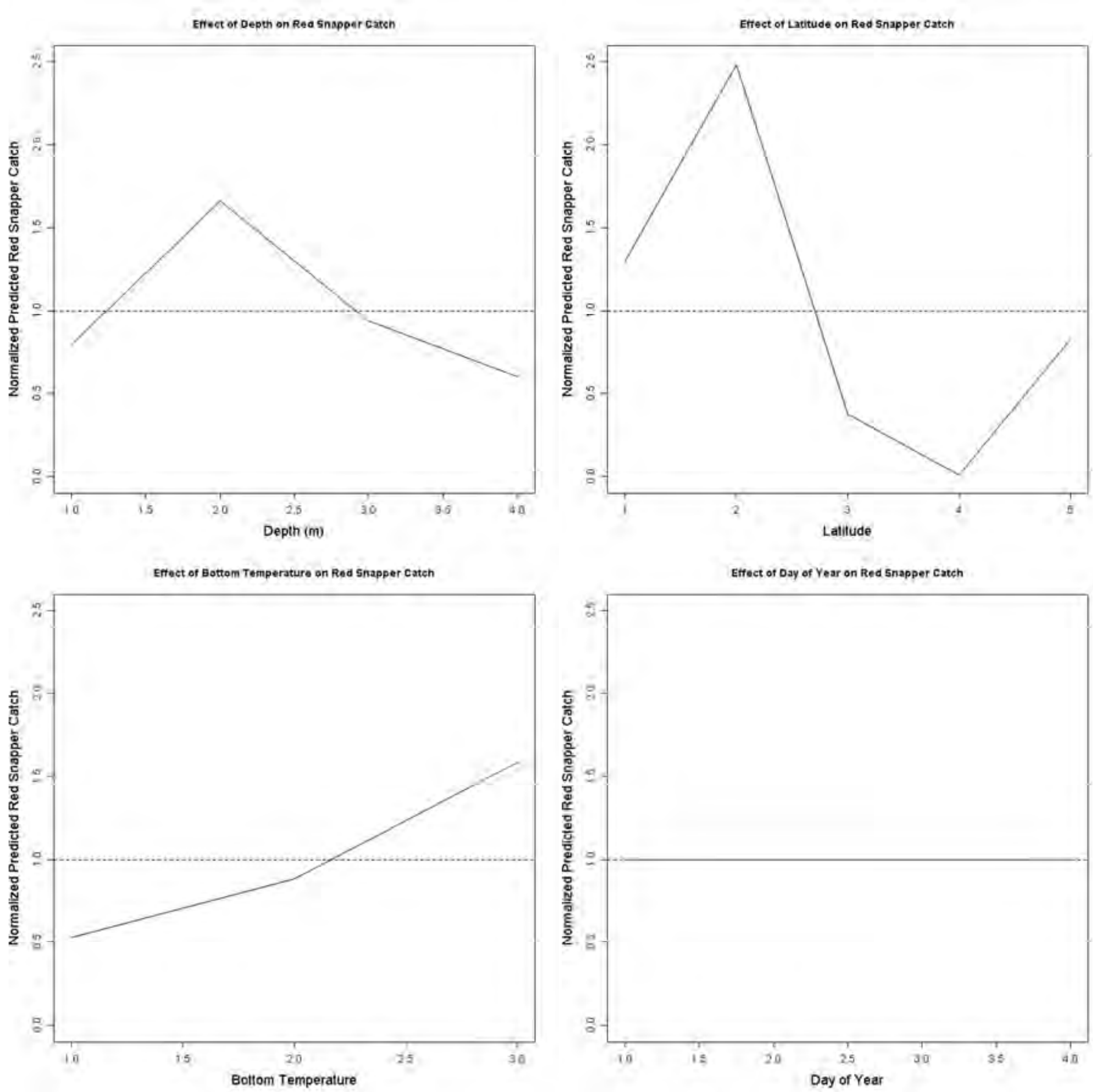


Figure 34. Covariate effects on predicted Red Snapper catch (Day of Year not included in the final model).

Preliminary standardized catch rates of Southeast US Atlantic red snapper (*Lutjanus campechanus*) from headboat logbook data

Sustainable Fisheries Branch, National Marine Fisheries Service (contact: Eric Fitzpatrick)

SEDAR41-DW12

Submitted: 23 July 2014
Addendum: 20 August 2014

***Addendum added to reflect changes made during Data Workshop.**
Final index is found in the addendum.

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Notice on SEDAR Working Papers

Preliminary standardized catch rates of Southeast US Atlantic red snapper (*Lutjanus campechanus*) from headboat logbook data

Sustainable Fisheries Branch, National Marine Fisheries Service,
Southeast Fisheries Science Center,
101 Pivers Island Rd, Beaufort, NC 28516
July 22 2014

***Addendum at end of document reflecting changes made at Data Workshop**

Abstract
Standardized catch rates were generated from the Southeast headboat survey trip records (logbooks) from 1976-2009. The analysis included areas from central North Carolina through south Florida. Data filtering and subsetting steps were applied to the data to model trips that were likely to have directed red snapper effort. The preliminary decisions made prior to the data workshop are presented here. The final results of the headboat index will be presented in the SEDAR 41 Data Workshop Report.

Background

The headboat fishery in the south Atlantic includes for-hire vessels. The fishery uses hook and line gear, generally targets hard bottom reefs as the fishing grounds, and generally targets multiple species in the snapper-grouper complex. One of the key characteristics defining a headboat from other recreational fishing such as charter boats is the number of anglers. Prior to 2000 headboats were defined as vessels carrying 15 or more recreational anglers. This criteria changed to 7 or more passengers in 2000 in the Atlantic (Ken Brennan, pers. comm. Dec. 2011).

Headboats in the south Atlantic are sampled from North Carolina to the Florida Keys.
Data have been collected since 1972, but logbook reporting did not start until 1973. In addition, only North Carolina and South Carolina were included in the earlier years of the data set. In 1976, data were collected from North Carolina, South Carolina, Georgia, and northern Florida, and starting in 1978, data were collected from southern Florida (Areas 1-17, Figure 1).

Variables reported in the data set include year, month, day, area, location, trip type, number of anglers, species, catch, and vessel id. Biological data and discard data were recorded for some trips in some years.

A 20” TL minimum size limit for red snapper has been in place since 1992. A 2 fish bag limit began in 1992. The red snapper fishery closed in 2010.

The headboat logbook index was used for SEDAR 24. Additional headboat records from 2010 to 2013 were examined to determine if sufficient data exists to extend this standardized index of abundance for south Atlantic red snapper. Due to the closure and potential effect on the index, these data were not considered.

Data treatment

Data from area 1 (Figure 1) were excluded as this area was not recorded during most of the time series. The minimum number of anglers per vessel was set at 6, which excluded the lower 0.1% of trips. These trips were excluded because they were possibly misreported and likely don't reflect the behavior of headboats in general.

Subsetting trips

Trips to be included in the computation of the index need to be determined based on effort directed at red snapper. Effort can be determined directly for trips which had positive red snapper catches, but some trips likely directed effort at red snapper, but were unsuccessful at landing red snapper. Given that information on directed effort for trips without red snapper harvest is not available, another method must be used to compute total effort.
In order to determine effort that was likely directed at red snapper and which trips should be used to compute an index, the method of Stephens and MacCall (2004) was applied. The Stephens and MacCall method uses multiple logistic regression to estimate a probability for each trip that the focal species was caught, given other species caught on that trip. Species compositions differ across the south Atlantic; thus, the method was applied separately for two different regions: north (areas 2-10) and south (areas 11, 12, and 17; Shertzer *et al.* 2009). To avoid computation errors, the number of species in each analysis was limited to those species that occurred in 1% or more of trips. The most general model therefore included all species in the snapper-grouper complex which occurred in 1% or more of trips as main effects, excluding red porgy. Red porgy was removed because of regulation changes, which could erroneously remove trips likely to have caught red snapper in recent years. A backwards stepwise AIC procedure (Venables and Ripley 1997) was then used to perform further selection among possible species as predictor variables. In this procedure, a generalized linear model with Bernoulli response was used to relate presence/absence of red snapper in headboat trips to presence/absence of other species (Figure 2 – Figure 5).

Model Input

Response and explanatory variables

CPUE – catch per unit effort (CPUE) has units of fish/angler and was calculated as the number of red snapper caught divided by the number of anglers.

Year – Because year is the explanatory variable of interest, it was necessarily included in the analysis. A summary of the total number of trips with red snapper effort per year and area is provided in Table 1 and 2.

Area – Areas were pooled into regions of North Carolina (NC=2,3,9,10), South Carolina (SC=4,5), Georgia and North Florida (GNFL=6,7,8), and south Florida (sFL=11,12,17).

Season – The seasons were defined as winter (January, February, March), spring (April, May, June), summer (July, August, September) and fall (October, November, December).

Party – Five categories for the number of anglers on a boat were considered in the standardization process. The categories included: ≤20 anglers, 20-40 anglers, 40-60 anglers, 60-80 anglers, and >80 anglers. The minimum number of anglers per vessel was set at 6, which excluded the lower 0.5% of trips. These trips were excluded because they were possibly misreported and likely don't reflect the behavior of headboats in general.

Trip Type – Trip types of half and full day trips were included in the analysis. Three-quarter day trips were pooled with half-day trips (<10%). Multi-day trips were removed because most were in Florida and likely targeting deepwater species for some portion of the trip. The codes for first and second half-day trips designation for day and night trips were combined.

Standardization

CPUE was modeled using the delta-glm approach (Lo et al. 1992; Dick 2004; Maunder and Punt 2004). In particular, fits of lognormal and gamma models were compared for positive CPUE. Also, the combination of predictor variables was examined to best explain CPUE patterns (both for positive CPUE and or positive CPUE). All analysis were performed in the R programming language, with much of the code adapted from Dick (2004).

BERNOULLI SUBMODEL

One component of the delta-GLM is a logistic regression model that attempts to explain the probability of either catching or not catching red snapper on a particular trip. First, a model was fit with all main effects in order to determine which effects should remain in the binomial component of the delta-GLM. Stepwise AIC (Venables and Ripley1997) with a backwards selection algorithm was then used to eliminate those that did not improve model fit.

POSITIVE CPUE SUBMODEL

Then, to determine predictor variables important for predicting positive CPUE, the positive portion of the model was fitted with all main effects using both the lognormal and gamma distributions. Stepwise AIC (Venables and Ripley1997) with a backwards selection algorithm was then used to eliminate those that did not improve model fit. All predictor variables were modeled as fixed effects (and as factors rather than continuous variables).

Both components of the model were then fit together (with the code adapted from Dick 2004) using the lognormal and gamma distributions and compared them using AIC. With CPUE as the dependent variable.

Preliminary model diagnostics are presented in Figures 6-7.

It should be noted that the Stephens and MacCall method is most appropriate for species which have strong species associations. In other words, if a species is ubiquitous in the catch, or does not have well-defined effort, Stephens and MacCall may not work well to identify directed effort.

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Table 1. Proportion positive trips of red snapper in the south Atlantic Headboat fishery.

Year	pos.RS.trips	HB.all.trips	% pos
1973	298	688	43%
1974	366	1182	31%
1975	421	1913	22%
1976	1033	3002	34%
1977	1228	3559	35%
1978	1803	4891	37%
1979	1460	8173	18%
1980	1577	11378	14%
1981	1416	11324	13%
1982	1283	12256	10%
1983	1642	12125	14%
1984	1493	11190	13%
1985	1908	11157	17%
1986	1605	13854	12%
1987	1758	13966	13%
1988	1683	11996	14%
1989	1411	10933	13%
1990	1335	11365	12%
1991	1070	10740	10%
1992	938	15007	6%
1993	1295	13894	9%
1994	1411	12575	11%
1995	1506	12275	12%
1996	1154	9060	13%
1997	649	6284	10%
1998	1250	9123	14%
1999	1386	7618	18%
2000	1430	7645	19%
2001	1602	6820	23%
2002	1516	5590	27%
2003	1225	5542	22%
2004	1558	6278	25%
2005	1379	5695	24%
2006	1177	5909	20%
2007	1326	6381	21%
2008	1770	9215	19%
2009	2134	10250	21%
2010	53	10922	0%
2011	19	10585	0%
2012	93	11294	1%
2013	89	13102	1%
Total	49750	366756	14%

Table 2. Number of red snapper headboat trips by area, positive and zero trips following Stephens & MacCall (SM) method.

	Total Trips					Positive Trips					Proportion Positive				
Year	GF	NC	SC	SF	Total	GF	NC	SC	SF	Total	GF	NC	SC	SF	Total
1976	464	142	229		835	441	37	118		596	0.95	0.26	0.52		0.71
1977	608	57	208		873	542	30	69		641	0.89	0.53	0.33		0.73
1978	1132	144	249	3	1528	953	67	99	1	1120	0.84	0.47	0.40	0.33	0.73
1979	1028	163	78	28	1297	821	78	30	3	932	0.80	0.48	0.38	0.11	0.72
1980	1032	118	176	48	1374	787	50	104	10	951	0.76	0.42	0.59	0.21	0.69
1981	871	107	52	63	1093	772	69	27	28	896	0.89	0.64	0.52	0.44	0.82
1982	911	189	211	49	1360	733	108	110	4	955	0.80	0.57	0.52	0.08	0.70
1983	1212	173	208	54	1647	1005	91	109	7	1212	0.83	0.53	0.52	0.13	0.74
1984	1160	84	194	86	1524	915	37	130	21	1103	0.79	0.44	0.67	0.24	0.72
1985	1258	72	255	147	1732	1105	40	169	46	1360	0.88	0.56	0.66	0.31	0.79
1986	1591	98	264	184	2137	995	64	118	26	1203	0.63	0.65	0.45	0.14	0.56
1987	1564	106	306	171	2147	1048	44	149	23	1264	0.67	0.42	0.49	0.13	0.59
1988	1529	112	346	87	2074	902	64	196	15	1177	0.59	0.57	0.57	0.17	0.57
1989	1142	46	196	43	1427	855	19	128	6	1008	0.75	0.41	0.65	0.14	0.71
1990	1135	65	242	16	1458	828	19	161	1	1009	0.73	0.29	0.67	0.06	0.69
1991	1043	135	284	11	1473	695	45	138	1	879	0.67	0.33	0.49	0.09	0.60
1992	1612	245	231	62	2150	406	72	110	16	604	0.25	0.29	0.48	0.26	0.28
1993	1451	175	274	66	1966	420	81	217	17	735	0.29	0.46	0.79	0.26	0.37
1994	1167	181	233	44	1625	605	57	138	16	816	0.52	0.31	0.59	0.36	0.50
1995	1108	186	209	19	1522	620	57	103	5	785	0.56	0.31	0.49	0.26	0.52
1996	746	177	207	14	1144	445	42	66	6	559	0.60	0.24	0.32	0.43	0.49
1997	560	115	116	8	799	331	24	32	2	389	0.59	0.21	0.28	0.25	0.49
1998	1209	207	213	4	1633	692	30	80	1	803	0.57	0.14	0.38	0.25	0.49
1999	1301	177	208	1	1687	729	61	137		927	0.56	0.34	0.66	0.00	0.55
2000	1026	192	206	13	1437	672	59	86	7	824	0.65	0.31	0.42	0.54	0.57
2001	1079	162	285	11	1537	732	106	175	2	1015	0.68	0.65	0.61	0.18	0.66
2002	991	179	276	7	1453	687	100	205	1	993	0.69	0.56	0.74	0.14	0.68
2003	825	134	155	15	1129	558	49	111		718	0.68	0.37	0.72	0.00	0.64
2004	1059	219	288	30	1596	818	43	173	4	1038	0.77	0.20	0.60	0.13	0.65
2005	949	103	184	35	1271	776	7	87	8	878	0.82	0.07	0.47	0.23	0.69
2006	993	133	222	43	1391	687	14	70	13	784	0.69	0.11	0.32	0.30	0.56
2007	1085	94	280	40	1499	767	3	89	31	890	0.71	0.03	0.32	0.78	0.59
2008	1116	130	174	113	1533	985	23	68	31	1107	0.88	0.18	0.39	0.27	0.72
2009	1389	123	149	255	1916	1256	33	43	78	1410	0.90	0.27	0.29	0.31	0.74
Grand Tot	37346	4743	7408	1770	51267	25583	1723	3845	430	31581	0.69	0.36	0.52	0.24	0.62

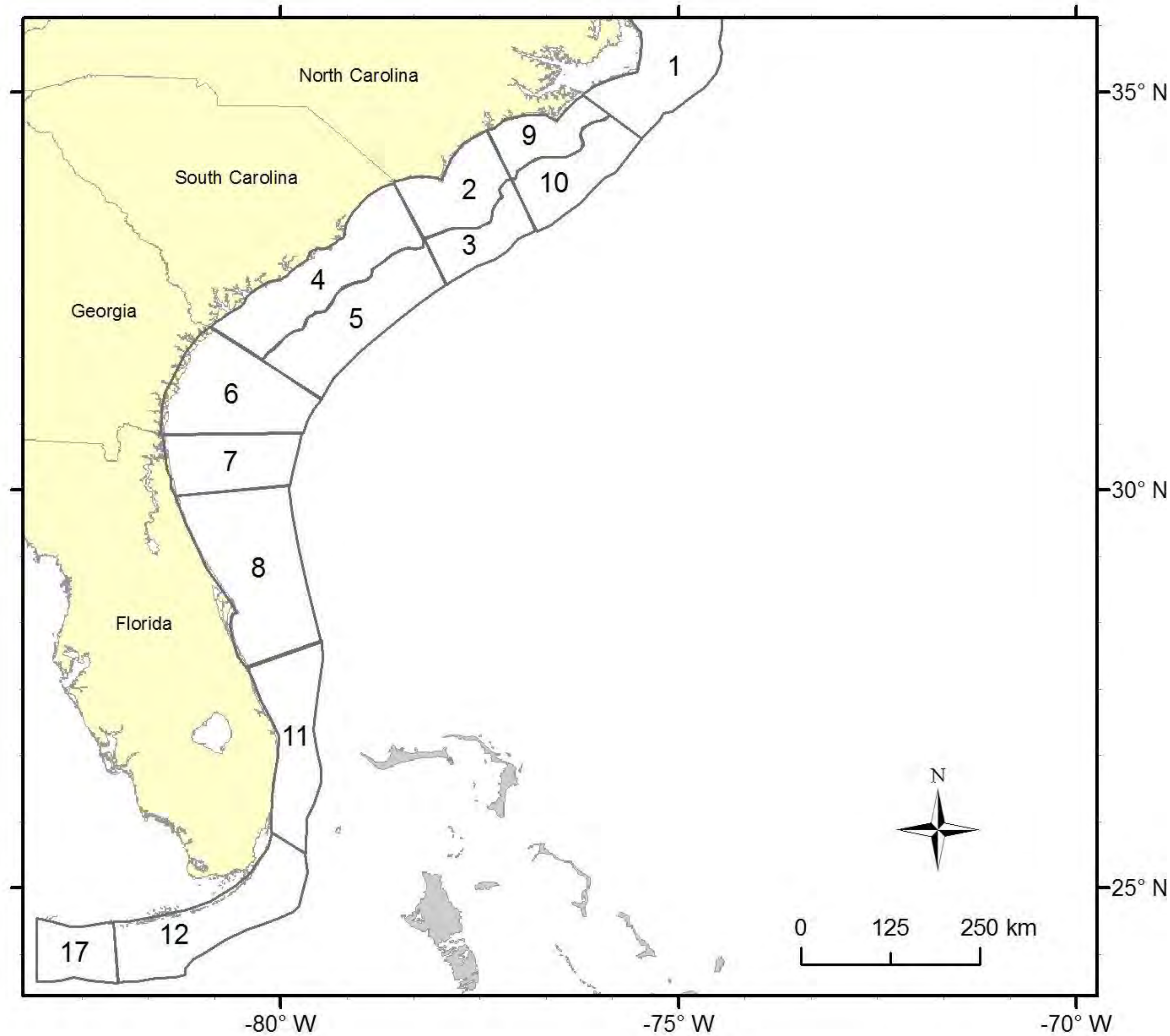


Figure 1. Map of headboat sampling area definition. These areas were pooled into regions of North Carolina (NC=2,3,9,10), South Carolina (SC=4,5), Georgia and North Florida (GNFL=6,7,8), and south Florida (sFL=11,12,17).

Figure 2. Estimates of species-specific regression coefficients from Stephens and MacCall method applied to headboat data from areas in the northern region (excludes areas 11, 12, and 17), as used to estimate each trip's probability of catching the focal species.

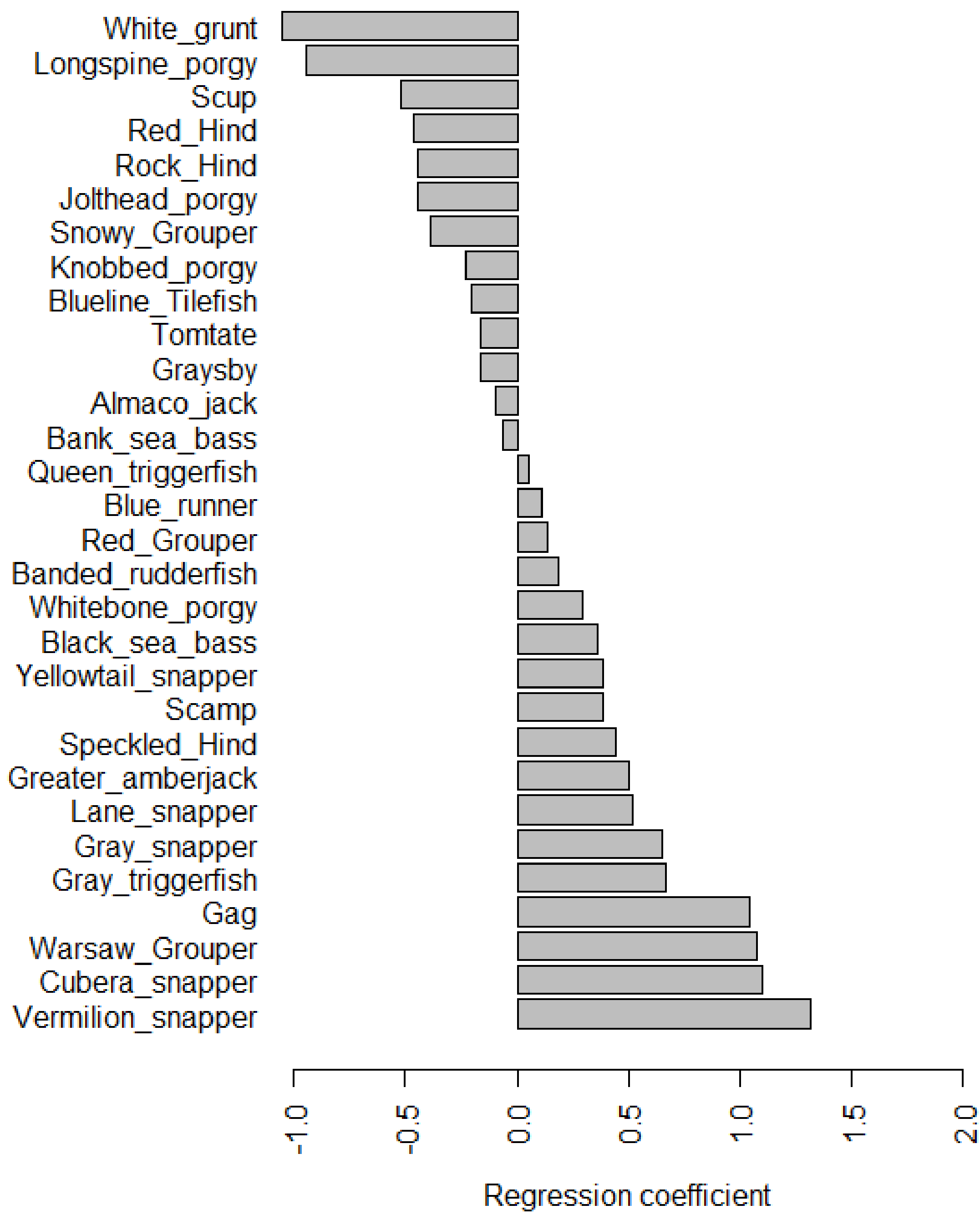


Figure 3. Estimates of species-specific regression coefficients from Stephens and MacCall method applied to headboat data from areas in the southern region (includes areas 11, 12, and 17), as used to estimate each trip's probability of catching the focal species.

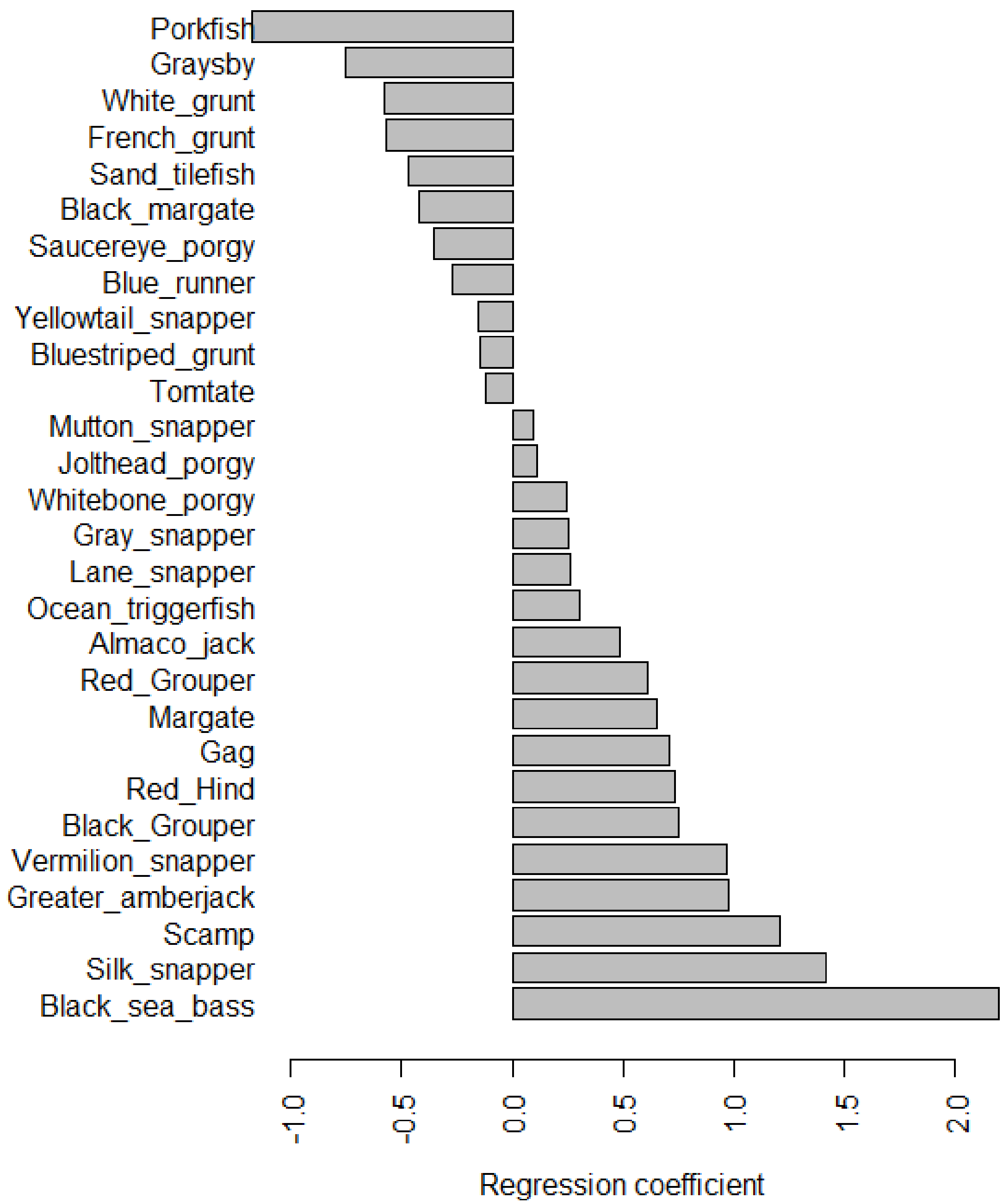


Figure 4. Absolute difference between observed and predicted number of positive trips from Stephens and MacCall method applied to headboat data from the northern region (excludes areas 11, 12, and 17). Left and right panels differ only in the range of probabilities shown.

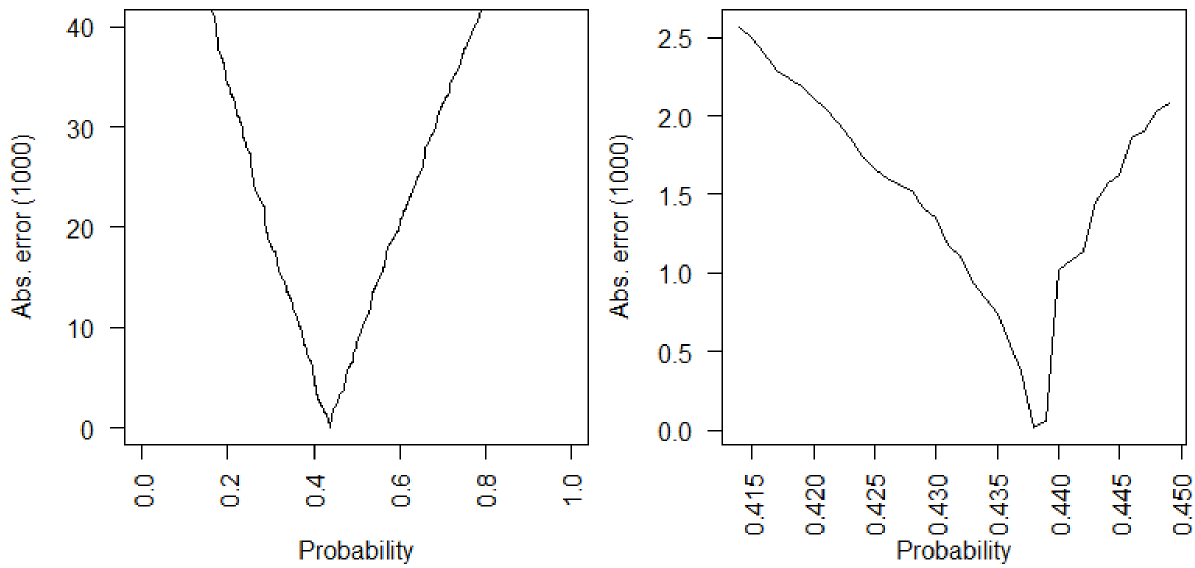


Figure 5. Absolute difference between observed and predicted number of positive trips from Stephens and MacCall method applied to headboat data from the southern region (includes areas 11, 12, and 17). Left and right panels differ only in the range of probabilities shown.

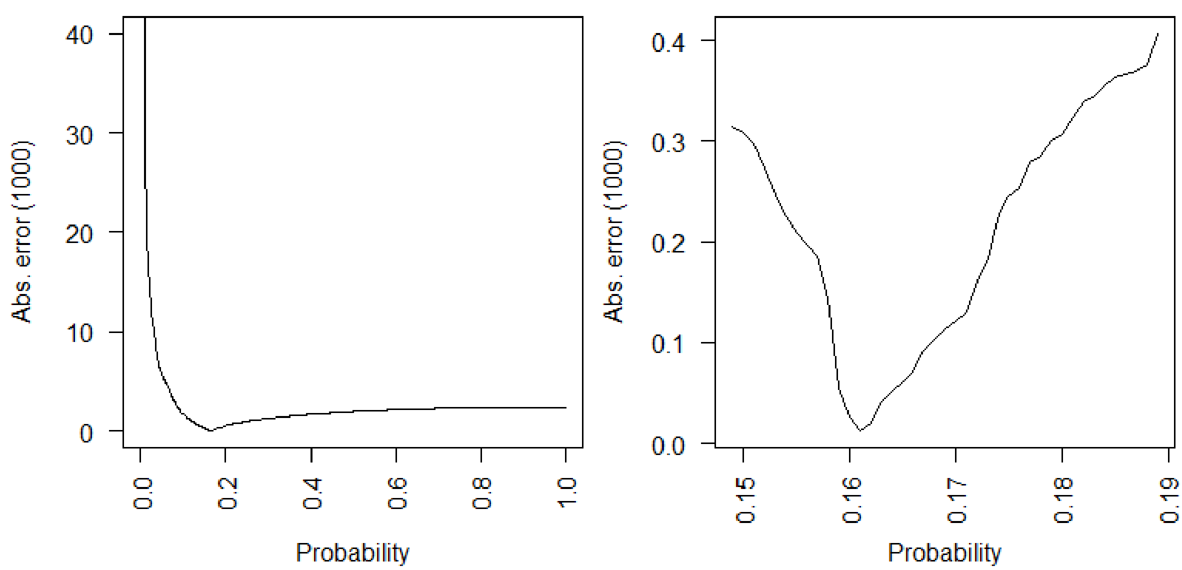
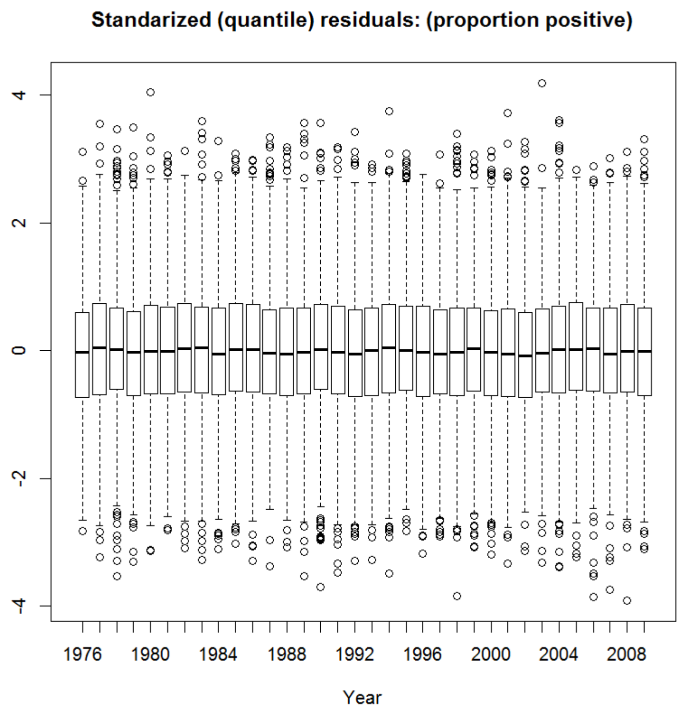


Figure 6. CPUE binomial residuals for year, area, season, trip type and party size.



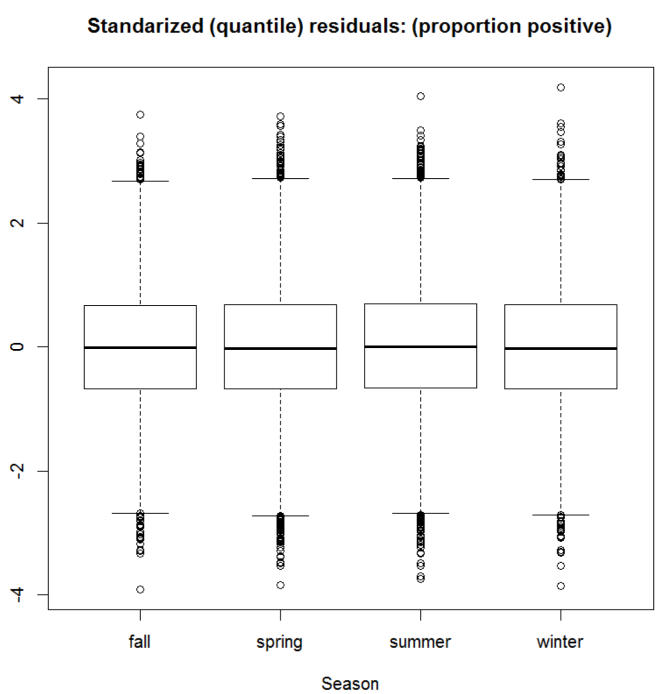
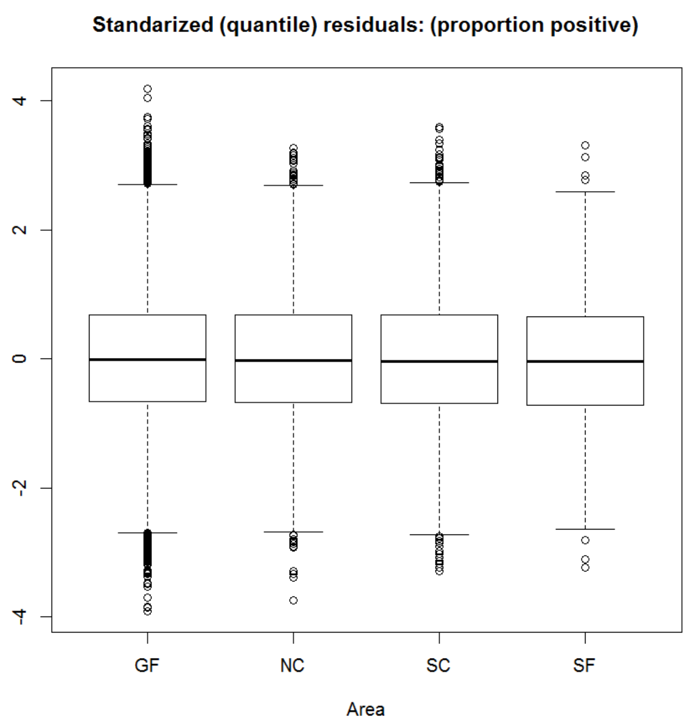


Figure 6. Continued.



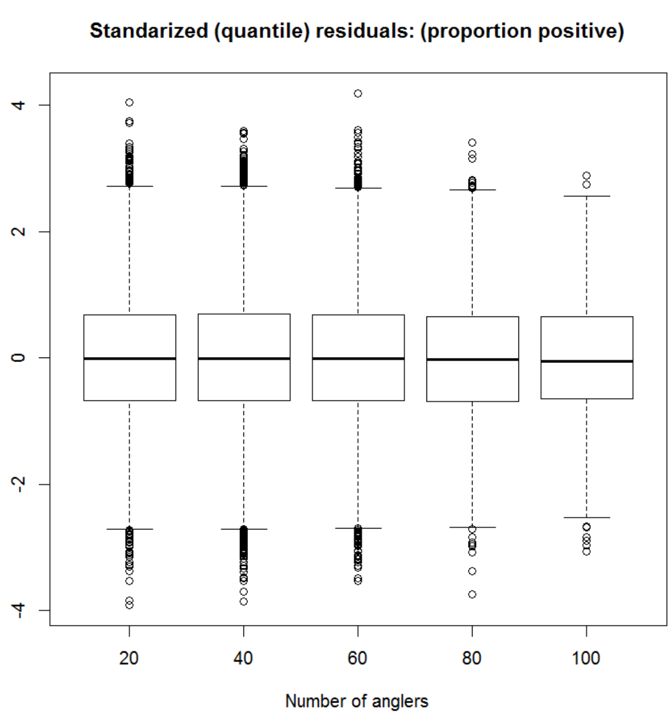
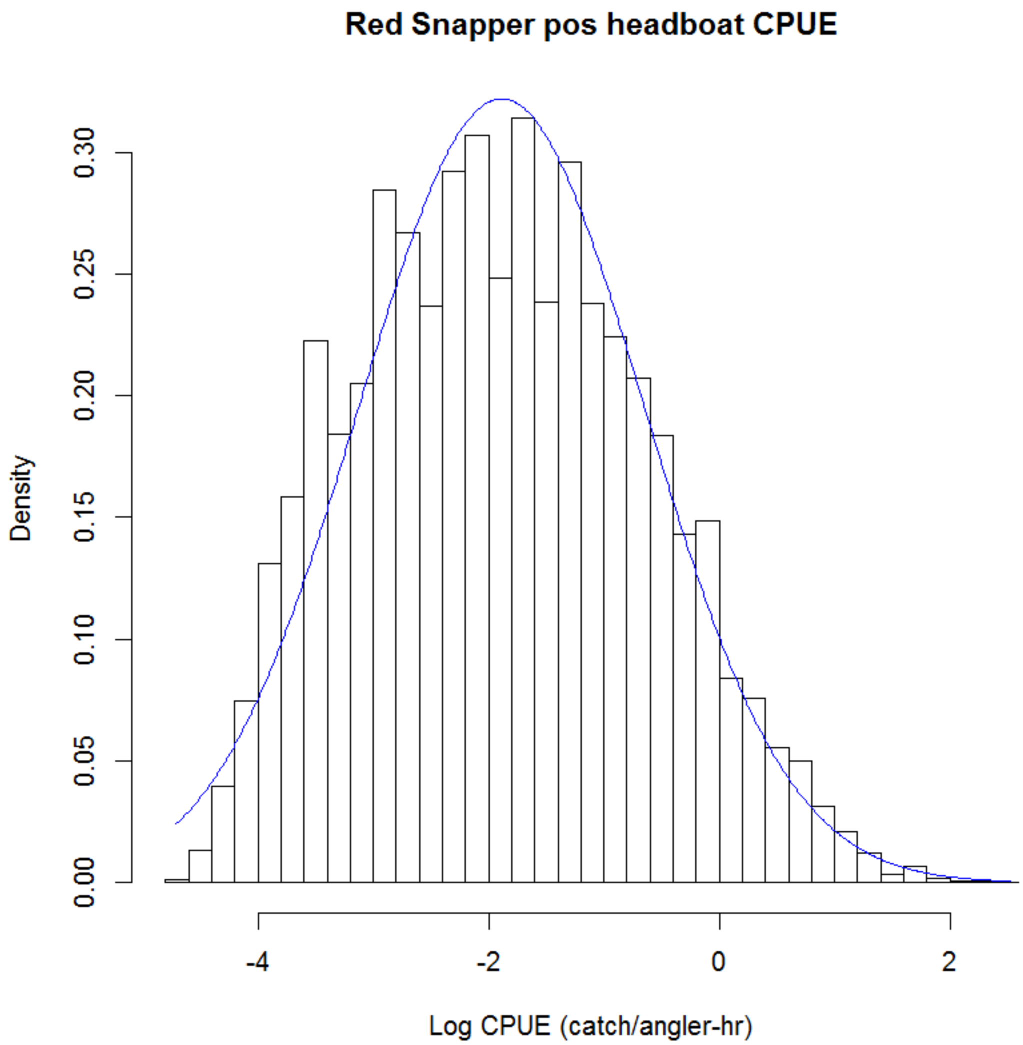


Figure 7. The lognormal distribution of catch for the south Atlantic red snapper headboat logbook during 1995-2013.



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ADDENDUM

Standardized catch rates of Southeast US Atlantic red snapper (*Lutjanus campechanus*) from headboat logbook data

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Abstract
Standardized catch rates were generated from the Southeast headboat survey trip records (logbooks) from 1976-1991 and from 1992-2009. The analysis included areas from central North Carolina through south Florida. Data filtering and subsetting steps were applied to the data to model trips that were likely to have directed red snapper effort.

SEDAR 41 Index Working Group Review

The SEDAR 41 index working group (IWG) reviewed the methods used to develop an index of abundance for red snapper from headboat logbook data. The following topics were discussed at the data workshop and include the final decisions and justification.

Start year
For a fisheries dependent index like the headboat logbook index, identifying changes in angler behavior are important when developing an index. Beginning in 1992, a 20" minimum size regulation influenced angler behavior. Because of these changes in angler behavior before and after 1992, the IWG agreed to split the index (1976-1991 & 1992-2009).

End year
SEDAR 41 IWG participants along with fisherman present at the meeting discussed the red snapper closure in 2010 and its potential impact on the red snapper headboat logbook index in 2010-2013. Because of this shift in behavior (avoidance), the IWG recommended to end the red snapper headboat logbook index in 2009.

Subsetting technique- Stephens & MacCall

A run using a 5% cutoff was explored. Red snapper in the southern region did not meet this upper cutoff so the 1% was used in the final model run.

The following information represents the final model input and dGLM results for the red snapper headboat logbook index.

Model Input

Response and explanatory variables

CPUE – catch per unit effort (CPUE) has units of fish/angler and was calculated as the number of red snapper caught divided by the number of anglers.

Year – Because year is the explanatory variable of interest, it was necessarily included in the analysis. Early time period (1976-1991), Late time period (1992-2009)

Area – Areas were pooled into regions of North Carolina (NC=2,3,9,10), South Carolina (SC=4,5), Georgia and North Florida (GNFL=6,7,8), and south Florida (sFL=11,12,17).

Season – The seasons were defined as winter (January, February, March), spring (April, May, June), summer (July, August, September) and fall (October, November, December).

Party – Five categories for the number of anglers on a boat were considered in the standardization process. The categories included: ≤20 anglers, 20-40 anglers, 40-60 anglers, 60-80 anglers, and >80 anglers. The minimum number of anglers per vessel was set at 6, which excluded the lower 0.5% of trips. These trips were excluded because they were possibly misreported and likely don't reflect the behavior of headboats in general.

Trip Type – Trip types of half and full day trips were included in the analysis. Three-quarter day trips were pooled with half-day trips (<10%). Multi-day trips were removed because most were in Florida and likely targeting deepwater species for some portion of the trip. The codes for first and second half-day trips designation for day and night trips were combined.

Standardization

CPUE was modeled using the delta-glm approach (Lo et al. 1992; Dick 2004; Maunder and Punt 2004). In particular, fits of lognormal and gamma models were compared for positive CPUE. Also, the combination of predictor variables was examined to best explain CPUE patterns (both for positive CPUE and or positive CPUE). All analysis were performed in the R programming language, with much of the code adapted from Dick (2004).

BERNOULLI SUBMODEL
One component of the delta-GLM is a logistic regression model that attempts to explain the probability of either catching or not catching red snapper on a particular trip. First, a model was fit with all main effects in order to determine which effects should remain in the binomial component of the delta-GLM. Stepwise AIC (Venables and Ripley1997) with a backwards selection algorithm was then used to eliminate those that did not improve model fit.

POSITIVE CPUE SUBMODEL
Then, to determine predictor variables important for predicting positive CPUE, the positive portion of the model was fitted with all main effects using both the lognormal and gamma distributions. Stepwise AIC (Venables and Ripley1997) with a backwards selection algorithm

was then used to eliminate those that did not improve model fit. All predictor variables were modeled as fixed effects (and as factors rather than continuous variables).

Both components of the model were then fit together (with the code adapted from Dick 2004) using the lognormal and gamma distributions and compared them using AIC. With CPUE as the dependent variable.

In the model for the earlier time period (1976-1991) the lognormal was the preferred model (Table 3 & Figures 2-8). But in the later time period, the gamma was the preferred model (Table 4 & Figures 9-15).

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Shertzer, K.W., E.H. Williams, and J.C. Taylor. 2009. Spatial structure and temporal patterns in a large marine ecosystem: Exploited reef fishes of the southeast United States. Fish. Res. 100:126−133.

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Table 1. Proportion positive trips of red snapper in the south Atlantic Headboat fishery.

Year	pos.RS.trips	HB.all.trips	% pos
1973	298	688	43%
1974	366	1182	31%
1975	421	1913	22%
1976	1033	3002	34%
1977	1228	3559	35%
1978	1803	4891	37%
1979	1460	8173	18%
1980	1577	11378	14%
1981	1416	11324	13%
1982	1283	12256	10%
1983	1642	12125	14%
1984	1493	11190	13%
1985	1908	11157	17%
1986	1605	13854	12%
1987	1758	13966	13%
1988	1683	11996	14%
1989	1411	10933	13%
1990	1335	11365	12%
1991	1070	10740	10%
1992	938	15007	6%
1993	1295	13894	9%
1994	1411	12575	11%
1995	1506	12275	12%
1996	1154	9060	13%
1997	649	6284	10%
1998	1250	9123	14%
1999	1386	7618	18%
2000	1430	7645	19%
2001	1602	6820	23%
2002	1516	5590	27%
2003	1225	5542	22%
2004	1558	6278	25%
2005	1379	5695	24%
2006	1177	5909	20%
2007	1326	6381	21%
2008	1770	9215	19%
2009	2134	10250	21%
2010	53	10922	0%
2011	19	10585	0%
2012	93	11294	1%
2013	89	13102	1%
Total	49750	366756	14%

Table 2. Number of red snapper headboat trips by area, positive and zero trips following Stephens & MacCall (SM) method.

	Total Trips					Positive Trips					Proportion Positive				
Year	GF	NC	SC	SF	Total	GF	NC	SC	SF	Total	GF	NC	SC	SF	Total
1976	464	142	229		835	441	37	118		596	0.95	0.26	0.52		0.71
1977	608	57	208		873	542	30	69		641	0.89	0.53	0.33		0.73
1978	1132	144	249	3	1528	953	67	99	1	1120	0.84	0.47	0.40	0.33	0.73
1979	1028	163	78	28	1297	821	78	30	3	932	0.80	0.48	0.38	0.11	0.72
1980	1032	118	176	48	1374	787	50	104	10	951	0.76	0.42	0.59	0.21	0.69
1981	871	107	52	63	1093	772	69	27	28	896	0.89	0.64	0.52	0.44	0.82
1982	911	189	211	49	1360	733	108	110	4	955	0.80	0.57	0.52	0.08	0.70
1983	1212	173	208	54	1647	1005	91	109	7	1212	0.83	0.53	0.52	0.13	0.74
1984	1160	84	194	86	1524	915	37	130	21	1103	0.79	0.44	0.67	0.24	0.72
1985	1258	72	255	147	1732	1105	40	169	46	1360	0.88	0.56	0.66	0.31	0.79
1986	1591	98	264	184	2137	995	64	118	26	1203	0.63	0.65	0.45	0.14	0.56
1987	1564	106	306	171	2147	1048	44	149	23	1264	0.67	0.42	0.49	0.13	0.59
1988	1529	112	346	87	2074	902	64	196	15	1177	0.59	0.57	0.57	0.17	0.57
1989	1142	46	196	43	1427	855	19	128	6	1008	0.75	0.41	0.65	0.14	0.71
1990	1135	65	242	16	1458	828	19	161	1	1009	0.73	0.29	0.67	0.06	0.69
1991	1043	135	284	11	1473	695	45	138	1	879	0.67	0.33	0.49	0.09	0.60
1992	1612	245	231	62	2150	406	72	110	16	604	0.25	0.29	0.48	0.26	0.28
1993	1451	175	274	66	1966	420	81	217	17	735	0.29	0.46	0.79	0.26	0.37
1994	1167	181	233	44	1625	605	57	138	16	816	0.52	0.31	0.59	0.36	0.50
1995	1108	186	209	19	1522	620	57	103	5	785	0.56	0.31	0.49	0.26	0.52
1996	746	177	207	14	1144	445	42	66	6	559	0.60	0.24	0.32	0.43	0.49
1997	560	115	116	8	799	331	24	32	2	389	0.59	0.21	0.28	0.25	0.49
1998	1209	207	213	4	1633	692	30	80	1	803	0.57	0.14	0.38	0.25	0.49
1999	1301	177	208	1	1687	729	61	137		927	0.56	0.34	0.66	0.00	0.55
2000	1026	192	206	13	1437	672	59	86	7	824	0.65	0.31	0.42	0.54	0.57
2001	1079	162	285	11	1537	732	106	175	2	1015	0.68	0.65	0.61	0.18	0.66
2002	991	179	276	7	1453	687	100	205	1	993	0.69	0.56	0.74	0.14	0.68
2003	825	134	155	15	1129	558	49	111		718	0.68	0.37	0.72	0.00	0.64
2004	1059	219	288	30	1596	818	43	173	4	1038	0.77	0.20	0.60	0.13	0.65
2005	949	103	184	35	1271	776	7	87	8	878	0.82	0.07	0.47	0.23	0.69
2006	993	133	222	43	1391	687	14	70	13	784	0.69	0.11	0.32	0.30	0.56
2007	1085	94	280	40	1499	767	3	89	31	890	0.71	0.03	0.32	0.78	0.59
2008	1116	130	174	113	1533	985	23	68	31	1107	0.88	0.18	0.39	0.27	0.72
2009	1389	123	149	255	1916	1256	33	43	78	1410	0.90	0.27	0.29	0.31	0.74
Grand Tot	37346	4743	7408	1770	51267	25583	1723	3845	430	31581	0.69	0.36	0.52	0.24	0.62

Table 3. The relative nominal CPUE, number of trips, standardized index, and CV for the red snapper headboat logbook data in the south Atlantic from **1976-1991**.

Year	Relative nominal CPUE	N	Proportion N positive	Standardized index	CV (index)
1976	1.6299	899	0.6986	1.7498	0.0726
1977	1.5785	921	0.7264	1.3927	0.0735
1978	1.6491	1606	0.7298	1.5162	0.0591
1979	1.6736	1303	0.7222	1.5119	0.0630
1980	0.9662	1414	0.6888	1.0036	0.0606
1981	1.6433	1100	0.8164	1.9763	0.0569
1982	0.6403	1339	0.7095	0.8565	0.0586
1983	0.8841	1586	0.7440	1.1115	0.0565
1984	0.9705	1506	0.7264	0.8998	0.0611
1985	1.2860	1742	0.7876	1.4966	0.0539
1986	0.3583	2185	0.5579	0.2802	0.0654
1987	0.4070	2197	0.5799	0.3532	0.0643
1988	0.5032	2082	0.5677	0.3241	0.0705
1989	0.6836	1444	0.7091	0.5475	0.0684
1990	0.6155	1458	0.6893	0.5332	0.0656
1991	0.5108	1476	0.5942	0.4468	0.0689

Table 4. The relative nominal CPUE, number of trips, standardized index, and CV for the red snapper headboat logbook data in the south Atlantic from **1992-2009**.

Year	Relative nominal CPUE	N	Proportion N positive	Standardized index	CV (index)
1992	0.2416	2150	0.2809	0.1263	0.0968
1993	0.5234	1966	0.3739	0.3249	0.0941
1994	0.5727	1625	0.5022	0.5245	0.0872
1995	0.6106	1522	0.5158	0.6574	0.1067
1996	0.4018	1144	0.4886	0.4068	0.0859
1997	0.4272	799	0.4869	0.4864	0.0961
1998	0.4989	1633	0.4917	0.4242	0.0762
1999	0.6254	1687	0.5495	0.5092	0.0747
2000	0.7963	1437	0.5734	0.7341	0.0782
2001	1.3520	1537	0.6604	1.4582	0.0749
2002	1.4643	1453	0.6834	1.5199	0.0718
2003	0.9405	1129	0.6360	0.8941	0.0787
2004	1.2954	1596	0.6504	1.3129	0.0705
2005	1.1150	1271	0.6908	1.2282	0.0708
2006	0.9035	1391	0.5636	0.8762	0.0856
2007	0.8620	1499	0.5937	0.7001	0.0750
2008	2.7844	1533	0.7221	2.9499	0.0630

2009	2.5851	1916	0.7359	2.8668	0.0583

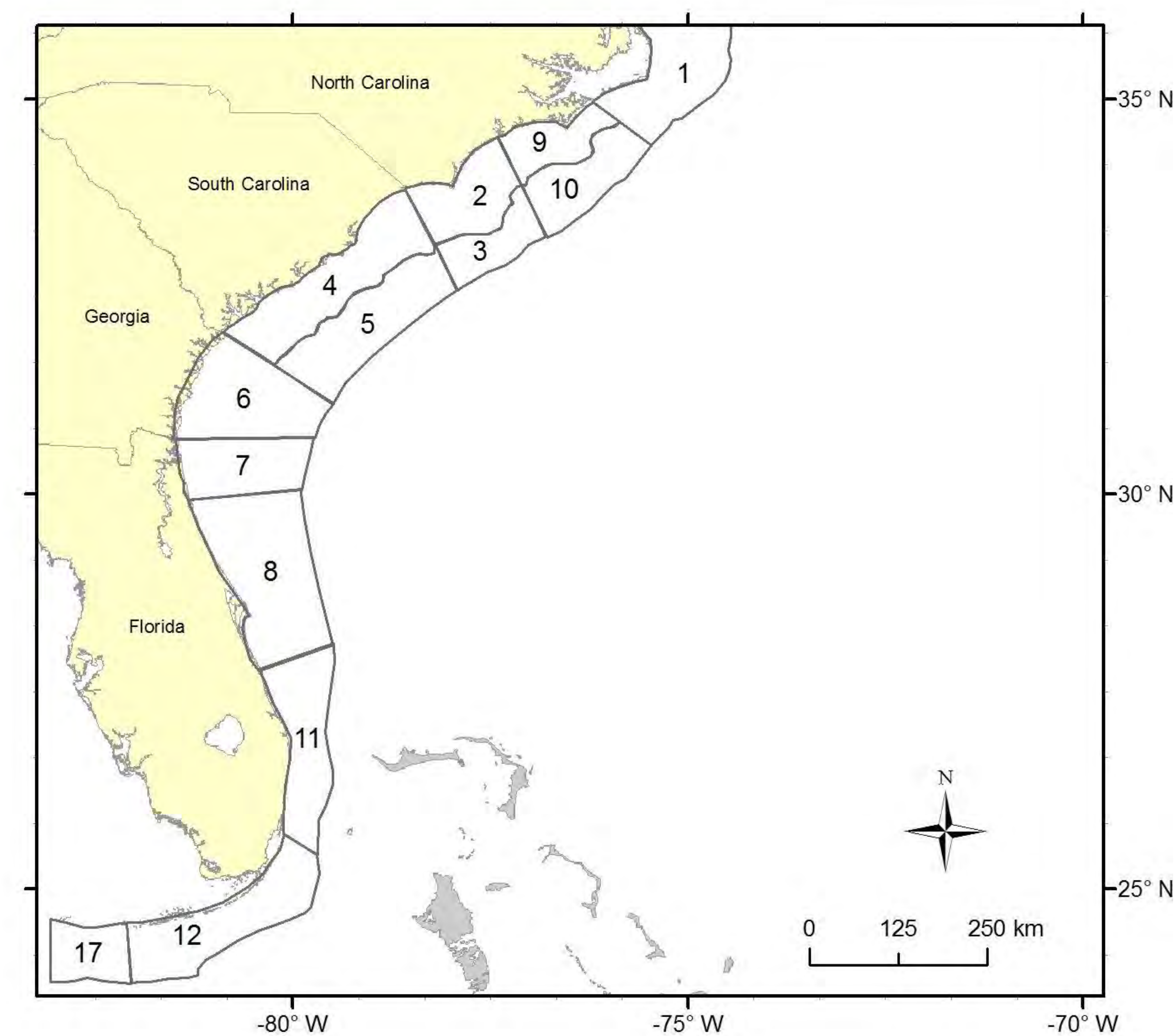


Figure 2. Map of headboat sampling area definition. These areas were pooled into regions of North Carolina (NC=2,3,9,10), South Carolina (SC=4,5), Georgia and North Florida (GNFL=6,7,8), and south Florida (sFL=11,12,17).

Red Snapper Headboat Logbook Index (1976-1991)

Figure 2. Estimates of species-specific regression coefficients from Stephens and MacCall method applied to headboat data from areas in the northern region **1976-1991** (excludes areas 11, 12, and 17), as used to estimate each trip's probability of catching the focal species.

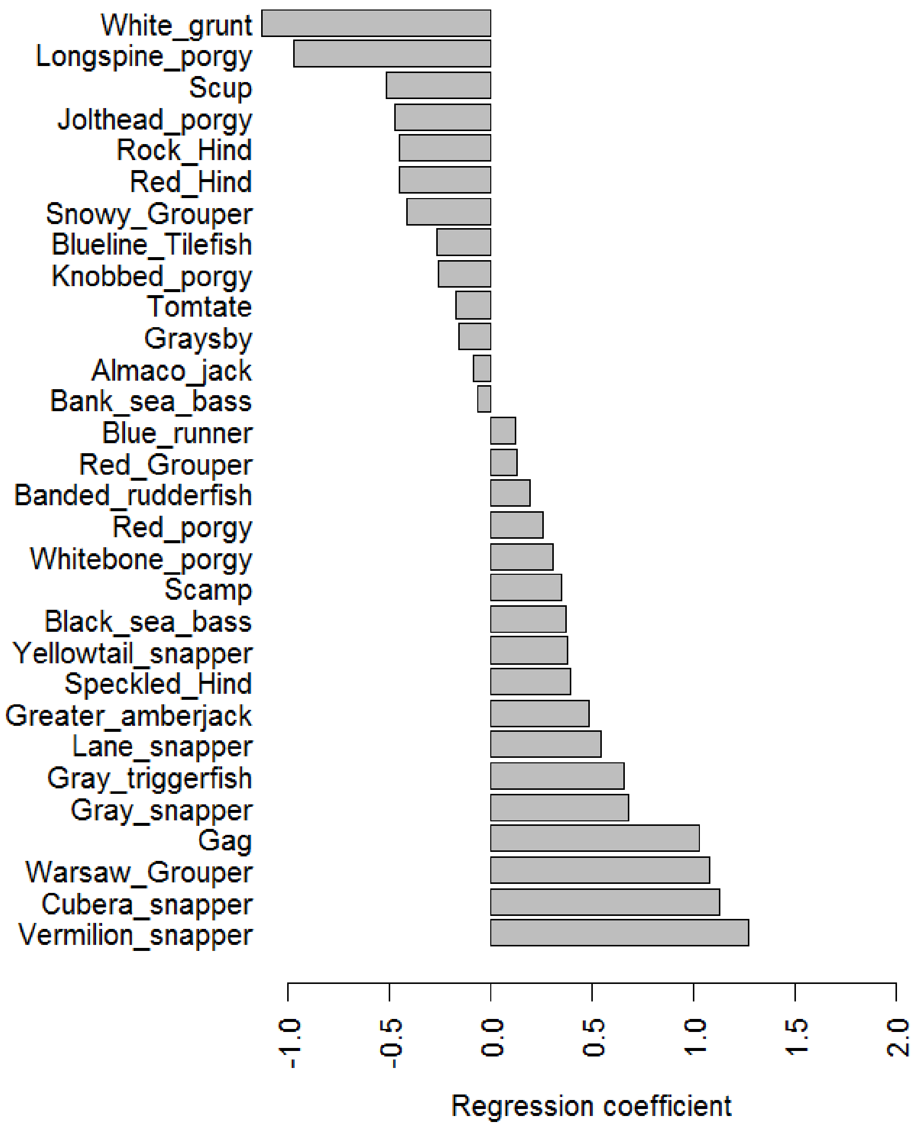


Figure 3. Estimates of species-specific regression coefficients from Stephens and MacCall method applied to headboat data from areas in the southern region **1976-1991** (includes areas 11, 12, and 17), as used to estimate each trip's probability of catching the focal species.

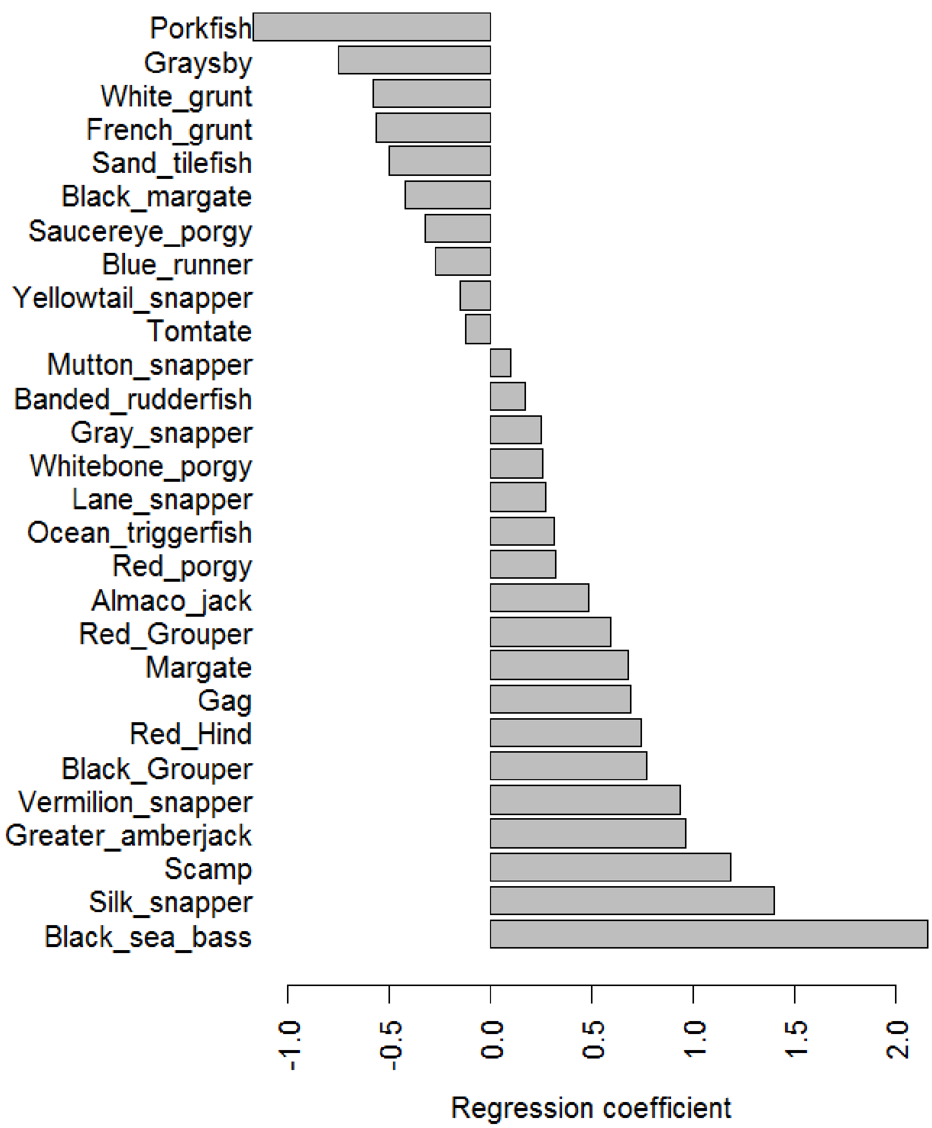


Figure 4. Absolute difference between observed and predicted number of positive trips from Stephens and MacCall method applied to headboat data from the northern region **1976-1991** (excludes areas 11, 12, and 17). Left and right panels differ only in the range of probabilities shown.

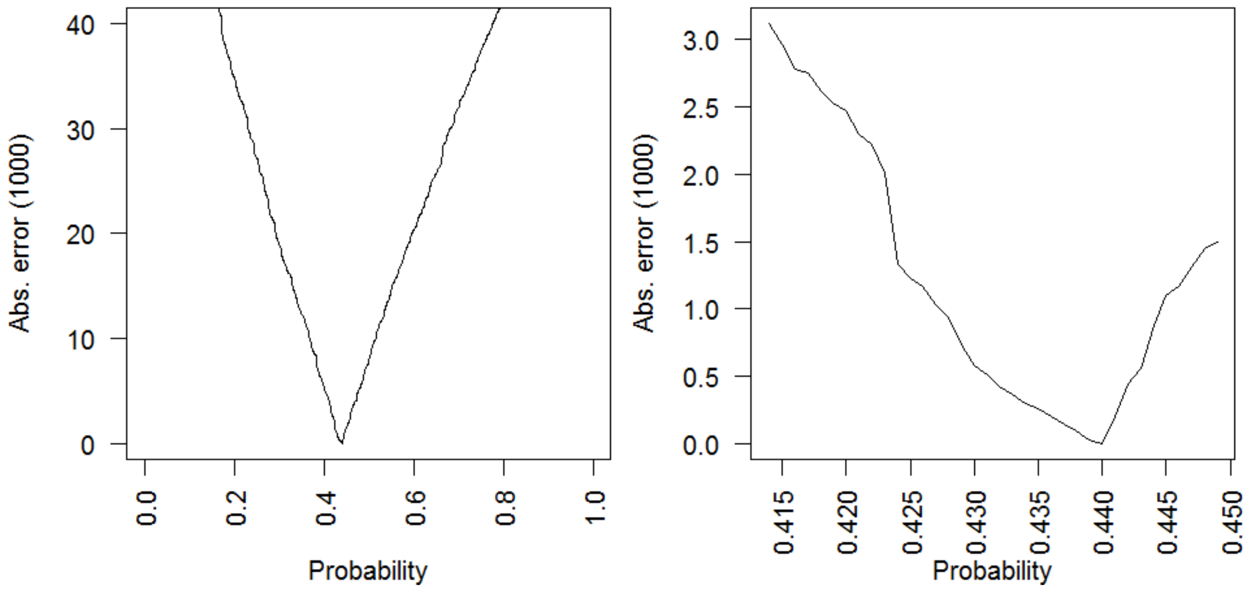


Figure 5. Absolute difference between observed and predicted number of positive trips from Stephens and MacCall method applied to headboat data from the southern region **1976-1991** (includes areas 11, 12, and 17). Left and right panels differ only in the range of probabilities shown.

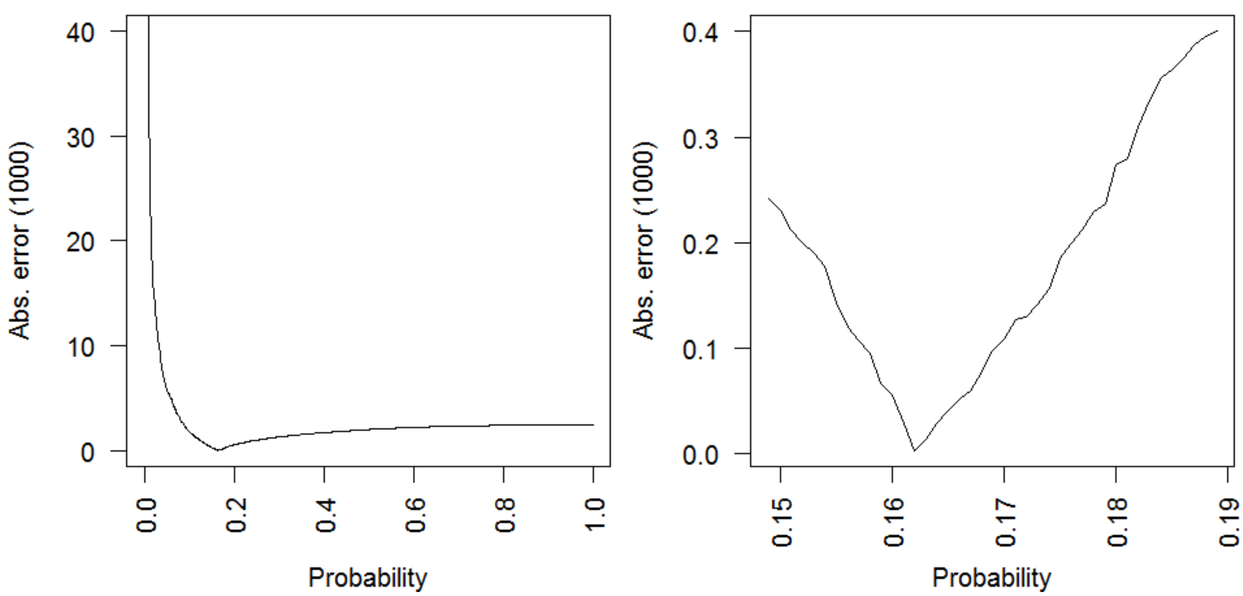
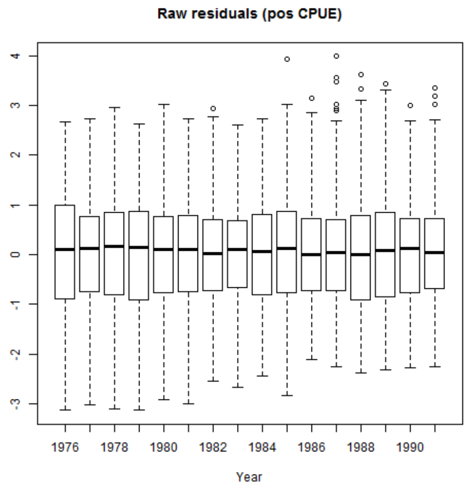
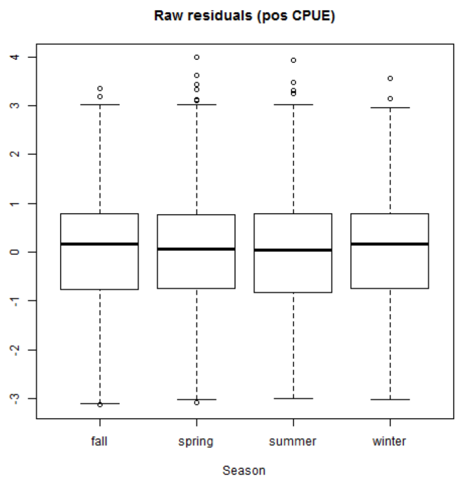
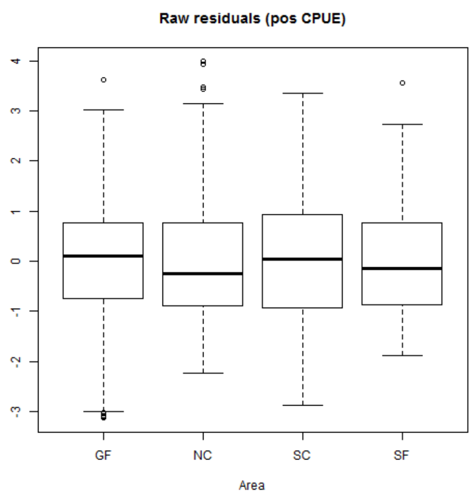
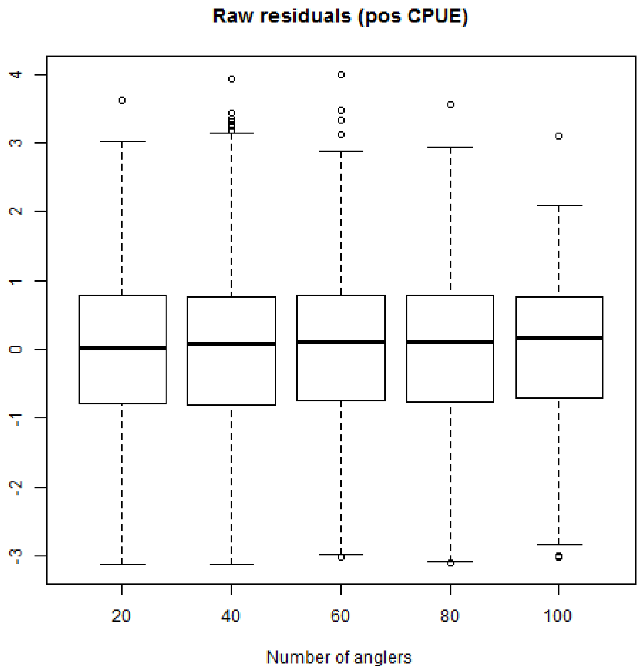


Figure 6. CPUE binomial residuals for year, area, season, trip type and party size **1976-1991**








Raw residuals (pos CPUE)
4
3
2
1
0
-1
-2
-3
20
40
60
80
100
Number of anglers

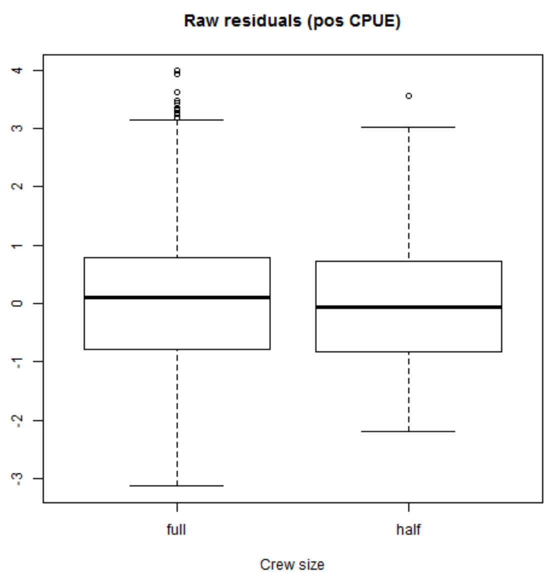
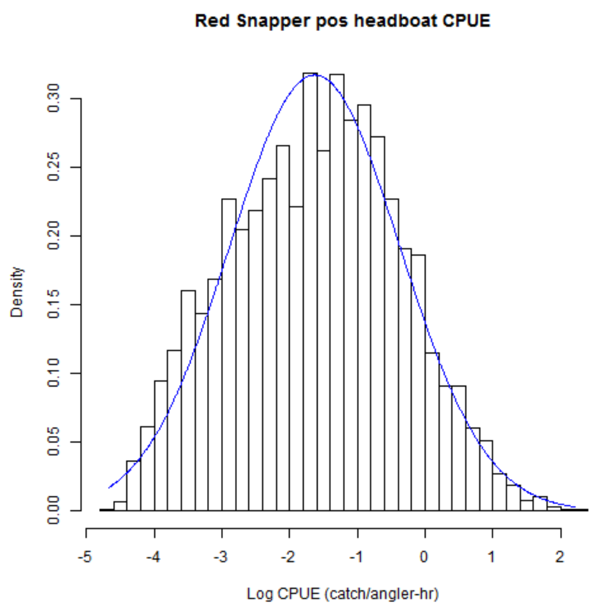

Raw residuals (pos CPUE)
4
3
2
1
0
-1
-2
-3
full
half
Crew size

Figure 7. The lognormal distribution and qq plot of catch for the south Atlantic red snapper headboat logbook during **1976-1991**.



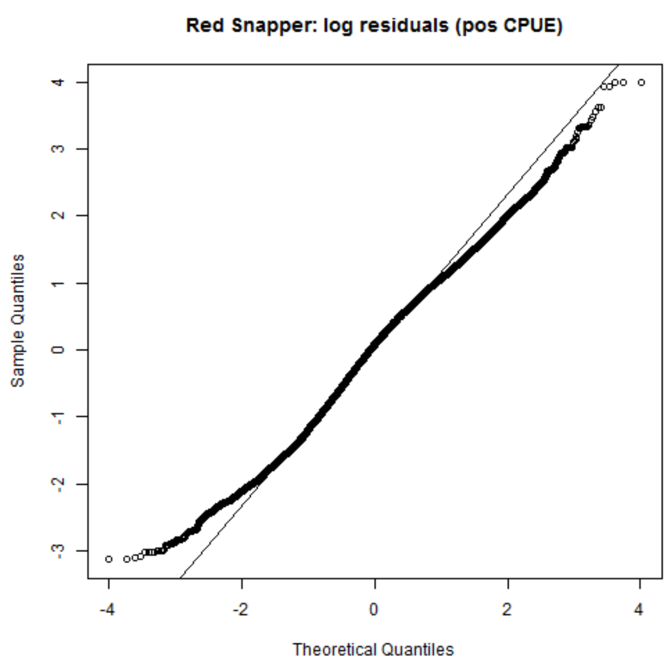
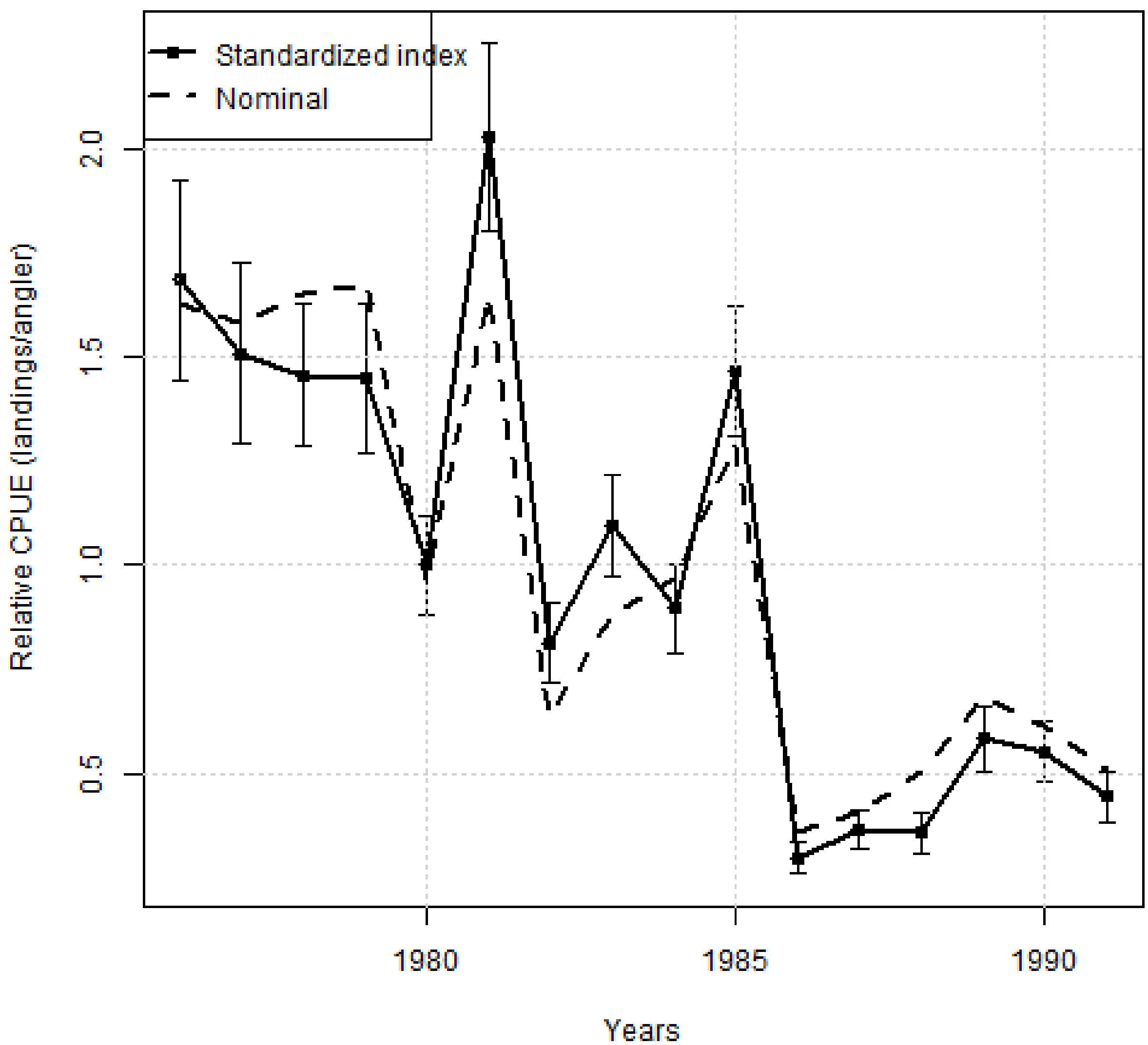


Figure 8. The standardized and nominal CPUE index with error bars at (+/-) 2 standard deviations (nominal by area below) computed for red snapper in the south Atlantic using the headboat logbook data during **1976-1991**.



Red Snapper Headboat Logbook Index (1992-2009)

Figure 9. Estimates of species-specific regression coefficients from Stephens and MacCall method applied to headboat data from areas in the northern region **1992-2009** (excludes areas 11, 12, and 17), as used to estimate each trip's probability of catching the focal species.

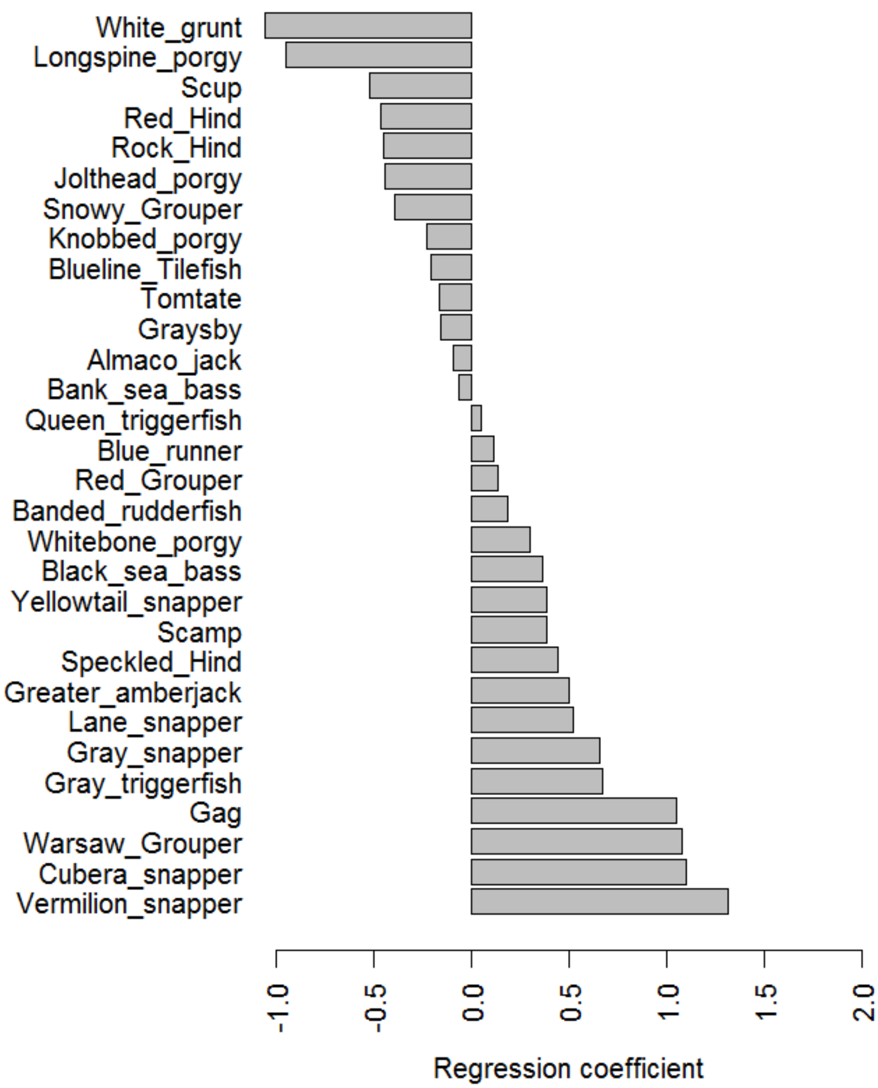


Figure 10. Estimates of species-specific regression coefficients from Stephens and MacCall method applied to headboat data from areas in the southern region **1992-2009** (includes areas 11, 12, and 17), as used to estimate each trip's probability of catching the focal species.

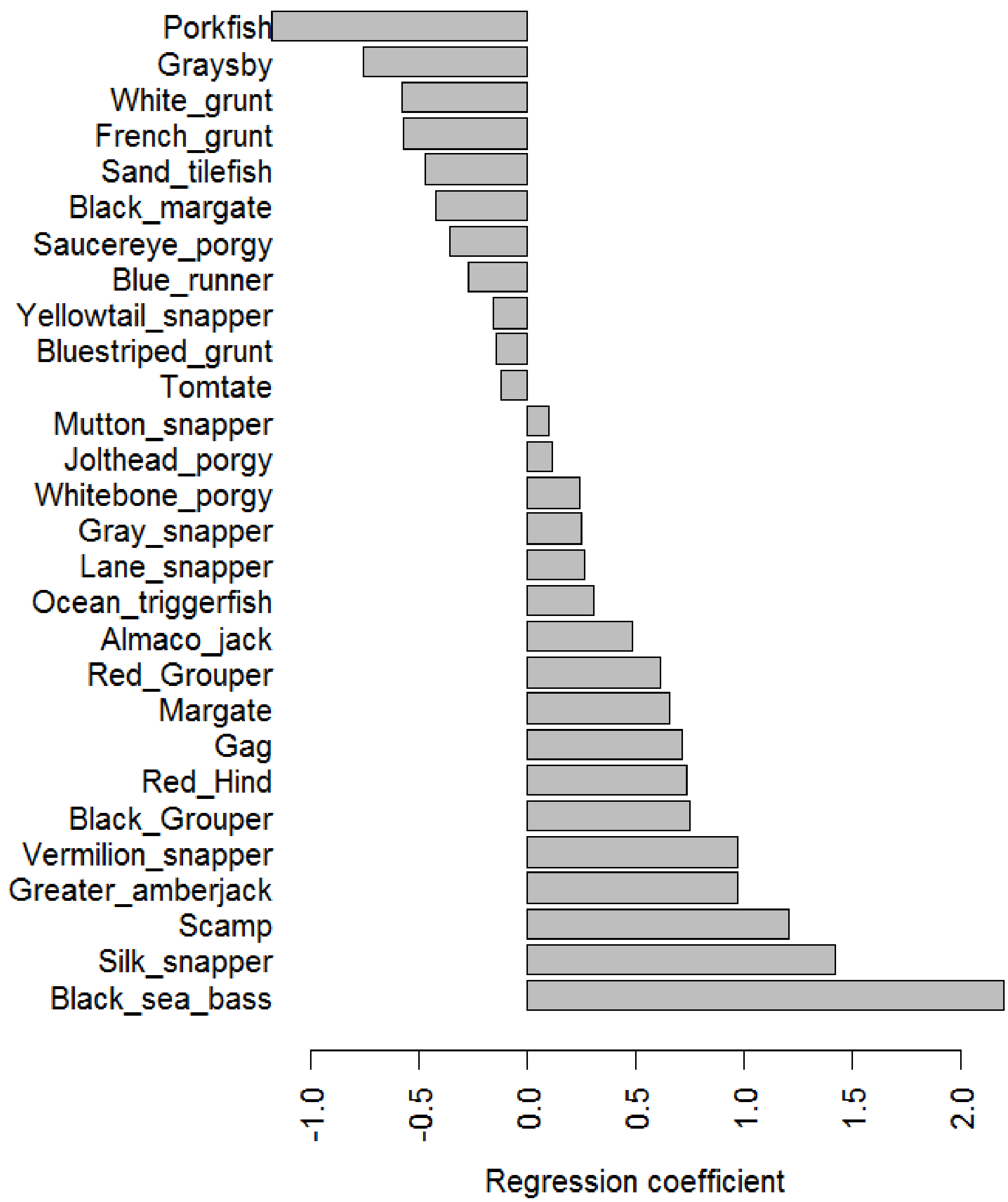


Figure 11. Absolute difference between observed and predicted number of positive trips from Stephens and MacCall method applied to headboat data from the northern region **1992-2009** (excludes areas 11, 12, and 17). Left and right panels differ only in the range of probabilities shown.

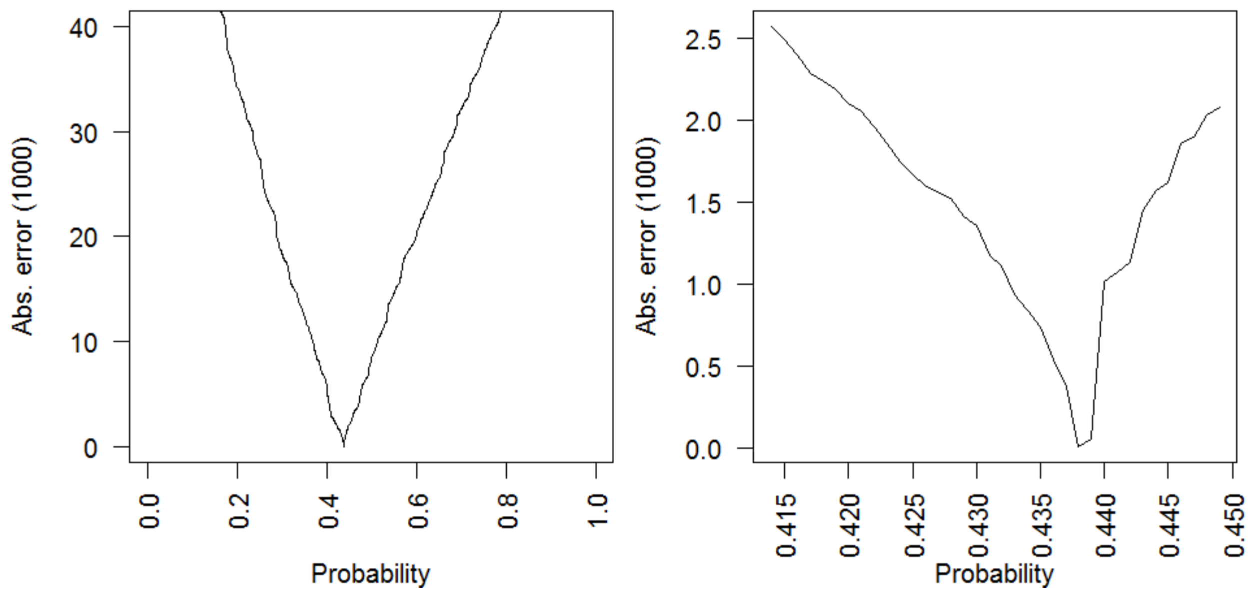


Figure 12. Absolute difference between observed and predicted number of positive trips from Stephens and MacCall method applied to headboat data from the southern region **1992-2009** (includes areas 11, 12, and 17). Left and right panels differ only in the range of probabilities shown.

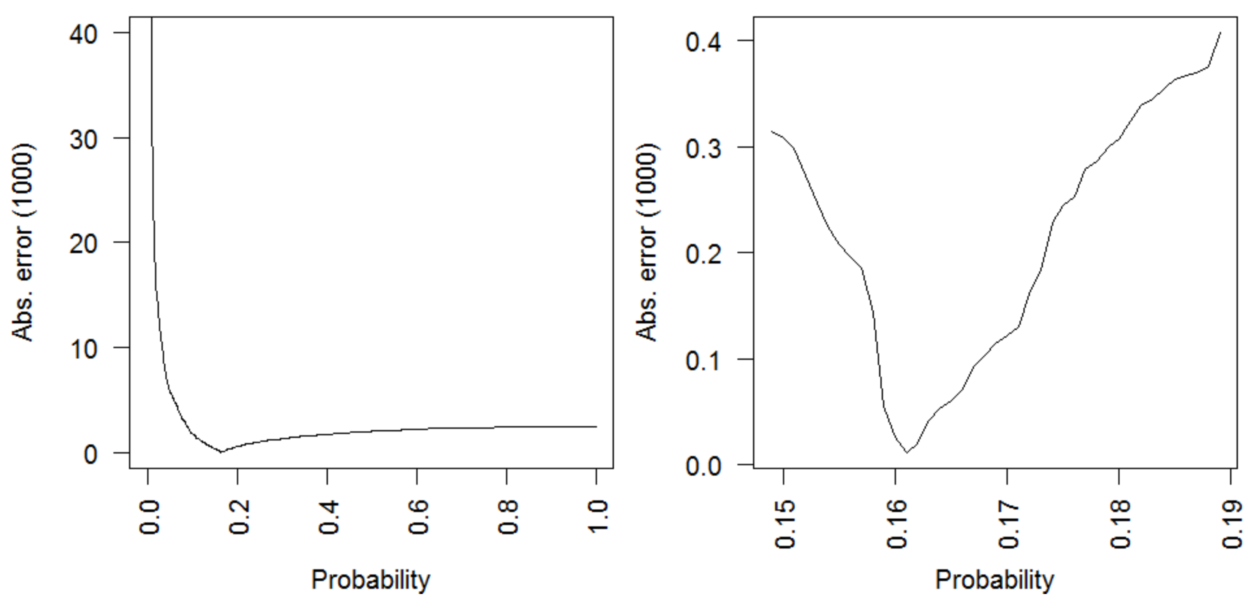


Figure 13. CPUE residuals for year, area, season, trip type and party size **1992-2009.**

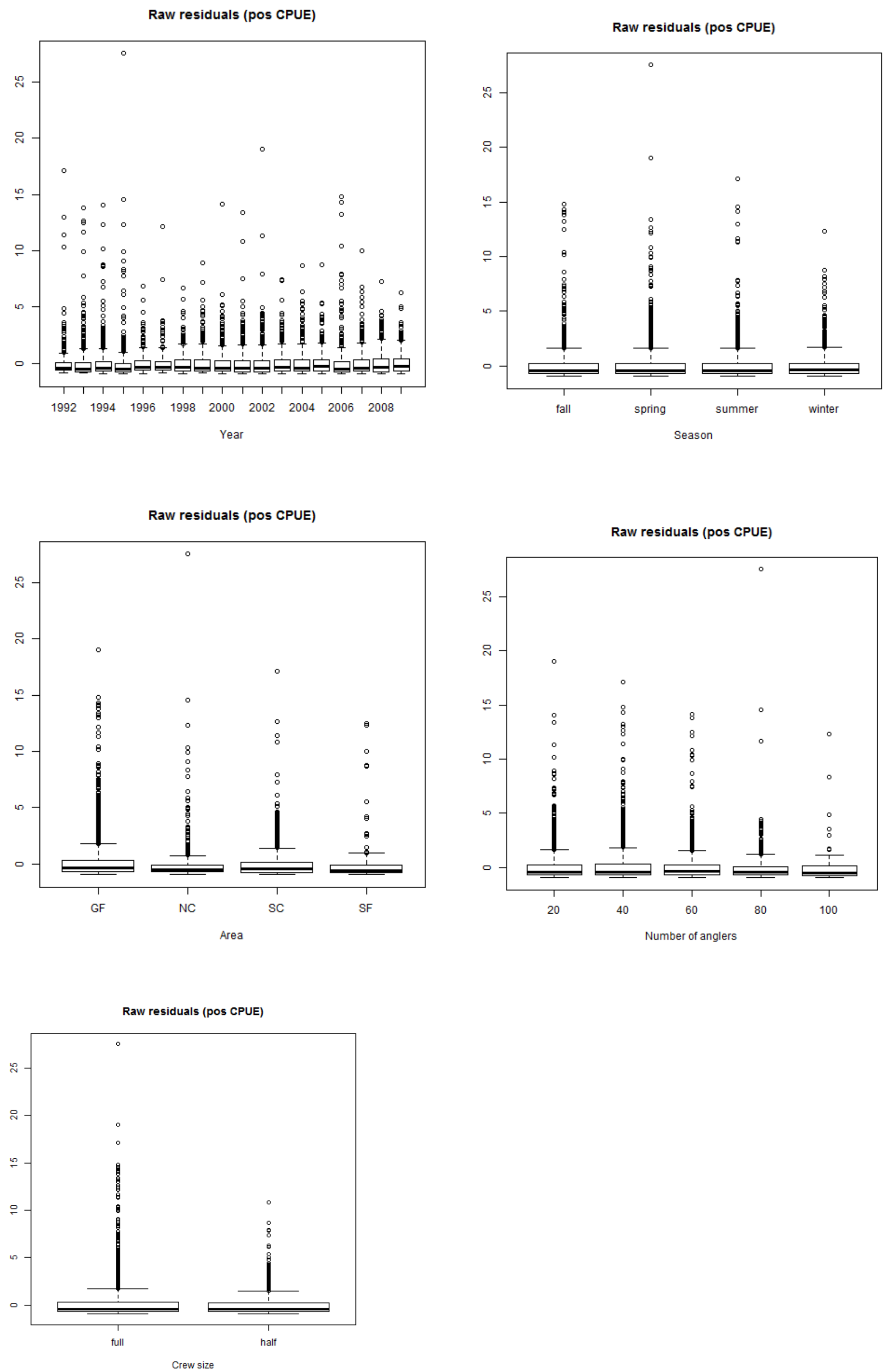
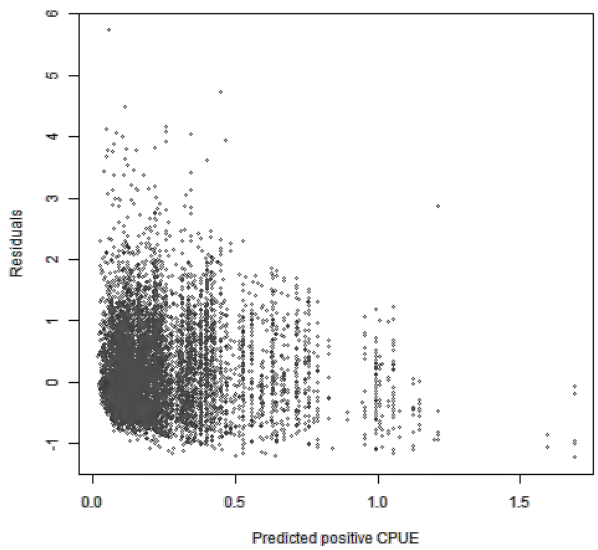


Figure 14. The gamma distribution and qq plot of catch for the south Atlantic red snapper headboat logbook during **1992-2009**.



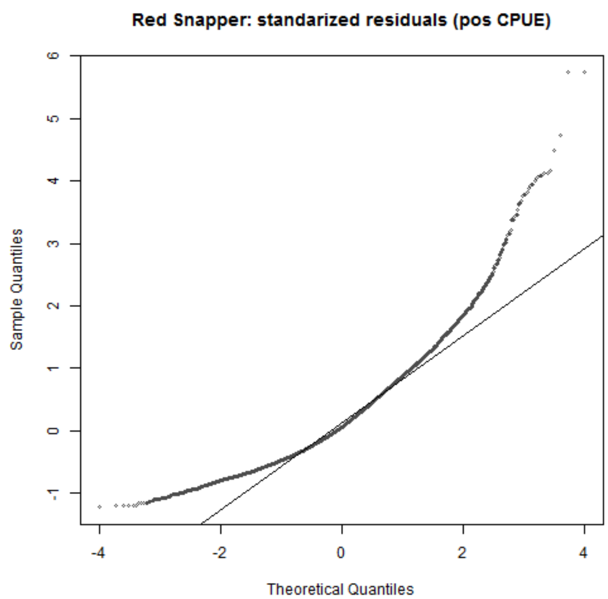
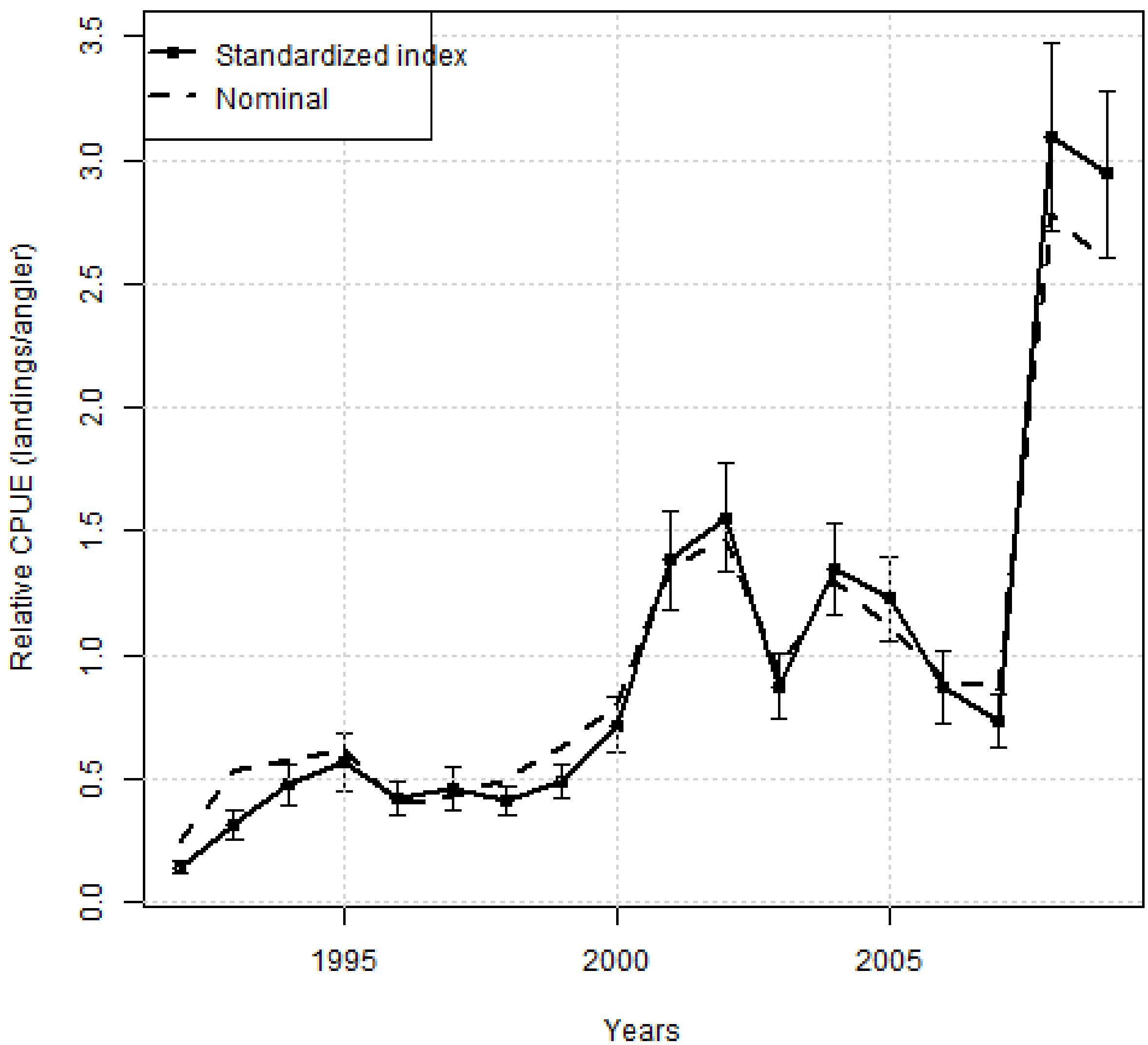


Figure 15. The standardized and nominal CPUE index with error bars at (+/-) 2 standard deviations (nominal by area below) computed for red snapper in the south Atlantic using the headboat logbook data during **1992-2009**.



Standardized catch rates of red snapper (*Lutjanus campechanus*) from headboat at-sea-observer data

Sustainable Fisheries Branch, National Marine Fisheries Service (contact: Eric Fitzpatrick)

SEDAR41-DW14

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***Addendum added to reflect changes made during Data Workshop.**
Final index is found in the addendum.

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***Addendum at end of document reflecting changes made at Data Workshop**

Abstract
Standardized catch rates were generated from the Southeast headboat at-sea-observer program for 2005-2013. The analysis included areas from central North Carolina through south Florida. The index is meant to describe population trends of fish in the size/age range of fish discarded by headboat vessels. Data filtering and subsetting steps were applied to the data to model trips that were likely to have directed red snapper effort.

Background and Data Description

The data used for this index were all trips in the headboat at-sea observer database which discarded red snapper from 2005-2013. The at-sea-observer program occurred from 2004-2009 in North and South Carolina, but did not occur in Florida and Georgia in 2004. In addition, after 2007 the Florida Keys were no longer included in the at-sea observer program.
Trip-level information included state, county, Florida region, year, month, day, dock to dock hours (total trip hours), the number of hours fished (to the nearest half hour), the total number of anglers on the boat, the number of anglers observed on a trip, the number of red snapper discarded, minimum depth of the fishing trip, and maximum depth of the fishing trip. Depth information was not collected for South Carolina, North Carolina, and Georgia; therefore, it was not used in this analysis. Refer to working paper SEDAR41-DW33 for more details regarding this program.

Methods

Data treatment
Data from 2004 were dropped from the analysis because Georgia and Florida were not sampled. Observer trips by year and area relative to all headboat trips as well as total red snapper observed are presented in Table 1.

~~Data were subsetted to include trips with the presence of at least one of the following associated species identified in Shertzer and Williams (2008) (bank seabass, black seabass, gag, gray triggerfish, greater amberjack, knobbed porgy, red porgy, red snapper, scamp, tomtate, vermillion snapper, white grunt, whitebone porgy).~~

A 20" TL minimum size regulation has been in place since 1992. In SEDAR 24, headboat at-sea observer data was used to index discards below 20" TL minimum. A 2010 closure has created a scenario where all fish observed are discarded (mini-seasons in 2012 & 2013 were removed). During this closure period, discards greater than 20" were removed.

Response and explanatory variables

CPUE – Discards per unit effort (DPUE) is defined as units of fish/ angler interviewed and was calculated as the number red snapper discarded divided by the number of anglers interviewed. CPUE relative to each explanatory variable is provided in Figure 1-6.

YEAR – A summary of the total number of trips with red snapper effort per year is provided in Table 1.

AREA –Area was defined as North Carolina, South Carolina and Georgia, north Florida (nFL), south Florida, (excluding the keys, flreg=3)

SEASON – The seasons were defined as winter (January, February, March), spring (April, May, June), summer (July, August, September) and fall (October, November, December).

PARTY – Four categories for the number of anglers on a vessel were considered in the standardization process.

HRSF– Four categories for the number of hours fished were considered in the standardization process.

Objective for SEDAR 41 Data Workshop

- Approve or modify proposed factors and factor definitions
- Discuss cpue definition (anglers vs angler-hours)
- Discuss filtering using associated species (bank seabass, black seabass, gag, gray triggerfish, greater amberjack, knobbed porgy, red porgy, red snapper, scamp, tomtate, vermillion snapper, white grunt, whitebone porgy)
- Disscuss management regulations and their potential influence on index
- Run GLM based on DW decisions regarding data and factors
- Estimate uncertainty
- Update working paper and provide text, figures, and research recommendations for the SEDAR 41 DW report

LITERATURE CITED

Shertzer. K. W. and E. H. Williams. 2008. Fish assemblages and indicator species: reef fishes off the southeastern United States. Fisheries Bulletin. 106:257-269.

Table 1. Trips by area and year and discarded red snapper in the south Atlantic headboat at-sea-observer data relative to the proportion of all headboat trips by state and year. (n.HB.obs= total observer trips, n.HB=total headboat trips, %cov= percent of all headboat trips observed, num.d= number of red snapper discards less than 20 " TL.)

*ADDENDUM(n.HB is incorrect, disregard percent coverage, correct table is in the Addendum below)

	NC				SC/GA				nFL				sFL				All			
year	n.HB.obs	n.HB	%cov	num.d	n.HB.obs	n.HB	%cov	num.d	n.HB.obs	n.HB	%cov	num.d	n.HB.obs	n.HB	%cov	num.d	n.HB.obs	n.HB	%cov	num.d
2005	97	2080	5%	0	64	4502	1.4%	10	42	6379	0.7%	512	76	6266	1.2%	50	279	19227	1.5%	572
2006	88	2109	4%	0	52	5316	1.0%	12	35	6696	0.5%	721	53	5449	1.0%	0	228	19570	1.2%	733
2007	91	1795	5%	14	60	6395	0.9%	10	48	7166	0.7%	1592	49	5789	0.8%	34	248	21145	1.2%	1650
2008	78	2140	4%	25	42	5200	0.8%	39	50	8031	0.6%	1619	57	12940	0.4%	28	227	28311	0.8%	1711
2009	69	1747	4%	3	43	6237	0.7%	32	52	9487	0.5%	414	61	16965	0.4%	8	225	34436	0.7%	457
2010	83	2179	4%	22	29	6515	0.4%	16	46	8782	0.5%	171	54	17614	0.3%	13	212	35090	0.6%	222
2011	79	1808	4%	13	25	6218	0.4%	9	46	6667	0.7%	199	47	15256	0.3%	0	197	29949	0.7%	221
2012	70	1924	4%	43	44	5379	0.8%	53	48	6440	0.7%	315	48	19843	0.2%	3	210	33586	0.6%	414
2013	53	1941	3%	145	52	5078	1.0%	45	46	6259	0.7%	224	66	20253	0.3%	1	217	33531	0.6%	415
total	708	17723	4%	265	411	50840	0.8%	226	413	65907	0.6%	5767	511	120375	0.4%	137	2043	254845	0.8%	6395

Figure 1. Discards/angler box plots by year and area.

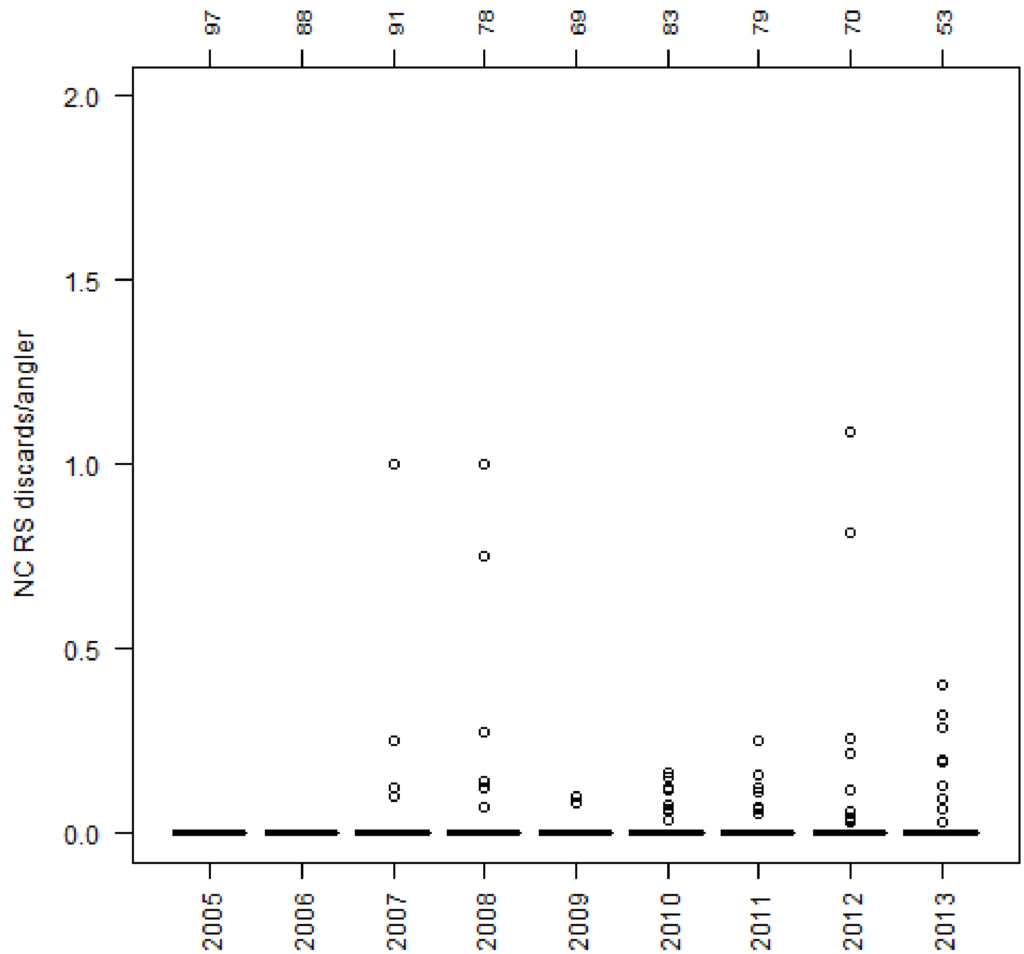


Figure 1. (continued)

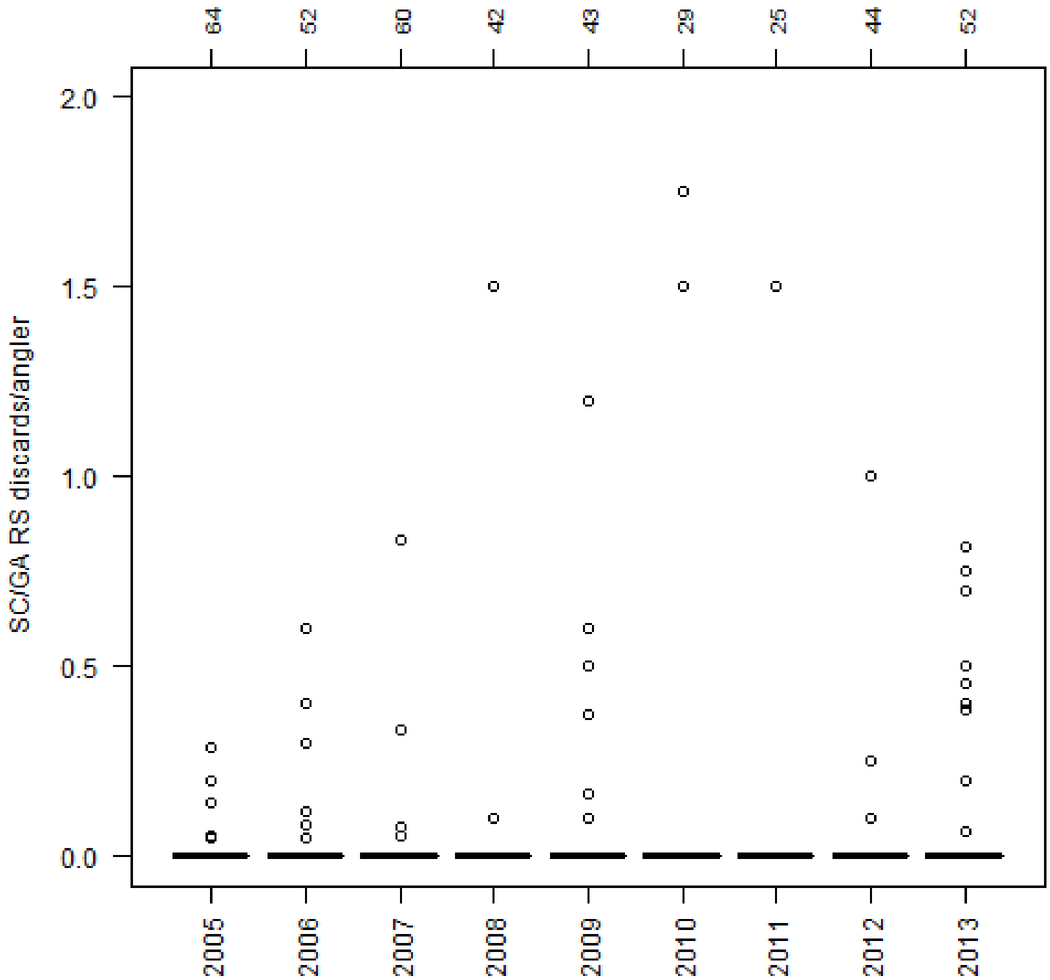


Figure 1. (continued)

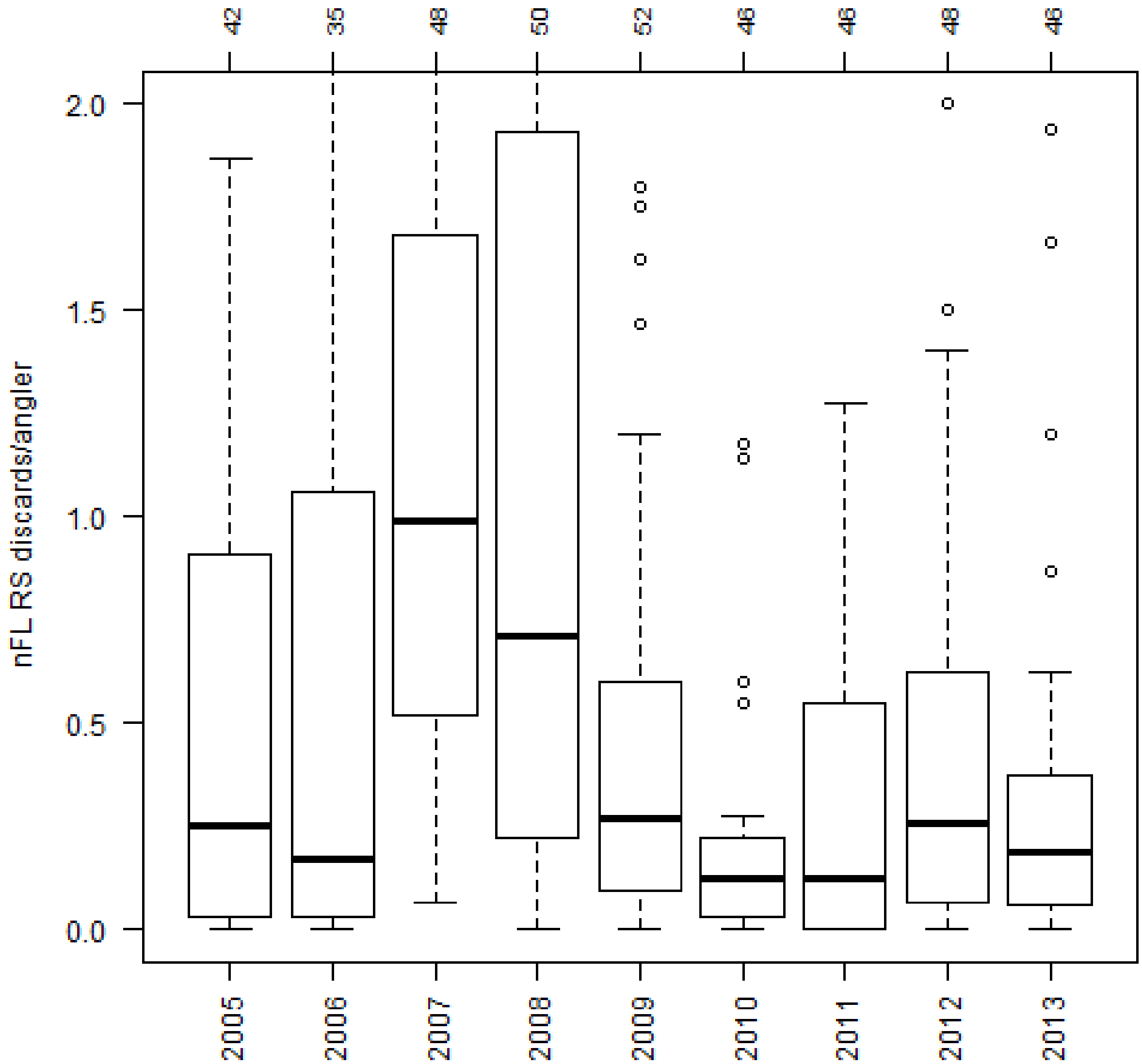


Figure 1. (continued)

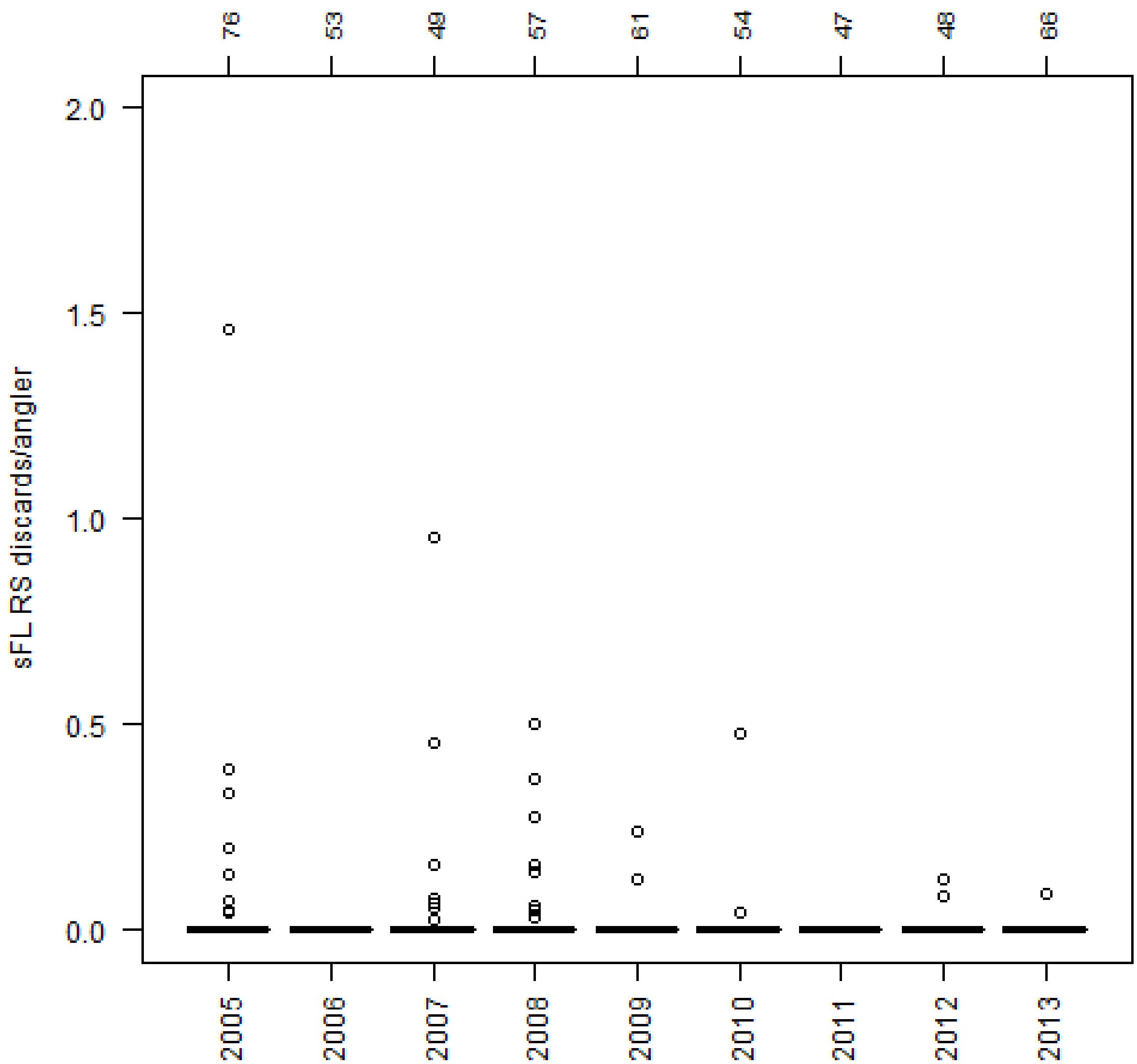


Figure 2. Discards/angler by year and area.

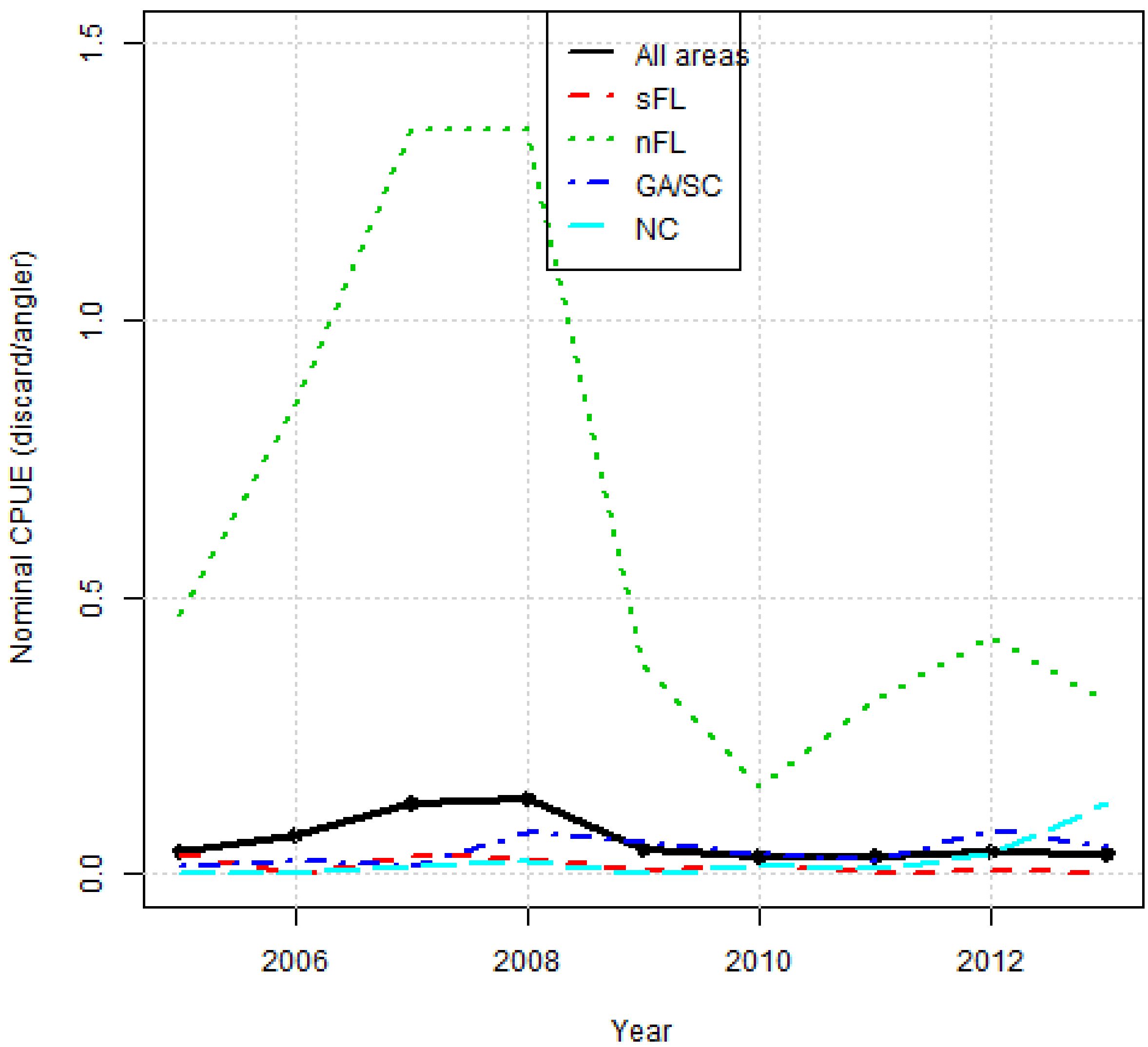


Figure 3. Discards/angler by year and season.

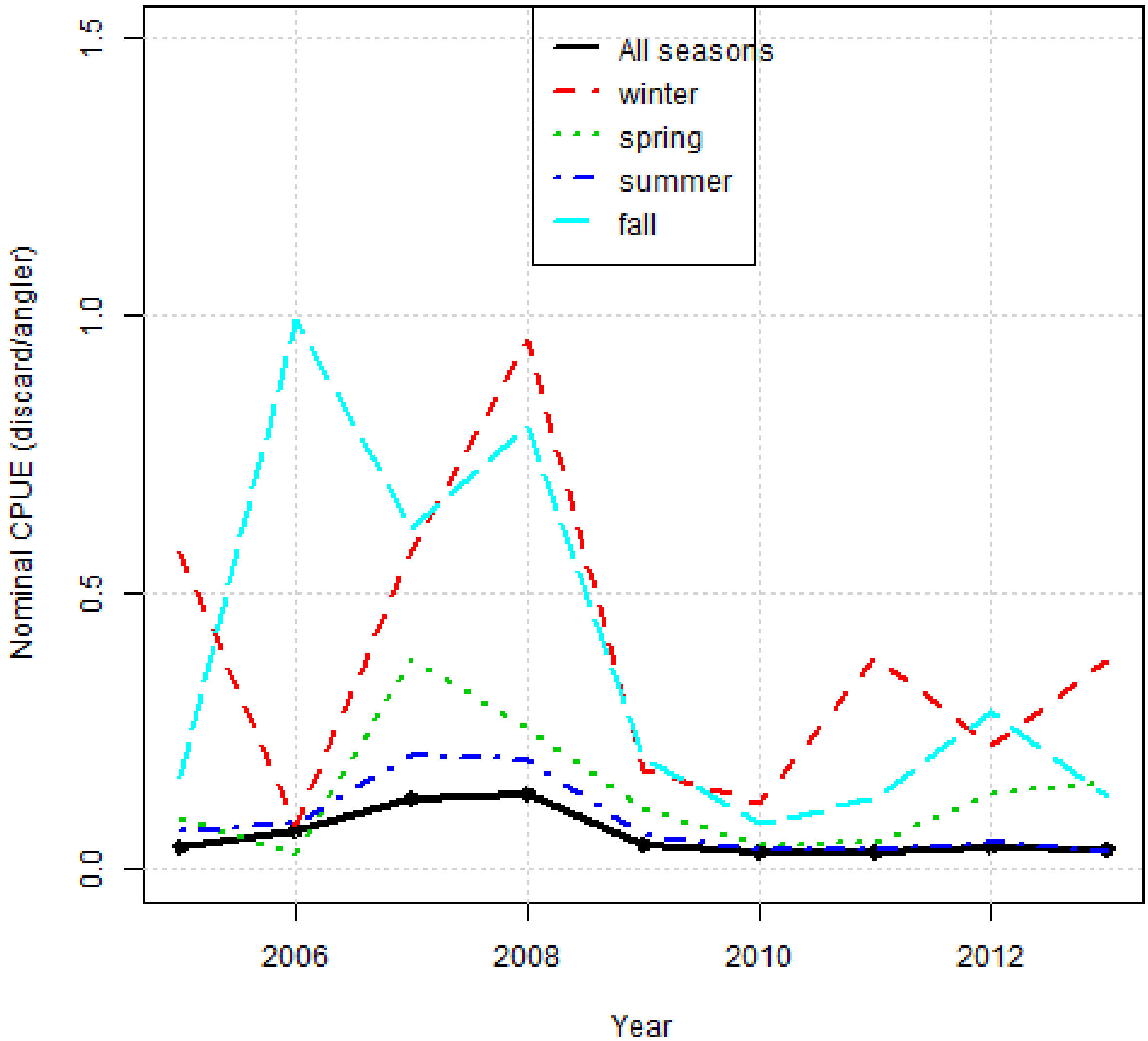


Figure 4. Discards/angler by year and party size.

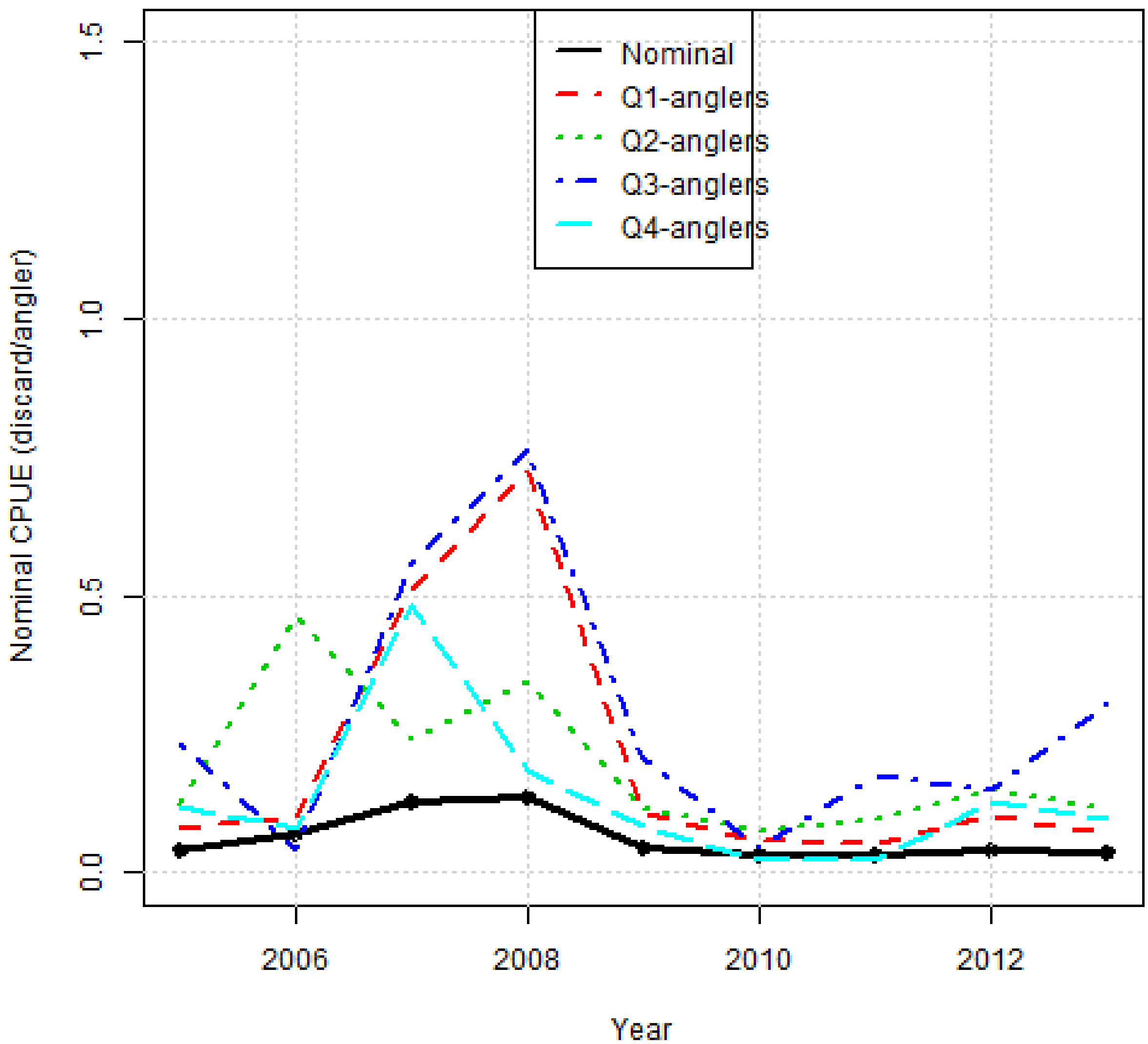
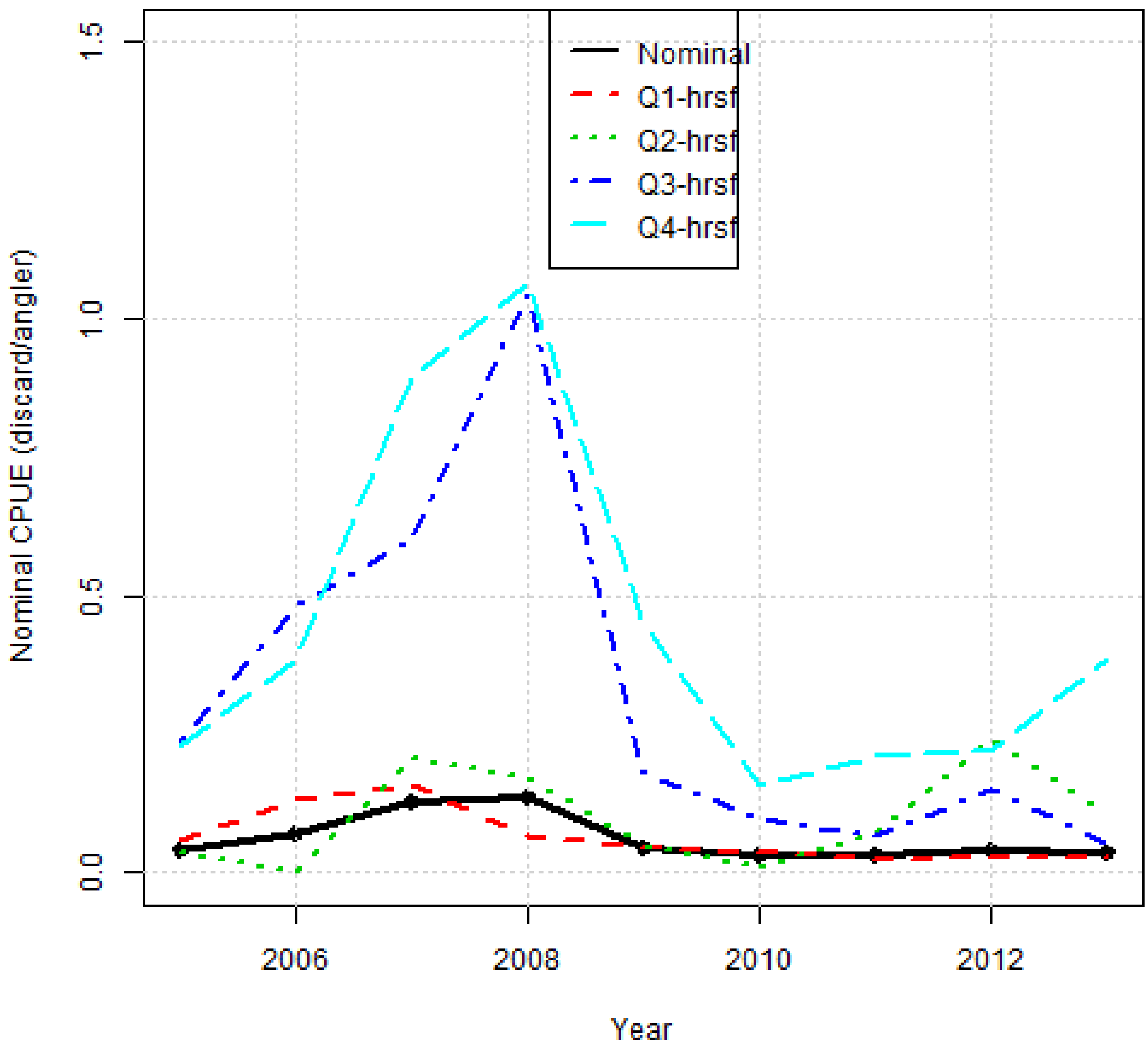


Figure 5. Discards/angler by year and hours fished.



ADDENDUM

Standardized catch rates of red snapper (*Lutjanus campechanus*)
from headboat at-sea-observer data

Sustainable Fisheries Branch, National Marine Fisheries Service,
Southeast Fisheries Science Center, 101 Pivers Island Rd, Beaufort, NC 28516

Abstract
Standardized catch rates were generated from the Southeast headboat at-sea-observer program for ~~2005-2013~~two time periods (2005-2009 and 2010-2013. The analysis included areas from central North Carolina through south Florida. The index is meant to describe population trends of fish in the size/age range of fish discarded by headboat vessels.

SEDAR 41 Index Working Group Review

Data workshop findings

Changes to data treatment

Trips that fished at night targeting sharks or trips that were designated drift fishing were removed from the analysis. All other trips were thought to be fishing for snapper-grouper species.

The IWG, along with headboat captains, discussed several key issues related to this index:

- Beginning in 1992, a 20” TL minimum size regulation influenced the fishing behavior of headboats that relied heavily on red snapper catch. Prior to 1992, red snapper was reportedly a target species, whereas after 1992, red snapper was sought more as by-catch. Because of these changes that likely affected catchability of red snapper, the IWG decided to split the index (1976-1991 & 1992-2009).
- Similarly, the red snapper closure starting in 2010 led to a shift in fishing behavior (avoidance). Because of that, and because this index is based on landings only (i.e., no discards included), the IWG decided to end the index in 2009.

Standardization

CPUE was modeled using the delta-glm approach (Lo *et al*. 1992; Dick 2004; Maunder and Punt 2004). In particular, fits of lognormal and gamma models were compared for positive CPUE. Also, the combination of predictor variables was examined to best explain CPUE patterns (both for positive CPUE and the Bernoulli submodels). All analyses were performed in the R programming language (R Development Core Team 2012), with much of the code adapted from Dick (2004).

Bernoulli submodel. One component of the delta-GLM is a logistic regression model that attempts to explain the probability of either catching or not catching red snapper on a particular trip. First, a model was fit with all main effects to determine which effects should remain in the binomial component of the delta-GLM. Stepwise AIC (Venables and Ripley1997) with a backward selection algorithm was then used to eliminate those that did not improve model fit. In this case, the stepwise AIC procedure did not remove any predictor variables. No concerning patterns were apparent in the quantile residuals (Dunn and Smyth 1996).

Positive CPUE submodel. To determine predictor variables important for describing positive CPUE, the positive portion of the model was fitted with all main effects using both the lognormal and gamma distributions. Stepwise AIC (Venables and Ripley1997) with a backward selection algorithm was then used to eliminate those that did not improve model fit. All predictor variables were modeled as factors rather than continuous variables.

Both submodels (Bernoulli and either lognormal or gamma) were then combined, and the models were compared using AIC. In this case, the lognormal distribution outperformed the gamma distribution in the earlier time series while the gamma outperformed the lognormal distribution in the later time series. No concerning patterns were apparent in standard diagnostic plots of residuals. The gamma model with all factors was used for computing the positive component of the index (2005-2009), and the binomial with all factors was used for computing the Bernoulli component of the index. The lognormal model with all factors was used for computing the positive component of the index (2010-2013), and the binomial with all factors was used for computing the Bernoulli component of the index.

The following data represents the dGLM results for the red snapper headboat at sea observer indices (2005-2009 & 2010-2013).

Table 1. Trips by area and year and discarded red snapper in the south Atlantic headboat at-sea-observer data by state and year.

	N.fish.catch				N.fish.harvest				N.fish.discard				N.trips			
Year	FL	GA	NC	SC	FL	GA	NC	SC	FL	GA	NC	SC	FL	GA	NC	SC
2005	578	4	1	12	14	2	1	9	564	2		3	155	6	97	58
2006	730	14	1	4	9	6	1	2	721	8		2	144	7	88	45
2007	1639	10	15	4	13	1	1	2	1626	8	14	2	144	8	91	52
2008	1660	60	30	3	13	22	6	2	1647	38	24	1	107	3	78	39
2009	429	82	4	0	7	50	1		422	32	3		114	9	69	34
2010	341	16	23	0					341	16	22		100	3	83	26
2011	311	9	14	0	130				202	9	13		34	3	79	22
2012	511	52	47	1	215		4		320	52	43	1	42	11	78	36
2013	377	45	176	0	156		19		229	45	155		37	11	55	41
Total	6576	292	311	24	557	81	33	15	6072	210	274	9	877	61	718	353

Table 2. The relative nominal CPUE, number of trips, standardized index, and CV for the red snapper headboat at-sea observer data in the south Atlantic from **2005-2009**.

Year	Relative nominal CPUE	N	Proportion N positive	Standardized index	CV (index)
2005	0.5063	206	0.1748	0.2952	0.3445
2006	0.8188	184	0.1630	0.2730	0.4356
2007	1.4983	205	0.2927	2.1325	0.2431
2008	1.5834	180	0.3222	1.5113	0.3700
2009	0.5932	168	0.3333	0.7879	0.3291

Table 3. The relative nominal CPUE, number of trips, standardized index, and CV for the red snapper headboat at-sea observer data in the south Atlantic from **2010-2013**.

Year	Relative nominal CPUE	N	Proportion N positive	Standardized index	CV (index)
2010	0.8226	165	0.3091	0.6865	0.2501
2011	0.8747	160	0.2375	0.6065	0.3452
2012	1.2203	169	0.3077	1.6057	0.2728
2013	1.0824	163	0.3313	1.1014	0.2494

Figure 1. Raw residuals by factor from **2005-2009**.

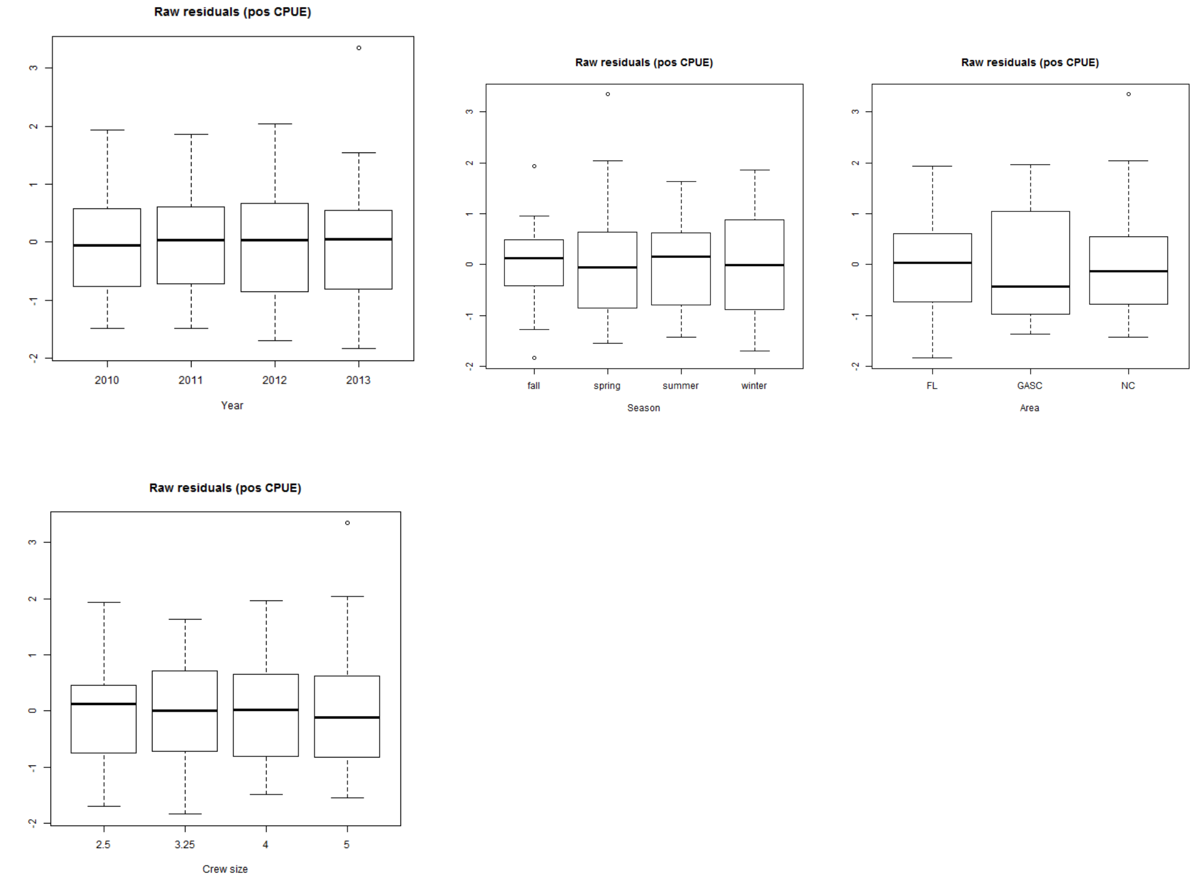


Figure 2. The lognormal distribution and qq plot of catch for the south Atlantic headboat at sea observer during **2005-2009**.

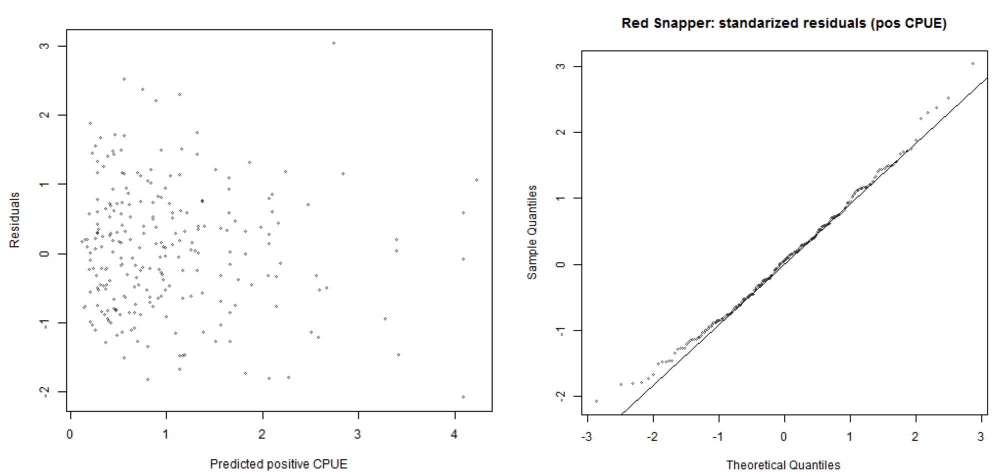


Figure 3. The standardized and nominal CPUE index with error bars at (+/-) 2 standard deviations (nominal by area below) computed for red snapper in the south Atlantic using the headboat at-sea observer data during **2005-2009**.

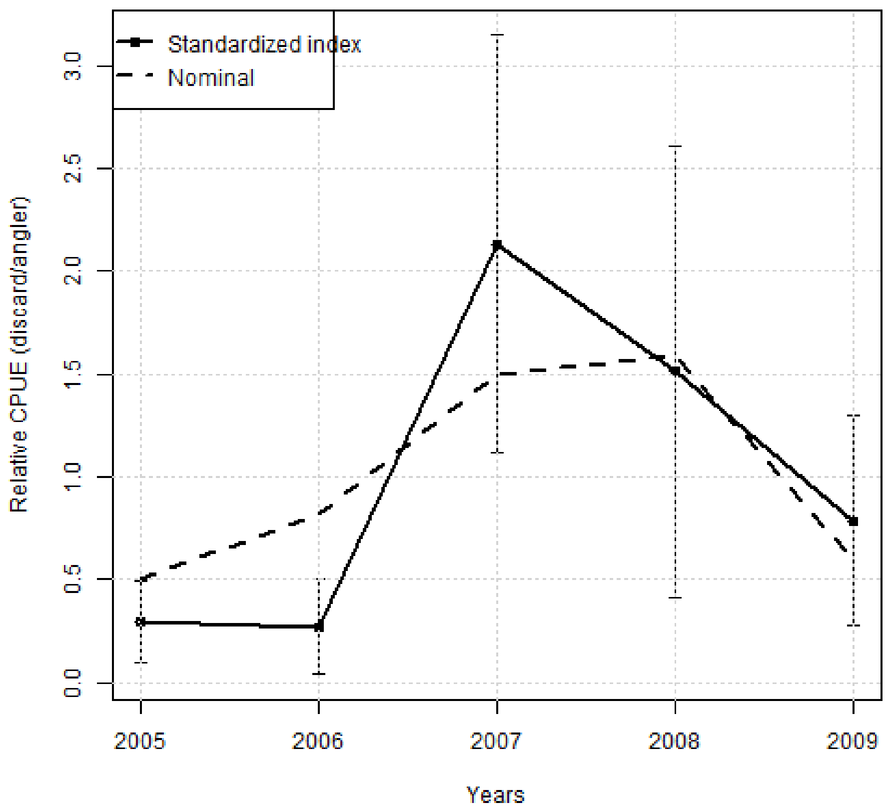


Figure 4. Discards/angler box plots by year and area from **2010-2013**.

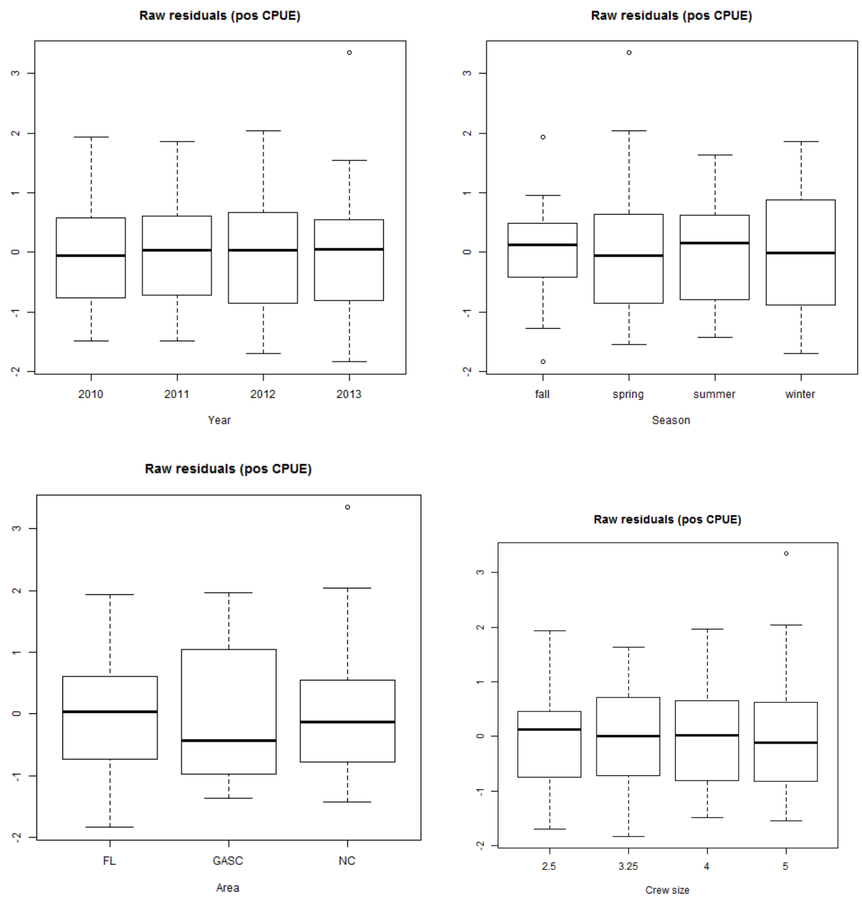


Figure 5. The lognormal distribution and qq plot of catch for the south Atlantic headboat at sea observer during **2010-2013**.

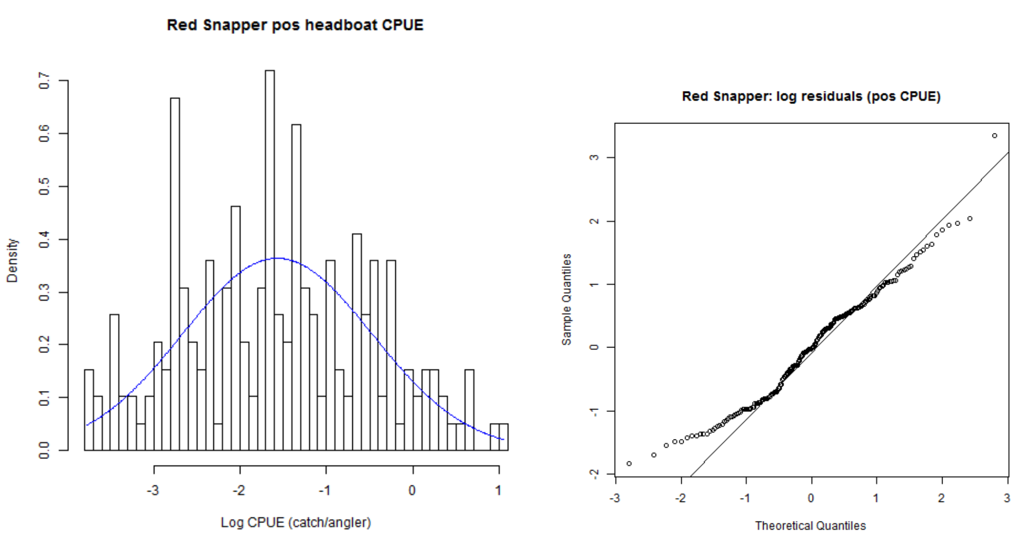
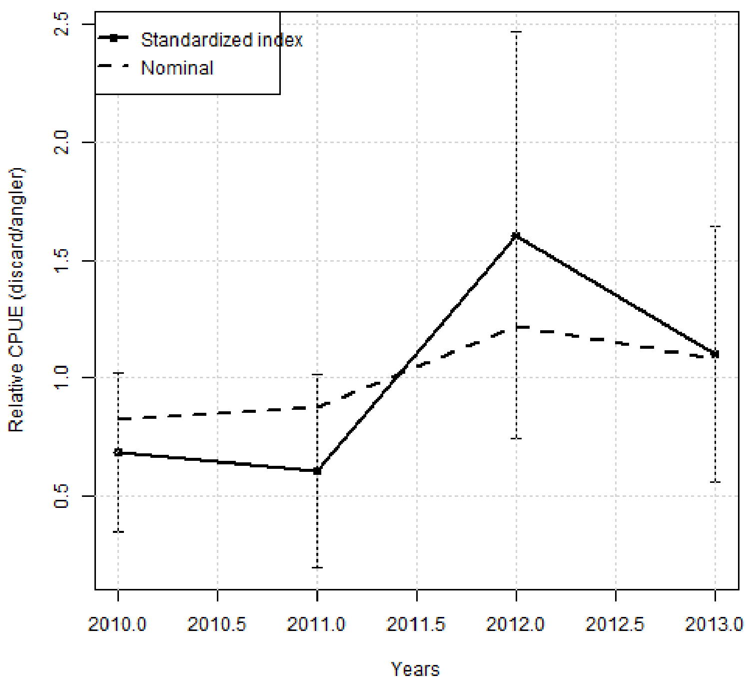


Figure 6. The standardized and nominal CPUE index with error bars at (+/-) 2 standard deviations (nominal by area below) computed for red snapper in the south Atlantic using the headboat at-sea observer data during **2010-2013**.



Standardized catch rates of red snapper (*Lutjanus campechanus*) in the southeast U.S. from commercial logbook data

Sustainable Fisheries Branch, National Marine Fisheries Service (contact: Rob Cheshire)

SEDAR41-DW19

Submitted: 24 July 2014
Addendum: 29 August 2014
***Addendum added to reflect changes made during Data Workshop.**
Updated to correct coding error: 30 July 2015

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Standardized catch rates of red snapper (Lutjanus campechanus) in the southeast U.S. from commercial logbook data

Sustainable Fisheries Branch, National Marine Fisheries Service
Southeast Fisheries Science center
101 Pivers Island Rd, Beaufort, NC 28516
July 2014
Ammended July 2015
(see Addendum, Tables 4–6, and Figures 18–26)

1.1 Introduction

Landings and fishing effort of commercial vessels operating in the southeast U.S. Atlantic have been monitored by the NMFS Southeast Fisheries Science Center through the Coastal Fisheries Logbook Program (CFLP). The program collects information about each fishing trip from all vessels holding federal permits to fish in waters managed by the Gulf of Mexico and South Atlantic Fishery Management Councils. Initiated in the Gulf in 1990, the CFLP began collecting logbooks from Atlantic commercial fishers in 1992, when 20% of Florida vessels were targeted. Beginning in 1993, sampling in Florida was increased to require reports from all vessels permitted in coastal fisheries, and since then has maintained the objective of a complete census of federally permitted vessels in the southeast U.S.

Catch per unit effort (CPUE) from the logbooks was used to develop an index of abundance for red snapper landed with vertical lines (manual handline and electric reel), the dominant gear for this red snapper stock (Tables 1 and 2). Thus, the size and age range of fish included in the index is the same as that of landings from this same fleet. The time series used for construction of the index spanned 1993 to 2009, when all vessels with federal snapper-grouper permits were required to submit logbooks on each fishing trip. For this southeast U.S. Atlantic stock, areas used in analysis were those between 24 and 37 degrees latitude, inclusive of the boundaries (Figure 1). A red snapper closure was implemented in January, 2010 which prevents the use of the CFLP data as an index for 2010-present.

1.2 Commercial Diving

The CFLP diving data was considered and rejected due to small sample sizes and limited spatial coverage (Tables 1 and 2, Figure 2).

1.3 Commercial Handline

1.3.1 Data filtering

For each fishing trip, the CFLP database included a unique trip identifier, the landing date, fishing gear deployed, areas fished, number of days at sea, number of crew, gear-specific fishing effort, species caught, and weight of the landings (reported fields described in Appendix). Fishing effort data available for vertical line gear included number of lines fished, hours fished, and number of hooks per line.

Data were restricted to include only those trips with landings and effort data reported within 45 days of the completion of the trip (some reporting delays were longer than one year). Reporting delays beyond 45 days likely resulted in less reliable effort data (landings data may be reliable even with lengthy reporting delays if trip ticket reports were referenced by the reporting fisher). This restriction excluded approximately 24% of the full data set (i.e., the data set with all gears and all areas, including Gulf of Mexico). Also excluded were records reporting multiple gears fished, which prevents designating catch and effort to specific gears. Therefore, only trips which reported one gear fished were included in these analyses. For records where more than one area was reported, the first area reported was used to determine the latitude associated with the trip.

Clear outliers in the data used as factors in the model or to calculate cpue were excluded from the analyses. Outliers were defined as values falling outside the 99.5 percentile of the data. For trip-level data (crew, days at sea, hours fished, number of lines, and number of hooks per line) all snapper-grouper trips were evaluated instead of the positive red snapper trips as in SEDAR 24 (Table 3). For hours fished, both upper and lower outliers were removed. Outliers related to CPUE for positive red snapper trips were removed (Table 3).

The analysis of data from the CFLP was completed through 2009 in SEDAR 24 for handline gear (electric and manual reels combined). The analysis could not be extended further due to the January 2010 closure of the red snapper fishery. Minimal open seasons that were implemented in recent years are biased due to targeting and could not be used in the development of an index of abundance.

1.3.2 Explanatory variables considered

YEAR - Year was necessarily included, as standardized catch rates by year are the desired outcome. Years modeled were 1993-2009. The total number of red snapper trips by year is provided in table 1 and catch per year is provided in table 2.

SEASON - Season included four levels: winter (JanuaryMarch), spring (AprilJune), summer (JulySeptember), and fall (OctoberDecember). The relative number of trips per month is shown in figure 3. The annual cpue associated with each season is given figure 4.

AREA - Area (latitude) is reported in the logbook on a one degree grid (Figure 1). For SEDAR 41, we propose keeping the data at the level it was collected with the exception of pooling the latitudes at the fringe of the range. Pooling latitudes 24 to 29 to 29 degrees and 34 to 38 to 34 degrees (Figure 3). This pooling gives 2000 to 3000 trips per latitude bin. Other methods for pooling areas were considered including quantiles. However, these methods require assigning latitude bins with large sample size to pooled bins when the geographical boundary (e.g. states) or quartile value falls in the middle of a latitude bin. The annual cpue associated with each latitude is given figure 5.

DAYS AT SEA - 'Days at sea' were pooled into three levels: one to two days, three to four days (twotofour), and five or more days (fiveplus). The relative number of trips per year by days at sea is shown in Figure 3. The annual cpue associated with days at sea is given figure 6.

CREW SIZE - Crew size (crew) could influence the total effort and could be a psuedo–factor for vessel size. The quantile split values (at 25, 50, and 75%) for red snapper crew size fall at 2, 2, and 3 crew per trip. Therefore crew size was pooled more subjectively into three levels: one (one), two (two), and three or more days (threeplus). The relative number of trips in each level is given in figure 3. Trips with one crew member were not pooled even though the relative sample size is small because it is believed there would be a significant difference trip efficiency between a crew size of one and two. The annual cpue associated with crew size is given figure 7.

1.3.3 Response variable (CPUE) data considerations

The distribution of positive red snapper trips generally showed a maximum off NC and SC with a moderate decline to about cape canaveral and then a precipitous decline further South (Figure 8). However, the trend in CPUE the mean nominal CPUE has the opposite spatial pattern with larger values further south (Figure 9). This may partially be explained by much shorter trips in South Florida on average. Fishermen are known to target other species at night on multi–day trips and this effort is counted towards the total effort for the trip.

The response variable, CPUE, was calculated for each trip as,

CPUE = pounds of red snapper/hook-hours

where hook-hours is the product of number of lines fished, number of hooks per line, and total hours fished. Spatio-temporal trends were examined for cpue and each of its components (Figures 10 – 9). The mean cpue increased dramatically from 2006–2009 in GA and North Florida while other areas showed no increase (Figure 9). Mean cpue was examined by latitude with northern latitudes grouped 34 degrees and southern latitudes pooled at 29 degrees (Figure 5). The trends in cpue diverge at approximately 32 degrees (near Savannah, GA) after 2005 with the South showing a dramatic increase in CPUE. Inversely, at the beginning of the series the South has the lowest CPUE values. The recent divergence appears to be driven more by catch than effort (Figures 14 – 16).

1.4 Objectives for SEDAR 41 Data Workshop

- Approve or modify proposed factors and factor definitions
- Discuss other possible factors (fuel price index, lunar phase) if time pemits
- Approve or modify cpue definition
  - Discuss possible issue with correlation between cpue denominator component, hours fished, and days at sea factor (Figure 17)
- Discuss filtering (Stephens and MacCall method)
  - The Stephens and MacCall approach used in SEDAR 24 is problematic for habitats with many correlated species. Trips that have split effort among habitats or modified fishing behavior (hook size or bait size) within a trip excaserbate the problem because species assemblages become nonsense. Vermilion snapper was one of the highest correlated species with red snapper and and although they occur in the same locations as red snapper the typical method to prosecute vermilion snapper is quite different then red snapper in most regions. For these reasons we propose running a GLM on positive red snapper trips for SEDAR 41.
- Run GLM based on DW decisions regarding data and factors
- Estimate uncertainty
- Update working paper and provide text, figures, and research recommendations for the SEDAR 41 DW report

Addendum

1.5 Workgroup decisions and justifications

- The proposed factors and definitions were accepted by the panel.
- Since the 2010 closure of red snapper mini-seasons were established for commercial fishermen in 2012 and 2013. These short openings had a restrictive trip limit of 75 pounds. Commercial fishermen indicated they would target red snapper briefly to catch the limit and move to other habitats. This makes the limited data available for 2012 and 2013 invalid and would be biased toward low CPUE for red snapper.
- Lunar phase and a fuel price index were discussed briefly. Lunar phase can be calculated for each trip and might be of possible use after further investigation but was not recommended for inclusion in SEDAR 41. It was not clear how annual fuel price index would be incorporated and would be currently be absorbed in the year effect.
- The "days at sea" factor correlation with the hours fished which is a component of the CPUE denominator was discussed. The "days at sea" factor was binned into 3 categories. The workgroup did not have a concern that the correlation would influence the model.
- The use of the Stephens and MacCall (2004) approach was discussed and the panel felt, even though there are caveats with the method, it is still the best method to define effective effort. The usual method of determining species association based on presence–absence of both target and predictor species was evaluated. In addition, the species associations were evaluated using presence-absence of the target species and the catch of the predictor species. The species and distribution of species associations were very similar. However, there was some concern that trip limits might influence the regression coefficients when using catch as a predictor. The group also evaluated a positive–only model. The Stephens and MacCall approach was recommended through 2009 as in SEDAR 24 because it is based on effective effort.

1.6 Subsetting

Effective effort was based on those trips from areas where red snapper were available to be caught. Without fine-scale geographic information on fishing location, trips to be included in the analysis must be inferred, which was done here using the method of Stephens and MacCall (2004) The method uses multiple logistic regression to estimate a probability for each trip that the focal species was caught, given other species caught on that trip. Because a zoogeographic boundary is apparent near Cape Canaveral (Shertzer et al. 2009), the method was applied separately to data from regions north and south of 29 degrees latitude (near Cape Canaveral). To avoid undue influence of rare species on regression estimates, species included in each analysis were limited to those occurring in 1% or more of trips . Red porgy was also omitted because of strict harvest regulations since 1999 (including a temporary moratorium), which creates the potential for erroneously removing trips likely to have caught red snapper during years of red porgy restrictions. A backwards stepwise AIC procedure (Venables and Ripley 1997) was then used to perform further selection among possible species as predictor variables, where the most general model included all listed species as main effects. In this procedure, a generalized linear model with Bernoulli response was used to relate presence/absence of gray triggerfish in each trip to presence/absence of other species. For the northern sampling area (NC, SC, GA, north FL), stepwise AIC eliminated mutton snapper and sand tilefish; for the southern sampling area (south FL), it eliminated black grouper and almaco jack. Regression coefficients of included species for the northern sampling areas are shown in figure 18, and for the southern areas in figure 19. A trip was then included if its associated probability of catching red snapper was higher than a threshold probability (Figures 20, 21). The threshold was defined to be that which resulted in the same number of predicted and observed positive trips, as suggested by Stephens and MacCall (2004). After applying the Stephens and MacCall method, and the constraints described above, the resulting subsetted data set contained 17,255 trips in the northern sampling areas, of which 63% were positive, and 1,724 trips from the southern sampling area, of which 43% were positive.

1.7 Standardization

CPUE was modeled using the delta-GLM approach (Lo et al. 1992; Dick 2004; Maunder and Punt 2004). This approach combines two separate generalized linear models (GLMs), one to describe presence/absence of the focal species, and one to describe catch rates of successful trips (trips that caught the focal species). Estimates of variance were based on 1000 bootstrap runs where trips were chosen randomly with replacement (Efron and Tibshirani 1993). All analyses were programmed in R, with much of the code adapted from Dick (2004).

1.8 Bernoulli submodel

The bernoulli component of the delta-GLM is a logistic regression model that attempts to explain the probability of either catching or not catching red snapper on any given trip. Initially, all explanatory variables were included in the model as main effects, and then stepwise AIC (Venables and Ripley 1997) with a backwards selection algorithm was used to eliminate those variables that did not improve model fit. In this case, the stepwise AIC procedure did not remove any explanatory variables (Table 5). Diagnostics, based on randomized quantile residuals (Dunn and Smyth 1996), suggested reasonable fits of the Bernoulli submodel (Figure 22).

1.9 Explanatory variables considered

All explanatory factors considered in the data evaluation were included in the model. Year, season (3–month intervals), latitude (29.5–34.5 degrees pooled at the tails), number of crew including captain (1,2 and 3–plus), and days at sea (1–2,3–4, and 5–plus).

1.10 Positive CPUE submodel

Two parametric distributions were considered for modeling positive values of CPUE, lognormal and gamma. For both distributions, all explanatory variables were initially included as main effects, and then stepwise AIC (Venables and Ripley 1997) with a backwards selection algorithm was used to eliminate those variables that did not improve model fit. For both lognormal and gamma distributions, the best model fit included all explanatory variables (lognormal shown in Table 5). The two distributions, each with their best set of explanatory variables (all of them), were compared using AIC lognormal(AIC=58) highly outperformed gamma (AIC=2793), and was therefore applied in the final delta–GLM. Diagnostics suggested reasonable fits of the lognormal submodel (Figures 23, 24).

1.11 Results

The Stephens and MacCall (2004) method had the effect of concentrating the higher CPUE values at the center of the population distribution (Figure 25). The standardization process adjusted the CPUE values higher from 2000 to 2006 and lower for 2008 and 2009 (Figure 26 and Table 6). Overall, the SEDAR 41 index developed using the Stephens and MacCall (2004) approach is only slightly different then the alternative approach using the positive red snapper trips (Figure 26).Over the last four years of the index (2006–2009), the pattern has been one of strict increase, culminating in the highest expected value of the full series.

1.12 References

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1.13 Tables

Table 1. Commercial logbook red snapper trips by gear.

Year	Diving	Handline	Other
1993	24	1155	24
1994	61	1790	30
1995	60	1624	22
1996	99	1255	15
1997	122	1349	15
1998	85	1221	30
1999	83	1234	14
2000	89	1158	25
2001	122	1764	21
2002	69	1775	13
2003	80	1181	25
2004	48	1032	10
2005	50	980	9
2006	86	729	14
2007	90	824	20
2008	65	1025	26
2009	73	1216	33

Table 2. Commercial logbook red snapper landings by gear (Thousand pounds).

Year	Diving	Handline	Other
1993	0.64	71.87	1.15
1994	1.71	112.95	0.57
1995	2.61	117.65	1.48
1996	4.40	78.99	0.48
1997	5.63	81.67	0.42
1998	2.77	63.40	1.40
1999	3.40	63.53	0.93
2000	3.18	73.04	1.13
2001	6.45	156.42	1.37
2002	3.02	130.72	0.40
2003	3.40	98.26	1.11
2004	4.25	107.48	0.26
2005	2.89	86.03	0.43
2006	3.27	50.77	0.44
2007	6.12	66.17	0.47
2008	3.34	158.16	1.57
2009	4.89	256.63	0.96

Table 3. CFLP Handline cutoff values for outliers (records reporting more (upper),or less (lower) were excluded).

Year	s24manual	s24electric	s41manual	s41electric
lines fished (upper)	8	5	6	6
hooks per line (upper)	8	8	8	10
days at sea (upper)	8	11	10	12
crew (upper)	4	5	5	5
hours fished (lower)			4	4
hours fished (upper)			105	143
cpue (upper)			24	24

Table 4. Proportion positive by year and factor (s–season followed by months, l–latitiude, c–crew size, a–days at sea)

Year	s1-3	s4-6	s7-9	s10-12	l29.5	l30.5	l31.5	l32.5	l33.5	l34.5	c1	c2	c3plus	a1-2	a3-4	a5plus
1993	0.69	0.75	0.70	0.61	0.54	0.82	0.83	0.86	0.76	0.66	0.47	0.65	0.81	0.52	0.77	0.85
1994	0.77	0.75	0.64	0.64	0.62	0.85	0.88	0.82	0.63	0.58	0.55	0.66	0.76	0.51	0.73	0.84
1995	0.80	0.66	0.56	0.66	0.72	0.77	0.88	0.78	0.54	0.43	0.61	0.60	0.72	0.49	0.66	0.83
1996	0.61	0.61	0.48	0.60	0.65	0.77	0.85	0.62	0.37	0.35	0.42	0.53	0.63	0.44	0.52	0.72
1997	0.62	0.56	0.48	0.45	0.69	0.64	0.76	0.61	0.36	0.28	0.58	0.51	0.53	0.43	0.52	0.62
1998	0.53	0.56	0.46	0.57	0.55	0.80	0.86	0.59	0.33	0.40	0.34	0.48	0.62	0.42	0.49	0.68
1999	0.50	0.60	0.55	0.57	0.51	0.75	0.94	0.68	0.41	0.40	0.25	0.48	0.64	0.40	0.53	0.73
2000	0.54	0.53	0.53	0.62	0.61	0.83	0.94	0.63	0.26	0.46	0.46	0.51	0.60	0.44	0.54	0.71
2001	0.71	0.72	0.64	0.71	0.71	0.91	0.90	0.70	0.55	0.70	0.55	0.66	0.74	0.55	0.74	0.78
2002	0.77	0.82	0.67	0.68	0.56	0.87	0.95	0.78	0.66	0.70	0.60	0.70	0.77	0.57	0.74	0.84
2003	0.65	0.78	0.56	0.63	0.61	0.94	0.90	0.74	0.53	0.49	0.55	0.60	0.72	0.46	0.63	0.79
2004	0.79	0.70	0.56	0.60	0.69	0.95	0.92	0.75	0.54	0.38	0.39	0.57	0.76	0.41	0.60	0.81
2005	0.67	0.62	0.56	0.59	0.54	0.86	0.84	0.74	0.47	0.40	0.42	0.51	0.70	0.42	0.52	0.77
2006	0.56	0.58	0.39	0.44	0.54	0.88	0.75	0.49	0.37	0.27	0.48	0.43	0.54	0.32	0.45	0.58
2007	0.52	0.43	0.46	0.52	0.62	0.85	0.78	0.45	0.25	0.30	0.40	0.39	0.57	0.38	0.41	0.60
2008	0.61	0.55	0.49	0.63	0.76	0.95	0.75	0.58	0.31	0.38	0.53	0.44	0.66	0.43	0.55	0.66
2009	0.68	0.58	0.59	0.83	0.82	0.93	0.82	0.56	0.31	0.42	0.67	0.50	0.72	0.63	0.54	0.69

Table 5. Model selection results from delta-lognormal model.

Factor	Df	Deviance	AIC
Bernouli submodel			
none		22245	22303
crew	2	22296	22350
season	3	22353	22405
away	2	22742	22796
year	16	22783	22809
lat	5	23564	23612
Lognormal submodel			
none		79760	55197
crew	2	79812	55201
season	3	80059	55235
away	2	81365	55424
lat	5	83285	55687
year	16	84963	55896

Table 6. Standardized index of red snapper from commercial logbook data.).

Year	N	Proportion Positive	Relative nominal	Standardized CPUE	CV
1993	772	0.72	0.571	1.086	0.063
1994	1210	0.7	0.521	0.891	0.051
1995	1400	0.66	0.716	0.891	0.046
1996	1101	0.57	0.525	0.612	0.055
1997	1390	0.53	0.662	0.589	0.054
1998	1222	0.53	0.694	0.659	0.055
1999	1068	0.56	0.507	0.798	0.060
2000	1067	0.55	0.746	0.737	0.056
2001	1282	0.7	0.94	1.274	0.049
2002	1386	0.73	0.903	1.383	0.046
2003	1117	0.66	0.699	1.042	0.053
2004	1030	0.65	0.84	1.423	0.054
2005	1067	0.61	0.786	1.188	0.058
2006	893	0.49	0.44	0.597	0.071
2007	1108	0.48	0.599	0.665	0.064
2008	955	0.56	1.933	1.223	0.066
2009	911	0.63	4.918	1.942	0.073

1.14 Figures

Figure 1. CFLP Latitude Stratification (midpoint of each latitudinal grid is labeled with the floor for the bin).

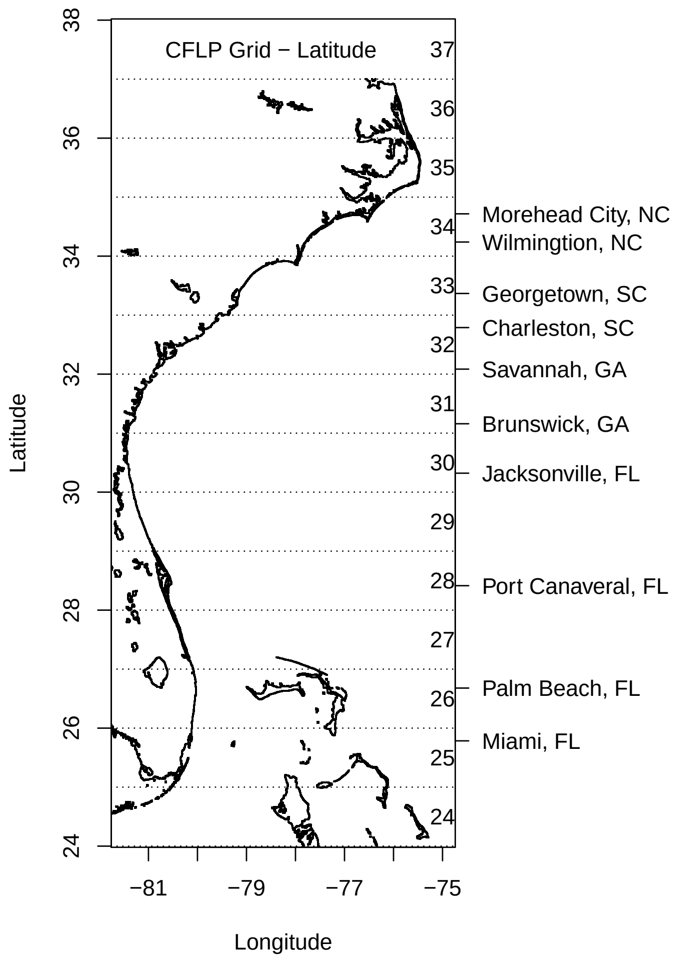


Figure 2. Red snapper diving trips by year and latitude. Symbol size relative to number of trips, 'X' signifies confidential data and represents a small percentage of the total trips.

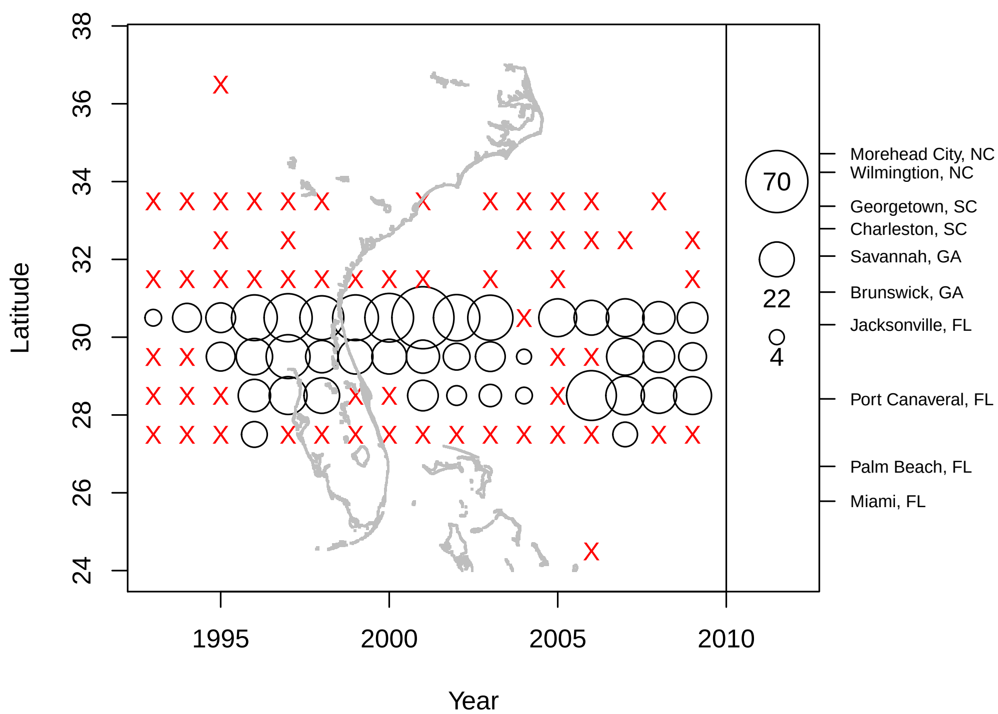


Figure 3. Red snapper handline explanatory variable factor deliniation. Line represents the relative number of trips in each categorical variable. Vertical lines represent proposed breaks for factors).

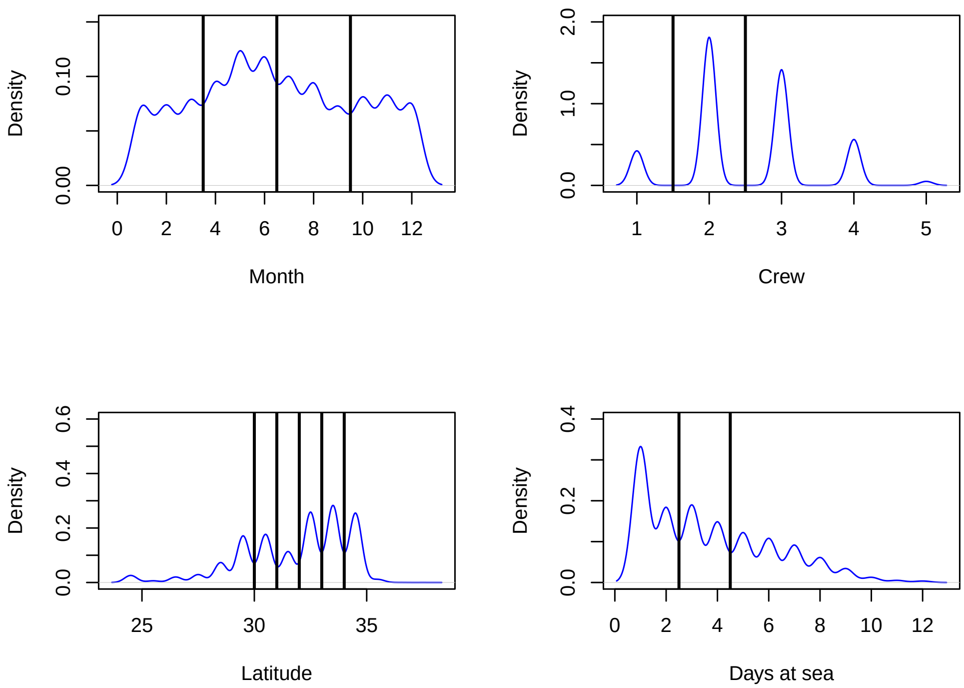


Figure 4. Red snapper handline nominal cpue by year and season.

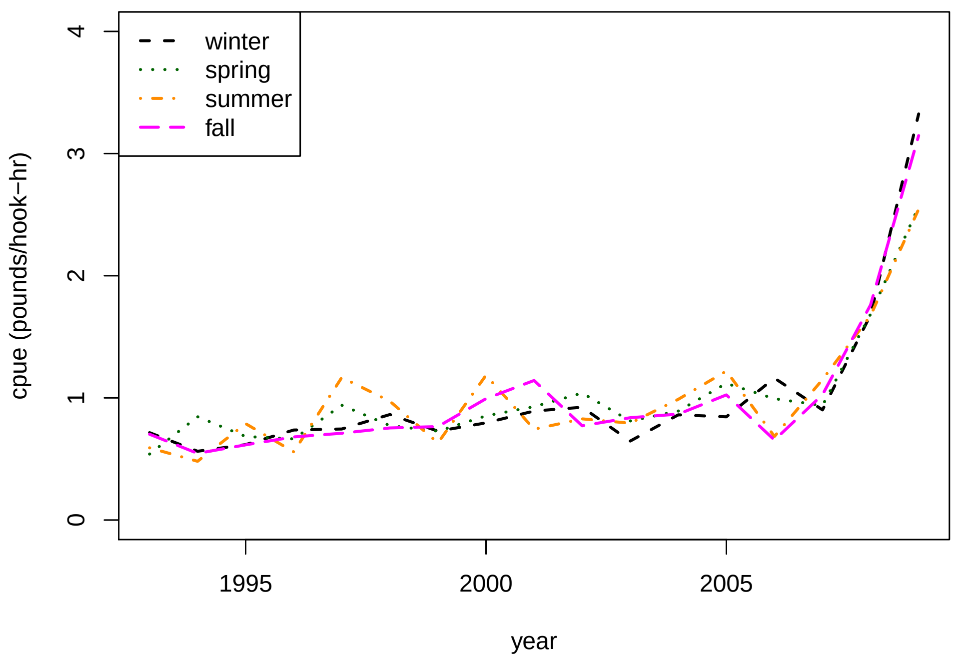


Figure 5. Red snapper handline mean cpue (whole pounds/hook-hour) by year and latitude. Latitudes in the North are pooled at 34 degrees and latitudes in the South are pooled at 29 degrees.

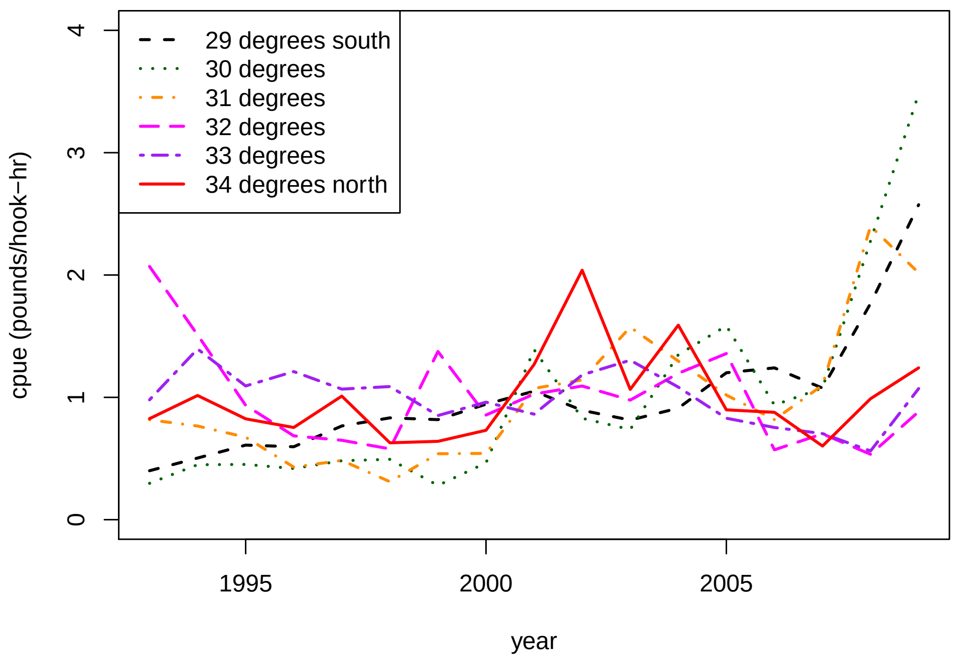


Figure 6. Red snapper handline nominal cpue by year and days at sea.

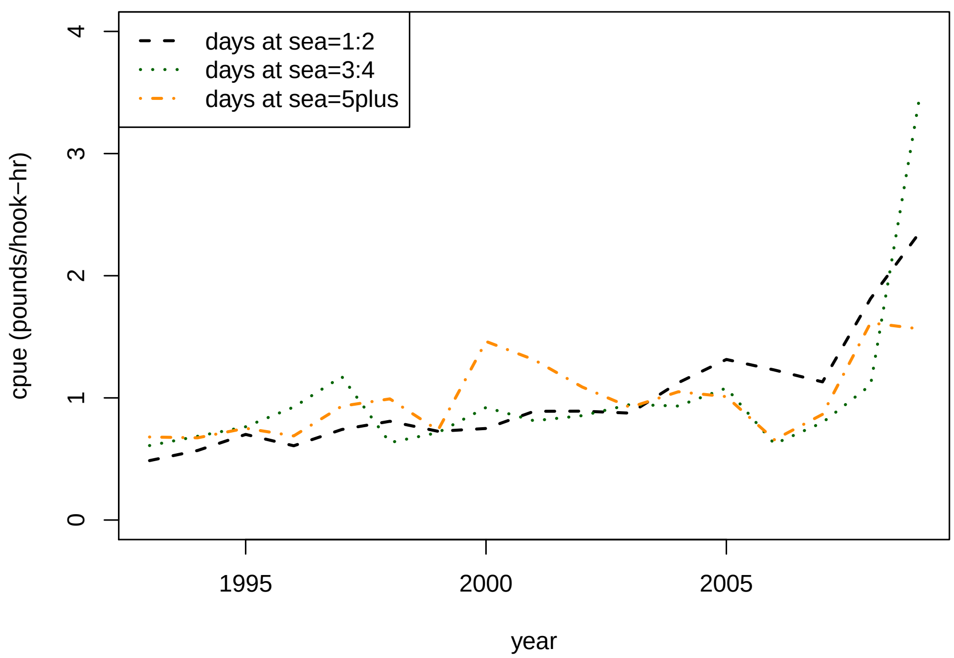


Figure 7. Red snapper handline nominal cpue by year and crew.

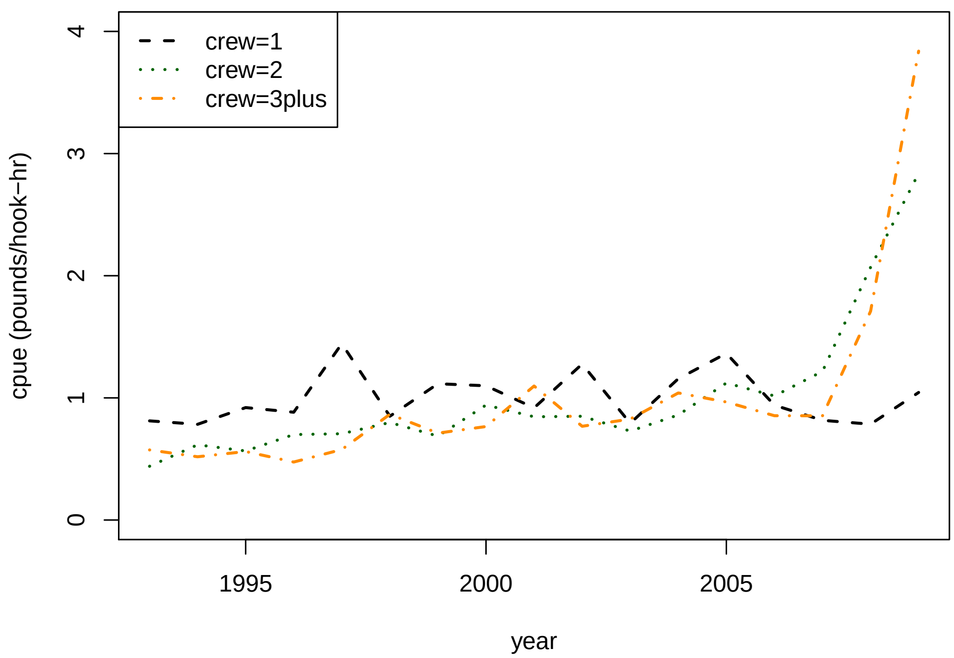


Figure 8. Red snapper handline trips by year and latitude. Symbol size relative to number of trips, 'X' signifies confidential data and represents a small percentage of the total trips.

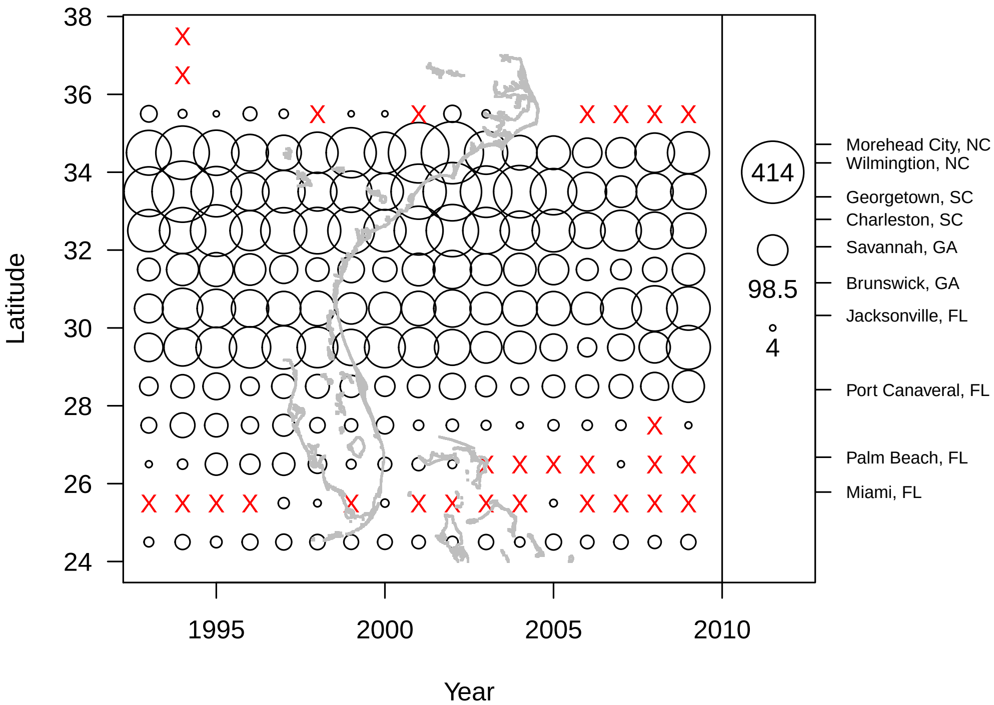


Figure 9. Red snapper handline mean cpue (whole pounds/hook-hour) by year and latitude. Symbol size relative to cpue, X signifies confidential data and represents a small percentage of the total records.

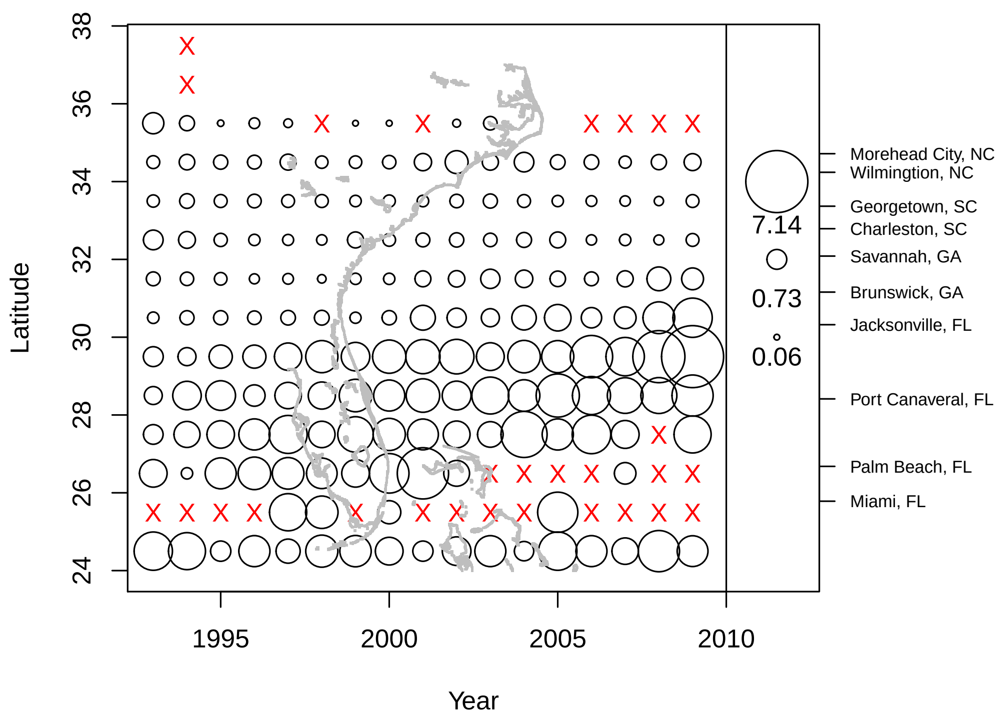


Figure 10. Red snapper handline catch (whole pounds) by year and latitude. Symbol size relative to catch, X signifies confidential data and represents a small percentage of the total catch.

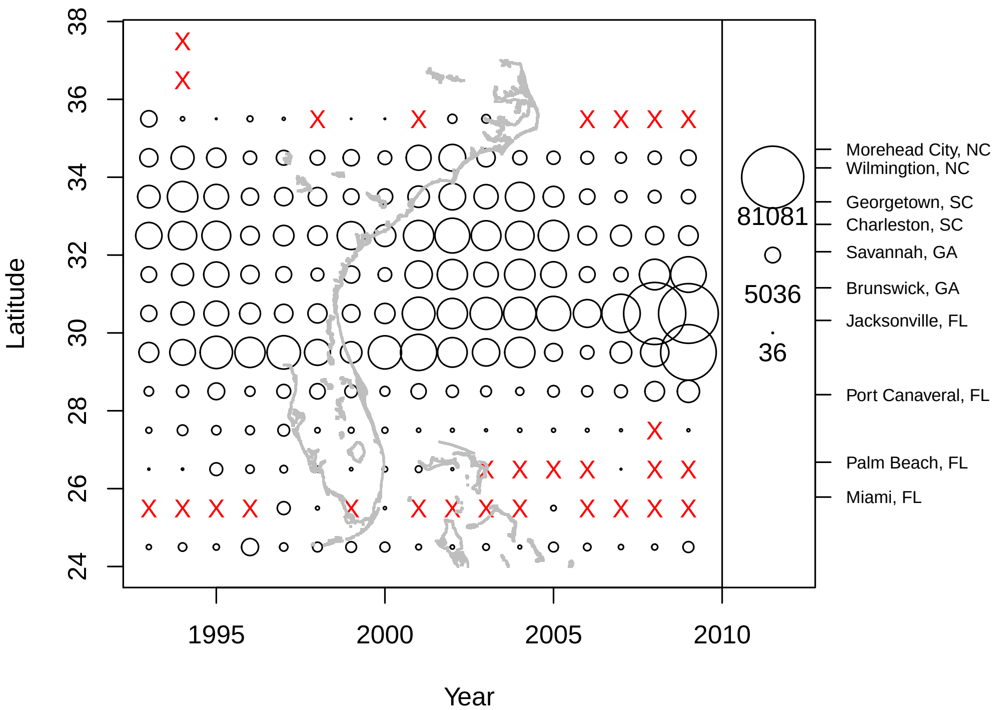


Figure 11. Red snapper handline mean hours fished by year and latitude. Symbol size relative to hours fished, X signifies confidential data and represents a small percentage of the total hours fished.

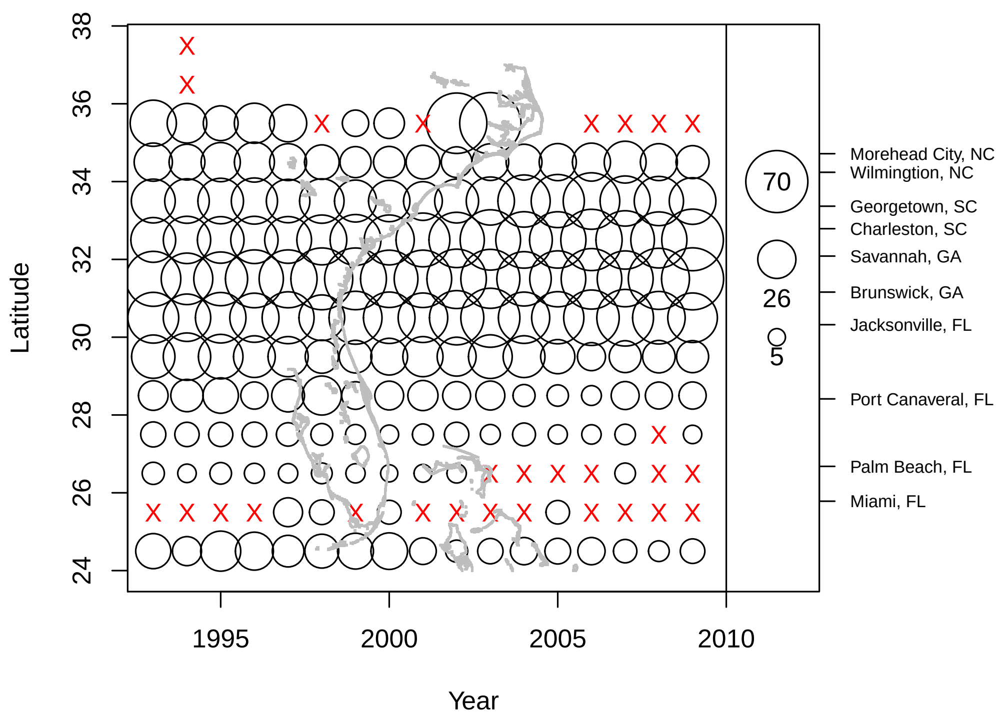


Figure 12. Red snapper handline mean number hooks per line by year and latitude. Symbol size relative to number of hooks, X signifies confidential data and represents a small percentage of the total records.

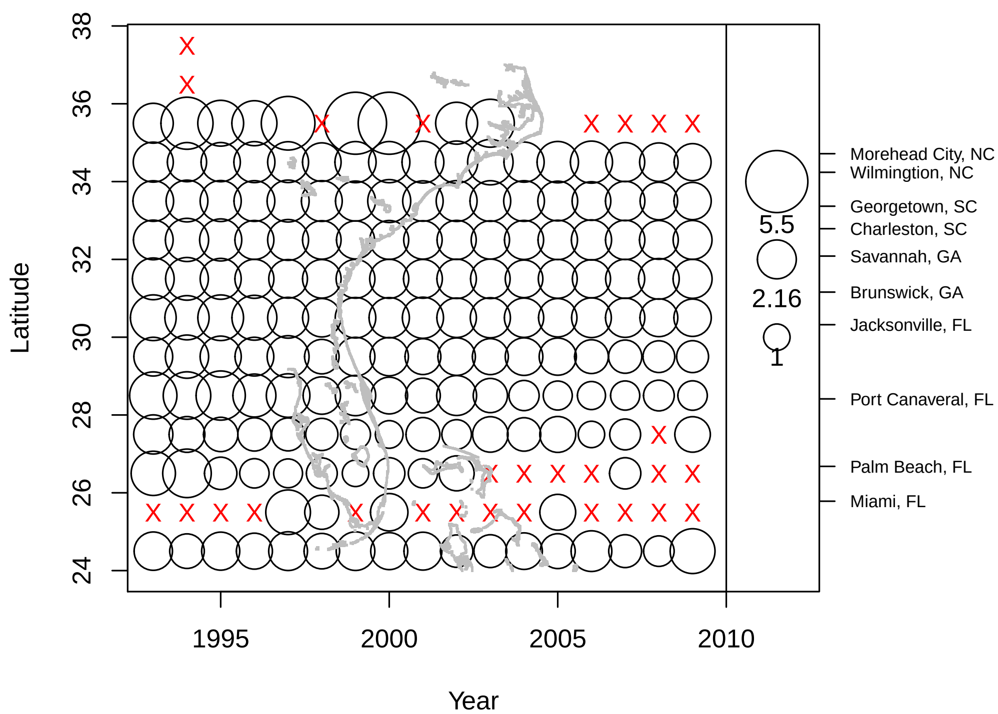


Figure 13. Red snapper handline mean number of lines fished by year and latitude. Symbol size relative to number of lines, X signifies confidential data and represents a small percentage of the total records.

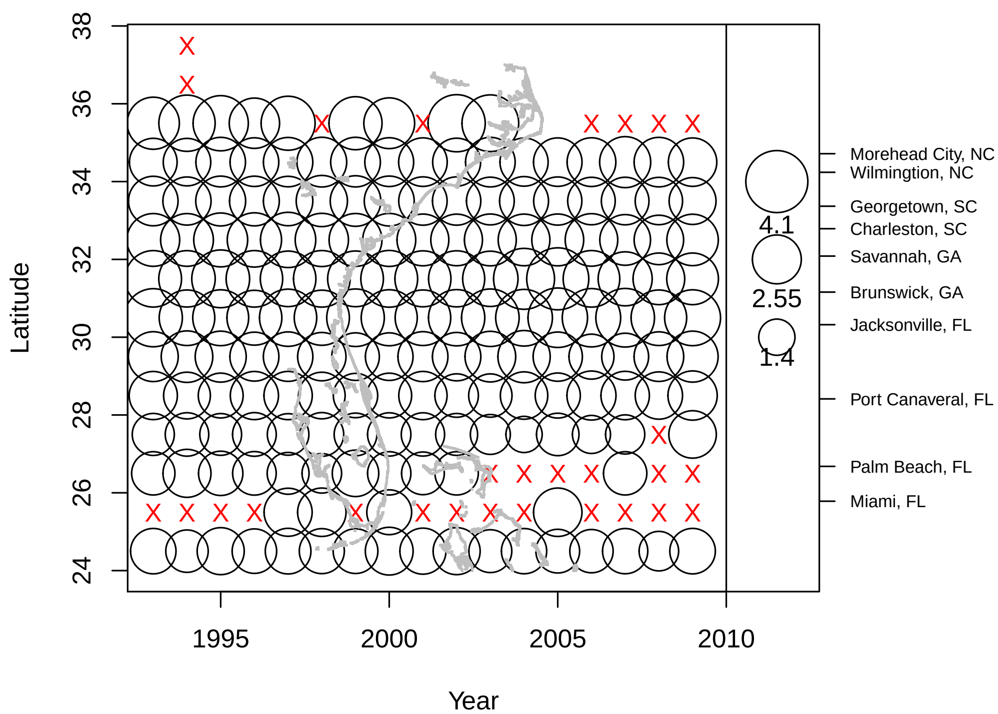


Figure 14. Red snapper handline catch distribution (whole pounds) by year and latitude divided into north of 32 degrees Latitude (orange above 0) and South of 32 degrees Latitude (blue, below 0).

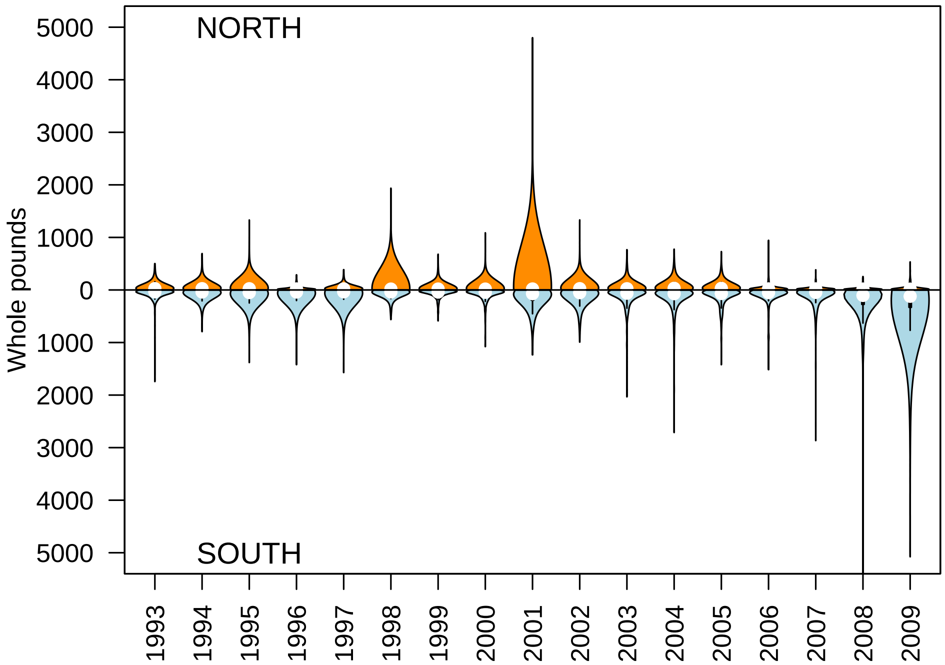


Figure 15. Red snapper handline hook-hours distribution by year and latitude divided into north of 32 degrees Latitude (orange above 0) and South of 32 degrees Latitude (blue, below 0).

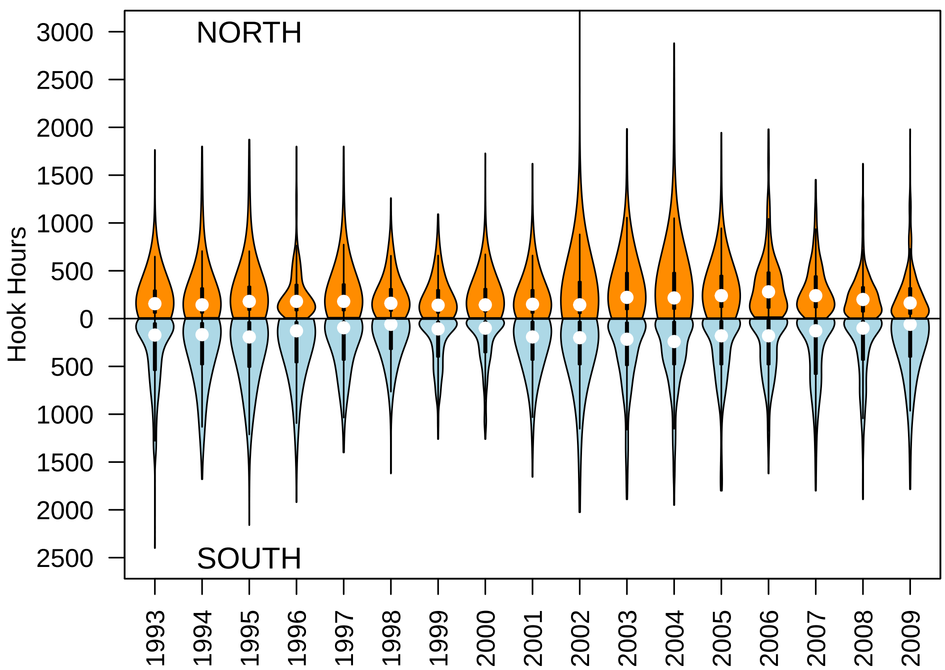


Figure 16. Red snapper handline cpue (whole pounds/hook-hr) distribution by year and latitude divided into north of 32 degrees Latitude (orange above 0) and South of 32 degrees Latitude (blue, below 0).

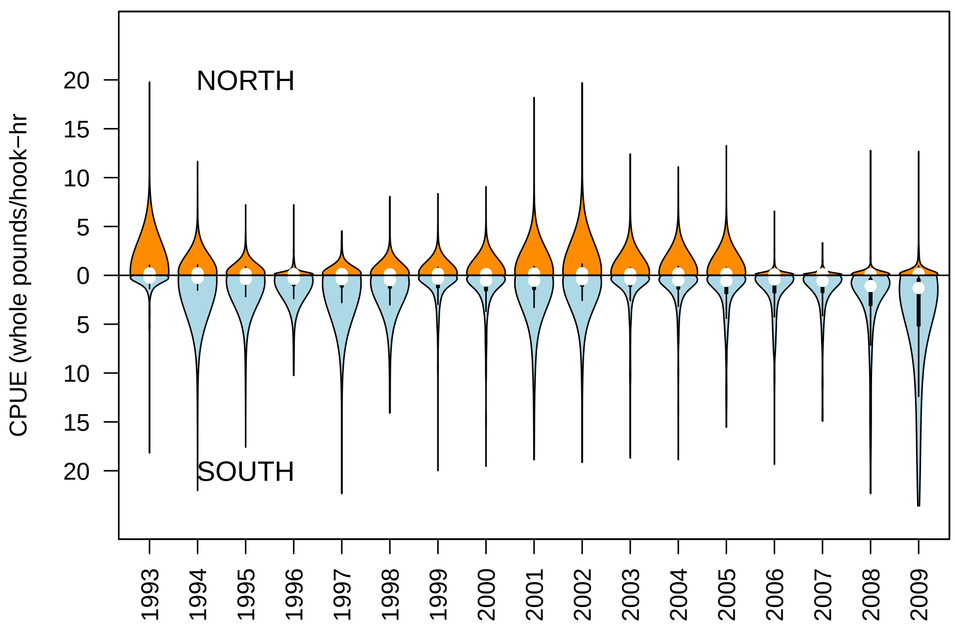


Figure 17. Red snapper handline hours fished by days at sea with correlation coefficient. The mean of approximately 10 hours per day fished applies through approximately 9 days at sea with a pearson correlation coefficient of 0.86.

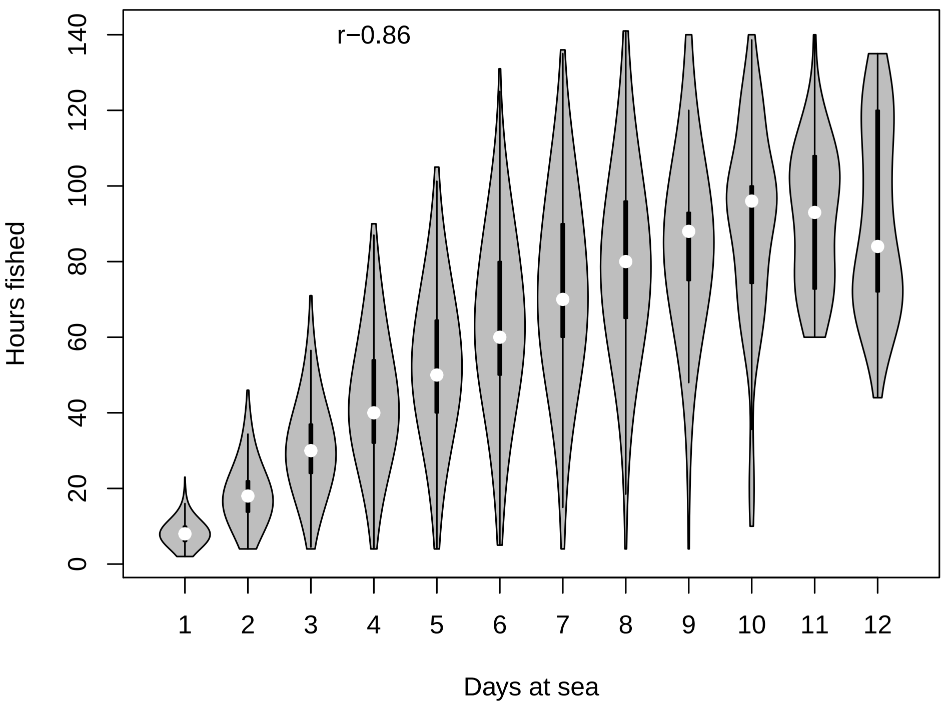


Figure 18. Estimates of species-specific regression coefficients from Stephens and MacCall method applied to logbook data from areas in the northern region (NC, SC, GA, north FL), as used to estimate each trips probability of catching the focal species.

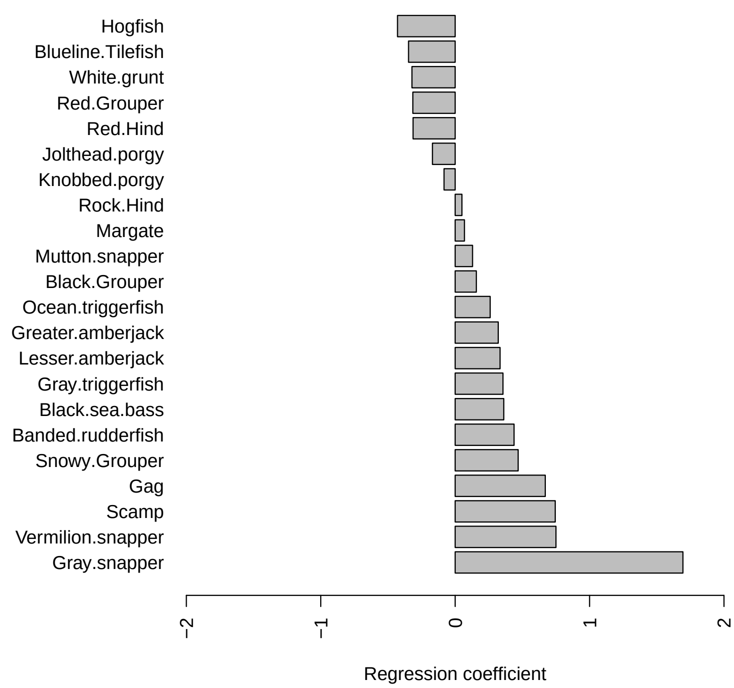


Figure 19. Estimates of species-specific regression coefficients from Stephens and MacCall method applied to logbook data from areas in the southern region (south FL), as used to estimate each trips probability of catching the focal species.

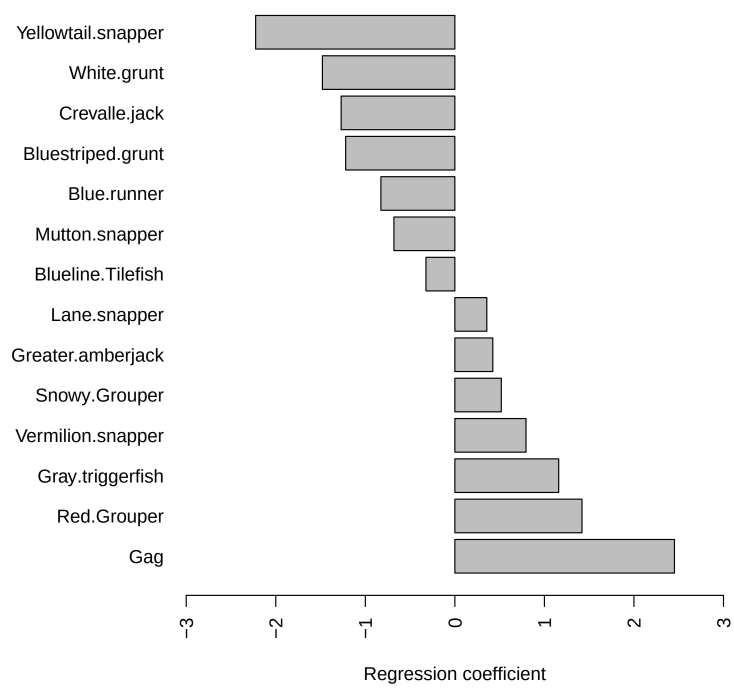


Figure 20. Absolute difference between observed and predicted number of positive trips from Stephens and MacCall method applied to logbook data from the northern region (NC, SC, GA, north FL). Left and right panels differ only in the range of probabilities shown.

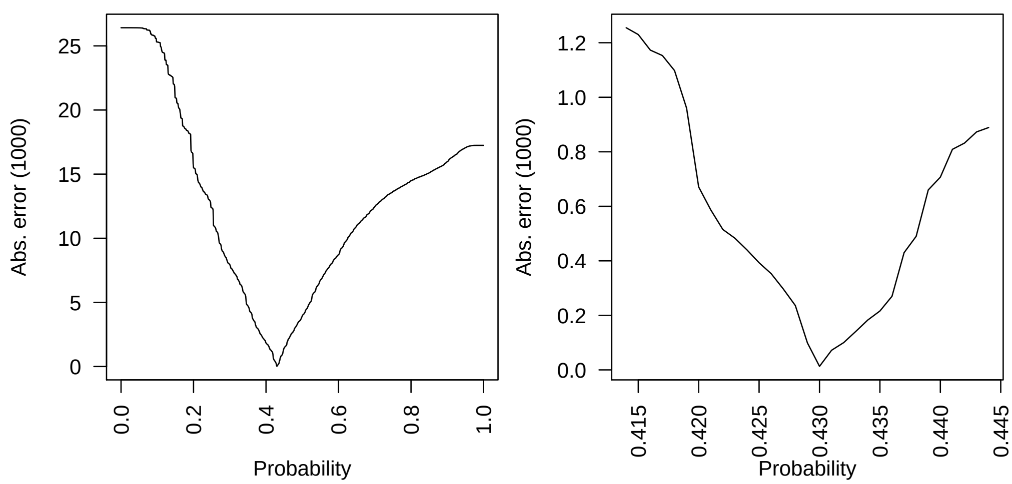


Figure 21. Absolute difference between observed and predicted number of positive trips from Stephens and MacCall method applied to logbook data from the southern region (south FL). Left and right panels differ only in the range of probabilities shown.

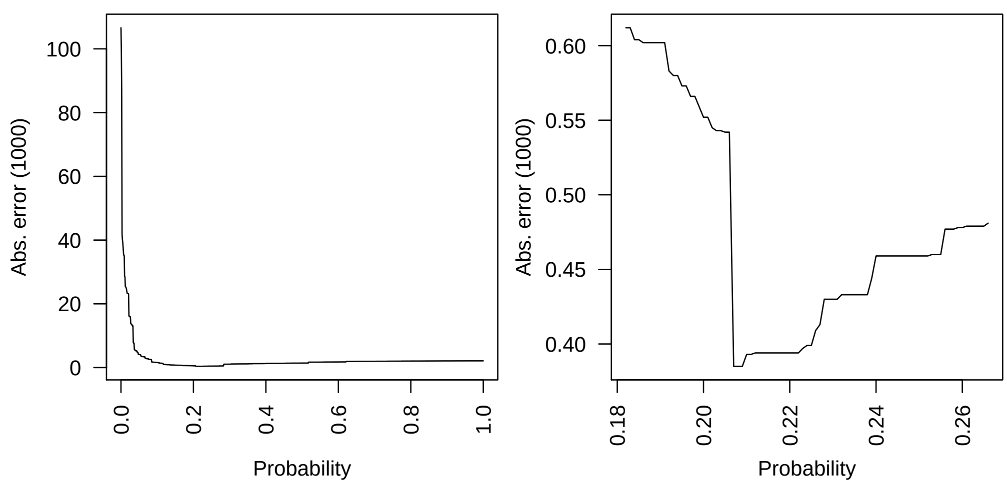


Figure 22. Diagnostics of Bernoulli submodel fits to positive versus zero CPUE data. Box-andwhisker plots give first, second (median), and third quartiles, as well as limbs that extend approximately one interquartile range beyond the nearest quartile, and outliers (circles) beyond the limbs. Residuals are randomized quantile residuals.

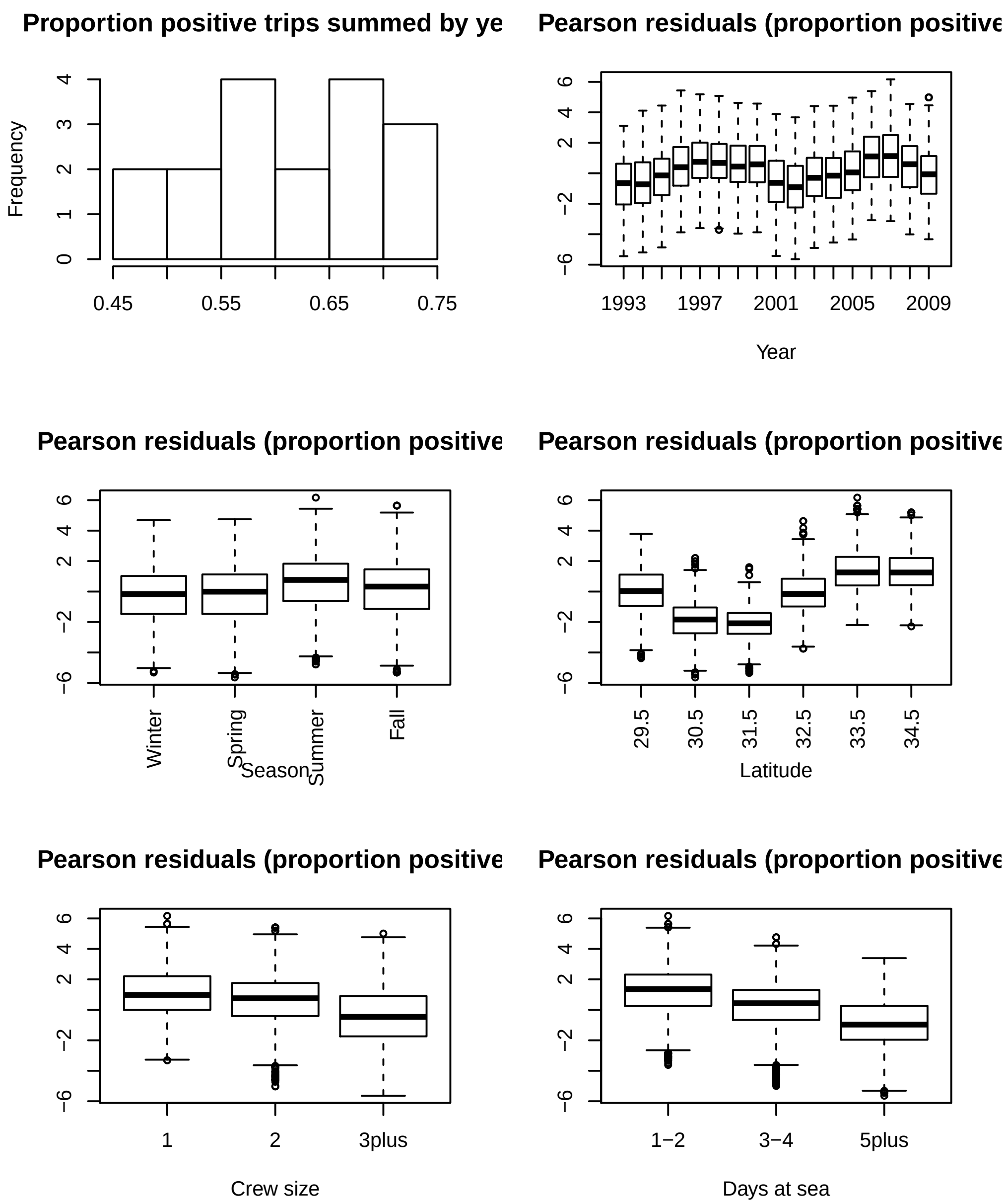


Figure 23. Diagnostics of lognormal submodel fits to positive CPUE data. Top left panel shows the histogram of empirical log CPUE, with the normal distribution (empirical mean and variance) overlaid. Box-and-whisker plots give first, second (median), and third quartiles, as well as limbs that extend approximately one interquartile range beyond the nearest quartile, and outliers (circles) beyond the limbs. Residuals are raw.

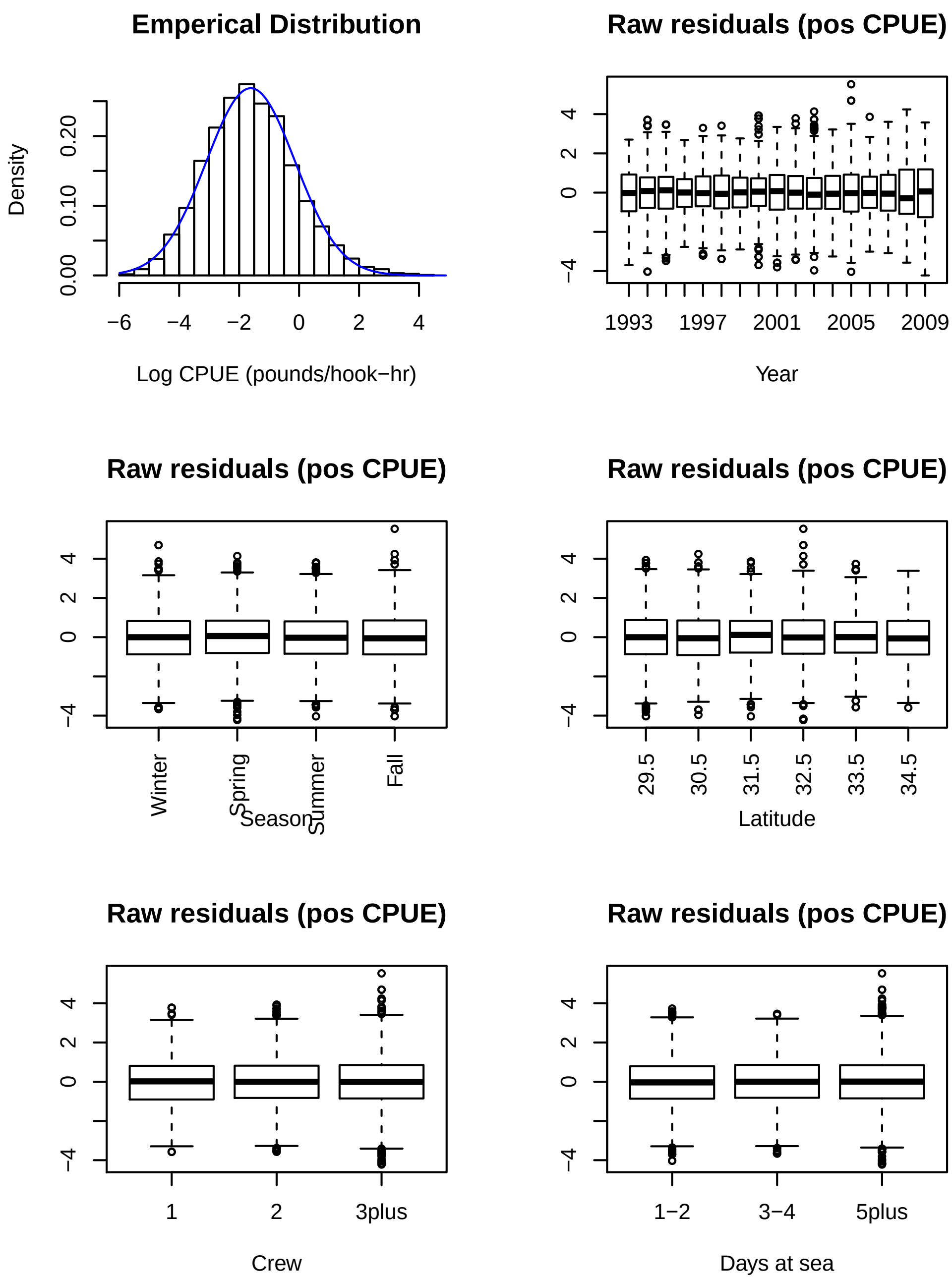


Figure 24. Quantile-quantile plot of residuals from the fitted lognormal submodel to the positive cpue data.

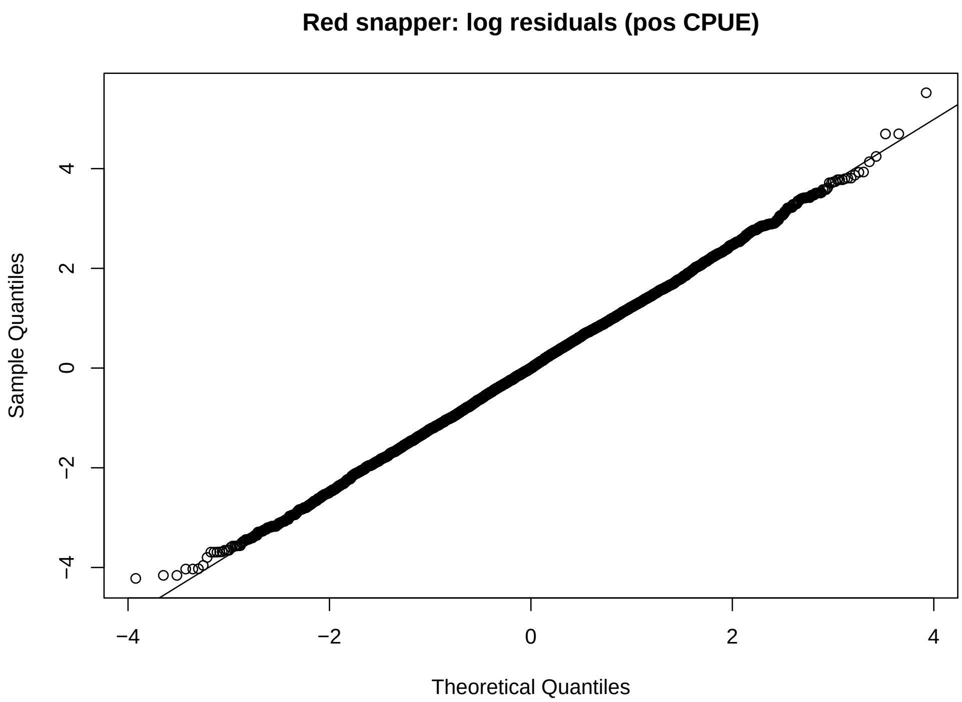


Figure 25. Red snapper handline mean nominal cpue (whole pounds/hook-hour) by year and latitude after applying the Stephens and MacCall method. The symbol size is relative to cpue.

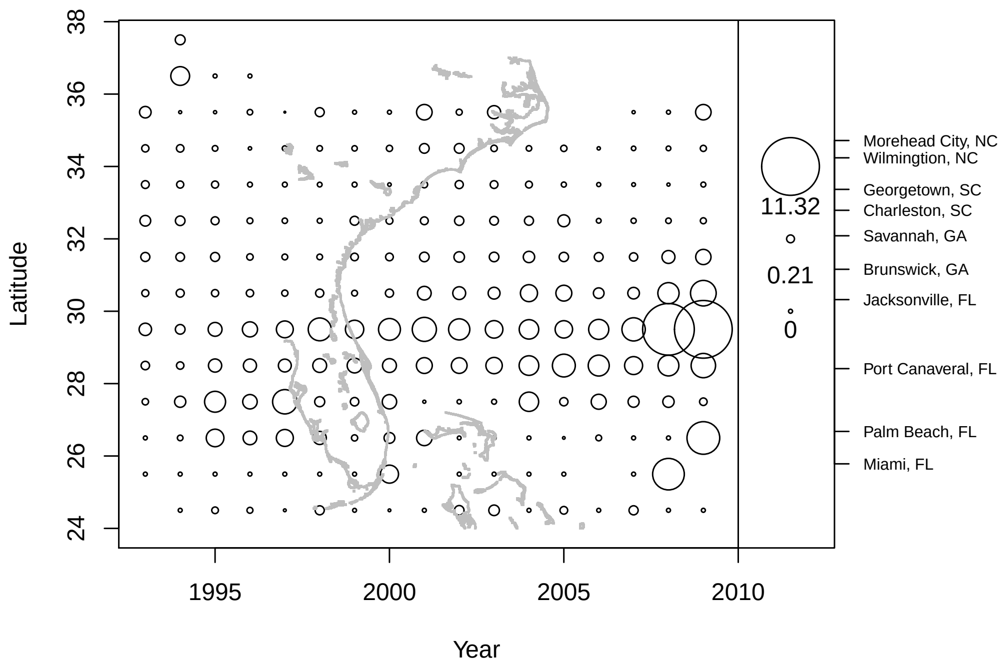
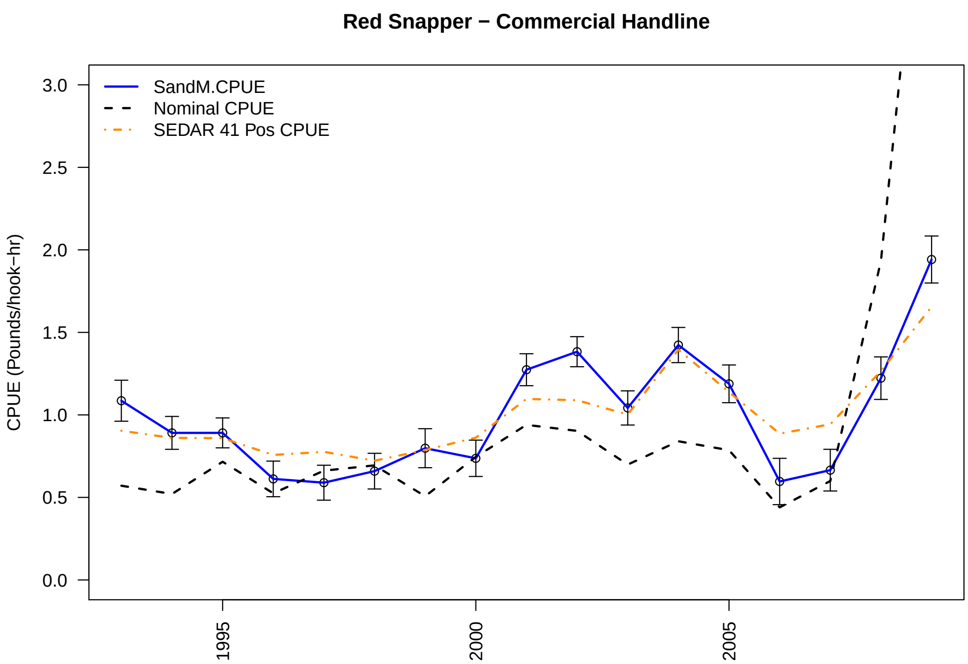


Figure 26. Relative standardized index (solid line, black circles, 95% error bars), relative nominal index (dashed), and alternative positive–only model (dash–dot).



2 Appendix A. The commercial logbook data set contains the following variables (all are numeric unless otherwise noted)

schedule: this is a unique identifier for each fishing trip and is a character variable

species: a character variable to identify species caught.

gear: a character variable, the gear type, multiple gear types may be used in a single trip, L = longline, H = handline, E = electric reels, B = buoy gear, GN = gill net, P = diver using power head gear, S = diver using spear gun, T = trap, TR = trolling

area: area fished, in the south Atlantic these codes have four digits- the first two are degrees of latitude and the second two are the degrees of longitude

totlbs: a derived variable that sums the gutted (with conversion factor) and whole weights, this is the total weight in pounds of the catch for a particular species, trip, gear, and area

length: length of longline (in miles) or gill net (in yards)

numgear: the amount of a gear used, number of lines (handlines, electric reels), number of sets (longlines), number of divers, number of traps, number of gill nets

fished: hours fished on a trip, this is problematic for longline data as discussed later

effort: like numgear, the data contained in this field depends upon gear type; number of hooks/line for handlines, electric reels, and trolling; number of hooks per longline for longlines; number of traps pulled for traps; depth of the net for gill nets, this field is blank for divers

vesid: a character variable, a unique identifier for each vessel

landed: numeric (mmddyy8) variable, date the vessel returned to port

unload: numeric (mmddyy8) variable, date the catch was unloaded

received: numeric (mmddyy8) variable, date the logbook form was received from the fisherman

away: number of days at sea, this value should equal (landed-started+1)

crew: number of crew members, including the captain

state: character variable, the state in which the catch was sold

area1 - area3: areas fished, if the trip included catch from multiple areas, those areas will be listed here

SCDNR Charterboat Logbook Program Data, 1993-2013

Eric Hiltz

SEDAR41-DW32

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SCDNR Charterboat Logbook Program Data, 1993 - 2013

Date: **7/25/2014**

Prepared by: **Eric Hiltz, South Carolina Department of Natural Resources**

For: **SEDAR 41 Data Workshop, August 2014**

Abstract:

The South Carolina Department of Natural Resources (SCDNR) charterboat logbook program was used to develop indices of abundance for red snapper from 1993 – 2010. The indices of abundance are standardized catch per unit effort (CPUE; catch per angler hour). A delta-gamma GLM was used to produce annual abundance estimates. The indices are meant to describe the population trends of fish caught by V1 (6-pack) charter vessels operating in or off of South Carolina.

Background:

The South Carolina Department of Natural Resources (SCDNR) issues three types of charter vessel licenses: V1 (vessels carrying six or fewer passengers), V2 (vessels carrying 7 to 49 passengers), and V3 (vessels carrying 50 or more passengers). In 1993, SCDNR's Marine Resources Division (MRD) initiated a mandatory logbook reporting system for all charter vessels to collect basic catch and effort data. Under state law, vessel owners/operators purchasing South Carolina Charter Vessel Licenses (V1, V2, or V3) and carrying fishermen on a for-hire basis are required to submit trip level reports of their fishing activity in waters off of SC. Logbook reports are submitted by mail or fax to the SCDNR Fisheries Statistics section monthly. Reporting compliance is tracked by staff, and charter vessel owners/operators failing to submit reports can be charged with a misdemeanor. The charterboat logbook program is a complete census and should theoretically represent the total catch and effort of the charterboat trips in waters off of SC.

Logbook Data:

The charterboat logbook reports include: date, number of fishermen, fishing locale (inshore, 0-3 miles, >3miles), fishing location (based on a 10x10 mile grid map), fishing method, hours fished, target species, and catch (number of landed and released fish by species) per vessel per trip. The logbook forms have remained similar throughout the program's existence with a few exceptions: in 1999 the logbook forms were altered to begin collecting the number of fish released alive and the number of fish released dead (prior to 1999 only the total numbers of fish released were recorded) and in 2008 additional fishing methods were added to the logbook forms, including 4) cast, 5) cast and bottom, and 6) gig.

After being tracked for compliance each V1 charterboat logbook report is coded and entered into an existing Access database. (V2 and V3 charterboat logbook reports are tracked for compliance but are currently not coded and entered electronically. Most of these vessels participate in the NMFS Beaufort Headboat Logbook Survey.) Since the inception of the program, a variety of staff have coded the charterboat logbook data. From ~1999 to 2006, only information that was explicitly filled out by the charterboat owners/operators on the logbook forms was coded and entered into the database. No efforts were made to fill in incomplete reports. From 2007 to the present, staff have tried to fill in incomplete trip reports through conversations with charterboat owners/operators and by making assumptions based on the submitted data (i.e. if a location description was given instead of a grid location – a grid location was determined, if fishing method was left blank – it was determined based on catch, etc.). From 1999 to 2006 each individual trip record was reviewed to look for anomalies in the data. Starting in 2007 queries were used to look for and correct anomalous data and staff began checking a component of the database records against the raw logbook reports. Coding and QA/QC measures prior to 1999 were likely similar to those used from 1999 to the present. However, details on these procedures were not available since staff members working on this project prior to 1998 are no longer with the SCDNR. Data are not validated in the field and currently no correction factors are used to account for reporting errors. Recall periods for logbook records are typically one month or less. However, in the case of delinquent reports recall periods could be up to several months.

Data:

SCDNR charterboat logbook vessel trips included in the analysis for red snapper represent reported fishing trips that caught red snapper or other species that were caught at least 35% of the time when red snapper were caught. These species include: black seabass, vermillion snapper, triggerfishes, gag grouper, red porgy, scamp, and white grunt. For a list of percent occurrences of species when red snapper were caught see table 1.

For all model runs for, catch per unit effort was calculated as the total number of fish caught per angler-hour. Management measures (bag and size limits) have been in place for red snapper throughout most of the dataset's time series (see management histories on red snapper provided for SEDAR 41 in RD12). To limit the possible influence of bag limits, total catch (includes harvest and discards) was used to calculate the CPUE instead of harvest.

Methods:

The indices were standardized using a delta generalized linear model (GLM) approach. All analyses were conducted in R, based primarily on code adapted from Dick (2004). A delta GLM model was chosen due to the significant amount of zeros in the CPUE data. A delta model has 2 components to it. First, the probability of a positive catch is modeled. Then the positive catch rates are modeled separately. Finally, the two are multiplied together to get the predicted CPUE (Dick 2004, Li et al. 2011, Siquan et al. 2009, and Yu et al. 2011)

$$\widehat{CPUE} = \hat{d}\ x\ \hat{q}$$

Where $\widehat{CPUE}$ is the standardized CPUE, $\hat{d}$ is the predicted catch rate of the positive catches, and $\hat{q}$ is the probability of a positive catch. The models for red snapper were built assuming a gamma distribution. The model of the positive catch rates used was:

$$ln(\hat{d}) = \beta_0 + \sum_{i=1} \beta_i X_i$$

Where β_0 is the intercept and β_i is the coefficient for the i^{th} explanatory variable X_i. The probability of a positive catch was modeled as:

$$ln\left(\frac{\hat{q}}{1-\hat{q}}\right) = \alpha_0 + \sum_{i=1} \alpha_i X_i$$

Where α_0 is the intercept and α_i is the coefficient for the i^{th} explanatory variable X_i.

The modeling approach used the year and the month as explanatory variables. A Jackknife approach was used to estimate the amount of variation in the model runs as per Dick (2004).

Results:

The SCDNR charterboat logbook data used to create the index represent 23,223 fishing trips in which anglers caught 12,972 red snapper and harvested 4,450 red snapper. Summarized catch and effort data are presented in Table 2. The indices are presented in Table 3 and Figure 2. Diagnostics for the monthly model run are found in Figures 3 and 4.

Literature Cited:

Dick, E.J. 2004. Beyond 'lognormal versus gamma': discrimination among error distributions for generalized linear models. Fisheries Research 70:351-366.

Li, Y., Jiao, Y., He, Q. 2011. Decreasing uncertainty in catch rate analyses using Delta-AdaBoost: An alternative approach in catch and bycatch analyses with high percentage of zeros. Fisheries Research 107: 261-271.

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Yu, Hao, Jiao, Y., and Winter, A. 2011. Catch rate standardization of yellow perch in Lake Erie: a comparison of the spatial generalized linear model and generalized additive model. Transactions of the American Fisheries Society 140 (4): 905-918.

Table 1. Species caught when red snapper were caught. Percent occurrence was calculated by trips when species in question was caught when red snapper was caught / total trips when red snapper was caught.

Species	Trips	% Occurrence
Snapper, Red, Unclassified	2455	100.00%
Black Sea Bass, Unclassified	2035	82.89%
Snapper, Vermilion, Unclassified	1456	59.31%
Triggerfishes	1307	53.24%
Grouper, Gag	1293	52.67%
Porgy, Red, Unclassified	1157	47.13%
Scamp	952	38.78%
Grunt, White	911	37.11%
King Mackerel	816	33.24%
Shark, Atlantic Sharpnose	750	30.55%
Amberjack	593	24.15%
Dolphin	376	15.32%
Pinfish, Spottail	317	12.91%
Shark, Unclassified	302	12.30%
Porgy, Whitebone	294	11.98%
Grunts	265	10.79%
Barracuda	244	9.94%
Grouper, Red	218	8.88%
Cobia	197	8.02%
Porgy, Unclassified	159	6.48%
Tuna, Little	151	6.15%
Flounder, Unclassified	86	3.50%
Mackerel, Spanish	73	2.97%
Bonito	52	2.12%
Wahoo	45	1.83%
Grouper, Snowy	35	1.43%
Drum, Red	35	1.43%
Bluefish	35	1.43%
Shark, Black Tip	28	1.14%
Finfish, Unclassified	27	1.10%
Sailfishes	23	0.94%

Species	Trips	% Occurrence
Spadefish	22	0.90%
Sheepshead	20	0.81%
Tuna, Blackfin	19	0.77%
Grouper, Unclassified	19	0.77%
Tuna, Yellowfin	17	0.69%
Banded Rudderfish	16	0.65%
Rays,Unc.	10	0.41%
Shark, Dogfish, Smooth	10	0.41%
Hind, Speckled	10	0.41%
Seatrout, Gray (Weakfish)	8	0.33%
Drum, Black	6	0.24%
Hogfish	6	0.24%
Shark, Dogfish,Spiny	6	0.24%
Hind, Rock	5	0.20%
Crevalle Jack	5	0.20%
Bank Sea Bass	5	0.20%
Porgy, Knobbed	4	0.16%
Shark, Bonnethead	4	0.16%
Shark, Bull	4	0.16%
Grouper, Warsaw	3	0.12%
Tomtate	3	0.12%
Rudderfish	3	0.12%
Jack, Almaco	3	0.12%
Shark, Dusky	3	0.12%
Snapper, Cubera	3	0.12%
Shark, Lemon	3	0.12%
Porgy, Red, Large	3	0.12%
Tilefish, Golden, Unclassified	2	0.08%
Shark, Tiger	2	0.08%
Porgy, Jolthead	2	0.08%
Toadfishes	2	0.08%

Species	Trips	% Occurrence
Snapper, Silk	2	0.08%
Shark, Nurse	2	0.08%
Sea Catfish	2	0.08%
Snapper, Yellowtail	2	0.08%
Snapper, Unclassified	2	0.08%
Ladyfish	2	0.08%
King Whiting	2	0.08%
Graysby	2	0.08%
Blue Runner	1	0.04%
Squirrelfishes	1	0.04%
Snapper, Mutton	1	0.04%
Eel, Pac.	1	0.04%
Eels, Moray	1	0.04%
Tarpon	1	0.04%
Filefishes	1	0.04%
Snapper, Blackfin	1	0.04%
Scup	1	0.04%
Pinfish	1	0.04%
Sand Perch	1	0.04%
Shark, Thresher	1	0.04%
Shark, Dogfish	1	0.04%
Seatrout, Spotted	1	0.04%
Finfishes, General	1	0.04%
Triggerfish, Queen	1	0.04%
Rainbow Runner	1	0.04%
Tuna, Skipjack	1	0.04%
Marlin, Blue	1	0.04%
Triggerfish, Grey	1	0.04%

Table 2. Annual red snapper catch, harvest, and effort from SCDNR Charterboat Logbook Program, 1993-2013. Vessel trips were determined from the number of trips used in the index as defined above.

Year	Vessel Trips	% Trips With Red Snapper	Red Snapper Catch (# fish)	Red Snapper Harvest (# fish)	Red Snapper Released (# fish)	% Released
1993	571	16.81%	531	286	245	46.14%
1994	694	15.56%	410	189	221	53.90%
1995	558	11.47%	192	104	88	45.83%
1996	715	7.97%	174	155	19	10.92%
1997	773	5.17%	79	42	37	46.84%
1998	946	11.52%	401	222	179	44.64%
1999	883	16.65%	680	457	223	32.79%
2000	1047	15.28%	1273	343	930	73.06%
2001	1036	18.05%	1831	591	1240	67.72%
2002	985	16.85%	1238	575	663	53.55%
2003	941	12.33%	541	246	295	54.53%
2004	1104	9.06%	365	211	154	42.19%
2005	1205	9.13%	362	208	154	42.54%
2006	1249	5.60%	229	107	122	53.28%
2007	1307	8.57%	425	181	244	57.41%
2008	1300	11.31%	845	233	612	72.43%
2009	982	12.12%	662	247	415	62.69%
2010	1164	11.94%	647	1	646	99.85%
2011	1423	9.91%	916	19	897	97.93%
2012	1989	5.98%	681	17	664	97.50%
2013	2351	4.85%	490	16	474	96.73%

Table 3. Red snapper catch per unit effort (catch per angler hour) for the standardized index model runs.

Year	Nominal CPUE	Standardized CPUE	SE	Upper	Lower
1993	0.21138535	0.228034666	0.058800474	0.169234193	0.28683514
1994	0.12503812	0.112603611	0.024008548	0.088595064	0.136612159
1995	0.07643312	0.068251716	0.01425174	0.053999976	0.082503457
1996	0.05335787	0.046288437	0.011625903	0.034662534	0.05791434
1997	0.02241135	0.023081839	0.009274894	0.013806945	0.032356734
1998	0.0920358	0.091752285	0.01982818	0.071924105	0.111580465
1999	0.17250127	0.174759478	0.037760517	0.136998961	0.212519996
2000	0.25665323	0.283302109	0.041945362	0.241356747	0.325247471
2001	0.38825276	0.333114983	0.053478258	0.279636725	0.386593242
2002	0.27652446	0.261014268	0.068395934	0.192618334	0.329410202
2003	0.12345961	0.182318065	0.067852277	0.114465788	0.250170342
2004	0.07224861	0.060941999	0.010441077	0.050500922	0.071383076
2005	0.06485131	0.072807797	0.014234379	0.058573417	0.087042176
2006	0.04090747	0.04868721	0.018607226	0.030079984	0.067294436
2007	0.06871463	0.070046166	0.018815039	0.051231127	0.088861205
2008	0.12733574	0.145831279	0.034917405	0.110913875	0.180748684
2009	0.14010582	0.118338725	0.028436763	0.089901961	0.146775488
2010	0.12100243	0.116740875	0.026749078	0.089991797	0.143489953
2011	0.14745654	0.146053434	0.037032182	0.109021252	0.183085617
2012	0.07858297	0.07629779	0.015503507	0.060794283	0.091801296
2013	0.04869323	0.044773705	0.009532571	0.035241134	0.054306276

Table 4. AIC values for the red snapper standardized index model run. SE is the standard error calculated from the model jack knife. % Total CPUE is sum(SE)/sum(CPUE).

AIC	Standardized CPUE
Binomial	100.1791019
Positive	-537.157572501
Sum of SE	0.621491315
% Total CPUE	22.98%

Figure 1. Distribution of red snapper catch from SCDNR 6-pack Charterboat Logbook data. Each square represents a 10 mile^2 area. Only data from 2008-2013 were used because prior to 2008 approximately 80% of the logbook trips included in the analysis did not include location information.

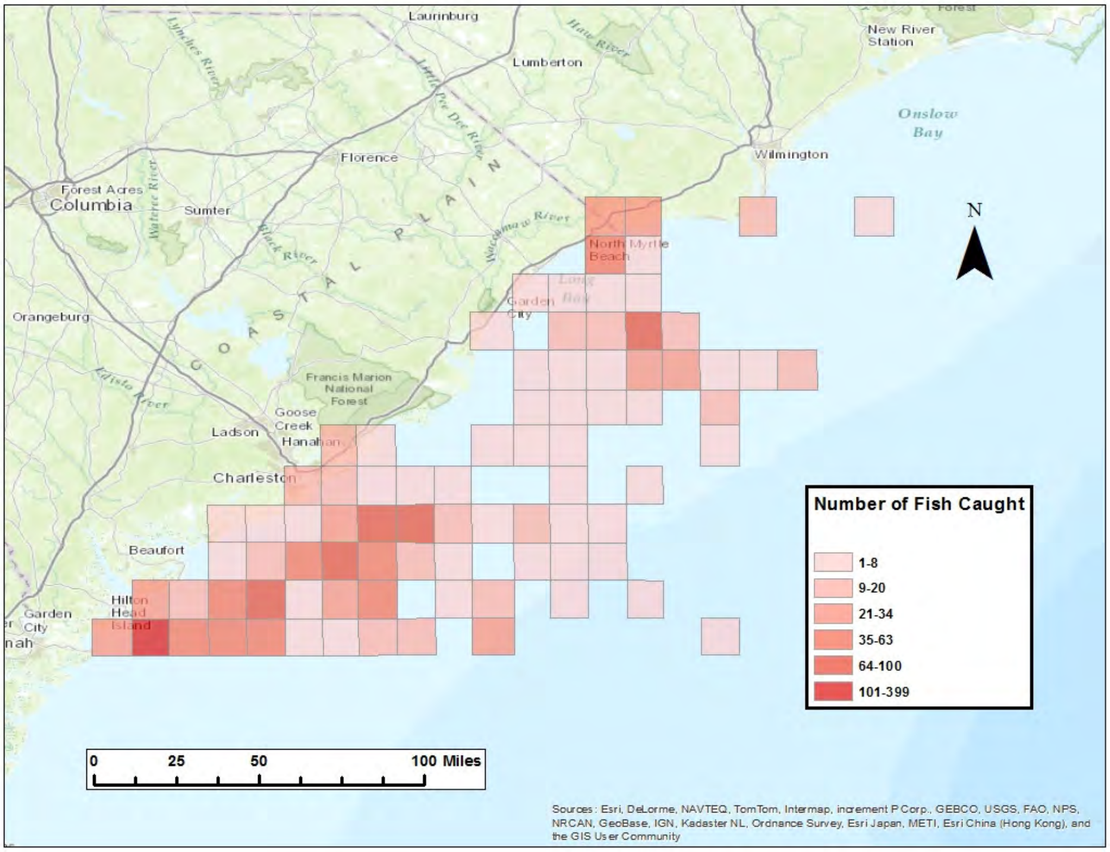


Figure 2. Red snapper CPUE from SCDNR 6-pack Charterboat Logbook data from 1993-2010. Nominal (blue) and monthly standardized (green)catch per angler-hour are shown. The dotted lines show 1 standard error from the standardized CPUE.

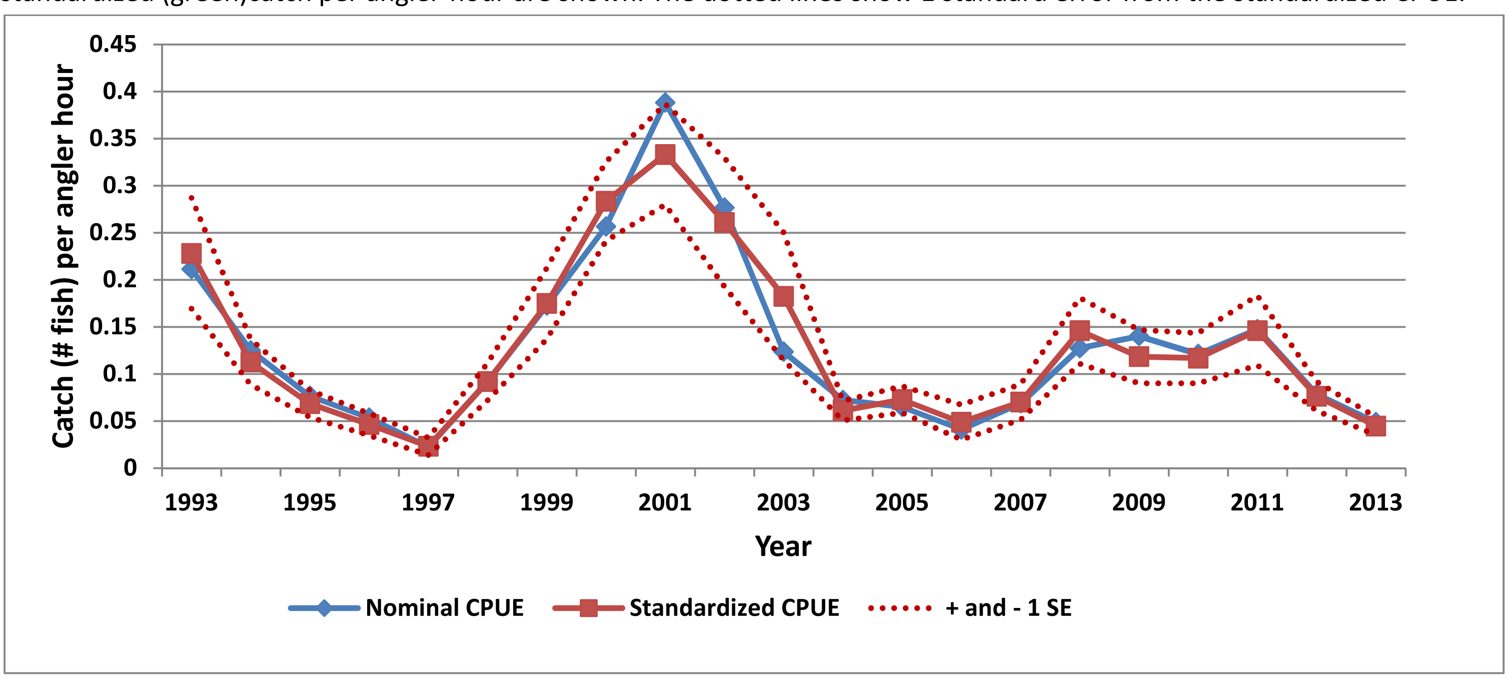


Figure 3. Diagnostic plots for gamma component of the red snapper SCDNR 6-pack Charterboat Logbook monthly model: **A.** residuals plotted against predicted values; **B.** the cumulative normalized residuals (QQ plot); **C.** the residuals by year; **D.** the residuals by month

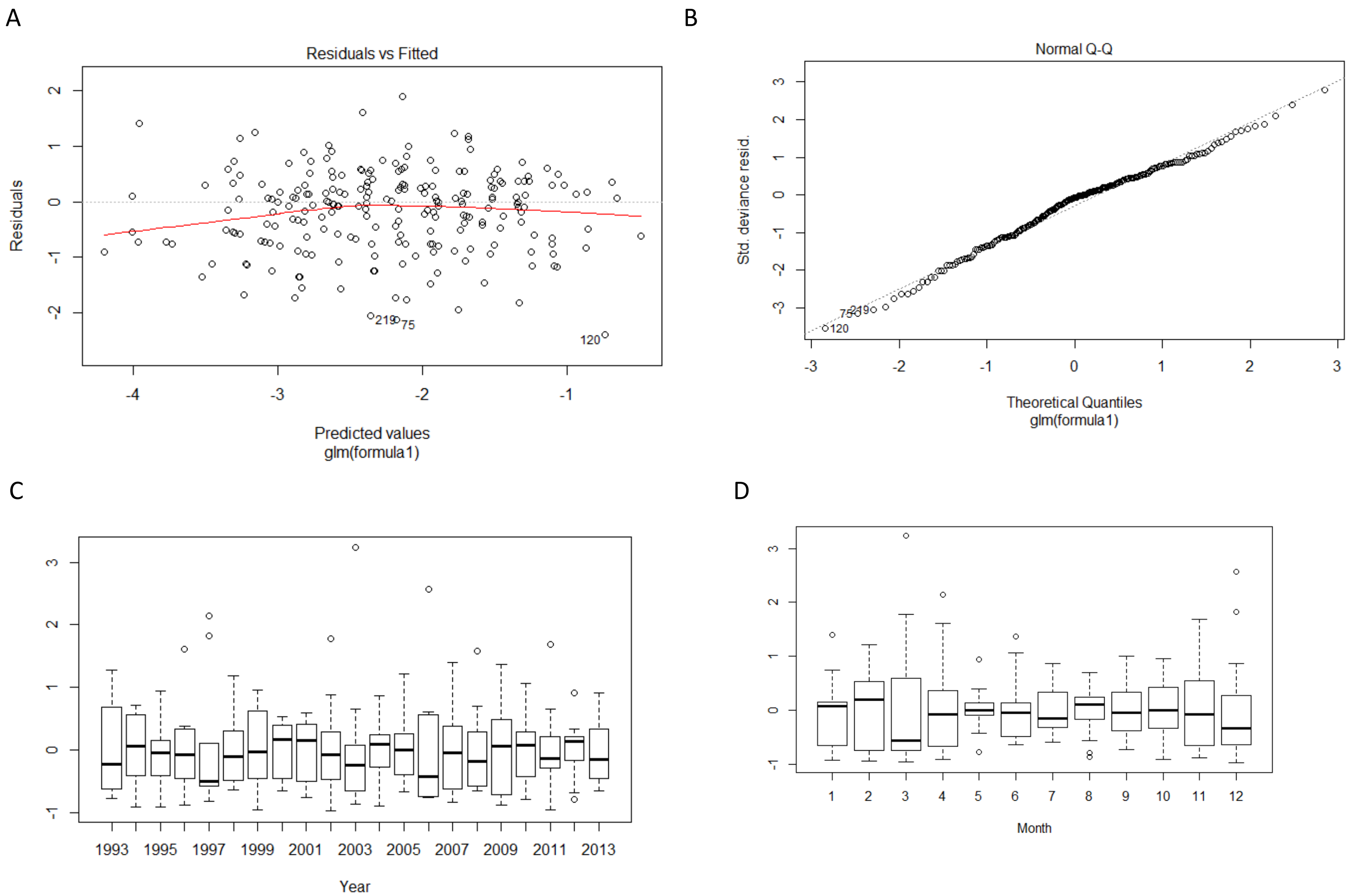
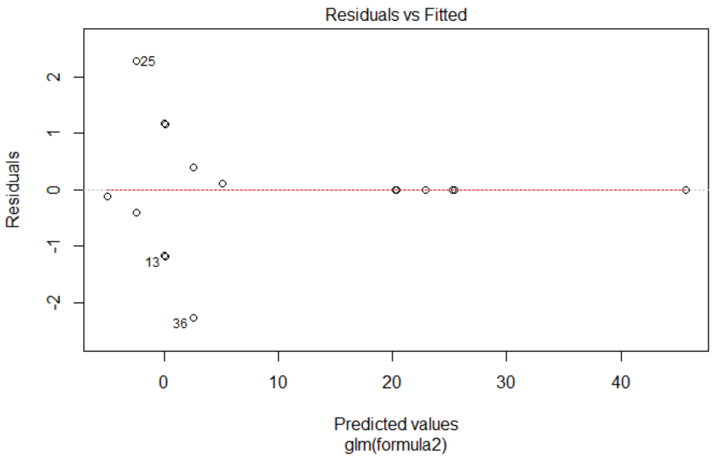
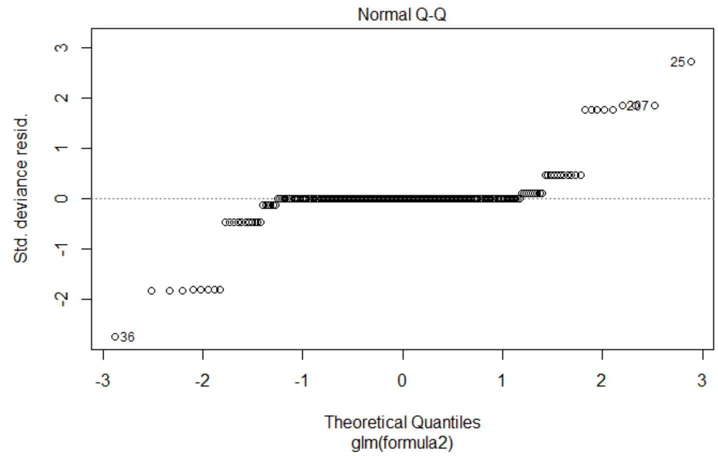


Figure 4. Diagnostic plots for binomial component of the red snapper SCDNR 6-pack Charterboat Logbook monthly model: **A.** residuals plotted against predicted values; **B.** the cumulative normalized residuals (QQ plot); **C.** the residuals by year, **D.** the residuals by month

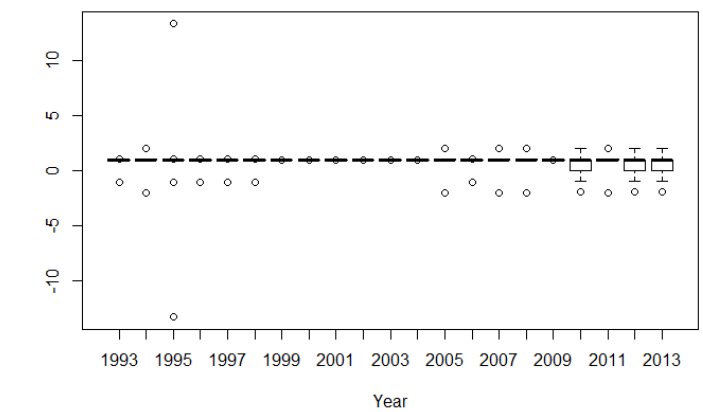
A



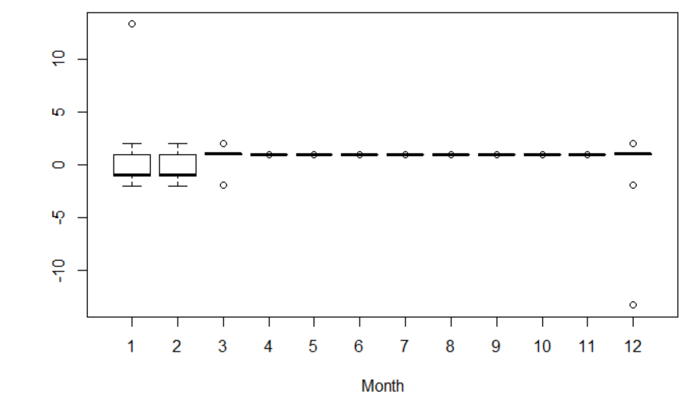
B



C



D



Size Distribution, Release Condition, and Estimated Discard Mortality of Red Snapper Observed in For-Hire Recreational Fisheries in the South Atlantic

Beverly Sauls, Alisha Gray, Chris Wilson, and Kelly Fitzpatrick

SEDAR41-DW33

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Size Distribution, Release Condition, and Estimated Discard Mortality of Red Snapper Observed in For-Hire Recreational Fisheries in the South Atlantic

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For: SEDAR 41 Atlantic Red Snapper Data Workshop, July, 2015.

Detailed information on the size and release condition of discarded fish is not collected in traditional dockside surveys of recreational fisheries. At-sea observer surveys provide valuable information on the size and condition of discarded fish. Such surveys have been conducted on headboat vessels in the south Atlantic since 2004. Coverage was expanded in 2013 to include charter vessels on the east coast of Florida. This report provides a summary of available information on the size, release condition, and disposition of red snapper collected from headboats and charter boats from the Atlantic coast of Florida through North Carolina.

Coverage

Fishery observer coverage for headboats and charter vessels operating in the South Atlantic is summarized in Table 1.

Headboat Coverage

In 2004, at-sea observer surveys were conducted on headboats from North Carolina and South Carolina, and coverage was extended to east Florida in 2005. In the Florida Keys, the at-sea headboat survey was funded by the Gulf Fisheries Information Network (Gulf FIN) from 2005 through 2007. In 2010, the state of Florida secured alternative funds to continue limited at-sea observer coverage for headboats in the Keys through 2013. There were no headboats sampled in the Keys in 2014 due to loss of funding.

Charter Vessel Coverage

In 2010, observer coverage in the Florida Keys was expanded to include charter vessels. In 2013, a MARFIN project that employs fishery observers on charter vessels on the entire Atlantic coast of Florida was initiated. The MARFIN project is funded through 2015.

Table 1. Fishery observer coverage for headboats (H) and charter vessels (C).

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
NC	H	H	H	H	H	H	H	H	H	H	H
SC	H	H	H	H	H	H	H	H	H	H	H
GA	H	H	H	H	H	H	H	H	H	H	H
EFL		H	H	H	H	H	H	H	H	H, C	H, C
Keys		H	H	H			H, C	H, C	H, C	H, C	C

Cooperative vessels in each state were randomly selected each week for observer coverage. Sampling occurred year-round. The state of Florida was stratified into three regions: Northeast (Nassau through Brevard Counties, sub-region=5), Southeast (Indian River through Dade Counties, sub-region=4), and Keys (Monroe County, sub-region=3). Operators from selected vessels were contacted by state biologists and one or two observers were scheduled to sample a single trip in a selected week. For trips in Florida with 15 or less passengers, only one observer accompanied passengers during the scheduled trip.

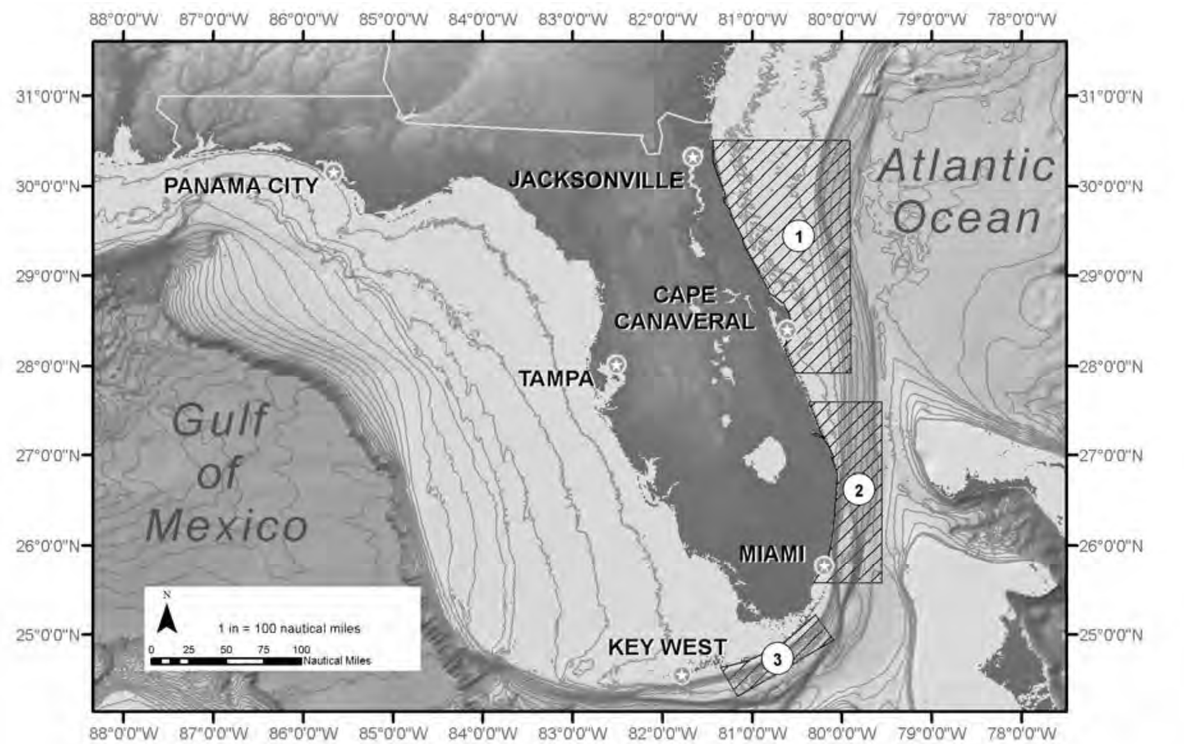


Figure 1. Areas in Florida with at-sea observer coverage. Area 1 is the northeast region, area 2 is the southeast region, and area 3 is the Key West Region.

Data Elements:

All sampled trips
Trip level data are available for all regions and years of observer coverage (Table 1). Trip level information for each sampled trip includes:

- Year, month and day of trip
- area where the majority of fishing took place,
    - coded as 3 miles or less from shore or more than 3 miles from shore
- duration of fishing (to the nearest half hour)
- total number of anglers on board
- number of anglers observed
- minimum and maximum depths fished (collected in Florida only)

A brief interview with each angler observed during a trip was also conducted to collect information on primary and secondary target species, angler avidity, and state and county of residence (discontinued in Florida when new methods were implemented, discussed in next section).

For each angler observed during a sampled trip, the following information was collected:
- total number of fish retained by species
- total number of fish discarded alive by species
- total number of fish discarded dead by species

For each fish caught by an observed angler during a sampled trip, biologists recorded:
- species
- size (fork length in mm)
- disposition, coded as:
    - 1: thrown back alive, legal
    - 2: thrown back alive, not legal
    - 3: plan to eat
    - 4: used for bait or plan to use for bait
    - 5: sold or plan to sell
    - 6: thrown back dead or plan to throw away
- Release condition, collected in Florida only, coded as:
    - 1 = Good, fish swam toward bottom immediately upon entry into the water
    - 2 = Fair, fish was disoriented upon release and slowly swam towards the bottom
    - 3 = Poor, fish was very disoriented upon release and remained at the surface
    - 4 = Dead, fish was either dead or unresponsive upon entering the water
    - 5 = Eaten, fish was eaten by a bird, another fish, or a marine mammal
    - 9 = Unobserved, unable to observe or not applicable (fish retained)

Florida only
Data collection methods were modified in Florida to collect more detailed station-level information beginning in 2010 in the Keys and 2011 on the east coast of Florida (Table 2).

For each location fished during a sampled trip, the following station-level information was recorded:

- latitude and longitude (degrees and minutes)
- fishing zone and subzone (same as commercial zones)
- depth (meters)
- up to three target species and percentage of time targeting each

For each angler observed at a given station, the following information was collected:

- total number of fish retained by species
- total number of fish discarded alive by species
- total number of fish discarded dead by species

For each rod fished by an observed angler at a given station, the following information was recorded:

- leader type and strength
- hook type (circle hook, J hook, kahle hook, treble hook, other)
- hook offset (yes or no)
- hook size (using a standard hook sizing chart)
- bait type (live, whole dead fish, cut fish, squid, cocktail, artificial)

For each fish observed from a given rod at a given station, the following information was recorded:

- species
- mid-line length (mm)
- disposition (same as above)
- release condition (same as above)
- anatomical location of embedded hooks (lip, mouth, throat, gill, gut, eye, external)
- method of hook removal (easy or difficult; by hand, dehooking tool, pliers, or left in place)
- presence of barotrauma symptoms (inflated bladder, everted stomach, extruded intestines, exopthalmia)
- venting method (released without venting, bladder vented, stomach vented)
- presence of gill injury (visible bleeding from gills)

Table 2. Availability of detailed station level data for headboats (H) and charter trips (C).

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
NC											
SC											
GA											
EFL								H	H	H, C	H, C
Keys							H, C	H, C	H, C	H, C	C

Sample Weights:

Headboat vessels report fishing effort in logbook trip reports, and effort data were provided by the NMFS Southeast Fisheries Science Center in Beaufort, NC. To generate weighting factors for sampled headboat trips throughout the survey area, fishing effort for the years 2005 through 2013 was used to calculate proportional fishing effort by state or region (for Florida). Sample weights were calculated as:

$$W_{ay} = (N_{ay}/N_y) / (n_{ay}/n_y) \qquad \text{Equation 1}$$

Where N_{ay} /N is the total number of headboat trips reported from area a (state or region) during year y divided by total number of trips reported in the South Atlantic, and n_{ay}/n is the number of trips sampled in area a during year y, divided by the total number of sampled trips in the South Atlantic. Areas with $W_{ay} < 1$ are down weighted to account for higher sampling effort and areas with $W_t > 1$ are upweighted to account for undersampling.

Numbers of headboat trips sampled in each state/region are provided in Table 3, and calculated sample weights are provided in Table 4.

Table 3. Headboat at-sea observer trips sampled by state/region and year.

Year	NC (n_i)	SC (n_i)	GA-NEFL (n_i)	SEFL (n_i)	Sum (n)
2005	97	57	49	93	296
2006	88	45	45	71	249
2007	91	52	57	69	269
2008	78	39	55	74	246
2009	69	34	61	76	240
2010	83	26	51	72	232
2011	79	22	51	68	220
2012	78	36	62	64	240
2013	55	41	61	79	236
2014	70	41	68	79	258

Table 4. Sample weights (W_{ay}).

Year	NC	SC	GA-NEFL	SEFL
2005	0.229	0.588	0.708	1.489
2006	0.146	0.772	0.564	1.399
2007	0.180	1.024	0.705	1.732
2008	0.164	1.320	0.859	1.217
2009	0.210	1.493	0.889	1.025
2010	0.184	2.030	0.823	1.169
2011	0.162	2.485	0.718	1.136
2012	0.178	1.444	0.587	1.450
2013	0.213	0.970	0.563	1.367
2014	0.198	1.186	0.511	2.034

Length Frequency

Raw, unweighted sample sizes for red snapper lengths are provided in Table 5. Fork length (in mm) was converted to maximum total length using the equation provided by the SEDAR41 Life History Workgroup (TL_{max} = 2.22 + 1.07FL). Individual fish were then assigned to one cm length bin categories (40 cm bin = fish 39.5 cm to 40.4 cm). The numbers of fish in each length bin category were summed by area (state or region), year and disposition (harvested, released), and multiplied by appropriate sample weights. Weighted values for each area within a length bin were then summed so that weighted proportions of fish in each length bin could be calculated (Figure 2).

Table 5. Raw (unweighted) sample sizes for red snapper lengths.

Year	Disposition	NC	SC	GA-NEFL	SEFL	Total
2005	Discard	0	0	366	48	414
	Harvest	1	4	106	4	115
2006	Discard	0	0	672	0	672
	Harvest	1	0	50	0	51
2007	Discard	13	2	1,450	34	1,499
	Harvest	1	2	59	0	62
2008	Discard	23	1	1,626	28	1,678
	Harvest	5	2	234	1	242
2009	Discard	3	0	425	8	436
	Harvest	1	0	186	0	187
2010	Discard	7	0	325	14	346
	Harvest	0	0	0	0	0
2011	Discard	8	0	307	0	315
	Harvest	0	0	0	0	0
2012	Discard	18	1	635	3	657
	Harvest	3	0	12	0	15
2013	Discard	28	0	472	1	501
	Harvest	4	0	9	0	13
2014	Discard	7	0	606	0	613
	Harvest	0	0	0	0	0

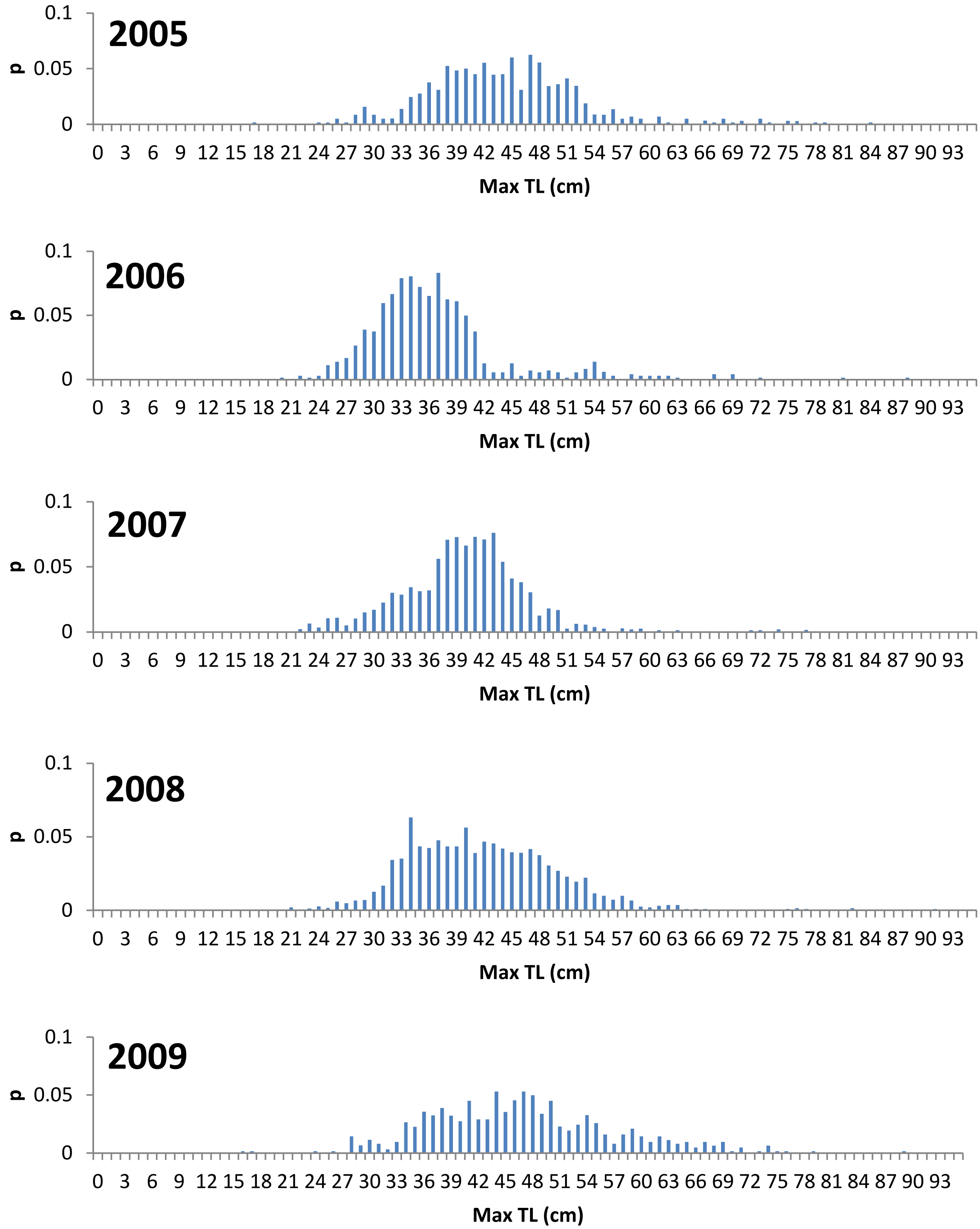


Figure 2. Weighted length frequency of red snapper discards. Continued on next page.

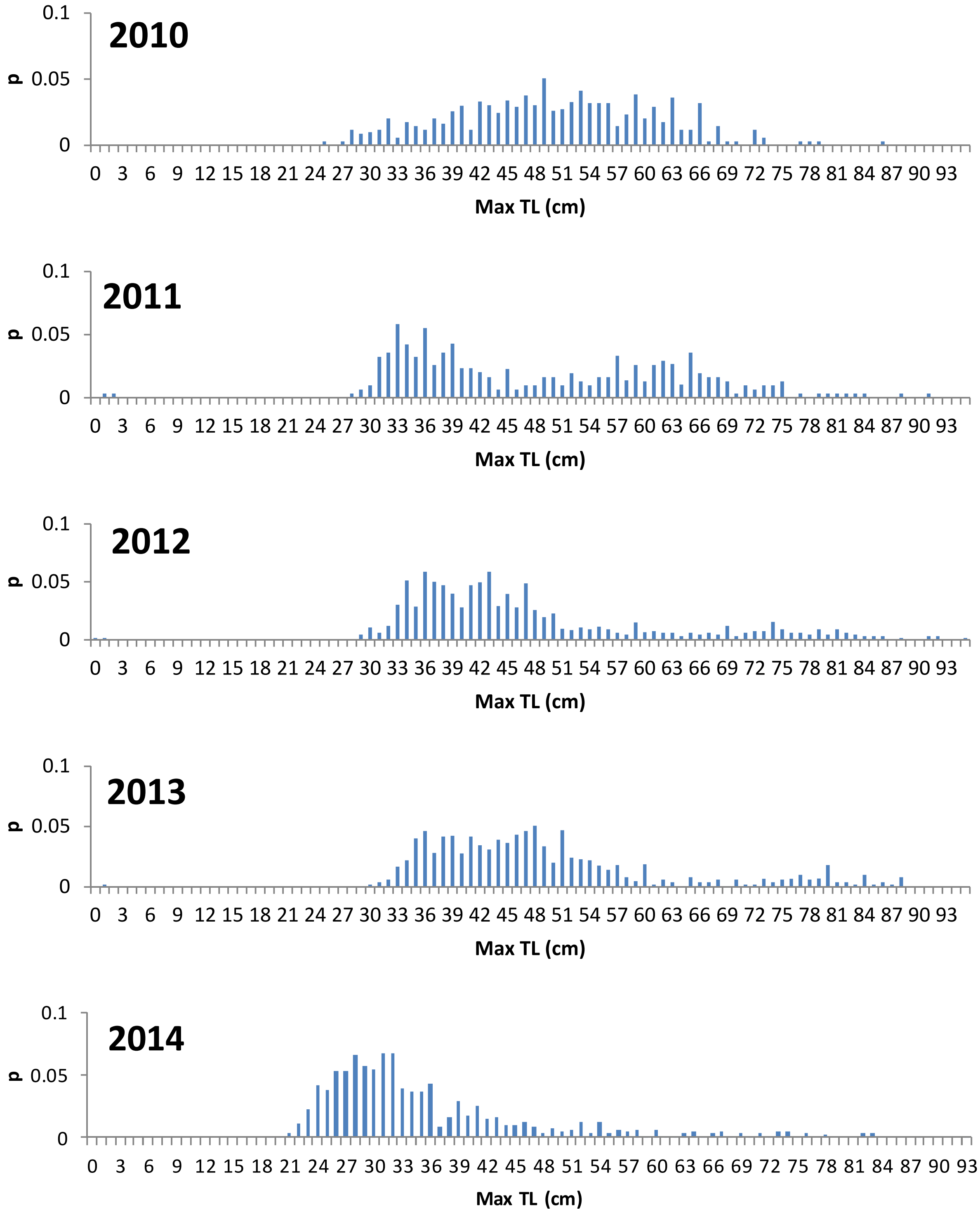
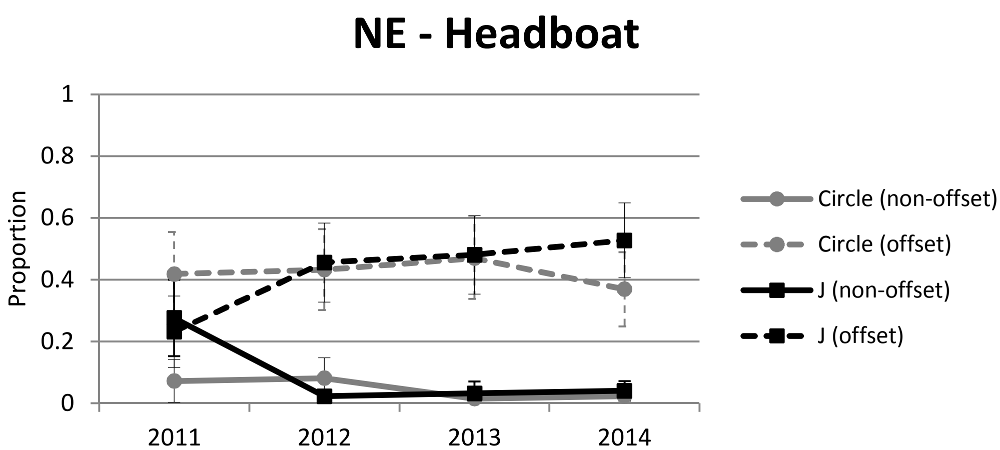


Figure 2. Continued.

Hook Type Usage in the For-Hire Fishery
Circle hooks have been required in the South Atlantic since 3/3/2011 when fishing for species in the snapper-grouper management group north of 28 degrees north latitude (the boundary between Brevard and Indian River Counties in Florida). Among trips sampled off the Atlantic coast of Florida, the prevalence of circle hook use on headboats and charter vessels varied north and south of this demarcation (Figures 3 and 4).

On headboat trips in the SE region of Florida, non-offset (flat) J hooks were used almost exclusively, although there was a slight increase during 2014 in the use of offset circle hooks (Figure 3). In the NE region, where circle hooks are required when fishing for snapper and grouper, offset circle hooks and offset J hooks were equally prevalent on headboats (Figure 3).

On charter trips, in the SE region of Florida, both offset and non-offset J hooks were prevalent. Non-offset circle hooks was the most prevalent gear used on charter trips observed in the NE region (Figure 4).



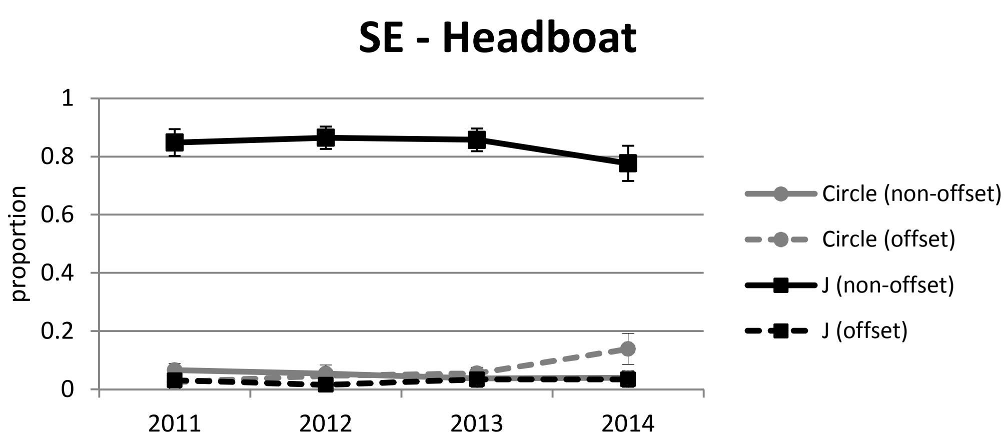


Figure 3. Mean proportion of fishing rigs by hook type observed during headboat trips sampled on the Atlantic coast of Florida for regions north (top panel) and south (bottom panel) of 28 degrees north latitude. Circle hooks were required after 3/3/2011 when fishing for snapper and grouper north of 28 degrees north latitude.

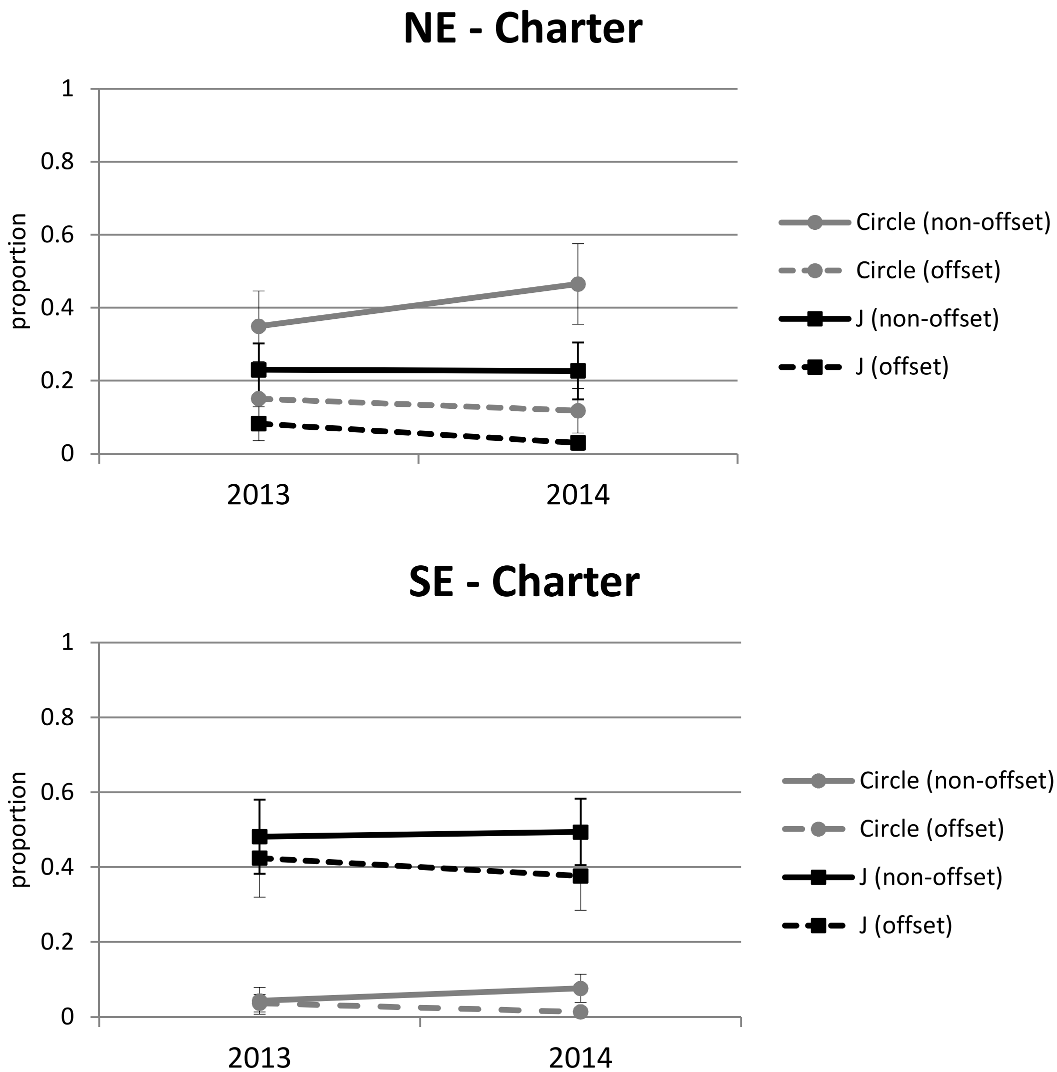


Figure 4. Mean proportion of fishing rigs by hook type observed during charter trips sampled on the Atlantic coast of Florida for regions north (top panel) and south (bottom panel) of 28 degrees north latitude. Circle hooks were required after 3/3/2011 when fishing for snapper and grouper north of 28 degrees north latitude.

Hook Injuries

Out of 3,116 red snapper observed on the Atlantic coast of Florida, 65% were caught with circle hooks, 35% were caught with J hooks, and <1% were caught with kahle or treble hooks. Among red snapper caught with circle hooks, 66% were caught with offset hooks; and among those caught with J hooks, 85% were caught on offset hooks. The overall percentage of potentially lethal hook locations (including eyes, gills, esophagus and gut) was lowest among red snapper caught with non-offset circle hooks (Table 6). Logistic regression was used to test the significance of hook type on the probability that hooks embed in a potentially lethal location (versus in the lip or jaw). When compared to flat non-offset circle hooks, circle hooks with an offset were 1.6 times more likely to embed in potentially lethal locations, flat non-offset J hooks were 2.4 times more likely, and offset J hooks performed the worst and were 4.8 times more likely to embed internally in a harmful location (Table 7). Offset circle hooks and flat non-offset J hooks performed similarly, and offset J hooks performed worse than all other hook types (Table 7).

Table 6. Numbers of red snapper observed by hook-type and location where the hook was embedded, and percent of red snapper with potentially lethal hook injuries.

Hook-type	Lip or jaw	Potentially lethal location	Percent potentially lethal
Non-offset circle hook	652	31	4.54
Offset circle hook	1,245	96	7.16
Non-offset J hook	141	16	10.19
Offset J hook	743	170	18.62
Other (kahle, treble)	19	3	13.64

Table 7. Results of a logistic regression that modeled the probability for hooks to embed in potentially lethal locations. For odds ratios >1.0, confidence intervals that do not overlap with 1.0 indicate a significantly higher probability for potentially lethal hook injuries.

Hook-type Comparison	Odds Ratio	95% Confidence Interval
Offset circle vs. non-offset circle	1.621	1.070, 2.457
Non-offset J vs. non-offset circle	2.386	1.271, 4.481
Non-offset J vs. offset circle	1.472	0.843, 2.569 (not significant)
Offset J vs. non-offset circle	4.811	3.235, 7.155
Offset J vs. offset circle	2.967	2.274, 3.873
Offset J vs. non-offset J	2.016	1.171, 3.471

Implications of Circle Hook Requirement for Discard Mortality

Data on hook type were not collected from at-sea surveys in Florida until the first year that circle hook use was required in the South Atlantic; therefore, characteristics of the fishery prior to the circle hook requirement are not available. However, some inferences can be made. The four year time series for headboats in the NE region of Florida (the area north of 28 degrees latitude where the circle hook requirement is in effect) indicates an increasing trend in offset circle hook use and a decrease in flat non-offset J hooks since 2011 when the circle hook rule went into effect (Figure 3, top panel). Circle hook use is not required in the SE region and non-offset J hooks were used almost exclusively across all four years. Assuming the NE region shifted to offset circle hooks as a result of the circle hook requirement, no net conservation benefit is expected, since performance for this hook type is similar to non-offset J hooks. If the NE region was using offset J hooks prior to 2011, a potential net benefit could be expected, since this gear performed the worst among all hook types (Table 7). However, the prevalence of offset J hooks increased over the four years of observation (Figure 3, top panel); although this has not led to a noticeable decline in the proportion of red snapper observed on headboats that were hooked in the lip or jaw over the time series (Figure 5).

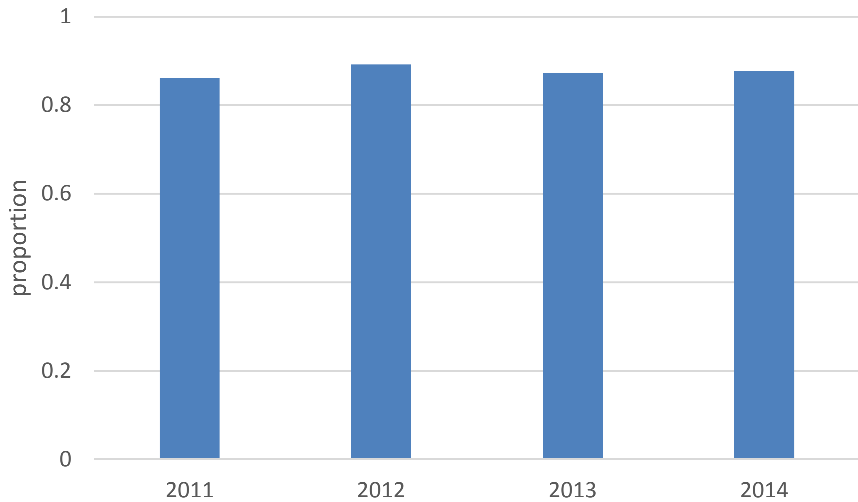


Figure 5. Proportion of red snapper observed on headboats each year that were hooked in the mouth or jaw.

On charter boat trips sampled in the NE region, non-offset circle hooks were the most frequently observed hook type in both years, and this gear also had the lowest incidence of deep hooking. Like the headboat fishery, J hooks are most prevalent on charter trips in the SE region, where circle hooks are not required. Assuming J hooks were used more frequently prior to 2011 in the NE charter fishery, there is a potential net conservation benefit from a shift to non-offset circle hooks in this segment of the recreational fishery.

Condition of Red Snapper Discards in Florida

Immediate mortality percentages for red snapper observed from for-hire vessels in the Gulf of Mexico adjacent to Florida are reported to be low (<1%, SEDAR41-RD16). On the Atlantic coast of Florida, no dead discards were recorded by fishery observers on for-hire vessels (all discards observed were released alive).

Live red snapper discards observed from the Atlantic coast of Florida were assigned to one of three release condition categories used to model relative survival of red snapper discards in the Gulf of Mexico (described in Table 8 and SEDAR41-RD16). The majority of red snapper discards observed from headboats were captured from depths of 30 meters or less; whereas, a higher portion of red snapper observed from charter boats were captured in depths of 31-40 meters and 41-50 meters (Figure 6). In both fisheries, the majority (67.4%) of red snapper were vented prior to release and did not exhibit obvious impairments (Figure 6). Among fish that were classified as impaired (16.3% of all fish observed), the majority were due to hook injury rather than swimming impairments associated with barotrauma and other stressors.

In the Gulf, survival percentages for fish released in each condition category were estimated from a model that was derived from gag grouper discarded during for-hire recreational trips and marked with conventional tags prior to release (Sauls 2014). The same model was also applied to red snapper that were tagged prior to discarding in the Gulf of Mexico (SEDAR41-DW16, percentages provided in Table 9). When these percentages are applied to red snapper observed on the Atlantic coast of Florida, the overall portion of discards that suffer mortality is estimated to be approximately 27-28% for charter boats and headboats, respectively (Table 10). This result is comparable to overall discard mortality estimates in the Gulf (Table 9).

Table 8. Description of live release condition categories for reef fishes observed during recreational hook-and-line fishing (SEDAR41-RD16).

Condition category	Description
1. Not impaired, not vented	Fish immediately submerged without the assistance of venting and did not suffer internal hook injuries or visible injury to the gills.
2. Not impaired, vented	Fish was vented first and submerged immediately, and did not suffer internal hook injuries or visible injury to the gills.
3. Impaired	Fish was either initially disoriented before it submerged or remained floating at the surface (regardless of whether it was vented), suffered internal hook injuries, suffered visible injury to the gills, or any combination of the three impairments.

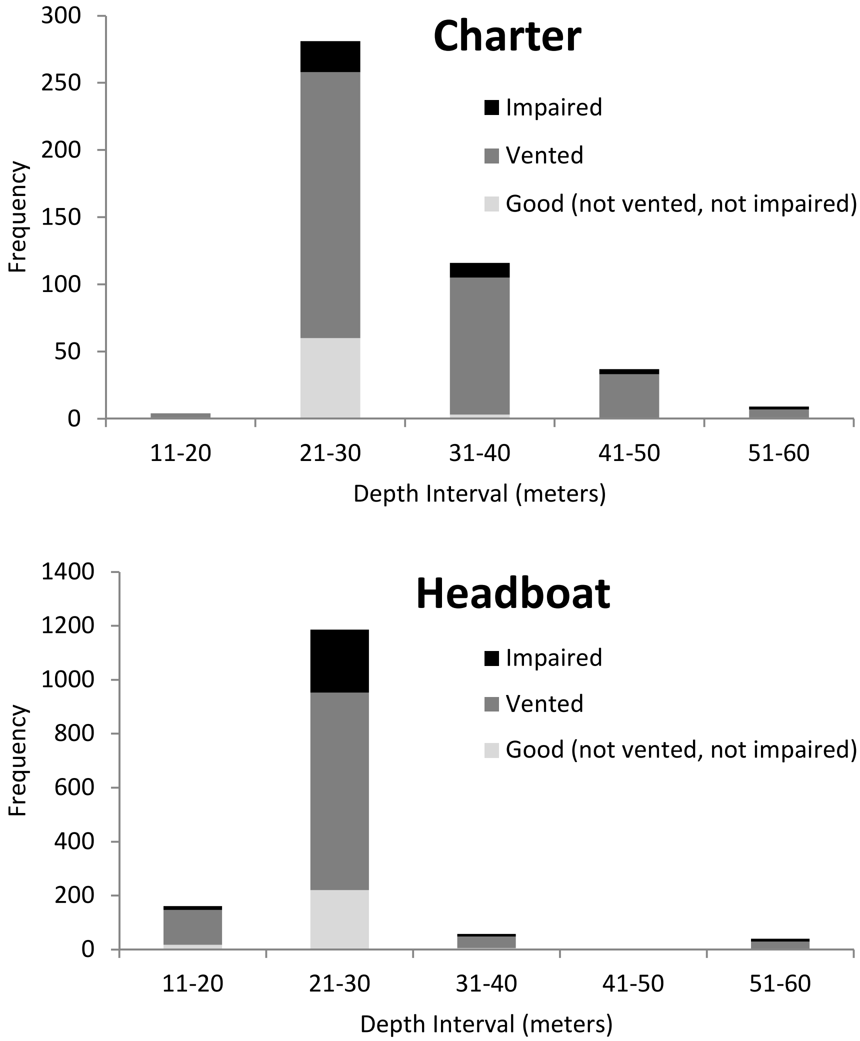


Figure 6. Release conditions for red snapper observed from charter boats (top) and headboats (bottom), by depth of capture.

Table 9. Proportion of live discarded red snapper caught with recreational hook-and-line gear in the eastern Gulf of Mexico estimated to survive catch-and-release, by release condition category (SEDAR41-RD16).

Release Condition Category	**Estimated Survival Portion**	**Overall estimated discard mortality**
1, not impaired, not vented	0.925 (range 0.85, 1.0)	Point estimate range 0.207 to 0.257
2, not impaired, vented	0.724 (95% CI 0.652, 0.804)	
3, impaired	0.495 (95% CI 0.391, 0.599)	

Table 10. Numbers of red snapper discards observed off the Atlantic coast of Florida by release condition category, estimated number of discard mortalities (based on estimated percent survival in Table 9), and overall proportion estimated to suffer mortality.

Vessel Type	**Release Condition Category**	**Discards observed**	**Estimated mortalities**	**Estimated mortality proportion**
Headboat	1, not impaired, not vented	237	17.8 (0, 35.6)	
	2, not impaired, vented	1,103	304.4 (216.2, 383.8)	
	3, impaired	327	165.1 (131.1, 199.1)	
	Total	1,667	487.3 (347.3, 618.5)	0.292 (0.208, 0.360)
Charter	1, not impaired, not vented	81	6.1 (0, 12.2)	
	2, not impaired, vented	610	168.4 (119.6, 212.3)	
	3, impaired	92	46.5 (36.9, 56.0)	
	Total	783	221.0 (156.5, 280.5)	0.282 (0.200, 0.358)

References

Sauls, B. 2014. Relative survival of gags ***Mycteroperca microlepis*** released within a recreational hook-and-line fishery: application of the Cox regression model to control for heterogeneity in a large-scale mark-recapture study. Fisheries Research 150: 18-27.

SEDAR41-RD16. Sauls, B., R. Cody, O. Ayala, B. Cermak. 2013. A directed study of the recreational red snapper fisheries in the Gulf of Mexico along the West Florida Shelf. Federal Grant NA09NMF4720265, Final report submitted to National Marine Fisheries Service, Southeast Regional Office.

SEDAR 41 Indices of Abundance Report Cards

SEDAR 41 Index Working Group

SEDAR41-DW39

Submitted: 27 August 2014

This information is distributed solely for the purpose of pre-dissemination peer review. It does not represent and should not be construed to represent any agency determination or policy.

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Evaluation of Abundance Indices:
SERFS Chevron Traps Red Snapper (Working Paper #06)

DESCRIPTION OF THE DATA SOURCE

1. Fishery Independent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.				✓
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)				✓
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)				✓
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).				✓
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓

2. Fishery Dependent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).				
B. Describe any changes to reporting requirements, variables reported, etc.				
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				

METHODS

1. Data Reduction and Exclusions

	Not Applicable	Absent	Incomplete	Complete
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).	✓			
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?	✓			

Working Group Comments:

Survey did not consistently cover the center of distribution for Red Snapper in the South Atlantic (Georgia and northern Florida). Survey best covered the center from 2010 to 2013. Percent positives also were less than 5% prior to these years. Decision was made to split the index to 2010-2013 and 2009 and earlier. The percent positives in 1990-2009 were too low to develop an index, consistent with the decision made in SEDAR 24.

2. Management Regulations (for FD Indices)

	Not Applicable	Absent	Incomplete	Complete
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).				
B. Describe the effects (if any) of management regulations on CPUE				
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.				

3. Describe Analysis Dataset (after exclusions and other treatments)

	Not Applicable	Absent	Incomplete	Complete
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.				✓
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.				✓
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓

4. Model Standardization

	Not Applicable	Absent	Incomplete	Complete
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)				✓
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?		✓		
E. Provide a table summarizing the construction of the GLM components.				✓
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.				✓

Working Group Comments:

Initial model was a zero-inflated negative binomial model using polynomials to describe the effects of variables on catch rates. We investigated reducing the highest order that the polynomials could take and also considered including all lower order polynomials when a high order was selected by Bayesian Information Criterion. Since this approach has not been fully peer-reviewed, the decision was made to bin covariates based on preliminary generalized additive model fits. Inclusion of covariates in the sub-models was done by forward selection with Akaike's Information Criterion.

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

1. Binomial Component

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include plots of the chi-square residuals by factor.	✓				
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)				✓	
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).				✓	

2. Lognormal/Gamma Component

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				
F. Include plots of the residuals by factor	✓				

3. Poisson Component

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).				✓	
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.				✓	
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.				✓	
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.				✓	
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***

4. Zero-inflated model

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include ROC curve to quantify goodness of fit.		✓			
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).				✓	
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.				✓	

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.				✓
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.				✓

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance	✓			
2. Table of model statistics (e.g. AIC criteria)	✓			

	Date Received	*Workshop Recommendation*	*Revision Deadline ****	*Author and Rapporteur Signatures*
First Submission	8/11/2014	Continue pursuing		
Revision				

The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author ***DOES NOT*** *commit to any* ***LEGAL OBLIGATION*** *by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

The SERFS chevron trap index is the only fishery-independent survey that can be used to develop a relative abundance index of Red Snapper that collects associated biological information (e.g. age/length comps) that can be used to inform selectivity of the gear. That being said, during SEDAR 24 the SERFS chevron trap index was not recommended for use due to the low percent positive rate of Red Snapper in the traps, the perceived inability of the trap to capture Red Snapper (i.e. low detectability, despite reports that chevron traps were capable of capturing Red Snapper in the Gulf of Mexico), and the limited sampling of the survey in the center of Red Snapper abundance off Georgia and northern Florida. While nothing could rectify the lack of positive occurrences in early years (1990-2009), the other two concerns were alleviated for the years 2010-2013 for SEDAR 41. During these years ample sampling occurred throughout the region and the percent positive occurrences were acceptable. Although the sampling distribution of the survey with regards to specific covariates (e.g. bottom temperature, depth, latitude, etc.) varied from year to year, the zero-inflation standardization approach effectively removes the effects of this variability from relative abundance trends. Finally, being a fishery-independent survey, standardized sampling techniques have been used and the survey has been immune to regulation changes. These observations generally make relative abundance trends suggested by fishery-independent surveys superior to parallel fishery-dependent abundance trends, especially as stricter management regulations are placed on the fishery.

Evaluation of Abundance Indices:
SERFS Video Index (SEDAR41-DW04)

DESCRIPTION OF THE DATA SOURCE

	Not Applicable	Absent	Incomplete	Complete
1. Fishery Independent Indices				
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.				✓
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)				✓
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)				✓
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).				✓
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓
2. Fishery Dependent Indices				
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).	✓			
B. Describe any changes to reporting requirements, variables reported, etc.	✓			
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).	✓			
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓			

METHODS

	Not Applicable	Absent	Incomplete	Complete
1. Data Reduction and Exclusions				
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).	✓			
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?	✓			

Working Group Comments:

Working Group Comments:

2. Management Regulations (for FD Indices)

Item	Not Applicable	Absent	Incomplete	Complete
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).	✓			
B. Describe the effects (if any) of management regulations on CPUE	✓			
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.	✓			

3. Describe Analysis Dataset (after exclusions and other treatments)

Item	Not Applicable	Absent	Incomplete	Complete
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.	✓			
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.	✓			
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓

4. Model Standardization

Item	Not Applicable	Absent	Incomplete	Complete
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)	✓			
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?	✓			
E. Provide a table summarizing the construction of the GLM components.	✓			
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.				✓

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
1. Binomial Component					
A. Include plots of the chi-square residuals by factor.	✓				
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)	✓				
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
2. Lognormal/Gamma Component					
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				
F. Include plots of the residuals by factor	✓				
3. Poisson Component					
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***
4. Zero-inflated model					
A. Include ROC curve to quantify goodness of fit.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).				✓	
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.				✓	

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓			

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance	✓			
2. Table of model statistics (e.g. AIC criteria)				✓

	Date Received	*Workshop Recommendation*	*Revision Deadline* ***	*Author and Rapporteur Signatures*
First Submission	7/21/14	Recommended		
Revision				

*The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author **DOES NOT** commit to any **LEGAL OBLIGATION** by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

Evaluation of Abundance Indices of red snapper: Headboat logbook 1976-1991, SEDAR41-DW12

DESCRIPTION OF THE DATA SOURCE

	Not Applicable	Absent	Incomplete	Complete
1. Fishery Independent Indices				
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.	✓			
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)	✓			
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)	✓			
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).	✓			
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).	✓			
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓			
2. Fishery Dependent Indices				
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).				✓
B. Describe any changes to reporting requirements, variables reported, etc.				✓
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓

METHODS

	Not Applicable	Absent	Incomplete	Complete
1. Data Reduction and Exclusions				
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).				✓
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?				✓

Working Group Comments:

2. Management Regulations (for FD Indices)

	Not Applicable	Absent	Incomplete	Complete
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).				✓
B. Describe the effects (if any) of management regulations on CPUE				✓
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.				✓

Working Group Comments:

3. Describe Analysis Dataset (after exclusions and other treatments)

	Not Applicable	Absent	Incomplete	Complete
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.				✓
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.				✓
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓

4. Model Standardization

	Not Applicable	Absent	Incomplete	Complete
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)				✓
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?		✓		
E. Provide a table summarizing the construction of the GLM components.		✓		
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.				✓

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
1. Binomial Component					
A. Include plots of the chi-square residuals by factor.				✓	
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)				✓	
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).				✓	
2. Lognormal/Gamma Component					
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.				✓	
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.				✓	
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.				✓	
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				
F. Include plots of the residuals by factor				✓	
3. Poisson Component					
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***
4. Zero-inflated model					
A. Include ROC curve to quantify goodness of fit.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).	✓				
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.	✓				

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓			

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance	✓			
2. Table of model statistics (e.g. AIC criteria)	✓			

	Date Received	*Workshop Recommendation*	*Revision Deadline* ***	*Author and Rapporteur Signatures*
First Submission		recommend for use		
Revision				

The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author ***DOES NOT*** *commit to any* ***LEGAL OBLIGATION*** *by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

Evaluation of Abundance Indices of red snapper: Headboat logbook 1992-2009, SEDAR41-DW12

Working Group Comments:

DESCRIPTION OF THE DATA SOURCE

1. Fishery Independent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.	✓			
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)	✓			
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)	✓			
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).	✓			
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).	✓			
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓			

2. Fishery Dependent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).				✓
B. Describe any changes to reporting requirements, variables reported, etc.				✓
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓

METHODS

1. Data Reduction and Exclusions

	Not Applicable	Absent	Incomplete	Complete
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).				✓
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?				✓

	Not Applicable	Absent	Incomplete	Complete
2. Management Regulations (for FD Indices)				
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).				✓
B. Describe the effects (if any) of management regulations on CPUE				✓
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.				✓
3. Describe Analysis Dataset (after exclusions and other treatments)				
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.				✓
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.				✓
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓
4. Model Standardization				
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)				✓
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?		✓		
E. Provide a table summarizing the construction of the GLM components.		✓		
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.				✓

Working Group Comments:

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

1. Binomial Component

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include plots of the chi-square residuals by factor.				✓	
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)				✓	
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).				✓	

2. Lognormal/Gamma Component

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.				✓	
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.				✓	
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.				✓	
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				
F. Include plots of the residuals by factor				✓	

3. Poisson Component

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***

4. Zero-inflated model

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include ROC curve to quantify goodness of fit.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).	✓				
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.	✓				

MODEL DIAGNOSTICS (CONT.)

Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓			

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance	✓			
2. Table of model statistics (e.g. AIC criteria)	✓			

	Date Received	*Workshop Recommendation*	*Revision Deadline* ***	*Author and Rapporteur Signatures*
First Submission		recommend for use		
Revision				

The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author ***DOES NOT*** *commit to any* ***LEGAL OBLIGATION*** *by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

Evaluation of Abundance Indices of Red snapper: Headboat at-sea observer 2005-2009, SEDAR41-DW14

DESCRIPTION OF THE DATA SOURCE

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
1. Fishery Independent Indices					
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.	✓				
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)	✓				
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)	✓				
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).	✓				
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).	✓				
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓				
2. Fishery Dependent Indices					
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).				✓	
B. Describe any changes to reporting requirements, variables reported, etc.				✓	
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓	
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓	

METHODS

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
1. Data Reduction and Exclusions					
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓	
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).				✓	
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?				✓	

	Not Applicable	Absent	Incomplete	Complete
2. Management Regulations (for FD Indices)				
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).				✓
B. Describe the effects (if any) of management regulations on CPUE				✓
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.				✓
3. Describe Analysis Dataset (after exclusions and other treatments)				
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.				✓
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.				✓
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓
4. Model Standardization				
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)				✓
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?		✓		
E. Provide a table summarizing the construction of the GLM components.		✓		
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.				✓

Working Group Comments:

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

1. Binomial Component

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include plots of the chi-square residuals by factor.				✓	
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)				✓	
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).				✓	

2. Lognormal/Gamma Component

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.				✓	
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.				✓	
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.				✓	
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				
F. Include plots of the residuals by factor				✓	

3. Poisson Component

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***

4. Zero-inflated model

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include ROC curve to quantify goodness of fit.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).	✓				
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.	✓				

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓			

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance	✓			
2. Table of model statistics (e.g. AIC criteria)	✓			

	Date Received	***Workshop Recommendation***	***Revision Deadline ******	***Author and Rapporteur Signatures***
First Submission		recommend for use		
Revision				

The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author ***DOES NOT*** *commit to any* ***LEGAL OBLIGATION*** *by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

Evaluation of Abundance Indices of Red snapper: Headboat at-sea observer 2010-2013, SEDAR41-DW14

DESCRIPTION OF THE DATA SOURCE

Working Group Comments:

1. Fishery Independent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.	✓			
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)	✓			
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)	✓			
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).	✓			
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).	✓			
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓			

2. Fishery Dependent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).				✓
B. Describe any changes to reporting requirements, variables reported, etc.				✓
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓

METHODS

1. Data Reduction and Exclusions

	Not Applicable	Absent	Incomplete	Complete
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).				✓
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?				✓

2. Management Regulations (for FD Indices)

	Not Applicable	Absent	Incomplete	Complete
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).				✓
B. Describe the effects (if any) of management regulations on CPUE				✓
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.				✓

Working Group Comments:

3. Describe Analysis Dataset (after exclusions and other treatments)

	Not Applicable	Absent	Incomplete	Complete
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.				✓
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.				✓
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓

4. Model Standardization

	Not Applicable	Absent	Incomplete	Complete
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)				✓
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?		✓		
E. Provide a table summarizing the construction of the GLM components.		✓		
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.				✓

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
1. Binomial Component					
A. Include plots of the chi-square residuals by factor.				✓	
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)				✓	
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).				✓	
2. Lognormal/Gamma Component					
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.				✓	
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.				✓	
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.				✓	
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				
F. Include plots of the residuals by factor				✓	
3. Poisson Component					
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***
4. Zero-inflated model					
A. Include ROC curve to quantify goodness of fit.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).	✓				
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.	✓				

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓			

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance	✓			
2. Table of model statistics (e.g. AIC criteria)	✓			

	Date Received	*Workshop Recommendation*	*Revision Deadline* ***	*Author and Rapporteur Signatures*
First Submission		recommend for use		
Revision				

The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author ***DOES NOT*** *commit to any* ***LEGAL OBLIGATION*** *by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

Evaluation of Abundance Indices: Red Snapper Commercial Logbook - Handline Index Title (Working Paper SEDAR 41 DW 19)

Working Group Comments:

DESCRIPTION OF THE DATA SOURCE

	Not Applicable	Absent	Incomplete	Complete
1. Fishery Independent Indices				
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.	✓			
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)	✓			
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)	✓			
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).	✓			
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).	✓			
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓			
2. Fishery Dependent Indices				
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).				✓
B. Describe any changes to reporting requirements, variables reported, etc.				✓
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓

METHODS

	Not Applicable	Absent	Incomplete	Complete
1. Data Reduction and Exclusions				
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).				✓
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?				✓

Working Group Comments:

2. Management Regulations (for FD Indices)

	Not Applicable	Absent	Incomplete	Complete
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).				✓
B. Describe the effects (if any) of management regulations on CPUE				✓
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.				✓

3. Describe Analysis Dataset (after exclusions and other treatments)

	Not Applicable	Absent	Incomplete	Complete
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.				✓
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.				✓
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓

4. Model Standardization

	Not Applicable	Absent	Incomplete	Complete
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)				✓
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?	✓			
E. Provide a table summarizing the construction of the GLM components.				✓
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.	✓			

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
1. Binomial Component					
A. Include plots of the chi-square residuals by factor.				✓	
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)		✓			
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).		✓			
2. Lognormal/Gamma Component					
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.				✓	
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.		✓			
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.				✓	
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.		✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.		✓			
F. Include plots of the residuals by factor				✓	
3. Poisson Component					
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***
4. Zero-inflated model					
A. Include ROC curve to quantify goodness of fit.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).	✓				
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.	✓				

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓			

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance	✓			
2. Table of model statistics (e.g. AIC criteria)	✓			

	Date Received	*Workshop Recommendation*	*Revision Deadline ****	*Author and Rapporteur Signatures*
First Submission	8/26/2014	Recommended for use		
Revision				

*The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author **DOES NOT** commit to any **LEGAL OBLIGATION** by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

Evaluation of Abundance Indices of Red Snapper: Charter Logbook (SCDNR) (SEDAR41-DW-32)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
DESCRIPTION OF THE DATA SOURCE					
1. Fishery Independent Indices					
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.	✓				
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)	✓				
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)	✓				
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).	✓				
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).	✓				
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓				
2. Fishery Dependent Indices					
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).				✓	
B. Describe any changes to reporting requirements, variables reported, etc.				✓	
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓	
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓				
METHODS					
1. Data Reduction and Exclusions					
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓	
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).				✓	
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?	✓				

	Not Applicable	Absent	Incomplete	Complete
2. Management Regulations (for FD Indices)				
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).				✓
B. Describe the effects (if any) of management regulations on CPUE				✓
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.				✓
3. Describe Analysis Dataset (after exclusions and other treatments)				
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.				✓
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.				✓
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓
4. Model Standardization				
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)				✓
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?		✓		
E. Provide a table summarizing the construction of the GLM components.		✓		
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.				✓

Working Group Comments:

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
1. Binomial Component					
A. Include plots of the chi-square residuals by factor.				✓	
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)				✓	
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).				✓	
2. Lognormal/Gamma Component					
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.				✓	
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.				✓	
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.				✓	
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.				✓	
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.				✓	
F. Include plots of the residuals by factor				✓	
3. Poisson Component					
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***
4. Zero-inflated model					
A. Include ROC curve to quantify goodness of fit.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).	✓				
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.	✓				

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓			

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance				✓
2. Table of model statistics (e.g. AIC criteria)				✓

	Date Received	*Workshop Recommendation*	*Revision Deadline ****	*Author and Rapporteur Signatures*
First Submission	8/4/2014	Do not use		
Revision				

The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author ***DOES NOT*** *commit to any* ***LEGAL OBLIGATION*** *by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

Due to the limited geographic scope of the data set the working group decided not to use the data set for the stock assessment. However, the working group did use the data set to corroborate the South Carolina head-boat data being used.

Evaluation of Abundance Indices: MRFSS/MRIP (Working Paper # NA)

DESCRIPTION OF THE DATA SOURCE

	Not Applicable	Absent	Incomplete	Complete
1. Fishery Independent Indices				
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.	✓			
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)	✓			
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)	✓			
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).	✓			
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).	✓			
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓			
2. Fishery Dependent Indices				
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).		✓		
B. Describe any changes to reporting requirements, variables reported, etc.		✓		
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).		✓		
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.		✓		

METHODS

	Not Applicable	Absent	Incomplete	Complete
1. Data Reduction and Exclusions				
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.		✓		
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).		✓		
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?		✓		

Working Group Comments:

Working Group Comments:

2. Management Regulations (for FD Indices)

Item	Not Applicable	Absent	Incomplete	Complete
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).		✓		
B. Describe the effects (if any) of management regulations on CPUE		✓		
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.		✓		

3. Describe Analysis Dataset (after exclusions and other treatments)

Item	Not Applicable	Absent	Incomplete	Complete
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.		✓		
B. Include tables and/or figures of number of positive observations by factors and interaction terms.		✓		
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.		✓		
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.				✓
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).		✓		
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.		✓		
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓

4. Model Standardization

Item	Not Applicable	Absent	Incomplete	Complete
A. Describe model structure (e.g. delta-lognormal)	✓			
B. Describe construction of GLM components (e.g. forward selection from null etc.)	✓			
C. Describe inclusion criteria for factors and interactions terms.	✓			
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?	✓			
E. Provide a table summarizing the construction of the GLM components.	✓			
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)	✓			
G. Report convergence statistics.	✓			

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
1. Binomial Component					
A. Include plots of the chi-square residuals by factor.	✓				
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)	✓				
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
2. Lognormal/Gamma Component					
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				
F. Include plots of the residuals by factor	✓				
3. Poisson Component					
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***
4. Zero-inflated model					
A. Include ROC curve to quantify goodness of fit.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).	✓				
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.	✓				

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓			

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report		✓		
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).		✓		

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance		✓		
2. Table of model statistics (e.g. AIC criteria)		✓		

	Date Received	*Workshop Recommendation*	*Revision Deadline* ***	*Author and Rapporteur Signatures*
First Submission	1 Aug 2014	Not recommended		
Revision				

The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author ***DOES NOT*** *commit to any* ***LEGAL OBLIGATION*** *by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

- Nominal index only, not standardized
- Fishery dependent (i.e., potentially affected by regulations, targeting, hyperdepletion, hyperstability)
- Catchability may vary over time or with abundance
- Potential bias in trips intercepted
- High variability
- Effective effort is difficult to identify

Evaluation of Abundance Indices:
SERFS Chevron Traps Gray Triggerfish (Working Paper #05)

DESCRIPTION OF THE DATA SOURCE

1. Fishery Independent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.				✓
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)				✓
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)				✓
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).				✓
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓

2. Fishery Dependent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).				
B. Describe any changes to reporting requirements, variables reported, etc.				
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				

METHODS

1. Data Reduction and Exclusions

	Not Applicable	Absent	Incomplete	Complete
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).	✓			
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?	✓			

Working Group Comments:

Full time series covered the center of distribution of Gray Triggerfish and had sufficient percent positives for index development.

2. Management Regulations (for FD Indices)

	Not Applicable	Absent	Incomplete	Complete
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).				
B. Describe the effects (if any) of management regulations on CPUE				
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.				

3. Describe Analysis Dataset (after exclusions and other treatments)

	Not Applicable	Absent	Incomplete	Complete
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.				✓
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.				✓
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓

4. Model Standardization

	Not Applicable	Absent	Incomplete	Complete
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)				✓
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?		✓		
E. Provide a table summarizing the construction of the GLM components.				✓
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.				✓

Working Group Comments:

Initial model was a zero-inflated negative binomial model using polynomials to describe the effects of variables on catch rates. We investigated reducing the highest order that the polynomials could take and also considered including all lower order polynomials when a high order was selected by Bayesian Information Criterion. Since this approach has not been fully peer-reviewed, the decision was made to bin covariates based on preliminary generalized additive model fits. Inclusion of covariates in the sub-models was done by forward selection with Akaike's Information Criterion.

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

1. Binomial Component

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include plots of the chi-square residuals by factor.	✓				
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)				✓	
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).				✓	

2. Lognormal/Gamma Component

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				
F. Include plots of the residuals by factor	✓				

3. Poisson Component

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).				✓	
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.				✓	
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.				✓	
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.				✓	
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***

4. Zero-inflated model

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include ROC curve to quantify goodness of fit.		✓			
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).				✓	
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.				✓	

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.				✓
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.				✓

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance	✓			
2. Table of model statistics (e.g. AIC criteria)	✓			

	Date Received	*Workshop Recommendation*	*Revision Deadline* ***	*Author and Rapporteur Signatures*
First Submission	8/11/2014	Continue pursuing		
Revision				

The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author ***DOES NOT*** *commit to any* ***LEGAL OBLIGATION*** *by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

The SERFS chevron trap index represents the longest time series of fishery-independent data available for Gray Triggerfish in the region, beginning in 1990. The survey exhibited ample geographical coverage throughout this time series and there was little concern that the survey missed significant areas of the range of Gray Triggerfish in the region. Being one of the most abundant species captured in the chevron trap survey, there is ample supporting biological data (e.g. age/length comps) that can be used to inform the selectivity of the gear. Although the sampling distribution of the survey with regards to specific covariates (e.g. bottom temperature, depth, latitude, etc.) varied from year to year, the zero-inflation standardization approach effectively removes the effects of this variability from relative abundance trends. Finally, being a fishery-independent survey, standardized sampling techniques have been used and the survey has been immune to regulation changes. These observations generally make relative abundance trends suggested by fishery-independent surveys superior to parallel fishery-dependent abundance trends, especially as stricter management regulations are placed on the fishery.

Evaluation of Abundance Indices:
SERFS Video Index (SEDAR41-DW03)

Working Group Comments:

DESCRIPTION OF THE DATA SOURCE

1. Fishery Independent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.				✓
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)				✓
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)				✓
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).				✓
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓

2. Fishery Dependent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).	✓			
B. Describe any changes to reporting requirements, variables reported, etc.	✓			
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).	✓			
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓			

METHODS

1. Data Reduction and Exclusions

	Not Applicable	Absent	Incomplete	Complete
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).	✓			
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?	✓			

2. Management Regulations (for FD Indices)

	Not Applicable	Absent	Incomplete	Complete
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).	✓			
B. Describe the effects (if any) of management regulations on CPUE	✓			
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.	✓			

Working Group Comments:

3. Describe Analysis Dataset (after exclusions and other treatments)

	Not Applicable	Absent	Incomplete	Complete
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.	✓			
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.	✓			
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓

4. Model Standardization

	Not Applicable	Absent	Incomplete	Complete
A. Describe model structure (e.g. delta-lognormal)	✓			
B. Describe construction of GLM components (e.g. forward selection from null etc.)	✓			
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?	✓			
E. Provide a table summarizing the construction of the GLM components.	✓			
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.				✓

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

1. Binomial Component

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include plots of the chi-square residuals by factor.	✓				
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)	✓				
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				

2. Lognormal/Gamma Component

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				
F. Include plots of the residuals by factor	✓				

3. Poisson Component

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***

4. Zero-inflated model

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
A. Include ROC curve to quantify goodness of fit.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).				✓	
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.				✓	

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓			

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance				✓
2. Table of model statistics (e.g. AIC criteria)				✓

	Date Received	*Workshop Recommendation*	*Revision Deadline ****	*Author and Rapporteur Signatures*
First Submission	7/21/14	Recommended		
Revision				

The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author ***DOES NOT*** *commit to any* ***LEGAL OBLIGATION*** *by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

Evaluation of Abundance Indices of GTF: Headboat logbook 1995-2009, SEDAR41-DW13

Working Group Comments:

DESCRIPTION OF THE DATA SOURCE

1. Fishery Independent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.	✓			
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)	✓			
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)	✓			
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).	✓			
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).	✓			
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓			

2. Fishery Dependent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).				✓
B. Describe any changes to reporting requirements, variables reported, etc.				✓
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓

METHODS

1. Data Reduction and Exclusions

	Not Applicable	Absent	Incomplete	Complete
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).				✓
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?				✓

2. Management Regulations (for FD Indices)

	Not Applicable	Absent	Incomplete	Complete
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).				✓
B. Describe the effects (if any) of management regulations on CPUE				✓
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.				✓

3. Describe Analysis Dataset (after exclusions and other treatments)

	Not Applicable	Absent	Incomplete	Complete
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.				✓
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.				✓
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓

4. Model Standardization

	Not Applicable	Absent	Incomplete	Complete
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)				✓
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?		✓		
E. Provide a table summarizing the construction of the GLM components.		✓		
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.				✓

Working Group Comments:

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
1. Binomial Component					
A. Include plots of the chi-square residuals by factor.				✓	
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)				✓	
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).				✓	
2. Lognormal/Gamma Component					
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.				✓	
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.				✓	
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.				✓	
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				
F. Include plots of the residuals by factor				✓	
3. Poisson Component					
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***
4. Zero-inflated model					
A. Include ROC curve to quantify goodness of fit.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).	✓				
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.	✓				

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓	
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓	

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance	✓				
2. Table of model statistics (e.g. AIC criteria)	✓				

	Date Received	*Workshop Recommendation*	*Revision Deadline ****	*Author and Rapporteur Signatures*
First Submission		recommend for use		
Revision				

The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author ***DOES NOT*** *commit to any* ***LEGAL OBLIGATION*** *by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

Evaluation of Abundance Indices of Gray Triggerfish: General recreational (MRFSS) (SEDAR32-DW-06)

DESCRIPTION OF THE DATA SOURCE

Working Group Comments:

	Not Applicable	Absent	Incomplete	Complete
1. Fishery Independent Indices				
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.				
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)				
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)				
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).				
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				
2. Fishery Dependent Indices				
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).				✓
B. Describe any changes to reporting requirements, variables reported, etc.	✓			
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).			✓	
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓

METHODS

	Not Applicable	Absent	Incomplete	Complete
1. Data Reduction and Exclusions				
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).				✓
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?		✓		

Working Group Comments:

2. Management Regulations (for FD Indices)

Item	Not Applicable	Absent	Incomplete	Complete
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).		✓		
B. Describe the effects (if any) of management regulations on CPUE		✓		
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.		✓		

3. Describe Analysis Dataset (after exclusions and other treatments)

Item	Not Applicable	Absent	Incomplete	Complete
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.				✓
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.		✓		
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).		✓		
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓

4. Model Standardization

Item	Not Applicable	Absent	Incomplete	Complete
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)				✓
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?	✓			
E. Provide a table summarizing the construction of the GLM components.				✓
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.				✓

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
1. Binomial Component					
A. Include plots of the chi-square residuals by factor.		✓			
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)		✓			
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).		✓			
2. Lognormal/Gamma Component					
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.		✓			
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.				✓	
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.				✓	
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.				✓	
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.		✓			
F. Include plots of the residuals by factor	✓				
3. Poisson Component					
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).					
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.					
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.					
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.					
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.					***The feasibility of this diagnostic is still under review.***
4. Zero-inflated model					
A. Include ROC curve to quantify goodness of fit.					
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).					
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.					

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.				

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report			✓	
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance				
2. Table of model statistics (e.g. AIC criteria)				

	Date Received	*Workshop Recommendation*	*Revision Deadline ****	*Author and Rapporteur Signatures*
First Submission	2/11/13			
Revision	2/14/13			

The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author ***DOES NOT*** *commit to any* ***LEGAL OBLIGATION*** *by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

Evaluation of Abundance Indices: Gray Triggerfish Commercial Logbook - Handline Index Title (Working Paper SEDAR 41 DW 20)

Working Group Comments:

DESCRIPTION OF THE DATA SOURCE

1. Fishery Independent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.	✓			
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)	✓			
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)	✓			
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).	✓			
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).	✓			
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓			

2. Fishery Dependent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).				✓
B. Describe any changes to reporting requirements, variables reported, etc.				✓
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓

METHODS

1. Data Reduction and Exclusions

	Not Applicable	Absent	Incomplete	Complete
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).				✓
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?				✓

Working Group Comments:

2. Management Regulations (for FD Indices)

	Not Applicable	Absent	Incomplete	Complete
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).				✓
B. Describe the effects (if any) of management regulations on CPUE				✓
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.				✓

3. Describe Analysis Dataset (after exclusions and other treatments)

	Not Applicable	Absent	Incomplete	Complete
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.				✓
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.				✓
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓

4. Model Standardization

	Not Applicable	Absent	Incomplete	Complete
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)				✓
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?	✓			
E. Provide a table summarizing the construction of the GLM components.				✓
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.	✓			

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
1. Binomial Component					
A. Include plots of the chi-square residuals by factor.				✓	
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)		✓			
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).		✓			
2. Lognormal/Gamma Component					
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.				✓	
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.		✓			
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.				✓	
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.		✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.		✓			
F. Include plots of the residuals by factor				✓	
3. Poisson Component					
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				***The feasibility of this diagnostic is still under review.***
4. Zero-inflated model					
A. Include ROC curve to quantify goodness of fit.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).	✓				
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.	✓				

MODEL DIAGNOSTICS (CONT.)

	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓			

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance	✓			
2. Table of model statistics (e.g. AIC criteria)	✓			

	Date Received	*Workshop Recommendation*	*Revision Deadline* ***	*Author and Rapporteur Signatures*
First Submission	8/26/2014	Recommended for use		
Revision				

*The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author **DOES NOT** commit to any **LEGAL OBLIGATION** by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

Evaluation of Abundance Indices of GTF:
Headboat at-sea observer 2005-2009, SEDAR41-DW15

Working Group Comments:

DESCRIPTION OF THE DATA SOURCE

1. Fishery Independent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the survey design (e.g. fixed sampling sites, random stratified sampling), location, seasons/months and years of sampling.	✓			
B. Describe sampling methodology (e.g. gear, vessel, soak time etc.)	✓			
C. Describe any changes in sampling methodology (e.g. gear, vessel, sample design etc.)	✓			
D. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).	✓			
E. What species or species assemblages are targeted by this survey (e.g. red snapper, reef fish, pelagic).	✓			
F. Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.	✓			

2. Fishery Dependent Indices

	Not Applicable	Absent	Incomplete	Complete
A. Describe the data source and type of fishery (e.g. commercial handline, commercial longline, recreational hook and line etc.).				✓
B. Describe any changes to reporting requirements, variables reported, etc.				✓
C. Describe the variables reported in the data set (e.g. location, time, temperature, catch, effort etc.).				✓
D Describe the size/age range that the index applies to. Include supporting figures (e.g. size comp) if available.				✓

METHODS

1. Data Reduction and Exclusions

	Not Applicable	Absent	Incomplete	Complete
A. Describe any data exclusions (e.g. gears, fishing modes, sampling areas etc.). Report the number of records removed and justify removal.				✓
B. Describe data reduction techniques (if any) used to address targeting (e.g. Stephens and MacCall, 2004; gear configuration, species assemblage etc).				✓
C. Discuss procedures used to identify outliers. How many were identified? Were they excluded?				✓

Working Group Comments:

2. Management Regulations (for FD Indices)

	Not Applicable	Absent	Incomplete	Complete
A. Provide (or cite) history of management regulations (e.g. bag limits, size limits, trip limits, closures etc.).				✓
B. Describe the effects (if any) of management regulations on CPUE				✓
C. Discuss methods used (if any) to minimize the effects of management measures on the CPUE series.				✓

3. Describe Analysis Dataset (after exclusions and other treatments)

	Not Applicable	Absent	Incomplete	Complete
A. Provide tables and/or figures of number of observations by factors (including year, area, etc.) and interaction terms.				✓
B. Include tables and/or figures of number of positive observations by factors and interaction terms.				✓
C. Include tables and/or figures of the proportion positive observations by factors and interaction terms.				✓
D. Include tables and/or figures of average (unstandardized) CPUE by factors and interaction terms.				✓
E. Include annual maps of locations of survey sites (or fishing trips) and associated catch rates ***OR*** supply the raw data needed to construct these maps (Observation, Year, Latitude, Longitude (or statistical grid, area), Catch, Effort).				✓
F. Describe the effort variable and the units. If more than one effort variable is present in the dataset, justify selection.				✓
G. What are the units of catch (e.g. numbers or biomass, whole weight, gutted weight, kilograms, pounds).				✓

4. Model Standardization

	Not Applicable	Absent	Incomplete	Complete
A. Describe model structure (e.g. delta-lognormal)				✓
B. Describe construction of GLM components (e.g. forward selection from null etc.)				✓
C. Describe inclusion criteria for factors and interactions terms.				✓
D. Were YEAR*FACTOR interactions included in the model? If so, how (e.g. fixed effect, random effect)? Were random effects tested for significance using a likelihood ratio test?		✓		
E. Provide a table summarizing the construction of the GLM components.		✓		
F. Summarize model statistics of the mixed model formulation(s) (e.g. log likelihood, AIC, BIC etc.)				✓
G. Report convergence statistics.				✓

MODEL DIAGNOSTICS

Comment: Other model structures are possible and acceptable. Please provide appropriate diagnostics to the CPUE indices working group.

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:
1. Binomial Component					
A. Include plots of the chi-square residuals by factor.				✓	
B. Include plots of predicted and observed proportion of positive trips by year and factor (e.g. year*area)				✓	
C. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).				✓	
2. Lognormal/Gamma Component					
A. Include histogram of log(CPUE) or a histogram of the residuals of the model on CPUE. Overlay the expected distribution.				✓	
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.				✓	
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.				✓	
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				
F. Include plots of the residuals by factor				✓	
3. Poisson Component					
A. Report overdispersion parameter and other fit statistics (e.g. chi-square / degrees of freedom).	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor.	✓				
C. Include QQ-plot – (e.g. Student deviance residuals vs. theoretical quantiles), Overlay expected distribution.	✓				
D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓				
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓				*The feasibility of this diagnostic is still under review.*
4. Zero-inflated model					
A. Include ROC curve to quantify goodness of fit.	✓				
B. Include plots describing error distribution (e.g. Studentized residuals vs. linear predictor).	✓				
C. Include QQ-plot (e.g. Student dev. residuals vs. theoretical quantiles), Overlay expected distribution.	✓				

MODEL DIAGNOSTICS (CONT.)

Item	Not Applicable	Absent	Incomplete	Complete	Working Group Comments:

D. Include diagnostic plot for variance function (e.g. square root of std residuals vs. fitted values). Overlay expected distribution.	✓			
E. Include diagnostic plot for link function (e.g. linear response variable vs. linear predictor). Overlay expected distribution.	✓			

MODEL RESULTS

A. Tables of Nominal CPUE, Standardized CPUE, Observations, Positive Observations, Proportion Positive Observations and Coefficients of Variation (CVs). Other statistics may also be appropriate to report				✓
B. Figure of Nominal and Standardized Indices with measure of variance (i.e. CVs).				✓

IF MULTIPLE MODEL STRUCTURES WERE CONSIDERED:

(***Note: this is always recommended but required when model diagnostics are poor***.)

1. Plot of resulting indices and estimates of variance	✓			
2. Table of model statistics (e.g. AIC criteria)	✓			

	Date Received	*Workshop Recommendation*	*Revision Deadline* ***	*Author and Rapporteur Signatures*
First Submission		recommend for use		
Revision				

The revision deadline is negotiated by the author, the SEDAR coordinator and the CPUE rapporteur. The author ***DOES NOT*** *commit to any* ***LEGAL OBLIGATION*** *by agreeing to submit a manuscript before this deadline. The maximum penalty for failure to submit a revised document prior to the submission deadline is rejection of the CPUE series.*

Justification of Working Group Recommendation

Standardized video counts of Southeast U.S. Atlantic red snapper (*Lutajanus campechanus*) from the Southeast Reef Fish Survey

Nicholas G. Ballew, Nathan Bacheler, and Kevin Purcell

SEDAR41-DW45

Submitted: 18 July 2015

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Standardized video counts of Southeast U.S. Atlantic red snapper (*Lutjanus campechanus*) from the Southeast Reef Fish Survey

Nicholas G. Ballew, Nathan Bacheler, and Kevin Purcell
Southeast Fisheries Science Center
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Abstract

Standardized video counts of red snapper were generated from video cameras deployed by the Southeast Reef Fish Survey from 2010 – 2014. Samples between Cape Hatteras, North Carolina, and St. Lucie Inlet, Florida, were included in the analyses. The index is meant to describe population trends for red snapper in the region. To obtain an index of video counts, a zero-inflated negative binomial model was used to standardize video count data by a variety of predictor variables, differences across years in sampling effort (with respect to the predictor variables investigated) were accounted for, and a camera calibration calculation was used to calibrate counts of red snapper between two different cameras that were used during monitoring.

Background

The Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program has conducted most of the historical fishery-independent sampling in the U.S. South Atlantic (North Carolina to Florida). MARMAP has used a variety of gears over time, but chevron traps are one of the primary gears used to monitor reef fish species and have been deployed since the late 1980s. In 2009, MARMAP began receiving additional funding to monitor reef fish from the SEAMAP-SA program. In 2010, the SouthEast Fishery-Independent Survey (SEFIS) was initiated by NMFS to work collaboratively with MARMAP/SEAMAP-SA using identical methods to collect additional fishery-independent samples in the region. Together, these three programs are now called the Southeast Reef Fish Survey (SERFS).

The SERFS survey currently samples between Cape Hatteras, North Carolina, and St. Lucie Inlet, Florida. This survey targets hardbottom habitats between approximately 15 and 100 meters deep. SERFS began affixing high-definition video cameras to chevron traps on a limited basis in 2010 (Georgia and Florida only), but since 2011 has attached cameras to all chevron traps as part of their normal monitoring efforts. All five years of data are included here, as recommended by Bacheler and Carmichael (2014; SEDAR41-RD23).

Hard-bottom sampling stations were selected for sampling in one of three ways. First, most sites were randomly selected from the SERFS sampling frame that consisted of approximately 3,000 sampling stations on or very near hard bottom habitat. Second, some stations in the sampling frame were sampled opportunistically even though they were not randomly selected for sampling in a given year. Third, new hard-bottom stations were added during the study period through the use of information from various sources including fishermen, charts, and historical surveys. These new locations were investigated using a vessel echosounder or drop cameras and sampled if hard bottom was detected. Only those new stations landing on hardbottom habitat were included in the analyses. All sampling for this study occurred during daylight hours between April and October on the R/V *Savannah*, R/V *Palmetto*, NOAA Ship *Nancy Foster*, or the NOAA Ship *Pisces* using identical methodologies as described below.

Samples were intentionally spread out spatially on each cruise (see Figure 2 in Bacheler and Carmichael 2014).

Chevron fish traps with attached video cameras were deployed at each station sampled in our study (Figure 1). Chevron traps were constructed from plastic-coated, galvanized 2-mm diameter wire (mesh size = 3.4 cm2) and measured 1.7 m × 1.5 m × 0.6 m, with a total volume of 0.91 m^3. Trap mouth openings were shaped like a teardrop and measured approximately 18 cm wide and 45 cm high. Each trap was baited with 24 menhaden (*Brevoortia* spp.). Traps were typically deployed in groups of six, and each trap in a set was deployed at least 200 m from all other traps to provide some measure of independence between traps. A soak time of 90 minutes was targeted for each trap deployed.

GoPro Hero (2010) or Canon Vixia HFS-200 high-definition video cameras in Gates underwater housings (2011 – 2014) were attached to chevron traps. A second high-definition GoPro Hero video or Nikon Coolpix S210/S220 still camera was attached over the nose of most traps in an underwater housing, and was used to quantify microhabitat features in the opposite direction. Cameras were turned on and set to record before traps were deployed, and were turned off after trap retrieval. Trap-video samples were excluded from our analysis if videos were unreadable for any reason (e.g., too dark, camera out of focus, files corrupt) or the traps did not fish properly (e.g., bouncing or dragging due to waves or current, trap mouth was obstructed).

For each fish trap deployed with a camera, video reading time was limited to an interval of 20 total minutes, commencing 10 minutes after the trap landed on the bottom to allow time for the trap to settle. One-second snapshots were read every 30 seconds for the 20-minute time interval, totaling 41 snapshots read for each video sample. SERFS employs video readers to count fish on videos. There was an extensive training period for each video reader, and all videos from new readers are re-read by fish video reading experts until they are very high quality. After that point, 10% or 15 videos (whichever is larger) are re-read annually by fish video reading experts. Video readers also quantify microhabitat features (percent of bottom that is hardbottom, maximum substrate relief, substrate size, coverage of attached biota, predominant biotic type, and maximum biotic height), in order to standardize for habitat types sampled over time. Water clarity was also scored for each sample as poor, fair, or good. If bottom substrate could not be seen, then water clarity was considered poor, and if bottom habitat could be seen but the horizon was not visible, water clarity was considered fair. If the horizon could be seen in the distance, water clarity was considered to be good. Including water clarity in index models allowed for a standardization of fish counts based on variable water clarities over time and across the study area. A CTD cast was also taken for each simultaneously deployed group of traps, within 2 m of the bottom, and water temperature from these CTD casts was available for standardization models.

Camera calibration

GoPro cameras were used for fish counts in 2010, while Canon cameras were used in 2011 – 2014. To calibrate fish counts between these two cameras, side-by-side Canon-GoPro videos were taken during the summer of 2013 and read for red snapper. Additionally, a lab experiment was conducted to quantify differences in field of view between the two cameras. Results indicated the Canon cameras saw 51% of the field of video of GoPro cameras, but the quality of GoPro videos was perhaps slightly lower than that of Canon videos. A total of 15 calibration videos were read that included red snapper. Based on a regression analysis applied to the calibration video results, there were 53% (1 minus the regression slope parameter) fewer red snapper seen on Canon cameras compared to GoPro cameras, which is almost exactly what one would predict based on the reduction of field of view on Canon cameras compared to GoPro cameras (see Figures 7-9 in Bacheler and Carmichael 2014). Therefore, it was recommended that the 2010 relative abundance data point be reduced by 53% to account for differences in viewing areas among the cameras.

Data and Treatment

Data subsetting

Overall, there were 4923 survey videos with *L. campechanus* data during the 5 year sampling period (2010-2014). We removed data points in which the survey video was considered unreadable by an analyst, or if the survey point was located at a depth greater than 100 meters, due to very limited samples in waters deeper than 100 m. Additionally, survey video for which less than 41 video frames were read was removed from the full data set. Standardizing the number of readable frames was essential due to our use of *SumCount* as a response variable (see below). We also identified any video sample in which corresponding predictor variables were missing and removed them from the final data set.

Of the total 4923 video samples considered for inclusion in our modeling analysis, 514 were removed based on the data subsetting procedure described above, leaving 4409 samples in the *L. campechanus* analyses for 2010 – 2014 (Figure 2).

Standardization

Response Variable

For the video index of *L. campechanus*, we modeled the *SumCount*, or total number of red snapper observed across all readable video frames for each sample. There are a number of viable candidate response variables applicable for the estimation of abundance from video surveys, the relative merits of which were discussed at length during the video index development workshop (Bacheler and Carmichael 2014). The panel recommended the use of *SumCount* as a response variable suitable for a zero-inflated modeling approach (we employed a zero-inflated model in our analysis). The use of *SumCount* requires that an equal number of video frames be considered for each data point considered in the model estimation. As a result, only samples with 41 readable frames (the maximum number) were included in our analysis (~99% of all samples).

Explanatory Variables

We considered 9 explanatory variables in our model analysis, which included year, season, depth, latitude, water temperature, turbidity, and current direction, all of which were recommended during the video index development workshop (Bacheler and Carmichael 2014). The workshop panel also suggested including habitat variables, for which we included biotic density and substrate composition.

YEAR (*y*) – Year was included because standardized catch rates by year are the objective of this analysis. We modeled data from 2010-2014, data from 2010 was spatially limited due to reduced video deployment during this initial year. Due to the high spatial overlap between the sampled region and the spatial occupancy of *L. campechanus,* data from 2010 were included in this analysis. This decision was supported by recommendations from the video index development panel (Bacheler and Carmichael 2014). Annual summaries of data points considered are outlined in Table 2.

SEASON (*t*) – a temporal parameter based on the Julian day the sample was collected (Figure 3). The season parameter was treated as an octile factor based on the recommendations of the video index development workshop.

DEPTH (*d*) – Water depth is a key component effecting the distribution of *L. campechanus*, we considered all data points in waters shallower than 100m. Data points were excluded from deeper waters generally due to limited samples and rare occurrence (Figure 3). Annual depth distribution for survey data are outlined in Table 2. The depth parameter was treated as a quantile factor based on the recommendations of the video index development workshop.

LATITUDE (*lat*) – The latitude of video samples were included as a spatial parameter in the model (Figure 3). Based on recommendations made by the video index development workshop, latitude was treated as a factor in the model and divided into 8 levels based on octiles.

TEMPERATURE (*temp*) – Bottom water temperature was collected from each group of traps and incorporated as a predictor variable. Bottom water temperature ranged from 12 – 29 degrees Celsius (Figure 3). For the standardization model temperature was treated as a factor with 4 levels based on quantiles.

TURBIDITY (*wc*) – Due to the effect of turbidity on both species distributions and on the ability of an analyst to process video survey samples, we included water clarity (*wc*) in our standardization model. Turbidity information was recorded during video analysis based on the ability of an analyst to perceive the horizon and surrounding habitat and was scored at 3 levels (0 – Horizon visible, 1 – Horizon not visible but habitat is still visible, 2 – Both horizon and habitat are not visible).

CURRENT DIRECTION (*cd*) – A categorical variable estimating current direction based on the video point of view. Current direction data was included to better account for variability in detection due to the current moving fish away or towards the camera. This variable is collected during video processing and scored natively as a 4 level categorical variable (Towards, Away, Left to Right, and Right to Left). It was incorporated into the model as “Towards”, “Away”, and “Sideways”.

BIOTIC DENSITY (*bd*) – An estimation of the percent cover of attached biota visible during any video. The estimation is made based on percentage cover and ranged from 0 – 98%. For our analysis, *bd* was treated as a categorical variable with 4 levels: none (0%), low (1-9%), moderate (10-39%), and high (>40%).

SUBSTRATE COMPOSITION (*sc*) – An estimate of the total percent of substrate that is consolidated sediments. Consolidated sediment is defined as rocks or boulders the size of a fist or larger, or hard pavement habitats. For our analysis, substrate composition was treated as a categorical variable with 4 levels: none (0%), low (1-9%), moderate (10-39%), and high (>40%).

Zero-Inflated Model

The recommendation of the video index workshop was to apply a zero-inflated modeling approach to develop a fishery-independent video index for *L. campechanus* in the South Atlantic. Zero-inflated models are valuable tools for modeling distributions that do not fit a standard error distribution due to an excessive number of zeroes. These data distributions are often referred to as “zero-inflated” and are a common condition of count based ecological data. Zero inflation is considered a special case of over dispersion that is not readily addressed using traditional transformation procedures (Hall 2000). Due to the high proportion of zero counts found in our data set (Figure 4), we used a zero inflated mixed model approach that models the occurrence of zero values using two different processes, a binomial process and a count process (Zuur et al. 2009). The benefit and utility of this approach was discussed at length during the video index workshop (Bacheler and Carmichael 2014) and was the final recommendation of the panel.

Initially, both a zero-inflated Poisson (ZIP) and a zero-inflated negative binomial (ZINB) formulation were considered and each model included all nine of the predictor variables.

(1) $$SumCount = y + wc + cd + sc + bd + d + t + lat + temp \,|\, y + wc + cd + sc + bd + d + t + lat + temp$$

We compared the variance structure of each model formulation using a likelihood ratio test (Zuur et al 2009), to determine the most appropriate model formulation for the development of a video index for red snapper. A likelihood ratio test (Table 1) showed strong support for application of a ZINB formulation, as did a comparison of model fit for both the ZIP and ZINB formulations (Figure 5), which resulted in the decision to use a ZINB approach. The results concurred with expectations based on the level of zero-inflation and over dispersion within the original red snapper data and with the recommendations of the video index development panel (Bacheler and Carmichael 2014).

A backwards step-wise model selection procedure was used to exclude unnecessary model parameters from the full model (1) formulation. The optimum red snapper model formulation (2) was determined using a combination of AIC and likelihood ratio tests (Zuur et al. 2009). Water clarity (*wc*) was excluded from the negative binomial component of the model and both water clarity (*wc*) and season (*t*) were excluded from the binomial component of the model (Table 3).

(2) $$SumCount = y + cd + sc + bd + d + t + lat + temp \,|\, y + cd + sc + bd + d + lat + temp$$

Model diagnostics showed no discernable pattern of association between Pearson’s residuals and fitted values or the fitted values and the original data (Figure 6). Additionally, an examination of model residuals for the spatio-temporal (Figure 7) and environmental model parameters (Figure 8) showed no clear patterns of association, indicating correspondence to underlying model assumptions (Zuur et al. 2009). Finally, a comparison of predicted values against the original data distribution (Figure 9) shows how our model fits the original data.

All data manipulation and analysis was conducted using R version 3.1.2 (R Core Team 2014). Modeling was executed using the *zeroinfl* function in the *pscl* package (Jackman 2008), available from the Comprehensive R Archive Network (CRAN).

Results

The relative nominal CPUE for *L. campechanus* was 2.609 in 2010, 0.433 in 2011, 0.567 in 2012, 0.639 in 2013, and 0.752 in 2014 (Table 4). After standardizing the original data set by each of the predictor variables included in the final model, we obtained a CPUE estimate of 2.913 in 2010, 0.379 in 2011, 0.503 in 2012, 0.537 in 2013, and 0.880 in 2014. When also accounting for unequal sampling across years (with respect to the predictor variables included in the final model), we obtained a CPUE estimate of 2.016 in 2010, 0.467 in 2011, 0.831 in 2012, 0.626 in 2013, and 1.060 in 2014. When we applied the camera calibration calculation for 2010 to these standardized annual values, we obtained a CPUE estimate of 1.206 in 2010, 0.592 in 2011, 1.056 in 2012, 0.798 in 2013, and 1.348 in 2014 (Table 4).

Only the 2011 relative nominal value falls within the 2.5% and 97.5% confidence intervals of the standardized index (Figure 10). The nominal value for 2010 was considerably higher than the standardized index value for 2010 while the nominal values for 2011, 2012, 2013, and 2014 were all considerably lower than their standardized index values, which was expected due to the integration of the camera calibration calculation into the standardized index. The standardized video index indicates that while there is a considerable amount of fluctuation in relative annual abundance from year to year, red snapper relative abundance has been generally stable across the survey years (Figure 10). However, due to the short temporal extent of this index (5 years), limited inferences can be made concerning long term patterns of *L. campechanus* relative abundance.

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Table 1: Preliminary model formulation comparison

	df	Likelihood	df	χ^2	*p*-value
ZIP	70	-14517			
ZINB	71	-5257	1	18520	<0.001

Table 2: Annual total number of video samples included in the analysis

Year	Number of video samples	Depth range (m)	Latitude range	Date range
2010	166	23-64	28.71-31.74	209-300
2011	575	15-93	27.23-34.54	139-298
2012	1075	15-98	27.23-35.02	115-284
2013	1219	15-92	27.33-35.02	114-277
2014	1374	15-99	27.23-35.02	113-294

Table 3: Model selection results for Zero-Inflated Negative Binomial model for red snapper observed during SERFS video surveys, 2010-2014

	Removed Term						
Step	Binomial Process	Count Process	*df*	AIC	$\chi 2$	*df*	*p-value*
null	<none>	<none>	71	10655.88			
1	*wc*	<none>	69	10652.49	0.62	2	0.735
2	*wc*	*t*	62	10648.46	9.97	2	0.191
3	*wc*	*t*, *wc*	60	10645.86	1.40	2	0.497

Table 4: The relative nominal *SumCount*, number of stations sampled, proportion positive, standardized index, and CV for the SERFS red snapper video index

Year	Relative nominal *SumCount*	N	Proportion positive	Standardized index	CV
2010	2.61	166	0.355	1.21	0.22
2011	0.43	575	0.233	0.59	0.17
2012	0.57	1075	0.241	1.06	0.14
2013	0.64	1219	0.267	0.80	0.12
2014	0.75	1374	0.218	1.35	0.14

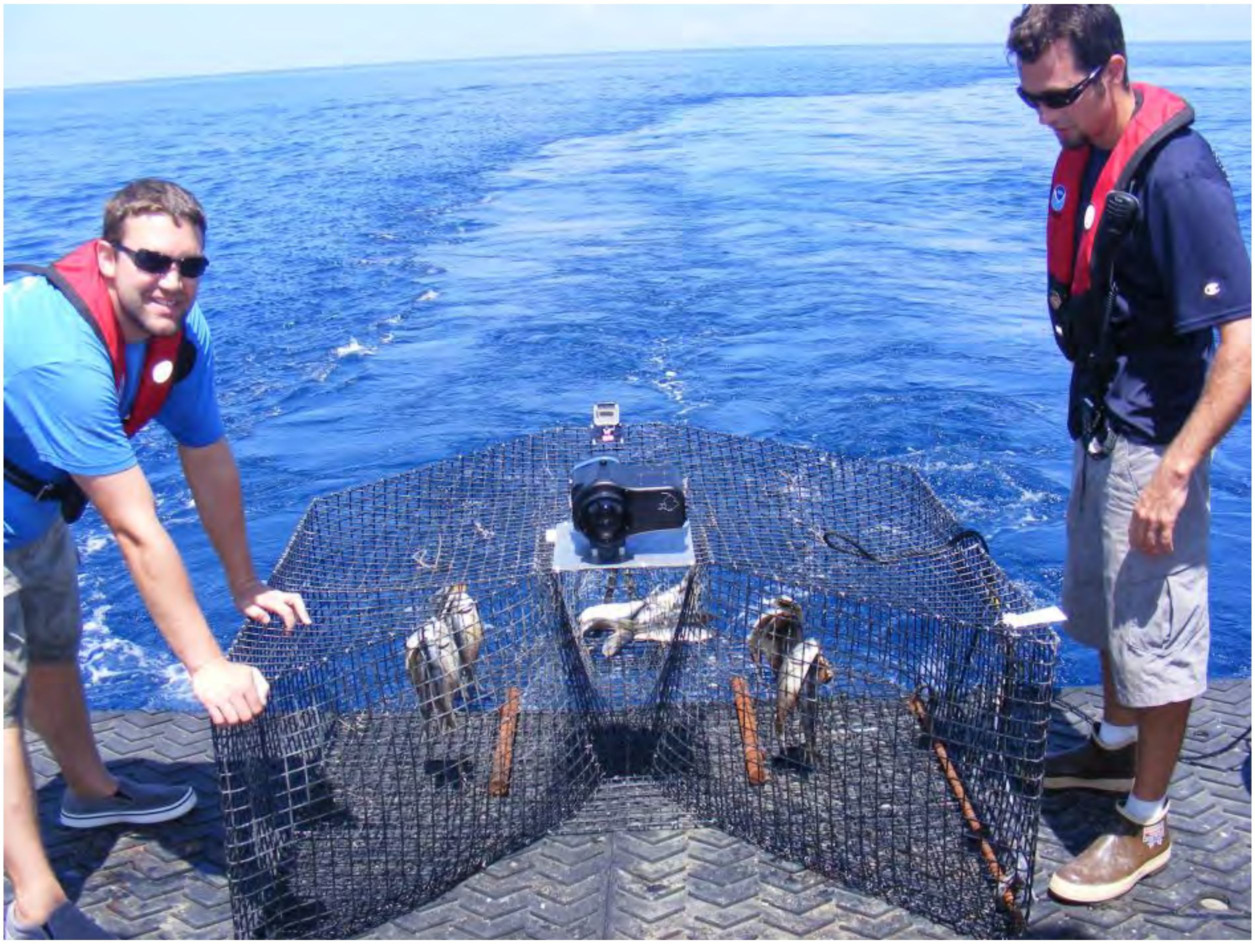

Figure 1: Chevron trap used by SERFS showing the attached underwater video cameras.

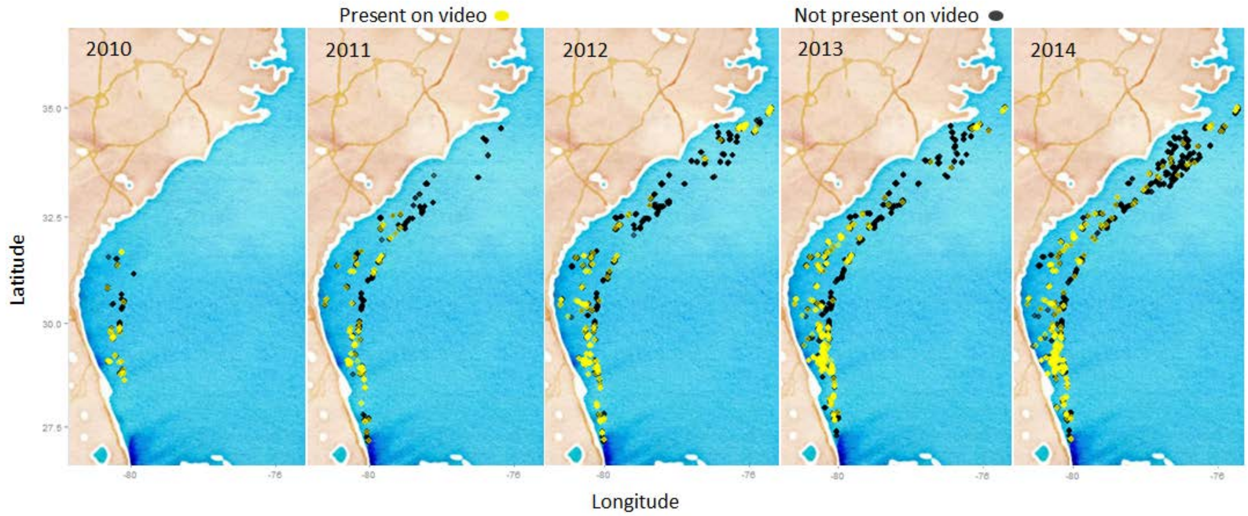

Figure 2: Annual spatial distribution of underwater video samples collected by SERFS in 2010 – 2014. Dark gray points indicate no red snapper were seen on video and yellow points indicate red snapper were seen on video. Note that yellow points were overlaid on top of gray points, and points may overlap. As a result, points were made slightly transparent.

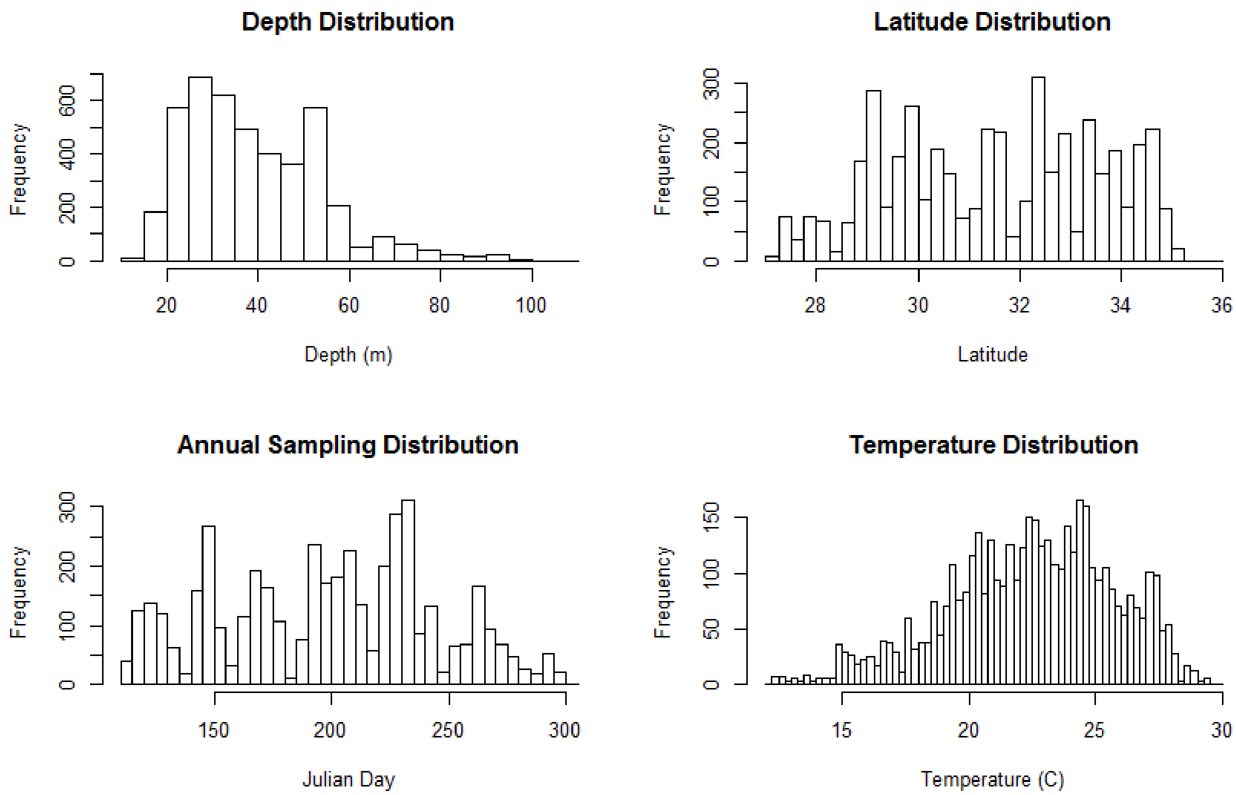

Figure 3: Sample distribution for original data continuous variables

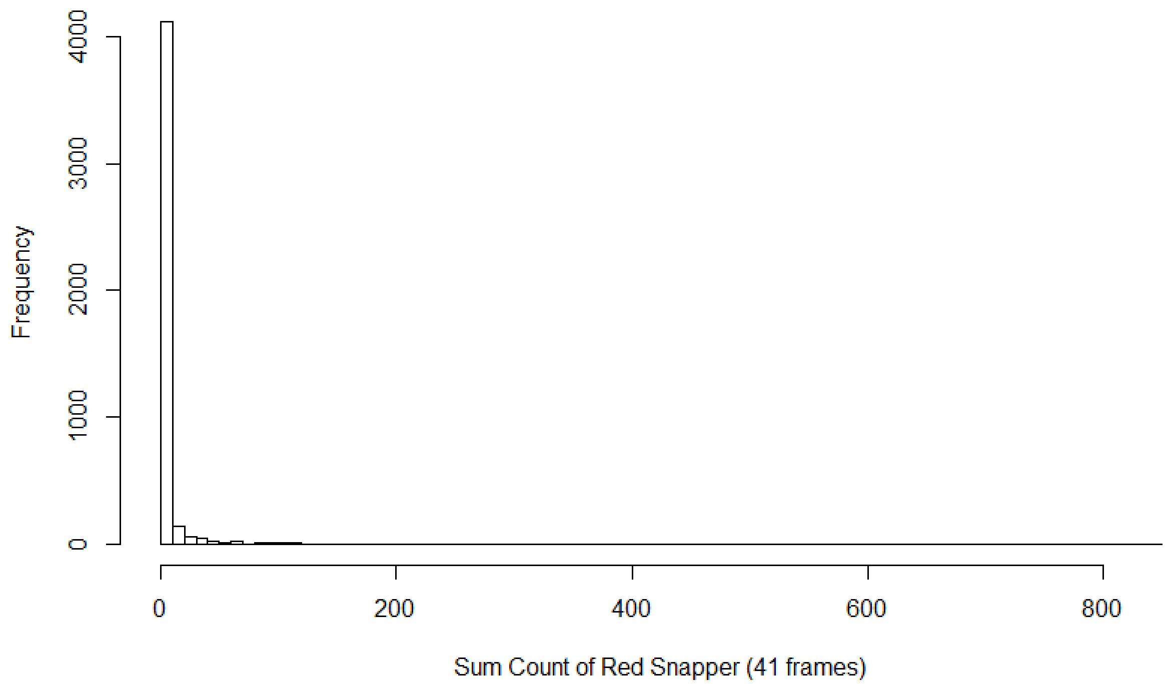

Figure 4: *SumCount* distribution for red snapper video observations in the South Atlantic.

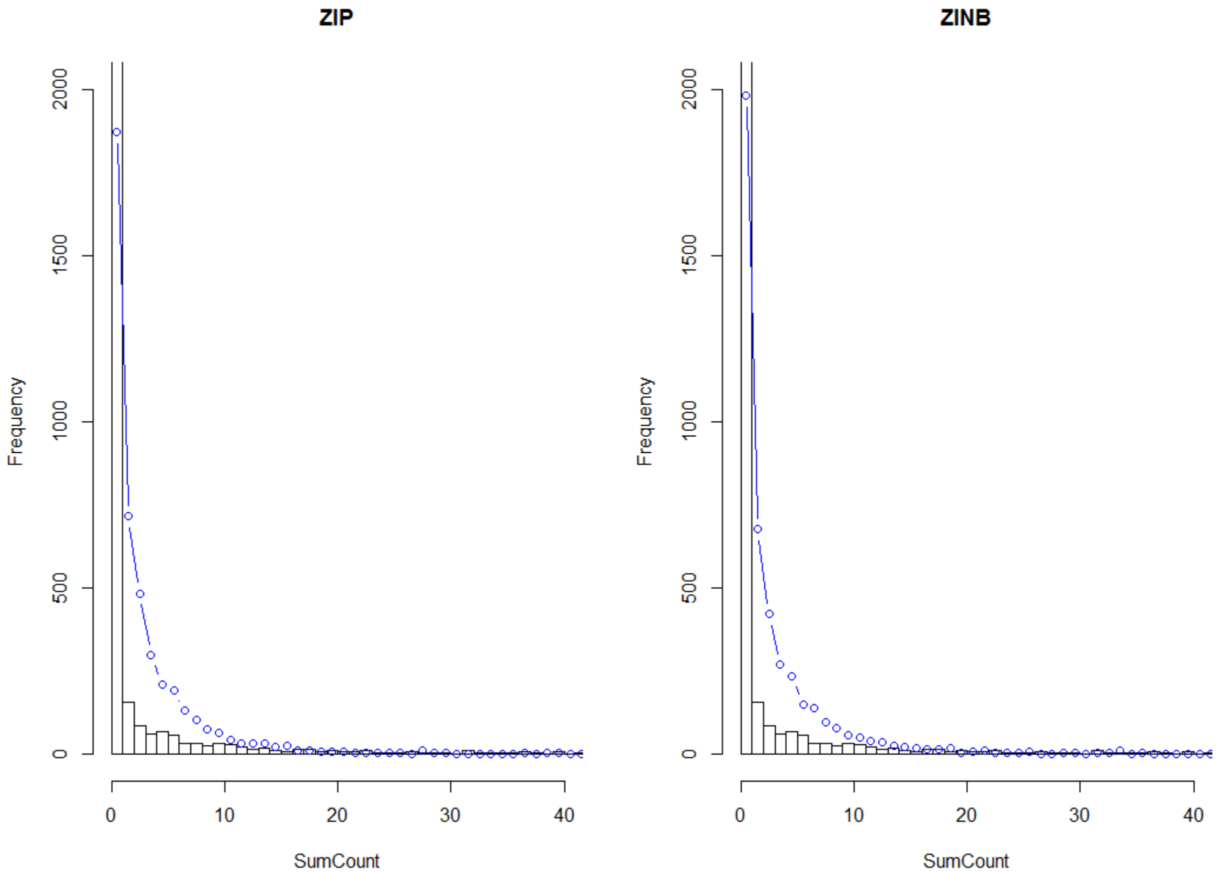

Figure 5: Model formulation comparison, with ZIP (left) and ZINB (right) fitted values plotted against the original data distribution

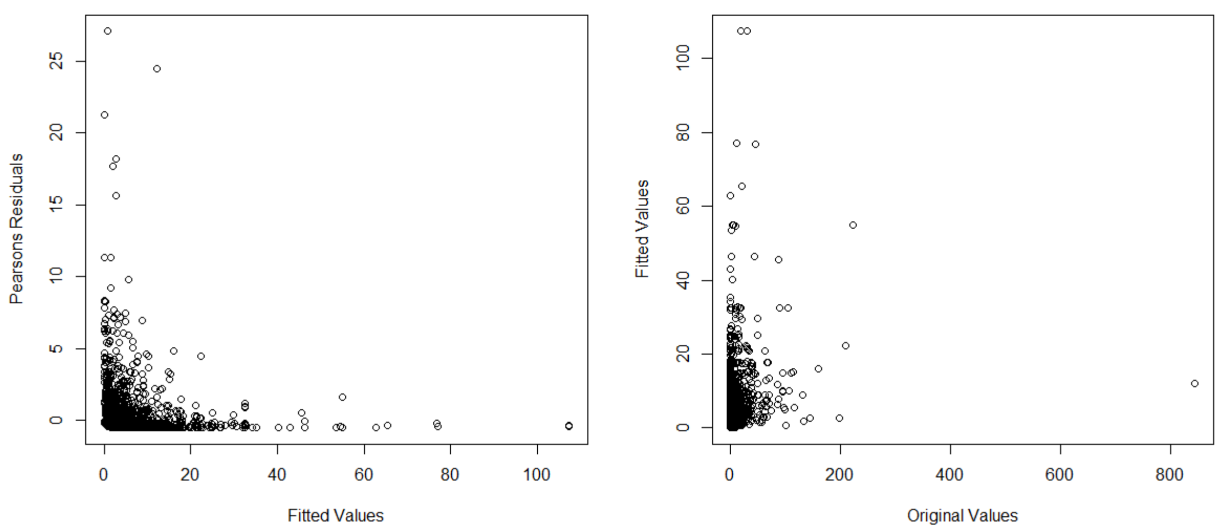

Figure 6: Model diagnostic plots showing fitted model values against Pearson's residuals (left) and fitted values plotted against original data values (right)

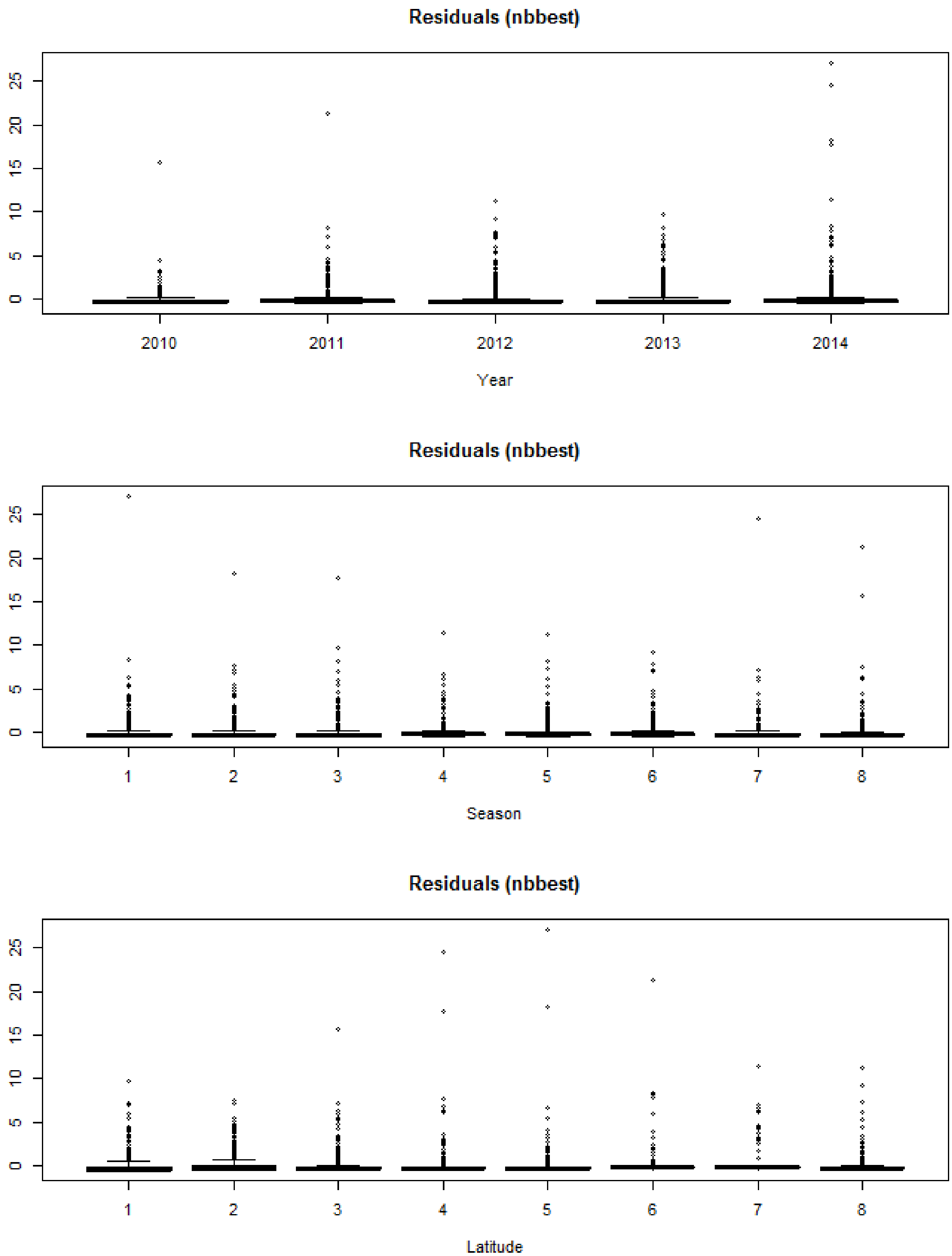

Figure 7: Model diagnostic plots showing Pearson's residuals from the final model plotted against both the temporal and spatial model variables

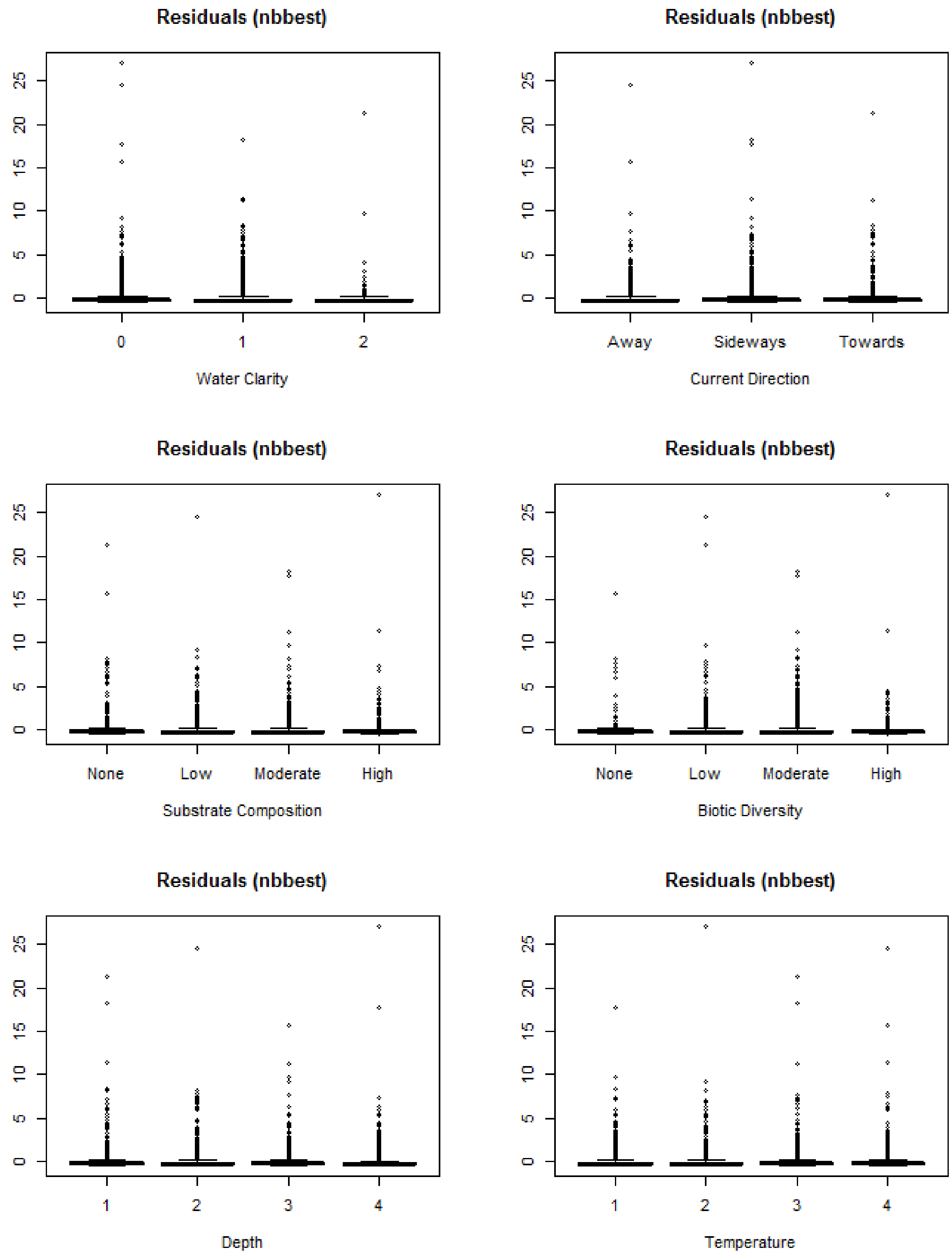

Figure 8: Model diagnostic plots showing Pearson's residuals for the final model plotted against environmental model parameters

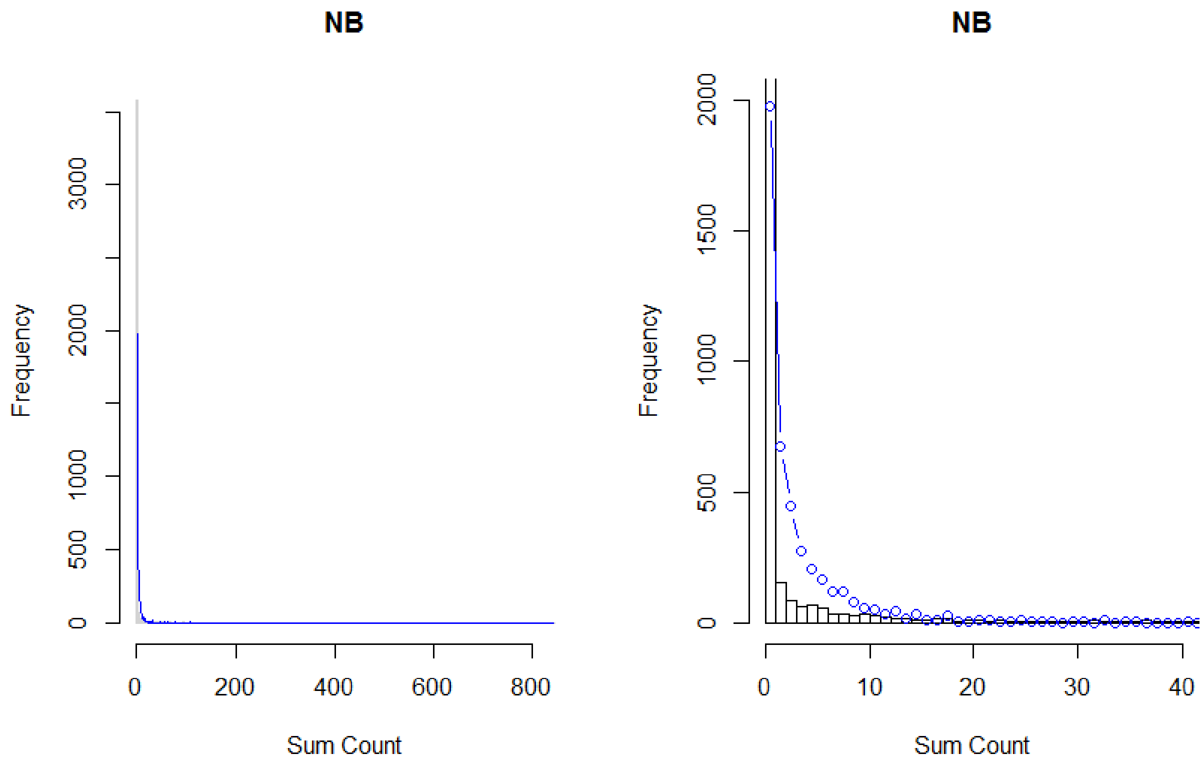

Figure 9: Model diagnostic plots of fitted model values (blue line) against the original data distribution. Full distribution view (left) and limited axis view (right)

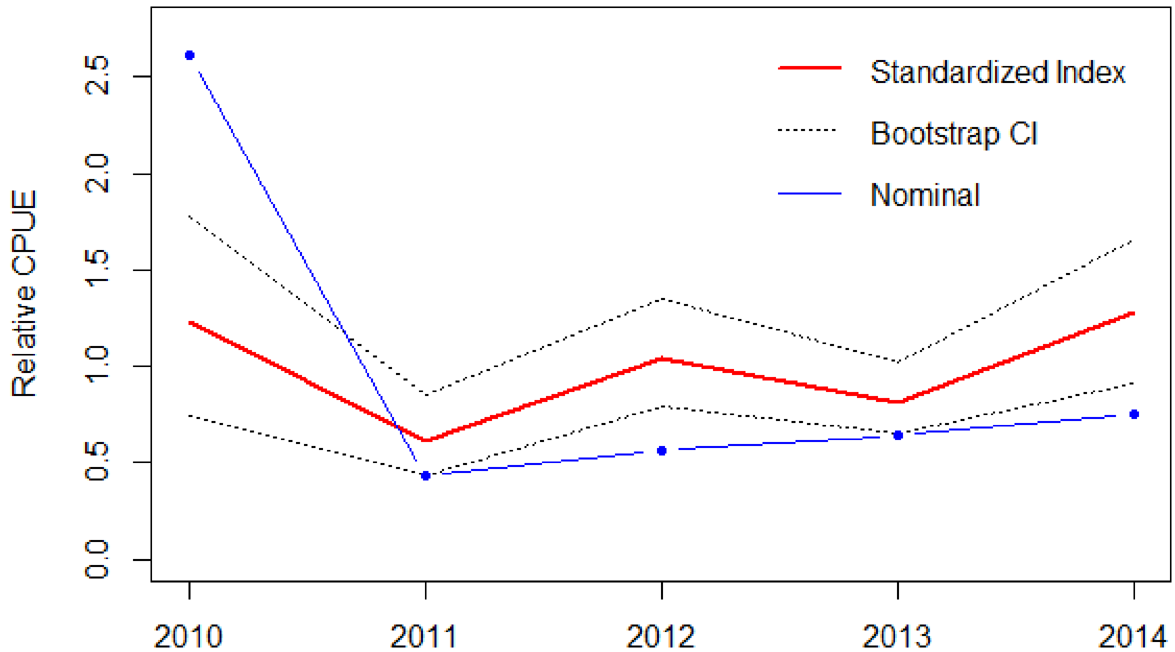

Figure 10: Relative standardized index (solid line) with 2.5% and 97.5% confidence intervals (dashed lines) and the relative nominal index (blue) for red snapper CPUE in the SERFS video survey

SERFS Chevron Trap Red Snapper Index of Abundance: An Investigation of the Utility of Historical (1990-2009) Chevron Trap Catch Data

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SEDAR41-DW51

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Joseph C. Ballenger

SEDAR41-DW51

Submitted: August 17, 2015

*Report documents initial explorations made prior to the SEDAR 41 Data Workshop as well as final recommendations made during the Data Workshop

SERFS Chevron Trap Red Snapper Index of Abundance: An Investigation of the Utility of Historical (1990-2009) Chevron Trap Catch Data

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This work represents partial fulfillment of the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program contract (NA11NMF4540174) sponsored by the National Marine Fisheries Service (Southeast Fisheries Science Center) and the South Carolina Department of Natural Resources.

Background

Though widely used for a host of other species, researchers involved in previous assessments of Red Snapper in the South Atlantic region have not used the fishery-independent chevron trap relative abundance index. A primary reason for this is that Red Snapper catches (and number of positive traps) were generally low in the MARMAP (Marine Resources Monitoring, Assessment & Prediction Program) chevron trap reef fish survey prior to 2010. SEDAR 24 panelists cited two primary reasons for the exclusion of the survey from the final assessment model, 1) the large spatial variability in abundance and sampling locations and 2) the low catches and high variability in the data. At the time, panelists did not know why catches of Red Snapper in the chevron trap survey were so low. Three (among others) possible explanations for the low catches were 1) because the chevron trap was a poor gear to index the relative abundance of Red Snapper, 2) the traditional areas sampled by the chevron trap index were not in core Red Snapper habitat, and hence may not track overall regional abundance, and 3) that the low catches in the chevron trap survey were truly indicative of regional Red Snapper abundance, with abundances being extremely low in totality throughout the survey area. The final assessment model derived from SEDAR 24, based on a host of other data sources, concluded that indeed Red Snapper regional abundance was at low levels throughout the history of the traditional MARMAP chevron trap survey (1990-2009; Figure 1).

Since (or in some cases during the terminal year of) SEDAR 24 there have been a host of management changes aimed at increasing Red Snapper abundance throughout the region. Most notable of these was the prohibition of harvest and possession of Red Snapper that began in early 2010 that continues today, with the exception of some very limited harvest in 2012-2014 as part of the Red Snapper “mini-seasons”.

There have also been some significant changes made to the SERFS chevron trap survey since SEDAR 24 due to the availability of additional fishery-independent funds to study reef fish in the region. The first new funding source, the Reef Fish Complement project funded by the Southeast Area Monitoring and Assessment Program, South Atlantic region (SEAMAP-SA), initially allocated funds in 2008, with a first field season in 2009. The second new funding source, the creation of the Southeast Fishery Independent Survey (SEFIS), had a first field season in 2010. This infusion of resources into the traditional MARMAP chevron trap survey has allowed for a large expansion in the geographical coverage of the survey, particularly off Florida (Table 1, Figure 2 and Figure 3) and an increase in the annual sample size of the chevron trap survey. The combined efforts of MARMAP, SEAMAP-SA Reef Fish Complement, and SEFIS to conduct fishery-independent monitoring in the US South Atlantic region are now referred to as the Southeast Reef Fish Survey (SERFS).

Objective

This report presents a summary of an investigation to determine what the net effect of the changes in management regulations pertaining to Red Snapper (and other species in this mixed species fishery) and the changes in the SERFS chevron trap survey has on the utility of the SERFS chevron trap survey in the SEDAR 41 assessment model. Specifically, this report investigates two primary questions:

1) Does the recent increase in capture rate (and relative abundance) of Red Snapper in the survey reflect shifts in spatial sampling distribution of the survey or changes in relative abundance?
2) What does the increase in capture rate since 2010 mean for the utility of the historical (1990-2009) chevron trap data?
    a) Does the historical data accurately represent historical relative abundance in the region?

The investigation focuses on comparing relative abundance trends of Red Snapper derived from valid samples taken from known live-bottom and/or hard-bottom chevron trap stations identified prior to 2010 (MARMAP Universe) to relative abundance trends of Red Snapper derived from valid samples taken from all stations currently identified as part of the SERFS chevron trap universe of known live-bottom and/or hard-bottom habitats (SERFS Universe). Primarily, these two chevron trap universes differ in the number of known live-bottom and/or hard-bottom stations identified (Figure 4) and the geographic distribution of the identified stations (Table 1, Figure 2 and Figure 3; pay particular attention to the distribution in 2009 vs. 2014). As such, the MARMAP Universe dataset can be thought of as a subset of all available data from any given year, representing only data derived from traditional MARMAP chevron trap stations.

A secondary objective is to evaluate the performance of models modeling continuous covariates (e.g. depth or latitude) as polynomials vs. the traditional approach of binning continuous covariates into discrete bins and subsequently modeling them as discrete covariates in index standardization models.

Methods

Survey Design and Gear
(see Smart et al. 2015 for full description)

Sampling area
- Cape Hatteras, NC, to St. Lucie Inlet, Fl (Figure 5)
    - General expansion of geographic coverage through time
- Sampling depths range from 13 to 218 m
    - Generally less than 100 m

Sampling season
- May through September
    - Limited earlier and later sampling in some years

Survey Design
- Simple random sample survey design
    - Annually, randomly select stations from a chevron trap universe of confirmed live-bottom and/or hard-bottom habitat stations
    - No two stations are randomly selected that are closer than 200 m from each other
        - Minimum distance is typically closer to 400 m

- Traps deployed on suspected live-bottom and/or hard-bottom in a given year (reconnaissance) are evaluated based on catch and/or video or photographic evidence of bottom type for inclusion in the universe in subsequent years
  - If added to the known habitat universe, data from the reconnaissance deployment is included in CPUE analysis

Sampling Gear – Chevron Traps
(see Collins 1990 and MARMAP 2009 for descriptions that are more complete)

- Arrowhead shaped, with a total interior volume of 0.91 m^3
- Constructed of 35 x 35 mm square mesh plastic-coated wire with a single entrance funnel ("horse neck")
- Baited with a combination of whole or cut clupeids (*Brevoortia* or *Alosa* spp., family Clupeidae), with *Brevoortia* spp. most often used
  - Four whole clupeids on each of four stringers suspended within the trap
  - Approximately 8 clupeids placed loose in the trap
- Soak time of approximately 90 minutes

Oceanographic Data
- Hydrographic data collected via CTD during soaking of a "set" (typically 6 traps, but may be less) of chevron traps deployed at the same time
  - Bottom temperature (^{o}C) is defined as the temperature of the deepest recording within 5 m of the bottom

Data Filtering/Inclusion
Chevron trap data were limited to:
- Projects conducting monitoring efforts (project IDs: P05, T59, T60; data sources: MARMAP, SEAMAP-SA, SEFIS)
- Reef fish monitoring samples (Data source ≠ "Tag-MARMAP")
  - "Tag-MARMAP" denotes special historic MARMAP cruises that were used to tag various species of fish, with all species captured not being counted and measured
- Traps that fished properly (catch IDs: 0-2, 8, 9, 90-92)
- Traps on live-bottom and/or hard-bottom habitat (station types: Random, NonRandom, ReconConv, Null)
- Traps with soak times that were neither extremely short nor long which often indicates an issue with the deployment not captured elsewhere (included 45-150 minutes)
- For Red Snapper specifically, only the depths at which Red Snapper have ever been captured by any of the monitoring programs (included 15-75 m)
- Excluded any chevron trap samples missing covariate information

Index Model Structure
- Response variable – Catch/Trap
- Offset term – natural log of soak time ($\ln(soak\ time)$)

- Dependent variables
  - Year
  - Covariates
    - Depth, latitude (^oN), bottom temperature (^oC), and day of year
- Model structure – zero-inflated negative binomial GLM (ZINB)
  - Other model structures considered: Poisson GLM, negative binomial GLM, and zero-inflated Poisson GLM (ZIP)
    - ZINB favored over other model structures in all analyses
- Annual year effect coefficients of variation (CVs) computed using bootstrapping
- Software used
  - R (Version 3.1.0; R Development Core Team 2014)
  - Function zeroinfl in package *pscl* (Jackman 2011; Zeileis et al. 2008)
  - Function gam in package *mgcv* (wood 2011; Wood 2006; Wood 2004; Wood 2003; Wood 2000)

Models and Data

<u>Data</u>

- Time periods (see Figure 5 for annual geographic distribution of SERFS chevron trap sampling)
  - 1990-2014
    - The full SERFS chevron trap survey time-series over which a standardized approach to chevron trap sampling was used
  - 2010-2014
    - Restricted SERFS chevron trap survey time-series during which the annual percent positive rate in each year was greater than 5% and geographic coverage of sampling was increased off the coast of FL
    - Time period during which sampling effort in the region was greatly increased due to the addition of SEAMAP-SA Reef Fish Complement and SEFIS funds
- Data sets (see Table 2 for annual sample size, percent positive rate, and number of Red Snapper captured; see Table 3 for a comparison of several summary metrics comparing the two data sets)
  - Data set derived from stations present in the current SERFS chevron trap station universe of known live-bottom and/or hard-bottom habitats
    - SERFS Universe data set (see Figure 5 for annual geographic distribution of realized sampling from the SERFS Universe)
  - Data set derived from stations sampled annually that were present in the MARMAP chevron trap station universe of known live-bottom and/or hard bottom habitats at the beginning of the 2010 sampling season
    - MARMAP Universe data set (see Figure 6 for annual geographic distribution of realized sampling from the MARMAP Universe during the period 2010-2014)

(Note: there is no difference in annual geographic sampling distribution based on the two data sets during the period 1990-2009)

- Covariate treatment

- Polynomial treatment
  - The covariates were each modeled as polynomials in the ZINB standardization model (used function poly in package *stats* (R Core Team 2014); with option raw = TRUE)
    - For each covariate, coefficients were estimated for each raw polynomial from degree 1 to maximum polynomial order
  - Maximum allowed polynomial order for each covariate was based on preliminary generalized additive models (GAMs)
    - Used function gam in package *mgcv* (Wood 2011; Wood 2006; Wood 2004; Wood 2003; Wood 2000)
      - Used Restricted Maximum Likelihood (REML) estimation for smoothing parameter estimation
      - Investigated use of several different spline options (see gam function help in R for available options and descriptions)
        - Chose maximum polynomial order based on the effective degrees of freedom estimate (rounded to the nearest whole number) for the covariate in question using the spline type that provided the lowest REML estimate
    - Modeled Red Snapper abundance versus all covariates
      - Used to inform maximum polynomial order for the count sub-model of the ZIP and ZINB models
      - Used to inform maximum polynomial order for the Poisson GLM and negative binomial GLM models
    - Modeled Red Snapper presence/absence versus all covariates
      - Used to inform maximum polynomial order for the zero-inflation sub-model of the ZIP and ZINB models
  - Model selection based on Bayesian information criterion (BIC; Schwarz 1978) to increase the penalty associated with adding parameters to the model
    - ZIP and ZINB Models (2 step process, optimizing one sub-model during each step; needed because of computational demand)
      - Remove all covariates from the zero-inflation sub-model (i.e., intercept only zero-inflation sub-model) and optimize count sub-model for all covariates
      - Fixing count sub-model to the optimum values found during step 1, optimize the covariate structure of the zero-inflation sub-model
- Discrete treatment
  - Binned each covariate according to decisions made during the SEDAR 41 Data Workshop held in 2014 (Table 4)
  - Model selection based on BIC, optimizing both sub-models of ZIP and ZINB models simultaneously

Models

(see Figure 7 for model hierarchy)

Results

Model Structure, Stability and Performance
(see Table 5 for model structure of each of the best-fit models)

- BIC estimates of model pairs (same data set, different covariate treatment) indicate models using continuous covariates fit with polynomials provide better fit that discrete covariate models (Table 5)
- Despite containing more parameters (Table 5), models using continuous covariates fit with polynomials exhibit higher convergence rates and do a superior job fitting observed catch frequency distribution (Table 6)
- Models based on the SERFS Universe data set produced lower CV estimates than those based on the MARMAP Universe data set (Table 6 and Figure 8)
    - Driven by the larger sample size and higher percent positive rate of Red Snapper in SERFS Universe data set

Covariate Effects
(see Figure 9, Figure 10, and Figure 11)

- Given the same method of modeling covariates (polynomial vs. discrete), predicted covariate effects are similar across models
    - Continuous covariates modeled as polynomials
        - Day of Year – covariate is not retained when using the SERFS Universe data set and short time-series
            - Only very slight negative effect of day of year in the full time series SERFS Universe data set model
            - Models based on the MARMAP Universe data set predict a negative exponential effect of day of year on Red Snapper catch
                - Covariate effect is reduced in the full time-series model compared to the restricted time-series model
        - Depth – effect depends on what data set is used
            - SERFS Universe data set – dome shaped relationship of catch at depth, with maximum catch being at 30-50 m of depth
                - More non-linearity of this depth effect is apparent when using the full time-series
            - MARMAP Universe data set – still see a peak in catch at around 30-50 m of depth, though it also predicts high catch of Red Snapper at deep (> 60 m) depths
                - Peak at 30-50 m of depth is shifted deeper when the full time-series of data is used
                - Increase at deep depth is driven by low sample size at these depths to inform covariate effect
        - Latitude – predicted highest catch of Red Snapper at latitudes <30^{o}N, with smaller increases in catch at approximately 32^{o}N and >34^{o}N
            - Most models are remarkably similar in their predicted effect of latitude over the range 28-34.5^{o}N

            - MARMAP Universe data set models have less data informing covariate effect at extreme latitudes, thus predicted effect differs marginally at extremes when compared to models based on SERFS Universe
        - Temperature – models based on both data sets produce very similar predicted effects of temperature, regardless of survey start data
            - Catch of Red Snapper is predicted to increase exponentially as temperature increases through the range of temperatures observed
    - Discrete covariates
        - Day of Year – covariate is not retained in any of the final models
        - Depth – All models predict higher than average catches at 30-44 m depths
            - Predicted effect of depth on catch is smaller when using the MARMAP Universe data set
            - Similar to above, MARMAP Universe data set predicts above average catch rates of Red Snapper at deep (≥ 60 m) depths
        - Latitude – All models predict higher than average catch at <30°N, with lowest catches between 32.5 and 34°N
            - Predicted effect of latitude on catch is smaller when using the MARMAP Universe data set
        - Bottom temperature – covariate is only retained in the full time-series models
            - When retained, the predicted effect of bottom temperature differs depending on the data set used
                - SERFS Universe data set – generally increases over the range of temperatures observed
                - MARMAP Universe data set – catch peaks at temperatures of 15-26.9°C, decreasing at lower and higher temperatures
- Predicted effect of covariates are generally more coarse when modeling the covariates as discrete covariates than suggested when model covariates as continuous variables using polynomials
- Predicted covariate effects are generally more extreme (see y-axis scale of Figure 9) when covariates are modeled as polynomials instead of as discrete variables

2010 – 2014 Time Series Models

Initially, the goal was to focus on only the four relative abundance index models constructed using the data available from 2010-2014. By excluding the data from 1990-2009, one can focus on the impact that each individual data set (SERFS Universe vs. MARMAP Universe) had on the predicted relative abundance trends. This allows one to investigate whether the recent increase in capture rate (and relative abundance) of Red Snapper in the survey reflect shifts in spatial sampling distribution of the survey or changes in relative abundance? Under the null hypothesis of no change in the predicted relative abundance trend of Red Snapper as a function of data set, one would expect a significant positive correlation among indices, regardless of data set used. This indicates whether the traditional MARMAP chevron trap survey stations, as randomly sampled from 2010 to 2014, can adequately characterize the recent abundance trends of Red Snapper in the region, assuming the abundance trend observed using all the data (SERFS Universe) is the "true" abundance trend.

<u>Relative Abundance and Index Correlation</u>

(see Table 7 and Figure 12)

- Relative abundance trend is similar across all four models (generally increasing throughout the time series)
  - Exception is the model using the MARMAP Universe data set and treating covariates as discrete variables (exhibits least correlation with other models)
    - Indicates increasing trend in relative abundance from 2012-2013 while all other models suggest decreasing trend
    - Indicates higher terminal year relative abundance and lower relative abundance in 2012 compared to other models
- All models are correlated at >90% confidence level
  - Models using continuous covariates modeled as polynomials correlated at >95% confidence level
  - Model using SERFS Universe data set and discrete covariates is correlated with the two models modeling the continuous covariates using polynomials at >95% confidence level

<u>Summary</u>

- Indices produce similar relative abundance trends
  - Regardless of data set used
    - Suggest traditional MARMAP stations (representing traditional MARMAP annual spatial distribution of samples) adequately characterize changes in relative abundance of Red Snapper throughout the region
  - Regardless of covariate treatment methodology in standardization model
- Continuous covariate models…
  - More stable despite estimating more parameters
  - Better capture "catch patterns" of Red Snapper in the region
- Models using the SERFS Universe data set produce lower coefficient of variation estimates (Figure 8)

1990 – 2014 Time Series Models

Now the goal is to focus on comparing the short time-series models presented above to relative abundance indices of a similar structure based on the full chevron trap survey time-series (1990-2014; Figure 7) to answer the question does the historical data accurately represent historical relative abundance in the region. If one concludes, based on the above analysis, that the traditional MARMAP chevron trap stations identified prior to 2010 do an adequate job characterizing regional Red Snapper abundance during the period 2010-2014, one can then assume that they would adequately characterize Red Snapper relative abundance in the region over the period 1990-2009. Given this assumption, under the null hypothesis that the historical data does accurately characterize regional Red Snapper abundance, we would expect a high degree of positive correlation in the predicted abundance trends of the full time-series models to the short time-series models. To simplify interpretation, in the correlation analysis I will only compare the four long time-series models presented here to the two "best" short time-series models, those being the two using the SERFS Universe data set (differ in covariate treatment only).

<u>Relative Abundance and Index Correlation</u>

(see Table 8, Figure 13 and Figure 14)

- Relative abundance trend is similar across all models considered
    - All models suggest increasing trend in relative abundance from 2010-2014
        - Excellent agreement in relative abundance trends among models using same data set and covariate treatment approach, but different start years (Figure 14)
    - All full time-series models exhibit good agreement regarding relative abundance over the period 1990-2009
- All models compared are correlated at >90% confidence level (Table 8)
    - All full time-series models are correlated at >99.9% confidence level
    - Most (7 of 8) full time-series models are correlated with the SERFS Universe data restricted time-series models at >95% confidence level
        - Exception is the full time-series model using MARMAP Universe data set and discrete covariates is correlated with the restricted time-series model using the SERFS Universe data set and discrete covariates at only >90% confidence level

<u>Summary</u>

- High degree of positive correlation among all models investigated
    - All models developed using the current station universe (SERFS Universe data set), and hence most data to inform covariate effects, correlated at >95% confidence level
        - Regardless of covariate treatment
        - Suggest they are modeling the same "signal," after accounting for covariate effects, regarding Red Snapper relative abundance
            - Standardization model appears to be working appropriately and as expected by removing the effect of annual variability in sampling distribution with regards to important environmental variables from observed relative abundance
- Indices produce similar relative abundance trends
    - Regardless of data set used
        - Suggest traditional MARMAP chevron trap stations (representing traditional MARMAP annual spatial distribution of samples) adequately characterize changes in relative abundance of Red Snapper throughout the region
    - Regardless of covariate treatment methodology in standardization model
- Continuous covariate models…
    - More stable despite estimating more parameters
    - Better capture "catch patterns" of Red Snapper in the region
- Model stability greater for full time-series models compared to same configuration restricted time-series models
    - Continuous covariate models are more stable despite estimating more parameters
- Continuous covariate models better capture "catch patterns" of Red Snapper in the region
    - Full time-series models do better job than other models
- Time series average CV estimates for full time-series models are larger than restricted time-series counterparts
    - Product of smaller sample sizes in earlier years

   - Produce similar CV estimates as their restricted time-series counterparts during the period 2010-2014
- Within model structure (covariates modeled as polynomials vs. discrete variables), CV estimates are similar when using full vs. restricted time-series

Comparison to SEDAR 24 Indices

(see Figure 15)

- All indices seem to be in general agreement regarding the overall time-series pattern
   - Decreasing relative abundance pattern from late 1970s through early- and mid-1990s
   - Low relative abundance through late 1990s
   - Brief increase in relative abundance in early 2000s prior to another decrease in relative abundance
   - Consistent increase in relative abundance since the late 2000s

Conclusions

- Strong evidence that, after accounting for annual shifts in sampling distribution with regard to several covariates, that data derived solely from historical MARMAP chevron trap stations can adequately track annual Red Snapper relative abundance
   - If wasn't the case, wouldn't expect the high degree of correlation exhibited between indices developed using data only from historical chevron trap stations (MARMAP Universe data set) and those using the current chevron trap data set (SERFS Universe data set)
   - Further, models developed from different data sets are predicting similar effects of covariates on Red Snapper relative abundance
- As expected, CV estimates for the years 1990-2009 are somewhat larger than those estimated for 2010-2014
   - This is a product of annual sample size of the chevron trap survey, with the net effect of increasing sampling intensity in the recent time period being to decrease uncertainty around relative abundance trends
- Models that allow covariates that are originally measured on a continuous scale to be modeled as continuous variables, with a possibly non-linear effect on the response variable, perform better than analogous models that convert the continuous covariates to discrete variables

Pre-Data Workshop Recommendation

- Use the full time-series relative abundance index using data from all valid stations sampled via chevron traps (SERFS Universe data set) and modeling covariates as continuous variables using polynomials in the assessment model
   - Extends the fishery-independent chevron trap index back an additional 20 years
      - Bridges the gap between the termination of most of the fishery-dependent surveys used in SEDAR 24 and the other fishery-independent index developed using videos that begins in 2010

- Brings the available length comp and age comp data associated with the index into the assessment model for consideration, which can be important for informing year class strength

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Tables

Table 1: Annual distribution of stations in the chevron trap universe (known live-bottom/hard-bottom stations available for selection via random sampling annually) according to latitude and depth strata. Strata are defined based on multivariate partitioning based on changes in chevron trap catch species composition. Each column represents the number of stations in the universe found in each stratum in a given year.

	Survey Strata											
	Southern Latitudes (<29.71°N)				Mid Latitudes (29.71-32.60°N)				Northern Latitudes (≥32.61°N)			
Year	Inner Shelf (<30 m)	Mid Shelf (30-42 m)	Outer Shelf (43-63 m)	Slope (≥64 m)	Inner Shelf (<30 m)	Mid Shelf (30-42 m)	Outer Shelf (43-63 m)	Slope (≥64 m)	Inner Shelf (<30 m)	Mid Shelf (30-42 m)	Outer Shelf (43-63 m)	Slope (≥64 m)
1990	0	0	0	0	489	109	393	10	286	276	104	1
1991	0	0	0	0	498	109	396	10	286	276	104	1
1992	0	0	0	0	498	109	396	10	286	276	104	1
1993	0	0	0	0	498	131	396	10	287	276	104	1
1994	0	0	0	0	498	133	427	15	287	276	105	2
1995	0	0	0	0	499	137	450	15	287	276	105	2
1996	0	0	0	0	499	141	462	16	297	276	105	2
1997	6	0	0	0	499	146	487	19	312	279	105	2
1998	72	2	8	0	499	154	501	19	320	295	106	5
1999	72	2	22	0	499	155	507	19	320	297	107	5
2000	72	2	22	0	502	158	531	19	325	317	107	6
2001	72	2	22	0	502	159	546	33	328	323	125	6
2002	72	2	22	0	502	163	572	43	328	326	125	6
2003	75	2	22	0	502	163	574	43	330	330	125	6
2004	75	2	22	0	502	163	575	60	330	330	127	6
2005	75	2	22	0	502	163	575	60	330	330	127	6
2006	75	2	22	0	502	163	578	60	341	330	127	6
2007	77	2	22	0	502	164	579	60	348	333	130	11
2008	77	2	22	0	502	164	579	60	348	333	130	11
2009	77	2	22	0	502	164	579	60	348	333	130	19
2010	101	28	65	3	528	238	670	75	352	339	130	19
2011	139	48	117	3	565	252	713	76	390	347	132	25
2012	168	64	122	3	574	294	729	79	450	427	207	65
2013	272	114	145	3	612	360	785	90	456	453	214	65
2014	279	116	150	3	621	360	793	90	567	623	293	101

Table 2: Number of chevron trap stations sampled, proportion of traps positive for Red Snapper, and the total number of Red Snapper captured annually, by data set.

	SERFS Universe			MARMAP Universe		
Year	**# of Traps**	**Prop. Pos.**	**# of Fish**	**# of Traps**	**Prop. Pos.**	**# of Fish**
1990	300	0.023	23	300	0.023	23
1991	265	0.023	17	265	0.023	17
1992	288	0.028	20	288	0.028	20
1993	391	0.031	31	391	0.031	31
1994	388	0.049	45	388	0.049	45
1995	333	0.021	13	333	0.021	13
1996	365	0.016	6	365	0.016	6
1997	382	0.016	24	382	0.016	24
1998	428	0.019	25	428	0.019	25
1999	216	0.005	1	216	0.005	1
2000	286	0.028	17	286	0.028	17
2001	237	0.03	9	237	0.03	9
2002	238	0.055	33	238	0.055	33
2003	219	0.005	7	219	0.005	7
2004	283	0.014	5	283	0.014	5
2005	303	0.023	12	303	0.023	12
2006	286	0.014	5	286	0.014	5
2007	330	0.024	29	330	0.024	29
2008	297	0.024	19	297	0.024	19
2009	391	0.02	10	391	0.02	10
2010	581	0.069	89	402	0.027	14
2011	674	0.096	116	290	0.028	10
2012	1114	0.125	398	413	0.022	15
2013	1331	0.105	367	423	0.035	22
2014	1429	0.105	614	343	0.07	51
Total	**11355**	**0.059**	**1935**	**8097**	**0.026**	**463**

Table 3: Summary metrics for the two data sets considered in the report. Note the similar annual sample size between the two times using the MARMAP Universe data set. "–" represents NA

Metric	**Time Period**	**SERFS Universe**	**MARMAP Universe**
Annual Sample Size	1990-2009	–	311 (216-428)
	2010-2014	1026 (581-1429)	374 (290-402)
# of Years Proportion Positive > 5%	1990-2009	–	1
	2010-2014	5	1
Avg. Proportion Positive	1990-2009	–	0.023
	2010-2014	0.1	0.036
Avg. Fish/Year	1990-2009	–	18
	2010-2014	317	22
Avg. Fish/Positive Trap	1990-2009	–	2.4
	2010-2014	3	1.7
Nominal Catch/Trap	1990-2009	–	0.0564
	2010-2014	0.3088	0.0599

Table 4: Covariate bin structure as defined during the SEDAR 41 Data Workshop held in 2014.

	Covariate			
Bin	**Depth (m)**	**Latitude (oN)**	**Bottom Temperature (oC)**	**Day of Year**
1	< 30	< 28.00	< 15.0	< 150
2	30 – 44	28.00 – 29.99	15.0 – 26.9	150 – 199
3	45 – 59	30.00 – 32.49	≥ 27.0	200 – 249
4	≥ 60	32.50 – 33.99	–	≥ 250
5	–	≥ 34.00	–	–

Table 5: Model structures of each of the best-fit models. Numbers represent the maximum polynomial order for individual covariates. ✓ indicates discrete covariate retained in model. Count = indicates the count sub-model of the ZINB. ZI = zero-inflation sub-model of the ZINB. Lower BIC among pairs of models (1 per column) not separated by line (dashed or solid) indicates most parsimonious model.

		Index Model							
		1990-2014 Time Period				**2010-2014 Time Period**			
		SERFS Universe Data Set		**MARMAP Universe Data Set**		**SERFS Universe Data Set**		**MARMAP Universe Data Set**	
Variable	**Model**	**Polynomial Covariates**	**Discrete Covariates**	**Polynomial Covariates**	**Discrete Covariates**	**Polynomial Covariates**	**Discrete Covariates**	**Polynomial Covariates**	**Discrete Covariates**
Latitude	Count	7	–	5	–	7	✓	1	–
Depth	Count	7	–	3	–	3	✓	4	–
Temperature	Count	1	✓	1	✓	2	–	1	–
Day of Year	Count	–	–	1	–	–	–	1	–
Year	ZI	–	–	–	–	–	–	–	–
Latitude	ZI	4	✓	2	✓	4	✓	4	✓
Depth	ZI	3	✓	1	✓	3	✓	1	✓
Temperature	ZI	–	–	–	–	–	–	–	–
Day of Year	ZI	1	–	–	–	–	–	2	–
	Year Parameters	24	24	24	24	4	4	4	4
	Total Parameters	50	36	40	36	26	21	21	14
	BIC	6760	6936	2656	2674	4757	4950	735	724

Table 6: Model fit diagnostic comparison. Convergence rate is the percentage of 10,000 bootstraps that converged. Obs. Max # in Trap is the maximum number of Red Snapper captured in any trap. Pred. Max # in Trap is the maximum number of Red Snapper predicted to be caught in any given trap according to the model.

Model Structure			**Stability and Performance**			**Coefficient of Variation**		
Time Period	**Data Set**	**Covariate Treatment**	**Convergence Rate (%)**	**Obs. Max # in Trap**	**Pred. Max # in Trap**	**Mean**	**Median**	**Range**
2010 – 2014	SERFS	Polynomial	99.94%	54 fish	3.7 fish	0.141	0.119	0.113 – 0.198
2010 – 2014	MARMAP	Polynomial	96.62%	9 fish	3.2 fish	0.342	0.364	0.214 – 0.425
2010 – 2014	SERFS	Discrete	51.87%	54 fish	2.3 fish	0.150	0.137	0.115 – 0.201
2010 – 2014	MARMAP	Discrete	81.91%	9 fish	0.6 fish	0.313	0.335	0.154 – 0.397
1990 – 2014	SERFS	Polynomial	99.91%	54 fish	6.3 fish	0.485	0.448	0.185 – 1.023
1990 – 2014	MARMAP	Polynomial	98.44%	20 fish	4.5 fish	0.539	0.470	0.306 – 1.175
1990 – 2014	SERFS	Discrete	94.78%	54 fish	1.8 fish	0.464	0.432	0.162 – 1.000
1990 – 2014	MARMAP	Discrete	71.05%	20 fish	0.6 fish	0.501	0.423	0.266 – 1.019

Table 7: Pearson's correlation among all pairwise comparisons of the four relative abundance indices using a start year of 2010.

Model 1		**Model 2**		**Correlation Statistics**		
Data Set	**Covariate Treatment**	**Data Set**	**Covariate Treatment**	**df**	**r**	**p-value**
SERFS	Polynomial	SERFS	Discrete	3	0.9503	0.0066
SERFS	Polynomial	MARMAP	Polynomial	3	0.9301	0.011
SERFS	Polynomial	MARMAP	Discrete	3	0.8959	0.0198
SERFS	Discrete	MARMAP	Polynomial	3	0.9626	0.0043
SERFS	Discrete	MARMAP	Discrete	3	0.7217	0.0843
MARMAP	Polynomial	MARMAP	Discrete	3	0.7125	0.0884

Table 8: Pearson's correlation among all pairwise comparisons of the four full time-series (1990-2014) relative abundance indices and the two restricted time series (2010-2014) relative abundance indices using the SERFS Universe data set.

Model 1			Model 2			Correlation Statistics		
Data Set	**Time Period**	**Covariate Treatment**	**Data Set**	**Time Period**	**Covariate Treatment**	**df**	**r**	**p-value**
SERFS	1990-2014	Polynomial	SERFS	1990-2014	Discrete	23	0.872	<0.0001
SERFS	1990-2014	Polynomial	MARMAP	1990-2014	Continuous	23	0.8122	<0.0001
SERFS	1990-2014	Polynomial	MARMAP	1990-2014	Discrete	23	0.7092	<0.0001
SERFS	1990-2014	Polynomial	SERFS	2010-2014	Continuous	3	0.9335	0.0102
SERFS	1990-2014	Polynomial	SERFS	2010-2014	Discrete	3	0.8765	0.0256
SERFS	1990-2014	Discrete	MARMAP	1990-2014	Continuous	23	0.7533	<0.0001
SERFS	1990-2014	Discrete	MARMAP	1990-2014	Discrete	23	0.7131	<0.0001
SERFS	1990-2014	Discrete	SERFS	2010-2014	Continuous	3	0.9416	0.0084
SERFS	1990-2014	Discrete	SERFS	2010-2014	Discrete	3	0.978	0.0019
MARMAP	1990-2014	Polynomial	MARMAP	1990-2014	Discrete	23	0.8968	<0.0001
MARMAP	1990-2014	Polynomial	SERFS	2010-2014	Continuous	3	0.9833	0.0013
MARMAP	1990-2014	Polynomial	SERFS	2010-2014	Discrete	3	0.9096	0.0161
MARMAP	1990-2014	Discrete	SERFS	2010-2014	Continuous	3	0.8931	0.0206
MARMAP	1990-2014	Discrete	SERFS	2010-2014	Discrete	3	0.7131	0.0881

Figures

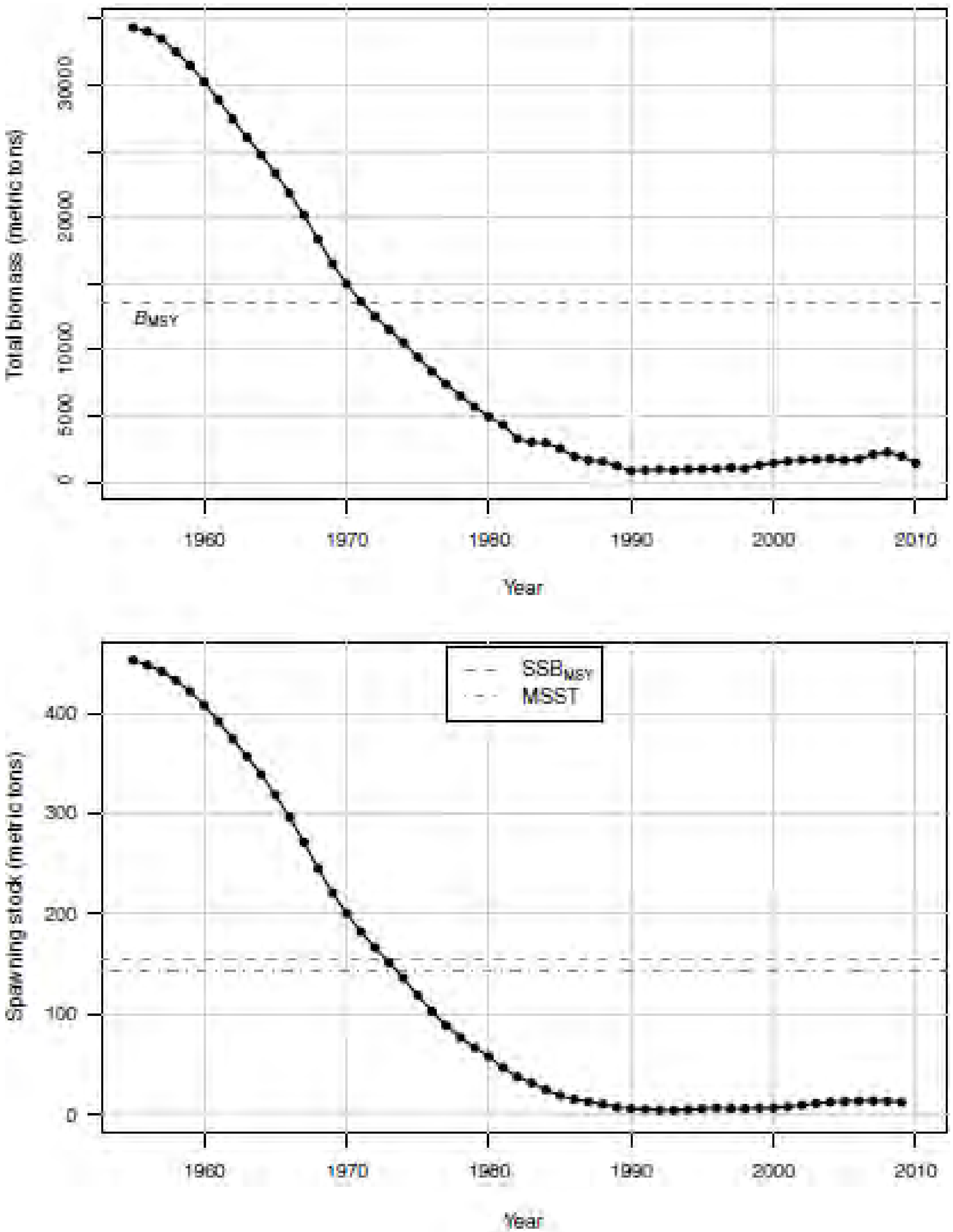

Figure 1: Predicted total biomass (top panel) and spawning stock biomass (bottom panel) of Red Snapper derived from final SEDAR 24 stock assessment (SEDAR 24).

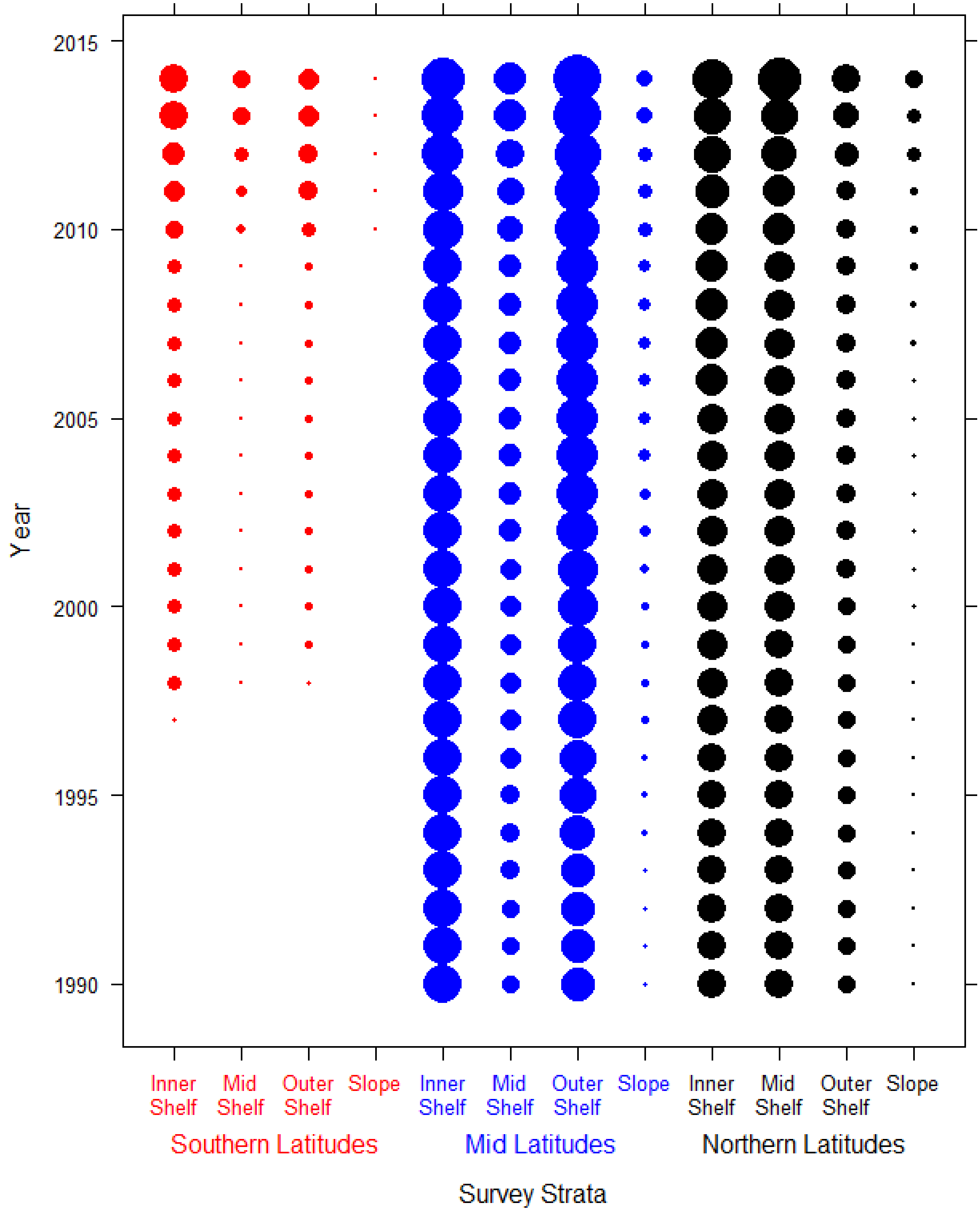

Figure 2: Distribution of SERFS chevron trap stations according to latitude and depth strata. Area of each circle is proportion to the total number of stations found in the strata.

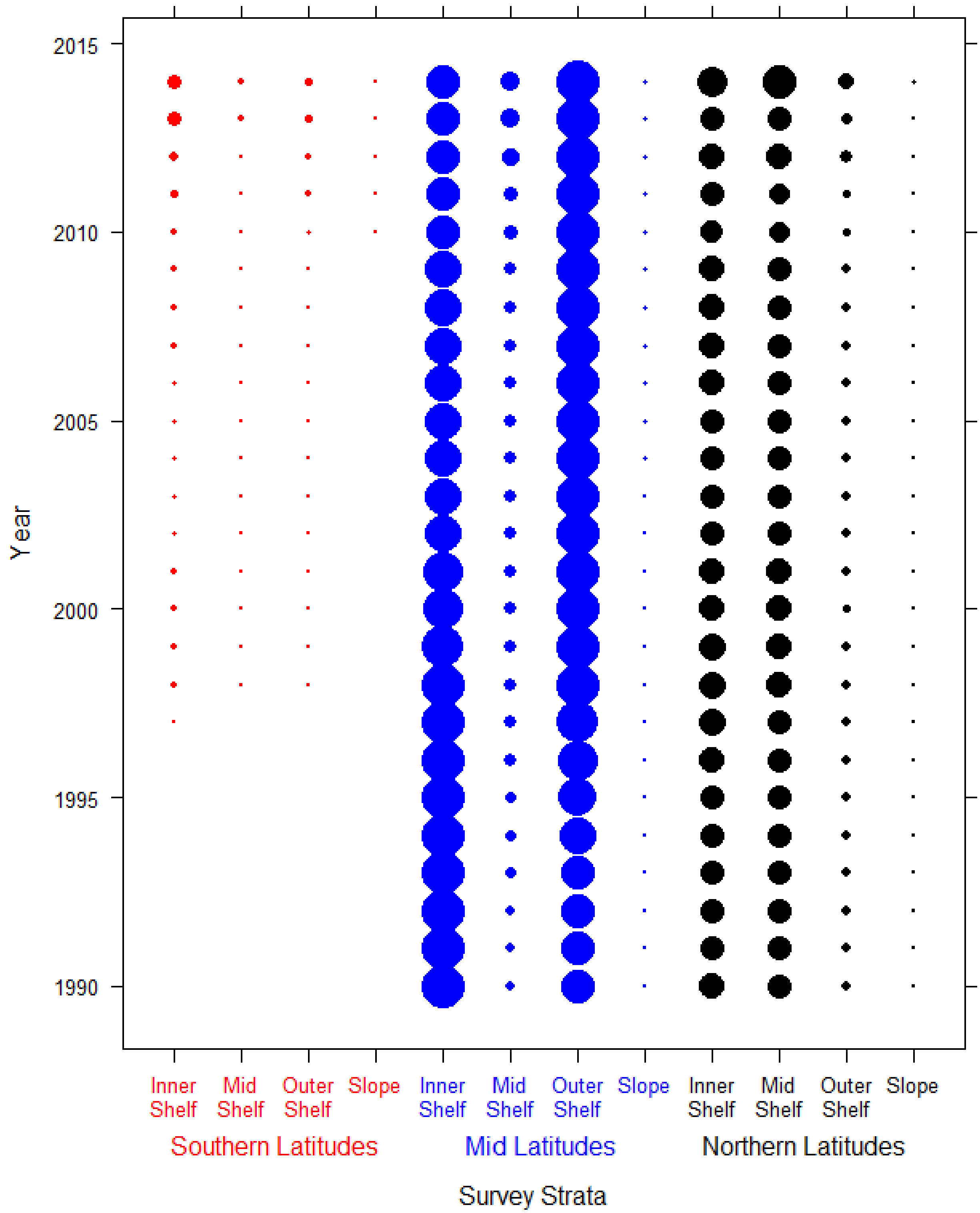

Figure 3: Distribution of SERFS chevron trap universe stations according to latitude and depth strata. Size of each circle in each year is proportional to the strata possessing the maximum number of stations in that year.

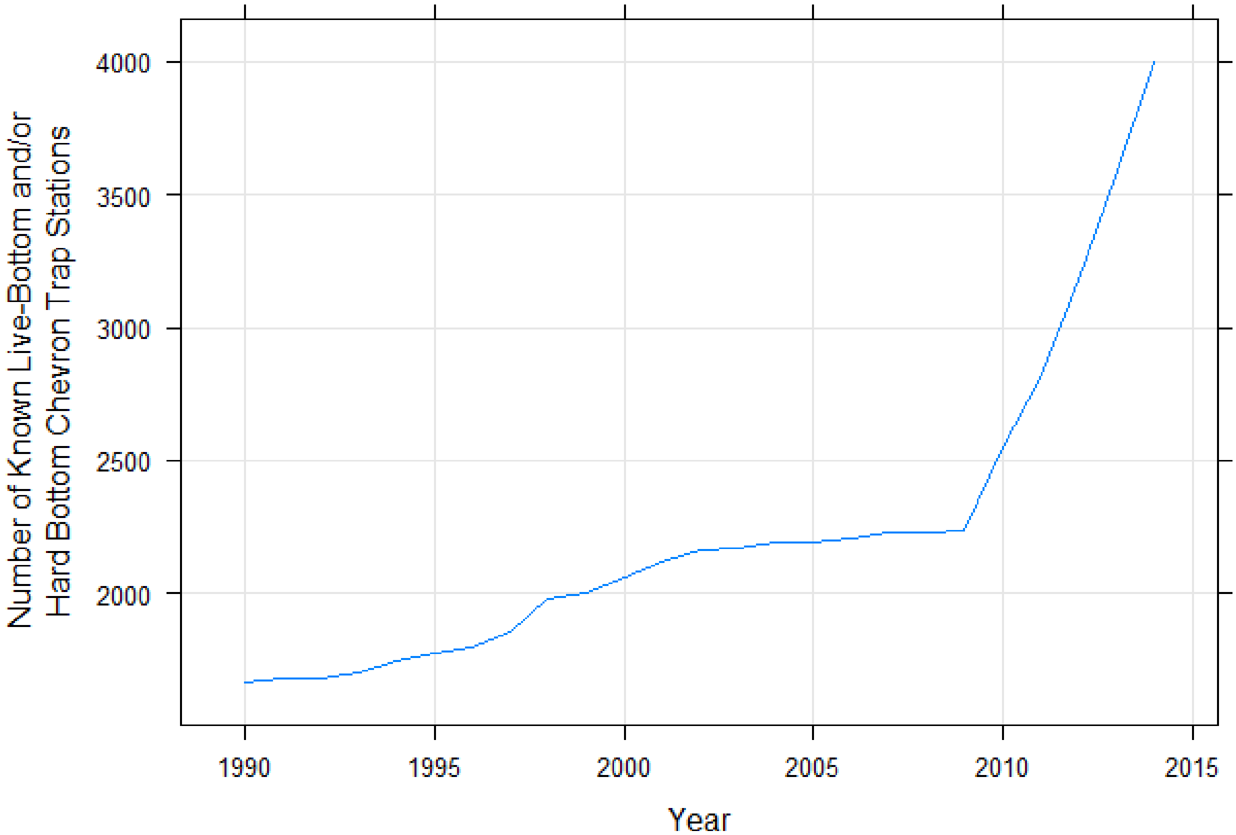

Figure 4: Time series of the number of stations composing the chevron trap station universe (locations with known live-bottom and/or hard-bottom habitat suitable for sampling via chevron traps). The drastic increase in known live-bottom and/or hard bottom stations since 2009 is driven primarily by the geographic expansion in the survey made possible due to the addition of funds via the SEAMAP-SA Reef Fish Complement and SEFIS programs. The chevron trap universe in 2009 represents the traditional MARMAP chevron trap universe, representing the geographic distribution of stations available for random sampling by the SERFS program during all years of the chevron trap index. The chevron trap universe in 2014 represents the current universe of known live-bottom and/or hard-bottom habitat identified by the SERFS program, with many of these new stations being found off the coast of Florida.

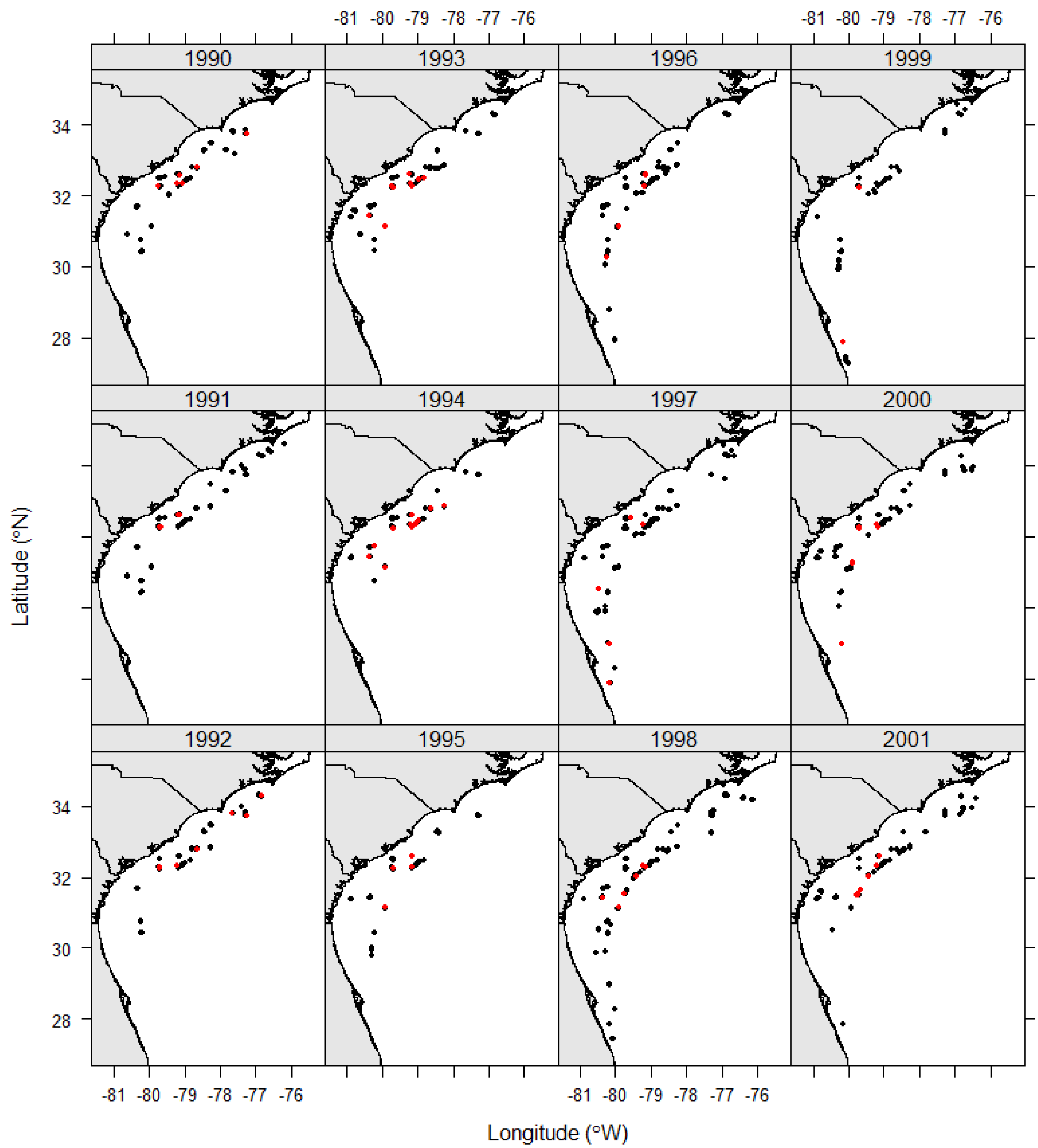

Figure 5: Annual sampling distribution of the SERFS chevron trap survey from 1990-2014 using the SERFS Universe (all valid chevron trap samples from a given year). Black dots represent samples absent of Red Snapper. Red dots represent samples where Red Snapper were captured.

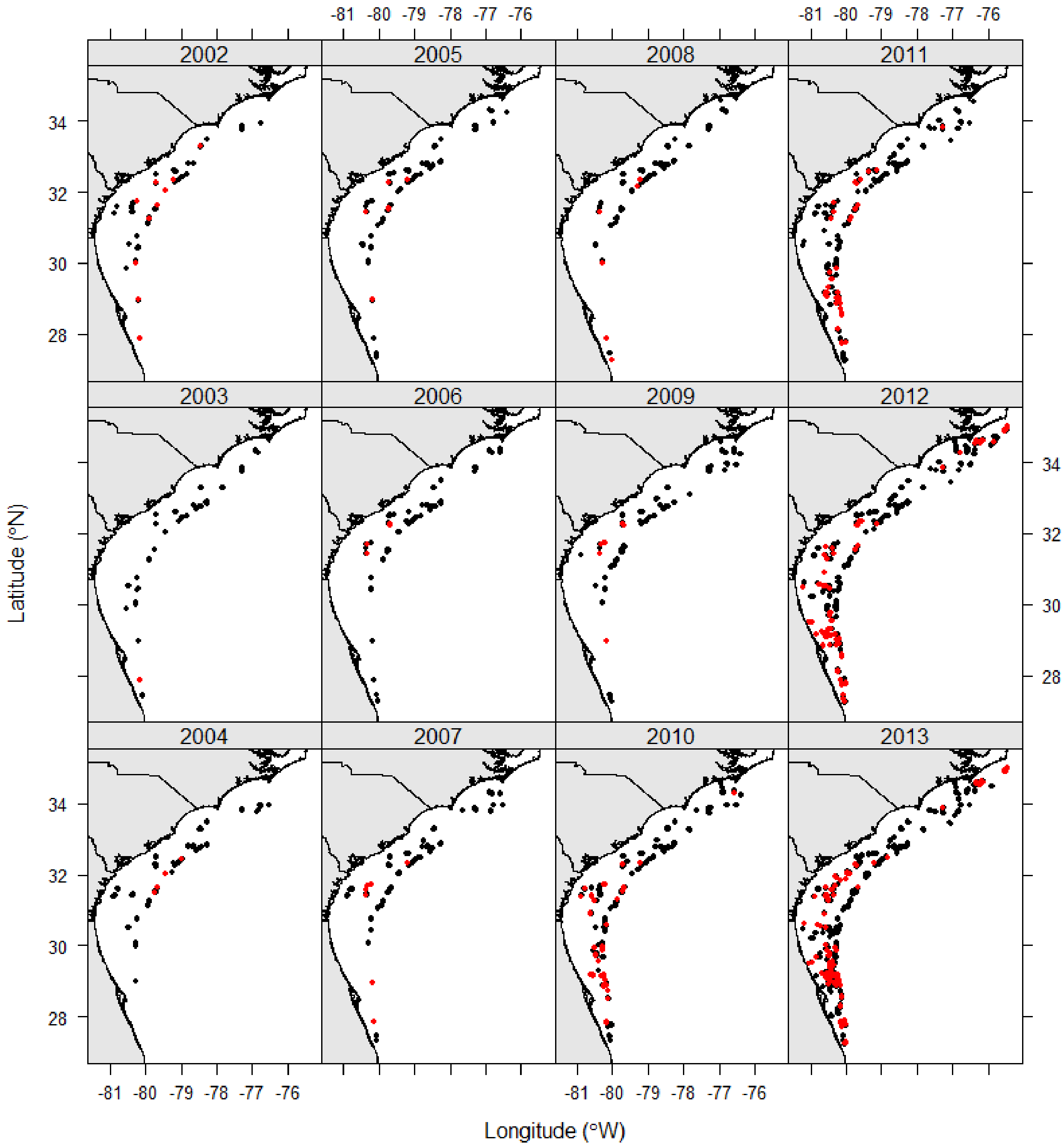

Figure 5: continued

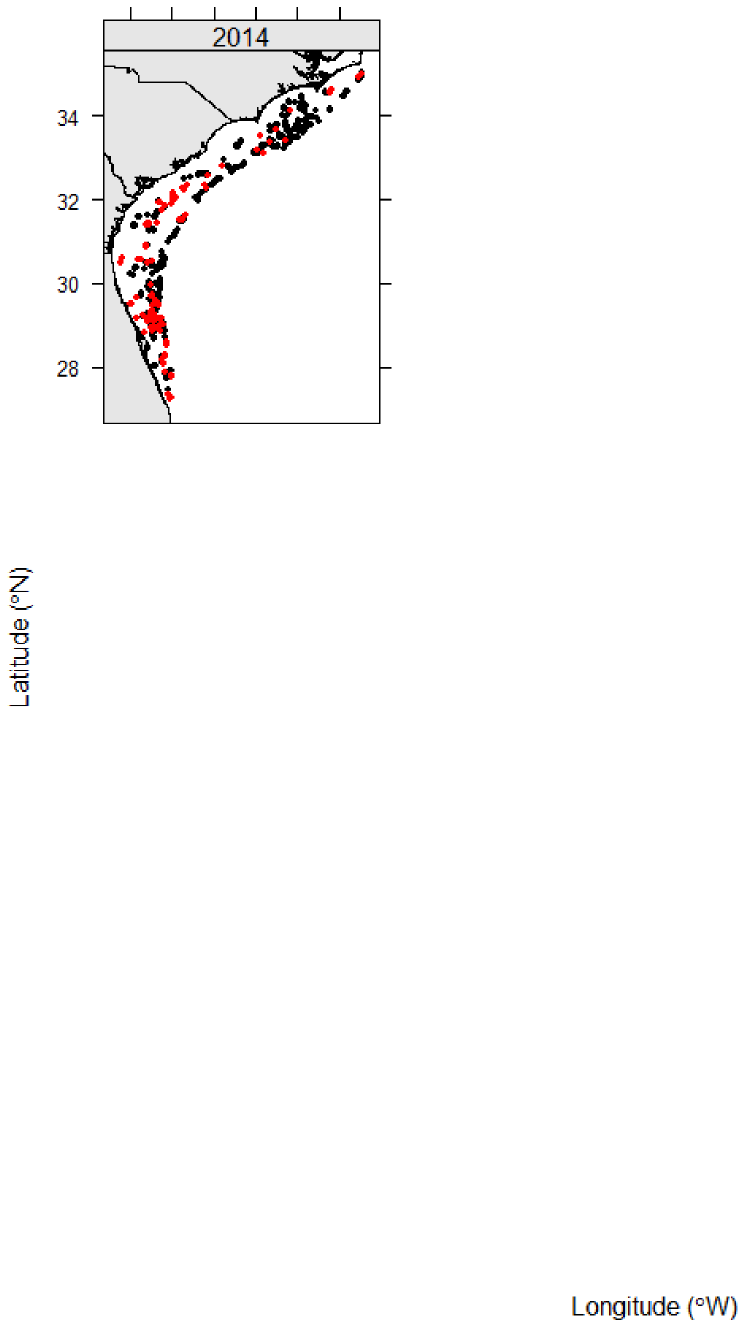

Figure 5: continued

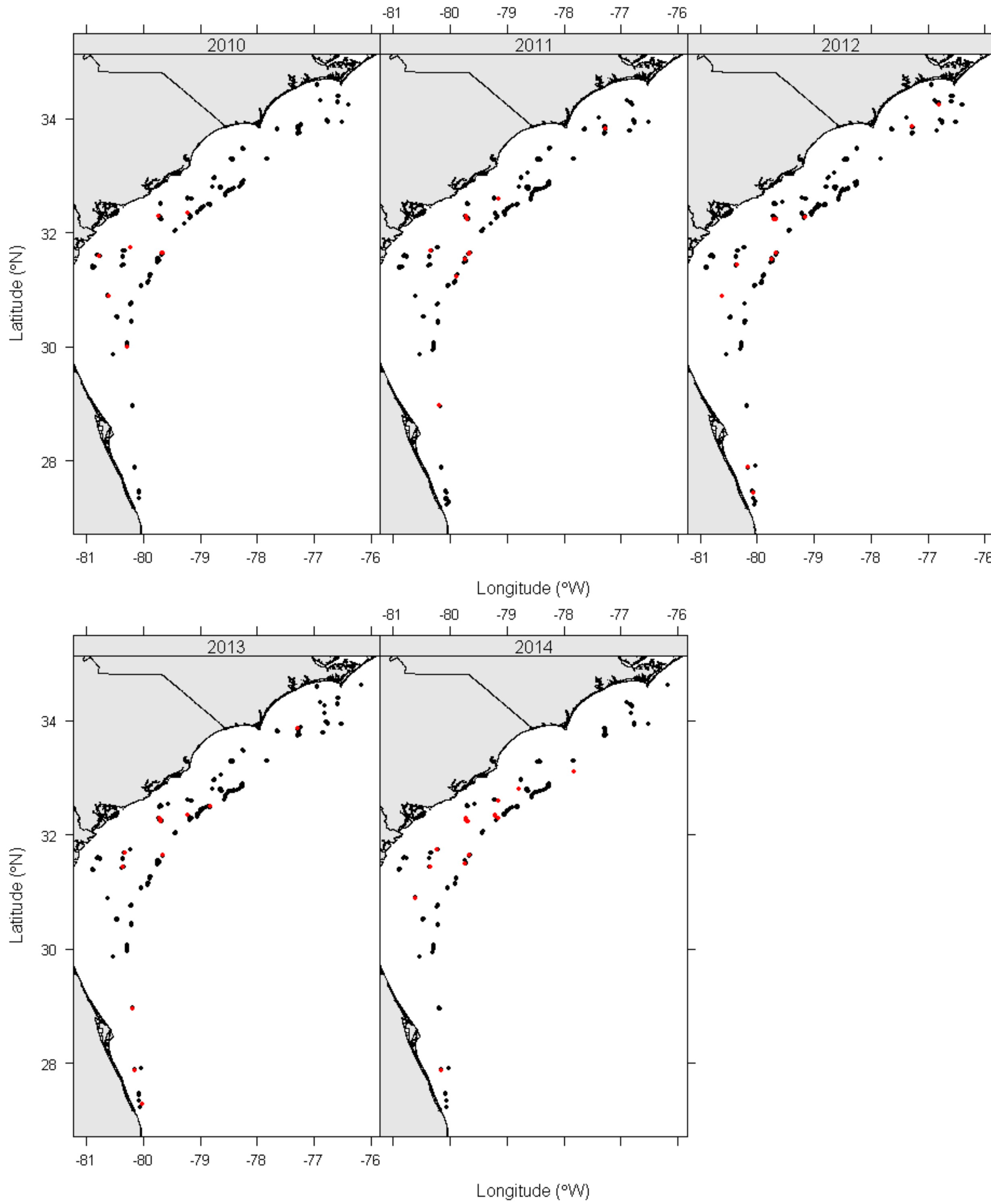

Figure 6: Annual sampling distribution of the SERFS chevron trap survey from 2010-2014 based only on those stations contained within the MARMAP chevron trap station universe at the beginning of the 2010 sampling season (identified as known live-bottom and/or hard-bottom habitat prior to 2010).

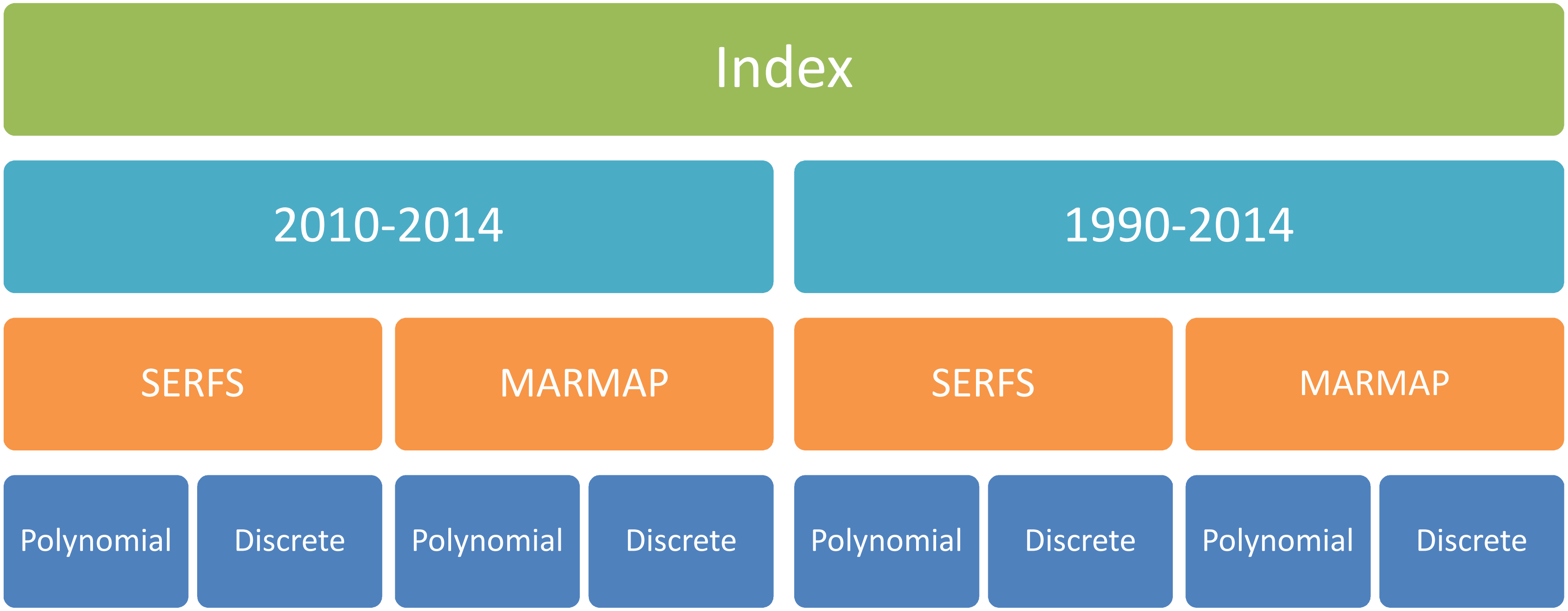

Figure 7: Hierarchical depiction of the eight relative abundance indices considered.

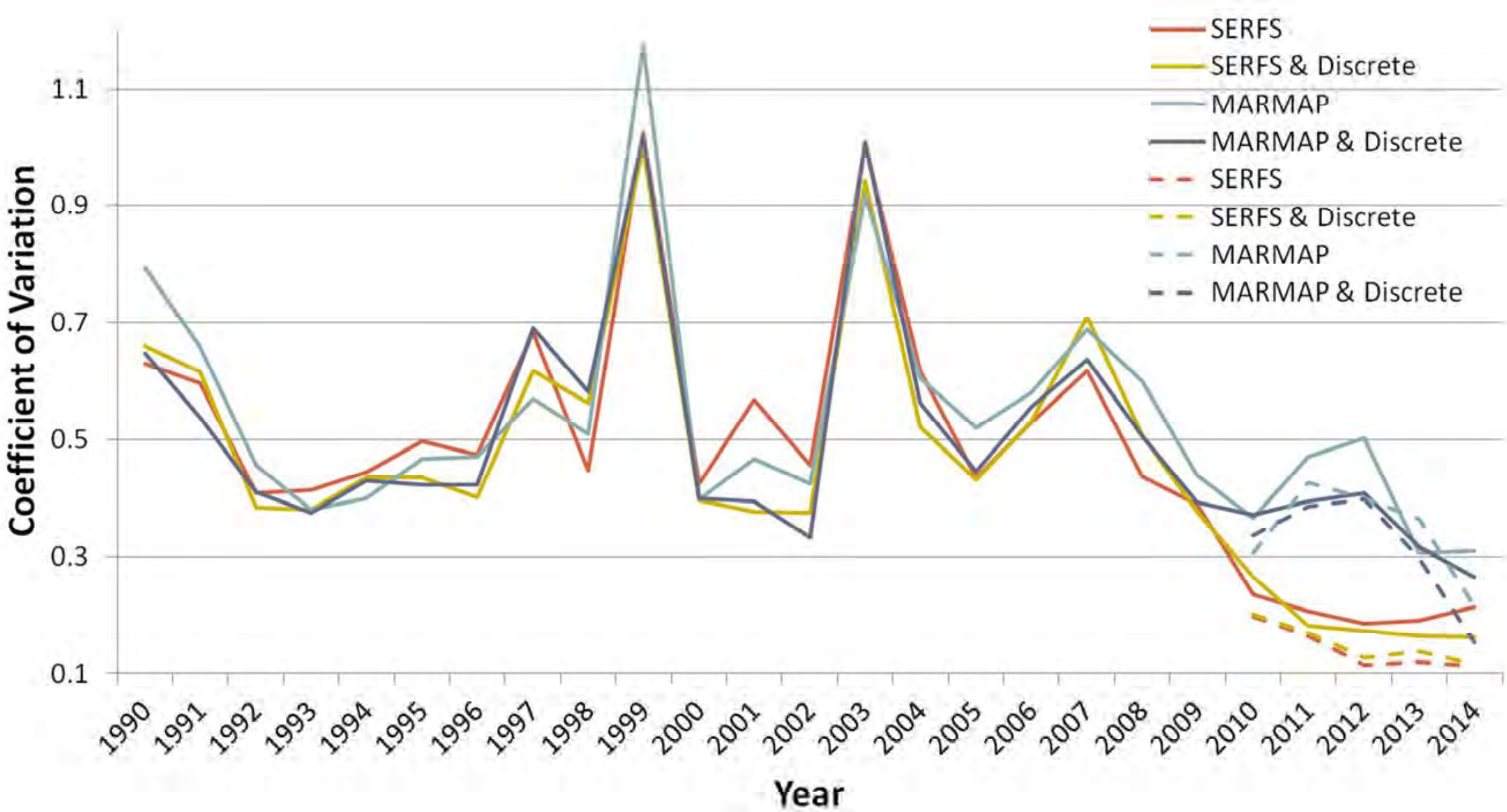

Figure 8: Annual coefficient of variation estimates from each of the eight models considered. Dashed lines represent models based on the restricted time series (2010-2014). Discrete in the legend refers to models using discrete covariates in the model (if missing indicates used covariates modeled as polynomials). SERFS and MARMAP refer to the data set used in the analysis, the SERFS Universe data set and MARMAP universe data set, respectively.

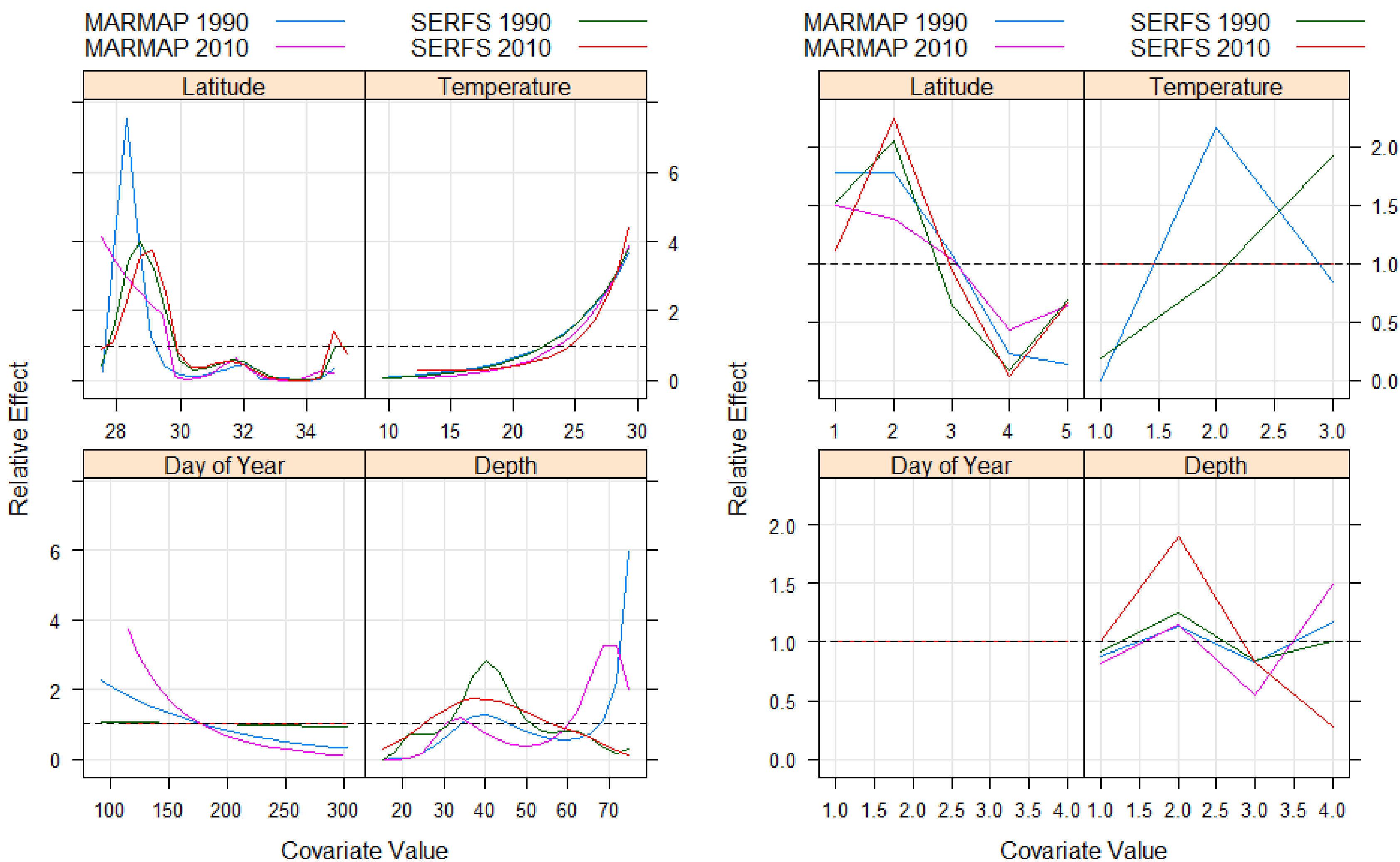

Figure 9: Predicted covariate effects from each of the eight models. Left side presents the covariate effects using continuous covariates modeled as polynomials. Right side presents the covariate effects using discrete covariates, with x-axis numbers representing bin number (refer to Table 4

Year	SERFS Universe			MARMAP Universe		
	# of Traps	Prop. Pos.	# of Fish	# of Traps	Prop. Pos.	# of Fish
1990	300	0.023	23	300	0.023	23
1991	265	0.023	17	265	0.023	17
1992	288	0.028	20	288	0.028	20
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Total	**11355**	**0.059**	**1935**	**8097**	**0.026**	**463**

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	2010-2014	5	1
Avg. Proportion Positive	1990-2009	–	0.023
	2010-2014	0.1	0.036
Avg. Fish/Year	1990-2009	–	18
	2010-2014	317	22
Avg. Fish/Positive Trap	1990-2009	–	2.4
	2010-2014	3	1.7
Nominal Catch/Trap	1990-2009	–	0.0564
	2010-2014	0.3088	0.0599

Table 4). MARMAP and SERFS refer to the use of the MARMAP Universe data set and SERFS Universe data set in the model, respectively. 1990 and 2010 represent the start year of the model in question.

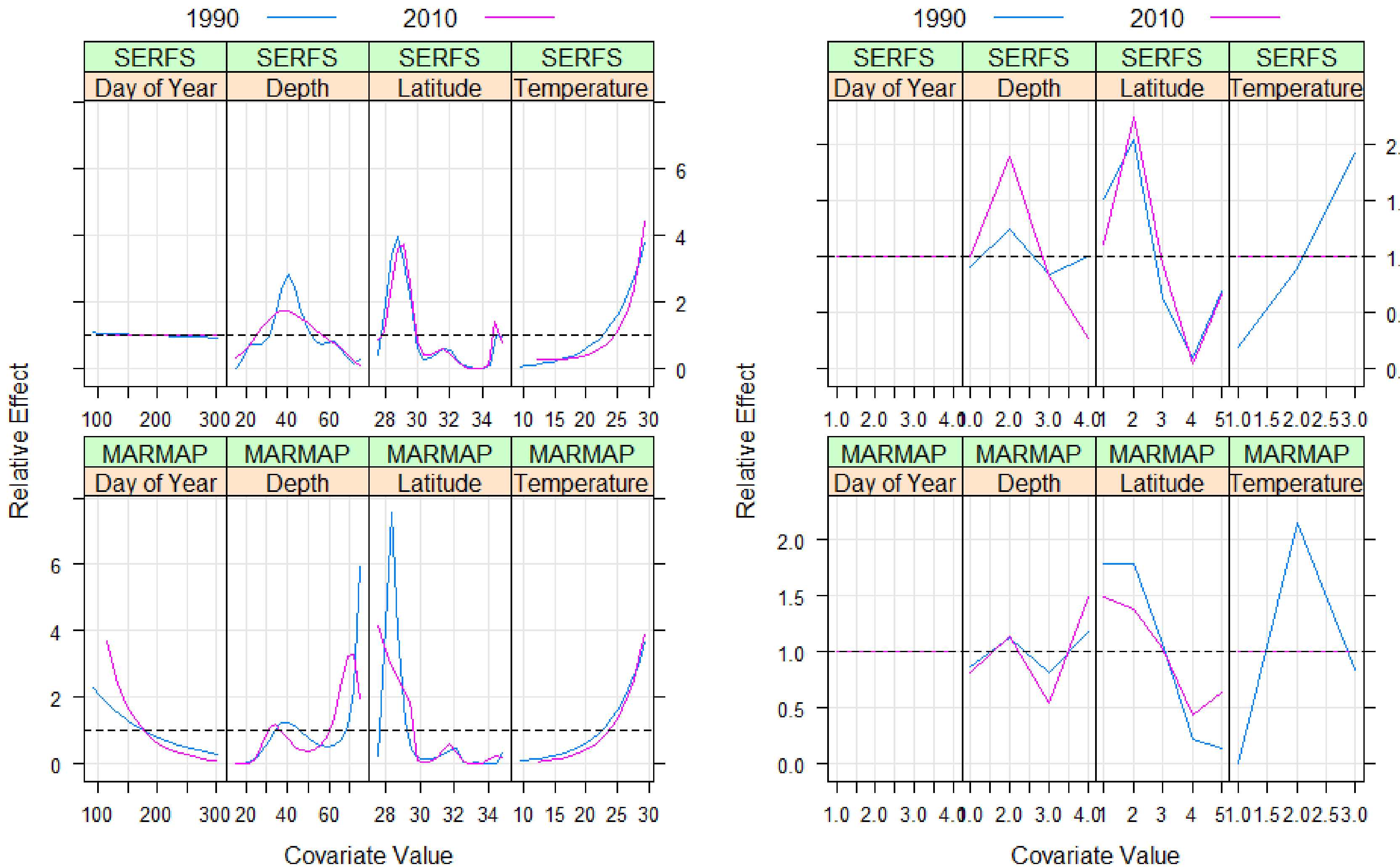


Figure 10: Same data presented in Figure 9, here comparing models with different start years within a given data set.

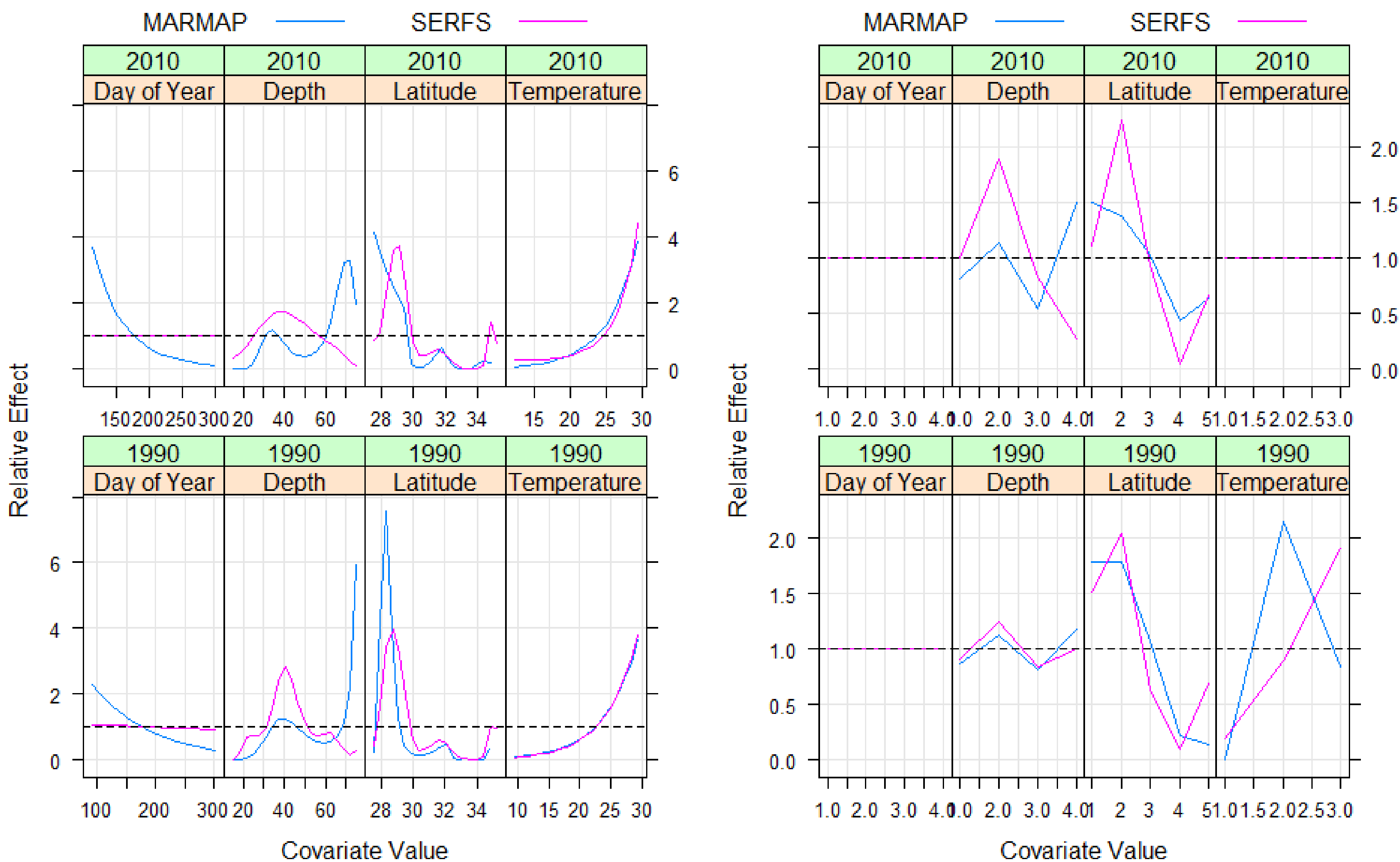


Figure 11: Same data presented in Figure 9, here comparing models using different data sets within a given survey start year.

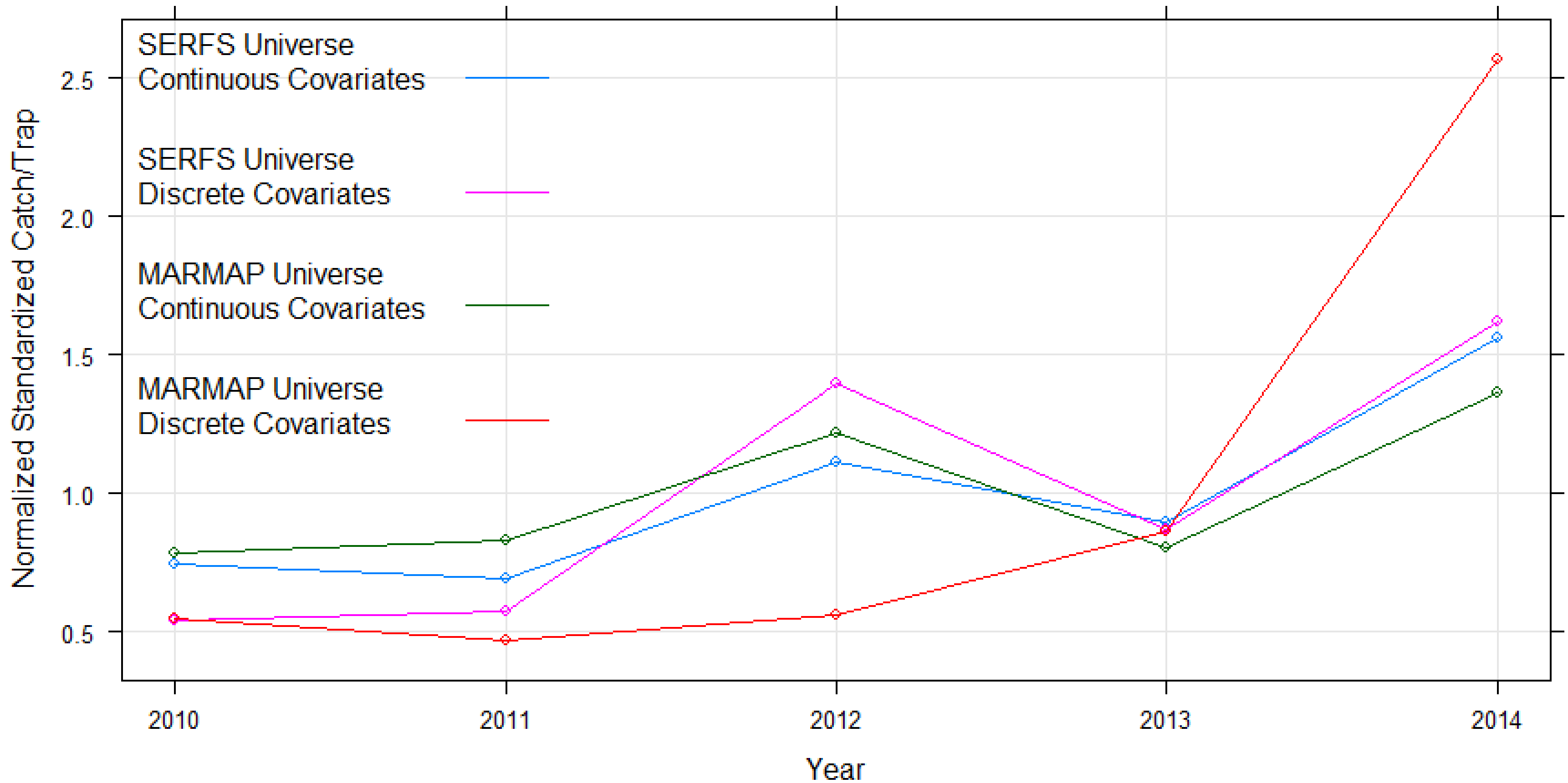


Figure 12: Relative abundance index for Red Snapper based on four different index models using only data from 2010-2014. Continuous covariates refer to models using polynomials.

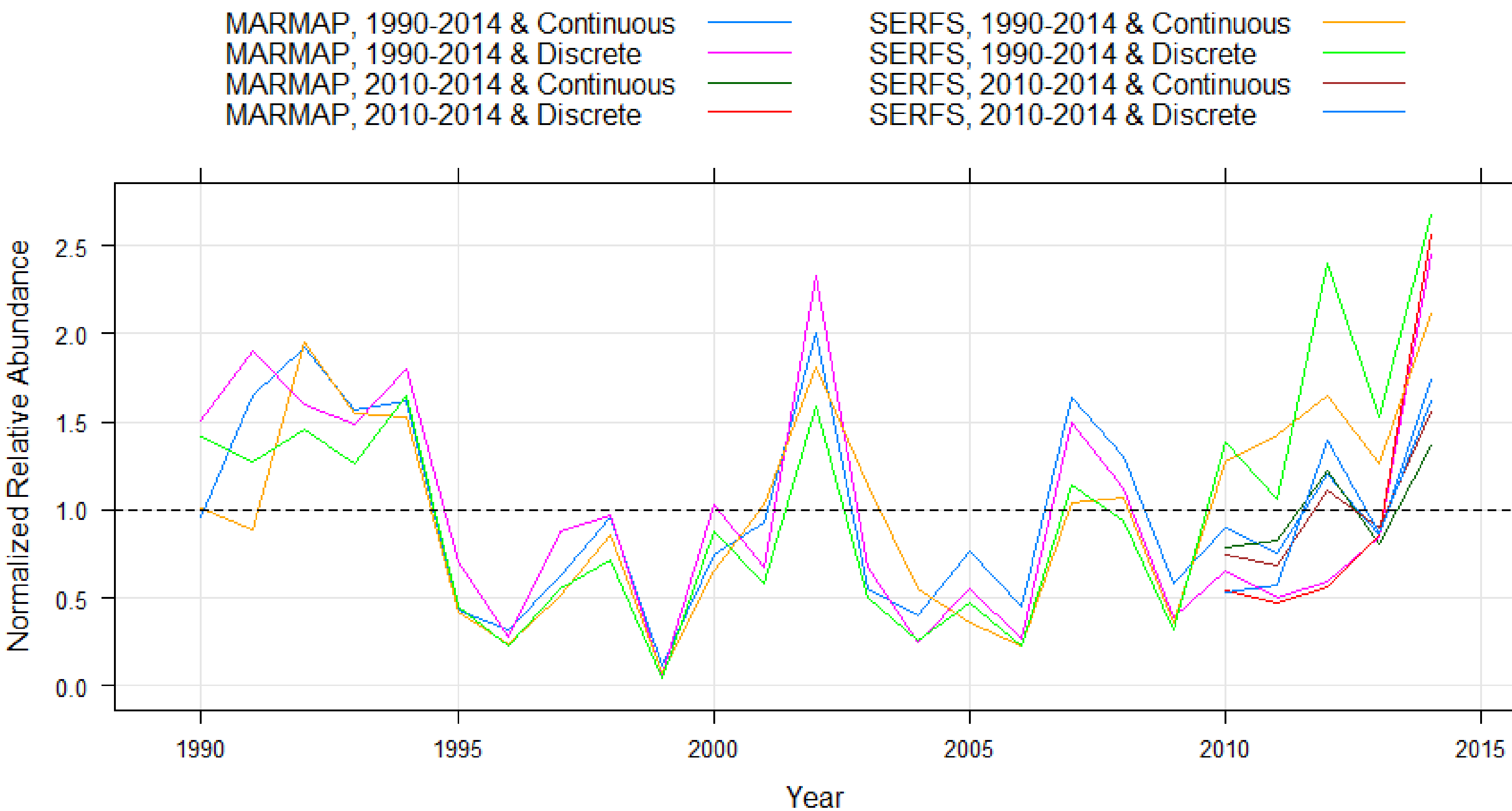


Figure 13: Relative abundance index for Red Snapper based on eight different index models (see Figure 7). Continuous identifies those models using polynomials to model covariates.

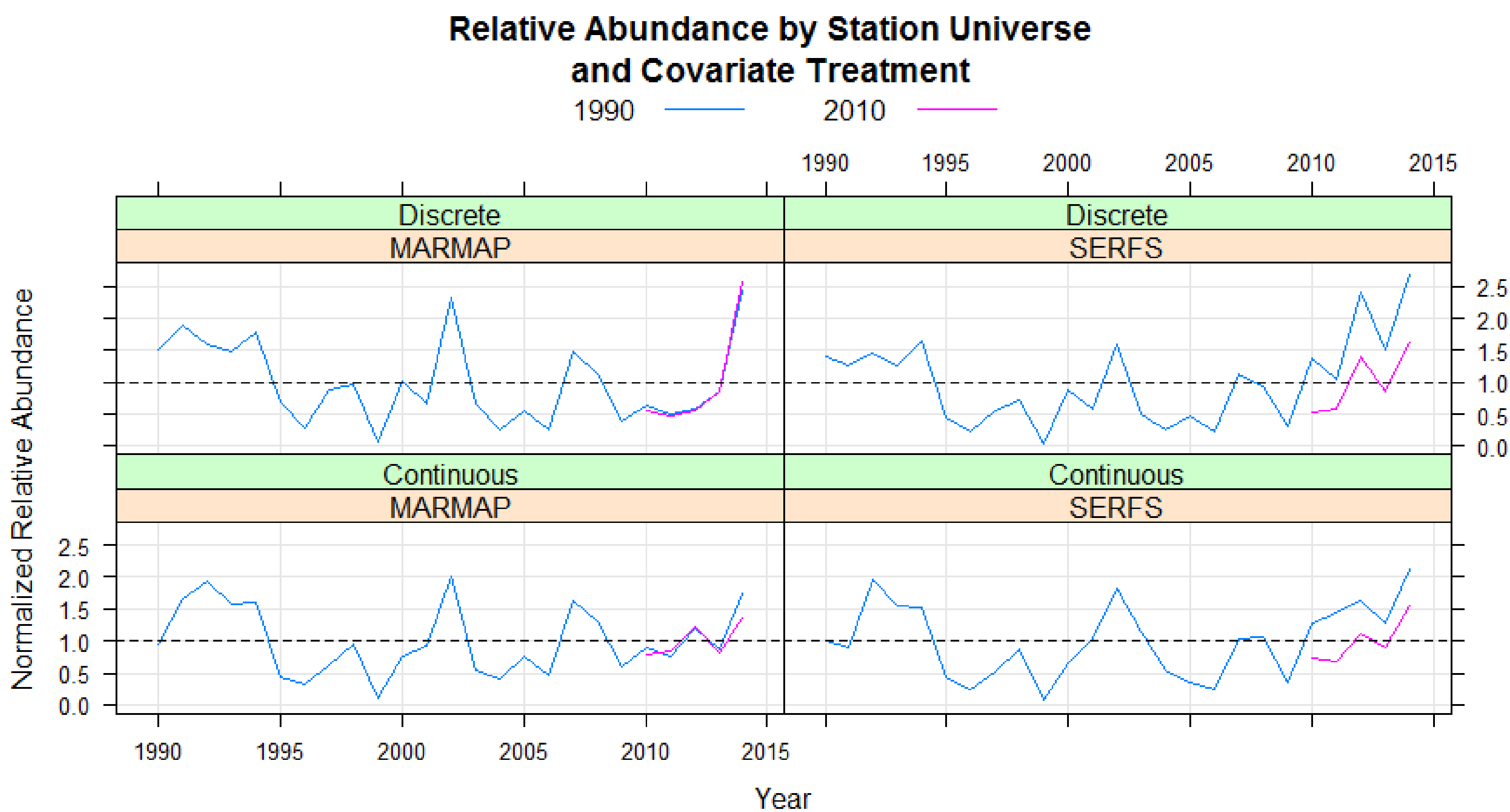


Figure 14: Same data as presented in Figure 13, here comparing pairs of models using the same data set and covariate treatment technique, but different start years.

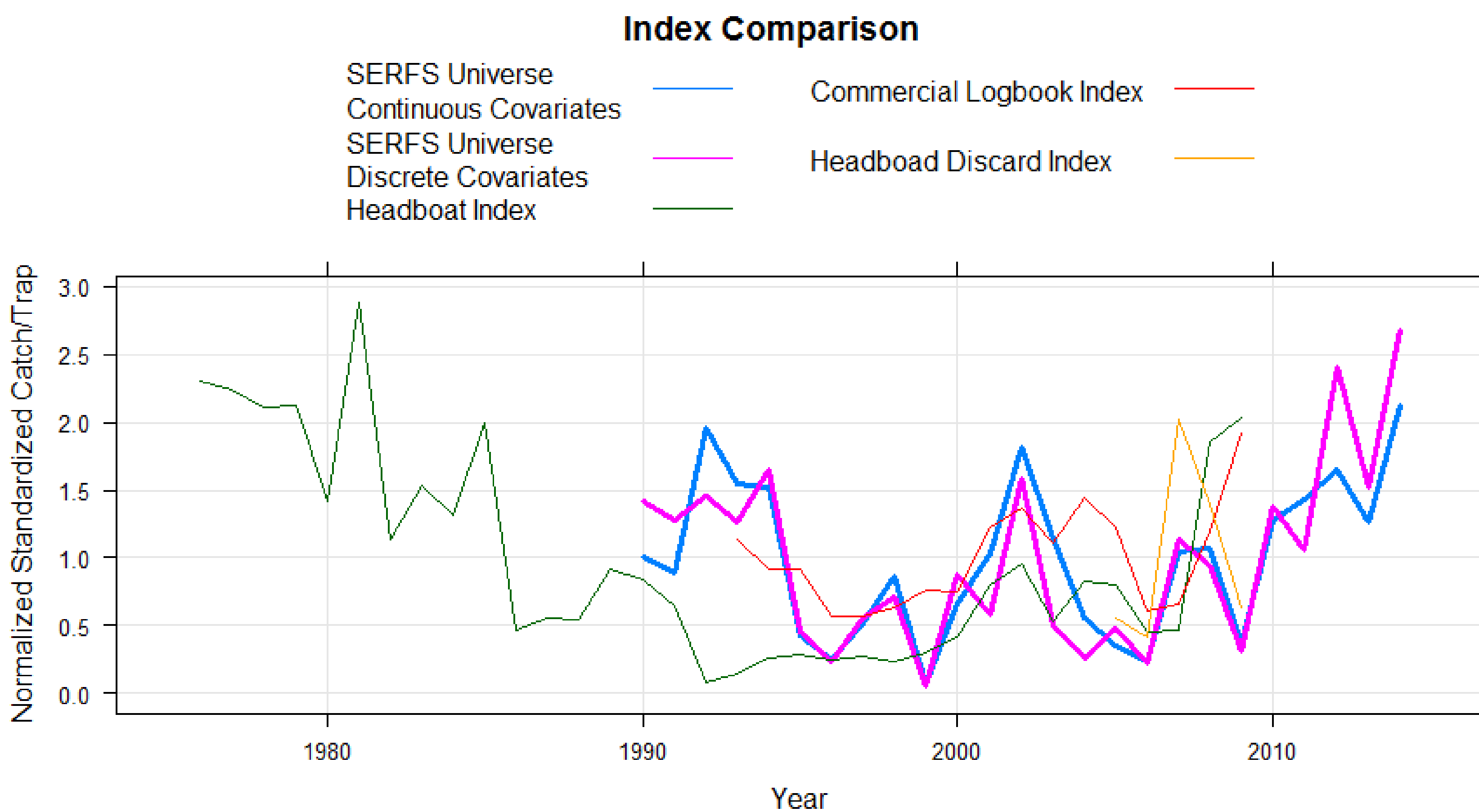


Figure 15: Comparison of the two full time-series indices using the SERFS Universe data set to the three fishery-dependent relative abundance indices of Red Snapper produced for SEDAR 24.

ABC determination methods by Center - email communications

PIFSC:

Standard P* approach

AFSC:

Tier 1: Geometric mean of F_MSY*fishable biomass
Tier 3: F40*fish_sel*natage*wt_age
Tier 4: F40*survey biomass
Tier 5: Recent survey biomass or average * 0.75* M (this is just an assumption of q=1)
Tier 6: Average catch over some fixed period * 0.75

NWFSC:

On the US continental Pacific coast, the council predominantly uses assessment based OFLs (with SSC final determination depending on stock assessment output/rigor/available data) and ABCs (with Council final determination depending on risk level). The one that I'm aware of that is different is Pacific Sardine. Here they use an environmentally driven (SST) formulation to specify Emsy, which is then related to specifying the OFL and ABC. You can find the assessment here (http://www.pcouncil.org/wp-content/uploads/2017/05/Appendix-C-2017-sardine-assessment-NOAA-TM-NMFS-SWFSC-576.pdf), and a brief description of this approach is in the executive summary (pages 13-14). I pasted below a few summary points from that document.

NEFSC:

You are correct that the Georges Bank yellowtail flounder assessment uses survey biomass expanded to population biomass through a catchability estimate along with an exploitation rate to derive the ABC (see https://www.nefsc.noaa.gov/saw/trac/ for the latest assessment). This approach is also used for Gulf of Maine winter flounder and Witch flounder (see https://www.nefsc.noaa.gov/publications/crd/crd1717/ for the latest updates and https://www.nefsc.noaa.gov/publications/crd/crd1117/ and https://www.nefsc.noaa.gov/publications/crd/crd1703/ for the most recent benchmarks).

We also have a survey smoothing approach that modifies recent catch according to changes in the survey. This approach has been used for both Georges Bank cod (https://www.nefsc.noaa.gov/publications/crd/crd1717/), Eastern Georges Bank cod (https://www.nefsc.noaa.gov/saw/trac/), and Monkfish (https://www.nefsc.noaa.gov/publications/crd/crd1609/crd1609.pdf), although in slightly different forms. The approach is currently under consideration by the NEFMC SSC for application to Southern New England Mid-Atlantic yellowtail flounder (no citeable reference, but see attached WP for details of the approach).

The Windowpane flounder stocks use AIM (An Index Method) to set ABC (https://www.nefsc.noaa.gov/publications/crd/crd1717/). Ocean Pout uses the survey and catch history to set ABC (https://www.nefsc.noaa.gov/publications/crd/crd1717/). The seven stocks in the Skate complex use the surveys in a different way to set the ABCs (https://www.nefsc.noaa.gov/publications/crd/crd0902/). We also have a truly data-poor assessment for deep sea red crab that only has two video surveys separated by 40 years along with catch information (https://www.nefsc.noaa.gov/publications/crd/crd0902/).

Another different approach is found in the surfclam assessment that uses SS for trend but doesn't believe the absolute magnitude of the estimates (https://www.nefsc.noaa.gov/publications/crd/crd1705/).

Methods used at other Centers:

PIFSC: Standard P* approach

i. Has the method been vetted through the SAFMC SSC?
    1. Yes and is used by the SSC for ABC determination
ii. What are the pros and cons of each method?
    1. Pros: Includes scientific uncertainty and a risk tolerance for management
    2. Cons: Doesn't include structural uncertainty
iii. Are the data for red snapper sufficient for the method?
    1. Yes and this has already been completed for red snapper

AFSC: Look at p.5 of document called "species profiles"
Tier 1: **Harmonic** mean of pdf of F_MSY*fishable biomass (fishable biomass is projected 1 year forward)
Tier 2: Point estimate of F_MSY*fishable biomass*F40/f35 (fishable biomass is projected 1 year foward) -- Tier 2 hasn't been used.
Tier 3: F40*fish_sel*natage*wt_age (natage is projected 1 year forward)
Tier 4: F40*survey biomass
Tier 5: Recent survey biomass or average * 0.75* M (this is just an assumption of q=1)
Tier 6: Average or maximum catch over some fixed period * 0.75

i. Has the method been vetted through the SAFMC SSC?
    1. Most of these, if not all, have been vetted through the SAFMC SSC in some form. The Average Catch approach is used for some stocks by the SAFMC SSC. SPR based approaches (F30, F35, and F40) have been discussed by the SAFMC SSC.
ii. What are the pros and cons of each method?
    1. Pros: Well studied and used to effectively manage some stocks. Leverages all of the data available for a species given the tiered nature of the harvest control rule.
    2. Cons: Data not available in the SA for some of the options.
iii. Are the data for red snapper sufficient for the method?
    1. Yes. Using average catch would not use all of the data available for red snapper (under utilization of data).

NWFSC: On the US continental Pacific coast, the council predominantly uses assessment based OFLs (with SSC final determination depending on stock assessment output/rigor/available data) and ABCs (with Council final determination depending on risk level). The one that I'm aware of that is different is Pacific Sardine. Here they use an environmentally driven (SST) formulation to specify Emsy, which is then related to specifying the OFL and ABC. You can find the assessment here (http://www.pcouncil.org/wp-content/uploads/2017/05/Appendix-C-2017-sardine-assessment-NOAA-TM-NMFS-SWFSC-576.pdf), and a brief description of this approach is in the executive summary (pages 13-14). I pasted below a few summary points from that document.

- i. Has the method been vetted through the SAFMC SSC?
    1. No, use of environmental metrics to help determine ABCs (as implemented through a harvest control rule) have not been vetted by the SAFMC SSC.
- ii. What are the pros and cons of each method?
    1. Pros: Includes environmental components and uncertainty into the determination of an ABC.
    2. Cons: Requires identification of an environmental factor linked to a species population dynamics.
- iii. Are the data for red snapper sufficient for the method?
    1. No, no specific link between red snapper and an environmental factor has been identified. Thus, this methods cannot be used.

NEFSC: You are correct that the Georges Bank yellowtail flounder assessment uses survey biomass expanded to population biomass through a catchability estimate along with an exploitation rate to derive the ABC (see https://www.nefsc.noaa.gov/saw/trac/ for the latest assessment). This approach is also used for Gulf of Maine winter flounder and Witch flounder (see https://www.nefsc.noaa.gov/publications/crd/crd1717/ for the latest updates and https://www.nefsc.noaa.gov/publications/crd/crd1117/ and https://www.nefsc.noaa.gov/publications/crd/crd1703/ for the most recent benchmarks).

The basic model of abundance would be based on empirical measures of abundance and assumed parameters as follows □ = (□□/ □□□)(□□ /□) Where N is the estimated total population , It is the index of abundance expressed as numbers or weight per tow, Ad is the total area within the sampling domain, a is the average area swept per tow, pd is the fraction of the total area within the population domain, (i.e., pd=Ad/A where A is the total area where the stock resides), and e is the efficiency of the gear, expressed as probability of capture given encounter. (From document called "Center methods…"

- iv. Has the method been vetted through the SAFMC SSC?
    1. No, use of absolute biomass metrics to help determine ABCs has not been vetted by the SAFMC SSC.
- v. What are the pros and cons of each method?
    1. Pros: "Direct" estimate of population size.

2. Cons: Requires estimation of a known catchability, which we do not have the ability to estimate. Requires an estimate of the total population that is contained within the survey sampling frame, which we do not have an estimate of. Requires an index with a long time series and contrast.

vi. Are the data for red snapper sufficient for the method?

1. No, we do not have a broad index with estimated catchability and a long time series.

We also have a survey smoothing approach that modifies recent catch according to changes in the survey. This approach has been used for both Georges Bank cod (https://www.nefsc.noaa.gov/publications/crd/crd1717/), Eastern Georges Bank cod (https://www.nefsc.noaa.gov/saw/trac/), and Monkfish (https://www.nefsc.noaa.gov/publications/crd/crd1609/crd1609.pdf), although in slightly different forms. The approach is currently under consideration by the NEFMC SSC for application to Southern New England Mid-Atlantic yellowtail flounder (no citeable reference, but see attached WP for details of the approach).

SEE reference on Google drive - Application of planBsmooth approach to groundfish stocks

vii. Has the method been vetted through the SAFMC SSC?

1. No, the method if using a smoothed, average biomass time series has not been vetted by the SAFMC SSC. [This is just an expansion of the method directly above this.]

viii. What are the pros and cons of each method?

1. Pros: "Direct" estimate of population size.
2. Cons: Requires estimation of a known catchability, which we do not have the ability to estimate. Requires an estimate of the total population that is contained within the survey sampling frame, which we do not have an estimate of. Requires an index with a long time series and contrast.

ix. Are the data for red snapper sufficient for the method?

1. No, we do not have a broad index with estimated catchability and a long time series.

x. Note - this was looked at to address severe retrospective patterns.

The Windowpane flounder stocks uses bottom trawl survey data and the AIM (An Index Method) package to set ABCs (https://www.nefsc.noaa.gov/publications/crd/crd1717/). A long time series of catch and FI survey data are used to identify trends in survey biomass catch/tow, relative F (catch/3-yr moving average catch/tow), and the replacement ratio (current relf/moving average refF). This approach involves either selecting MSY by calculating the median catch during a reference period in which fishing did not result in index declines and applying MSY/IBmsy = relF at MSY (IBmsy = kg/tow at MSY); or examining trends in replacement ratio and identifying a period where it is around 1, then applying the above equation to get MSY. Overfished = 3-yr moving average IB relative to Bthreshold = 50%IBmsy, Fmsy = relF at MSY or AIM-based replacement ratio=1. Requires an index of abundance and catch covering the same time period which includes a reference period of low exploitation. AIM's randomization test provides limited bootstrapped CIs and some stochastic projection runs can be generated.

i. Has the method been vetted through the SAFMC SSC?
   1. No, the SSC has not reviewed the use of AIM or any other survey-based relF approach to set ABCs in the South Atlantic.

Comment [1]: Is this true? I'm a newbie to the SSC.

Comment [2]: I think that this is true. We can run it by the work group, some of them have been on the committee for quite some time.

ii. What are the pros and cons of each method?
   1. Pros: Leverages long time series of reliable catch and an index of abundance spanning pre- and post high exploitation periods to identify sustainable fishery removal rates using very little data.
   2. Cons: Requires time series of reliable catch and an index of abundance spanning pre- and post high exploitation periods which may not exist for red snapper. Assumes catchability has not changed over the assessment period. Sensitive to smoothing decisions. Limited uncertainty and projection capabilities.

iii. Are the data for red snapper sufficient for the method?
   1. No, not unless a new long time series index of abundance can be generated from existing data sources. Index should span the early period prior to modern/high red snapper exploitation or at least cover a period during which the replacement ratio = 1.

Ocean Pout is similar to windowpane, but only uses the survey and catch history to set ABCs (https://www.nefsc.noaa.gov/publications/crd/crd1717/). It does not use AIM because of lack of a significant relationship between relative F and replacement ratio. This approach involves selecting MSY by calculating the median landings during a reference period in which fishing did not result in index declines and applying MSY/IBmsy = relF at MSY (IBmsy = kg/tow at MSY).

iv. Has the method been vetted through the SAFMC SSC?
   1. No, the SSC has not reviewed the use a AIM or any other survey-based relF approach to set ABCs in the South Atlantic.

v. What are the pros and cons of each method?
    1. Pros: Leverages long time series of reliable catch and an index of abundance spanning pre- and post high exploitation periods to identify sustainable fishery removal rates using very little data.
    2. Cons: Requires time series of reliable catch and an index of abundance spanning pre- and post high exploitation periods which may not exist for red snapper. Assumes catchability has not changed over the assessment period. Sensitive to smoothing decisions. No uncertainty or projection capabilities.

vi. Are the data for red snapper sufficient for the method?
    1. No, not unless a new long time series index of abundance can be generated from existing data sources. Index must span an early period prior to modern/high red snapper exploitation.

The seven stocks in the Skate complex use the surveys in a different way to set the ABCs (https://www.nefsc.noaa.gov/publications/crd/crd0902/). BMSY Proxy is the 75th percentile of the given survey time series (3-yr moving average), and half that value for Bthreshold. It was assumed that all species had at some time passed through BMSY at some point in the time series. The exception is barndoor skate for which the mean of the first four years of the autumn survey were used instead, given that biomass had been extremely low during most of the time series. The thresholds for fishing mortality are based on annual percentage declines of the three-year average of the NEFSC trawl survey time series chosen for the biomass reference points. The percentages are specified for each species individually based on historical variation within the survey. Overfishing is occurring when the three-year moving average of the given survey biomass index declines by more than the average CV of the time series.

vii. Has the method been vetted through the SAFMC SSC?
    1. No?

viii. What are the pros and cons of each method?
    1. Pros: Only survey index of abundance and biological knowledge of the species needed.
    2. Cons: Requires time series of reliable catch and an index of abundance that covers a time period during which Bmsy was achieved.

ix. Are the data for red snapper sufficient for the method?

1. No, not unless a new long time series index of abundance can be generated from existing data sources. Time series must span time period during which Bmsy was achieved.

We also have a truly data-poor assessment for deep sea red crab that only has two video surveys separated by 40 years along with catch information (https://www.nefsc.noaa.gov/publications/crd/crd0902/). Based on the FMP, the red crab stock will be considered to be in an overfished condition if one of the following three conditions is met:

Condition 1 -- The current biomass of red crab is below ½ BMSY in the New England Council's management area (excluding the Gulf of Maine). Bmsy based on Schaefer surplus production model for male crabs.

Condition 2 -- The annual fleet average CPUE, measured as marketable crabs landed per trap haul, continues to decline below a baseline level for three or more consecutive years.

Condition 3 -- The annual fleet average CPUE, measured as marketable crabs landed per trap haul, falls below a minimum threshold level in any single year. Similarly two potential approaches or proxies for identifying overfishing are described: Proxy #1: F / FMSY -- It is common for data sparse stocks to estimate trends in fishing mortality as an exploitation ratio, i.e., landings or catch divided by an index of abundance, usually from a survey. As a proxy for FMSY, Councils in the past have selected an exploitation level that existed during a time with no trend in biomass at an intermediate biomass level. Proxy #2: Landings / MSY – In the absence of other information, overfishing can be defined as catches in excess of an estimate of MSY. Although crude, provides an indication of current fishing effort relative to MSY conditions.

The FMP describes a default control rule that could be used by managers, although this has proved impractical due to lack of biomass, exploitation, natural mortality and reference point estimates.

x. Has the method been vetted through the SAFMC SSC?
    1. Some aspects have, others not. Certainly not this complete package.

xi. What are the pros and cons of each method?
    1. Pros: Uses surveys with gap (surveys combined across time gap as would likely need to be done in SA). Some status setting conditions involve use of fishery CPUE instead of survey CPUE.
    2. Cons: SPM-based MSY available but not accepted as primary model for management, right?

xii. Are the data for red snapper sufficient for the method?

1. Perhaps...would depend on which surveys were selected for consideration. Do we have a reliable logbook index?

Another different approach is found in the surfclam assessment that uses SS for trend but doesn't believe the absolute magnitude of the estimates (https://www.nefsc.noaa.gov/publications/crd/crd1705/). The OFL was determined to be not estimable, so The recommended ABC was based on a recent catch that has been sustained by the stock historically and shown to show no harm. This ABC is recommended for three years. *Survey data, including survey indices and swept area estimates of biomass (when available)*, catch records, and spatial distribution of the fishery will be examined as interim metrics.

xiii. Has the method been vetted through the SAFMC SSC?

1. In the form of average catch….yes, but this is a very unique stock with almost 0% chance of overfishing occurring (so not red snapper!). Also, doesn't use surveys directly to set the ABC, but only as rumble strips.

xiv. What are the pros and cons of each method?

1. Pros: easy to calculate
2. Cons: Doesn't use survey data. Need a stock as lightly exploited as surfclam to be so confident in this type of approach

xv. Are the data for red snapper sufficient for the method?

1. Yes, but not a survey-based method desired by Council.

Rcrit method for Atlantic halibut (document: Halibut-Assessment-Report-draft-12-01-17.pdf)

Builds off of GB cod index based method - reviewed by NE SSC

A method to determine if the differences seen over the duration of an index (Rcrit), specifically at the end of a time series, are significantly different. Method is outlined in reference document on page 13 of the pdf. If the change is significantly different, then an estimate of the catchability is needed to determine the scale or magnitude of the change. (from pdf p.16 of reference document - "While Rcrit provides a way of quantifying the rate of change in population size, it cannot distinguish the change in scale. For example a population that increase 3 fold during some period could increase from 2% to 6% of the virgin stock size for from 20 to 60%."). Thus, in order to use the Rcrit method an index that has a long time series and continues until the end of the time series is needed, as well as an estimate of catchability to determine the scale of the change and historic fishing mortality rates.

Application of PlanBsmooth approach to groundfish stocks

Chris Legault (NEFSC)

Introduction

During the October 23-24, 2017 NEFMC SSC meeting to set OFL and ABC for 19 groundfish stocks, I provided results of the PlanBsmooth approach for some stocks verbally. After the meeting, PDT members Paul Nitschke and Jamie Cournane contacted me regarding details of the PlanBsmooth approach for the SNEMA Yellowtail Flounder stock. This stock had an ASAP model that was accepted by the review panel and used by the PDT to provide possible OFL and ABC values. However, during our deliberations the SSC decided to use the PlanBsmooth approach to set the OFL and ABC. When I prepared a full description of the approach for the PDT, I realized that I had inadvertently used the wrong years to define the recent catch. I had used 2015-2017 instead of 2014-2016. The amount of SNEMA YT catch in 2017 was much less than 2014, causing a large change in the OFL and ABC. During my review of the application across all 19 groundfish stocks I also realized that some surveys that were in the database I drew from were not used in the assessment. This document provides details of the PlanBsmooth application for all 19 groundfish stocks so that the SSC is more informed about the approach during its upcoming conference call.

Data

Catch data from the PDT report for years 2014 through 2017 and the two three year means (2014-2016 and 2015-2017) are provided by stock in Table 1. The ordering of the stocks follows the order in the PDT presentation. Note that only three stocks have a higher mean catch during 2015-2017 compared to 2014-2016 (wolffish, gomhaddock, and gbhaddock). During the SSC meeting, I reported OFL and ABC values using the 2015-2017 mean catch instead of the 2014-2016 mean catch for gbwinter (OFL, ABC = 550, 412 mt), snemawinter (681, 510), snemayt (69, 52), ccgomyt (452, 339), and plaice (1461, 1096). These reported values are incorrect due to using the wrong time period for the three year recent catch.

While examining the SNEMA Yellowtail Flounder stock in more detail, I realized there were both stocks with missing surveys in our ADIOS database as well as stocks with extra surveys in our ADIOS database (Table 2). The values I reported during the SSC meeting used all the surveys available in ADIOS (those listed as either U or AN in Table 2). This means the multipliers I used for snemawinter (multiplier = 0.995), snemayt (multiplier = 0.360), and witch (multiplier = 1.133, OFL, ABC = 669, 502) were incorrect and thus the OFL and ABC I reported during the meeting were incorrect.

Methods and Results

The PlanBsmooth approach estimates OFL as the recent change in the smoothed, averaged biomass index from surveys applied to the recent catch. The ABC is calculated as 0.75 * OFL. Thus, when surveys are declining, the OFL declines, while increasing surveys cause the OFL to increase. There are of course many details in how exactly the approach is applied. An R package for PlanBsmooth is available at https://github.com/cmlegault/PlanBsmooth.

As shown in Table 2, the PlanBsmooth approach cannot always use the same information used in an analytical assessment. This is due to data availability for this exercise (I drew from a database called ADIOS that does not contain all surveys). It is also due to incomplete time series, such as the NMFS winter survey. The default approach in PlanBsmooth is to not standardize the surveys before combining them. This means that incomplete surveys, especially ones with much higher or lower catch rates than the other surveys, will cause a discontinuity in the average survey time series that could influence the loess smooth well beyond the years where it is included. Surveys covering few years, such as the MENH surveys, are particularly problematic for this approach. The surveys that were available and used in the assessment (only those denoted "U" in Table 2) were used in the results presented in this document.

To compute the average biomass index, the surveys are first lagged ahead one year if they occurred during the fall (meaning a fall survey value in 2016 becomes 2017 for the analysis). The lagged fall and standard spring surveys are then combined using a simple arithmetic average to produce the average survey time series. Years with missing survey information for any of the used surveys become NA in this average survey time series. Thus, only years where all appropriately lagged surveys are available are included in the average biomass index.

The average biomass index time series is then smoothed. A loess smooth is applied to the recent 33 years (1985-2017) using a span of 0.3. If the average survey time period is less than 33 years, for example during a retrospective analysis, then the span is changed to 9.9/nyears so that the same amount of smoothing is applied despite the change in the number of years. The loess smooth of each average biomass index time series along with approximate 95% confidence intervals of the smooth are shown for each stock in the accompanying file GARM2017PlanBsmooth.pdf. The smooth for SNEMA YT is shown in Figure 1 with the caption providing a guide for how to interpret the figure for all the stocks.

Once the surveys are averaged and smoothed, the most recent three years are used to determine the directional change in the recent surveys. The natural logarithm is taken of the three recent loess smooth predicted values and a linear regression fit through these points. The estimated slope of this regression is transformed back to regular scale using the exponentiation function to create the Multiplier value labeled in Figure 1. The retransformed linear fit is shown in Figure 1 as a dashed red line. This Multiplier is used to calculate the OFL as OFL = recent mean catch * Multiplier. The ABC is then calculated as 0.75 * OFL.

The results of these OFL and ABC calculations for each stock are shown in Table 3. Note the shaded columns in Table 3 are for comparison only, they use the incorrect years 2015-2017 to compute the mean catch. The correct values use years 2014-2016 to compute the mean catch and are not shaded in Table 3.

Multipliers for the 19 groundfish stocks estimated by PlanBsmooth are compared in Figure 4. The two stocks that use PlanBsmooth correspond to the largest (gbcod = 1.5173) and smallest (snemayt = 0.3595) multipliers across all 19 stocks. The remaining 17 stocks have multipliers between 0.7 and 1.3 (meaning OFL changes by less than 30% from recent catch).

Biomass index Mohn's rho values for 18 groundfish stocks estimated by PlanBsmooth are compared in Figure 5. The two stocks that use PlanBsmooth correspond to the smallest (snemayt = -0.318) and 5th smallest (gbcod = -0.04) of the 18 stocks. All of the 18 stocks have minor retrospective patterns because the rho adjusted terminal value is within the 90% confidence intervals of the terminal year. The one stock not included in Figure 5 is Gulf of Maine Haddock. As seen in the included pdf file, the Mohn's rho value for this stock is -18.9, indicating something has gone wrong because Mohn's rho should not have a value less than -1. The reason for this result is that the 0 year peel (the original data) has a loess smooth predicted value that is negative for 2012. Thus, when the retrospective value is computed as (tip – term)/term for the 5 year peel (making 2012 the terminal values) the negative value for term causes the Mohn's rho calculation to produce a large negative value (-131.8). This could be fixed by taking the absolute value of the term in the denominator, but would result in a very large positive value and would be a deviation from the standard Mohn's rho calculation. Instead of trying to plot this stock with the rest, I decided to take it out of the plot and note the reason why here in the text. Dropping just the 5 year peel for this stock (meaning using only peels 1-4, 6, and 7), results in a Mohn's rho value of -0.047. This value is well within the range seen in the other groundfish stocks.

Discussion

The changes to SNEMA YT recent catch (mt) were major (193 to 371) while the changes to the multiplier were minor (0.360 to 0.3595) resulting in a major change to OFL (69 to 134 mt) and ABC (52 to 100 mt) for this stock. This result causes an even larger issue when comparing this new ABC with the OFL for 2018 from the model, 45 mt, because the PlanBsmooth ABC is now more than twice as large as the model OFL. I cannot speak for NMFS, but this comparison will certainly raise questions about whether the ABC can be approved, as noted by Mike Simpkins during the SSC meeting for the previously agreed ABC of 52 mt.

A sharp-eyed reader may notice in Figure 2 that peel 1 does not end in 2016 for SNEMA YT as would be expected. This is because the loess smooth for the 1 year peel estimates a negative biomass value for 2016. Since the natural logarithm of a negative number is undefined, the 2016 value is not included in the 1 year peel regression, meaning only year 2014 and 2015 are used in the regression for that peel when computing the multiplier. The ability of the loess smooth to estimate negative biomass values despite all the observations being positive can cause problems for the PlanBsmooth approach.

The PlanBsmooth approach has a number of decisions that could be made differently. For example, the year range to define recent catch, whether to standardize surveys before averaging, use of biomass or numbers as the catch per tow index for a survey, the time frame and span for the loess smoother, whether to apply the loess smooth in regular or log space, use of smoothing approaches other than loess, the number of years in the regression to estimate the multiplier, the conversion of the log-scale slope to a multiplier, and whether the recent catch times the multiplier is the OFL or ABC are all decisions that could be made differently. As mentioned by John Wiedenmann during the SSC meeting, we do not have a policy for how to apply these data-limited harvest control rules currently. Adopting one that was not examined during the review meeting for a particular stock puts the SSC in the position of creating the “assessment” (quotes used because we did not reject the accepted assessment for SNEMA YT) and also serving as the review body of that decision. In my opinion, it would be better if the SSC sub-group on harvest control rules for data-limited approaches could provide guidance regarding this situation that could be reviewed by the appropriate panel before being brought to the SSC for OFL and ABC setting.

I hope this document improves transparency of the PlanBsmooth approach and reduces questions during our upcoming SSC conference call. Feel free to email me or give me a call (office phone 508-495-2025) prior to the conference call if you have any questions.

Table 1. Catch (mt) by stock for years 2014 through 2017 and the arithmetic average of years 2014-2016 and 2015-2017.

		Year				Mean Catch	
IDnum	Stock	2014	2015	2016	2017	2014-2016	2015-2017
1	gbwinter	1216	941	493	574	883.33	669.33
2	gomwinter	275	217	221	217	237.67	218.33
3	snemawinter	753	749	678	625	726.67	684.00
4	snemayt	625	337	152	90	371.33	193.00
5	ccgomyt	475	351	368	353	398.00	357.33
6	swindowpane	539	539	571	466	549.67	525.33
7	nwindowpane	215	188	85	83	162.67	118.67
8	pout	74	63	49	39	62.00	50.33
9	wolffish	1	1	1	2	1.00	1.33
10	plaice	1328	1316	1108	1226	1250.67	1216.67
11	witch	675	585	512	617	590.67	571.33
12	gomcod	1471	325	599	428	798.33	450.67
13	gbcod	2081	1962	1982	1312	2008.33	1752.00
14	gomhaddock	1012	1106	2313	2306	1477.00	1908.33
15	gbhaddock	18601	20687	17274	18920	18854.00	18960.33
16	whitehake	1980	1680	1396	1634	1685.33	1570.00
17	pollock	5777	4212	3676	4296	4555.00	4061.33
18	redfish	5083	5040	3925	4630	4682.67	4531.67
19	gbyt	159	118	44	33	107.00	65.00

Table 2. Survey and stock combinations considered for this analysis. The letter “U” denotes the survey was used for the stock both in the assessment and the PlanBsmooth calculations. The letter “M” denotes the stock was missing from the PlanBsmooth calculations but was used in the stock assessment. The letters “AN” denote the survey was available in the ADIOS database but was not included in the PlanBsmooth approach because either the survey was incomplete in recent years (NMFS winter survey) or else the surveys were not used in the stock assessment (pout and witch). The Other surveys for snemawinter are the Rhode Island spring, Connecticut spring, two New Jersey, Massachusetts young of year, Connecticut young of year, and University of Rhode Island Graduate School of Oceanography surveys.

IDnum	Stock	NMFS fall	NMFS spring	NMFS winter	MADMF fall	MADMF spring	MENH fall	MENH spring	DFO	AS Sh
1	gbwinter	U	U						M	
2	gomwinter	U	U		U	U	M	M		
3	snemawinter	U	U	AN		U				
4	snemayt	U	U	AN						
5	ccgomyt	U	U		U	U	M	M		
6	swindowpane	U								
7	nwindowpane	U								
8	pout		U	AN		AN				
9	wolffish	U	U			U				
10	plaice	U	U		U	U				
11	witch	U	U		AN	AN				
12	gomcod	U	U			U				
13	gbcod	U	U							
14	gomhaddock	U	U							
15	gbhaddock	U	U						M	
16	whitehake	U	U							
17	pollock	U	U							
18	redfish	U	U							
19	gbyt	U	U						M	

Table 3. Results of PlanBsmooth by stock. The shaded columns use mean catch for years 2015-2017 and are shown only for comparison. The unshaded columns use mean catch for years 2014-2016 and are the ones that should be used. OFL = Mean Catch * Multiplier. ABC = OFL * 0.75.

		Mean Catch			OFL		ABC	
ID	Stock	2014-2016	2015-2017	Multi-plier	2014-2016	2015-2017	2014-2016	2015-2017
1	gbwinter	883.33	669.33	0.8211	725	550	544	412
2	gomwinter	237.67	218.33	1.1585	275	253	207	190
3	snemawinter	726.67	684.00	0.9954	723	681	542	511
4	snemayt	371.33	193.00	0.3595	134	69	100	52
5	ccgomyt	398.00	357.33	1.2661	504	452	378	339
6	swindowpane	549.67	525.33	0.9517	523	500	392	375
7	nwindowpane	162.67	118.67	0.7493	122	89	91	67
8	pout	62.00	50.33	0.8468	53	43	39	32
9	wolffish	1.00	1.33	1.1463	1	2	1	1
10	plaice	1250.67	1216.67	1.2009	1502	1461	1126	1096
11	witch	590.67	571.33	1.1496	679	657	509	493
12	gomcod	798.33	450.67	1.2444	993	561	745	421
13	gbcod	2008.33	1752.00	1.5173	3047	2658	2285	1994
14	gomhaddock	1477.00	1908.33	1.2445	1838	2375	1379	1781
15	gbhaddock	18854.00	18960.33	1.0119	19078	19185	14308	14389
16	whitehake	1685.33	1570.00	1.1194	1886	1757	1415	1318
17	pollock	4555.00	4061.33	0.9567	4358	3885	3268	2914
18	redfish	4682.67	4531.67	1.0143	4750	4597	3562	3447
19	gbyt	107.00	65.00	0.7190	77	47	58	35

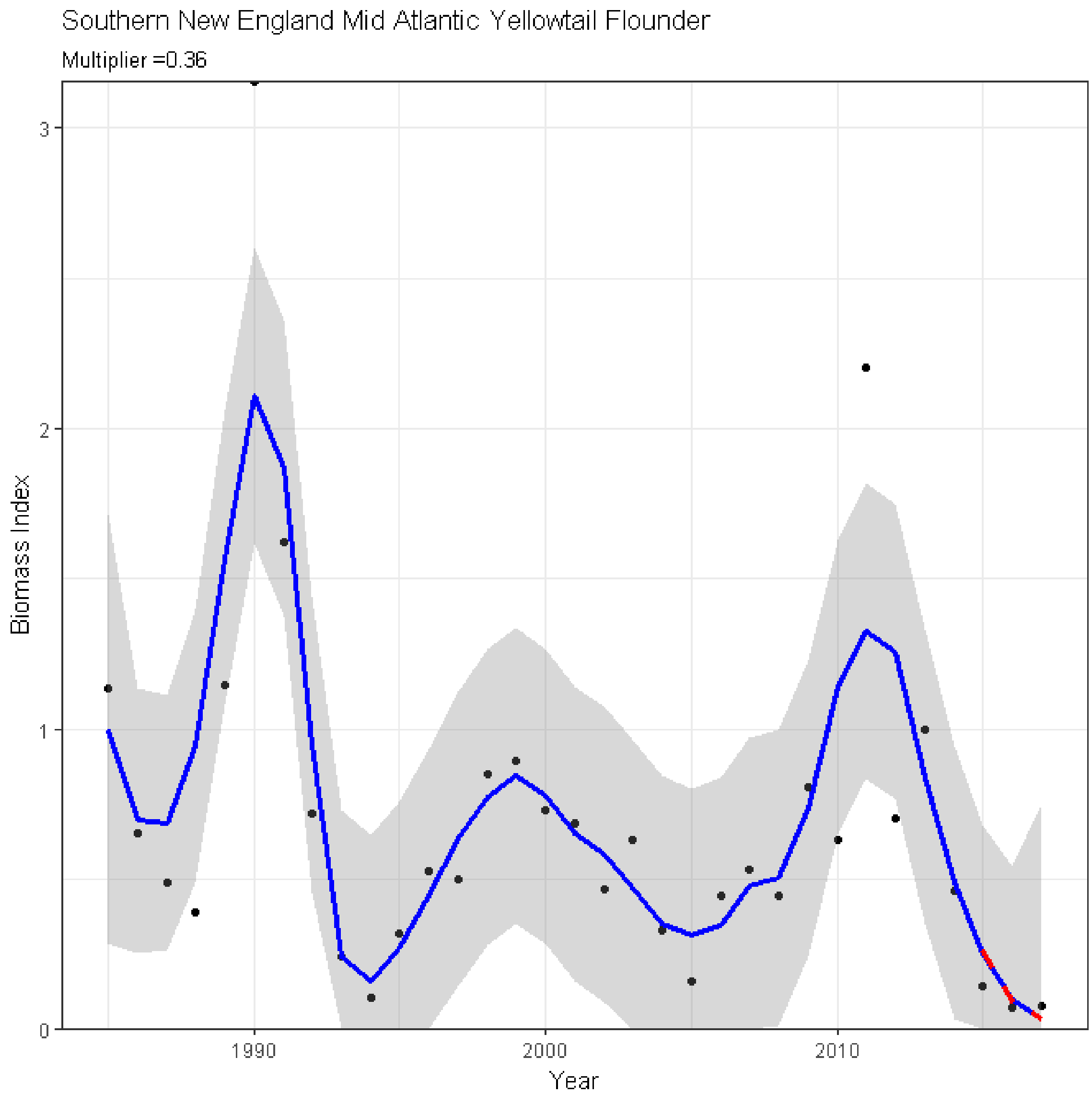


Figure 1. PlanBsmooth standard plot for Southern New England Mid-Atlantic Yellowtail Flounder. The dots denote the average survey values (arithmetic average of the NMFS fall survey lagged ahead one year and the NMFS spring survey). The blue line is the loess smooth. The gray area shows an approximate 95% confidence interval for the loess smooth. The red dashed line shows the retransformed log-linear fit to the most recent three years of the smoothed values. The Multiplier in the top left is the value used to generate the OFL as recent mean catch times the Multiplier.

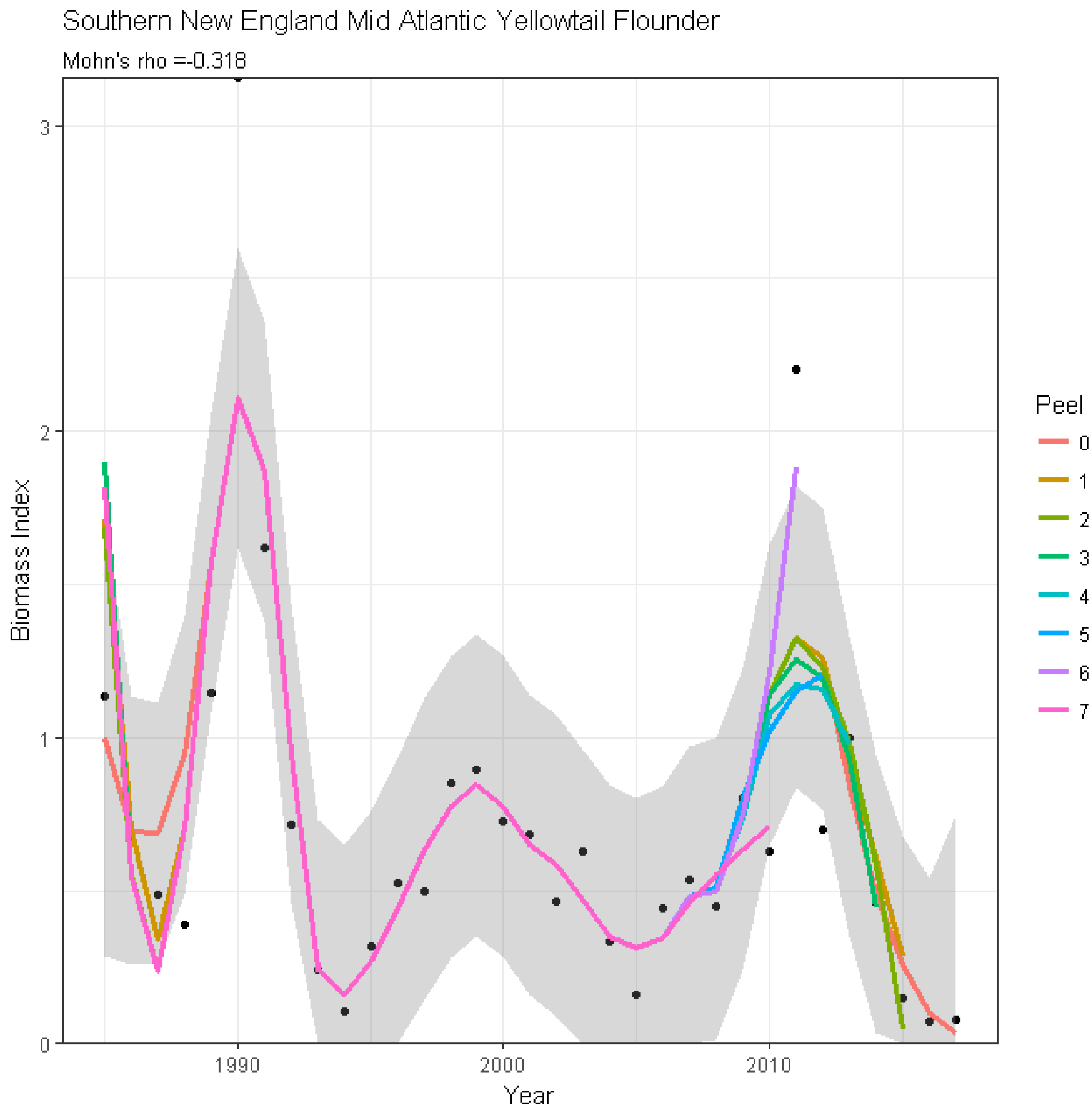


Figure 2. PlanBsmooth biomass index retrospective plot for Southern New England Mid-Atlantic Yellowtail Flounder. The dots show the average survey time series. The peel lines denote how many years from the terminal year have been removed when computing the loess smooth. The grey area shows an approximate 95% confidence interval for the loess smooth using peel 0 (the original data).

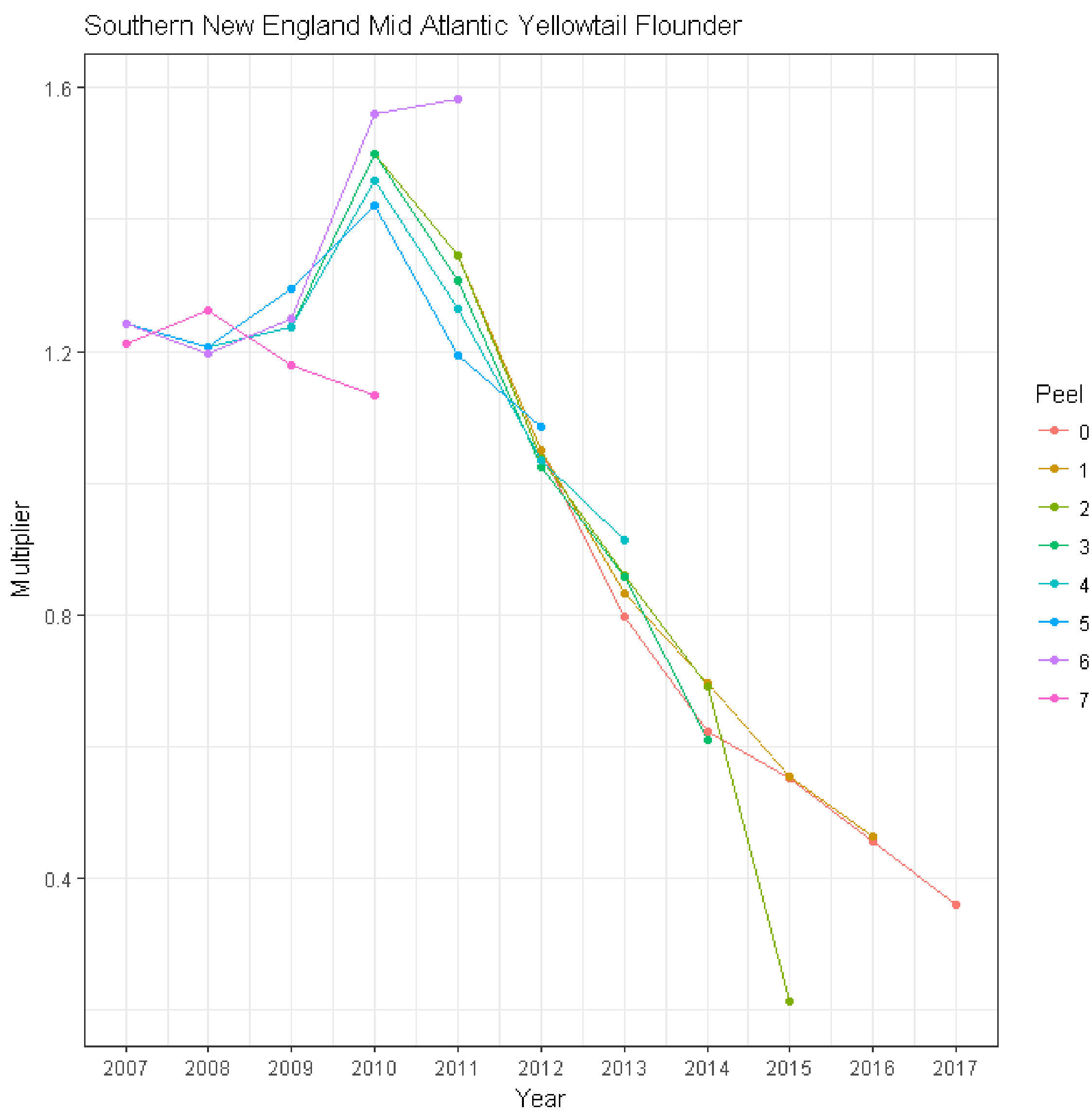


Figure 3. PlanBsmooth multiplier retrospective plot for Southern New England Mid-Atlantic Yellowtail Flounder. The log-linear regression is extended back in time using a three year moving window to estimate historical multipliers in addition to the standard terminal year multiplier. The peel indicates the number of years removed from the terminal year when computing the loess smooth.

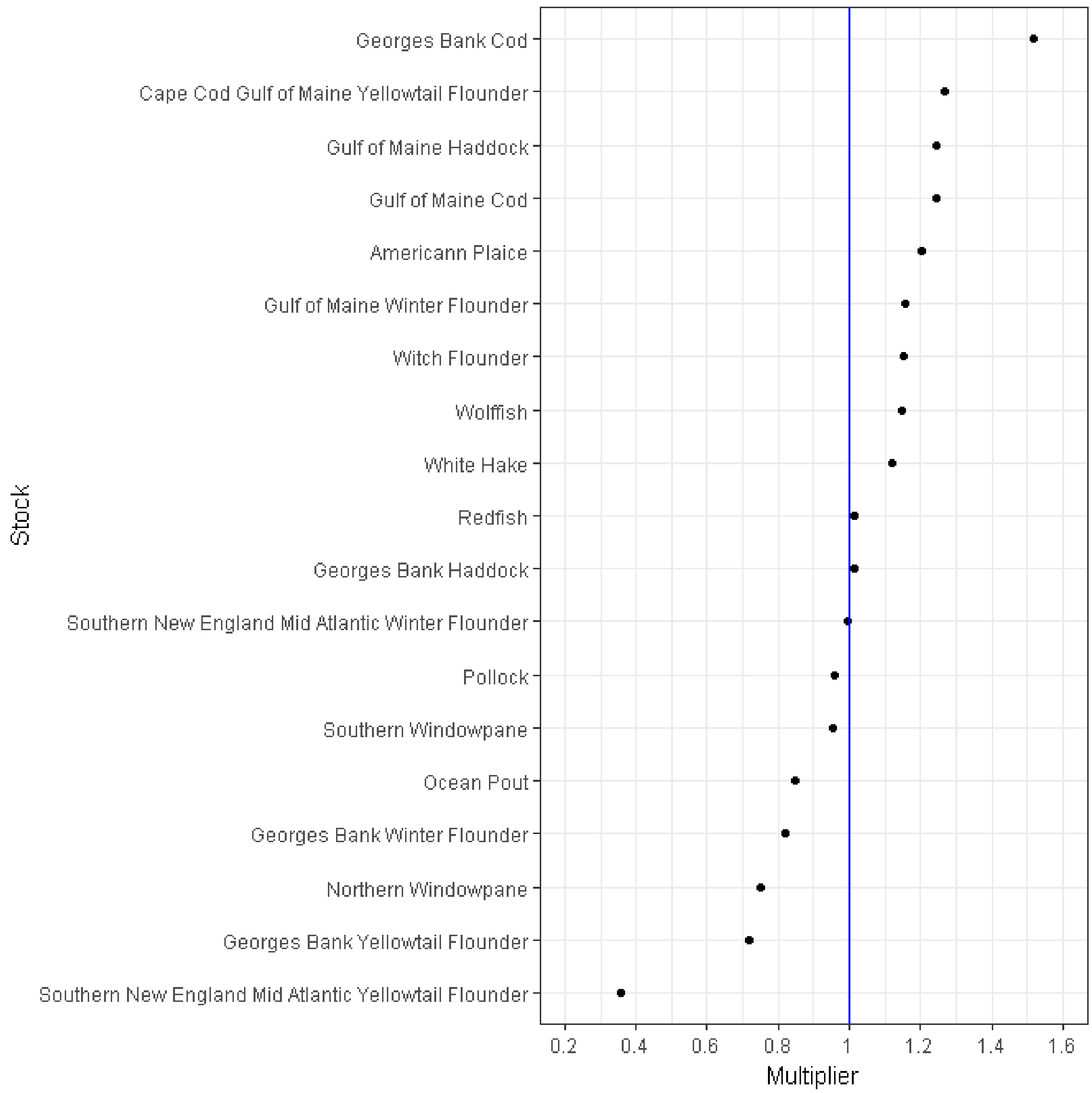


Figure 4. PlanBsmooth multipliers for the 19 groundfish stocks ordered from smallest to largest. The blue line denotes a multiplier of 1, meaning the OFL is equal to the recent mean catch.

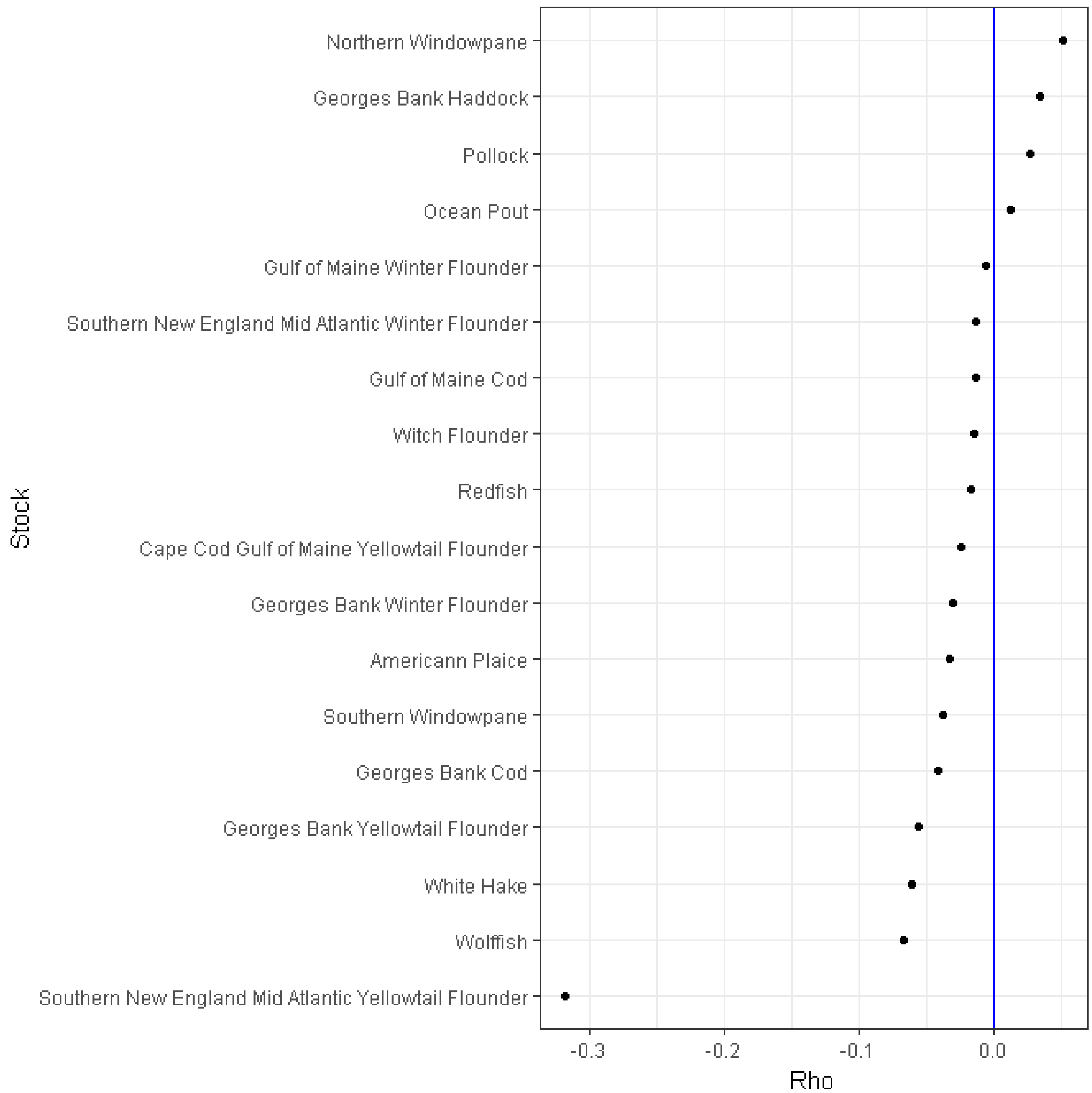


Figure 5. PlanBsmooth Mohn's rho values for 18 groundfish stocks ordered from smallest to largest. The GOM Haddock rho of -18.9 is not shown due to the negative 2012 prediction for the original data causing problems for this calculation (see Discussion section in text).

Plan B Assessment for Atlantic Halibut

Paul Rago

Webinar with NEFMC Science and Statistical Committee
December 14, 2017

Outline of this Presentation

- Follows the material in “Halibut Assessment for 2017”, Draft, December 1, 2017.
- Consideration of available data
- De-emphasizes the DCAC analyses
- Focuses on methodology used to project catch in 2018
  - Ratio methods and randomization tests to estimate magnitude and significance of changes in relative abundance.
  - Simulation tests of Ratio method
  - Proposed catch adjustment method based on rates of change in indices
  - Simulation tests of FSD method
  - Estimation of uncertainty of forecast
  - Application of method to DFO 3NOPs4VWX5Zc Atlantic halibut and IPHC Pacific halibut

The Plan B Dilemma

- Restrictions on introductions of new data and analytical models
- Rebuilding considerations
- No revisions of stock structure
- Accountability measures
- *How should catch be adjusted without measures of biomass and fishing mortality, and their respective reference points?*

Some Plan B Options

1. Use some function of recent catch
    1. Last year
    2. Some arbitrary average
    3. Some arbitrary scalar applied to some arbitrary average
2. Apply a method that relies entirely on the assumed state of the stock.
3. Apply a biologically based rate to a swept area estimate
4. Piggy back the US control rule on the management decisions applied to the adjoining Canadian stock
5. Develop an updating function that adjusts catches based on trends in one or more indices.

- First 4 options are either hard to justify or cause knife fights

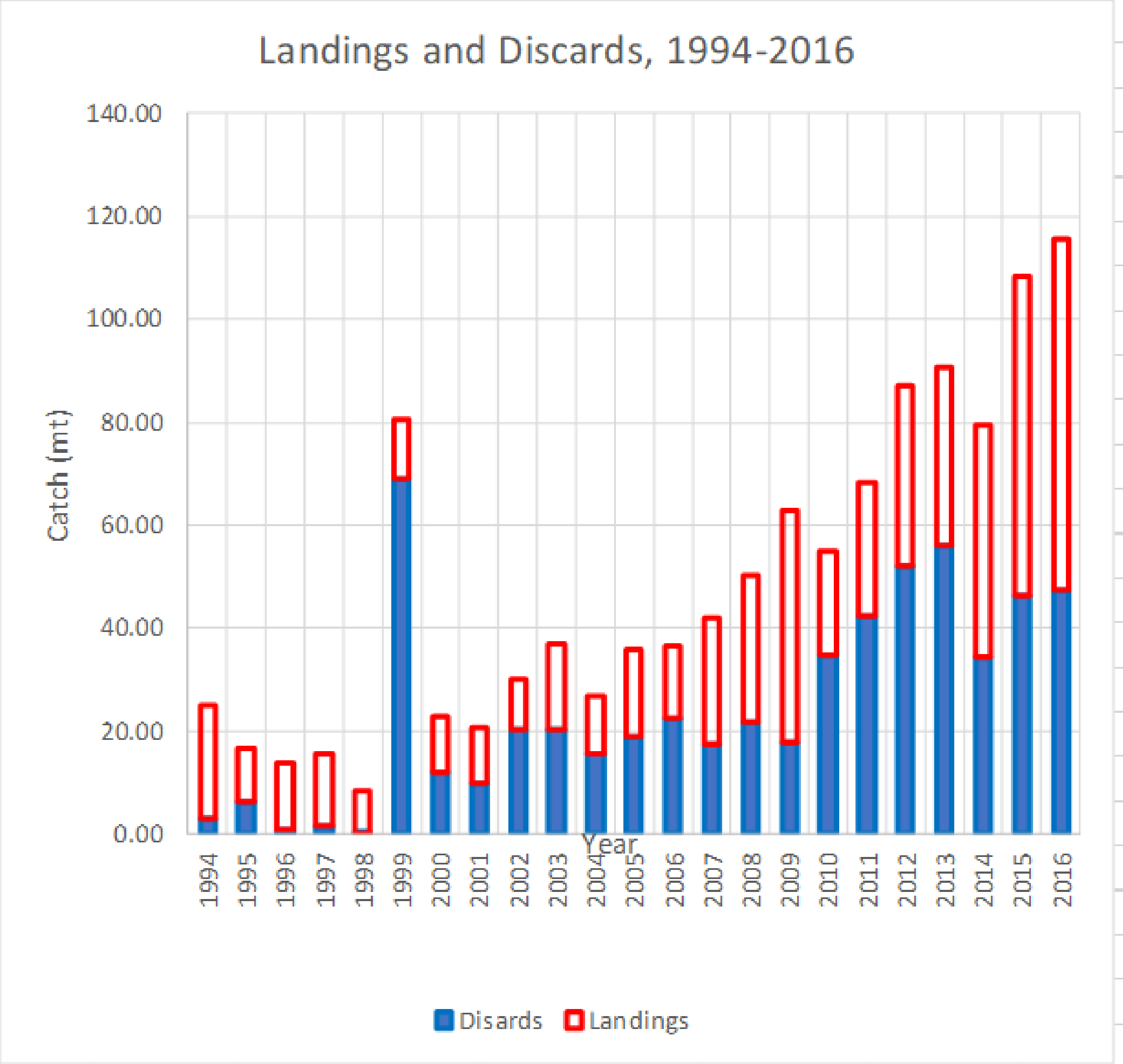
Perspectives

- Has the population changed in recent years?
- Is the change significant?
- Is the observed change supported by multiple indices?
- How does the proposed data poor method perform in simulation?
- Are there adverse effects for rebuilding, catches, and accountability measures?

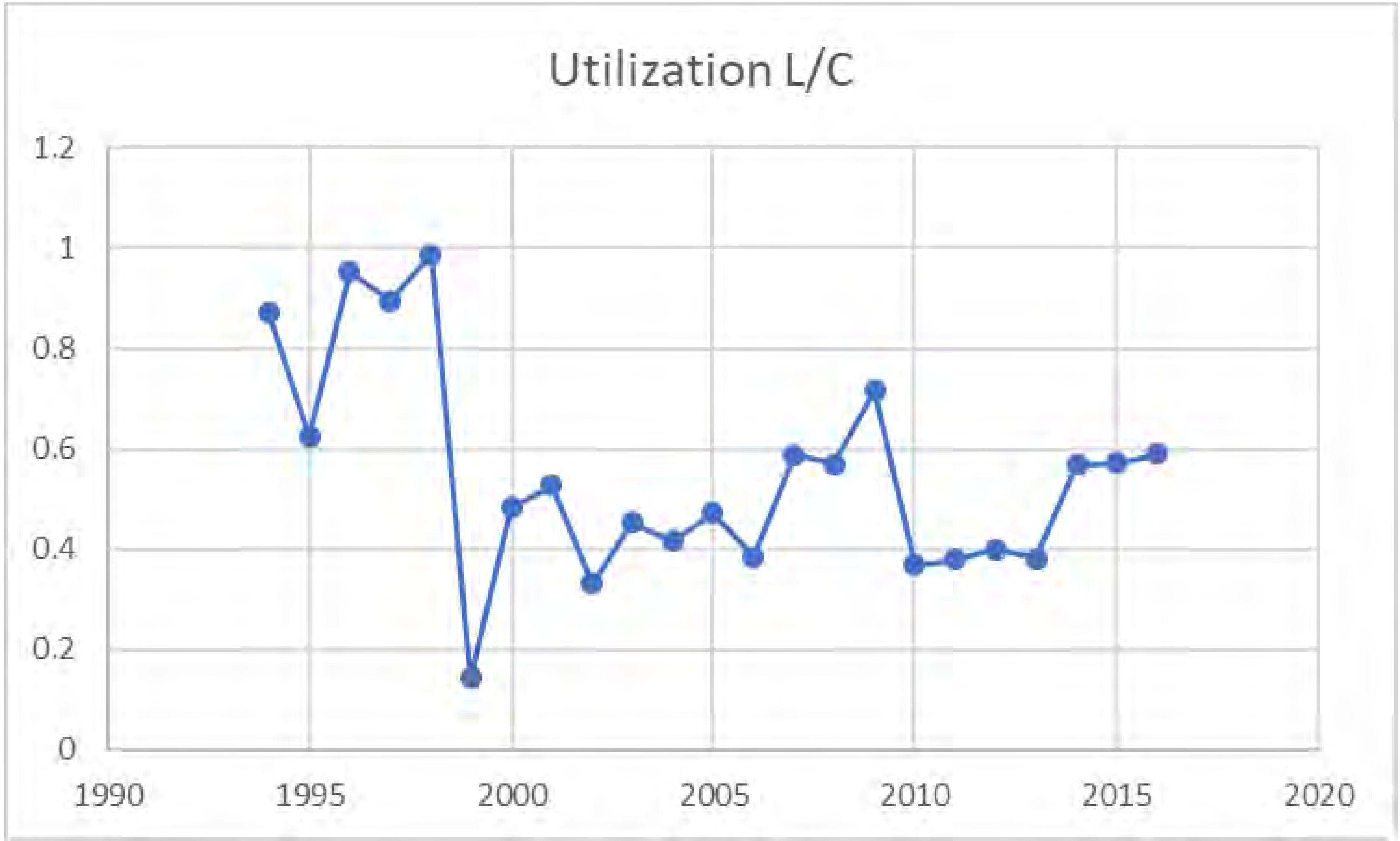
Data Sources Considered (Table 1)

- Standard NEFSC survey update
- Landings and Discard update
- Abundance Indices
  - d/k ratio gill net
  - d/k ratio trawl
  - Maine Standardized CPUE—Hansell et al.
  - Maine Survey indices
  - Maine Commercial Indices from logbooks
- Comparisons with Canada

Year	Disards	Landings	Catch
1994	3.16	21.77	24.93
1995	6.34	10.54	16.88
1996	0.65	13.32	13.97
1997	1.64	14.01	15.65
1998	0.10	8.41	8.51
1999	69.08	11.51	80.59
2000	11.87	11.07	22.94
2001	9.68	10.82	20.50
2002	20.20	10.01	30.21
2003	20.15	16.68	36.83
2004	15.71	11.22	26.93
2005	18.89	16.81	35.70
2006	22.45	14.08	36.53
2007	17.27	24.61	41.88
2008	21.66	28.69	50.35
2009	17.85	45.05	62.90
2010	34.68	20.20	54.88
2011	42.34	25.79	68.13
2012	52.18	34.80	86.98
2013	56.16	34.67	90.83
2014	34.33	44.99	79.32
2015	46.28	62.00	108.28
2016	47.39	68.20	115.59



Trends in Utilization Ratio (Landings/Catch), 2002-2016



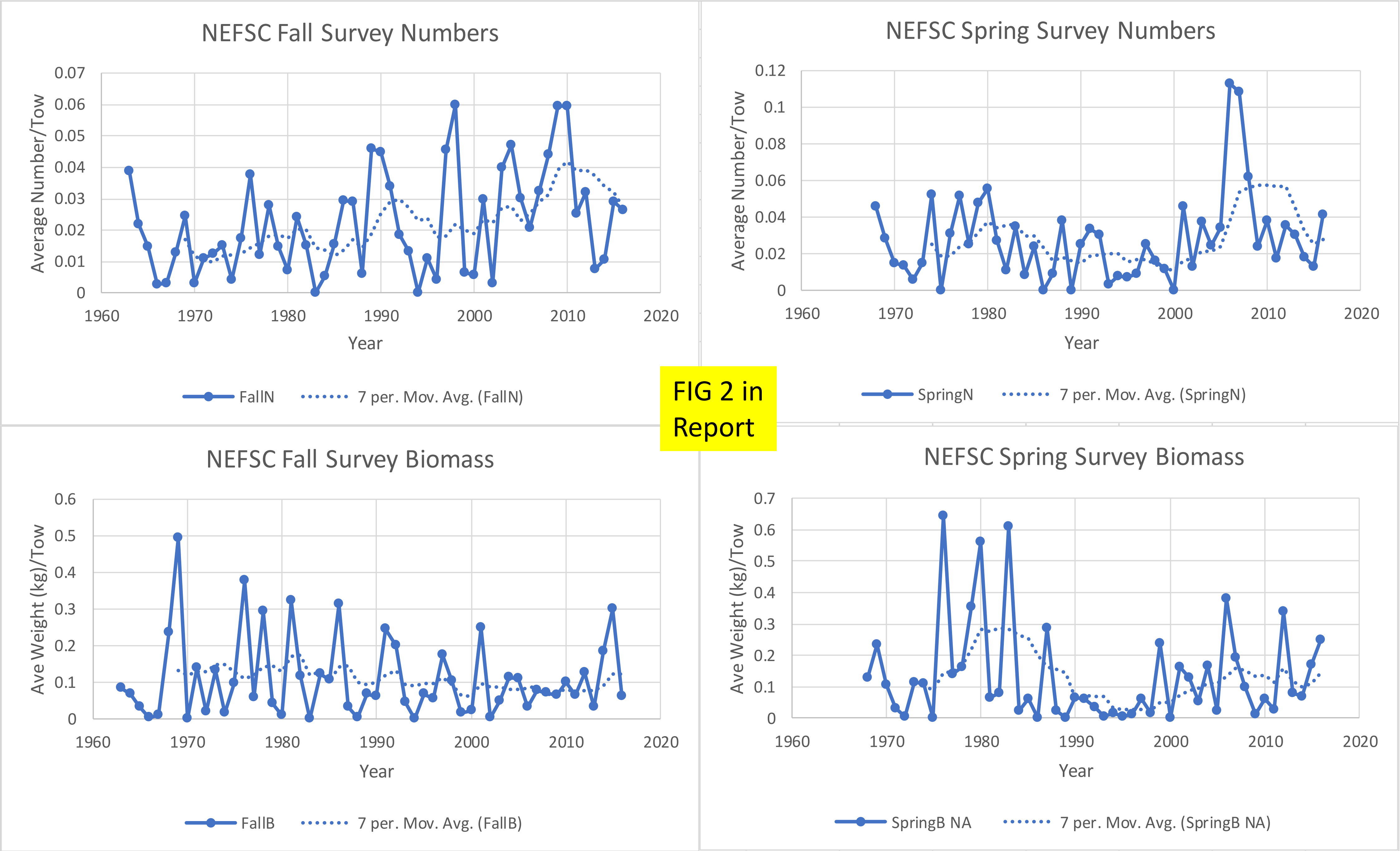
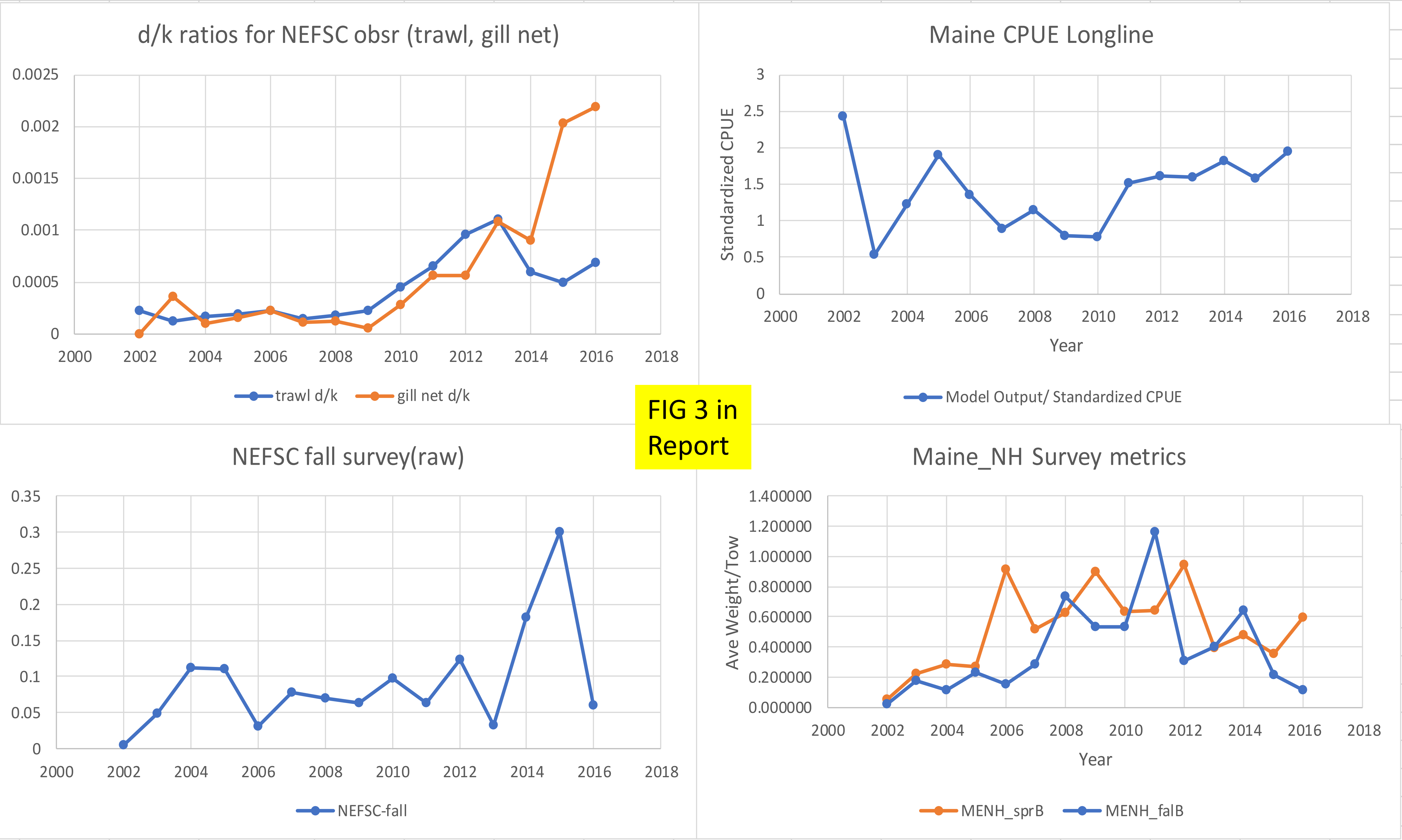
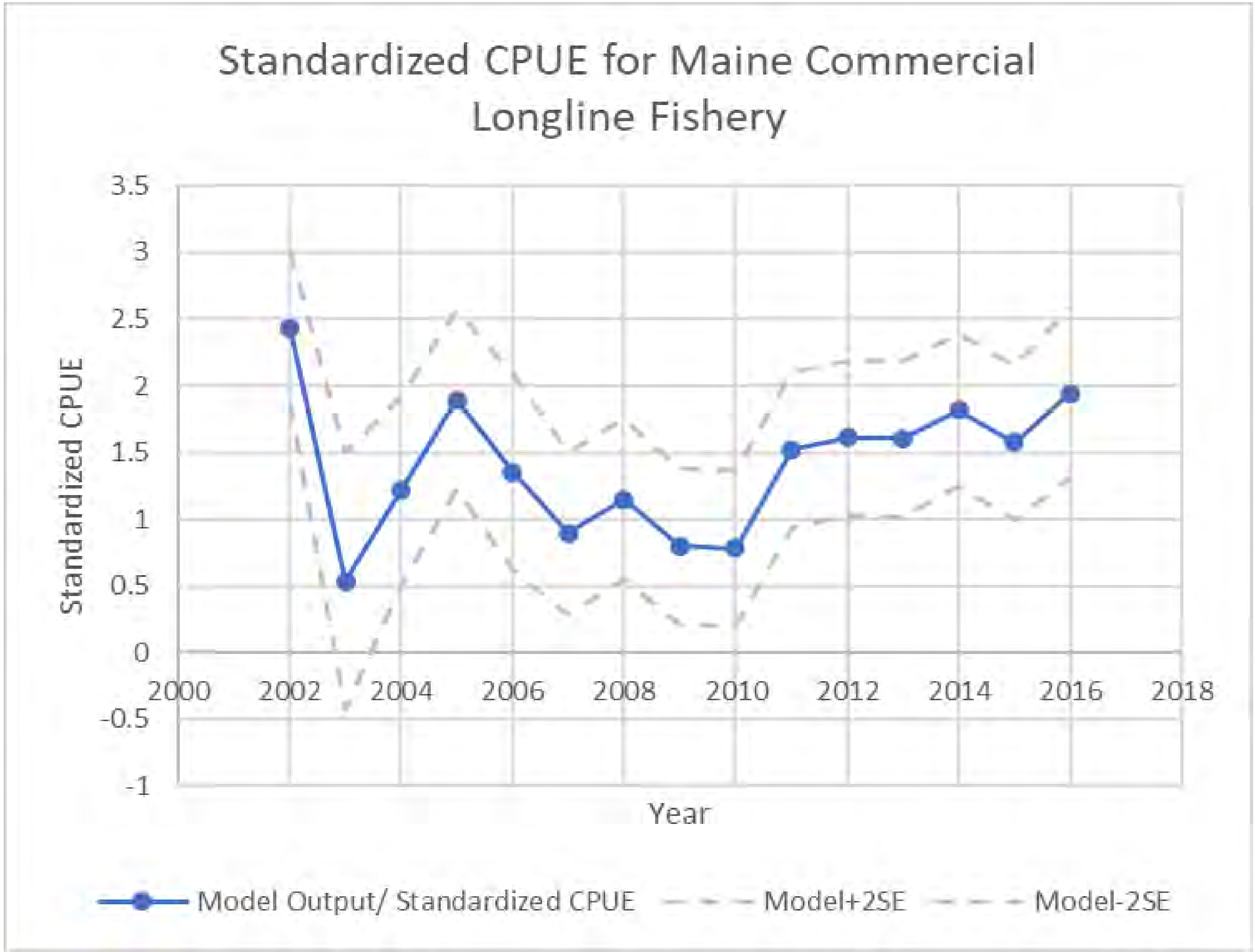


FIG 2 in Report

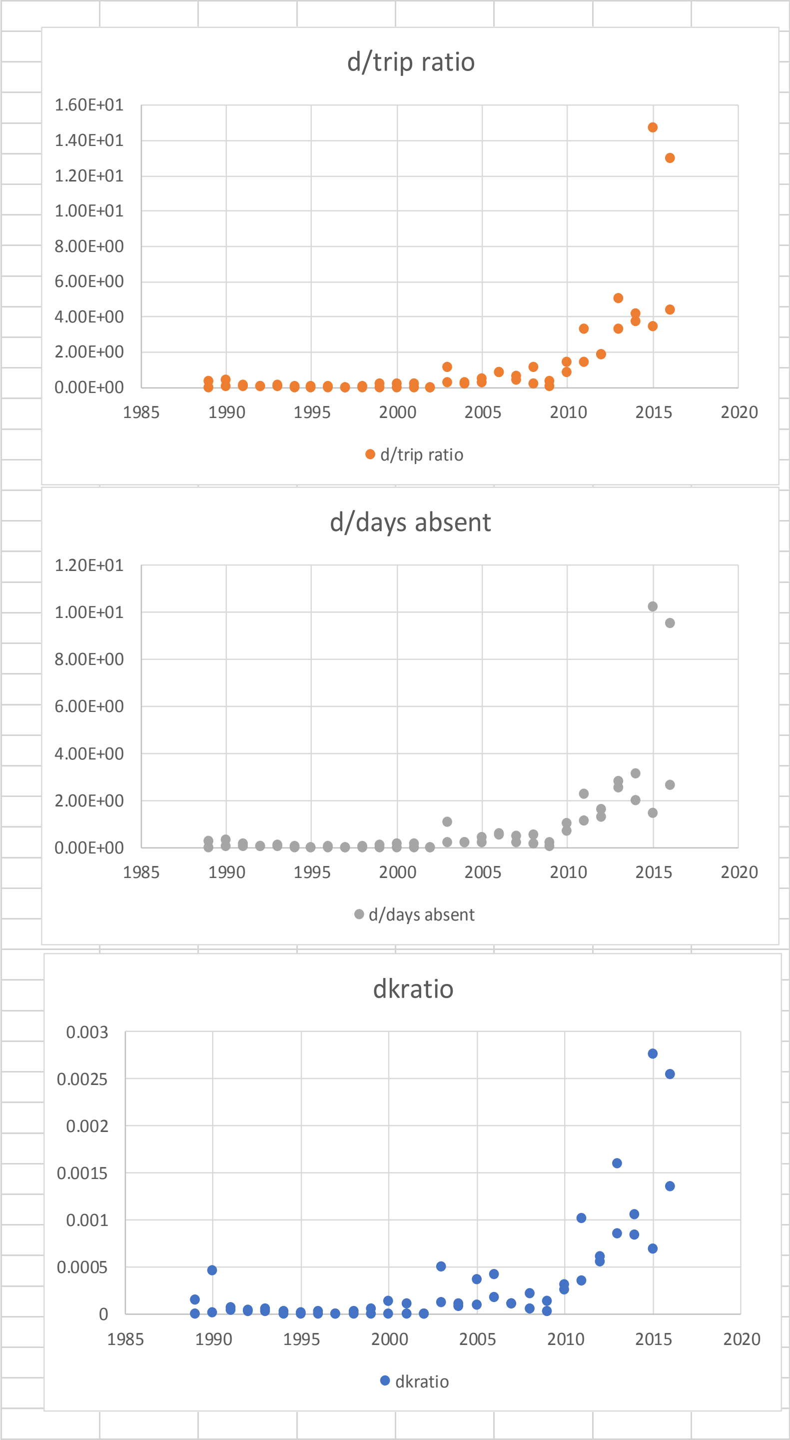
FIG 3 in Report

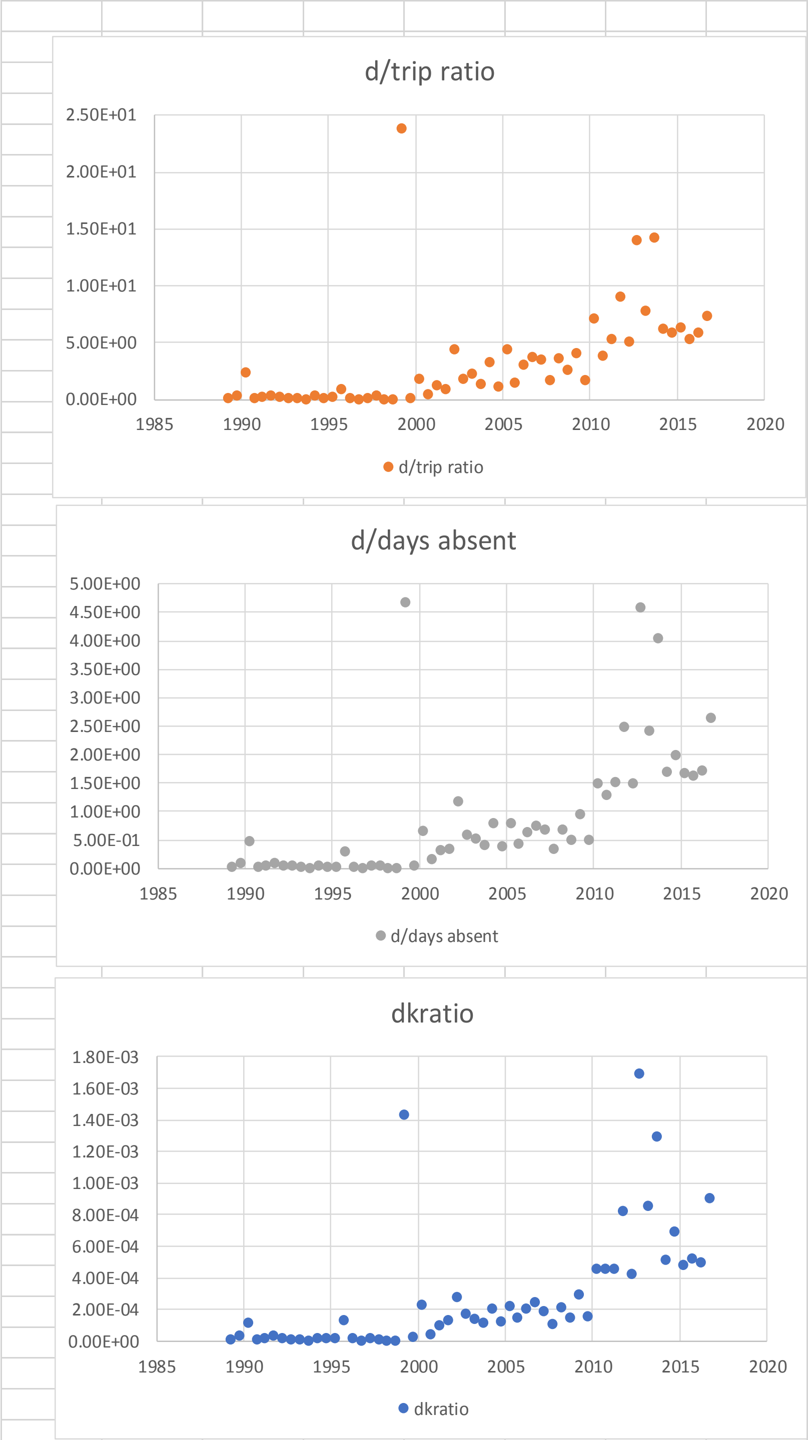




Analyses courtesy of Hansell et al. 2017

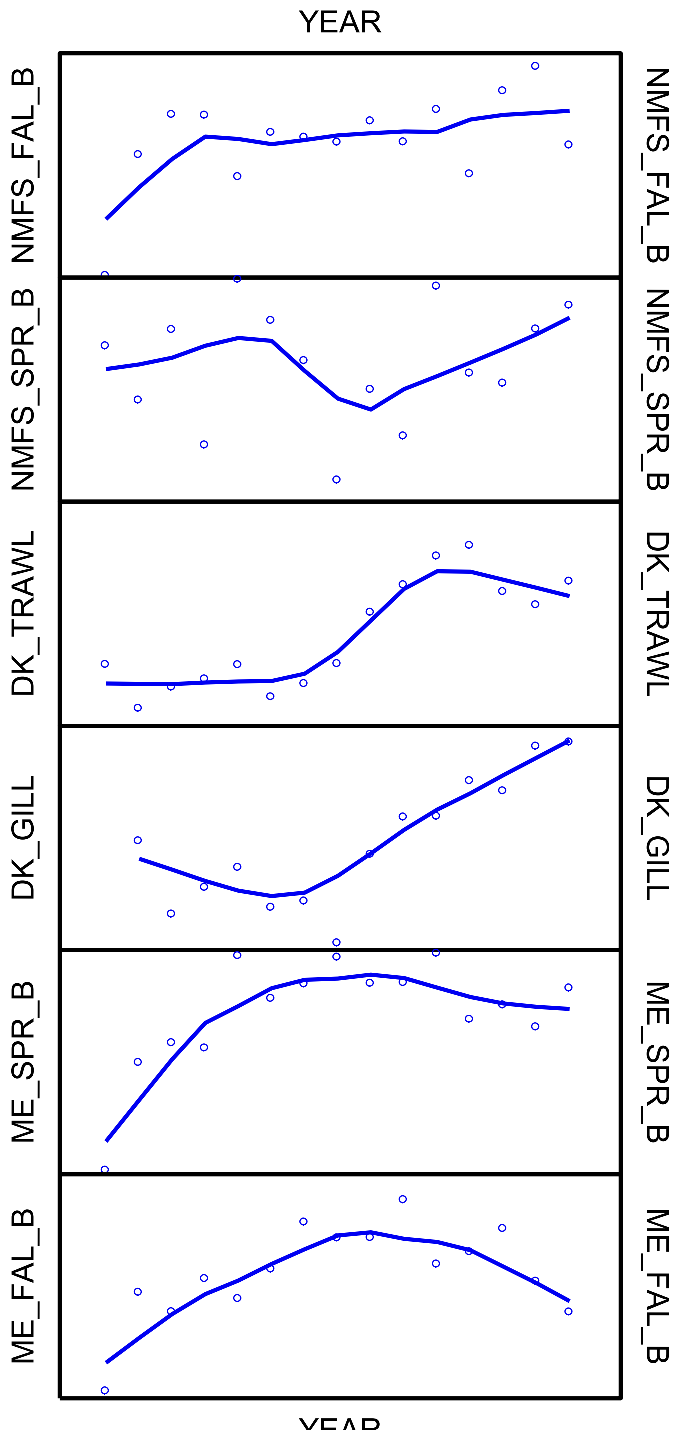
FIG 4 in Report

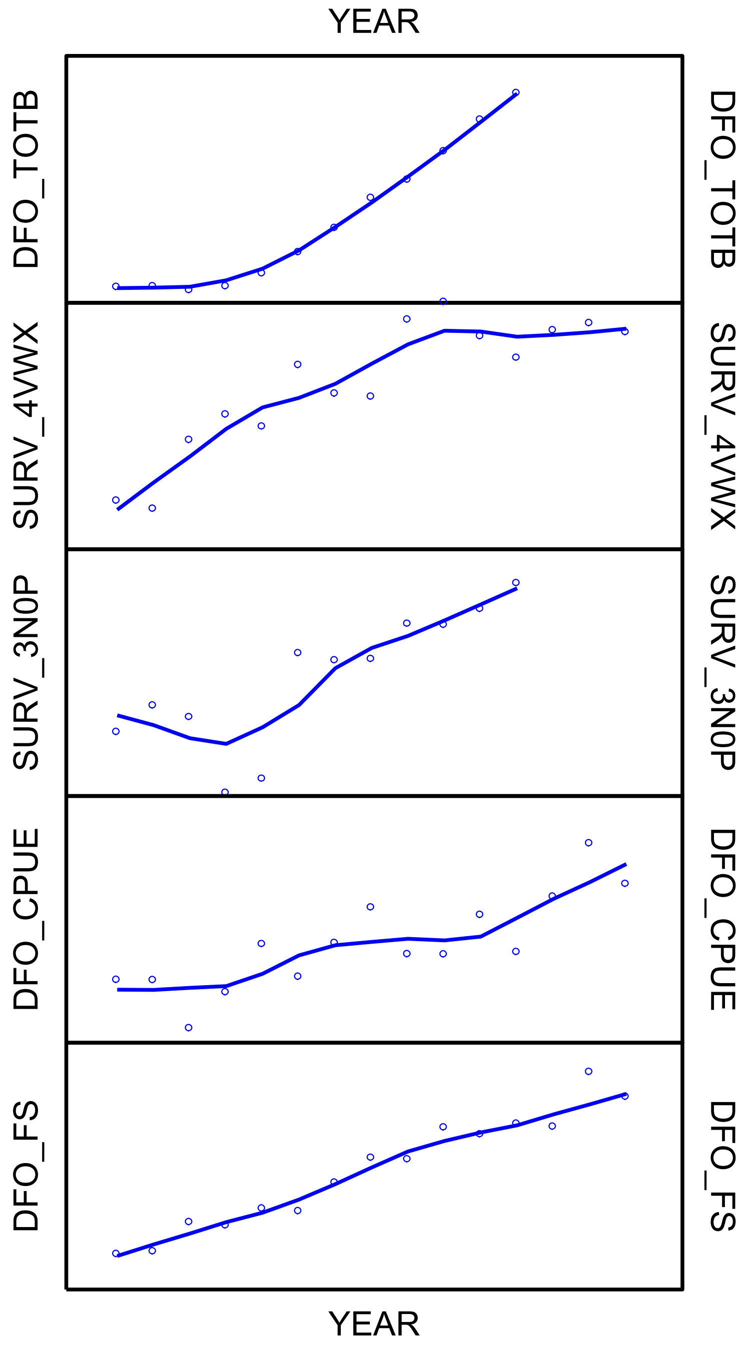




NEFSC observer program d/k ratios for gill nets (left) and trawls (right) for half-year intervals, 1989-2016

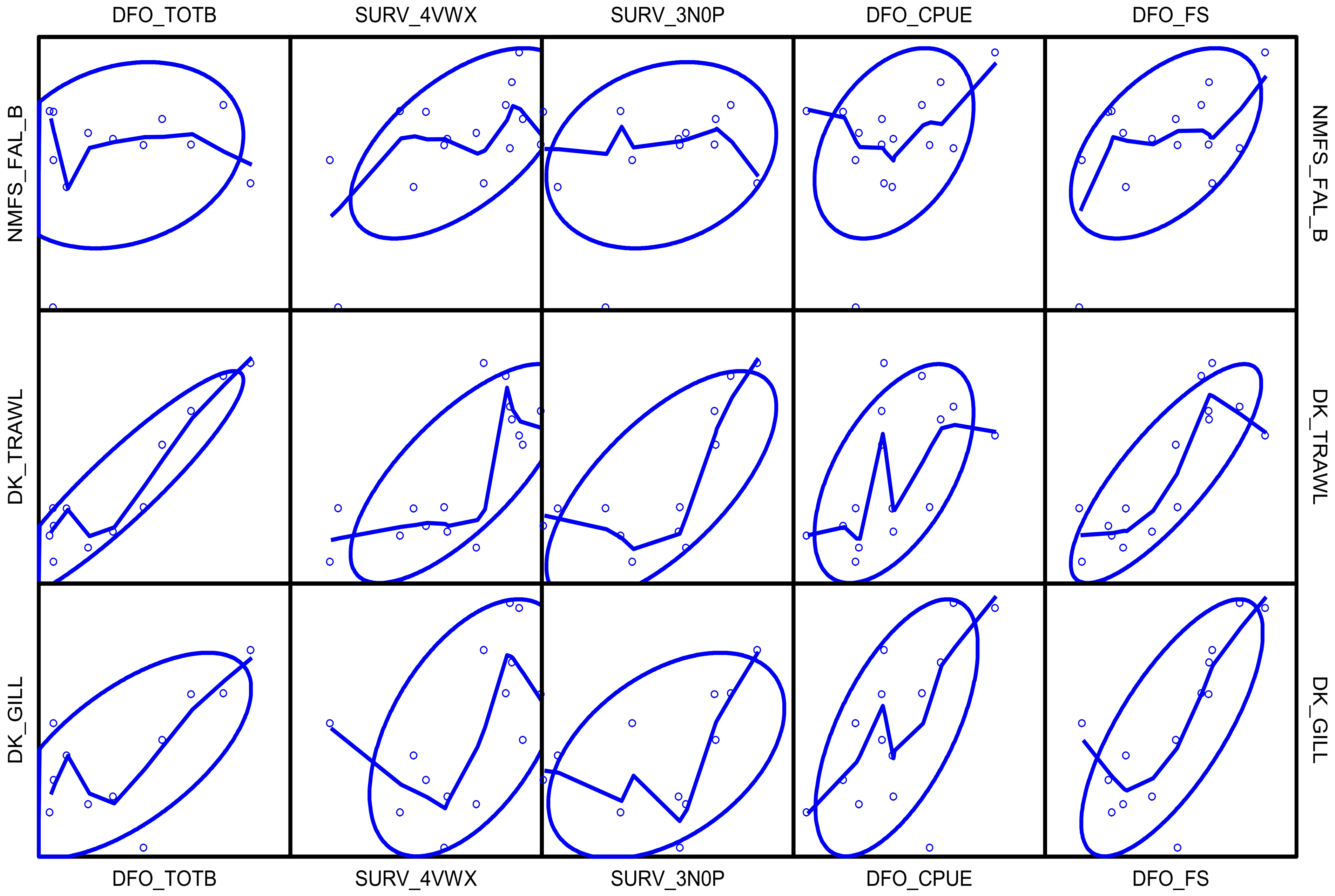
FIG 5 and 6 in Report





Comparison of time trends in US and Canada relative abundance indices for Atlantic Halibut, 2002-2016. DFO_TOTB is total abundance for Canada stock derived from assessment model.

FIG 7 (LEFT) and 8 (RIGHT) in Report



Comparison of core abundance indices for US and Canada, including results of model SSB for Canada

FIG 9 in Report

The Panoply of Data Poor Methods

- Methods that rely some arbitrary scalar adjustment to recent average catches with no rigorous analyses of population consequences.
  - ORCS
- Methods that rely on strong assumptions about current stock status
  - DCAC, DB-SRA etc.
- Methods that apply a biologically based harvest rate to a swept area estimate of abundance
  - Eg GOM winter flounder, GB yellowtail flounder, etc.
- Methods that adjust current catches based on measures of current trends or trends.
  - GB cod
  - MPA etc. Butterworth type, also Hillary, Apostolaki et al. etc.

DCAC = Plan C—served as a useful starting point

- Basic Equation
- $C_{sustainable} = \frac{\sum_{t=1}^{n} C_t}{n + \frac{Delta}{0.2\ M}}$ [3]
- $Delta = \frac{B_t - B_{t+n}}{B_{MSY}}$ [4]
- $C_t = C_{sustainable} \frac{B_t}{B_{MSY}}$ [5]
- Finding DELTA ?
  - Ratio Increase
  - Percentage increase with respect to current stock abundance

Rcrit and Randomization—is the observed trend in one or more indices significant?

- Definition:
- $R_{crit,j} = \frac{\sum_{t=T-m+1}^{T} \frac{I_{j.t}}{m}}{\sum_{t=1}^{n} I_{j,t} \frac{I_{j.t}}{n}}$ [6]
- Standardize the indices with respect to means (multiple indices)
- $R_{crit,.} = \frac{\sum_{j=1}^{J} \sum_{t=T-m+1}^{T} \frac{s(I_{j.t})}{m}}{\sum_{j=1}^{J} \sum_{t=1}^{n} \frac{s(I_{j,t})}{n}}$ [7]
- Create the sampling distribution of Rcrit.
- $R_{crit,k} = \frac{\sum_{j=1}^{J} \sum_{t=T-m+1}^{T} R_k\left(\frac{s(I_{j.t})}{m}\right)}{\sum_{j=1}^{J} \sum_{t=1}^{n} R_k\left(\frac{s(I_{j,t})}{n}\right)}$ [9]

Rcrit and Randomization (2)

- <u>Significance Level of Rcrit</u>
- $P(R_{crit,k} > Rcrit, obs) = \frac{\sum_k^{Nrand} g(R_{crit,k} \geq R_{crit,obs})}{N_{rand}}$ [10]

Rcrit Simulation tests

- Key factors to consider
  - True underlying rate of change
  - Observation error of the indices
  - Number of variables available

Results of Simulation Tests for Rcrit model

Table 2. Relative bias in estimates as function of true Rcrit, CV and number of indices considered.

Table xx. Summary of ratio test simulations for estimation of bias in mean and median of Rcrit as a function of the magnitude of true rate of change (Rcrit_true), the variation of the observation error (CV) and the number of relative abundance indices (Nvar). All simulations were based on a time series of length 10, and the ratio of the average of the last 3 to the first 3 observations for 2000 randomizations of each of 1000 stochastic realizations.

		Relative Bias in Estimated Rcrit vs True Rcrit							
		Nvar=1		Nvar=2		Nvar=3		Nvar=5	
Rcrit_true	CV	Rel Bias (mean)	Rel Bias (median)	Rel Bias (mean)2	Rel Bias (median)3	Rel Bias (mean)4	Rel Bias (median)5	Rel Bias (mean)6	Rel Bias (median)7
2.014	0.1	0.3%	0.2%	0.1%	-0.1%	0.0%	0.1%	0.2%	0.0%
2.014	0.15	0.4%	-0.3%	0.6%	0.1%	0.0%	-0.5%	0.2%	-0.1%
2.014	0.2	0.6%	-1.4%	0.1%	-0.5%	0.4%	0.1%	0.1%	0.1%
2.014	0.25	3.1%	1.2%	1.5%	0.5%	1.2%	0.5%	0.5%	-0.1%
2.014	0.3	2.5%	-0.9%	1.0%	0.4%	1.8%	0.6%	0.7%	-0.1%
2.014	0.35	3.5%	-0.8%	2.5%	0.9%	1.1%	-0.5%	0.7%	0.0%
2.014	0.4	4.9%	-0.9%	3.3%	0.4%	1.8%	0.3%	0.8%	-0.4%
2.014	0.45	10.1%	-0.9%	2.8%	-0.5%	1.9%	0.3%	1.6%	0.5%
2.014	0.5	9.8%	-1.3%	6.1%	0.5%	3.8%	0.2%	1.9%	0.1%
2.014	0.6	-51.9%	-3.0%	6.8%	-1.6%	4.8%	0.2%	2.8%	0.1%
2.014	0.65	18.4%	-1.4%	9.0%	-0.5%	5.1%	0.2%	2.8%	-1.1%
2.014	0.7	7.8%	-5.1%	12.9%	0.7%	3.8%	0.2%	4.1%	0.8%
1.419	0.1	0.1%	-0.1%	0.3%	0.2%	0.2%	0.0%	-0.1%	0.0%
1.419	0.15	1.2%	0.5%	0.8%	0.9%	0.5%	0.5%	0.0%	-0.3%
1.419	0.2	1.5%	1.1%	1.0%	0.1%	0.1%	-0.4%	0.5%	0.2%
1.419	0.25	0.7%	-1.8%	0.5%	-0.2%	0.8%	-0.1%	1.2%	1.1%
1.419	0.3	4.3%	0.1%	2.1%	0.9%	0.6%	-0.4%	0.5%	-0.8%
1.419	0.35	4.5%	0.4%	0.4%	-1.9%	1.0%	-0.1%	0.7%	-0.1%
1.419	0.4	5.9%	1.1%	3.7%	0.7%	1.9%	0.3%	1.0%	-0.3%
1.419	0.45	9.2%	-0.4%	2.0%	-1.2%	2.4%	0.0%	1.3%	-0.1%
1.419	0.5	8.5%	1.8%	5.1%	-0.6%	3.0%	0.5%	2.2%	0.2%
1.419	0.6	24.1%	-0.4%	6.8%	-0.6%	3.2%	-0.5%	2.4%	1.1%
1.419	0.65	17.5%	-0.6%	16.9%	2.1%	4.8%	-1.0%	3.1%	0.5%
1.419	0.7	23.5%	-3.0%	12.1%	3.1%	3.5%	-2.1%	1.6%	-2.1%
1.191	0.1	0.3%	0.5%	0.1%	0.1%	0.2%	-0.1%	-0.1%	-0.2%
1.191	0.15	0.4%	0.0%	0.3%	0.1%	0.2%	0.0%	0.2%	0.0%
1.191	0.2	1.7%	0.2%	0.4%	-0.4%	0.5%	0.1%	0.2%	-0.4%
1.191	0.25	1.5%	-0.4%	1.4%	0.5%	1.3%	1.3%	0.2%	-0.4%
1.191	0.3	2.8%	-0.2%	1.5%	0.7%	0.6%	-0.7%	-0.2%	-0.7%
1.191	0.35	4.6%	1.8%	2.8%	0.9%	2.1%	1.1%	0.6%	-0.9%
1.191	0.4	5.3%	0.1%	2.7%	-0.4%	1.9%	0.5%	1.1%	0.7%
1.191	0.45	8.3%	-0.2%	3.7%	1.7%	2.5%	1.4%	0.8%	-1.1%
1.191	0.5	20.9%	3.8%	3.8%	-1.0%	2.8%	-0.6%	2.1%	0.0%
1.191	0.6	14.8%	1.1%	7.3%	1.7%	3.5%	-0.5%	2.4%	-0.1%
1.191	0.65	26.4%	1.8%	11.9%	0.9%	4.9%	-1.1%	2.3%	-0.9%
1.191	0.7	0.3%	-2.6%	9.7%	-0.6%	8.1%	3.7%	3.1%	-1.8%

Table xx. Summary of ratio test simulations for estimation of bias in mean and median of R
rate of change (Rcrit_true), the variation of the observation error (CV) and the nu
All simulations were based on a time series of length 10, and the ratio of the ave
for 2000 randomizations of each of 1000 stochastic realizations.

		Relative Bias in Estimate			
		Nvar=1		Nvar=2	
Rcrit_true	CV	Rel Bias (mean)	Rel Bias (median)	Rel Bias (mean)2	Rel Bias (median)3
2.014	0.1	0.3%	0.2%	0.1%	-0.1%
2.014	0.15	0.4%	-0.3%	0.6%	0.1%
2.014	0.2	0.6%	-1.4%	0.1%	-0.5%
2.014	0.25	3.1%	1.2%	1.5%	0.5%
2.014	0.3	2.5%	-0.9%	1.0%	0.4%
2.014	0.35	3.5%	-0.8%	2.5%	0.9%
2.014	0.4	4.9%	-0.9%	3.3%	0.4%
2.014	0.45	10.1%	-0.9%	2.8%	-0.5%
2.014	0.5	9.8%	-1.3%	6.1%	0.5%
2.014	0.6	-51.9%	-3.0%	6.8%	-1.6%
2.014	0.65	18.4%	-1.4%	9.0%	-0.5%
2.014	0.7	7.8%	-5.1%	12.9%	0.7%
1.419	0.1	0.1%	-0.1%	0.3%	0.2%
1.419	0.15	1.2%	0.5%	0.8%	0.9%

Table xx. Summary of ratio test simulations for estimation of the average probability value for simulated Rcrit values as a functio
rate of change (Rcrit_true), the variation of the observation error (CV) and the number of relative abundance indices (N
All simulations were based on a time series of length 10, and the ratio of the average of the last 3 to the first 3 observa
for 2000 randomizations of each of 1000 stochastic realizations.

		Average Probability Value for Rcrit			
Rcrit_tru	**CV**	**Nvar=1**	**Nvar=2**	**Nvar=3**	**Nvar=5**
2.014	0.1	0.000	0.000	0.000	0.000
2.014	0.15	0.002	0.000	0.000	0.000
2.014	0.2	0.010	0.000	0.000	0.000
2.014	0.25	0.021	0.002	0.000	0.000
2.014	0.3	0.042	0.008	0.001	0.000
2.014	0.35	0.066	0.015	0.003	0.000
2.014	0.4	0.095	0.027	0.005	0.001
2.014	0.45	0.115	0.047	0.012	0.001
2.014	0.5	0.148	0.058	0.020	0.005
2.014	0.6	0.199	0.103	0.040	0.013
2.014	0.65	0.214	0.120	0.052	0.019
2.014	0.7	0.241	0.136	0.070	0.025
1.419	0.1	0.008	0.000	0.000	0.000
1.419	0.15	0.036	0.005	0.001	0.000
1.419	0.2	0.085	0.022	0.006	0.001
1.419	0.25	0.132	0.054	0.020	0.004
1.419	0.3	0.163	0.083	0.046	0.013
1.419	0.35	0.202	0.130	0.076	0.029
1.419	0.4	0.234	0.149	0.098	0.044
1.419	0.45	0.263	0.200	0.123	0.065
1.419	0.5	0.278	0.204	0.143	0.085
1.419	0.6	0.316	0.253	0.192	0.128
1.419	0.65	0.335	0.249	0.205	0.148
1.419	0.7	0.353	0.271	0.229	0.178
1.191	0.1	0.084	0.022	0.005	0.001
1.191	0.15	0.171	0.086	0.044	0.013
1.191	0.2	0.224	0.151	0.094	0.046
1.191	0.25	0.284	0.190	0.145	0.093
1.191	0.3	0.317	0.234	0.198	0.139
1.191	0.35	0.339	0.269	0.218	0.166
1.191	0.4	0.354	0.302	0.250	0.205
1.191	0.45	0.372	0.314	0.270	0.235
1.191	0.5	0.368	0.338	0.304	0.244
1.191	0.6	0.403	0.361	0.330	0.281
1.191	0.65	0.406	0.366	0.342	0.305
1.191	0.7	0.419	0.392	0.328	0.317

Table 3. Average Probability value of Rcrit estimates as function of true Rcrit, CV and number of indices considered.

Performance improves as CV decreases, as the number of indices increases and as the true underlying rate of increase increases.

lambda	Rcrit_true	CV	P0.005	P0.01	P0.025	P0.05	P0.1	P0.15	P0.2	P0.25
0.1	2.014	0.1	0.994	0.998	1	1	1	1	1	1
0.1	2.014	0.15	0.868	0.951	0.989	0.999	1	1	1	1
0.1	2.014	0.2	0.634	0.771	0.914	0.958	0.993	0.994	0.998	0.998
0.1	2.014	0.25	0.426	0.578	0.769	0.891	0.959	0.98	0.99	0.993
0.1	2.014	0.3	0.278	0.41	0.619	0.773	0.883	0.937	0.96	0.973
0.1	2.014	0.35	0.209	0.303	0.475	0.643	0.799	0.869	0.915	0.936
0.1	2.014	0.4	0.142	0.217	0.378	0.527	0.701	0.802	0.864	0.907
0.1	2.014	0.45	0.123	0.181	0.309	0.463	0.642	0.753	0.819	0.863
0.1	2.014	0.5	0.076	0.135	0.248	0.394	0.575	0.679	0.76	0.811
0.1	2.014	0.6	0.06	0.1	0.18	0.288	0.458	0.559	0.645	0.699
0.1	2.014	0.65	0.052	0.086	0.171	0.275	0.44	0.543	0.624	0.685
0.1	2.014	0.7	0.043	0.067	0.142	0.251	0.379	0.487	0.573	0.635
0.05	1.419	0.1	0.644	0.807	0.926	0.969	0.995	0.998	1	1
0.05	1.419	0.15	0.319	0.462	0.641	0.786	0.908	0.949	0.968	0.984
0.05	1.419	0.2	0.177	0.271	0.45	0.6	0.752	0.815	0.87	0.914
0.05	1.419	0.25	0.084	0.132	0.257	0.388	0.6	0.7	0.769	0.817
0.05	1.419	0.3	0.094	0.137	0.231	0.347	0.511	0.624	0.704	0.773
0.05	1.419	0.35	0.051	0.087	0.169	0.283	0.432	0.558	0.643	0.706
0.05	1.419	0.4	0.028	0.061	0.151	0.253	0.374	0.486	0.575	0.646
0.05	1.419	0.45	0.035	0.058	0.114	0.203	0.34	0.432	0.522	0.593
0.05	1.419	0.5	0.021	0.043	0.093	0.16	0.292	0.408	0.504	0.579
0.05	1.419	0.6	0.018	0.031	0.075	0.146	0.253	0.346	0.428	0.502
0.05	1.419	0.65	0.013	0.023	0.062	0.118	0.237	0.322	0.401	0.469
0.05	1.419	0.7	0.016	0.027	0.049	0.112	0.218	0.304	0.368	0.448
0.025	1.191	0.1	0.182	0.268	0.438	0.603	0.75	0.815	0.867	0.9
0.025	1.191	0.15	0.061	0.111	0.227	0.356	0.501	0.609	0.696	0.756
0.025	1.191	0.2	0.037	0.078	0.156	0.26	0.396	0.501	0.589	0.661
0.025	1.191	0.25	0.027	0.047	0.109	0.187	0.318	0.42	0.491	0.556
0.025	1.191	0.3	0.015	0.028	0.075	0.141	0.26	0.352	0.438	0.512
0.025	1.191	0.35	0.02	0.033	0.075	0.138	0.246	0.336	0.412	0.473
0.025	1.191	0.4	0.018	0.029	0.057	0.114	0.199	0.282	0.372	0.435
0.025	1.191	0.45	0.008	0.02	0.047	0.093	0.189	0.27	0.355	0.42
0.025	1.191	0.5	0.011	0.031	0.064	0.109	0.191	0.268	0.352	0.431
0.025	1.191	0.6	0.014	0.02	0.049	0.088	0.172	0.243	0.313	0.382
0.025	1.191	0.65	0.008	0.02	0.045	0.092	0.163	0.229	0.298	0.362
0.025	1.191	0.7	0.005	0.017	0.049	0.085	0.151	0.211	0.287	0.34

Table 4. Fraction of simulations with significance probabilities less than or equal to the value in the column header. Color coding is consistent across Tables 4-7.

Results in this table are for ONE index of relative abundance.

lambda	Rcrit_true	CV	P0.005	P0.01	P0.025	P0.05	P0.1	P0.15	P0.2	P0.25
0.1	2.014	0.1	1	1	1	1	1	1	1	1
0.1	2.014	0.15	1	1	1	1	1	1	1	1
0.1	2.014	0.2	1	1	1	1	1	1	1	1
0.1	2.014	0.25	1	1	1	1	1	1	1	1
0.1	2.014	0.3	1	1	1	1	1	1	1	1
0.1	2.014	0.35	0.996	0.998	1	1	1	1	1	1
0.1	2.014	0.4	0.981	0.991	0.996	0.999	0.999	1	1	1
0.1	2.014	0.45	0.93	0.968	0.986	0.996	1	1	1	1
0.1	2.014	0.5	0.849	0.912	0.956	0.977	0.993	0.998	0.998	0.999
0.1	2.014	0.6	0.709	0.81	0.889	0.934	0.962	0.983	0.991	0.994
0.1	2.014	0.65	0.598	0.697	0.821	0.9	0.956	0.973	0.984	0.989
0.1	2.014	0.7	0.541	0.657	0.797	0.863	0.922	0.958	0.974	0.987
0.05	1.419	0.1	1	1	1	1	1	1	1	1
0.05	1.419	0.15	1	1	1	1	1	1	1	1
0.05	1.419	0.2	0.973	0.992	0.999	0.999	1	1	1	1
0.05	1.419	0.25	0.869	0.921	0.965	0.982	0.994	0.998	0.999	1
0.05	1.419	0.3	0.647	0.747	0.856	0.931	0.976	0.986	0.993	0.997
0.05	1.419	0.35	0.53	0.627	0.761	0.85	0.929	0.953	0.971	0.977
0.05	1.419	0.4	0.382	0.497	0.647	0.765	0.862	0.912	0.943	0.967
0.05	1.419	0.45	0.3	0.413	0.554	0.674	0.819	0.863	0.898	0.927
0.05	1.419	0.5	0.247	0.321	0.473	0.599	0.749	0.818	0.87	0.899
0.05	1.419	0.6	0.151	0.221	0.356	0.496	0.64	0.722	0.775	0.824
0.05	1.419	0.65	0.132	0.199	0.322	0.447	0.591	0.674	0.738	0.782
0.05	1.419	0.7	0.101	0.159	0.262	0.354	0.51	0.599	0.682	0.741
0.025	1.191	0.1	0.964	0.981	0.995	1	1	1	1	1
0.025	1.191	0.15	0.664	0.767	0.869	0.938	0.971	0.988	0.994	0.997
0.025	1.191	0.2	0.381	0.482	0.632	0.745	0.855	0.909	0.936	0.961
0.025	1.191	0.25	0.22	0.308	0.452	0.579	0.719	0.801	0.857	0.893
0.025	1.191	0.3	0.121	0.18	0.314	0.453	0.608	0.699	0.766	0.809
0.025	1.191	0.35	0.103	0.161	0.253	0.363	0.498	0.619	0.693	0.749
0.025	1.191	0.4	0.079	0.14	0.236	0.334	0.481	0.572	0.638	0.692
0.025	1.191	0.45	0.061	0.098	0.18	0.268	0.396	0.498	0.566	0.629
0.025	1.191	0.5	0.055	0.085	0.164	0.263	0.385	0.468	0.551	0.617
0.025	1.191	0.6	0.031	0.056	0.126	0.194	0.323	0.416	0.489	0.554
0.025	1.191	0.65	0.036	0.054	0.119	0.197	0.295	0.379	0.45	0.529
0.025	1.191	0.7	0.035	0.068	0.115	0.181	0.281	0.356	0.423	0.484

Table 7. Fraction of simulations with significance probabilities less than or equal to the value in the column header. Color coding is consistent across Tables 4-7.

Results in this table are for FIVE indices of relative abundance.

Rcrit *Applications*

- US—6 candidate indices
- DFO—3 indices AND SSB from an analytical model

Finding the best estimate of Rcrit for multiple indices?

- Often a difficult problem in stock assessments—lots of group discussion
- Therefore-- Consider all possible models
- Combination of all possible models of n indices taken m at a time summed over m=1,…, n
- Comb(6,6)+Comb(6,5)+Comb(6,4)+Comb(6,3)+Comb(6,2)+Comb(6,1)
- 1 + 6 + 15 + 20 + 15 + 6=63

- Can now compare alternative models and compute average Rcrit and Pvalue of Rcrit across all possible models.

50000 replicates

ratio 2014/2016 to 2002-2004

USA Data (2002-2016)

Model #	Nvars	Combinati	Rcrit	Pvalue	Var 1	Var 2	Var 3	Var 4	Var 5	Var 6
1	6	1	3.231	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB
2	5	1	3.216	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	
3	5	2	2.436	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	FallSurvB	
4	5	3	3.196	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_gillnet	FallSurvB	
5	5	4	4.254	0.0000	ME_sprB	ME_falB	DK_trawl	DK_gillnet	FallSurvB	
6	5	5	3.242	0.0000	ME_sprB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB	
7	5	6	3.327	0.0000	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB	
8	4	1	2.184	0.0011	ME_sprB	ME_falB	LLcpueStd	DK_trawl		
9	4	2	3.166	0.0001	ME_sprB	ME_falB	LLcpueStd	DK_gillnet		
10	4	3	2.253	0.0006	ME_sprB	ME_falB	LLcpueStd	FallSurvB		
11	4	4	4.698	0.0000	ME_sprB	ME_falB	DK_trawl	DK_gillnet		
12	4	5	3.140	0.0000	ME_sprB	ME_falB	DK_trawl	FallSurvB		
13	4	6	4.471	0.0000	ME_sprB	ME_falB	DK_gillnet	FallSurvB		
14	4	7	3.228	0.0000	ME_sprB	LLcpueStd	DK_trawl	DK_gillnet		
15	4	8	2.354	0.0003	ME_sprB	LLcpueStd	DK_trawl	FallSurvB		
16	4	9	3.205	0.0000	ME_sprB	LLcpueStd	DK_gillnet	FallSurvB		
17	4	10	4.447	0.0000	ME_sprB	DK_trawl	DK_gillnet	FallSurvB		
18	4	11	3.339	0.0001	ME_falB	LLcpueStd	DK_trawl	DK_gillnet		
19	4	12	2.418	0.0007	ME_falB	LLcpueStd	DK_trawl	FallSurvB		
20	4	13	3.305	0.0001	ME_falB	LLcpueStd	DK_gillnet	FallSurvB		
21	4	14	4.649	0.0000	ME_falB	DK_trawl	DK_gillnet	FallSurvB		
22	4	15	3.352	0.0001	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB		
23	3	1	1.871	0.0122	ME_sprB	ME_falB	LLcpueStd			
24	3	2	3.053	0.0003	ME_sprB	ME_falB	DK_trawl			
25	3	3	5.259	0.0000	ME_sprB	ME_falB	DK_gillnet			
26	3	4	3.040	0.0002	ME_sprB	ME_falB	FallSurvB			
27	3	5	2.033	0.0037	ME_sprB	LLcpueStd	DK_trawl			
28	3	6	3.173	0.0004	ME_sprB	LLcpueStd	DK_gillnet			
29	3	7	2.128	0.0024	ME_sprB	LLcpueStd	FallSurvB			
30	3	8	5.125	0.0000	ME_sprB	DK_trawl	DK_gillnet			
31	3	9	3.142	0.0001	ME_sprB	DK_trawl	FallSurvB			
32	3	10	4.778	0.0000	ME_sprB	DK_gillnet	FallSurvB			
33	3	11	2.106	0.0091	ME_falB	LLcpueStd	DK_trawl			
34	3	12	3.310	0.0009	ME_falB	LLcpueStd	DK_gillnet			
35	3	13	2.196	0.0051	ME_falB	LLcpueStd	FallSurvB			
36	3	14	5.511	0.0000	ME_falB	DK_trawl	DK_gillnet			
37	3	15	3.305	0.0004	ME_falB	DK_trawl	FallSurvB			
38	3	16	5.074	0.0000	ME_falB	DK_gillnet	FallSurvB			
39	3	17	3.374	0.0003	LLcpueStd	DK_trawl	DK_gillnet			
40	3	18	2.319	0.0025	LLcpueStd	DK_trawl	FallSurvB			
41	3	19	3.331	0.0005	LLcpueStd	DK_gillnet	FallSurvB			
42	3	20	4.984	0.0000	DK_trawl	DK_gillnet	FallSurvB			
43	2	1	2.803	0.0042	ME_sprB	ME_falB				
44	2	2	1.611	0.0353	ME_sprB	LLcpueStd				
45	2	3	3.025	0.0014	ME_sprB	DK_trawl				
46	2	4	6.216	0.0000	ME_sprB	DK_gillnet				
47	2	5	3.014	0.0016	ME_sprB	FallSurvB				
48	2	6	1.680	0.0792	ME_falB	LLcpueStd				
49	2	7	3.317	0.0041	ME_falB	DK_trawl				
50	2	8	7.050	0.0003	ME_falB	DK_gillnet				
51	2	9	3.240	0.0045	ME_falB	FallSurvB				
52	2	10	1.901	0.0276	LLcpueStd	DK_trawl				
53	2	11	3.351	0.0046	LLcpueStd	DK_gillnet				
54	2	12	2.033	0.0180	LLcpueStd	FallSurvB				
55	2	13	6.509	0.0003	DK_trawl	DK_gillnet				
56	2	14	3.354	0.0028	DK_trawl	FallSurvB				
57	2	15	5.703	0.0009	DK_gillnet	FallSurvB				
58	1	1	2.550	0.0205	ME_sprB					
59	1	2	3.129	0.0520	ME_falB					
60	1	3	1.274	0.2200	LLcpueStd					
61	1	4	3.447	0.0256	DK_trawl					
62	1	5	11.217	0.0131	DK_gillnet					
63	1	6	3.291	0.0267	FallSurvB					

Average Rcrit value overall models=

3.522825

fraction of models with significance probability <0.05

0.952381

"Multi-model Inference"

Consideration of all possible models for 6 candidate indices.

See Table 8 in Report

Canadian Data

Model #	Nvars	ombinatioi	Rcrit	Pvalue	Var 1	Var 2	Var 3	Var 4
1	4	1	2.719	0.00000	Can.RV.Summer	Can.CRV.Spr	Can.CPUE	Can.SSB.Mod
2	3	1	2.703	0.00000	Can.RV.Summer	Can.CRV.Spr	Can.CPUE	
3	3	2	3.476	0.00000	Can.RV.Summer	Can.CRV.Spr	Can.SSB.Mod	
4	3	3	2.317	0.00000	Can.RV.Summer	Can.CPUE	Can.SSB.Mod	
5	3	4	2.532	0.00000	Can.CRV.Spr	Can.CPUE	Can.SSB.Mod	
6	2	1	3.967	0.00002	Can.RV.Summer	Can.CRV.Spr		
7	2	2	2.101	0.00004	Can.RV.Summer	Can.CPUE		
8	2	3	3.079	0.00000	Can.RV.Summer	Can.SSB.Mod		
9	2	4	2.420	0.00040	Can.CRV.Spr	Can.CPUE		
10	2	5	3.458	0.00004	Can.CRV.Spr	Can.SSB.Mod		
11	2	6	1.948	0.00000	Can.CPUE	Can.SSB.Mod		
12	1	1	3.519	0.00026	Can.RV.Summer			
13	1	2	4.410	0.01296	Can.CRV.Spr			
14	1	3	1.344	0.01606	Can.CPUE			
15	1	4	2.763	0.00000	Can.SSB.Mod			

[1] Average Rcrit value overall models=

[1] 2.850295

[1] fraction of models with significance probability <0.05

[1] 1

Rcrit average for models that do NOT include Can.SSB.Mod

2.923448

Changes in catches and indices for US and Canada. See Text table, p.16

		Changes in catches			Change in indices			
	Ratio Definition	***Statistic***	***Rcrit***	***%/yr***	***Statistic***	***Rcrit***	***%/yr***	***Model***
US	'02-04:'14-16	Rcrit(Catch)	3.227	9.4%	Rcrit(Indices)	3.23	9.4%	(all six indices)
						4.98	13.1%	(DK_g, DK_t, Survey)
						3.52	10.2%	average over 63 models
	'05-07:'14-16	Rcrit(Catch)	2.657	13.0%	Rcrit(Indices)	2.20	10.4%	(all six indices)
						4.11	19.3%	DK_g,DK_t, Survey
						2.44	11.8%	average over 63 models
	'02-04:'11-13	Rcrit(Catch)	2.617	10.1%	Rcrit(indices)	2.893	11.2%	(all six indices)
						5.033	17.5%	(DK_g, DK_t, Survey)
						3.144	12.1%	average over 63 models
Canada	2002-04: 2014-2016	Rcrit(Catch)	2.259	6.5%	Rcrit(Indices)	2.703	7.9%	(two surveys , one CPUE
						2.923	8.6%	average over 6 models
						2.763	8.1%	Analytical model results

Replacement Yield Model (RYM)

- Used in past assessment but unstable results when updated in 2015 (concluded to be REBUILT in 2014)

$$B_t = B_{t-1} + R_{t-1} - C_{t-1} \; [1]$$

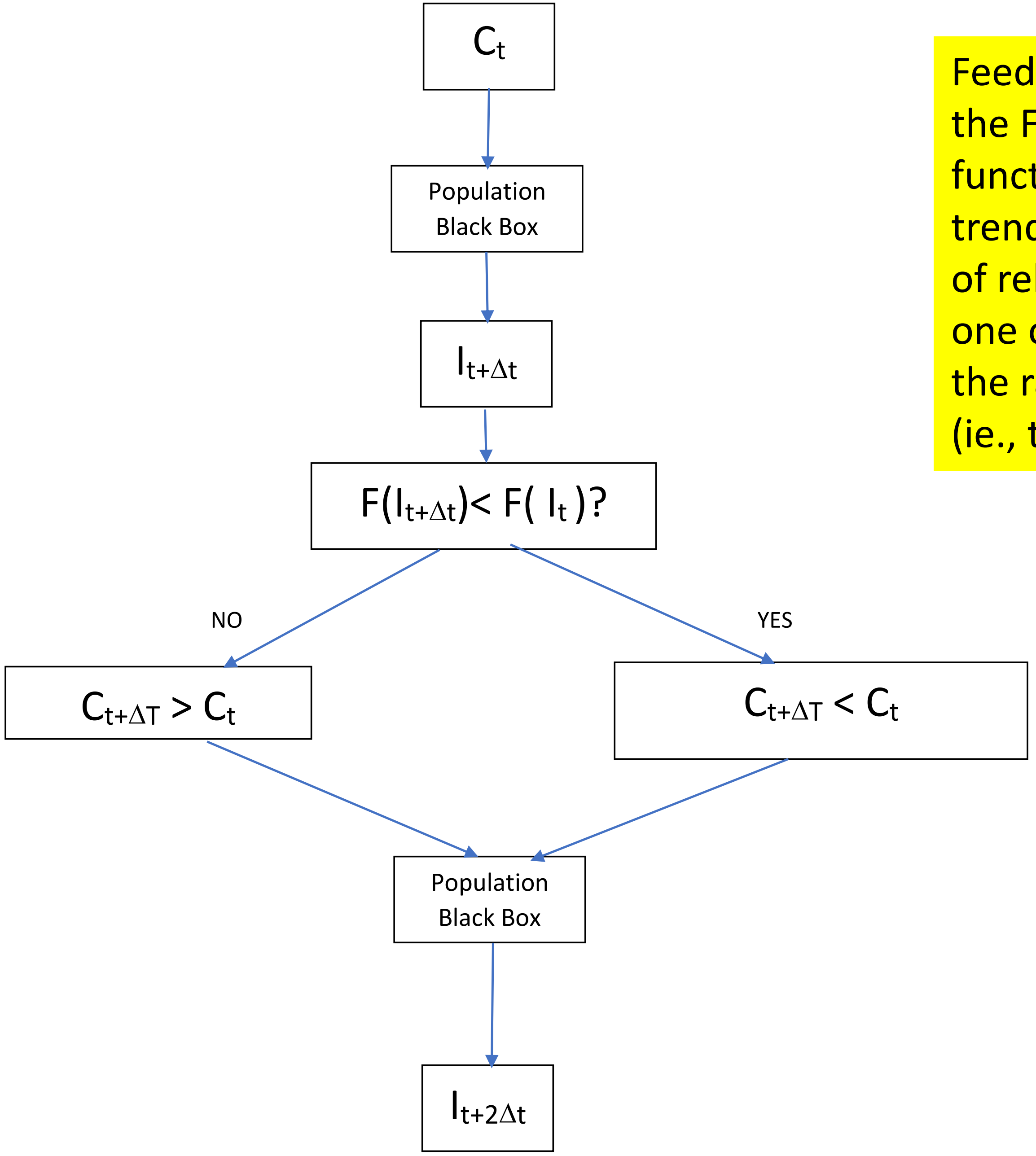
$$R_t = rB_t\left(1 - \frac{B_t}{K}\right) \quad [2]$$

- Basically a Surplus production model with constraints
  - Fixed r=2 F0.1
  - Fixed q=0.5 for fall survey
  - Assumptions about catch history
- Review panel “the updated assessment was not acceptable as a scientific basis for management advice. The updated assessment produced an unstable and unrealistic solution”

Revised model for stock dynamics

- Assume linear model BUT r and h vary with time
- $B_{t+1} = B_t + r_t B_t - h_t B_t$ [17]
- $C_t = h_t B_t$ [18]
- $\frac{C_{t+1}}{C_t} = \frac{h_{t+1} B_{t+1}}{h_t B_t}$ [22] $= C_{t+1} = \frac{h_{t+1}}{h_t} \frac{I_{t+1}}{I_t} C_t$ [24]
- $\frac{B_{t+1}}{B_t} = \frac{qI_{t+1}}{qI_t} = \frac{I_{t+1}}{I_t} = 1 + r_t - h_t$ [26]
- $\ln(I_{t+p}) = \left(p\, ln(1 + r - h) + \ln(I_t)\right)$ [29]
- $slope_t = \ln(1 + r_t - h_t)$

FIG 15 in Report



Feedback Process used in the FSD model. The F() function estimates the trend (ie., first derivative of relative abundance) in one or more indices AND the rate of change in trend (ie., the second derivative)

The magnitude of the change in C is determined by the values of the first and second derivatives and the gain parameters(Kp, Kd) applied.

Building the First and Second Derivative Model

- Recursive equation for updating catch
- $C_{t+1} \cong \frac{h_{t+1}}{h_t} e^{slope_t} C_t$ [31]
- This can be extended to multiple indices
- BUT also interested in ability to detect changes in the slope.
- Need to extend model
- $\beta(t, n) = slope(x_{t-n+1,} x_{t-n}, \dots . x_{t-1}, x_t)$
- $\Delta\beta(t, n) = \beta(t, n) - \beta(t-1, n)$ [34]

Controllability

- Do we want to take all of the increase in relative abundance and translate it to an equivalent increase in catch?
- Why not, it's only fair
  - Concerns about lag in signal—based on 5 year window of index observations
  - Possibly bad signal, observation error is high.
  - Longevity suggest that under harvest of halibut will be in the water next year to capture. Therefore can balance tradeoff.
  - Examples from control theory literature (eg. Thermostats) suggest potential instability in process if gain is set too high.
- Many MPA examples consider "slow up, fast down" policies
- One way to quantify is to consider rate of change in slope in terminal year, an approximation of the second derivative of abundance.
- Important because of potential changes in productivity over time (r(t)). Especially important if stock productivity is declining via slower growth or reduced recruitment

Weighting the slope and delta slope components

- Gain factors
  - Kp Gain on proportional rate of change
  - Kd Gain on derivative of change

- $C_{t+1} = e^{\left(K_p \beta(t,n) + K_d \Delta\beta(t,n)\right)} C_t$ [35]

- Equation 35 is the recursive updating equation for catch. Note that when Kp=Kd=0 this becomes a constant status quo catch model.

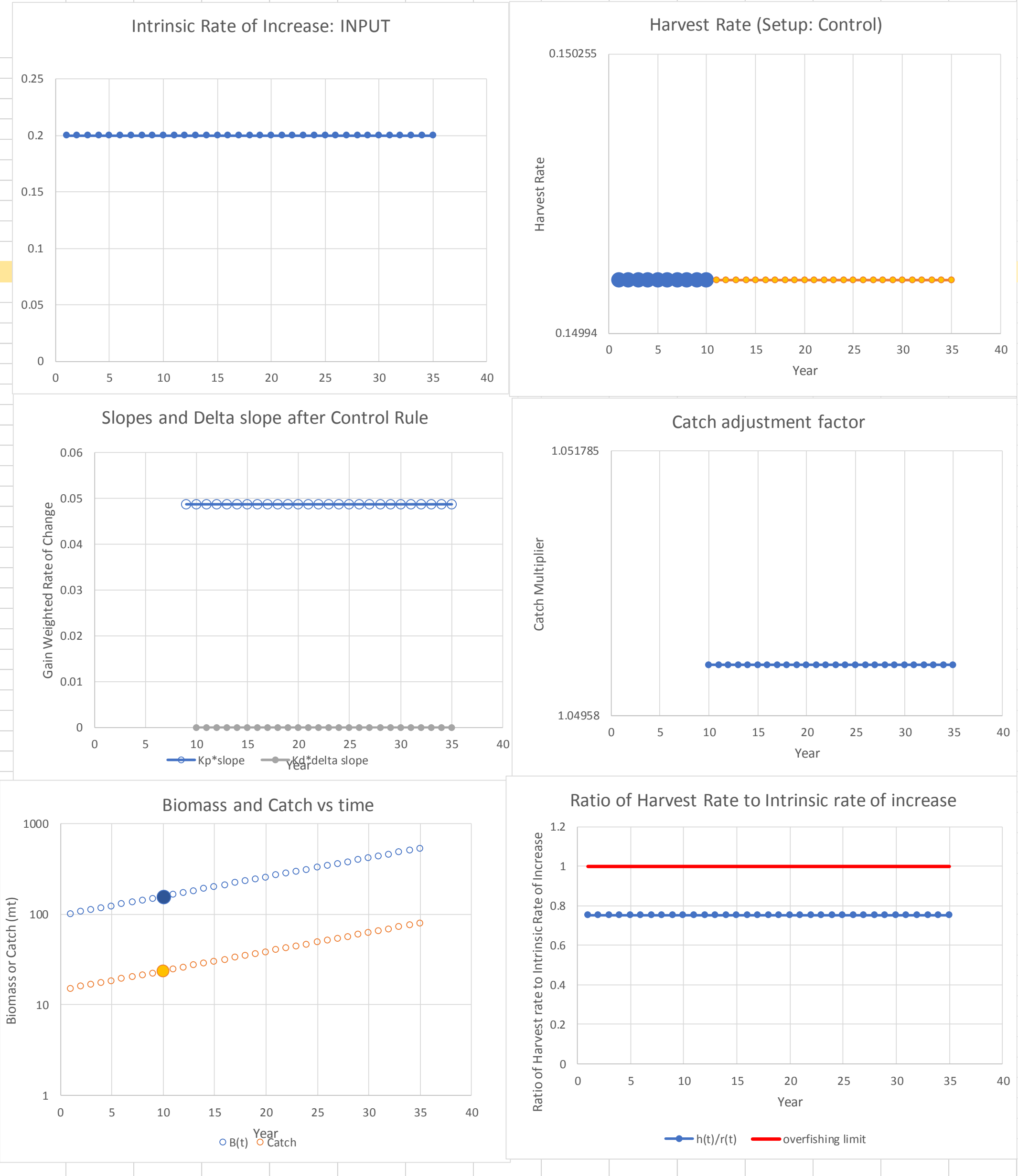
Simulation Tests on FSD model

- Observation error for the relative abundance indices ***CV={0.005,0.2}***
- Number of abundance indices available ***Nvar={2,6}***
- Number of years to consider for estimating average slope. ***Ntrend={3,5}***
- Effects of alternative values of Kp and Kd
- The underlying rate of population increase (r(t)) during the period before and after the control rule is applied.
- The pattern of harvesting (h(t)) prior to the application of the control rule.

What is expected behavior of population controlled by FSD?

- Depends on:
  - True rate of change in productivity
  - Initial conditions prior to implementation of controls
    - Harvest rates
    - Intrinsic rate of increase
  - Weighting factors applied to slope and Delta slope
  - Ability to track changes in relative abundance
- Any control system that relies on past information to forecast future conditions will have problems when
  - Lags in information—slope is based on n years, reflecting a balance between sensitivity and estimability –the Signal:Noise ratio.
  - The population biology changes—growth declines, recruitment fails etc (e.g., IPHC Pacific Halibut)
  - The fishery changes—fishing activity becomes more targeted resulting in stable CPUE while stock declines

Initial Harvest h(t) Scenario	Intrinsic rate of increase r(t) scenario	Number of years used for slope estimation	Kp Gain on Slope	KD Gain on slope derivative		Total Catch	CV of Catch	Max Cmult	Min Cmult	Fraction of Overfishing Events
1	1	5	1	0		1166	0.355	1.050	1.050	0.00



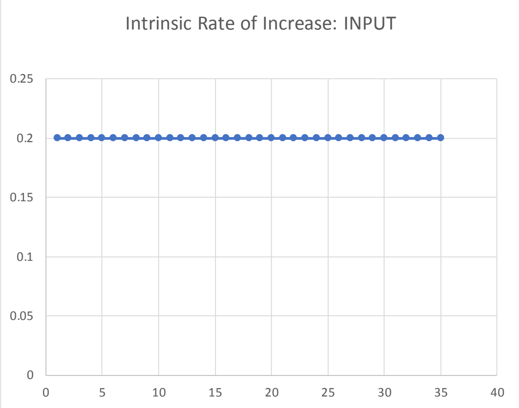
Example 1—the boring equilibrium:

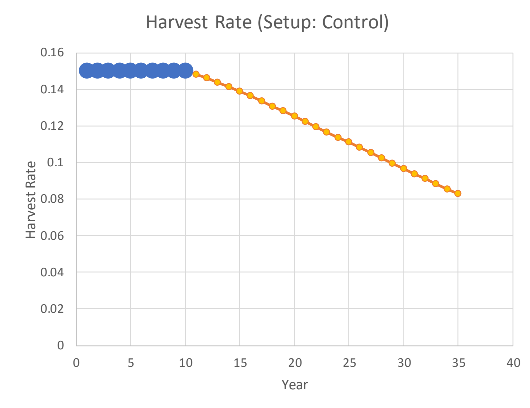
- Intrinsic rate of increase is constant =0.2
- Initial Harvest rate is below intrinsic rate during initial period h(t)=0.15
- Assume Kp=1.0 for proportional and Kd=0 for derivative controls

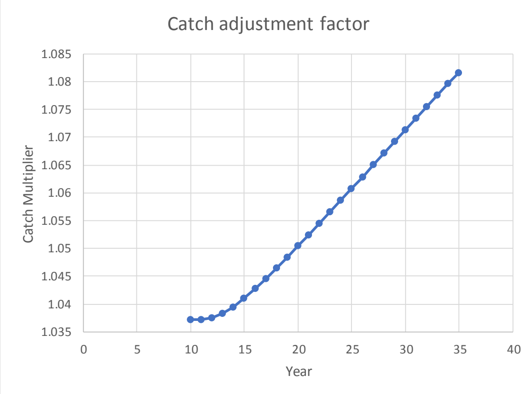
Key Results

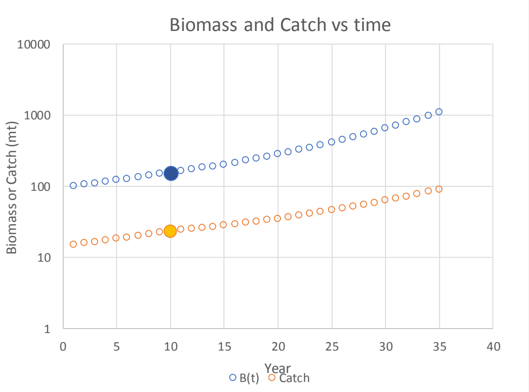
- High cumulative catch 1166 mt
- No Overfishing
- Multiplier is same over entire period= 1.05
- Stock size AND catch continuously increase.
- Rate of population growth during control period is same as in period of no direct control.

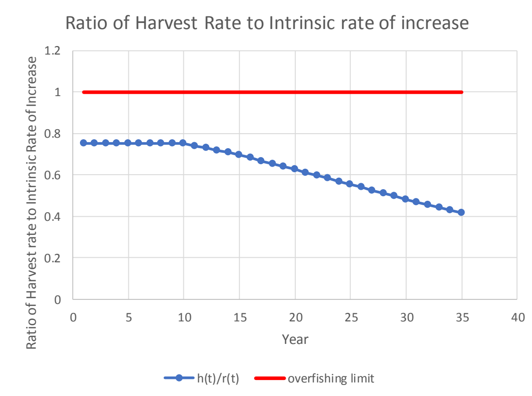
Initial Harvest h(t) Scenario	*Intrinsic rate of increase r(t) scenario*	*Number of years used for slope estimation*	*Kp Gain on Slope*	*KD Gain on slope derivative*		Total Catch	CV of Catch	Max Cmult	Min Cmult	Fraction of Overfishing Events
1	***1***	5	***0.75***	***0***		1157	0.42	1.082	1.037	0.00











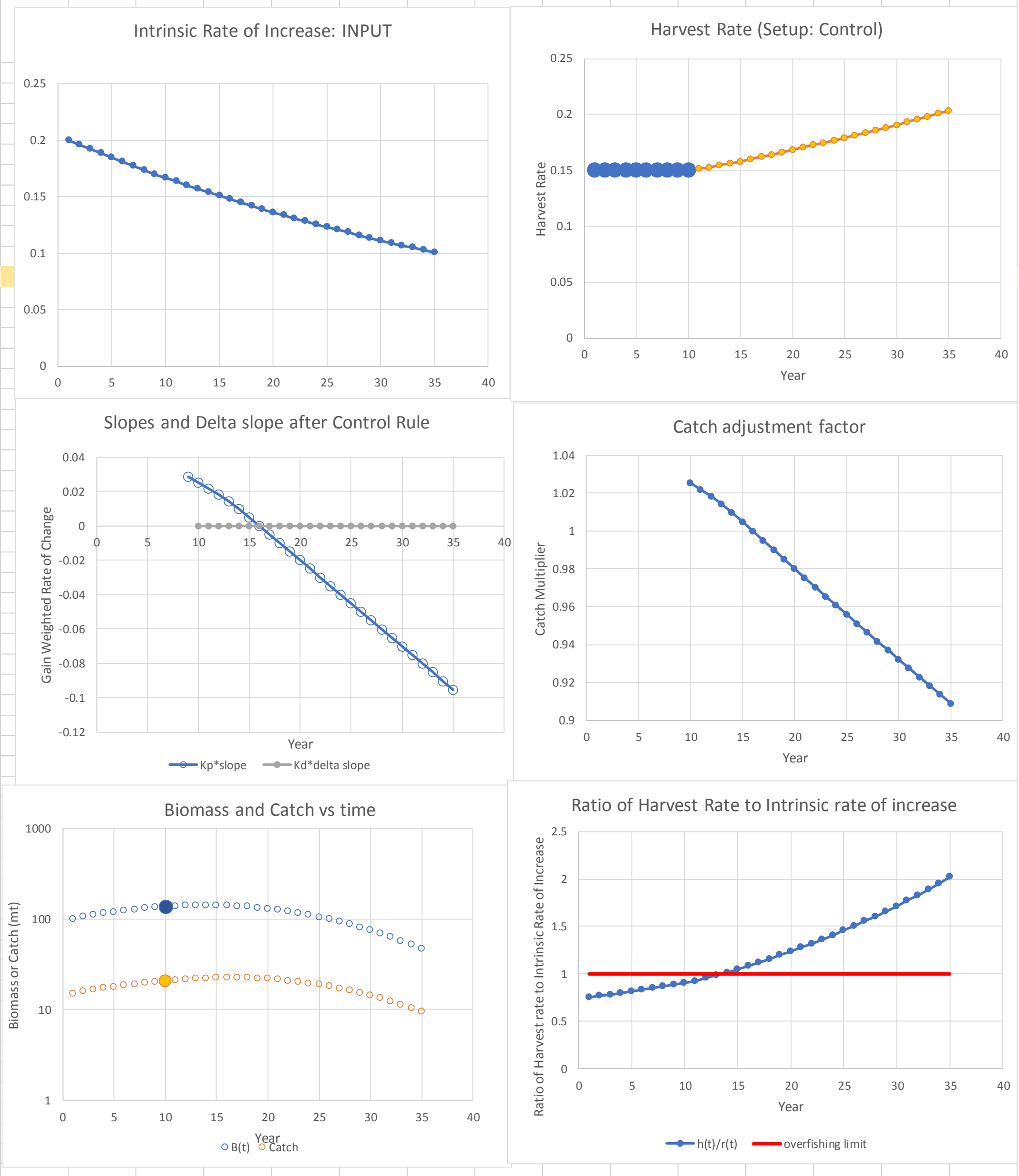
Example 2— Don't take it all policy:

- Intrinsic rate of increase is constant =0.2
- Initial Harvest rate is below intrinsic rate during initial period h(t)=0.15
- Assume Kp=0.75 for proportional and Kd=0 for derivative controls

Key Results

- High cumulative catch 1157 mt but much of this comes in the out years as population continues to increase
- No Overfishing AND Harvest Rate continues to decrease
- Multiplier increases over entire period= 1.05
- Stock size AND catch increases slightly.
- Rate of population growth increases continuously over the control period.

Initial Harvest h(t) Scenario	Intrinsic rate of increase r(t) scenario	Number of years used for slope estimation	Kp Gain on Slope	KD Gain on slope derivative		Total Catch	CV of Catch	Max Cmult	Min Cmult	Fraction of Overfishing Events
1	4	5	1	0		456.7	0.233	1.025	0.909	0.63



More challenging Control Problems: Stock productivity declines continuously

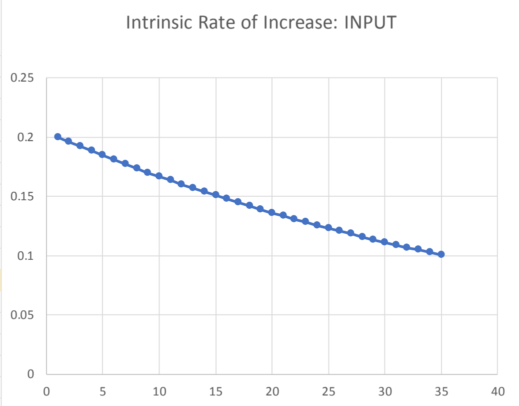
Example 3:

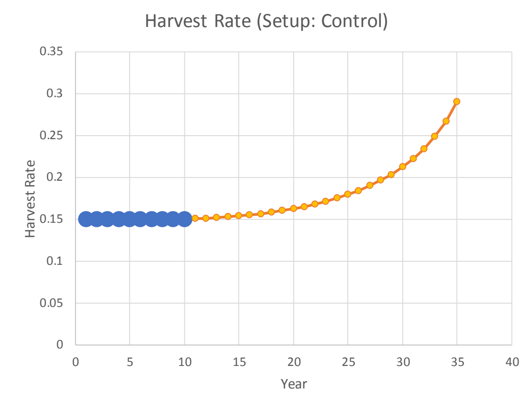
- Intrinsic rate of increase is DECLINING
- Initial Harvest rate is below intrinsic rate during initial period
- Set Kp=1 (take it all). Don't consider derivative. (Kd=0)

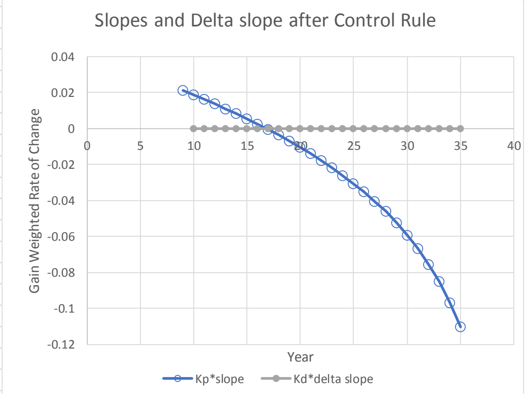
Key Results

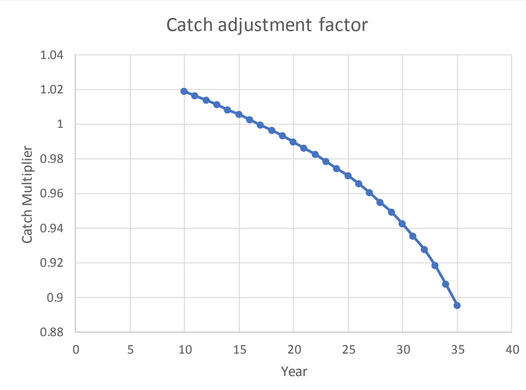
- Moderate cumulative catch 457 mt
- Overfishing commences about year 10. Frequency of overfishing years is 63%
- Minimum catch multiplier is 0.91 or 9% decrease
- Stock size gradually declines as do catches as the stock declines

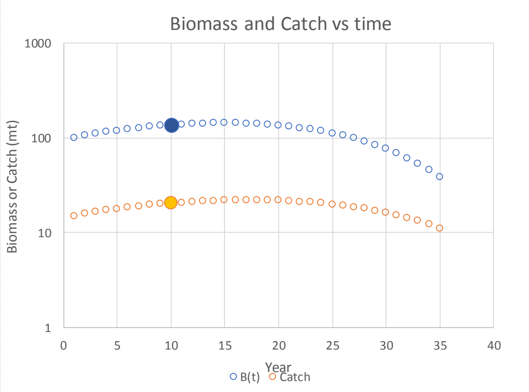
Initial Harvest h(t) Scenario	Intrinsic rate of increase r(t) scenario	Number of years used for slope estimation	Kp Gain on Slope	KD Gain on slope derivative		Total Catch	CV of Catch	Max Cmult	Min Cmult	Fraction of Overfishing Events
1	4	5	0.75	0		475.3	0.18	1.019	0.895	0.60

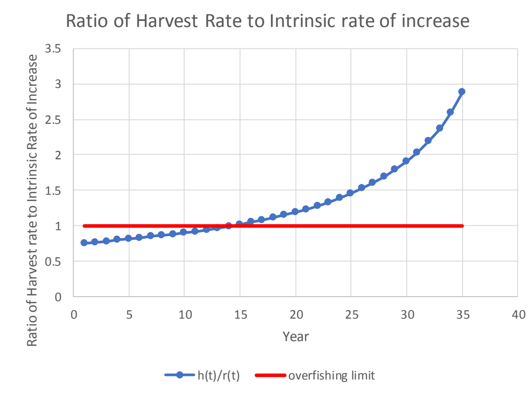












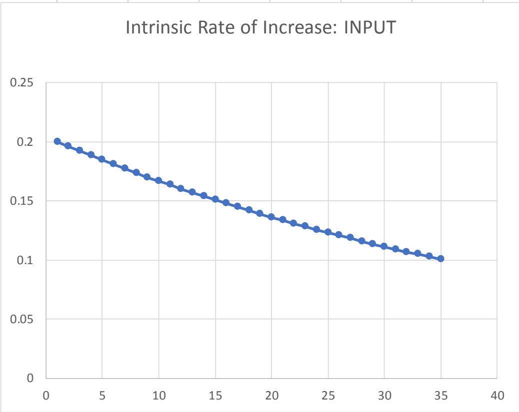
Example 4:

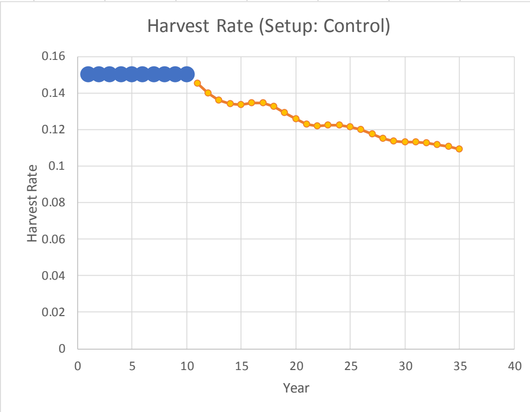
- Intrinsic rate of increase is DECLINING
- Initial Harvest rate is below intrinsic rate during initial period
- Set **Kp=0.75** (hold back). Don't consider derivative. (Kd=0)

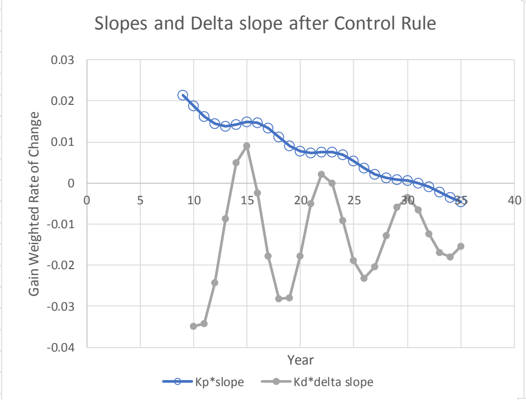
Key Results

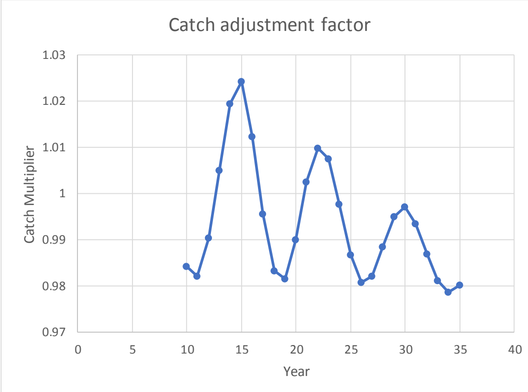
- Moderate cumulative catch 475 mt
- **Overfishing commences about year 15**. Frequency of overfishing years is 60%
- Minimum catch multiplier is 0.89 or 11% decrease
- Stock size gradually declines as do catches as the stock declines

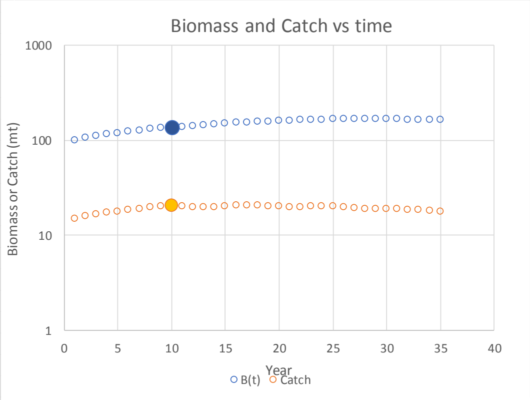
Initial Harvest h(t) Scenario	Intrinsic rate of increase r(t) scenario	Number of years used for slope estimation	Kp Gain on Slope	KD Gain on slope derivative		Total Catch	CV of Catch	Max Cmult	Min Cmult	Fraction of Overfishing Events
1	4	5	0.75	10		487.4	0.042	1.024	0.979	0.20

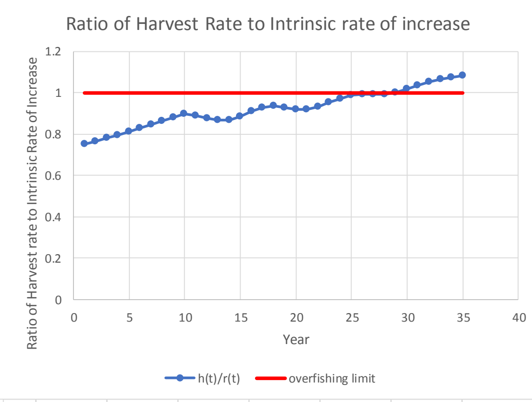












Using the gain on the second derivative Kd>0

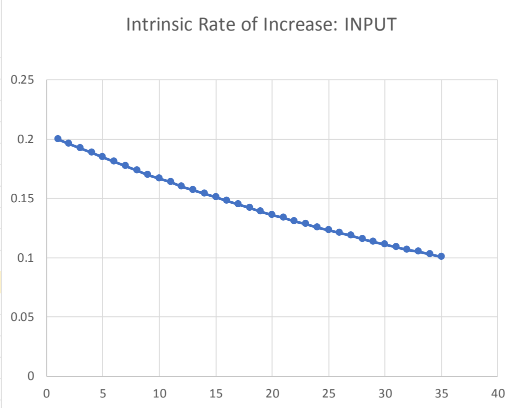
Example 5:

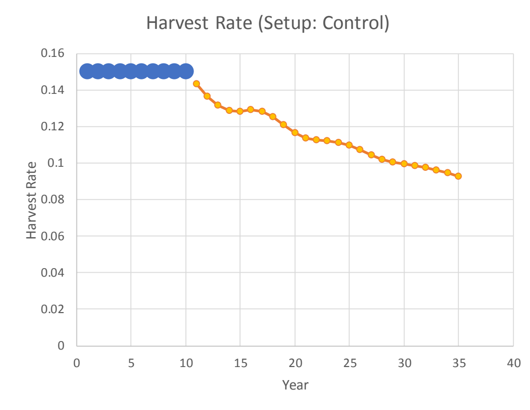
- Intrinsic rate of increase is DECLINING
- Initial Harvest rate is below intrinsic rate during initial period
- Differential weights on proportional and derivative controls:
  - Kp=0.75
  - Kd=10

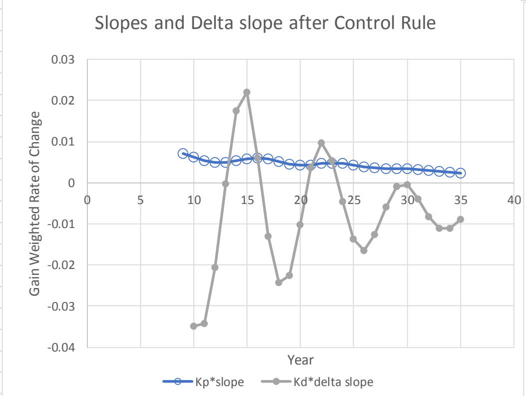
Key Results

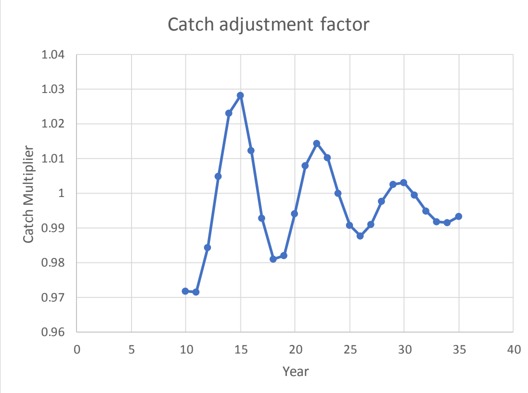
- Slightly higher cumulative catch 488 mt
- Overfishing commences about year 30. Frequency of overfishing years is 20%
- Minimum catch multiplier is 0.98 or 2% decrease
- Catch multiplier oscillates but within a narrow range.+/- 2%.
- Stock size remains stable despite decreasing trend in productivity as do catches

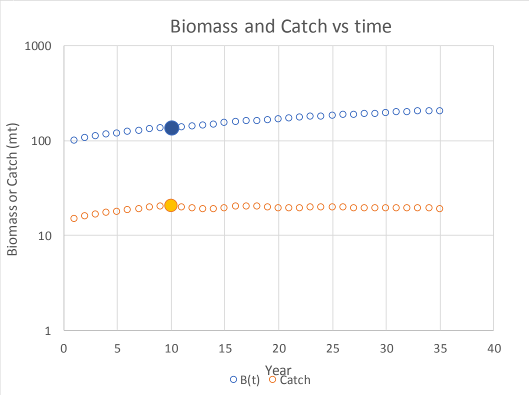
Initial Harvest h(t) Scenario	Intrinsic rate of increase r(t) scenario	Number of years used for slope estimation	Kp Gain on Slope	KD Gain on slope derivative		Total Catch	CV of Catch	Max Cmult	Min Cmult	Fraction of Overfishing Events
1	4	5	0.25	10		487.2	0.019	1.028	0.972	0.00

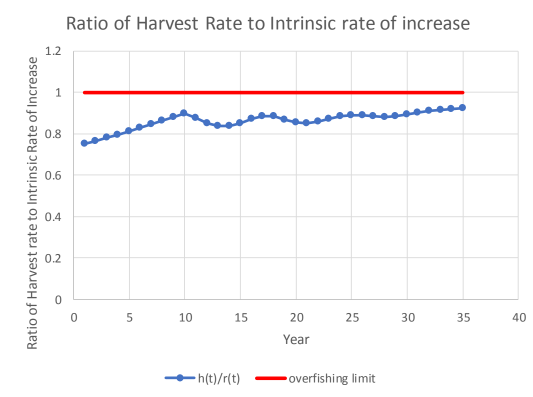












Fine tuning. Set Kp to a low value and rely more on gain on the second derivative Kd>0

Example 6:

- Intrinsic rate of increase is DECLINING
- Initial Harvest rate is below intrinsic rate during initial period
- Differential weights on proportional and derivative controls:
  - Kp=0.25 (less weight on proportional change)
  - Kd=10

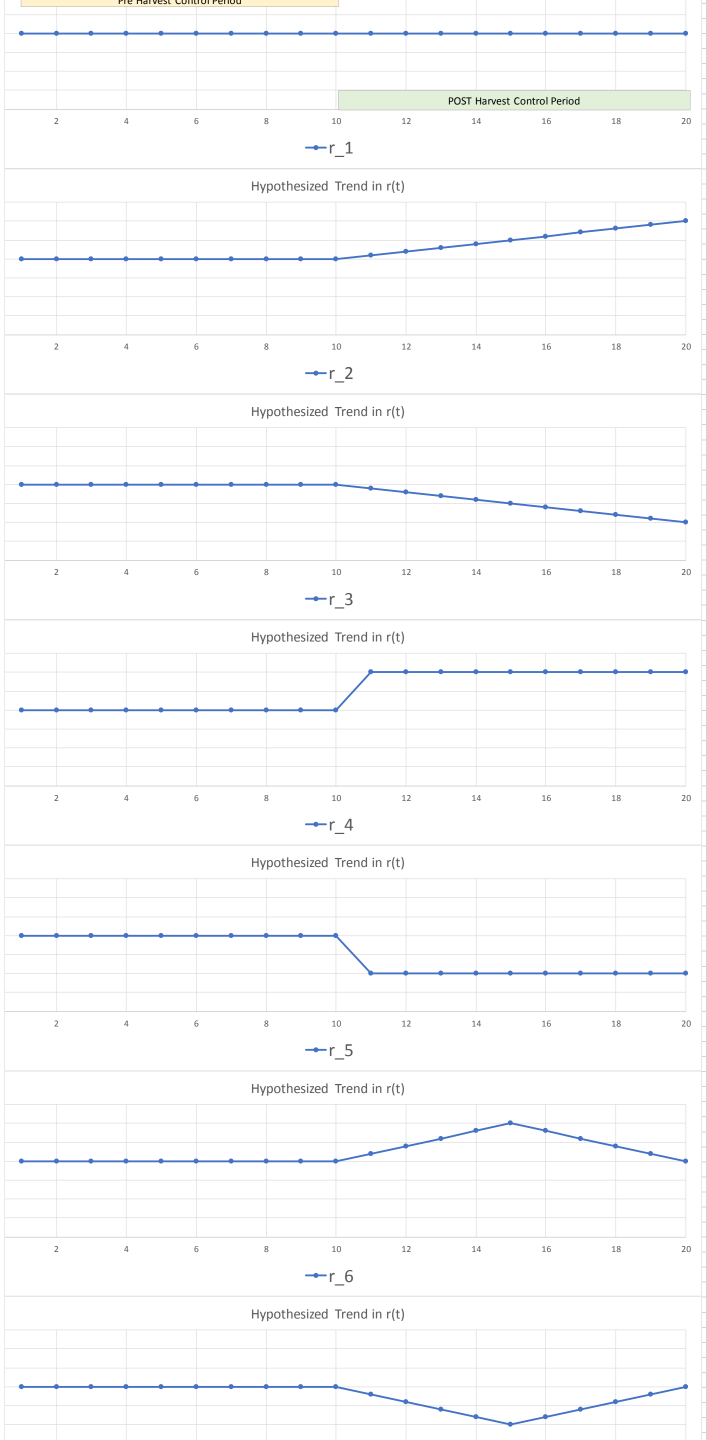
Key Results

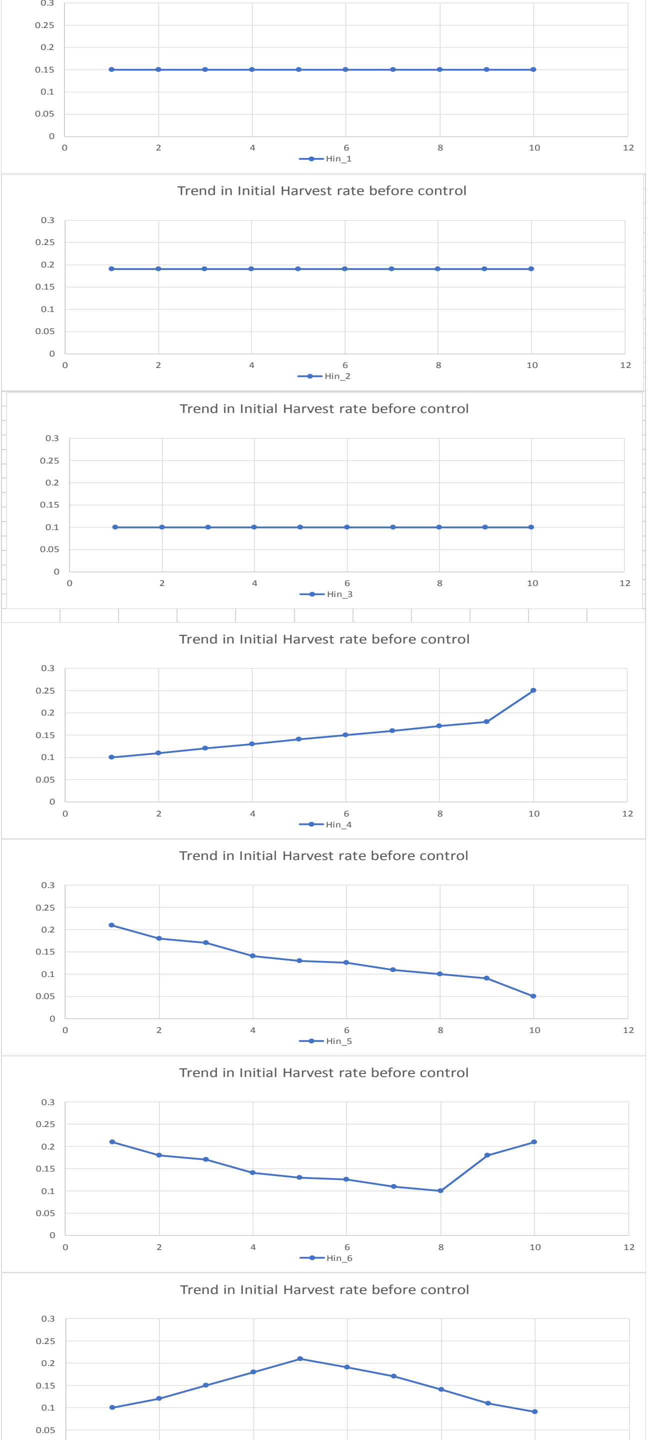
- About the same cumulative catch 487 mt
- NO overfishing over the entire period
- Minimum catch multiplier is 0.97 or 3% decrease
- Catch multiplier oscillates but within a narrow range.+/- 3%.
- Stock size remains stable despite decreasing trend in productivity as do catches

But of course, we don't know what the future holds and only have modest information about the initial conditions.

- So it is helpful to simulate various control strategies for different assumptions about the:
  - Intrinsic rate of increase
  - Harvest rate in the initial (pre-control) period
  - Variability of observations
  - Number of indices available
  - Number of years used to estimate slope
  - Alternative weighting factors for proportional and derivative gain (Kp, Kd)

Temporal Change in intrinsic rate of growth r(t). See Fig. 16





Temporal Change in initial harvest rate h(t) prior to implementation of the control rule governed by FSD.

See Fig. 17

FSD Simulation Results

- Consider effects of
  - Multiple set up conditions r(t) and h(t).
  - Multiple number of relative abundance indices
  - Varying levels of observation error
  - Varying number of years used to estimate slope.
  - Different gain factors applied to slope indices
- Need to consider multiple objectives as metrics for choosing a control strategy.
  - Average # of overfishing events
  - Average catch
  - CV of catch
  - Simulation failures—overshoots on catch
  - Net rate of population growth during the period where the FSD control is applied

Average % of overfishing events					
CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	0.171	0.201	0.229	0.282
	1	0.197	0.228	0.249	0.314
	5	0.244	0.254	0.269	0.280
	10	0.217	0.237	0.255	0.281
0.2	0	0.171	0.201	0.234	0.275
	1	0.196	0.231	0.271	0.309
	5	0.247	0.253	0.274	0.292
	10	0.226	0.241	0.258	0.279

Fraction of simulation failures					
CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	0.163	0.163	0.153	0.134
	1	0.122	0.112	0.111	0.071
	5	0.000	0.000	0.000	0.000
	10	0.000	0.004	0.010	0.022
0.2	0	0.166	0.164	0.157	0.151
	1	0.126	0.114	0.097	0.082
	5	0.034	0.035	0.029	0.028
	10	0.147	0.162	0.182	0.194

Average Catch					
CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	228.6	248.9	270.6	296.5
	1	236.0	254.8	275.3	298.9
	5	256.6	276.3	297.6	320.1
	10	294.4	313.5	332.1	348.2
0.2	0	227.8	248.3	270.6	295.6
	1	235.0	254.5	276.3	298.8
	5	256.6	277.2	297.1	319.4
	10	292.7	314.0	332.2	346.4

Net rate of population change during control period					
CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	0.078	0.071	0.061	0.047
	1	0.071	0.063	0.056	0.038
	5	0.058	0.054	0.049	0.043
	10	0.054	0.048	0.041	0.033
0.2	0	0.078	0.071	0.062	0.052
	1	0.072	0.062	0.050	0.038
	5	0.055	0.050	0.042	0.035
	10	0.050	0.044	0.036	0.027

Average CV of Catch					
CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	0.068	0.135	0.199	0.259
	1	0.097	0.159	0.219	0.283
	5	0.239	0.281	0.322	0.361
	10	0.401	0.430	0.458	0.483
0.2	0	0.070	0.137	0.203	0.266
	1	0.115	0.176	0.239	0.304
	5	0.368	0.410	0.457	0.503
	10	0.675	0.712	0.737	0.769

Summary of simulation results by Kp and Kd gain factors. Results are averaged over 7 different scenarios for population productivity and 7 scenarios for pre-control harvest rates.

Response variables are:

- Ave % overfishing events
- Average Catch
- Ave CV of Catch
- Fraction of Sim Failures
- Net of increase during control period

See Table 14 in report

Average % of overfishing events

CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	0.171	0.201	0.229	0.282
	1	0.197	0.228	0.249	0.314
	5	0.244	0.254	0.269	0.280
	10	0.217	0.237	0.255	0.281
0.2	0	0.171	0.201	0.234	0.275
	1	0.196	0.231	0.271	0.309
	5	0.247	0.253	0.274	0.292
	10	0.226	0.241	0.258	0.279

Average Catch

CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	228.6	248.9	270.6	296.5
	1	236.0	254.8	275.3	298.9
	5	[illegible]	[illegible]	[illegible]	[illegible]

Average Catch

CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	228.6	248.9	270.6	296.5
	1	236.0	254.8	275.3	298.9
	5	256.6	276.3	297.6	320.1
	10	294.4	313.5	332.1	348.2
0.2	0	227.8	248.3	270.6	295.6
	1	235.0	254.5	276.3	298.8
	5	256.6	277.2	297.1	319.4
	10	292.7	314.0	334.2	347.0

Number of simulation failures

CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	800	800	750	657
	1	600	550	543	350
	5	0	0	0	0
	1	617	557	475	404

Average CV of Catch

CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	0.068	0.135	0.199	0.259
	1	0.097	0.159	0.219	0.283
	5	0.239	0.281	0.322	0.361
	10	0.401	0.430	0.458	0.483

Net rate of population change during control period

CV	Kd	Kp=0.25	Kp=0.5	Kp=0.75	Kp=1
0.005	0	0.163	0.163	0.153	0.134
	1				0.071

Text table—Page 26. Effect of scenarios on frequency of simulation failures, averaged over all gain factors (Kp, Kd).

	tx<-ftable(tapply(is.na(Simout$perc_OFE),list(Simout$h_scenario,Simout$r_scenario),							
		R scenario							
		r=0.2	***r_up***	***r_down***	***r_step_up***	***r_step_dn***	***r_up_dn***	***r_dn_up***	
Descrip-tion	***Harvest Scenario***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	average
h=0.15	***1***	0.0159	0.0241	0.0178	0.0256	0.0191	0.0225	0.0181	0.020
h=0.19	***2***	0.0394	0.0375	0.0363	0.0525	0.3281	0.0456	0.0419	0.083
h=0.10	***3***	0.0053	0.0078	0.0091	0.0078	0.0078	0.0094	0.0053	0.008
h_up	***4***	0.3722	0.0816	0.5066	0.0691	0.5500	0.1044	0.5113	0.314
h_down	***5***	0.0016	0.0016	0.0013	0.0028	0.0013	0.0025	0.0019	0.002
h_dn_up	***6***	0.0469	0.0363	0.3153	0.0316	0.5028	0.0534	0.4019	0.198
h_up_dn	***7***	0.0119	0.0188	0.0156	0.0231	0.0184	0.0203	0.0141	0.017
	average	0.070	0.030	0.129	0.030	0.204	0.037	0.142	0.092

Application of FSD to US stock

- Used 3 core indices:
  - NEFSC fall survey weight per tow
  - d/k ratio for gill nets
  - d/k ratio for trawls
- Examined fit over a range of Kp and Kd gain factors

Ave slope

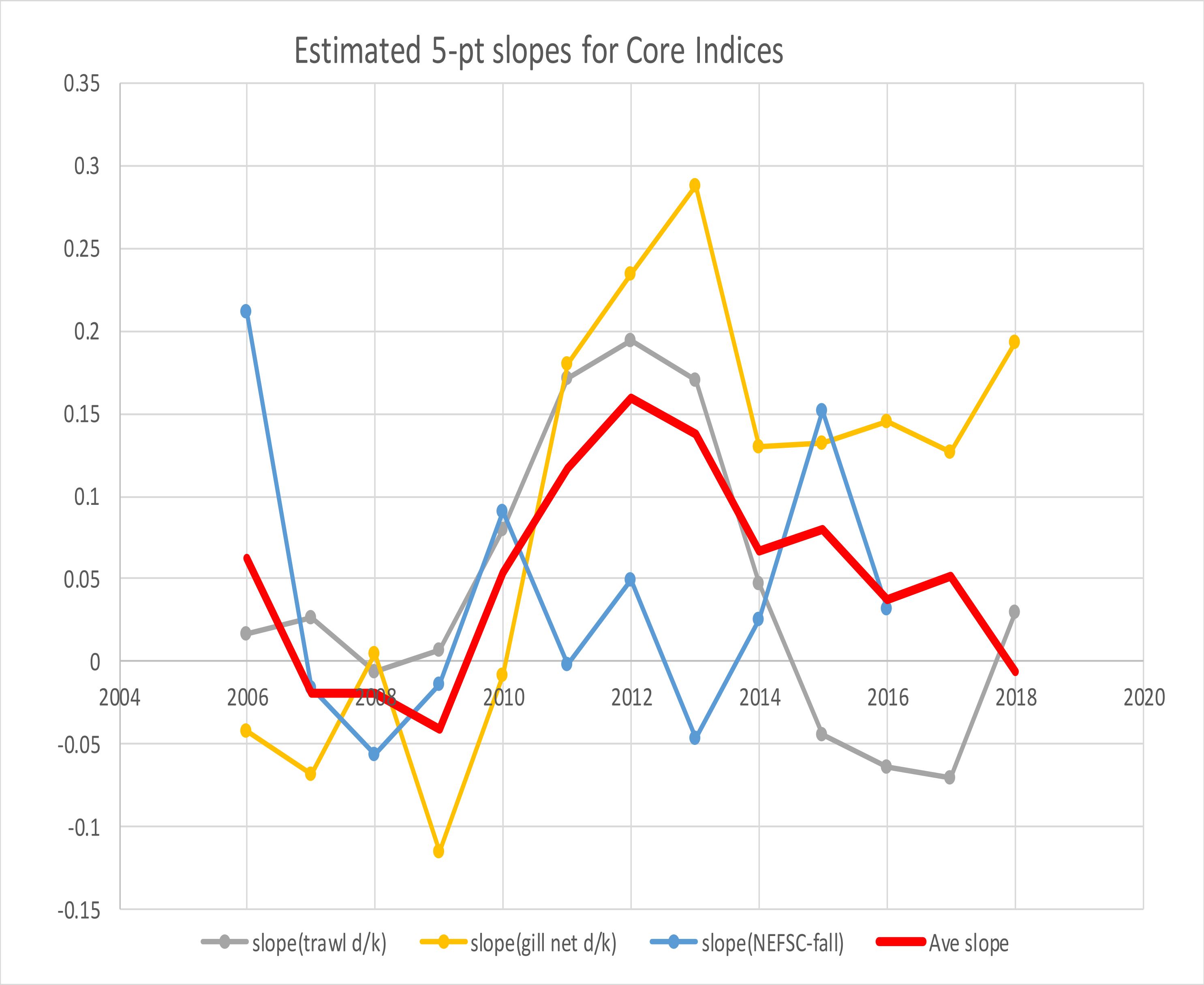


Figure 18 in Report (bottom)

Three Core Indices

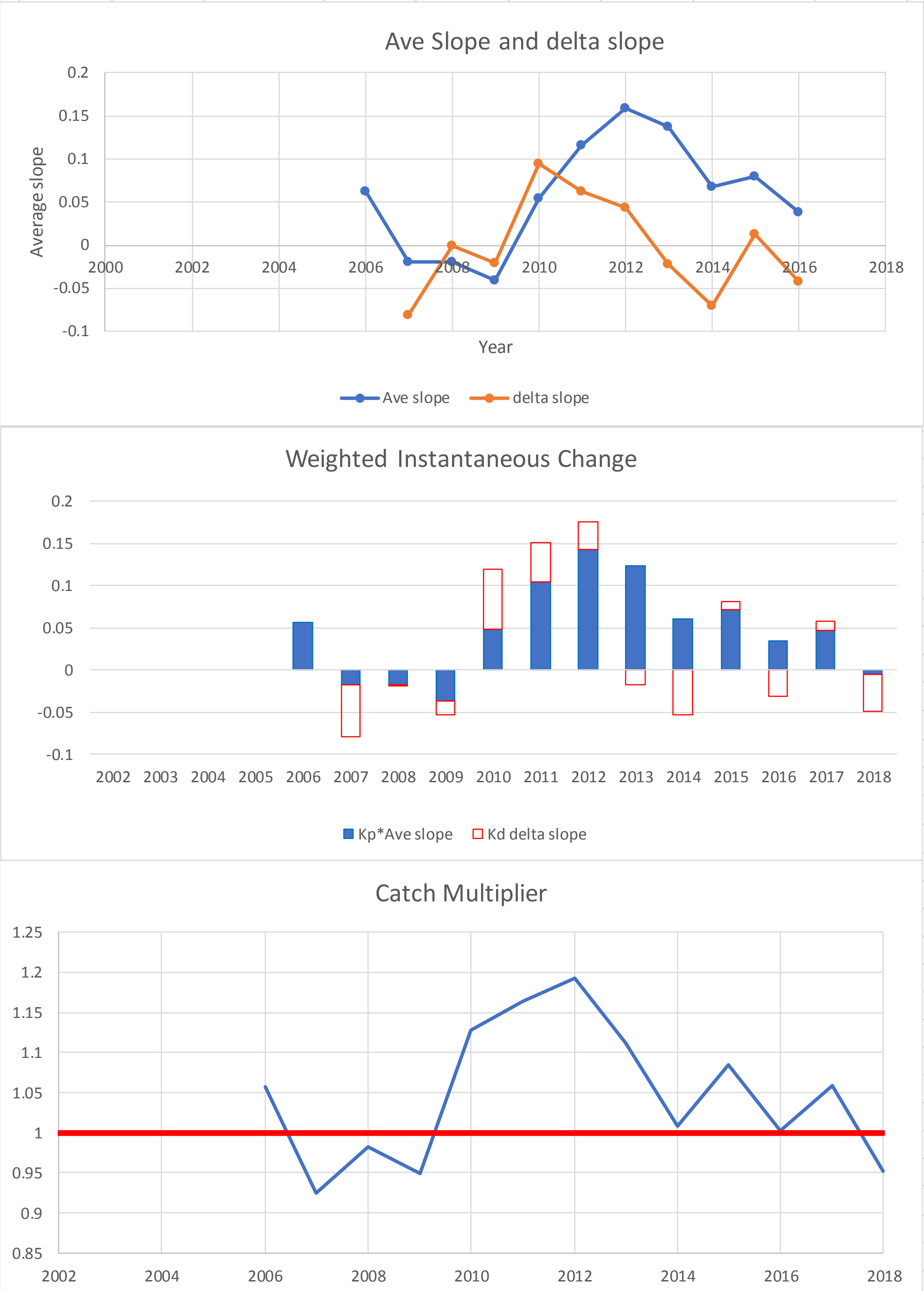


Figure 19 in Report

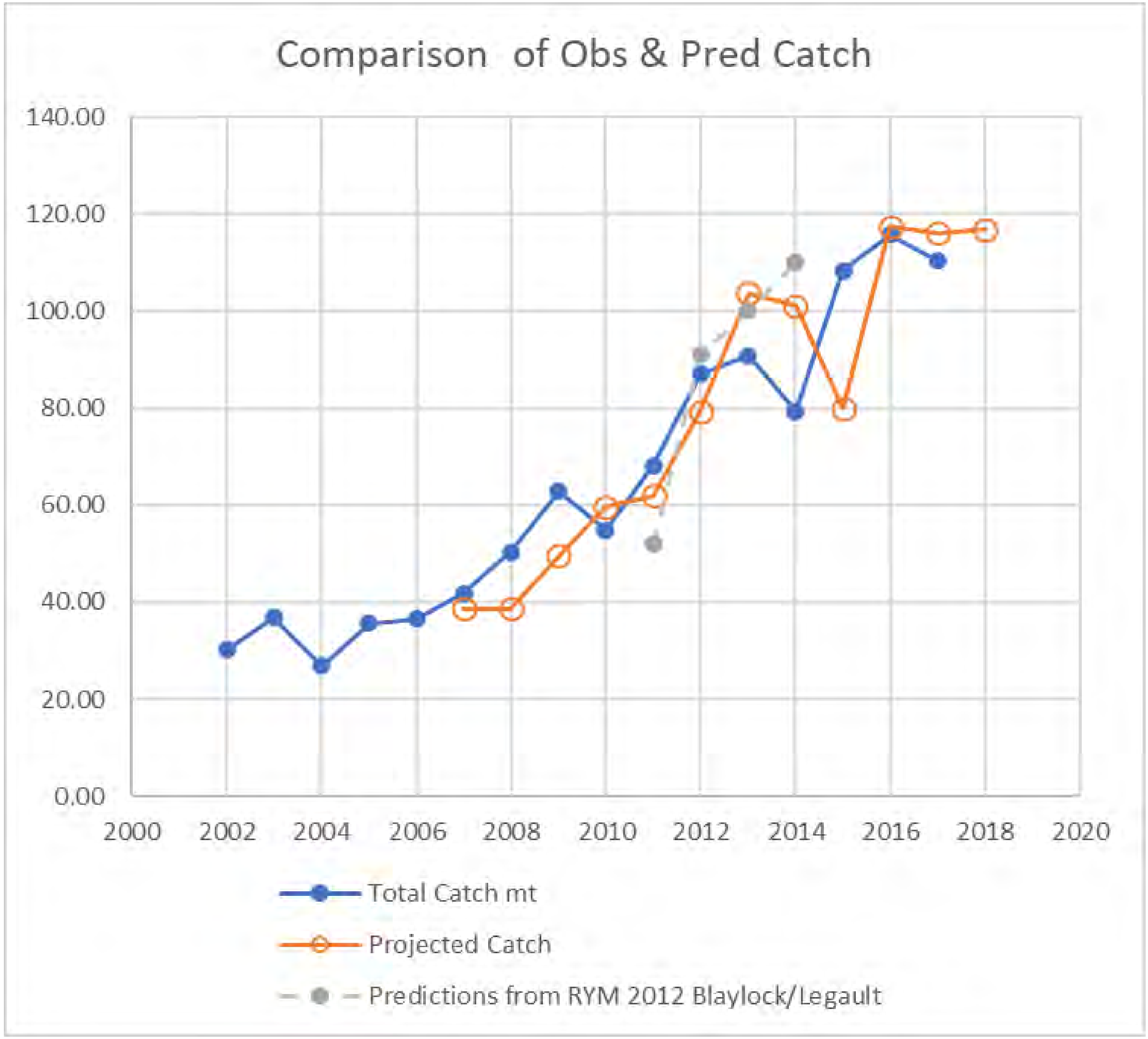


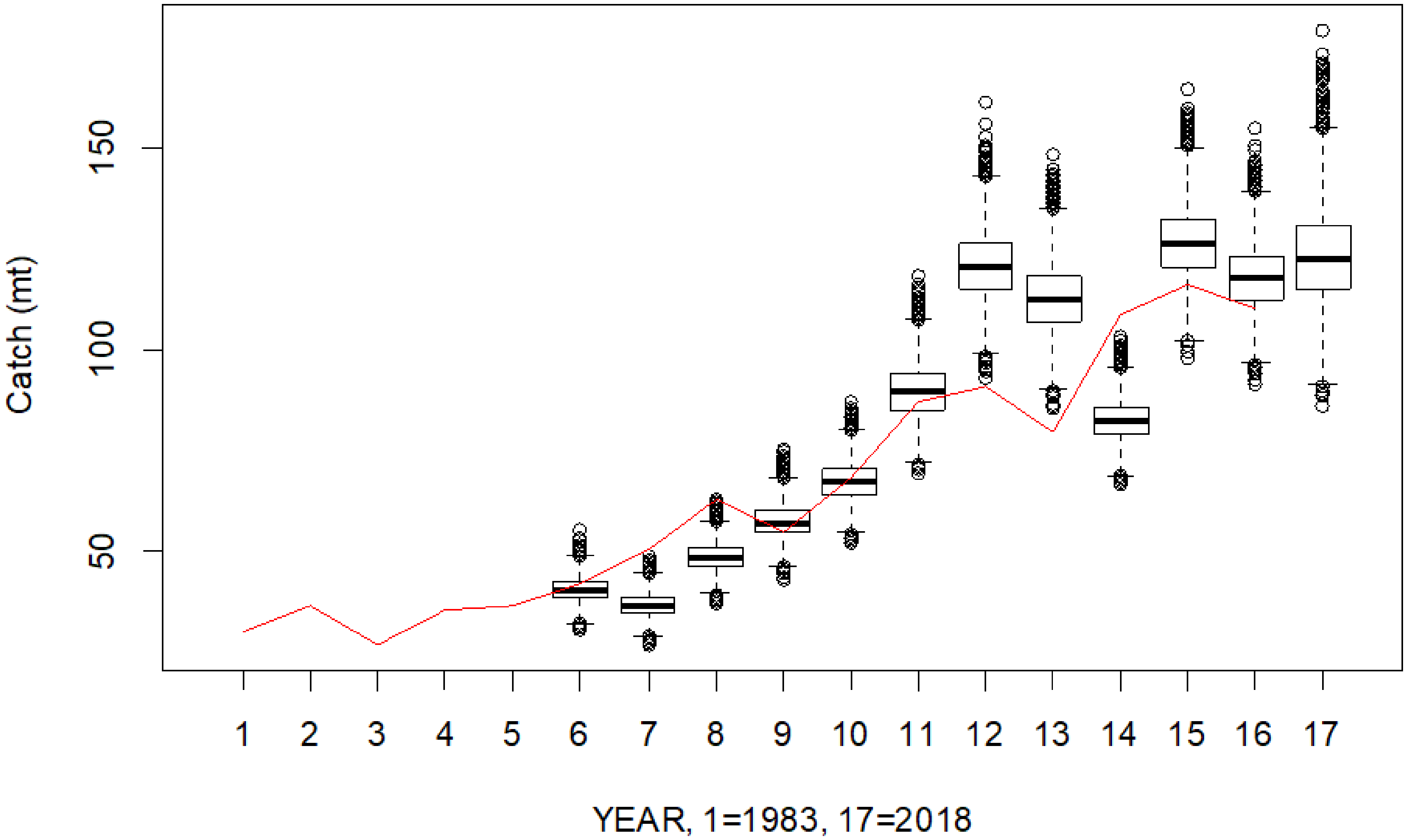
Figure 20 in Report

Bootstrap Method for Projections

- $Irand_{k,j,t} \sim LogNormal(Iobs_{j,t}, \sqrt{CV_{j,t}^2 + 1})$
- Apply to 3 core indices
  - d/k gill net
  - d/k trawl
  - NEFSC Fall Survey weight per tow
- Replicate 5000 times
- Compute sampling distribution of forecasts at each step

Uncertainty estimates for FSD projections

Figure 21 in Report



Projected Catch (mt) distribution for 2018

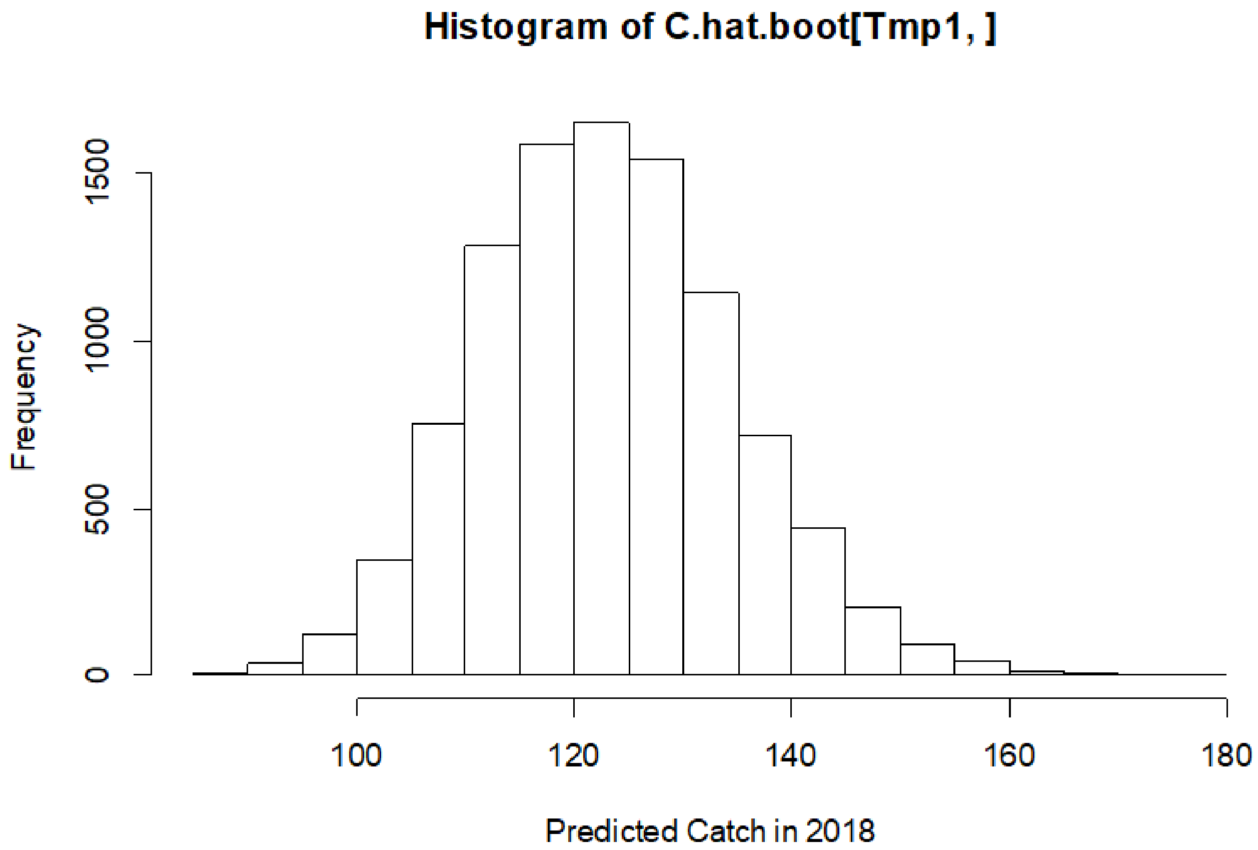


Figure 22 in Report

1%	5%	10%	25%	50%	75%	90%	95%	99%
98.24	104.98	108.61	114.88	122.65	130.69	138.34	143.16	152.26

The bootstrap mean of projected catch is 123.10 mt with a CV equal to 0.095.

Range of Possible Catch Estimates

- Examine implications of different weightings of Kp and Kd gain factors.
- How much weight for the proportional gain—how much of the population rate of increase translates into an increase in Catch?
- How much weight for the rate of change in population increase (ie the second derivative)?
  - IF second derivative has same sign as first then veracity of the population trend supported.
  - If second derivative has a different sign, then population may be going through an inflection --*Caveat coerator "Let the manager beware"*
- *If both* Kp and Kd are set to zero, the update function reverts to 1.0—NO change in catch in following year.

Data table for 2018 Catch give range of Kp and Kd gain factors

		Kp								
	122.67	0	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Kd	0	110.3	114.3	115.7	117.1	118.5	120.0	121.4	122.9	124.4
	0.25	111.2	115.3	116.7	118.1	119.5	120.9	122.4	123.9	125.4
	0.5	112.1	116.2	117.6	119.0	120.5	121.9	123.4	124.9	126.4
	0.75	113.0	117.2	118.6	120.0	121.5	122.9	124.4	125.9	127.4
	1	114.0	118.1	119.6	121.0	122.5	123.9	125.4	127.0	128.5
	1.25	114.9	119.1	120.5	122.0	123.5	125.0	126.5	128.0	129.5
	1.5	115.8	120.1	121.5	123.0	124.5	126.0	127.5	129.0	130.6
	1.75	116.8	121.1	122.5	124.0	125.5	127.0	128.6	130.1	131.7
	2	117.8	122.1	123.5	125.0	126.5	128.1	129.6	131.2	132.8
	2.25	118.7	123.1	124.6	126.1	127.6	129.1	130.7	132.3	133.8
	2.5	119.7	124.1	125.6	127.1	128.6	130.2	131.7	133.3	134.9
	2.75	120.7	125.1	126.6	128.1	129.7	131.2	132.8	134.4	136.1
	3	121.7	126.1	127.6	129.2	130.7	132.3	133.9	135.5	137.2
	3.25	122.7	127.2	128.7	130.2	131.8	133.4	135.0	136.6	138.3
	3.5	123.7	128.2	129.8	131.3	132.9	134.5	136.1	137.8	139.4
	3.75	124.7	129.3	130.8	132.4	134.0	135.6	137.2	138.9	140.6
	4	125.7	130.3	131.9	133.5	135.1	136.7	138.4	140.0	141.7
		min (C(2018))=		111.2	max(C(2018))=		141.7			

Estimated catch in 2018 for varying values of Kp and Kd.

Ratio of (SSQ-Min(SSQ)) to Minimum SSQ

		Kp								
		0	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Kd	0	0.12	0.13	0.14	0.16	0.19	0.22	0.25	0.30	0.34
	0.25	0.00	0.04	0.07	0.10	0.14	0.19	0.24	0.30	0.37
	0.5	0.13	0.22	0.26	0.31	0.37	0.44	0.51	0.59	0.69
	0.75	0.58	0.71	0.78	0.85	0.93	1.02	1.12	1.23	1.35
	1	1.40	1.61	1.69	1.79	1.90	2.02	2.15	2.30	2.45
	1.25	2.70	2.98	3.10	3.23	3.38	3.53	3.70	3.88	4.08
	1.5	4.56	4.95	5.11	5.28	5.46	5.66	5.88	6.11	6.36
	1.75	7.13	7.64	7.84	8.06	8.29	8.55	8.82	9.11	9.42
	2	10.54	11.20	11.46	11.73	12.03	12.35	12.69	13.05	13.43
	2.25	14.97	15.81	16.14	16.49	16.86	17.26	17.68	18.13	18.60
	2.5	20.63	21.70	22.11	22.55	23.02	23.51	24.03	24.58	25.16
	2.75	27.78	29.13	29.64	30.19	30.76	31.37	32.01	32.69	33.40
	3	36.71	38.40	39.04	39.71	40.42	41.17	41.96	42.79	43.65
	3.25	47.80	49.90	50.69	51.51	52.39	53.30	54.27	55.27	56.33
	3.5	61.46	64.06	65.03	66.04	67.11	68.23	69.41	70.63	71.92
	3.75	78.20	81.41	82.60	83.84	85.15	86.52	87.94	89.44	90.99
	4	98.65	102.60	104.05	105.57	107.16	108.82	110.55	112.36	114.25

Relative Goodness of Fit: Quantities expressed in terms of difference in SSQ to min SSQ

Rough boundaries on 2018 catch for solutions that are within 10% of the solution that minimizes differences between observed and projected catch for 2007 onward.

Data table for 2018 Catch give range of Kp and Kd gain factors

		Kp								
	122.67	0	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Kd	0	110.3	114.3	115.7	117.1	118.5	120.0	121.4	122.9	124.4
	0.25	111.2	115.3	116.7	118.1	119.5	120.9	122.4	123.9	125.4
	0.5	112.1	116.2	117.6	119.0	120.5	121.9	123.4	124.9	126.4
	0.75	113.0	117.2	118.6	120.0	121.5	122.9	124.4	125.9	127.4
	1	114.0	118.1	119.6	121.0	122.5	123.9	125.4	127.0	128.5
	1.25	114.9	119.1	120.5	122.0	123.5	125.0	126.5	128.0	129.5
	1.5	115.8	120.1	121.5	123.0	124.5	126.0	127.5	129.0	130.6
	1.75	116.8	121.1	122.5	124.0	125.5	127.0	128.6	130.1	131.7
	2	117.8	122.1	123.5	125.0	126.5	128.1	129.6	131.2	132.8
	2.25	118.7	123.1	124.6	126.1	127.6	129.1	130.7	132.3	133.8
	2.5	119.7	124.1	125.6	127.1	128.6	130.2	131.7	133.3	134.9
	2.75	120.7	125.1	126.6	128.1	129.7	131.2	132.8	134.4	136.1
	3	121.7	126.1	127.6	129.2	130.7	132.3	133.9	135.5	137.2
	3.25	122.7	127.2	128.7	130.2	131.8	133.4	135.0	136.6	138.3
	3.5	123.7	128.2	129.8	131.3	132.9	134.5	136.1	137.8	139.4
	3.75	124.7	129.3	130.8	132.4	134.0	135.6	137.2	138.9	140.6
	4	125.7	130.3	131.9	133.5	135.1	136.7	138.4	140.0	141.7
		min (C(2018))=		111.2	max(C(2018))=		141.7			

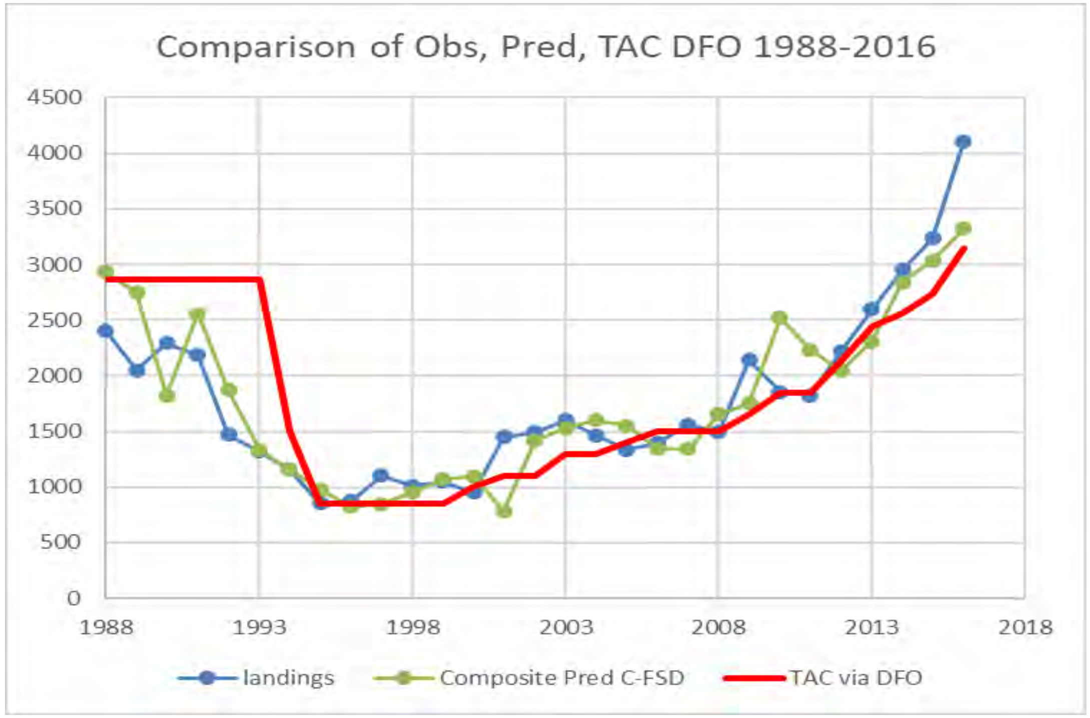
Ratio of (SSQ-Min(SSQ)) to Minimum SSQ

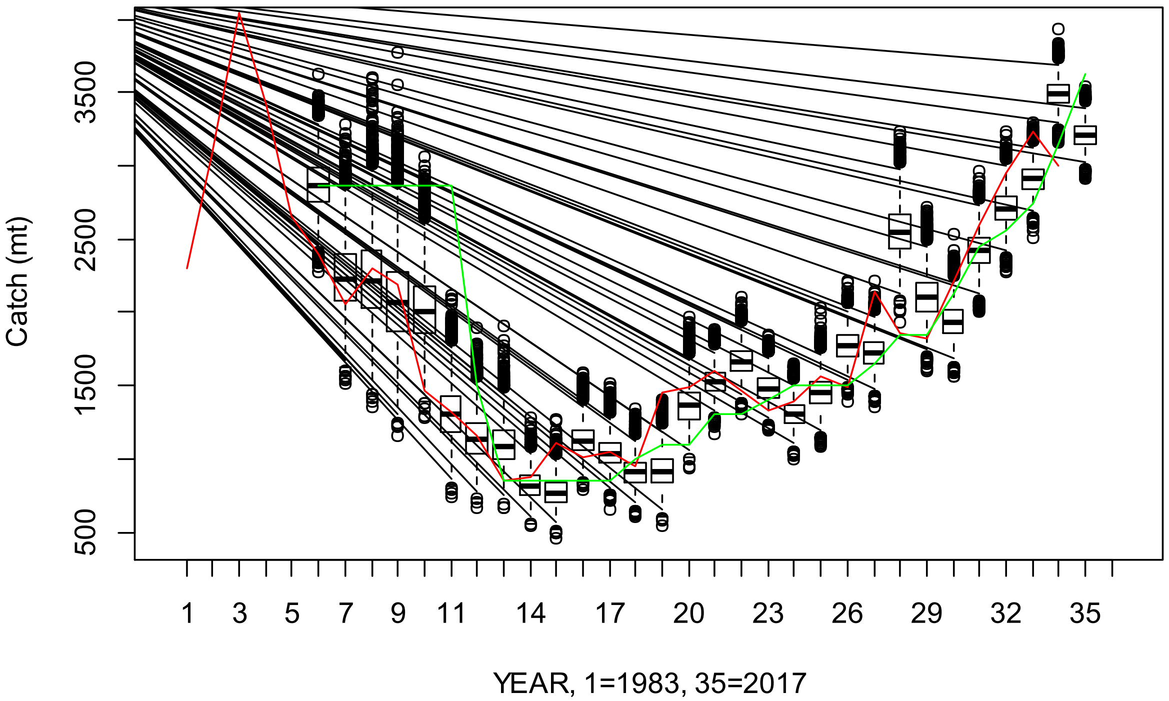
		Kp								
		0	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Kd	0	0.12	0.13	0.14	0.16	0.19	0.22	0.25	0.30	0.34
	0.25	0.00	0.04	0.07	0.10	0.14	0.19	0.24	0.30	0.37
	0.5	0.13	0.22	0.26	0.31	0.37	0.44	0.51	0.59	0.69
	0.75	0.58	0.71	0.78	0.85	0.93	1.02	1.12	1.23	1.35
	1	1.40	1.61	1.69	1.79	1.90	2.02	2.15	2.30	2.45
	1.25	2.70	2.98	3.10	3.23	3.38	3.53	3.70	3.88	4.08
	1.5	4.56	4.95	5.11	5.28	5.46	5.66	5.88	6.11	6.36
	1.75	7.13	7.64	7.84	8.06	8.29	8.55	8.82	9.11	9.42
	2	10.54	11.20	11.46	11.73	12.03	12.35	12.69	13.05	13.43
	2.25	14.97	15.81	16.14	16.49	16.86	17.26	17.68	18.13	18.60
	2.5	20.63	21.70	22.11	22.55	23.02	23.51	24.03	24.58	25.16
	2.75	27.78	29.13	29.64	30.19	30.76	31.37	32.01	32.69	33.40
	3	36.71	38.40	39.04	39.71	40.42	41.17	41.96	42.79	43.65
	3.25	47.80	49.90	50.69	51.51	52.39	53.30	54.27	55.27	56.33
	3.5	61.46	64.06	65.03	66.04	67.11	68.23	69.41	70.63	71.92
	3.75	78.20	81.41	82.60	83.84	85.15	86.52	87.94	89.44	90.99
	4	98.65	102.60	104.05	105.57	107.16	108.82	110.55	112.36	114.25

Application to DFO 3NOPs4WX5Zc halibut stock

- Utilized same abundance indices used in the statistical catch at age model used by DFO.
- Comparisons with TAC

Figure 23 in Report





Appendix 2. Figure 2.1 in Report

Application to IPHC Pacific Halibut

- Used same indices as used in IPHC assessment
- Assumed that observed catches were very close to TAC
- Residuals tend to be small in recent years, less than 10% of actual catch

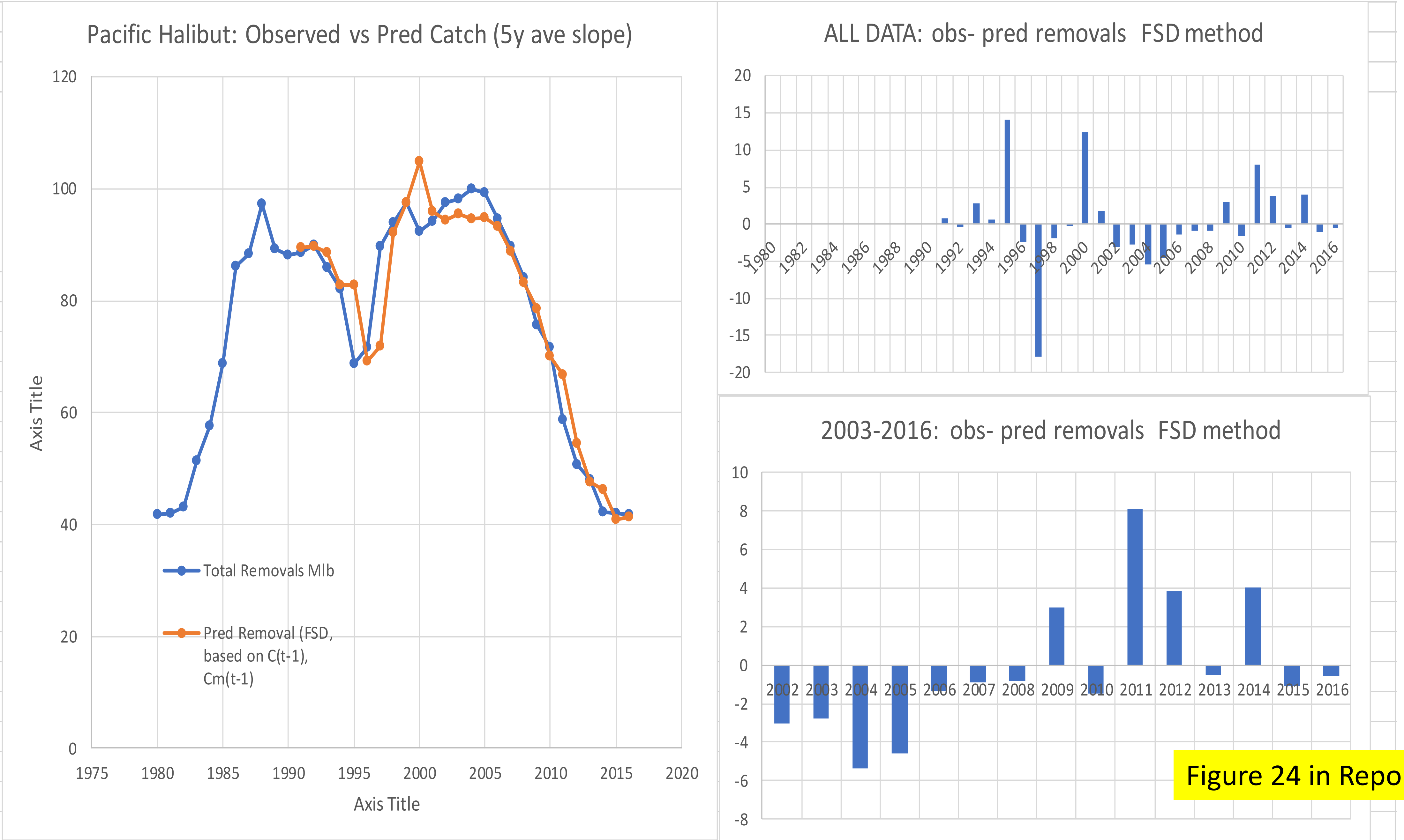


Figure 24 in Report

Add bootstrap for IPHC stock

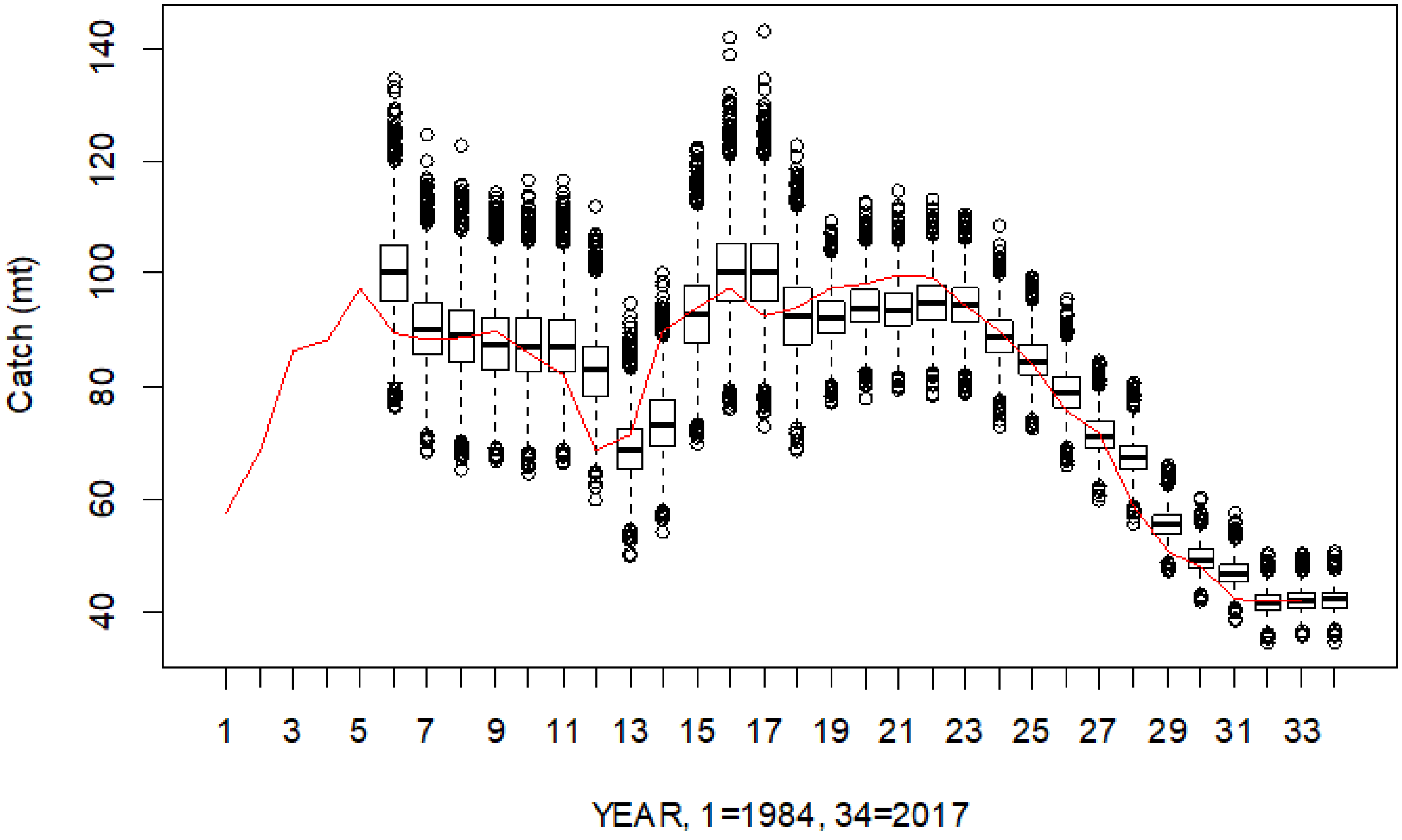


Figure 25 in Report

Odds and Ends—Discard Mortality and Alternative measure of relative abundance from Observed Trips

- Discard mortality
  - Concerns from harvesters and managers about effects of decreased mortality of captured halibut. See page 28-29 in report.
- d/k vs t/k revision
  - PDT suggested that ratio of total encounters to kept all (i.e., t/k)was a better measure of relative abundance that discards to kept all (i.e., d/k).
  - d/k ratio may be more influenced by regulations (min size, trip limits)

Effect of discard mortality on estimated discards and catch: 76% Trawl, 30% gill net, 10% hook

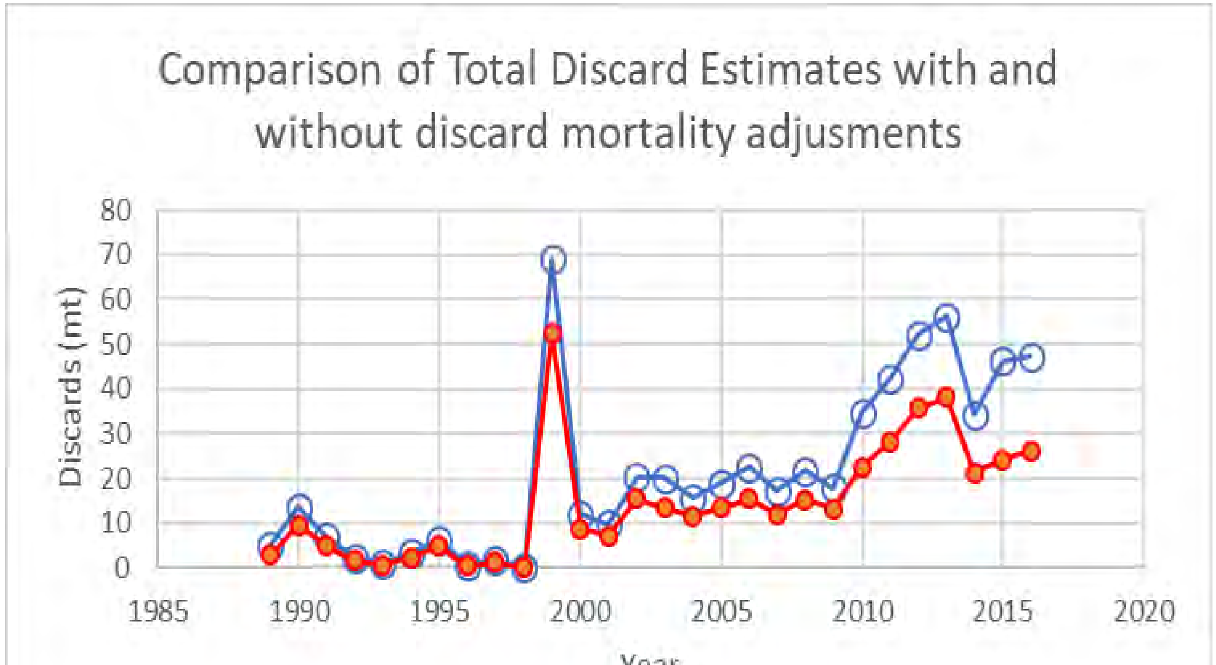


FIG 29

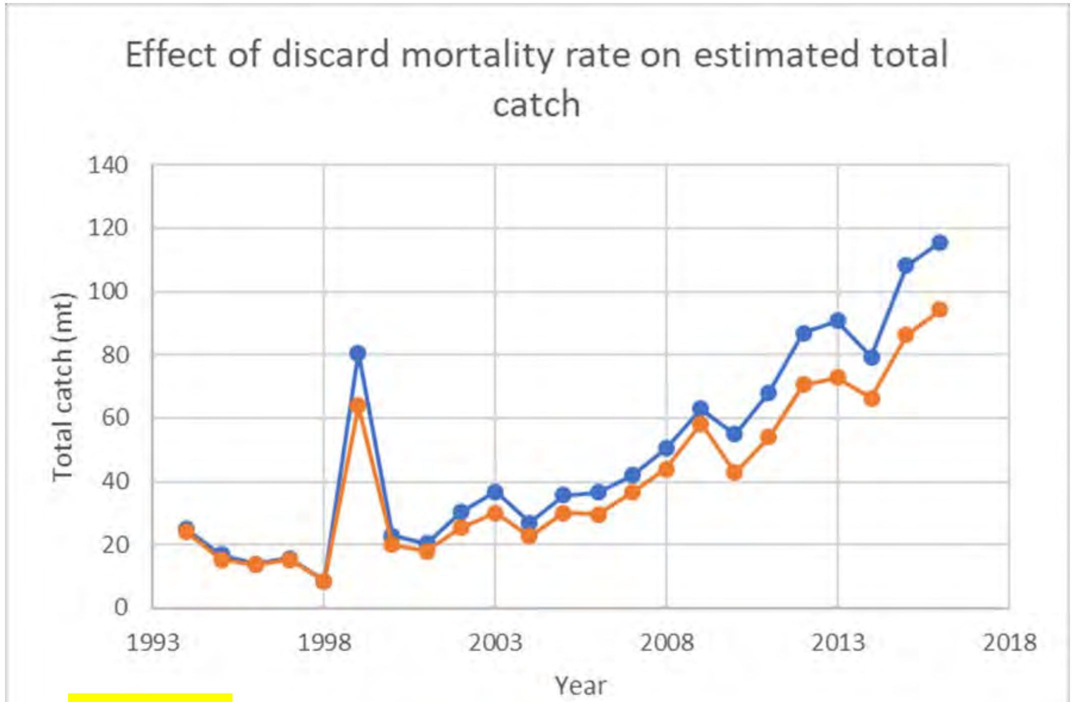
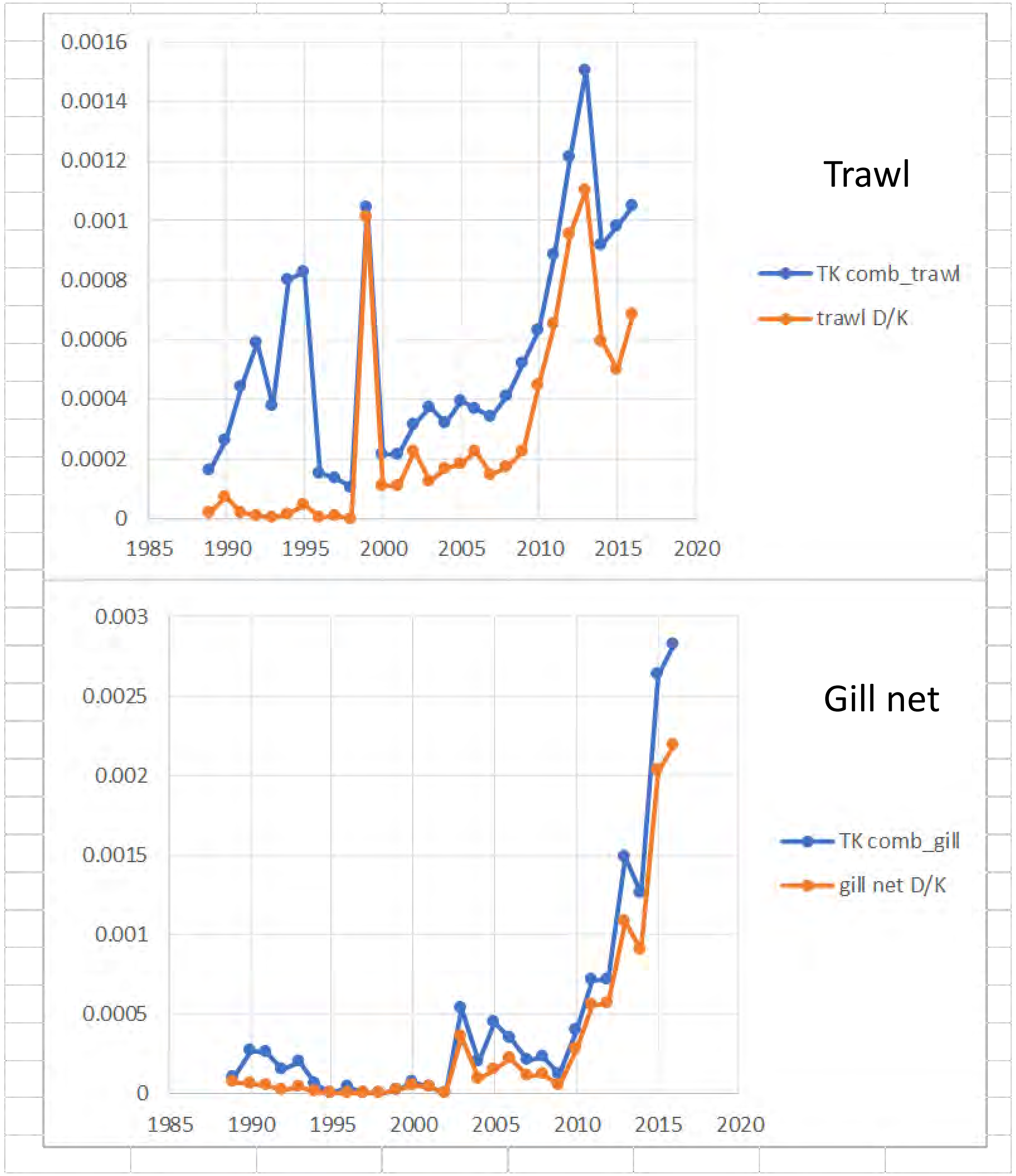
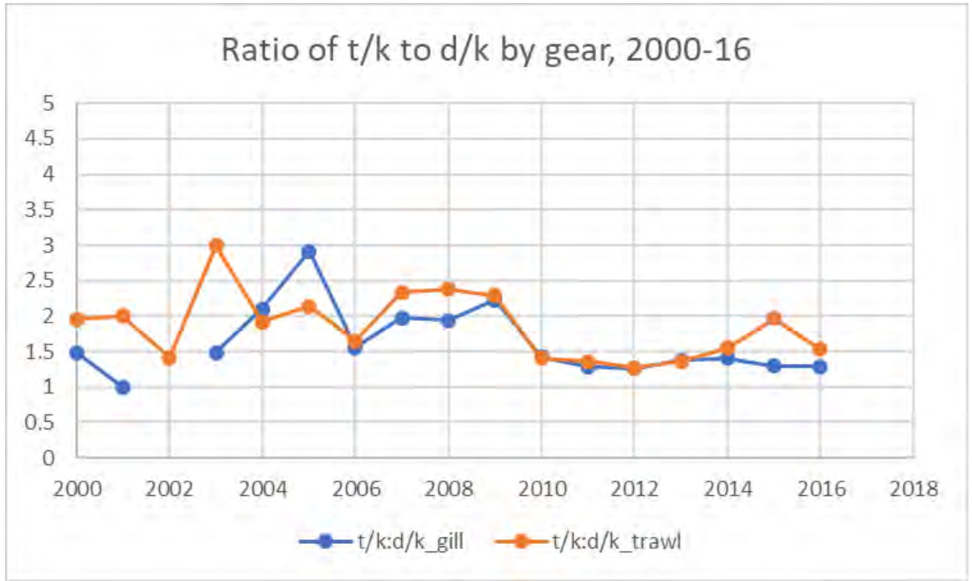


FIG 30



Hypothesis: total observed catch to kept all (t/k) is more representative of relative abundance than d/k ratio



Appendix 3. Figures 3.1 and 3.2

Application of discard mortality and use of t/k ratio have nominal effect on projected catch for 2018 UNLESS fraction of total discard by gear (ie trawl vs gill net vs hook) changes dramatically.

All models use Kp=0.75, Kd=0.5	Model based on d/k indices	Model Based on t/k indices
Assume 100% Mortality of discards	122.67 mt	122.82 mt
Assume discard Mortality varies by gear: 76% Trawl, 30% gill net, 10% hook	99.31 mt	99.44 mt

Summary

- Rcrit method may be useful for other stocks
- DCAC--a poor, assumption-driven, second choice
- Other methods require more assumptions, many of which would require “benchmark-level” discussions
- Proposed Model uses Management Procedure Approach for updating catches
- Does not introduce new data but uses d/k as measure of relative abundance.
- Method builds on the GB cod approach and examines the likely consequences for a population managed under such a policy.

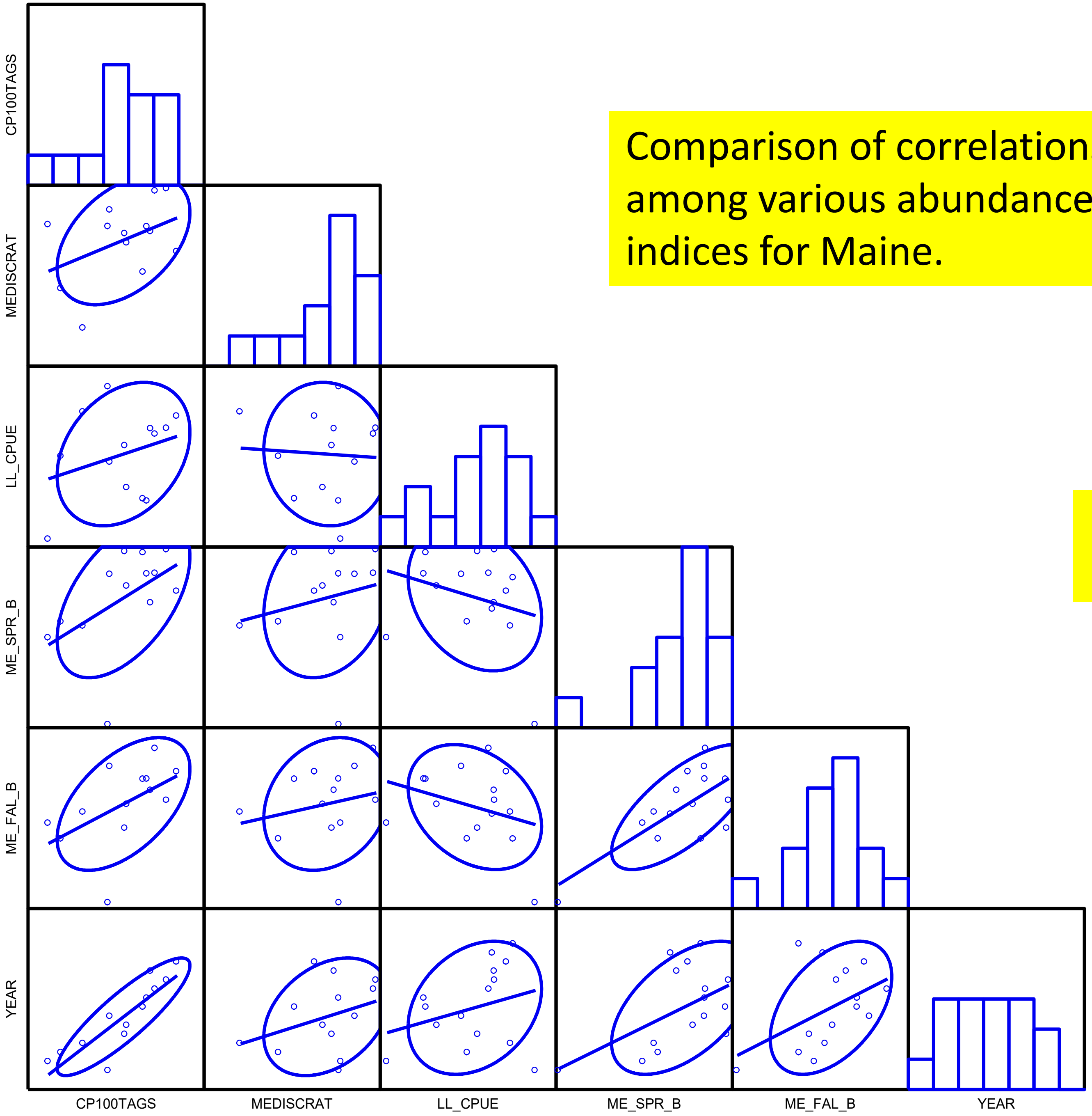
Proposed Model—Critique (1)

- Possible Advantages
  - Incorporates rate of change (slope) and CHANGES in rate of change (delta slope)
  - Does not assume equilibrium or constancy of model parameters
  - Does not assume density dependent regulation
  - Does not impose a causality model to observed patterns
  - Responds to what is rather than what we think it should be.
  - Recursively updates catch projections
  - Simulation experiments suggests that it is unlikely to cause overfishing during a rebuilding period
  - Can be used to examine trade-offs
  - Allows for evaluation of management options, e.g., max % TAC change/year
  - Can incorporate trends in multiple indices
  - Applications to other halibut stocks show some promise.

Proposed Model—Critique (2)

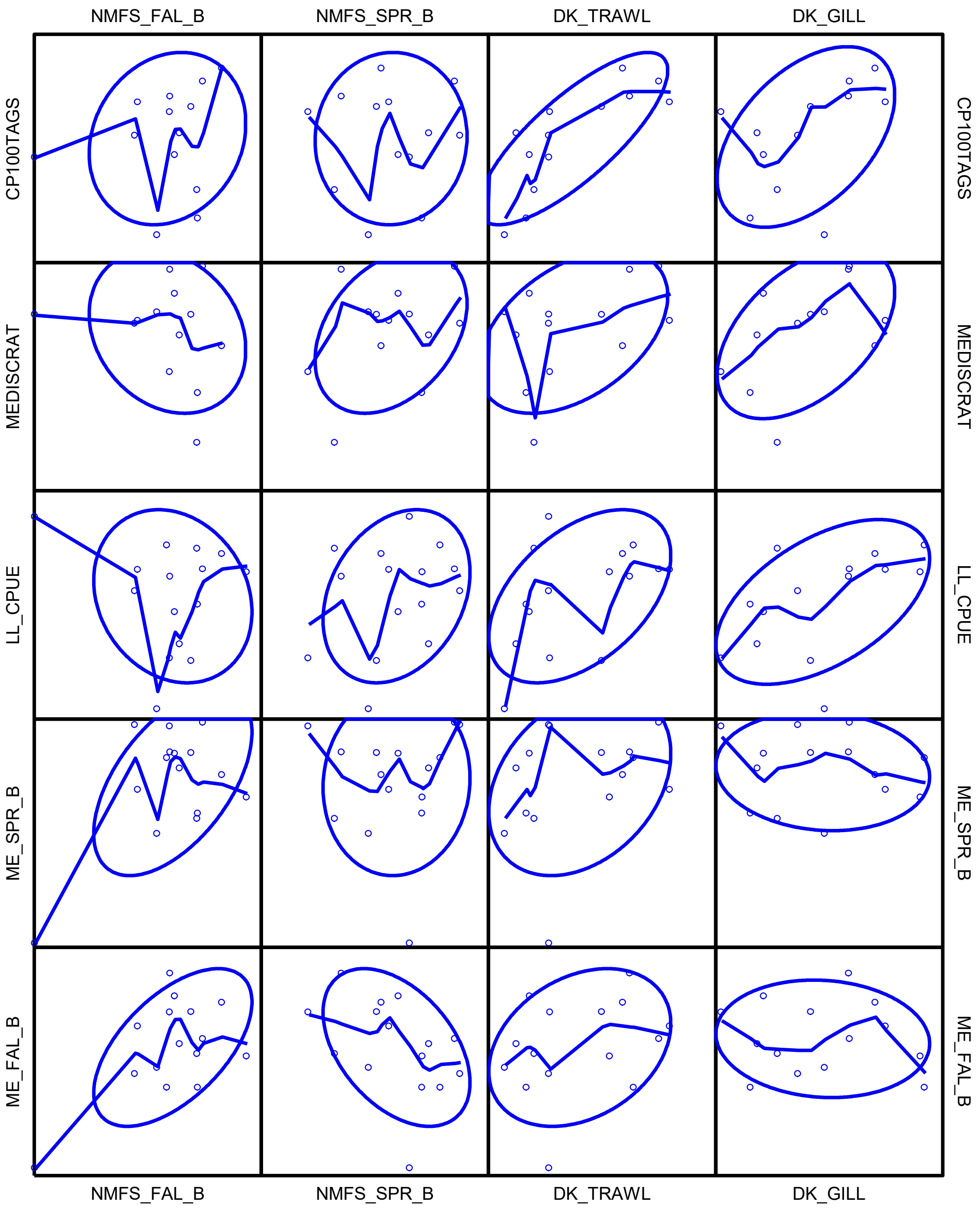
- Possible Disadvantages
  - A model too far—stretches the Plan B paradigm
  - Could follow false signals—e. g., makes unnecessary changes
  - Basis for selecting Kp and Kd is qualitative.
  - Potential for lags in signal identification—5 yr regression
  - Difficult to reduce catches quickly enough. Overshoots in catch can create long payback periods. (This is common to all models).
  - Observation error in indices may overwhelm ability to detect change
  - Effects of including indices without trend, (ie noise only) have not been evaluated. This is sometimes called the breakdown ratio—how much contaminated data can a model take?
  - Model is not designed to recalibrate for the effects of forgoing several years of potential increases. For example the model works only on the most recent year of catch, not the historical sequence.

MISC SLIDES



Comparison of correlations among various abundance indices for Maine.

FIG 10 in Report



Comparison of NEFSC and Maine abundance indices. Fig. 11, with log-log axes.

FIG 11 in Report

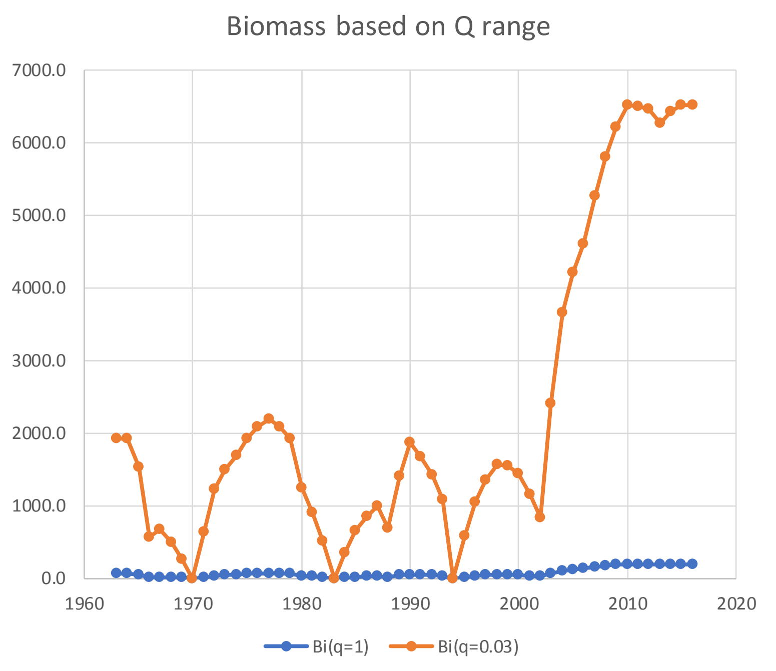
Q&D Executive Summary

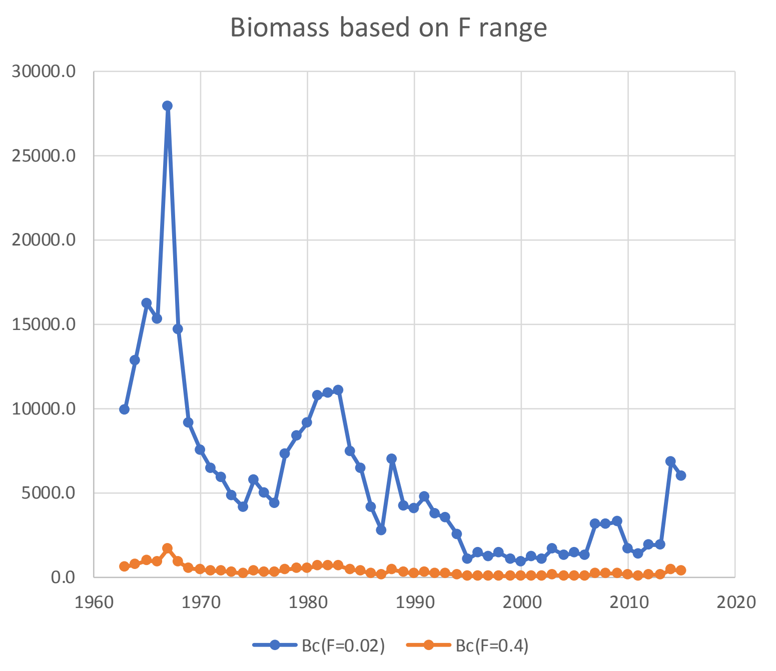
- Alternative measures of abundance from Maine sources were considered.
- A review of data poor methods suggests that most have limited utility for Atlantic halibut, however the DCAC model was considered further.
- A ratio method (Rcrit) was developed and tested to determine robust measures of population change and the significance of these changes.
- ~~The Envelope Method was applied to estimate relative scale~~
- ~~Results of the Rcrit and Envelope method were combined to improve the DCAC model but its overall performance is unreliable and still governed by strong assumptions.~~
- An updating algorithm, called the FSD model was developed and tested via simulation. The approach allows use of short term information and multiple indices.
- FSD model results suggest that the 2018 Atlantic halibut catch would be in the range of 116-120 mt.
- Application of the FSD model to Atlantic halibut and Pacific halibut stocks assessed with advanced statistical catch-at-age models suggest reasonable agreement between Observed and predicted TACs.

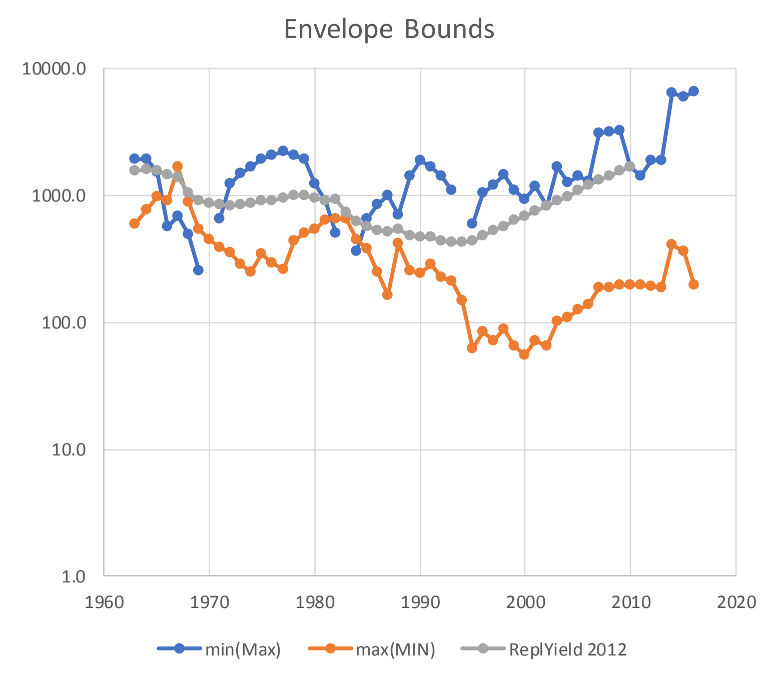
Misc—DCAC Results

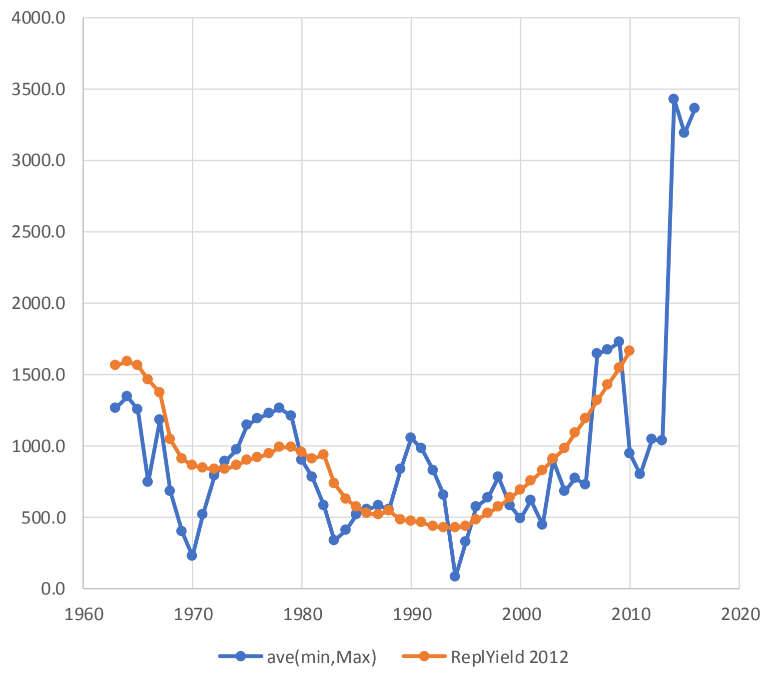
Envelope—finding a plausible range based on set of broad assumptions for q and F.

- *Biomass range based on q range*
- $B_t = \frac{I_t}{q'} \frac{A}{a}$ [13]
- Biomass range based on F range
- $B_{0,t} = \frac{C_t}{\frac{F}{F+M}(1-e^{-F-M})}$ [14]
- Upper bound = min of Max values
- Lower bound =max of minimum values
- Envelope satisfies both constraints

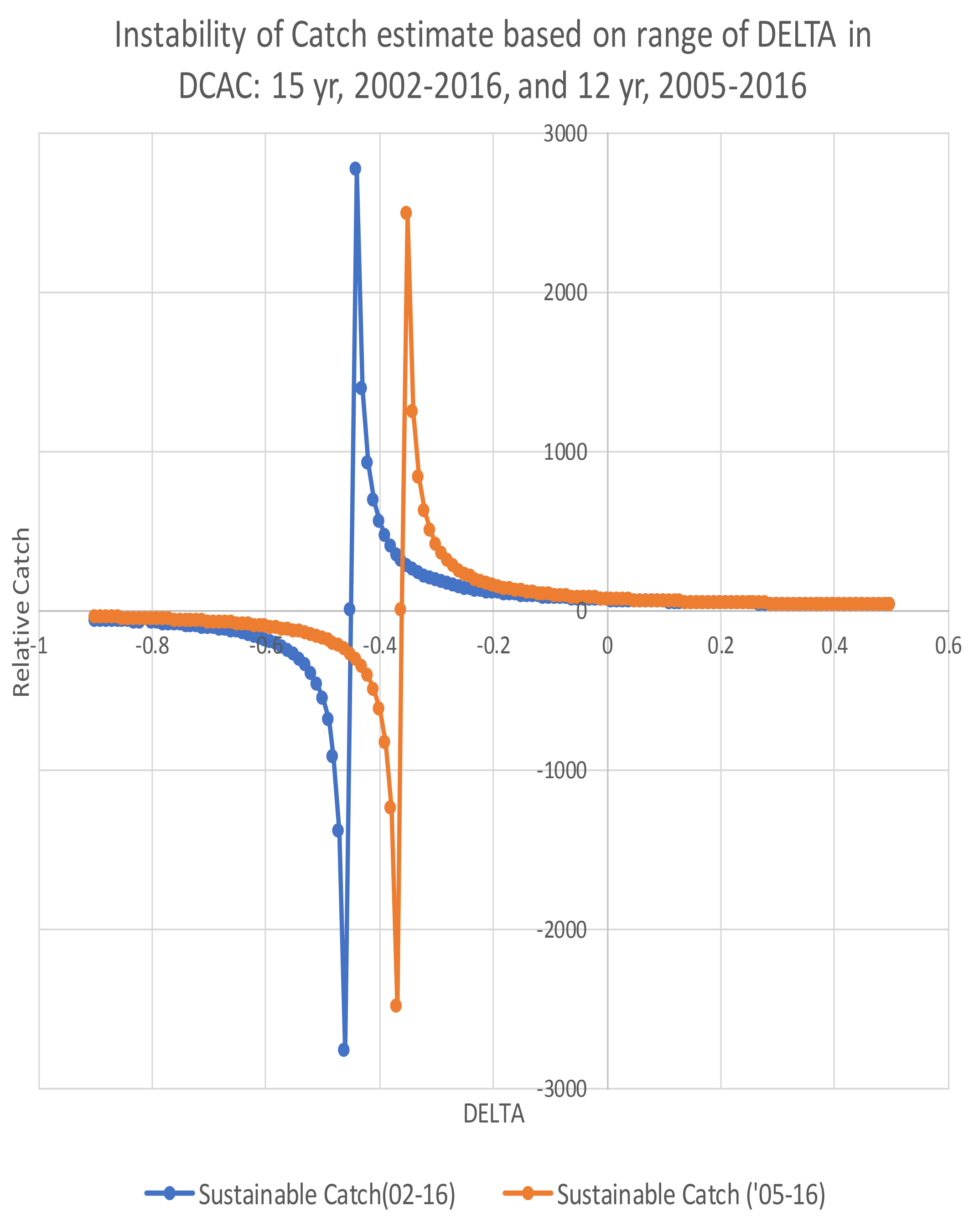

Biomass based on Q range
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
1960
1970
1980
1990
2000
2010
2020
Bi(q=1)
Bi(q=0.03)

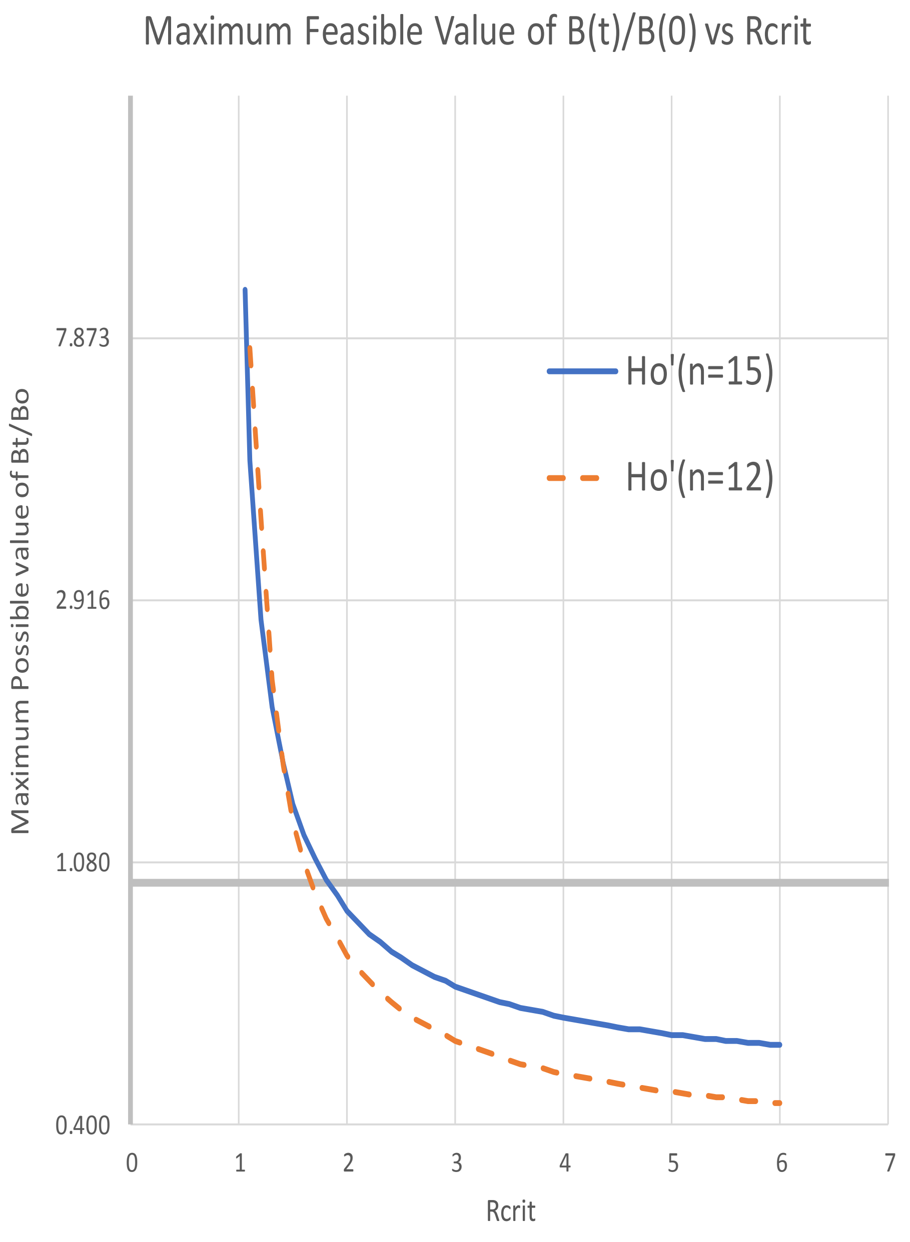

Biomass based on F range
30000.0
25000.0
20000.0
15000.0
10000.0
5000.0
0.0
1960
1970
1980
1990
2000
2010
2020
Bc(F=0.02)
Bc(F=0.4)


Envelope Bounds
10000.0
1000.0
100.0
10.0
1.0
1960
1970
1980
1990
2000
2010
2020
min(Max)
max(MIN)
ReplYield 2012


4000.0
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
1960
1970
1980
1990
2000
2010
2020
ave(min,Max)
ReplYield 2012

			Biomass Estimates				Estimated B(2016)/K		
Survey Type	***Basis for Estimating Max Biomass***	***Max Catch***	***max B(C,F)***	***min B(C,F)***	***Mid Range B(C,F)***	***Mid Range Biomass 2016***	***max B(C,F)***	***min B(C,F)***	***Mid Range B(C,F)***
Kalman	Max catch 1893-2016	4,908	266,850	15,952	141,401	3,363.2	0.013	0.211	0.024
Kalman	Max Catch since 1900	944	51,326	3,068	27,197	3,363.2	0.066	1.096	0.124
Kalman	Constrained range of B(1963-2016)		6,531	1,671	3,425	3,363.2	0.515	2.013	0.982
Raw	Max catch 1893-2016	4,908	266,850	15,952	141,401	3,407.4	0.013	0.214	0.024
Raw	Max Catch since 1900	944	51,326	3,068	27,197	3,407.4	0.066	1.111	0.125
Raw	Constrained range of B(1963-2016)	514	14,680	1,671	7,779	3,407.4	0.232	2.040	0.438





The pesky problems of singularities in DCAC when Delta is negative AND extreme sensitivity of Bt/Bo as Rcrit approaches one.

Putting Rcrit and Envelope Results back into DCAC

- Consider various values of potential increase based on Rcrit
- Consider various values of Bt/Bo based on Envelope
- Question
  - If Rcrit is 3.0 has the stock increased from 2% Bt/Bo to 6% Bt/Bo?
  - OR
  - Has the stock increased from 20% Bt/Bo to 60% Bt/Bo?
- Consequences for DELTA parameter in DCAC are different
  - Going from 2% to 6% means DELTA is -0.04
  - Going from 20% to 60% means DELTA is -0.40
  - There are an infinite range of possibilities in between!

Table hh. A. Summary of maximum fractional change in population abundance given alternative ranges of proportial stock increase for varying base period year ranges.

B. Derived Depletion corrected average catches of sustainable harvest alternative levels of rebuilding in 2016 and proportional increase in relative abundance.

Levels of rebuilding are based on envelope method. Natural mortality is assumed = 0.15

A

Ratio Definition	Changes in catches: Statistics	Value	Change in indices: Statistic	Value	Model	*Maximum Fractional Change (DELTA) in DCAC for varying assumed values of B(t)/K*: *Assume 98.2% rebuilt in 2016* 0.982	*Assume 43.8% rebuilt in 2016* 0.438	*Assume 12.5% rebuilt in 2016* 0.125	*Assume 2.4% rebuilt in 2016* 0.024	Total Catch
'02-04:'14-16	Rcrit(Catch)	3.227	Rcrit(Indices)	3.23	(all six indices)	-0.67798	-0.30240	-0.08630	-0.01657	925.3
				4.98	(DK_g, DK_t, Survey)	-0.78481	-0.35005	-0.09990	-0.01918	
				3.52	average over 120models	-0.70302	-0.31357	-0.08949	-0.01718	
'05-07:'14-16	Rcrit(Catch)	2.657	Rcrit(Indices)	2.44	average over 120models	-0.57954	-0.25849	-0.07377	-0.01416	831.4
				4.11	DK_g,DK_t, Survey	-0.74307	-0.33143	-0.09459	-0.01816	
				2.2	(all six indices)	-0.53564	-0.23891	-0.06818	-0.01309	
'02-04:'11-13	Rcrit(Catch)	2.617	Rcrit(indices)	2.893	(all six indices)	-0.64256	-0.28660	-0.08179	-0.01570	622.1
				5.033	(DK_g, DK_t, Survey)	-0.78689	-0.35097	-0.10016	-0.01923	
				3.144	average over 120models	-0.66966	-0.29869	-0.08524	-0.01637	

B

Nyears	Time Period	Total Catch	Derived Delta for Assumed Alpha: 0.982	0.438	0.125	0.024	Derived Sustainable Average Catch for Assumed Alpha: 0.982	0.438	0.125	0.024	Obs Ave Catch	Y Current --given assumed level of rebuilding: 0.982	0.438	0.125	0.024
15	2002-2016	925.3	-0.678	-0.302	-0.086	-0.017	-121.8	188.1	76.3	64.0	61.7	-119.6	82.4	9.5	1.5
15		925.3	-0.785	-0.350	-0.100	-0.019	-82.9	277.7	79.3	64.4		-81.4	121.6	9.9	1.5
15		925.3	-0.703	-0.314	-0.089	-0.017	-109.7	203.5	77.0	64.1		-107.7	89.1	9.6	1.5
12	2005-2016	831.4	-0.580	-0.258	-0.074	-0.014	-113.6	245.7	87.1	72.1	69.3	-111.6	107.6	10.9	1.7
12		831.4	-0.743	-0.331	-0.095	-0.018	-65.1	873.0	94.0	73.0		-63.9	382.4	11.7	1.8
12		831.4	-0.536	-0.239	-0.068	-0.013	-142.0	206.0	85.5	71.9		-139.4	90.2	10.7	1.7
12	2002-2013	622.1	-0.643	-0.287	-0.082	-0.016	-66.1	254.3	67.1	54.2	51.8	-64.9	111.4	8.4	1.3
12		622.1	-0.787	-0.351	-0.100	-0.019	-43.7	2067.9	71.8	54.8		-42.9	905.7	9.0	1.3
12		622.1	-0.670	-0.299	-0.085	-0.016	-60.3	304.4	67.9	54.3		-59.2	133.3	8.5	1.3

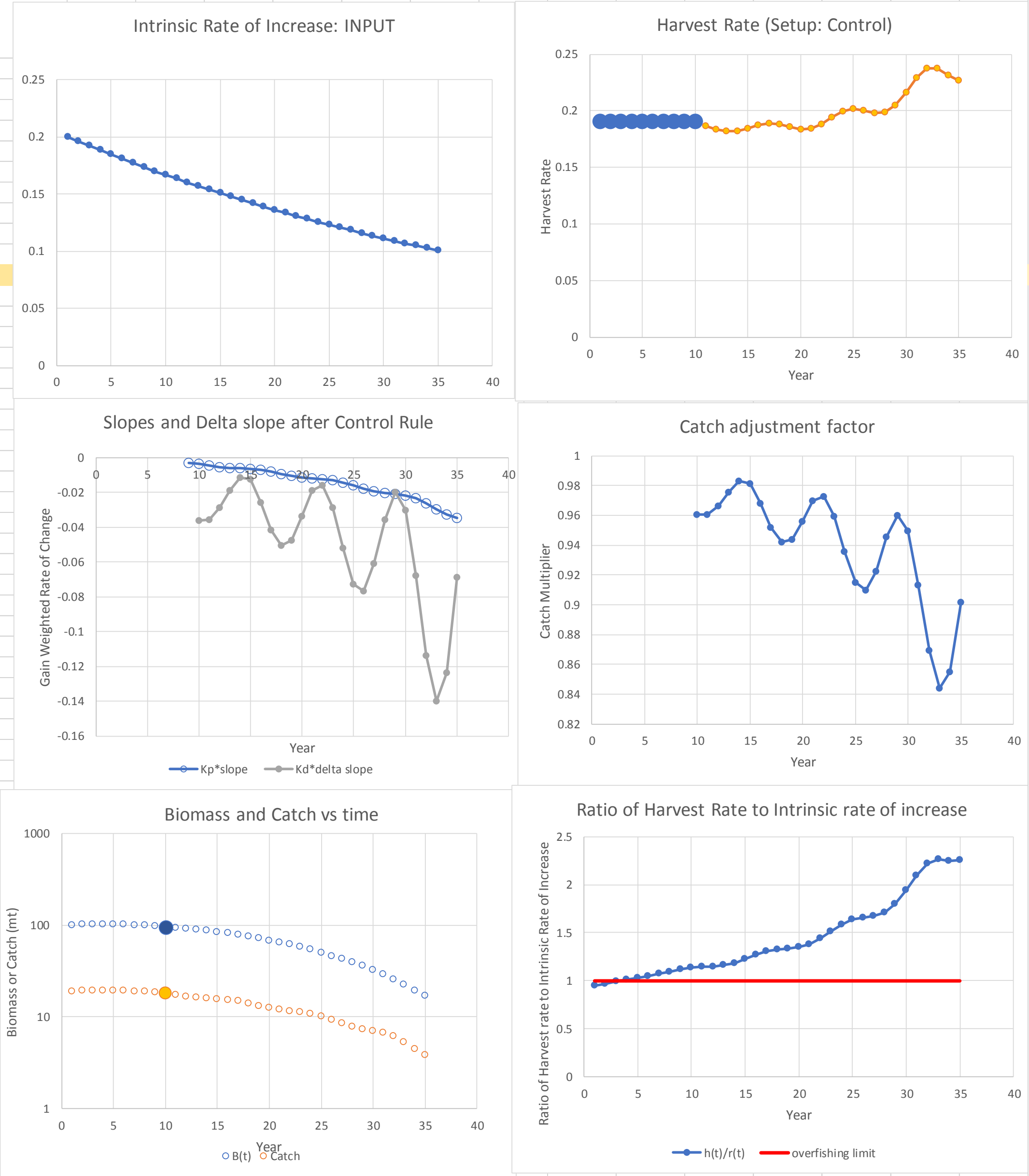
See Table 13 in report.

Assumed level of change in B(2016)/K is obtained from Table 12.

Ignoring the negative values, the sustained average catch ranges from 64 to 2,067 mt.

Ignoring negative values, the current recommended yield ranges from 1.3 to 905.7 mt.

Initial Harvest h(t) Scenario	Intrinsic rate of increase r(t) scenario	Number of years used for slope estimation	Kp Gain on Slope	KD Gain on slope derivative	Total Catch	CV of Catch	Max Cmult	Min Cmult	Fraction of Overfishing Events
3	4	5	0.25	10	272.9	0.379	0.983	0.844	0.91



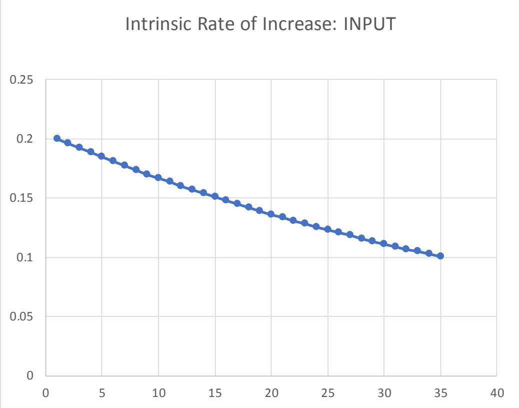
Example 4:

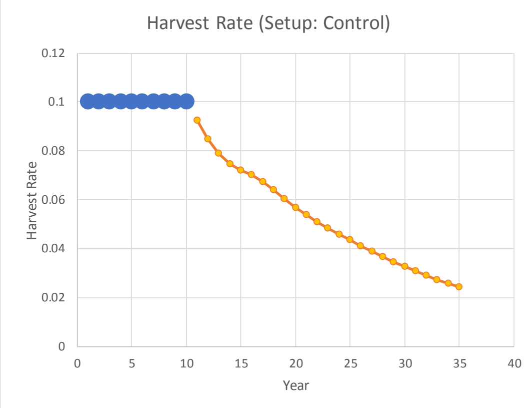
- Intrinsic rate of increase is DECLINING
- Initial Harvest rate is ABOVE intrinsic rate during much of the initial period
- Differential weights on proportional and derivative controls are SAME as Example 3:
  - Kp=0.25 (less weight on proportional change)
  - Kd=10

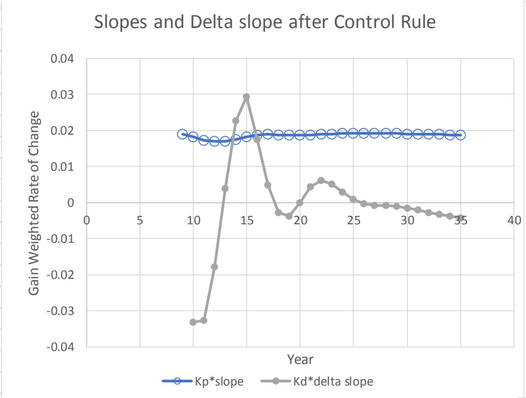
Key Results

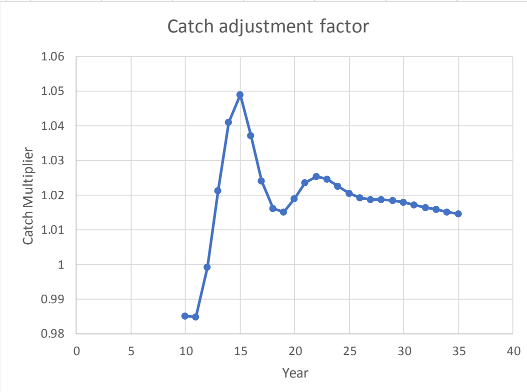
- Much lower cumulative catch 272 mt
- Overfishing over 91% of the entire period
- Maximum catch multiplier is 0.98 or 2% decrease
- Catch multiplier is always less than 1.0 and oscillates over a wide range, to as low as 84%
- Stock size and catches declines after initial control period.

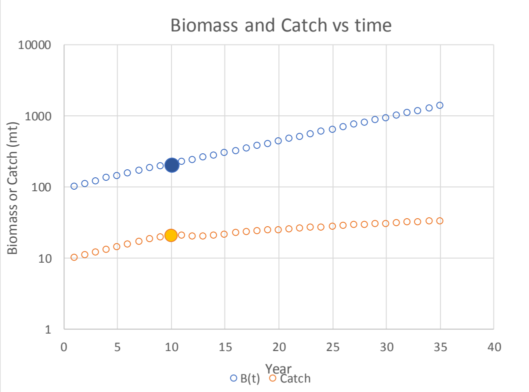
Initial Harvest h(t) Scenario	Intrinsic rate of increase r(t) scenario	Number of years used for slope estimation	Kp Gain on Slope	KD Gain on slope derivative	Total Catch	CV of Catch	Max Cmult	Min Cmult	Fraction of Overfishing Events
2	4	5	0.25	10	658.1	0.157	1.049	0.985	0.00

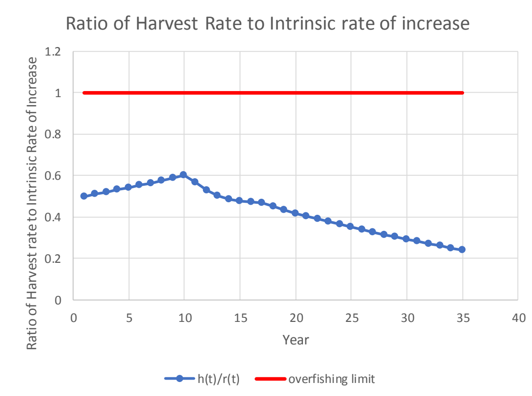












Example 5:

- Intrinsic rate of increase is DECLINING
- Initial Harvest rate is well BELOW intrinsic rate during the initial period
- Differential weights on proportional and derivative controls are SAME as Example 3 and 4:
  - Kp=0.25 (less weight on proportional change)
  - Kd=10

Key Results

- Much higher cumulative catch 658 mt
- NO Overfishing over the entire period
- Maximum catch multiplier is 1.05 or 5% decrease
- Catch multiplier is <u>mostly</u> above 1.0 and oscillates over a narrow range.
- Stock size and catches both increase at a steady pace but catch declines more slowly, thereby preserving the stock rebuilding program.
- Major difference is the lack of overfishing during the period prior to implementation of the control rule. This allows stock size to grow despite declines in productivity

Halibut Assessment Report for 2017

Draft

Paul J. Rago

for

New England Fishery Management Council

Last updated: December 1, 2017

Executive Summary

- Survey, landings and discard estimates were updated for the US stock area.
- Alternative measures of abundance from Maine sources were considered as potential measures of stock trend.
- A review of data poor methods suggests that most have limited utility for Atlantic halibut, however the DCAC model was considered further.
- A ratio method (Rcrit) was developed using randomization methods. Simulation tests suggested that the method had utility as a robust measure of population change and the significance of these changes.
- Application of the Rcrit method to the US and DFO stocks suggest comparable increases of about 9 to 12% per year since the early 2000's
- An "Envelope Method" was applied to estimate relative scale of the population. The Envelope consists of upper and lower bounds of relative abundance that jointly satisfy constraints on abundance based on a range of hypothesized historical fishing mortality and survey catchability estimates.
- Results of the Rcrit and Envelope method were combined to improve the DCAC model but its overall performance is considered unreliable and still governed by strong assumptions.
- A catch forecasting algorithm was developed based on the observed rates of change in one or more indices of relative abundance. The method resembles algorithms commonly used for control of linear systems in engineering applications. The magnitude of catch adjustment depends on the aggregate rate of change in one or more abundance indices in prior years. The method estimates the first and second derivative of population change using loglinear regression. The second derivative is approximated as the difference between successive n-point regressions.
- The method, termed the First and Second Derivative (FSD) model was tested via simulation of a wide variety of initial conditions and trends in stock productivity.
- No simple solution exists but instead the performance should be evaluated with respect to the risk of overfishing, magnitude and variability of projected catch, and the probability of continued increases in stock size.
- FSD model results suggest that the 2018 Atlantic halibut catch should be about 116-118 mt.
- A bootstrap approach was used to compute the uncertainty about the FSD prediction.

- Application of the FSD model to Atlantic halibut and Pacific halibut stocks assessed with advanced statistical catch at age models suggest reasonable agreement between Observed and predicted TACs.

<u>Background and Overview</u>

This is a “Plan B” assessment. It is a consequence of the unsuitability of the existing benchmark approach as a basis for deriving suitable catch limits for resource management. The Plan B assessment was conceived as an interim approach that could bridge the gap between the rejection of an existing methodology and a revised approach. The revised approach will be the product of a benchmark assessment that reviews all the existing information and potential modeling approaches and undergoes extensive levels of peer review. The distinctions between Plan B interim approaches and benchmark assessments are defined by various reports of the Northeast Regional Coordinating Committee (NRCC) (see NRCC 2011) and by precedents accrued over deliberations within the NRCC since 2012.

In general terms, the Plan B process constrains the introduction of new analytical assessment models whose applicability to the stock under consideration has not be subjected to extensive peer review. Practical application of stock assessment models typically requires numerous decisions about the definition of the “stock”, inclusion of available data, reliance of parameterization on literature values (e.g., natural mortality rates), plausibility of critical assumptions, and appropriate numerical methods. Such decisions usually benefit from the inclusion of a broad range of expert opinions. In view of the long-term biological and economic consequences of such decision, the benchmark process can lead to greater acceptance of model-based management decisions.

The Plan B process also implies restrictions on the introduction of new time series of indices or changes in estimation methodology. For example, use of time-series that have not been rigorously reviewed for applicability to stock assessments could be problematic, especially if such data are highly influential. Similarly, model parameters that are highly influential, but weakly supported by empirical data (e.g., natural mortality) are typically considered outside the range of Plan B assessments. Changes to the methods for estimating relative abundance or total removals have been allowed but are subject to a case-by-case examination. For example, revision of previous discard estimation methods to a the SBRM method has been allowed. Changes to discard mortality rates (i.e., the post capture survival of release fish) have been incorporated in several assessments (e.g., skates) when strong empirical evidence has been available.

An important management concern arises when the stock is in a rebuilding program. The rejection of the model on which the rebuilding program was based puts rebuilding in a limbo wherein the existing target biomass, rebuilding time-frame, and target fishing mortalities are obsolete. The management and legal processes are ill-suited to such reversals given the difficulties of putting existing targets in abeyance while new ones are derived. A rebuilding program without a target is ambiguous at best. For some species, the contrast between underlying biology (especially growth, longevity, geographic range) and existing population structure is sufficient to proceed with a rebuilding program, even when target biomasses and fishing mortality rates are unknown.

The preceding general issues aptly describe the particular issues for Atlantic halibut in US waters. The previous stock assessment model has been rejected and data to support a true benchmark analytical assessment are insufficient. The rebuilding target is officially defined for 2056 based on the perceived depleted stock abundance and expectations of slow growth and low recruitment. Harvests are restricted to a one fish per trip limit over the federal fishery but a more liberal harvest regulation is allowed in Maine state waters. Estimated discards constitute a large fraction of the fishery removals. While the stock in US waters is considered to be depleted, the immediately adjacent stock in Canada (NAFO areas 3NOPs4VWX5Zc) has been certified by MSC as sustainably harvested. Given the abundant tagging evidence of migrations of fish between the US and Canada, debates about stock definition will likely be a major component of a future benchmark assessment (Shackell et al. 2016, Tryzinski and Bowen 2016, Seitz et al. 2016).

One of the key objectives of this assessment is to employ intuitive and understandable approaches backed by theory and simulation testing. The methodology does not purport to develop biological reference points for a stock that has, by all accounts, declined considerably from a virgin stock size inferred to have existed about 200 years ago (Lear 1998). Given the massive change in fisheries, ecological and environmental conditions since then, it is unlikely that the present environment would support such biomasses in the short term. Or if it could, that a singular focus on catch reductions in halibut would be sufficient to achieve rebuilding to historic levels. The large historic stocks of halibut were also a function of lightly exploited stocks of many other species and unknown predator-prey and competitive relationships with these species.

The objectives of the approach herein are much more modest. Much of the available data suggests that the stock of halibut residing in US waters is increasing. Encounter rates in nontargeted fisheries and various fishermen reports support such perceptions. Various fishery independent surveys weakly support this hypothesis, however none of the current trawl surveys are efficient at capturing halibut. Perhaps the most compelling evidence for stock increase is the rapid changes observed in the Canadian stock. Large changes have occurred not only in targeted longline surveys but also in their trawl surveys which have low capture efficiency similar to US bottom trawl surveys

Stock structure and joint management of Atlantic halibut is well beyond the purview of this assessment report. One cannot deny the temptation to note that the current stock boundaries bisect habitats that are thought to be equivalent on either side of national boundaries. Moreover, tagging studies reveal widespread movements (>3000 km, Scott and Crossman 1988) of halibut. More recent data for electronically tagged fish at liberty for up to 210 days reveal maximum travel distances of about 200 km (Seitz et al. 2016). Conventional tagging studies can generate equivocal evidence unless differences in relative fishing effort and report rates of encountered tags are considered in the analyses of perceived migration patterns. Even Data Storage Tags can be problematic if they are not reported by fishermen.

Officially, halibut are in a rebuilding program with a target completion year of 2056. Increases in halibut abundance in US waters are desirable for both legal and economic reasons. Canada's stock has increased rapidly over the past 20 years but their recovery was also preceded by a long period of low abundance and catches. Comparisons shown later in this report reveal comparable patterns in the US stock area, although the baseline begins from a much lower relative abundance.

Under a rebuilding requirement, a desirable harvest control rule is one that does not reduce the rate of increase or decrease the chances for continued abundance increases. A desirable harvest rule should also avoid being overly restrictive. Increases in abundance that arise under contemporary rates of harvest will, under certain restrictive assumptions, continue to occur if the same harvest rate is applied in future years. These restrictive assumptions include constancy of recruitment, natural mortality and growth in future years. Of course, none of these factors are constant, so it is equally important that the aggregate effect of these processes is taken into account when catch limits are set. More critically, catch limits should be responsive to changes over time. Failure to increase catch limits, particularly when catches are driven largely by discards, may lead to accountability measures induced entirely by unavoidable encounters. At the limit, even elimination of all landings may be insufficient to achieve target catch. Failure to decrease catches when indicated can lead rapid increases in fishing mortality, and the loss of biomass accrued during the rebuilding period.

So the overall objective of the methodology described herein is to use readily available empirical data to adjust catches consistent with changes in relative abundance. The methodology is designed to be responsive and in particular, to be sensitive to metrics of changes in underlying productivity. Lessons learned in control of engineering problems suggest that slow responses to signals are one of the most difficult problems to overcome. As examples, low response times often lead to wide temperature swings in HVAC-controlled buildings and production losses in chemical plants. Simulation studies presented in this report support the need for regular updates of stock status information.

Biology Review

Among the world's flatfishes Atlantic halibut (*Hippoglossus hippoglossus*) attains the largest size (~2.5 m, but values up to 4.3 m are reported in fishbase.org) and oldest age (>40 y)(Seitz et al. 2016, Armsworthy and Campana 2010)). Maturation for females occurs at about age 9 (Armsworthy and Campana 2010). Despite their well-known history of serial depletion in US waters (Grasso 2008), Trzcinski and Bowen (2016) argue that rapid growth and high fecundity make the population resilient and capable of recovering quickly from a depleted state. Their modeling work suggested that reductions in landings quotas, increases in minimum sizes and reductions in otter trawl fleets were primary factors leading to the rebuilding of Atlantic halibut in Canada. Col and Legault (2009) provide an excellent summary of the history of halibut fishing in the US.

Shackell et al (2016) recently evaluated the distribution of imputed halibut habitat in US and Canadian waters and found occupancy rates four times higher in Canadian waters. Their analyses suggest finer scale stock structure than commonly assumed. Seitz et al. (2016) reporting on recent electronic tagging results also suggest that the failure of a concomitant increase in US compared to Canada may be due to different stock structures. Decisions about stock structure are among the most important in stock assessments and this topic will not be considered further in the Plan B assessment.

Past US YPR models (Brodziak 2002) used a natural mortality rate M =0.1 whereas the Canadian assessment model sets M=0.15.

Available Data

This report includes updated estimates of catch and discards consistent with estimates provided in past assessments, most recently in Hennen (2015). Estimates for spring and fall NEFSC and ME-NH bottom trawl surveys are also included. Several indices of commercial fishing catch per unit effort are also considered. The focus of this assessment is the interpretation of trends in recent years.

A succinct summary of the primary data considered in this assessment is found in Table1 for the years 2002-2016. Relevant data include recent landings, discards and total catch (FIG 1). Discards by gear type (Table 1.5) revealed that most discards were incidental takes in trawl fisheries until about 2009. Since then the proportion of gill net discards has increased to about 50% of the total. Estimates of average numbers and weight per tow in the NEFSC spring and fall bottom trawl surveys are summarized in FIG. 2. Catches are near detection limits over much of the survey period and inter-annual fluctuations were very large in the prior to about 2000. Abundance indices that rely on monitoring of commercial fisheries are depicted in FIG.3 for d/k ratios in observed trawl and gill net trips. These raw estimates are expanded to estimate total discards of halibut using the SBRM approach (Wigley et al. 2008). FIG.3 also includes trends in

ME-NH inshore bottom trawl survey. A standardized CPUE for long line fisheries in Maine was developed by Hansell,et al. (2017) and is shown with error bounds in FIG.4.

Data from an inshore sentinel longline and jig survey originally developed for monitoring cod were received from U. Maine (courtesy of Maddie Rodrigues and Yong Chen). The time series is relatively short (4 years). It was not possible to resolve key questions about survey methodology for inclusion in this report. The data may be useful as a measure of trend in a future assessment, particularly if state space modeling approaches described by Webster (2017) for Pacific halibut could be developed for Atlantic halibut

Trends in discard rates can be examined for several different measures of effort. In FIG. 5 discard rates in the gill net fishery are depicted as discards per trip, discards per days absent and discard per kept all. All metrics show a striking rise in discard rates (measured on a 6 month interval) beginning about 2002. For observed trawl trips the trends are remarkably similar (FIG. 6). Data depicted in FIG.5 and 6 were not used in the assessment directly but are shown at a finer temporal resolution to illustrate the consistency of encounters in fishing gears not directing on Atlantic halibut.

Relative abundance data for the Canadian 3NOPs4VWX5Zc stock are not part of this assessment but their results (courtesy of Nell den Heyer DFO, Halifax) are examined for coherence with trends observed in the US. All of the primary abundance indices in Canada show consistent increases since 2002 (FIG. 7). Trends in US surveys (FIG. 8) have generally increased but not as consistently as those in Canada. Correlations among the US and Canadian abundance indices (FIG. 9) show surprisingly good coherence given the large differences in scale and basis for these observations. Coherence among the Maine-based estimators of relative abundance is a little lower (FIG.10) with some slightly negative correlations for some indices. Similarly,correlations among the NEFSC and Maine-based indices (FIG. 11) is spotty, but this may overly pessimistic owing to the inclusion of all years.

Management Changes

Nies and Cournane (NEFMC, pers. Comm) summarized the major changes in regulations from 2001 to 2017. While many of the effort control measures could have reduced fishing mortality on Atlantic halibut, there have been only two measures directly related to halibut. In 2009 the one fish per trip regulation was put in place. Amendment 16 later implemented an increase in minimum size from 36 to 41 inches for the 2010 fishing year, beginning on May 1. Such changes would be expected to increase the discard rate, all thing being equal.

Previous Assessment Models

Prior to 2008 Atlantic halibut were assessed using index methods utilizing the NEFSC fall bottom trawl survey. Col and Legault (2009) succinctly summarized the early assessment history of halibut as follows:

> "In previous index-based assessments (NEFSC 2001; Brodziak 2002, Brodziak and Col 2005), Northeast Fisheries Science Center (NEFSC) autumn weight per tow survey indices were expanded to swept-area biomass estimates, and the 5-year average biomass index was compared to B_{MSY} proxy reference points for status determination (FIGure 3). Reference points for Atlantic halibut were originally determined by the New England Fisheries Management Council (Applegate et al. 1998) using Canadian Atlantic halibut length-weight equations (McCracken 1958) and von Bertalanffy growth curves (Nielson and Bowering 1989) to perform yield per recruit (YPR) and biomass per recruit analyses. Natural mortality was assumed to be 0.1, and a Maximum Sustainable Yield (MSY) proxy was chosen to be 300 mt, yielding a B_{MSY} proxy =5400 mt, a ½ B_{MSY} proxy = 2700 mt, and an F_{MSY} proxy (threshold) = $F_{0.1}$ = 0.06. Based on the Groundfish Assessment Review Meeting (GARM) 2005 assessment of Gulf of Maine-Georges Bank Atlantic halibut, the stock was overfished (B_{2004} was 5% of B_{MSY} proxy) and it was unknown whether overfishing was occurring (Brodziak and Col 2005)."

The Replacement Yield Model (RYM) was first applied to US Atlantic halibut in 2008 at the GARM III assessments (NEFSC 2009). The RYM was suggested by Butterworth (refs) at the 2008 GARM III meeting. Col and Legault (2009) implemented the model. The biomass at time t is expressed as

$$B_t = B_{t-1} + R_{t-1} - C_{t-1} \quad [1]$$

Where Bt is the biomass at time t, C_t is the catch at time t and R_t is the replacement yield. Replacement yield is based on the logistic growth model and is defined as

$$R_t = rB_t\left(1 - \frac{B_t}{K}\right) \quad [2]$$

Where K is defined as the estimated population size in 1800. Application of the model required several important assumptions

1. Catches between 1800 and 1893 are unknown but are assumed to increase linearly from zero in 1800 to 798 mt in 1893.
2. The intrinsic rate of increase in population size is assumed to be constant over the entire time series and equal to a life history approximation derived from a YPR analysis of contemporary estimates of growth rates and a natural mortality rate of ***M***=0.15. In the Col and Legault (2008) assessment, r was set to twice the value of $\boldsymbol{F_{0.1}}$.
3. A penalty function on survey catchabilty with ***q***=0.5 was imposed by Col and Legault for the NEFSC fall survey. Col and Legault (2009) also used a penalty function on population size.

4. The combination of an assumed trajectory of catch and a fixed value of $\boldsymbol{r}$ are sufficient to allow estimation of $\boldsymbol{K = B_{1800}}$ in the model. The carrying capacity $\boldsymbol{K}$ is also assumed to be constant over the assessment period.

When Hennen (2015) updated the assessment in 2015 the model estimates suggested that the stock had completely rebuilt to K, i.e., the population size in 1800 and twice the $\boldsymbol{SSB_{MSY}}$ proxy value (See Fig. 81 in Hennen 2015). Moreover, the population estimates had been well above SSB_{MSY} since the start of the fall survey time series in 1963. Analyses of the log likelihood profile over the $\boldsymbol{K}$ parameter revealed extreme sensitivity to $\boldsymbol{K}$ (Fig. 16 in Hennen 2015. (Supplemental material).

The combination of implausible estimates of stock status, extreme statistical uncertainty, and dependency on model assumptions, led to the rejection of this assessment approach for Atlantic halibut. While the model incorporates important biological information about growth and natural mortality, model cannot be estimated without imposing constraints on $\boldsymbol{q}$ and fixing the intrinsic rate of increase. In Col and Legault, penalty functions were included to help fix $\boldsymbol{q}$~0.5 and to impose bounds on biomass. Sensitivity analyses by Col and Legault revealed that the assumed trajectory for catch between 1800 and 1893 had almost no effect on estimation.

The Review Panel in 2015 concluded that "the updated assessment was not acceptable as a scientific basis for management advice. The updated assessment produced an unstable and unrealistic solution. Estimates of current stock size were highly sensitive to initial conditions and slight changes in assumed parameter values."

Plan B Assessment Process

In the Northeast US rejection of the accepted stock assessment model creates uncertainty about stock status and poses the problem of finding an alternative basis for setting catch limits. These are affectionately known as Plan B assessments (NRCC 2011). The written and implied constraints on Plan B assessments were discussed in the introduction. In the following sections, alternative approaches for providing scientific catch advice are considered. Numerous methods have been proposed for the assessment of data-poor stocks. A number of excellent reviews of both methodology and applications may be found in Berkson et al. (2011), Newman et al. (2015), Carruthers et al. (2014), and especially Edwards (2015). The potential utility of such methods for Atlantic halibut is considered in the following sections.

Life History Methods

Life-history based methods rely on various properties of growth and longevity, and draw upon so-called life history invariants for obtaining suitable target fishing mortality rates. If a population is at equilibrium then length frequency information should be sufficient to obtain a measure of total mortality. Assuming a rate of natural mortality then allows for derivation of a contemporary fishing mortality rate or target fishing mortality rate.

Length-based Methods

Length-based methods do not provide information on abundance or its trends (Edwards 2015). They are also typically slow to respond to changes fishing mortality because they rely on some degree of constancy in recruitment, fishery selectivity and natural mortality, and adequacy of biological sampling of landings and discards to define a meaningful rate of fishing mortality. Otherwise the derived rates can be biased. Gedamke and Hoenig (2006) developed approaches to address nonequilibrium populations.

Without a measure of scale, one can only interpret current fishing mortality rates with respect of target rates. If $F_t > F_{target}$, then the catch could be reduced by the degree of overage. However, such measures are not useful for setting catch limits unless they are viewed as part of feedback control system. Klaer et al (2012). noted that the feedback control rule had acceptable results for a high productivity demersal stock but that estimates of variability of length at age were essential for proper estimation. The overall sampling frequency for landed and discarded Atlantic halibut has increased in recent years but a full evaluation of the information content of such data is beyond the scope of this project. Introduction of new data requires consideration of potential sources of bias via a working group process.

Productivity-Susceptibility Analysis

The productivity susceptibility analysis method (Patrick et al. 2011) examines multiple attributes of life history, fisheries and habitats to derive a score for productivity P and susceptibility S. The overall vulnerability V of the species to overfishing is a function of P and S. Results suggest that halibut are only moderately vulnerable to overfishing owing to relatively high productivity scores. Regardless of the underlying PSA score, the widespread absence of halibut in the Gulf of Maine and in deeper waters of Georges Bank suggests that recovery has been slow since the peak periods of fishing in the early 1900's. The PSA method was not considered further for this assessment.

Catch-Based Methods

Catch-based methods are rely primarily on adjustments to recent average catches (Berkson et al. 2011). The basis for the adjustment varies but typically includes a scalar adjustment to recent average catches based on an assumed stock status. For example, Restrepo et al. (1998) employed 3 different scalars, all less than one, depending on whether the stock was below or above the inferred estimate of $\boldsymbol{B_{MSY}}$. While these methods are widely used in the US in data-poor stocks in the US, Carruthers et al. (2014) concluded that the utility of such methods as control strategies could not be evaluated reliably in a simulation context. Such measures are undoubtedly good starting points for managers until data collection procedures to support more robust measures can be implemented. However, the degree of data poverty in such stocks is far greater than for Atlantic halibut which has multiple indices of relative abundance and recent biological information. Catch-only based methods were not considered further for this assessment.

Depletion-Corrected Average Catch (DCAC)

Depletion corrected average catch methods were first proposed by MacCall (2009) as a way of interpreting catch histories in terms of an underlying surplus production model. The DCAC model represents an important conceptual advance for fisheries as it applies logical constructs to obtain rough estimates of sustainable yield and more importantly, contemporary catch for data poor stocks. The methodology combines standard principles of surplus production models with various “rules of thumb” from various meta-analyses in fisheries stock assessments. The Depletion-based Stock Reduction Analysis (DB-SRA) is conceptually similar but relies on more detailed biological information. Both DCAC and DB-SRA rely on assumptions about current stock status relative to biological reference points. As this is the usual *output* of an assessment, the need to supply it as an *input* does cause some conceptual problems.

Edwards(2015) provided a succinct summary of the utility of DCAC and DB-SRA as follows:

> “Both DCAC and DB-SRA have been shown to be highly sensitive to the assumed current status of the stock δ, and can easily produce overestimates of the OFL if an optimistic distribution for δ is assumed. This is a major shortcoming, since if depletion of the stock is known already, then it is unlikely to be considered data-poor. Consequently it is difficult to conclude that these methods are an improvement on the scalar methods already in use. Indeed it appears from recent simulation studies that DACS methods produce comparable results (Carruthers et al., 2014).”

Edwards conclusions were tempered somewhat by noting that most data poor assessment models embed such considerations into their definition (e.g., see Restrepo et al 1998 discussion above.)

> “Furthermore, when considering their utility it is worthwhile noting the philosophical stance represented by these catch-only methods. They are centrally based on prior assumptions regarding the state of the fishery (specifically the depletion), which is a departure from previous conceptions of prior information that typically refer directly to parameter values within a particular model specification. Including this type of “soft” information could allow more “sporadic, qualitative or subjective” data to partake in the estimation process (Bentley, 2015), and the methods described by MacCall (2009), Dick & MacCall (2011) and Martell & Froese (2013), represent an important step in that direction.”

Rewriting MacCall’s (2009) DCAC notation by replacing Y with C leads to

$$C_{sustainable} = \frac{\sum_{t=1}^{n} C_t}{n + \frac{Delta}{0.2\ M}} \quad [3]$$

Where ***Delta*** is defined as

$$Delta = \frac{B_t - B_{t+n}}{B_{MSY}} \quad [4]$$

MacCall noted that yields are sustainable only if the current biomass is greater than $\boldsymbol{B_{MSY}}$; otherwise the estimate of catch for the current time step may be approximated as

$$C_t = C_{sustainable} \frac{B_t}{B_{MSY}} \quad [5]$$

While conceptually simple and based on surplus production theory, the DCAC model requires an estimate of the biomass at MSY or equivalently the carrying capacity of the resource. Otherwise the proportion in the denominator of Eq. 3cannot be obtained.

The DCAC approach was first applied to US Atlantic halibut by Col and Legault (2009) as an exploratory exercise for two different cases. First they considered the entire time series of 208 years of catch (i.e., imputed+recorded) used in the replacement yield model (RYM). Using the model biomass estimates as a guide, the derived ***Delta***=0.987 estimate of $\boldsymbol{C_t}$ was 35 mt. Using the entire time series of recorded catch (1893-2007), ***Delta***=0.098, and the DCAC estimate of $\boldsymbol{C_t}$ is 10 mt. In their application of DCAC, the results of the RYM were used to estimate the key parameter ***Delta***.

Theory of DCAC implies that sustainable and current catch can be estimated when the population is increasing as well as decreasing. When the population is declining over time, ***Delta***>0 (and vice versa) but the magnitude of ***Delta*** depends not only the rate of change in abundance indices but also on the relative size of the current population. Col and Legault (2009) were able to use the results of the accepted assessment model to create their estimates. In the absence of such a model the estimation problem can be decomposed into two steps:

1. Estimate the relative rate of change in one or more abundance indices over some period of time. This is described in the section “Ratio Estimation”.
2. Obtain an estimate of approximate scale consistent with the catch and relative biomass indices. This is described in the section “Envelope” method.

The methodology for achieving steps 1 and 2 are described in the following sections.

The model requirement that the relative status of the resource must be known in order to estimate relative catch implies that the status must first be inferred from knowledge apart from the model. Several authors have noted the logical difficulty of this approach (Edwards 2015, Carruthers et al 2014) but have also noted that it is it valuable in many fisheries where reasonable guesses of stock status might be made. The approach has been used widely in the US for stocks in which biomass is thought to be well above $\boldsymbol{B_{MSY}}$**.** When biomass is well below $\boldsymbol{B_{MSY}}$ the scope for error in the ***Delta*** parameter is much less. Moreover, the method does not address the management requirement for rebuilding at very low stock levels. Both of these conditions are true for halibut, so it is important to define where the current stock is relative to some measure of $\boldsymbol{B_{MSY}}$ and to estimate the relative change that has occurred over the period of extraction.

Eq. 3 applies to instances where the stock has been increasing of the period in which catches have been taken. In this case Delta is less than zero. When ***Delta***/(0.2 ***M***) equals ***n*** the sustainable catch is undefined. When ***n*** <***Delta***/(0.2 ***M***) the predicted sustainable catch is negative. Subject to the assumptions underlying the model, the presence of infeasible solutions provides a rough boundary on the current relative state of the stock. The implications of this discontinuity for bounding of abundance estimates will be discussed later.

Ratio Estimation and Randomization Method

A randomization test is developed herein to estimate the magnitude of change in a time series of length t=1,…T. We are interested in the general problem of determining whether the observations at the end of the time series are statistically larger than the observations at the beginning of the time series. For the DCAC issue we are not particularly interested in the trajectory of the change, so a model-based approach is not necessary. Moreover, observation errors tend to be high so that a simple regression model may be misleading.

The first task is to create a test statistic that can be used to compare the population state at the ends of the series. For this exercise I assumed the population state could be estimated as the ratio of the average of the last three observations to the first three observations. Consider a time series with observations $\boldsymbol{x_1, x_2, \ldots x_T}$. If the times series is simply a random set of observations with no underlying trend, the test statistic should be near the center of the test statistics obtained by randomly shuffling the observations, and computing a new statistic. The collection of all statistics so generated is called the sampling distribution for the test statistic. The approximate significance level of the test statistic from the original time series can be compared to the sampling distribution. If it lies near the tails of the distribution on can assume that the observed value for the original series is improbable due to chance alone. These concepts are formalized in the following equations.

Let $\boldsymbol{I_{j,t}}$ represent the j-th index at time ***t*** where ***j=1,…J*** and ***t=1,…T.*** We compute the endpoint estimates of abundance using an average of multiple years (***n*** and ***m***) to help reduce the effects of random variation in catchability between years Let ***m***= number of years for most recent years and ***n*** for earlier period. Define test statistic or critical ratio for index $\boldsymbol{I_{jt}}$ as $\boldsymbol{R_{crit,j}}$ as

$$R_{crit,j} = \frac{\sum_{t=T-m+1}^{T} \frac{I_{j.t}}{m}}{\sum_{t=1}^{n} I_{j,t} \frac{I_{j.t}}{n}} \quad [6]$$

If the observations for the various $I_{j.}$ are not commensurate, then, without loss of generality, the indices can be standardized with respect to their individual means. The composite test statistic for multiple time series can be define as

$$R_{crit,.} = \frac{\sum_{j=1}^{J}\sum_{t=T-m+1}^{T}\frac{s(I_{j.t})}{m}}{\sum_{j=1}^{J}\sum_{t=1}^{n}\frac{s(I_{j,t})}{n}} \qquad [7]$$

Where ***s(.)*** refers to a standardization function in which the index is expressed as a ratio to its mean.

$$s(I_{j,t}) = \frac{I_{j,t}}{\sum_{t=1}^{T}\frac{I_{j,t}}{T}} \qquad [8]$$

The sampling distribution of the randomization statistic for ***Rcrit*** is obtained by shuffling the observed sequence of indices and computing a random realization of the indices. Let ***R(.)*** represent the randomization function which shuffles the original indices $I_{j,t}$ with respect to time. Let ***k*** represent the index for the ***k***th realization of the random ***Rcrit***.

$$R_{crit,k} = \frac{\sum_{j=1}^{J}\sum_{t=T-m+1}^{T} R_k\left(\frac{s(I_{j.t})}{m}\right)}{\sum_{j=1}^{J}\sum_{t=1}^{n} R_k\left(\frac{s(I_{j,t})}{n}\right)} \qquad [9]$$

The sampling distribution of ***Rcrit*** is obtained by repeatedly applying Eq. 9 over an arbitrarily large number of iterations, ***k=1…Nrand***. The approximate significance value of the observed ***Rcrit*** can be obtained by comparing it to the sampling distribution of realized observations $\{\mathbf{R_{crit,k}}\}$

The probability of obtaining a value greater than $R_{crit,obs}$ is simply

$$P(R_{crit,k} > Rcrit, obs) = \frac{\sum_{k}^{Nrand} g(R_{crit,k} \geq R_{crit,obs})}{N_{rand}} \qquad [10]$$

where g(.) is an indicator function equal to 1 when the logical argument is true and 0 otherwise. The probability of observing a critical value less the observed value may be obtained by simply reversing the order of the operator in the indicator function ***g(.)***

The sampling distribution of the ***Rcrit*** in Eq. 9 can be enumerated as the product of combinatorials. Total realizations = J* comb(T,n)* comb(T-n,T-m-n) * comb(m,m). For J=6, T=10, n=m=3, the number of potential combinations is 25,200. I approximated the sampling distribution with 2000 iterations.

SIMULATION TESTS for Randomization method

For the purposes of this assessment, the performance of the ***Rcrit*** statistic is defined as the ability to detect a true rate of change. This is affected by the magnitude a function of the true underlying rate of increase, the underlying observation error for each index and the number of indices. Intuitively one would expect the performance of ***Rcrit*** to improve with larger true rates of increase, as the observation error declines and as the number of indices increases. These hypotheses were tested in a series of simulations described below.

Let the true rate of annual increase be defined as $\boldsymbol{\lambda}$.

$$I_{true,t+1} = \exp(\lambda)\ I_{true,t} \quad [11]$$

The realized observations are assumed to be lognormally distributed random variables with mean defined by the true index value and the SD specifiec by the coefficient of variation CV.
Let

$$I_{realized,t} = LnNormal\left(I_{true,t}, SD\right) \quad [12]$$

Where $SD = \sqrt{\ln(CV^2 + 1)}$

Simulations were conducted for 3 levels of $\boldsymbol{\lambda}$,{0.1, 0.05,0.025} 12 levels of ***CV*** { 0.1, 0.15, 0.2,…0.65, 0.70} and four different levels of ***J***={1,2,3,5}. Random times series of 10 observations were computed for 1,000 realizations. For each realization, a $\boldsymbol{R_{crit,realized}}$ was computed. A randomization test with 2,000 iterations was then used to compute the significance level for each random realization Two million iterations were computed for each of the 3*12*4 combinations of $\boldsymbol{\lambda}$, ***CV*** and ***J***.

Randomization Simulation Results
Simulation tests suggest relatively little bias in the ratio estimator over a broad range of simulated values except when the true magnitude of increase is small (eg 2.5% per year) and the underlying variability of the observations is low (Table 2). Even then, the bias will decline as the number of indices increases. The probability of successfully detecting a change in population size is given in Table 3. As expected increases in the true magnitude of change, reductions in the variability of the observations and increases in the number of available indices all act to increase the probability of detecting the true change.

Overall results of the simulation studies are summarized in Tables 4, 5,6 and 7. Each table corresponds to different number of variables used for trend. Within each table lambda ranges from 0.1 to 0.25 and CV ranges from 0.1 to 0.7. The tabulated results are the fraction of test statistics that are significant at the P=0.005, 0.01, 0.05, …, 0.25 probability levels. For example, a value of 0.89 would mean that 89% of the test statistics were less than or equal to the probability level of the columns. In other words, the entries provide a metric of the ability of the estimator to correctly identify the true ratio. Color shading is scaled consistently across tables with green shading indicating good performance and red shading indicating poorer performance. As one would expect model performance generally increases with the magnitude of increase (eg. It’s easier to find the correct value when the true Rcrit is bigger), as CV gets smaller, and as the number of variables used for detection increases.

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Application of Rcrit Method to US and Canadian Indices

The Rcrit randomization method was applied to six candidate indices for the US stock and three candidate variables for the DFO 3NOPs4VWX5Zc stock (TABLE 1). Candidate indices for the US stock included the NEFSC fall trawl survey biomass, the d/k ratios for halibut taken in observed trips on gill net and trawl vessels, a modeled index of commercial catch per unit effort, and the fall and spring weight per tow estimates from the ME-NH inshore trawl survey. The inclusion of the d/k ratios for gill nets and trawls should not be interpreted as introduction of a new time series in the model since these are components of the SBRM discard estimate. For the purpose of establishing trend, the selection of the NEFSC trawl survey and d/k ratios should be considered consistent with the time series used in previous assessments. Other indices from Maine are useful for illustrating overall coherence of available information.

No attempt was made to define the "best" set of variables. Instead, the Rcrit method was applied to all possible combinations of indices. For 6 variables, this implies 63 different models based on the sum of combinatorials denoted as (6,6) {ie. 6 items, taken 6 at a time) +(6,5)+ (6,4)+ (6,3)+ (6,2)+ (6,1)=63 possible models. Tables 8, 9, and 10 summarize the results of the complete set of models for 2002-2016, 2005-2016, and 2002-2013, respectively. Nearly all of models configurations were statistically significant. For 2002-2016 95% of the models has significance values less than 5%, for the 2005-2016 period 78% were significant, and for 2002-2013, 95% were significant. The average Rcrit over all models and year ranges went from a low of 2.44 for the 2005-2016 to 3.52 for the 2002-2016 period.

For the Canadian stock three abundance indices are used in their analytical model. The average increase in Rcrit over 6 possible models was 2.92 (P<0.001) (Table 11). The Rcrit for the modeled biomass was 2.763. Overall the comparisons suggest that the US stock has increased at a rate comparable to that observed in Canada. Of course, the scale of these changes is considerably different. Landings in Canada in the last 3 years have averaged ~3400 mt, whereas in the US stock landings have been about 100 mt.

The implied annual rates of increase in relative abundance, given the Rcrit estimates below are on the order of 9 to 15% per year. The similarity in rates of increase between US and Canada stock areas potentially suggests favorable conditions in both areas during the past decade.

		Changes in catches			Change in indices		
	Ratio Definition	Statistics	Value		Statistic	Value	Model
US	'02-04:'14-16	Rcrit(Catch)	3.227		Rcrit(Indices)	3.23	(all six indices)
						4.98	(DK_g, DK_t, Survey)
						3.52	average over 63 models
	'05-07:'14-16	Rcrit(Catch)	2.657		Rcrit(Indices)	2.44	average over 63 models
						2.2	(all six indices)
						4.11	DK_g,DK_t, Survey
	'02-04:'11-13	Rcrit(Catch)	2.617		Rcrit(indices)	2.893	(all six indices)
						5.033	(DK_g, DK_t, Survey)
						3.144	average over 63 models
Canada	2002-04: 2014-2016	Rcrit(Catch)		2.259	Rcrit(Indices)	2.703	(two survey , one CPUE
						2.923	average over 6 models
						2.763	Analytical model results

While Rcrit provides a way of quantifying the rate of change in population size, it cannot distinguish the change in scale. For example a population that increase 3 fold during some period could increase from 2% to 6% of the virgin stock size for from 20 to 60%. Application of DCAC requires one to estimate the ***Delta*** parameter in terms of change relative to virgin stock size. To establish scale, the Envelope method was applied, as shown in the next section.

Envelope Method

The envelope method (Miller and Rago 2010) is an approach to establish a range of feasible biomass estimates conditional on an assumed range of feasible catchability estimates q and historic ranges of fishing mortality rates ***F***. The method combines concepts of swept area biomass and the standard Baranov catch equation. Biomass estimates based on swept area estimation are dependent on an assumed range of catchability estimates ***q'***. Biomass estimates based on observed catches rely on an estimate of fishing mortality rate. For any given time series of catch, one can assume it is the realization of a small population being fished consistently at a high rate, or a large population being fished at a low rate. Using the standard definition for swept area biomass

$$B_t = \frac{I_t}{q'}\frac{A}{a} \qquad [13]$$

The ratio ***A/a*** is the total area ***A*** covered by the survey and ***a*** is the average area swept per tow. The biomass estimate consistent with observed catch can be obtained from the Baranov catch equation

$$B_{0,t} = \frac{C_t}{\frac{F}{F+M}(1-e^{-F-M})} \qquad [14]$$

$$B_{f,t} = B_{0,t}e^{-(F+M)f}$$

The second equation in Eq 14. adjusts the biomass estimate to be on the same time scale as the survey estimates in Eq. ss. If we use the general notation that ***B(I,q)*** is the biomass estimate based on the observed ***I*** and assumed ***q***, and ***B'(C,F,M)*** is the biomass estimate based on the observed ***C*** and assumed ***F*** and ***M***, then one can generate the following set of biomass estimates:

$$\widehat{B_{1,t}} = B(I_t, q_{Low}) \qquad [15]$$

$$\widehat{B_{2,t}} = B\left(I_t, q_{High}\right)$$

$$\widehat{B_{3,t}} = B'(C_t, F_{Low}, M)$$

$$\widehat{B_{4,t}} = B'\left(C_t, F_{High}, M\right)$$

For many species, prior information on a suitable range of ***q*** may obtainable from gear comparison studies. Calibration studies for NEFSC failed to catch sufficient numbers of halibut in either net type to allow estimation of a conversion coefficient (Miller et al. 2008). A plausible range of fishing mortality estimates may be obtained by analogy with other halibut or flatfish fisheries.

The key concept in the envelope method is that the bounds represent extremes in the feasible range of parameter values. The upper and lower bounds of biomass estimates can then be defined as the set of estimates that jointly satisfy both constraints. These values are defined as

$$\hat{B}_{upper,t} = min\left(\hat{B}_{1,t}, \hat{B}_{3,t}\right) \qquad [16]$$

$$\hat{B}_{lower,t} = max\left(\hat{B}_{2,t}, \hat{B}_{4,t}\right)$$

Values of biomass that exceed $\boldsymbol{B_{upper,t}}$ imply catchabilities smaller than $\boldsymbol{q_{low}}$ or fishing mortalities less than F_{low}. Conversely, values of biomass less than $\boldsymbol{B_{lower,t}}$ imply catchabilities greater than $\boldsymbol{q_{high}}$ or fishing mortalities greater than $\boldsymbol{F_{high}}$. The bounds defined by Eq. 16 describe a set of feasible estimates that are consistent with the assumed ranges of *both* ***q*** and ***F***. In theory, a more mechanistic model of stock dynamics should also be within this feasible range. Additional layers of constraints might be applied to the model to further reduce the range of uncertainty. For example, one could reasonably hypothesize that the biomass in US waters in recent years should be less than or equal to the Canadian stock biomass in 3NOPs4VWX5Zc. If a particular constraint is binding, then it can be used to further refine the feasible ranges of q and F for those years. A mid-range estimate of central tendency (sensu Tukey 1977) for $\boldsymbol{B}$ can be obtained as the average of $\boldsymbol{B_{upper,t}}$ and $\boldsymbol{B_{lower,t}}$.

Envelope Results

The model was applied to the catch estimates from 1963 to 2016 and NEFSC fall trawl survey estimates of swept area biomass. The assumed range of $\boldsymbol{F}$ is{0.02,0.40} and $\boldsymbol{q}$ is {0.02,1.0}. The envelope model can only be applied to catches before 1963. FIG. 12. The Envelope model was also applied to the Kalman smoothed biomass estimates of fall survey biomass (FIG. 13). As might be expected the biomass estimates from the RYM do lie within the boundaries of the Envelope and correspond well with the mid-range estimator of average abundance (FIG.13). Quantitative results of the maximum biomass estimate and 2016 biomasses are summarized in Table12. Depending on the range of years used for estimation of biomass the mid range of the 2016 estimate ranges from 2.4% to 98.2% of the maximum observed value. The derived range is not terribly useful but it does highlight that the perception of the resource varies considerably with the inclusion of more long term data. The wide range of uncertainty in the biomass results is consistent with our limited understanding of the dynamics of halibut in US waters.

Factoring the Rcrit and Envelope Results into DCAC

The results of Rcrit and the Envelope methods can now be factored into the computation of DCAC to obtain estimates of sustainable yield and predictions for 2018 catches. Table 13 combines the observed ratio increases from Rcrit and the Envelope estimates of fraction rebuilt in 2016 to derive a set of possible Delta parameters. In part B of Table 13 the derived Delta are used to estimate sustainable catches for each combination. As noted in the methods above, the DCAC model can become unstable as the denominator in Eq. 3 approaches zero. The model produces infeasible results when the denominator becomes negative. Table13 shows the specific behavior of the model for this application. FIG. 14 general behavior of the estimator for varying values of ***Delta*** and ***Rcrit***.

The overall results of the DCAC approach are not reassuring even when the estimates of Delta are refined by explicit consideration of the recent trends in population indices. The fundamental problem appears to be uncertainty in the absolute biomass estimate. Even if a credible statistical catch at age model can be developed, the uncertainty of any biomass estimates is likely to be very large for the foreseeable future.

Proposed Assessment Approach

The proposed assessment approach is less ambitious in terms of estimating long-term parameters (***r, K***) and instead focuses on short-term changes in stock size and their implications for modifying catch. As a simplification, it is assumed that the current stock size is well below the historic carrying capacity K such that the expression $\boldsymbol{(1-B_t/K)}$ in Eq. 2 is negligible. This seems reasonable in the context of inferring an initial stock size that existed over 200 years ago and is

estimable only by assuming that the productivity of the stock has been fixed and constant at 2*$\boldsymbol{F_{0.1}}$ for a similar period. The $\boldsymbol{F_{0.1}}$ estimate is based on life history attributes from recent decades and the natural mortality is fixed at $\boldsymbol{M}$=0.15.
Relaxation of these assumptions leads to a simple linear equation for biomass as a function of a time-varying rate of increase $\boldsymbol{r_t}$ and a time-varying harvest rate $\boldsymbol{h_t}$.

$$B_{t+1} = B_t + r_t B_t - h_t B_t \qquad [17]$$

Catch is defined as the product of harvest rate and stock size

$$C_t = h_t B_t \qquad [18]$$

Which leads to

$$B_{t+1} = B_t + r_t B_t - C_t \qquad [19]$$

A key assumption in nearly all stock assessment models is that stock size is proportional to one or more indices of abundance $\boldsymbol{I_t}$ as

$$I_t = qB_t \qquad [20]$$

Stock assessment models can be fit to observed data by substituting Eq. 18 into Eq. 17 and by creating a likelihood function for one or more relative abundance indices. Derivation of $\boldsymbol{q}$ for each index and specifying an appropriate function for $\boldsymbol{r_t}$ can be problematic if $\boldsymbol{r_t}$ is changing and if observation error of $\boldsymbol{I_t}$ is high.
To avoid these problems the equation for biomass dynamics is transformed into a recursive expression for catch over time. The model can be derived as follows. The catch at time t+1 is written as

$$C_{t+1} = h_{t+1} B_{t+1} \qquad [21]$$

Dividing Eq. 21 by Eq. 18 gives

$$\frac{C_{t+1}}{C_t} = \frac{h_{t+1} B_{t+1}}{h_t B_t} \qquad [22]$$

Rearranging terms a bit provides a prediction of future catch as a function of current catch:

$$C_{t+1} = \frac{h_{t+1}}{h_t} \frac{B_{t+1}}{B_t} C_t \qquad [23]$$

Without loss of generality, one can substitute Eq. 20 $\boldsymbol{I_t=qB_t}$ in the Eq. 23 to obtain

$$C_{t+1} = \frac{h_{t+1}}{h_t} \frac{I_{t+1}}{I_t} C_t \qquad [24]$$

The problem with Eq. 24 is that it relies on having an estimate of I_{t+1} in order to estimate C_{t+1}. Furthermore, it also requires h_{t+1} and h_t which are also unknown. By definition the index I_{t+1} is a consequence of the removals at time C_t so it would not generally be available until most or all of the fishery that harvest catch in period t+1 would be complete.

However, from Eq[17] the ratio B_{t+1}/B_t is $1+r_t-h_t$ which is equivalent to I_{t+1}/I_t .

$$\frac{B_{t+1}}{B_t} = 1 + r_t - h_t \qquad [25]$$

Or by substituting Eq. 20 into Eq. 25.

$$\frac{B_{t+1}}{B_t} = \frac{qI_{t+1}}{qI_t} = \frac{I_{t+1}}{I_t} = 1 + r_t - h_t \qquad [26]$$

An approximate estimate of the expression ($1+r_t-h_t$) can be obtained by regression the $log(I_t)$ vs time. This is easily shown by recursively applying Eq. 6 over p time steps to obtain

$$B_{t+1} = (1 + r - h)B_t$$
$$\dots$$
$$B_{t+p} = (1 + r - h)^p B_t \qquad [27]$$

Taking log of both sides results in

$$\ln(B_{t+p}) = p\big(ln(1 + r - h) \quad + \ln(B_t\big) \quad [28]$$

Therefore, the slope of rate of change in biomass over time is $ln(1+r-h)$. The intercept is simply the log of the initial condition B_t. For an index I_t that is proportional to Biomass B_t as defined in Eq. 28, the slope is independent of the scaling factor q.

$$\ln(I_{t+p}) = p\big(ln(1 + r - h) \quad + \ln(I_t\big) \qquad [29]$$

Using a log-linear regression model for the abundance indices one can approximate as the slope of $ln(I_t)$vs t or the average slope of the composite indices. Recall that we hypothesized that the r and h were functions of time. The regression in Eq. 15 assumes that r and h are constant over the interval $t=t_1$ *to* t_2. To approximate the change in slope over time one can update the regression equation 15 by computing the slope at each time t for τ time steps (ie. A τ-point regression). For simplicity of notation, let

$$slope_t = \ln(1 + r_t + h_t) \qquad [30]$$

Substituting Eq. 26 and 30 into Eq. 24 gives

$$C_{t+1} \cong \frac{h_{t+1}}{h_t}(1+\widehat{r_t -} h_t)C_t$$

$$C_{t+1} \cong \frac{h_{t+1}}{h_t} e^{slope_t} C_t \qquad [31]$$

Technically Eq. 31 poses some additional problems since neither $\boldsymbol{h_t}$ nor $\boldsymbol{h_{t+1}}$ are known. The harvest rate $\boldsymbol{h_{t+1}}$ can be written as a function of the biomass and catch at t+1. So one is left with the assumption that the slope at time ***t+1*** is approximately equal to the slope at time ***t***.
In most real-world scenarios an index of the biomass at time ***t+1*** would not be available at the time when $\boldsymbol{C_{t+1}}$ is being set. In practical terms it means that the slope estimated over the set of points $\boldsymbol{\{t_i, t_{i+1}, \ldots t_{i+n}\}}$ approximates the slope estimated from the set $\boldsymbol{\{t_{i+1}, t_{i+2}, \ldots t_{i+n+1}\}}$. In other words, the slope estimate at time t_{i+n} is used to approximate the estimated slope at t_{i+n+1}.
Under these constraints, the updating function for catch can be written as

$$C_{t+1} \cong e^{slope_t} C_t \qquad [32]$$

Eq. 32 implies that the rate of change in catch should be equal to the rate of change in relative abundance. Note that scale of indices does not affect estimate of slope vs time.
The model can readily be extended to multiple indices by taking the simple average of the rates of change in index values when the $\boldsymbol{slope_j}$ is defined by the log-linear regression $\boldsymbol{ln(I_{j,t})}$ vs ***t***. Hence slopes from multiple indices can be combined without consideration of their underlying scale. One can estimate a common slope via a general linear model in which the various indices are considered factors. Alternatively, the common slope can be estimated as the average of the j=1,…J slope estimates. Without loss of generality Eq. 32 can be written as

$$C_{t+1} \cong e^{average\ \widehat{slope}(I_{j,t})}\ C_t \qquad [33]$$

The slope parameters of the composite regression incorporate a number of underlying proceses including growth, recruitment, natural mortality and harvesting. Since any or all of these processes can vary over time, it is important that the forecasting equation be responsive to processes as they begin to occur.
This type of control rule has been suggested by Geromont and Butterworth (2015a, 2015b) and several others (Pomaerde et al 2010, Apostaloki and Hillary 2009). Note that the control rule implies that next year's catch can be adjusted based on information about the stock trend in the current year. This basic concept can be extended by applying concepts from control theory as shown in the following section.

APPLICATION OF CONTROL THEORY CONCEPTS TO HARVEST Control Rules

Control theory, in the context of this assessment, refers to a general set of principles used to adjust a physical system toward a desired state. A simple example is the use of a thermostat to control temperature in a room. More complicated examples include control of complex chemical production processes or control of surfaces on airplane wings. In general control theory uses feedback from a monitoring device to adjust some input factor to achieve a desired output (e.g., the thermostat send a signal to the furnace or air conditioner depending on what the temperature is relative to the desired value).

One of the major concepts in control theory is that controls can destabilizing if signals about system state are corrupted by noise or delayed and if the change in input level is too large. Conceptually this could occur if the thermostat sensor drifts or is delayed by some software glitch. Consider the consequences if the daytime output of the furnace is governed by temperatures monitored the previous evening. Destabilization can also occur if the input control is too large relative to the observed deviation of system state. A simple example would be a large furnace in a well-insulated small house. Since most furnaces are simply on/off devices, the likelihood of putting out too much heat is possible, raising the temperature to too high a point which then persists.

So what does this have to do with fisheries management? Consider catch to be the input control and relative abundance to be the output signal. If a target output value is known, then catch can be adjusted to achieve a desired value by monitoring the system state. The system state is simply the slope of the relative abundance index or indices. If we want to continue to allow the population togrow then catch can be set at some level less than that indicated by the rate of change. In control theory terms this scalar is referred to as the proportional gain or ***Kp.*** A stock in a rebuilding program would be one in which the gain might be less than one, thereby allowing a population to continue to grow.

A stylized schematic of the proposed model is given in FIG 15. The population dynamics are treated as a black box that outputs one or more abundance indices as a function of changes in the input Catch. If some function of the output variable is less than the previous value, then it is assumed that the previous input signal was too high and the input value of catch for the next time step would be reduced. Conversely, if the index output function increased, there might be some scope for increased catch in the next time step. Of course, devil is always in the details and it is important to consider the responsiveness to the output signal and the magnitude of the inter-annual adjustments. In the following analyses some of these details are explored further for application to Atlantic halibut.

The history of fisheries science is replete with examples of where an underlying process that is assumed constant in a model changes over time. The consequences for management are often overfishing and economic loss. Decreases in growth rate, increases in unobserved mortality, or reduced recruitment will tend to increase the variability in model fit but more importantly, lead to bias in predictions. Analytical models accommodate such changes in varying ways, but many causes can give rise to the same symptoms, such as retrospective patterns. Unfortunately, models need the most adaptability at the end of the time series, where any emerging trends are difficult to distinguish from noise. As an example, decreases in average size of fish may be due to increased recruitment or changes in fishing areas where smaller fish are more abundant. Model parameters for selectivity are unlikely to reliably estimate this change as it could imply either an increase in the historical recruitment to match the observed catch at age, or it could adjust the fishery selectivity at age.

In the simple model proposed here it is not possible to dissect such changes from the measure of slope. The slope is an aggregate measure of multiple factors. However, it is possible to estimate the rate of change in slope as a measure of acceleration or deceleration of trends. In this context it might be called the second derivative of population change. If we let β(t,n)=average slope estimated at with terminal year t and based the last n points, then we can compute the second derivative of population change as

$$\beta(t,n) = slope(x_{t-n+1,}x_{t-n}, \ldots .\, x_{t-1}, x_t)$$
$$\Delta\beta(t,n) = \beta(t,n) - \beta(t-1,n) \qquad [34]$$

The relationship between the slope estimate and its rate of change is important for forecasting future catch. If ***β(t,n)*** and ***Δβ(t,n)*** are positive, then the population would be increasing at an increasing rate. If ***β(t,n)*** is positive and ***Δβ(t,n)*** is negative, then the population is increasing at a decreasing rate. In the former case, one would be more optimistic about continued increase in stock size. The latter case would suggest that population growth may be slowing. There are no hard and fast rules about how to weight the relative importance of these two situations but in the control theory literature, this is called a derivative control, and the weight assigned to this factor is called the derivative gain factor or ***Kd***.

With these concepts in mind, the updating function for catch can be improved by considering the proportional change in stock size and the derivative of the rate of change as follows:

$$C_{t+1} = e^{\left(K_p\beta(t,n)+K_d\Delta\beta(t,n)\right)}C_t \qquad [35]$$

The exponential term in Eq. 35 expresses the rate of change in catch as the weighted sum of the proportional change in abundance (i.e., the first derivative of population size with respect to time) and the derivative of the rate of population change (i.e., the second derivative). This leads to the somewhat hokey name of First and Second Derivative harvest control or FSD control for short. The utility of the model is evaluated over a broad range of simulation scenarios and by application of the model to two managed halibut stocks, the 3NOPs4VWX5Zc Atlantic halibut managed by DFO and Pacific halibut managed by the International Pacific Halibut Commission (IPHC). In both applications, the predicted catch from Eq. 35 is compared to the TAC derived from modern analytical models.

Simulation Experiments for FSD Control Rule

While the control rule (Eq. 35) has some intuitive appeal, its utility is ultimately governed by its ability to control a theoretical population subject to a variety of conditions that are largely unknown or unpredictable in a real world. Relevant factors for a simulation study include

- Observation error for the relative abundance indices ***CV={0.005,0.2}***
- Number of abundance indices available ***Nvar={2,6}***
- Number of years to consider for estimating average slope. ***Ntrend={3,5}***
- Effects of alternative measures of Kp and Kd
- The underlying rate of population increase (r(t)) during the period before and after the control rule is applied.
- The pattern of harvesting (h(t)) prior to the application of the control rule.

In this simulation experiment, the population was harvested without application of the control rule for the first 10 years. During the next 10 years the control was applied. Observation error of the indices was examined by letting the CV range between 0.005 and 0.2. A CV of 0.005 is highly improbable but allows for evaluation of performance in the near absence of observation error. The number of years to use for estimating the slope was varied between 3 and 5 data points. Increasing the number of years decreases the responsiveness of the slope estimator to rates of change. Decreased responsiveness trades off with the increased likelihood of noise-driven estimate of the slope when only 3 points are used. Of course, one expects the shorter interval slope estimators to less reliable as the observation error increases.

Process error in the simulation context was addressed by hypothesizing temporal trends in stock productivity r_t, during the control period. Prior to implementation of the control, all scenarios assumed r=0.2 for the first 10 years. After the control was implemented, ***r(t)*** in year 11 was assumed to be

- Constant for the next 10 years at 0.2
- Steadily increasing over the next 10 years to 0.3
- Steading decreasing over the next 10 years to 0.1
- Increased as a step function in year 11 to 0.3
- Decreased as a step function in year 11 to 0.2
- Increased steadily for 5 years followed by a steady decrease
- Decreased steadily for 5 years followed by a steady increase.

These scenarios are depicted in FIG. 16.

The history of harvesting prior to implementation of the control rule is important because it defines the set of indices that will be used to develop the average slope estimate. Deterministic simulations suggest that the proximity of the true fishing mortality rate to the true productivity of the stock is critical for the application of the control. Neither of these quantities are estimable, so the control rule should be robust to this uncertainty.

The harvest rate scenarios all assume that the true population is growing during the first 10 years. This mimics the observed pattern for US halibut (See ***Application of Rcrit Method to US and Canadian Indices***). Three scenarios assumed constant harvest rates with h_t=0.15, 0.19 and 0.10, for all t. Other scenarios assume continuously increasing h_t, continuously decreasing h_t, a harvest rate that increases then decreases, and one that decreases then increases (FIG. 17). 49 possible combinations of r_t and h_t were evaluated by pairing each r_t and h_t scenario.

The effect of the ***Kp*** and ***Kd*** gain parameters were developed by evaluating performance for each combination of ***Kp***={0, 0.25,0.5, 1.0} and ***Kd***={0,1,5,10}. Higher values of K_d were used to evaluate the consequences of testing quick responsiveness when the $\Delta\beta$ parameter was changing. There were a total of 16 combinations of ***Kp*** and ***Kd*** evaluated for each combination of ht, rt, Ntrend, and Nvar.

Each 20 year simulation was repeated 50 times resulting in 2*2*2*7*7*4*4*50=313,600 applications of the control rule. Summary statistics from each simulation during the control period included the average:

- Number of overfishing events induced by the control rule (i.e., when the predicted catch resulted in overfishing ($h_t > r_t$)
- Number of "extinctions" when the population is driven to arbitrarily low values
- Catch
- CV of catch
- Net rate of population increase

Simulation results are summarized in Table 14 for two levels of CV ={0.005,0.2} and 16 combinations of K_p and K_d. Averages are made over the 49 combinations of h_t and r_t and for tow values of Ntrend={3,5}. Results suggest that low rates of K_p reduce the frequency of overfishing events. As the weighting on the change in slope increases, the frequency of overfishing events tends to increase because of induced oscillations. The relative precision of the observations appears to have little effect on the probability of overfishing. As expected, increases in K_p result in increases in average catch, but the increases in average catch come at the expense of greater variability in catch.

The frequency of "extinctions" is more complicated to explain as it appears to be driven more by the underlying initial conditions based on r_t and h_t, rather than the control parameters K_p and K_d. When observation error is relatively low, there controls with K_d~5 appear to work well in terms of reducing the frequency of "extinctions". Further simulation work may be necessary to examine the dynamics related to overshooting catches.

The potential interactive effects of the r_t and h_t, can be examined by considering the extinction frequency summed over all values of K_p, K_d, ***Ntrend,*** and ***CV.*** The scenarios in the following text table are depicted in Fig. 16 and 17.

		R scenario							
		r=0.2	r_up	r_down	r_step_up	r_step_dn	r_up_dn	r_dn_up	
Descrip-tion	Harvest Scenario	1	2	3	4	5	6	7	average
h=0.15	1	0.0159	0.0241	0.0178	0.0256	0.0191	0.0225	0.0181	0.020
h=0.19	2	0.0394	0.0375	0.0363	0.0525	0.3281	0.0456	0.0419	0.083
h=0.10	3	0.0053	0.0078	0.0091	0.0078	0.0078	0.0094	0.0053	0.008
h_up	4	0.3722	0.0816	0.5066	0.0691	0.5500	0.1044	0.5113	0.314
h_down	5	0.0016	0.0016	0.0013	0.0028	0.0013	0.0025	0.0019	0.002
h_dn_up	6	0.0469	0.0363	0.3153	0.0316	0.5028	0.0534	0.4019	0.198
h_up_dn	7	0.0119	0.0188	0.0156	0.0231	0.0184	0.0203	0.0141	0.017
	average	0.070	0.030	0.129	0.030	0.204	0.037	0.142	0.092

Overshoots are more frequent when the harvest rates are increasing during the pre control period (Harvest #4) and when harvest rises just prior to the control period (Harvest #6). Declining productivity at the start of the control period is problematic as see in R scenarios #3,5 and 7. Most of the unstable trajectories occur at the intersections of H scenarios 4 and 6 with R scenarios 3, 5 and 7.

One of the primary factors influencing the responsiveness of the system is the number of data points in the regression equation. Slope estimates will always constitute lagged information. The high amount of observation error in available indices leads to concerns that short term changes, deduced from say the ratio of abundance indices in adjacent years is likely to be unreliable. Unfortunately, the most important information in the stock assessment is the changes in the current time period. Hence it is necessary to consider a larger number of time periods when estimating trend. There may be some improved methods for estimating trend that retain sufficient flexibility for signal detection. A Kalman filter that incorporates information about overall observation error may be useful in this regard for future research.

Application of the FSD Model to US Stock Area

Input data for the US stock area are given in Table1. The model was based on a Kp=0.9 and Kd=0.9 for three indices dk_trawl, dk_gillnet, and NEFSC fall bottom trawl biomass. (See Appendix 1 for the input data and relative errors in each index). A five-point slope regression was used compute the slope for all indices FIG 18. The composite average slope has been positive since 2009 but the slope estimates have been decreasing since 2012. The catch multiplier for each year (based on the K_p and K_d factors of 0.75 and 0.50, respectively) suggests that the rate of increase is declining. FIG 19.

Comparison of observed and predicted catches show reasonable coherence (FIG 20) and surprisingly, the forecasted estimates of catch for 2011 to 2014 given in Blaylock and Legault (2012) line up well with observed values.

Model forecasts for 2018 were examined over a range of $\boldsymbol{K_p}$ {0, 0.3,,1.0}and $\boldsymbol{K_d}$ gain factors from {0, 0.25,…, 4.0} in Table 15. The model performance was estimated by computing a total sum of squares differences between the observed and projected values. Over the range of gain factors tested, the 2018 catches range 110.3 to 141.7 mt. Using the region where the SSQ is within 10% of the minimum value, the highest possible catch is 118.1 mt.

Uncertainty Estimation for Catch Forecasts

The uncertainty in the projected catch forecast includes process error related to the potential change in relative productivity of the stock (i.e., r(t)), the inherent lag in information owing to the number of data points in the estimator of the slope, and the gain factors applied to the first and second derivatives. Observation error in the abundance indices themselves also contributes to the uncertainty of the estimate. While simulation experiments address some of the uncertainty for idealized abundance indices (in particular, indices with homogeneous CVs for all indices), simulations do not capture a real-world example with heterogeneous variability over time and among indices. To address the realized uncertainty of the FSD model applied to the US stock area, a parametric bootstrap method was applied to each index time series. Indices were assumed to be lognormally distributed with means equal to the observed value and standard deviations equal to the log of square root of the coefficient of variation squared plus one.

$$Irand_{k,j,t} \sim LogNormal(Iobs_{j,t}, \sqrt{\ln(CV_{j,t}^2 + 1\,)}, \qquad [36]$$

Note that the ***k***-th realization of the ***j***-th index at time t is a function of time varying means and variances. The sampling distribution of the projected catches were based on 5000 bootstrap realizations.

Projected catches by year are given in Fig. 21 and the sampling distribution of projected catch in 2018 is shown in Fig. 22. The sampling percentile statistics for this distribution are

1%	5%	10%	25%	50%	75%	90%	95%	99%
98.24	104.98	108.61	114.88	122.65	130.69	138.34	143.16	152.26

The bootstrap mean of projected catch is 123.10 mt with a CV equal to 0.095.

Application of the FSD control rule to DFO Canada and IPHC Pacific halibut

The FSD model was applied to both the DFO Atlantic halibut and the IPHC Pacific halibut stocks. For the DFO application, the $\boldsymbol{K_p}$ and $\boldsymbol{K_d}$ parameters were set to the same values used or the US application. The forecasted catches tend to be higher than the model based TACs (FIG. 23). While the apparent coherence of the methods is somewhat reassuring, the differences between the two methods are likely to be not inconsequential in any real world application. However further analyses of the differences in model fit may be useful for improving the decision rules for the US stock area.

The application of FSD to the Pacific halibut stock is summarized in FIG. 24. Data used in this application were obtained from Stewart (2017). Given the tight controls on the TACs for Pacific halibut, it is assumed that the realized catch is close to the TAC. Although the FSD model has some large outliers over the entire time series, the model forecasts are relatively close to the realized catches from 2003 onward. Maximum deviations between the observed and predicted catches are less than 8 mt and generally under 4 mt.

Parametric bootstrap results are summarized in Figure 25 and 26. In general the distribution of predicted catches based on the model covered the range of observed total removals. lTabular summaries of the relative error in the survey and commercial WPUE indices from the IPHC were not available. I assumed the CVs for surveys were 0.2 for WPUE were 0.25 based on overall patterns summarized in Stewart (2017).

These results are likely attributable to consistent downward trend in catches and reliable signals from the IPHC surveys. A comparison of these relative trends with modeled biomass is given in Fig. 27

Effects of discard mortality on catch projections

The survival of released halibut is a function of many factors including the type of gear employed and handling of catch on deck. Estimated and assumed discard mortality rates vary widely among fisheries. In Pacific halibut fisheries managed by the International Pacific Halibut Commission (IPHC), discard mortality rates are estimated directly by observers when available. For unobserved trips the IPHC uses a range of discard mortality rates that vary by region (Bering Sea vs Gulf of Alaska), by target species , by tow depth, and by gear type (trawl, pot, and longline). Forty two possible combinations are considered in Table 2 in Dykstra (2017). Averages across gears are as follows: trawls 75.6%, pot 14.3%, longline 9.9%.) The DFO assessments for Atlantic halibut. Davis and Ryer (2003) reported a mortality rate of 100% after 30 days of holding in laboratory setting but the effects of captivity could not be isolated.
den Heyer et al. (2015) reported roughly similar results for Atlantic halibut,

> "In general, halibut are thought to be robust to handling relative to other groundfish. Neilson et al. (1989) found that 35% of otter trawl-caught halibut and 77% of longline-caught halibut survived 48 hours in holding tanks. Recent deployments of PSAT tags

> suggest that the survival of larger halibut caught by longline gear could be 100% (Armsworthy et al. 2014). Kaimmer and Trumble (1998) found that careful handling of Pacific halibut can increase discard survival and that even those fish with mild or moderate injuries have a higher than expected probability of survival. For example, 69% of Pacific halibut with moderate injuries survived and 43% of halibut with severe injuries survived."

Handling mortality for fish with expensive tags is likely to be low given likely bias in the capture, selection and handling of such fish. Nonetheless, the discard mortality in fixed gear is likely to be lower than in mobile gear. Given the current mixture of gears (primarily longlines) used to prosecute the Canadian fishery, den Heyer et al. (2015) used a discard mortality rate of 23%. DFO (2015) noted that their parameterization of discard mortality in their assessment and management models was based on rather old data and needed to be updated. Similar concerns were expressed by Leaman and Stewart (2017) in their scholarly review of the bases for discard mortality rates for Pacific halibut.

Given that US trawl fisheries are unlikely to target halibut, it seems reasonable to use the average of the discard mortality rates applied to Pacific halibut of 76%. To the best of my knowledge, there are no documented studies of discard mortality rates of halibut in gill nets. It seems reasonable to hypothesize it should be lower than trawl caught mortality but greater than longline estimates. Field studies for spiny dogfish yielded estimates of 30% mortality (Rulifson, East Carolina State Univ., personal communication).

The expected effects of discard mortality rates on total yield can be described simply as

$$C_t = L_t + \sum_{g=1}^{G} \alpha_g D_{g,t} \qquad [37]$$

Where $\boldsymbol{\alpha_g}$ is the discard mortality rate for gear $\boldsymbol{g}$ and Dg,t is the total discard estimate for gear $\boldsymbol{g}$ at time $\boldsymbol{t}$. The relative effect of $\boldsymbol{\alpha_g}$ on the catch estimate will depend on the magnitude of the discard estimates. The FSD model projects the catch in year t+1 by adjusting the observed catch in year t by the estimated rates of change in the indices in year t. In terms of the observed index data, the effects of changes in the estimated catch do not change the adjustment factor applied. The two quantities are decoupled in this context. Discard mortality will not have any effect on the quota IF the relative magnitudes of the $\boldsymbol{D_{g,t}}$ remains constant. However, if the balance of discards shift to say a less lethal gear, then there may be some room for increased landings, or less penalty for discards.

The relative importance of discarding in gill nets has been increasing relative to trawls (Fig. 28) in recent years. Estimated discards with and without adjustment for discard mortality (Fig. 29) show some divergence in recent years due the increase in discarding by gill net trip. However, the overall effect on total catch (Fig. 30) shows less divergence.

Use of total rates (discard+kept) in observer data

The proposed methodology was presented to the NEFMC Plan Development Team on November 27, 2017. It was noted that the d/k ratio as a measure of relative abundance may underestimate relative abundance. The team suggested that the total catch of halibut (i.e., landings plus discards) would be a better estimate of relative abundance. Comparisons of the ratio of total halibut caught to the total landings of all species (t/k) with the halibut discard to total landings of all species (d/k) are summarized in Appendix 3 and Figure 3.1. As expected the t/k ratio is consistently greater than d/k but there are no marked changes in recent years (Appendix Fig. 3.2)

1%	5%	10%	25%	50%	75%	90%	95%	99%
98.51	105.14	109.21	115.539	122.80	130.90	138.64	143.37	151.91

The overall mean catch for 2018 using these parameters is 123.43 mt with a CV equal to 0.094. The time series projected catches based on t/k and the sampling distribution of catch in 2018 are shown in Fig. 31 and 32, respectively. FSD model results suggest no significant differences between catch estimates derived using the t/k indices vs the d/k indices. (See also FIG 3.3 to 3.5 in APPENDIX 3).

DISCUSSION

Quantification of the virgin stock size for a halibut fishery that began a quarter century after the Revolutionary War is difficult. Lear (1998) reported that Boston's Atlantic halibut market "began to outstrip the inshore supplies" in the 1820's and by 1836 a fishery was established on Georges Bank. Catches peaked in 1849 and declined rapidly since then. Landings reported in Hennen (2015) show a curious 2 year spike of 4,200 and 4,908 mt in 1895 and 1896 but no other landings have exceeded 943 mt since then. In the first 40 years of recorded landings (1893-1932) landings averaged about 5.5 times greater than during next 60 years (1933-2002).

Two factors, 1) large catches that occurred prior to the collection of synoptic catch recording programs and 2) an apparent dispersal of fishing activity to more fishing grounds even in the earliest years of the fishery, will make it difficult to interpret historic scale in analytic stock assessments. Such estimates will be driven necessarily by strong, but weakly supported assumptions. Whether the derived quantities are useful as an accurate reconstruction of the past is debatable. But the utility of such estimates for contemporary management will be undeniably low. Current stock sizes are likely to be a small fraction of the virgin abundance and rebuilding strategies will likely devolve into debates about the scientific credibility of the targets or dire externalities of restricting other fisheries to achieve halibut rebuilding targets.

These same basic concerns constrain the applicability of data poor methods. The basic methods essentially fall into four categories:

1. Methods that rely some arbitrary scalar adjustment to recent average catches with no rigorous analyses of population consequences.
2. Methods that rely on strong assumptions about current stock status
3. Methods that apply a biologically based harvest rate to a swept area estimate of abundance
4. Methods that adjust current catches based on measures of current trends or trends.

Methods based on category 1 are difficult to justify scientifically even if risk averse reductions are selected. Economic and social considerations, e.g., acceptable inter-annual percentage changes, will necessarily be major considerations. Many poor methods (Category 2) rely on assumptions that are usually the outcomes of complicated assessment models rather than the inputs to data-poor models. Swept area models (Category 3) were not considered for this analysis because catch rates for halibut appear to be very low. Given the low rates of encounter and likely overall low abundance it did not seem prudent to construct a proxy value for halibut capture efficiency. Notably, it was not possible to estimate calibration coefficients for halibut from experimental comparisons (Miller et al. 2010). Instead the calibration coefficient of 2.057 for halibut was taken as an average of estimates for 5 other flatfish species (Blaylock and Legault 2015).

The proposed approach is similar to Management Procedure (MP) approaches or Management Strategy Evaluation (MSE) methods as described by Geromont and Butterworth (2015), Kelly and Codling(2006), and many others. MPA methods have been applied to several ICES stocks, Greenland halibut (NAFO) and advocated by Parma (2002) for Pacific halibut and later by Webster (2017), Hicks and Stewart (2017)for Pacific halibut. Many recent surveys of data-poor methods conclude by supporting MP approaches in one form or another, and often concurrently highlighting poor performance of typical data poor methods (Carrruthers et al. 2014, Wilberg et al. 2011).

A set of papers in Aquatic Living Resources by Apostolaki and Hillary (2009) and Pomarede et al. (2010) provide a nice series of applications on the utility of control theory methods in fisheries assessments. Hillary (2009) illustrates these methods further and provides software appropriate for evaluating a suite of harvest control rules. Pomarede et al appears to be one of the first papers to introduce the PID control theory application. PID stands for Proportional Integral Derivative Controllers (Betts 2011, also http://controlguru.com). Geromont and Butterworth (2015, also 2001) describe a general “slope parameter” that is equivalent to what is typically referred to as a P controller. The FSD model would be referred to as a P-D controller (Betts 2010).

The proposed approach (FSD) to model halibut departs from the RYM in several important ways:

1. Does not assume r and K are constants
2. Focuses on recent changes and implications for catches
3. Does not attempt to estimate long-term reference points
4. Does not utilize M, or YPR concepts to define optimal r or F rates
5. Assumes that stock can be described by linear dynamics, i.e., stock is well below K
6. Applies no estimation of parameters except for aggregate rates of change in indices.

Two parameters are required to apply the FSD model. These are defined as the gain parameters for the proportional and derivative slope components. Their final selection is not currently based on any optimization. Instead, they are based on the likely tradeoffs such parameters imply in terms of average catch, variation in average catch, the likelihood of continued population growth and the risk of overfishing.

Because the FSD model does not compute any of the standard stock status parameters, it is not possible to rigorously define stock status. However, results of the Rcrit analyses do offer some insights into stock status. The review panel for the Operational Assessment in 2015 wrote:

> "The GARMIII benchmark assessment and the 2012 update assessment concluded that the stock was overfished but overfishing was not occurring. All information available in the update assessment indicates that stock size has not substantially increased. Therefore, based on the long-term exploitation history and survey trends, the Panel concludes that the stock is still overfished. However, the overfishing status is unknown. Considering the instability of the assessment model, the overfishing threshold was not updated."

Using the results of the Rcrit analyses, it would appear that the stock size has significantly increased since 2005. The overall Rcrit value for the 2005-2016 period suggests an increase of 3 to 5 times (Table 9). In turn these rates suggest annual abundance increases or 9 to 12% per year over the past decade. Randomization tests suggest that all of the increases are statistically significant ($P<0.01$, Table 9). Catches have increased about 3 fold over this period as well.

Computation of population increases (both relative and absolute) and total catch in the Canadian 3NOPs4VWX5Zc stock reveal increases of 2.25X in catch and 2.92X in relative abundance and 2.73X in modeled absolute abundance (Table 11). Hence the changes in US stock relative abundance have mirrored those observed for the much larger Canadian stock. Such increases in US stock would be unlikely if overfishing were still occurring. Model-based estimates of fishing mortality appear to be decreasing. Taken together, the evidence suggest that recent catches have been sufficiently low to allow the stock in US waters to increase at a rate comparable to that observed in Canada.

Results of the DCAC model based on the combination of Rcrit and Envelope methods were largely inconclusive with respect to the determination of overfished status. In contrast, the proposed FSD harvest control rule appears to have some desirable properties with respect to detection of underlying trends and with respect to continuation of rebuilding program for halibut. Simulation methods suggest the model can control populations when productivity is changing temporally. Bootstrap analyses of the model forecasts suggest and 80% confidence interval of 109 to 138 mt and median of 123 mt for 2018. Note that this assumes a K_p=0.75 and K_d=0.5

Applications of the model to two other managed halibut stocks suggests potential utility for the US stock of Atlantic halibut and perhaps other stocks in the Northeast. Comparisons between the FSD model and analytical models would be a first step. Another important consideration is the estimation of the slope and change in slope. The 5-point regression might be improved by using a Kalman filter or other state-space model. In theory a MLE based smooth of the index data would be preferable to slopes estimated by an n-point regression.

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TABLES

Table1. Summary of model inputs used in the Rcrit, Envelope, DCAC and FSD models for US and Canada (3NOPs4VWX5Zc) Atlantic halibut stocks.

Stock	*Year*	*Discards (mt)*	*Landings (mt)*	*Catch (mt)*	*NEFSC fall survey (kg/tow)*	*d/k ratio for gill-net trips*	*d/k ratio for trawl trips*	*Standardized Longline CPUE*	*ME_NH inshore trawl surey SPRING*	*ME_NH inshore trawl surey FALL*
	2002	20.20	10.01	30.21	0.0041	0.0000000	0.000224	2.431442	0.0521	0.0228
	2003	20.15	16.68	36.83	0.049	0.0003620	0.000125	0.536988	0.2198	0.1736
	2004	15.71	11.22	26.93	0.1119	0.0000950	0.000166	1.22045	0.2864	0.1164
	2005	18.89	16.81	35.70	0.1105	0.0001548	0.000185	1.894313	0.2672	0.2296
	2006	22.45	14.08	36.53	0.0312	0.0002231	0.000224	1.35618	0.9165	0.1528
	2007	17.27	24.61	41.88	0.0774	0.0001075	0.000146	0.894835	0.5177	0.2805
	2008	21.66	28.69	50.35	0.0701	0.0001204	0.000174	1.150346	0.6285	0.7342
US area	2009	17.85	45.05	62.90	0.0633	0.0000560	0.000227	0.800941	0.9003	0.5314
	2010	34.68	20.20	54.88	0.098	0.0002818	0.00045	0.78386	0.6337	0.5342
	2011	42.34	25.79	68.13	0.0638	0.0005589	0.000652	1.520806	0.6401	1.1621
	2012	52.18	34.80	86.98	0.1241	0.0005674	0.000957	1.61151	0.9459	0.3106
	2013	56.16	34.67	90.83	0.0331	0.0010828	0.001103	1.60406	0.3919	0.3996
	2014	34.33	44.99	79.32	0.1821	0.0009006	0.000595	1.817722	0.4755	0.6448
	2015	46.28	62.00	108.28	0.3011	0.0020334	0.000499	1.573949	0.3535	0.2180
	2016	47.39	68.20	115.59	0.0598	0.0021923	0.000684	1.943505	0.5943	0.1160

Stock	*Year*			*Catch (mt)*	*RV Summer*	*RV Spring*	*LL CPUE*	*FS Index*
	2002			1,493	0.15	0.0183	111.61	27.67
	2003			1,600	0.14	0.0258	111.49	28.35
	2004			1,465	0.25	0.0222	86.21	37.24
	2005			1,336	0.31	0.0083	104.49	36.12
	2006			1,395	0.28	0.0099	135.28	42.33
	2007			1,562	0.47	0.0512	113.48	41.3
Canada	2008			1,494	0.37	0.0467	136.1	53.84
	2009			2,144	0.36	0.0474	164.62	67.94
	2010			1,853	0.69	0.0751	128.1	66.98
	2011			1,822	0.8	0.0740	127.96	90.25
	2012			2,220	0.6	0.0911	158.07	84.55
	2013			2,599	0.5	0.1277	129.54	93.39
	2014			2,952	0.63		174.4	90.78
	2015			3,236	0.67		232.1	151.39
	2016			4,109	0.62		186.73	120.07

Table 1.5 Discard estimates by gear type 1989-2016 for adjusted for discard mortality rates. Estimates of discard mortality are based on Pacific halibut estimates.

	Discard Estimate (mt)				Fraction by Gear			Adjusted for Discard Mortality Rate			
								0.1	0.6	0.4	
Year	Handline	Trawl	Gill net	Total	Handline	Trawl	Gill net	Handline	Trawl	Gill net	Adj Total
1989	0.00	2.88	2.10	4.97	0.000	0.578	0.422	0.00	1.73	0.84	2.56
1990	0.00	12.09	1.46	13.55	0.000	0.892	0.108	0.00	7.25	0.58	7.84
1991	0.00	6.06	0.87	6.93	0.000	0.875	0.125	0.00	3.64	0.35	3.98
1992	0.00	1.92	0.27	2.19	0.000	0.878	0.122	0.00	1.15	0.11	1.26
1993	0.00	0.63	0.44	1.06	0.000	0.590	0.410	0.00	0.38	0.17	0.55
1994	0.00	2.94	0.22	3.16	0.000	0.930	0.070	0.00	1.76	0.09	1.85
1995	0.00	6.30	0.04	6.34	0.000	0.993	0.007	0.00	3.78	0.02	3.80
1996	0.00	0.52	0.14	0.65	0.000	0.791	0.209	0.00	0.31	0.05	0.36
1997	0.00	1.64	0.00	1.64	0.000	1.000	0.000	0.00	0.98	0.00	0.98
1998	0.00	0.00	0.10	0.10	0.000	0.000	1.000	0.00	0.00	0.04	0.04
1999	0.00	68.85	0.25	69.10	0.000	0.996	0.004	0.00	41.31	0.10	41.41
2000	0.00	11.38	0.49	11.87	0.000	0.958	0.042	0.00	6.83	0.20	7.03
2001	0.00	9.29	0.40	9.68	0.000	0.959	0.041	0.00	5.57	0.16	5.73
2002	0.00	20.20	0.00	20.20	0.000	1.000	0.000	0.00	12.12	0.00	12.12
2003	0.00	15.80	4.35	20.15	0.000	0.784	0.216	0.00	9.48	1.74	11.22
2004	0.02	14.81	0.88	15.71	0.001	0.943	0.056	0.00	8.89	0.35	9.24
2005	0.70	16.90	1.29	18.89	0.037	0.895	0.068	0.07	10.14	0.52	10.73
2006	0.00	19.05	3.40	22.45	0.000	0.849	0.151	0.00	11.43	1.36	12.79
2007	0.08	14.65	2.54	17.27	0.004	0.848	0.147	0.01	8.79	1.02	9.82
2008	0.00	18.87	2.79	21.66	0.000	0.871	0.129	0.00	11.32	1.12	12.44
2009	0.00	16.93	0.92	17.85	0.000	0.949	0.051	0.00	10.16	0.37	10.53
2010	2.52	27.55	4.63	34.69	0.073	0.794	0.134	0.25	16.53	1.85	18.63
2011	0.07	33.56	8.71	42.35	0.002	0.793	0.206	0.01	20.14	3.49	23.63
2012	0.00	43.51	8.68	52.19	0.000	0.834	0.166	0.00	26.11	3.47	29.58
2013	0.20	46.27	9.70	56.18	0.004	0.824	0.173	0.02	27.76	3.88	31.66
2014	0.00	23.95	10.39	34.34	0.000	0.697	0.303	0.00	14.37	4.16	18.52
2015	0.00	22.48	23.82	46.30	0.000	0.485	0.515	0.00	13.49	9.53	23.01
2016	0.00	26.00	21.40	47.40	0.000	0.549	0.451	0.00	15.60	8.56	24.16

Table 2.

Table xx. Summary of ratio test simulations for estimation of bias in mean and median of Rcrit as a function of the magnitude of true rate of change (Rcrit_true), the variation of the observation error (CV) and the number of relative abundance indices (Nvar). All simulations were based on a time series of length 10, and the ratio of the average of the last 3 to the first 3 observations for 2000 randomizations of each of 1000 stochastic realizations.

		Relative Bias in Estimated Rcrit vs True Rcrit							
		Nvar=1		Nvar=2		Nvar=3		Nvar=5	
Rcrit_true	CV	Rel Bias (mean)	Rel Bias (median)	Rel Bias (mean)2	Rel Bias (median)3	Rel Bias (mean)4	Rel Bias (median)5	Rel Bias (mean)6	Rel Bias (median)7
2.014	0.1	0.3%	0.2%	0.1%	-0.1%	0.0%	0.1%	0.2%	0.0%
2.014	0.15	0.4%	-0.3%	0.6%	0.1%	0.0%	-0.5%	0.2%	-0.1%
2.014	0.2	0.6%	-1.4%	0.1%	-0.5%	0.4%	0.1%	0.1%	0.1%
2.014	0.25	3.1%	1.2%	1.5%	0.5%	1.2%	0.5%	0.5%	-0.1%
2.014	0.3	2.5%	-0.9%	1.0%	0.4%	1.8%	0.6%	0.7%	-0.1%
2.014	0.35	3.5%	-0.8%	2.5%	0.9%	1.1%	-0.5%	0.7%	0.0%
2.014	0.4	4.9%	-0.9%	3.3%	0.4%	1.8%	0.3%	0.8%	-0.4%
2.014	0.45	10.1%	-0.9%	2.8%	-0.5%	1.9%	0.3%	1.6%	0.5%
2.014	0.5	9.8%	-1.3%	6.1%	0.5%	3.8%	0.2%	1.9%	0.1%
2.014	0.6	-51.9%	-3.0%	6.8%	-1.6%	4.8%	0.2%	2.8%	0.1%
2.014	0.65	18.4%	-1.4%	9.0%	-0.5%	5.1%	0.2%	2.8%	-1.1%
2.014	0.7	7.8%	-5.1%	12.9%	0.7%	3.8%	0.2%	4.1%	0.8%
1.419	0.1	0.1%	-0.1%	0.3%	0.2%	0.2%	0.0%	-0.1%	0.0%
1.419	0.15	1.2%	0.5%	0.8%	0.9%	0.5%	0.5%	0.0%	-0.3%
1.419	0.2	1.5%	1.1%	1.0%	0.1%	0.1%	-0.4%	0.5%	0.2%
1.419	0.25	0.7%	-1.8%	0.5%	-0.2%	0.8%	-0.1%	1.2%	1.1%
1.419	0.3	4.3%	0.1%	2.1%	0.9%	0.6%	-0.4%	0.5%	-0.8%
1.419	0.35	4.5%	0.4%	0.4%	-1.9%	1.0%	-0.1%	0.7%	-0.1%
1.419	0.4	5.9%	1.1%	3.7%	0.7%	1.9%	0.3%	1.0%	-0.3%
1.419	0.45	9.2%	-0.4%	2.0%	-1.2%	2.4%	0.0%	1.3%	-0.1%
1.419	0.5	8.5%	1.8%	5.1%	-0.6%	3.0%	0.5%	2.2%	0.2%
1.419	0.6	24.1%	-0.4%	6.8%	-0.6%	3.2%	-0.5%	2.4%	1.1%
1.419	0.65	17.5%	-0.6%	16.9%	2.1%	4.8%	-1.0%	3.1%	0.5%
1.419	0.7	23.5%	-3.0%	12.1%	3.1%	3.5%	-2.1%	1.6%	-2.1%
1.191	0.1	0.3%	0.5%	0.1%	0.1%	0.2%	-0.1%	-0.1%	-0.2%
1.191	0.15	0.4%	0.0%	0.3%	0.1%	0.2%	0.0%	0.2%	0.0%
1.191	0.2	1.7%	0.2%	0.4%	-0.4%	0.5%	0.1%	0.2%	-0.4%
1.191	0.25	1.5%	-0.4%	1.4%	0.5%	1.3%	1.3%	0.2%	-0.4%
1.191	0.3	2.8%	-0.2%	1.5%	0.7%	0.6%	-0.7%	-0.2%	-0.7%
1.191	0.35	4.6%	1.8%	2.8%	0.9%	2.1%	1.1%	0.6%	-0.9%
1.191	0.4	5.3%	0.1%	2.7%	-0.4%	1.9%	0.5%	1.1%	0.7%
1.191	0.45	8.3%	-0.2%	3.7%	1.7%	2.5%	1.4%	0.8%	-1.1%
1.191	0.5	20.9%	3.8%	3.8%	-1.0%	2.8%	-0.6%	2.1%	0.0%
1.191	0.6	14.8%	1.1%	7.3%	1.7%	3.5%	-0.5%	2.4%	-0.1%
1.191	0.65	26.4%	1.8%	11.9%	0.9%	4.9%	-1.1%	2.3%	-0.9%
1.191	0.7	0.3%	-2.6%	9.7%	-0.6%	8.1%	3.7%	3.1%	-1.8%

Table 3.

Table xx. Summary of ratio test simulations for estimation of the average probability value for simulated Rcrit values as a functio
rate of change (Rcrit_true), the variation of the observation error (CV) and the number of relative abundance indices (N
All simulations were based on a time series of length 10, and the ratio of the average of the last 3 to the first 3 observa
for 2000 randomizations of each of 1000 stochastic realizations.

		Average Probability Value for Rcrit			
Rcrit_true	CV	Nvar=1	Nvar=2	Nvar=3	Nvar=5
2.014	0.1	0.000	0.000	0.000	0.000
2.014	0.15	0.002	0.000	0.000	0.000
2.014	0.2	0.010	0.000	0.000	0.000
2.014	0.25	0.021	0.002	0.000	0.000
2.014	0.3	0.042	0.008	0.001	0.000
2.014	0.35	0.066	0.015	0.003	0.000
2.014	0.4	0.095	0.027	0.005	0.001
2.014	0.45	0.115	0.047	0.012	0.001
2.014	0.5	0.148	0.058	0.020	0.005
2.014	0.6	0.199	0.103	0.040	0.013
2.014	0.65	0.214	0.120	0.052	0.019
2.014	0.7	0.241	0.136	0.070	0.025
1.419	0.1	0.008	0.000	0.000	0.000
1.419	0.15	0.036	0.005	0.001	0.000
1.419	0.2	0.085	0.022	0.006	0.001
1.419	0.25	0.132	0.054	0.020	0.004
1.419	0.3	0.163	0.083	0.046	0.013
1.419	0.35	0.202	0.130	0.076	0.029
1.419	0.4	0.234	0.149	0.098	0.044
1.419	0.45	0.263	0.200	0.123	0.065
1.419	0.5	0.278	0.204	0.143	0.085
1.419	0.6	0.316	0.253	0.192	0.128
1.419	0.65	0.335	0.249	0.205	0.148
1.419	0.7	0.353	0.271	0.229	0.178
1.191	0.1	0.084	0.022	0.005	0.001
1.191	0.15	0.171	0.086	0.044	0.013
1.191	0.2	0.224	0.151	0.094	0.046
1.191	0.25	0.284	0.190	0.145	0.093
1.191	0.3	0.317	0.234	0.198	0.139
1.191	0.35	0.339	0.269	0.218	0.166
1.191	0.4	0.354	0.302	0.250	0.205
1.191	0.45	0.372	0.314	0.270	0.235
1.191	0.5	0.368	0.338	0.304	0.244
1.191	0.6	0.403	0.361	0.330	0.281
1.191	0.65	0.406	0.366	0.342	0.305
1.191	0.7	0.419	0.392	0.328	0.317

Table 4. Summary of fraction of simulations with significance probabilities less than or equal to the column headers (P0.005, P0.01…) for varying levels of lambda, Rcrit and the CV of the simulated observations. Estimates in this table assume **only one** index of abundance is available. The color formatting in this table is consistent for all tables 4,5, 6, and 7.

lambda	Rcrit_true	CV	P0.005	P0.01	P0.025	P0.05	P0.1	P0.15	P0.2	P0.25
0.1	2.014	0.1	0.994	0.998	1	1	1	1	1	1
0.1	2.014	0.15	0.868	0.951	0.989	0.999	1	1	1	1
0.1	2.014	0.2	0.634	0.771	0.914	0.958	0.993	0.994	0.998	0.998
0.1	2.014	0.25	0.426	0.578	0.769	0.891	0.959	0.98	0.99	0.993
0.1	2.014	0.3	0.278	0.41	0.619	0.773	0.883	0.937	0.96	0.973
0.1	2.014	0.35	0.209	0.303	0.475	0.643	0.799	0.869	0.915	0.936
0.1	2.014	0.4	0.142	0.217	0.378	0.527	0.701	0.802	0.864	0.907
0.1	2.014	0.45	0.123	0.181	0.309	0.463	0.642	0.753	0.819	0.863
0.1	2.014	0.5	0.076	0.135	0.248	0.394	0.575	0.679	0.76	0.811
0.1	2.014	0.6	0.06	0.1	0.18	0.288	0.458	0.559	0.645	0.699
0.1	2.014	0.65	0.052	0.086	0.171	0.275	0.44	0.543	0.624	0.685
0.1	2.014	0.7	0.043	0.067	0.142	0.251	0.379	0.487	0.573	0.635
0.05	1.419	0.1	0.644	0.807	0.926	0.969	0.995	0.998	1	1
0.05	1.419	0.15	0.319	0.462	0.641	0.786	0.908	0.949	0.968	0.984
0.05	1.419	0.2	0.177	0.271	0.45	0.6	0.752	0.815	0.87	0.914
0.05	1.419	0.25	0.084	0.132	0.257	0.388	0.6	0.7	0.769	0.817
0.05	1.419	0.3	0.094	0.137	0.231	0.347	0.511	0.624	0.704	0.773
0.05	1.419	0.35	0.051	0.087	0.169	0.283	0.432	0.558	0.643	0.706
0.05	1.419	0.4	0.028	0.061	0.151	0.253	0.374	0.486	0.575	0.646
0.05	1.419	0.45	0.035	0.058	0.114	0.203	0.34	0.432	0.522	0.593
0.05	1.419	0.5	0.021	0.043	0.093	0.16	0.292	0.408	0.504	0.579
0.05	1.419	0.6	0.018	0.031	0.075	0.146	0.253	0.346	0.428	0.502
0.05	1.419	0.65	0.013	0.023	0.062	0.118	0.237	0.322	0.401	0.469
0.05	1.419	0.7	0.016	0.027	0.049	0.112	0.218	0.304	0.368	0.448
0.025	1.191	0.1	0.182	0.268	0.438	0.603	0.75	0.815	0.867	0.9
0.025	1.191	0.15	0.061	0.111	0.227	0.356	0.501	0.609	0.696	0.756
0.025	1.191	0.2	0.037	0.078	0.156	0.26	0.396	0.501	0.589	0.661
0.025	1.191	0.25	0.027	0.047	0.109	0.187	0.318	0.42	0.491	0.556
0.025	1.191	0.3	0.015	0.028	0.075	0.141	0.26	0.352	0.438	0.512
0.025	1.191	0.35	0.02	0.033	0.075	0.138	0.246	0.336	0.412	0.473
0.025	1.191	0.4	0.018	0.029	0.057	0.114	0.199	0.282	0.372	0.435
0.025	1.191	0.45	0.008	0.02	0.047	0.093	0.189	0.27	0.355	0.42
0.025	1.191	0.5	0.011	0.031	0.064	0.109	0.191	0.268	0.352	0.431
0.025	1.191	0.6	0.014	0.02	0.049	0.088	0.172	0.243	0.313	0.382
0.025	1.191	0.65	0.008	0.02	0.045	0.092	0.163	0.229	0.298	0.362
0.025	1.191	0.7	0.005	0.017	0.049	0.085	0.151	0.211	0.287	0.34

Table 5. Summary of fraction of simulations with significance probabilities less than or equal to the column headers (P0.005, P0.01…) for varying levels of lambda, Rcrit and the CV of the simulated observations. Estimates in this table assume **two** indices of abundance are available. The color formatting in this table is consistent for all tables 4,5, 6, and 7.

lambda	Rcrit_true	CV	P0.005	P0.01	P0.025	P0.05	P0.1	P0.15	P0.2	P0.25
0.1	2.014	0.1	1	1	1		1	1	1	1
0.1	2.014	0.15	1	1	1		1	1	1	1
0.1	2.014	0.2	0.989	0.995	1		1	1	1	1
0.1	2.014	0.25	0.906	0.951	0.988		0.999	0.999	0.999	1
0.1	2.014	0.3	0.755	0.839	0.918		0.981	0.992	0.996	0.999
0.1	2.014	0.35	0.604	0.725	0.855		0.972	0.982	0.991	0.994
0.1	2.014	0.4	0.461	0.59	0.761		0.931	0.961	0.97	0.982
0.1	2.014	0.45	0.324	0.454	0.63		0.861	0.911	0.943	0.963
0.1	2.014	0.5	0.247	0.356	0.547		0.828	0.888	0.928	0.954
0.1	2.014	0.6	0.141	0.213	0.373		0.701	0.801	0.844	0.876
0.1	2.014	0.65	0.119	0.206	0.346		0.652	0.733	0.801	0.839
0.1	2.014	0.7	0.102	0.159	0.279		0.613	0.703	0.769	0.815
0.05	1.419	0.1	0.991	0.998	1		1	1	1	1
0.05	1.419	0.15	0.819	0.88	0.948		0.991	1	1	1
0.05	1.419	0.2	0.512	0.639	0.791		0.947	0.972	0.981	0.99
0.05	1.419	0.25	0.302	0.419	0.61		0.842	0.896	0.921	0.938
0.05	1.419	0.3	0.208	0.295	0.466		0.751	0.815	0.874	0.914
0.05	1.419	0.35	0.126	0.179	0.315		0.641	0.723	0.787	0.829
0.05	1.419	0.4	0.11	0.165	0.269		0.562	0.673	0.74	0.798
0.05	1.419	0.45	0.07	0.108	0.21		0.486	0.573	0.636	0.696
0.05	1.419	0.5	0.057	0.101	0.175		0.437	0.544	0.63	0.7
0.05	1.419	0.6	0.039	0.06	0.132		0.36	0.468	0.542	0.617
0.05	1.419	0.65	0.031	0.059	0.118		0.356	0.457	0.544	0.615
0.05	1.419	0.7	0.034	0.062	0.119		0.343	0.434	0.513	0.588
0.025	1.191	0.1	0.513	0.621	0.787		0.945	0.97	0.987	0.993
0.025	1.191	0.15	0.208	0.295	0.476		0.748	0.818	0.867	0.899
0.025	1.191	0.2	0.103	0.162	0.289		0.559	0.658	0.722	0.777
0.025	1.191	0.25	0.053	0.109	0.197		0.479	0.586	0.672	0.728
0.025	1.191	0.3	0.035	0.057	0.15		0.372	0.477	0.576	0.648
0.025	1.191	0.35	0.031	0.054	0.128		0.351	0.447	0.515	0.582
0.025	1.191	0.4	0.039	0.059	0.109		0.264	0.369	0.442	0.514
0.025	1.191	0.45	0.023	0.037	0.079		0.265	0.362	0.445	0.511
0.025	1.191	0.5	0.019	0.037	0.076		0.226	0.317	0.394	0.453
0.025	1.191	0.6	0.015	0.038	0.068		0.212	0.314	0.391	0.452
0.025	1.191	0.65	0.011	0.018	0.051		0.197	0.272	0.344	0.415
0.025	1.191	0.7	0.009	0.018	0.047		0.17	0.259	0.331	0.397

Table 6. Summary of fraction of simulations with significance probabilities less than or equal to the column headers (P0.005, P0.01…) for varying levels of lambda, Rcrit and the CV of the simulated observations. Estimates in this table assume **three** indices of abundance are available. The color formatting in this table is consistent for all tables 4,5, 6, and 7.

lambda	Rcrit_true	CV	P0.005	P0.01	P0.025	P0.05	P0.1	P0.15	P0.2	P0.25
0.1	2.014	0.1	1	1	1	1	1	1	1	1
0.1	2.014	0.15	1	1	1	1	1	1	1	1
0.1	2.014	0.2	1	1	1	1	1	1	1	1
0.1	2.014	0.25	0.996	0.999	1	1	1	1	1	1
0.1	2.014	0.3	0.972	0.984	0.996	0.998	1	1	1	1
0.1	2.014	0.35	0.891	0.927	0.972	0.996	0.999	0.999	0.999	0.999
0.1	2.014	0.4	0.807	0.884	0.945	0.977	0.996	0.998	0.999	1
0.1	2.014	0.45	0.691	0.783	0.884	0.932	0.967	0.985	0.992	0.998
0.1	2.014	0.5	0.596	0.695	0.828	0.901	0.95	0.971	0.983	0.987
0.1	2.014	0.6	0.408	0.522	0.675	0.794	0.882	0.928	0.954	0.969
0.1	2.014	0.65	0.371	0.479	0.642	0.751	0.846	0.892	0.917	0.946
0.1	2.014	0.7	0.292	0.387	0.557	0.674	0.799	0.849	0.887	0.914
0.05	1.419	0.1	1	1	1	1	1	1	1	1
0.05	1.419	0.15	0.971	0.987	0.994	0.999	1	1	1	1
0.05	1.419	0.2	0.771	0.856	0.929	0.972	0.993	0.998	0.999	1
0.05	1.419	0.25	0.566	0.666	0.811	0.897	0.953	0.975	0.984	0.99
0.05	1.419	0.3	0.383	0.487	0.634	0.756	0.862	0.913	0.942	0.964
0.05	1.419	0.35	0.268	0.367	0.527	0.648	0.764	0.835	0.882	0.918
0.05	1.419	0.4	0.221	0.31	0.455	0.572	0.696	0.787	0.843	0.881
0.05	1.419	0.45	0.155	0.233	0.364	0.5	0.637	0.721	0.778	0.83
0.05	1.419	0.5	0.118	0.184	0.321	0.458	0.576	0.673	0.744	0.792
0.05	1.419	0.6	0.071	0.126	0.223	0.332	0.467	0.563	0.648	0.703
0.05	1.419	0.65	0.071	0.121	0.216	0.309	0.435	0.544	0.625	0.699
0.05	1.419	0.7	0.055	0.092	0.157	0.268	0.389	0.489	0.584	0.651
0.025	1.191	0.1	0.796	0.885	0.951	0.98	0.992	0.997	0.998	1
0.025	1.191	0.15	0.354	0.485	0.645	0.784	0.875	0.921	0.948	0.961
0.025	1.191	0.2	0.19	0.279	0.433	0.568	0.718	0.798	0.853	0.881
0.025	1.191	0.25	0.119	0.192	0.327	0.442	0.589	0.684	0.757	0.816
0.025	1.191	0.3	0.083	0.121	0.211	0.319	0.457	0.564	0.641	0.701
0.025	1.191	0.35	0.059	0.098	0.195	0.293	0.451	0.54	0.61	0.665
0.025	1.191	0.4	0.039	0.065	0.139	0.224	0.358	0.465	0.544	0.605
0.025	1.191	0.45	0.036	0.058	0.118	0.202	0.339	0.441	0.524	0.59
0.025	1.191	0.5	0.035	0.063	0.118	0.182	0.288	0.389	0.463	0.517
0.025	1.191	0.6	0.022	0.038	0.076	0.141	0.242	0.328	0.413	0.483
0.025	1.191	0.65	0.031	0.041	0.083	0.142	0.243	0.322	0.391	0.446
0.025	1.191	0.7	0.029	0.045	0.084	0.166	0.266	0.342	0.41	0.482

Table 7. Summary of fraction of simulations with significance probabilities less than or equal to the column headers (P0.005, P0.01…) for varying levels of lambda, Rcrit and the CV of the simulated observations. Estimates in this table assume **five** indices of abundance are available. The color formatting in this table is consistent for all tables 4,5, 6, and 7.

lambda	Rcrit_true	CV	P0.005	P0.01	P0.025	P0.05	P0.1	P0.15	P0.2	P0.25
0.1	2.014	0.1	1	1	1	1	1	1	1	1
0.1	2.014	0.15	1	1	1	1	1	1	1	1
0.1	2.014	0.2	1	1	1	1	1	1	1	1
0.1	2.014	0.25	1	1	1	1	1	1	1	1
0.1	2.014	0.3	1	1	1	1	1	1	1	1
0.1	2.014	0.35	0.996	0.998	1	1	1	1	1	1
0.1	2.014	0.4	0.981	0.991	0.996	0.999	0.999	1	1	1
0.1	2.014	0.45	0.93	0.968	0.986	0.996	1	1	1	1
0.1	2.014	0.5	0.849	0.912	0.956	0.977	0.993	0.998	0.998	0.999
0.1	2.014	0.6	0.709	0.81	0.889	0.934	0.962	0.983	0.991	0.994
0.1	2.014	0.65	0.598	0.697	0.821	0.9	0.956	0.973	0.984	0.989
0.1	2.014	0.7	0.541	0.657	0.797	0.863	0.922	0.958	0.974	0.987
0.05	1.419	0.1	1	1	1	1	1	1	1	1
0.05	1.419	0.15	1	1	1	1	1	1	1	1
0.05	1.419	0.2	0.973	0.992	0.999	0.999	1	1	1	1
0.05	1.419	0.25	0.869	0.921	0.965	0.982	0.994	0.998	0.999	1
0.05	1.419	0.3	0.647	0.747	0.856	0.931	0.976	0.986	0.993	0.997
0.05	1.419	0.35	0.53	0.627	0.761	0.85	0.929	0.953	0.971	0.977
0.05	1.419	0.4	0.382	0.497	0.647	0.765	0.862	0.912	0.943	0.967
0.05	1.419	0.45	0.3	0.413	0.554	0.674	0.819	0.863	0.898	0.927
0.05	1.419	0.5	0.247	0.321	0.473	0.599	0.749	0.818	0.87	0.899
0.05	1.419	0.6	0.151	0.221	0.356	0.496	0.64	0.722	0.775	0.824
0.05	1.419	0.65	0.132	0.199	0.322	0.447	0.591	0.674	0.738	0.782
0.05	1.419	0.7	0.101	0.159	0.262	0.354	0.51	0.599	0.682	0.741
0.025	1.191	0.1	0.964	0.981	0.995	1	1	1	1	1
0.025	1.191	0.15	0.664	0.767	0.869	0.938	0.971	0.988	0.994	0.997
0.025	1.191	0.2	0.381	0.482	0.632	0.745	0.855	0.909	0.936	0.961
0.025	1.191	0.25	0.22	0.308	0.452	0.579	0.719	0.801	0.857	0.893
0.025	1.191	0.3	0.121	0.18	0.314	0.453	0.608	0.699	0.766	0.809
0.025	1.191	0.35	0.103	0.161	0.253	0.363	0.498	0.619	0.693	0.749
0.025	1.191	0.4	0.079	0.14	0.236	0.334	0.481	0.572	0.638	0.692
0.025	1.191	0.45	0.061	0.098	0.18	0.268	0.396	0.498	0.566	0.629
0.025	1.191	0.5	0.055	0.085	0.164	0.263	0.385	0.468	0.551	0.617
0.025	1.191	0.6	0.031	0.056	0.126	0.194	0.323	0.416	0.489	0.554
0.025	1.191	0.65	0.036	0.054	0.119	0.197	0.295	0.379	0.45	0.529
0.025	1.191	0.7	0.035	0.068	0.115	0.181	0.281	0.356	0.423	0.484

Table 8. Summary of Rcrit and Probability values for all possible models based on six candidate indices of relative abundance. Simulations are based US data from 2002-2016. 50,000 replicates were used for each model.

50000 replicates

ratio 2014/2016 to 2002-2004

USA Data (2002-2016)

Model #	Nvars	Combinati	Rcrit	Pvalue	Var 1	Var 2	Var 3	Var 4	Var 5	Var 6
1	6	1	3.231	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB
2	5	1	3.216	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	
3	5	2	2.436	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	FallSurvB	
4	5	3	3.196	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_gillnet	FallSurvB	
5	5	4	4.254	0.0000	ME_sprB	ME_falB	DK_trawl	DK_gillnet	FallSurvB	
6	5	5	3.242	0.0000	ME_sprB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB	
7	5	6	3.327	0.0000	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB	
8	4	1	2.184	0.0011	ME_sprB	ME_falB	LLcpueStd	DK_trawl		
9	4	2	3.166	0.0001	ME_sprB	ME_falB	LLcpueStd	DK_gillnet		
10	4	3	2.253	0.0006	ME_sprB	ME_falB	LLcpueStd	FallSurvB		
11	4	4	4.698	0.0000	ME_sprB	ME_falB	DK_trawl	DK_gillnet		
12	4	5	3.140	0.0000	ME_sprB	ME_falB	DK_trawl	FallSurvB		
13	4	6	4.471	0.0000	ME_sprB	ME_falB	DK_gillnet	FallSurvB		
14	4	7	3.228	0.0000	ME_sprB	LLcpueStd	DK_trawl	DK_gillnet		
15	4	8	2.354	0.0003	ME_sprB	LLcpueStd	DK_trawl	FallSurvB		
16	4	9	3.205	0.0000	ME_sprB	LLcpueStd	DK_gillnet	FallSurvB		
17	4	10	4.447	0.0000	ME_sprB	DK_trawl	DK_gillnet	FallSurvB		
18	4	11	3.339	0.0001	ME_falB	LLcpueStd	DK_trawl	DK_gillnet		
19	4	12	2.418	0.0007	ME_falB	LLcpueStd	DK_trawl	FallSurvB		
20	4	13	3.305	0.0001	ME_falB	LLcpueStd	DK_gillnet	FallSurvB		
21	4	14	4.649	0.0000	ME_falB	DK_trawl	DK_gillnet	FallSurvB		
22	4	15	3.352	0.0001	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB		
23	3	1	1.871	0.0122	ME_sprB	ME_falB	LLcpueStd			
24	3	2	3.053	0.0003	ME_sprB	ME_falB	DK_trawl			
25	3	3	5.259	0.0000	ME_sprB	ME_falB	DK_gillnet			
26	3	4	3.040	0.0002	ME_sprB	ME_falB	FallSurvB			
27	3	5	2.033	0.0037	ME_sprB	LLcpueStd	DK_trawl			
28	3	6	3.173	0.0004	ME_sprB	LLcpueStd	DK_gillnet			
29	3	7	2.128	0.0024	ME_sprB	LLcpueStd	FallSurvB			
30	3	8	5.125	0.0000	ME_sprB	DK_trawl	DK_gillnet			
31	3	9	3.142	0.0001	ME_sprB	DK_trawl	FallSurvB			
32	3	10	4.778	0.0000	ME_sprB	DK_gillnet	FallSurvB			
33	3	11	2.106	0.0091	ME_falB	LLcpueStd	DK_trawl			
34	3	12	3.310	0.0009	ME_falB	LLcpueStd	DK_gillnet			
35	3	13	2.196	0.0051	ME_falB	LLcpueStd	FallSurvB			
36	3	14	5.511	0.0000	ME_falB	DK_trawl	DK_gillnet			
37	3	15	3.305	0.0004	ME_falB	DK_trawl	FallSurvB			
38	3	16	5.074	0.0000	ME_falB	DK_gillnet	FallSurvB			
39	3	17	3.374	0.0003	LLcpueStd	DK_trawl	DK_gillnet			
40	3	18	2.319	0.0025	LLcpueStd	DK_trawl	FallSurvB			
41	3	19	3.331	0.0005	LLcpueStd	DK_gillnet	FallSurvB			
42	3	20	4.984	0.0000	DK_trawl	DK_gillnet	FallSurvB			
43	2	1	2.803	0.0042	ME_sprB	ME_falB				
44	2	2	1.611	0.0353	ME_sprB	LLcpueStd				
45	2	3	3.025	0.0014	ME_sprB	DK_trawl				
46	2	4	6.216	0.0000	ME_sprB	DK_gillnet				
47	2	5	3.014	0.0016	ME_sprB	FallSurvB				
48	2	6	1.680	0.0792	ME_falB	LLcpueStd				
49	2	7	3.317	0.0041	ME_falB	DK_trawl				
50	2	8	7.050	0.0003	ME_falB	DK_gillnet				
51	2	9	3.240	0.0045	ME_falB	FallSurvB				
52	2	10	1.901	0.0276	LLcpueStd	DK_trawl				
53	2	11	3.351	0.0046	LLcpueStd	DK_gillnet				
54	2	12	2.033	0.0180	LLcpueStd	FallSurvB				
55	2	13	6.509	0.0003	DK_trawl	DK_gillnet				
56	2	14	3.354	0.0028	DK_trawl	FallSurvB				
57	2	15	5.703	0.0009	DK_gillnet	FallSurvB				
58	1	1	2.550	0.0205	ME_sprB					
59	1	2	3.129	0.0520	ME_falB					
60	1	3	1.274	0.2200	LLcpueStd					
61	1	4	3.447	0.0256	DK_trawl					
62	1	5	11.217	0.0131	DK_gillnet					
63	1	6	3.291	0.0267	FallSurvB					

Average Rcrit value overall models=

3.522825

fraction of models with significance probability <0.05

0.952381

Table 9. Summary of Rcrit and Probability values for all possible models based on six candidate indices of relative abundance. Simulations are based US data from 2005-2016. 50,000 replicates were used for each model.

Ratio 2014-2016: 2005-2007

US data 2005-2016 50000 reps

Model #	Nvars	Combinati	Rcrit	Pvalue	Var 1	Var 2	Var 3	Var 4	Var 5	Var 6
1	6	1	2.202	0.0002	ME_sprB	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB
2	5	1	2.136	0.0004	ME_sprB	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	
3	5	2	1.644	0.0082	ME_sprB	ME_falB	LLcpueStd	DK_trawl	FallSurvB	
4	5	3	2.090	0.0008	ME_sprB	ME_falB	LLcpueStd	DK_gillnet	FallSurvB	
5	5	4	2.526	0.0001	ME_sprB	ME_falB	DK_trawl	DK_gillnet	FallSurvB	
6	5	5	2.314	0.0002	ME_sprB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB	
7	5	6	2.658	0.0000	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB	
8	4	1	1.428	0.0494	ME_sprB	ME_falB	LLcpueStd	DK_trawl		
9	4	2	1.985	0.0045	ME_sprB	ME_falB	LLcpueStd	DK_gillnet		
10	4	3	1.457	0.0498	ME_sprB	ME_falB	LLcpueStd	FallSurvB		
11	4	4	2.542	0.0006	ME_sprB	ME_falB	DK_trawl	DK_gillnet		
12	4	5	1.782	0.0115	ME_sprB	ME_falB	DK_trawl	FallSurvB		
13	4	6	2.419	0.0013	ME_sprB	ME_falB	DK_gillnet	FallSurvB		
14	4	7	2.267	0.0008	ME_sprB	LLcpueStd	DK_trawl	DK_gillnet		
15	4	8	1.672	0.0098	ME_sprB	LLcpueStd	DK_trawl	FallSurvB		
16	4	9	2.197	0.0012	ME_sprB	LLcpueStd	DK_gillnet	FallSurvB		
17	4	10	2.756	0.0002	ME_sprB	DK_trawl	DK_gillnet	FallSurvB		
18	4	11	2.720	0.0001	ME_falB	LLcpueStd	DK_trawl	DK_gillnet		
19	4	12	1.938	0.0036	ME_falB	LLcpueStd	DK_trawl	FallSurvB		
20	4	13	2.573	0.0004	ME_falB	LLcpueStd	DK_gillnet	FallSurvB		
21	4	14	3.390	0.0001	ME_falB	DK_trawl	DK_gillnet	FallSurvB		
22	4	15	2.913	0.0001	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB		
23	3	1	1.151	0.2737	ME_sprB	ME_falB	LLcpueStd			
24	3	2	1.505	0.0704	ME_sprB	ME_falB	DK_trawl			
25	3	3	2.393	0.0060	ME_sprB	ME_falB	DK_gillnet			
26	3	4	1.534	0.0719	ME_sprB	ME_falB	FallSurvB			
27	3	5	1.418	0.0568	ME_sprB	LLcpueStd	DK_trawl			
28	3	6	2.103	0.0056	ME_sprB	LLcpueStd	DK_gillnet			
29	3	7	1.453	0.0559	ME_sprB	LLcpueStd	FallSurvB			
30	3	8	2.886	0.0008	ME_sprB	DK_trawl	DK_gillnet			
31	3	9	1.857	0.0129	ME_sprB	DK_trawl	FallSurvB			
32	3	10	2.667	0.0019	ME_sprB	DK_gillnet	FallSurvB			
33	3	11	1.727	0.0203	ME_falB	LLcpueStd	DK_trawl			
34	3	12	2.613	0.0017	ME_falB	LLcpueStd	DK_gillnet			
35	3	13	1.721	0.0264	ME_falB	LLcpueStd	FallSurvB			
36	3	14	3.982	0.0001	ME_falB	DK_trawl	DK_gillnet			
37	3	15	2.337	0.0042	ME_falB	DK_trawl	FallSurvB			
38	3	16	3.437	0.0006	ME_falB	DK_gillnet	FallSurvB			
39	3	17	3.110	0.0002	LLcpueStd	DK_trawl	DK_gillnet			
40	3	18	2.049	0.0041	LLcpueStd	DK_trawl	FallSurvB			
41	3	19	2.856	0.0005	LLcpueStd	DK_gillnet	FallSurvB			
42	3	20	4.106	0.0000	DK_trawl	DK_gillnet	FallSurvB			
43	2	1	1.059	0.4341	ME_sprB	ME_falB				
44	2	2	1.067	0.3697	ME_sprB	LLcpueStd				
45	2	3	1.515	0.0945	ME_sprB	DK_trawl				
46	2	4	2.784	0.0097	ME_sprB	DK_gillnet				
47	2	5	1.551	0.1020	ME_sprB	FallSurvB				
48	2	6	1.351	0.1722	ME_falB	LLcpueStd				
49	2	7	2.220	0.0219	ME_falB	DK_trawl				
50	2	8	4.381	0.0015	ME_falB	DK_gillnet				
51	2	9	2.069	0.0399	ME_falB	FallSurvB				
52	2	10	1.820	0.0204	LLcpueStd	DK_trawl				
53	2	11	3.080	0.0023	LLcpueStd	DK_gillnet				
54	2	12	1.793	0.0306	LLcpueStd	FallSurvB				
55	2	13	6.028	0.0002	DK_trawl	DK_gillnet				
56	2	14	2.727	0.0057	DK_trawl	FallSurvB				
57	2	15	4.461	0.0016	DK_gillnet	FallSurvB				
58	1	1	0.837	0.7097	ME_sprB					
59	1	2	1.477	0.2675	ME_falB					
60	1	3	1.287	0.1577	LLcpueStd					
61	1	4	3.205	0.0215	DK_trawl					
62	1	5	10.559	0.0065	DK_gillnet					
63	1	6	2.478	0.0629	FallSurvB					

[1] Average Rcrit value overall models=
[1] 2.448565
[1] fraction of models with significance probability <0.05
[1] 0.777778

Table 10. Summary of Rcrit and probability values for all possible models based on six candidate indices of relative abundance. Simulations are based US data from 2002-2013. 50,000 replicates were used for each model. The reduced number of years was used to allow comparison with results from Canada.

50000 replicates
ratio 2011/2013 to 2002-2004
USA Data (2002-2013)

Model #	Nvars	Combinati	Rcrit	Pvalue	Var 1	Var 2	Var 3	Var 4	Var 5	Var 6
1	6	1	2.893	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB
2	5	1	3.360	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	
3	5	2	2.556	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl	FallSurvB	
4	5	3	2.539	0.0001	ME_sprB	ME_falB	LLcpueStd	DK_gillnet	FallSurvB	
5	5	4	3.686	0.0000	ME_sprB	ME_falB	DK_trawl	DK_gillnet	FallSurvB	
6	5	5	2.629	0.0001	ME_sprB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB	
7	5	6	2.820	0.0001	ME_falB	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB	
8	4	1	3.008	0.0000	ME_sprB	ME_falB	LLcpueStd	DK_trawl		
9	4	2	2.973	0.0001	ME_sprB	ME_falB	LLcpueStd	DK_gillnet		
10	4	3	2.068	0.0011	ME_sprB	ME_falB	LLcpueStd	FallSurvB		
11	4	4	4.865	0.0000	ME_sprB	ME_falB	DK_trawl	DK_gillnet		
12	4	5	3.372	0.0000	ME_sprB	ME_falB	DK_trawl	FallSurvB		
13	4	6	3.320	0.0000	ME_sprB	ME_falB	DK_gillnet	FallSurvB		
14	4	7	3.060	0.0000	ME_sprB	LLcpueStd	DK_trawl	DK_gillnet		
15	4	8	2.207	0.0006	ME_sprB	LLcpueStd	DK_trawl	FallSurvB		
16	4	9	2.196	0.0017	ME_sprB	LLcpueStd	DK_gillnet	FallSurvB		
17	4	10	3.389	0.0000	ME_sprB	DK_trawl	DK_gillnet	FallSurvB		
18	4	11	3.332	0.0001	ME_falB	LLcpueStd	DK_trawl	DK_gillnet		
19	4	12	2.422	0.0007	ME_falB	LLcpueStd	DK_trawl	FallSurvB		
20	4	13	2.406	0.0014	ME_falB	LLcpueStd	DK_gillnet	FallSurvB		
21	4	14	3.710	0.0000	ME_falB	DK_trawl	DK_gillnet	FallSurvB		
22	4	15	2.515	0.0007	LLcpueStd	DK_trawl	DK_gillnet	FallSurvB		
23	3	1	2.411	0.0006	ME_sprB	ME_falB	LLcpueStd			
24	3	2	4.880	0.0000	ME_sprB	ME_falB	DK_trawl			
25	3	3	4.709	0.0000	ME_sprB	ME_falB	DK_gillnet			
26	3	4	2.775	0.0003	ME_sprB	ME_falB	FallSurvB			
27	3	5	2.576	0.0006	ME_sprB	LLcpueStd	DK_trawl			
28	3	6	2.549	0.0017	ME_sprB	LLcpueStd	DK_gillnet			
29	3	7	1.589	0.0278	ME_sprB	LLcpueStd	FallSurvB			
30	3	8	4.633	0.0000	ME_sprB	DK_trawl	DK_gillnet			
31	3	9	2.927	0.0003	ME_sprB	DK_trawl	FallSurvB			
32	3	10	2.883	0.0011	ME_sprB	DK_gillnet	FallSurvB			
33	3	11	2.903	0.0004	ME_falB	LLcpueStd	DK_trawl			
34	3	12	2.864	0.0016	ME_falB	LLcpueStd	DK_gillnet			
35	3	13	1.825	0.0180	ME_falB	LLcpueStd	FallSurvB			
36	3	14	5.243	0.0000	ME_falB	DK_trawl	DK_gillnet			
37	3	15	3.332	0.0002	ME_falB	DK_trawl	FallSurvB			
38	3	16	3.270	0.0012	ME_falB	DK_gillnet	FallSurvB			
39	3	17	2.976	0.0011	LLcpueStd	DK_trawl	DK_gillnet			
40	3	18	2.003	0.0086	LLcpueStd	DK_trawl	FallSurvB			
41	3	19	1.997	0.0170	LLcpueStd	DK_gillnet	FallSurvB			
42	3	20	3.359	0.0007	DK_trawl	DK_gillnet	FallSurvB			
43	2	1	4.607	0.0001	ME_sprB	ME_falB				
44	2	2	1.728	0.0306	ME_sprB	LLcpueStd				
45	2	3	4.505	0.0000	ME_sprB	DK_trawl				
46	2	4	4.307	0.0009	ME_sprB	DK_gillnet				
47	2	5	2.015	0.0176	ME_sprB	FallSurvB				
48	2	6	2.114	0.0194	ME_falB	LLcpueStd				
49	2	7	5.533	0.0000	ME_falB	DK_trawl				
50	2	8	5.234	0.0008	ME_falB	DK_gillnet				
51	2	9	2.521	0.0108	ME_falB	FallSurvB				
52	2	10	2.352	0.0107	LLcpueStd	DK_trawl				
53	2	11	2.328	0.0253	LLcpueStd	DK_gillnet				
54	2	12	1.220	0.2429	LLcpueStd	FallSurvB				
55	2	13	5.033	0.0011	DK_trawl	DK_gillnet				
56	2	14	2.753	0.0068	DK_trawl	FallSurvB				
57	2	15	2.706	0.0173	DK_gillnet	FallSurvB				
58	1	1	3.543	0.0070	ME_sprB					
59	1	2	5.986	0.0031	ME_falB					
60	1	3	1.131	0.3690	LLcpueStd					
61	1	4	5.259	0.0009	DK_trawl					
62	1	5	4.834	0.0411	DK_gillnet					
63	1	6	1.339	0.2620	FallSurvB					

[1] Average Rcrit value overall models=
[1] 3.144086
[1] fraction of models with significance probability <0.05
[1] 0.952381

Table 11. Summary of Rcrit and Probability values for all possible models based on three indices of relative abundance and the assessment based estimate of absolute abundance in the Canadian 3NOPs4VWX5Zc assessment. Simulations are based Canadian data from 2002-2013. 50,000 replicates were used for each model. The shaded boxes indicate models that include the modeled biomass estimates from the DFO assessment. Results can be compared with Table 10 for US indices.

Canadian Data

Model #	Nvars	ombinatio	Rcrit	Pvalue	Var 1	Var 2	Var 3	Var 4
1	4	1	2.719	0.00000	Can.RV.Summer	Can.CRV.Spr	Can.CPUE	Can.SSB.Mod
2	3	1	2.703	0.00000	Can.RV.Summer	Can.CRV.Spr	Can.CPUE	
3	3	2	3.476	0.00000	Can.RV.Summer	Can.CRV.Spr	Can.SSB.Mod	
4	3	3	2.317	0.00000	Can.RV.Summer	Can.CPUE	Can.SSB.Mod	
5	3	4	2.532	0.00000	Can.CRV.Spr	Can.CPUE	Can.SSB.Mod	
6	2	1	3.967	0.00002	Can.RV.Summer	Can.CRV.Spr		
7	2	2	2.101	0.00004	Can.RV.Summer	Can.CPUE		
8	2	3	3.079	0.00000	Can.RV.Summer	Can.SSB.Mod		
9	2	4	2.420	0.00040	Can.CRV.Spr	Can.CPUE		
10	2	5	3.458	0.00004	Can.CRV.Spr	Can.SSB.Mod		
11	2	6	1.948	0.00000	Can.CPUE	Can.SSB.Mod		
12	1	1	3.519	0.00026	Can.RV.Summer			
13	1	2	4.410	0.01296	Can.CRV.Spr			
14	1	3	1.344	0.01606	Can.CPUE			
15	1	4	2.763	0.00000	Can.SSB.Mod			

[1] Average Rcrit value overall models=
[1] 2.850295
[1] fraction of models with significance probability <0.05
[1] 1

Rcrit average for models that do NOT include Can.SSB.Mod
2.923448

Table 12. Derived estimates for the K parameter and 2016 biomass using the Envelope method for various ranges of catch data and smoothed vs raw NEFSC fall bottom trawl indices.

			Biomass Estimates				*Estimated B(2016)/K*		
Survey Type	***Basis for Estimating Max Biomass***	***Max Catch***	***max B(C,F)***	***min B(C,F)***	***Mid Range B(C,F)***	***Mid Range Biomass 2016***	***max B(C,F)***	***min B(C,F)***	***Mid Range B(C,F)***
Kalman	Max catch 1893-2016	4,908	266,850	15,952	141,401	3,363.2	0.013	0.211	0.024
Kalman	Max Catch since 1900	944	51,326	3,068	27,197	3,363.2	0.066	1.096	0.124
Kalman	Constrained range of B(1963-2016)		6,531	1,671	3,425	3,363.2	0.515	2.013	0.982
Raw	Max catch 1893-2016	4,908	266,850	15,952	141,401	3,407.4	0.013	0.214	0.024
Raw	Max Catch since 1900	944	51,326	3,068	27,197	3,407.4	0.066	1.111	0.125
Raw	Constrained range of B(1963-2016)	514	14,680	1,671	7,779	3,407.4	0.232	2.040	0.438

Table 13.

Table hh. A. Summary of maximum fractional change in population abundance given alternative ranges of proportial stock increase for varying base period year ranges.
B. Derived Depletion corrected average catches of sustainable harvest alternative levels of rebuilding in 2016 and proportional increase in relative abundance.
Levels of rebuilding are based on envelope method. Natural mortality is assumed = 0.15

A

	Changes in catches		Change in indices			*Maximum Fractional Change (DELTA) in DCAC for varying assumed values of B(t)/K*				
						Assume 98.2% rebuilt in 2016	*Assume 43.8% rebuilt in 2016*	*Assume 12.5% rebuilt in 2016*	*Assume 2.4% rebuilt in 2016*	
Ratio Definition	***Statistics***	***Value***	***Statistic***	***Value***	***Model***	***0.982***	***0.438***	***0.125***	***0.024***	***Total Catch***
'02-04:'14-16	Rcrit(Catch)	3.227	Rcrit(Indices)	3.23	(all six indices)	-0.67798	-0.30240	-0.08630	-0.01657	925.3
				4.98	(DK_g, DK_t, Survey)	-0.78481	-0.35005	-0.09990	-0.01918	
				3.52	average over 120models	-0.70302	-0.31357	-0.08949	-0.01718	
'05-07:'14-16	Rcrit(Catch)	2.657	Rcrit(Indices)	2.44	average over 120models	-0.57954	-0.25849	-0.07377	-0.01416	831.4
				4.11	DK_g,DK_t, Survey	-0.74307	-0.33143	-0.09459	-0.01816	
				2.2	(all six indices)	-0.53564	-0.23891	-0.06818	-0.01309	
'02-04:'11-13	Rcrit(Catch)	2.617	Rcrit(indices)	2.893	(all six indices)	-0.64256	-0.28660	-0.08179	-0.01570	622.1
				5.033	(DK_g, DK_t, Survey)	-0.78689	-0.35097	-0.10016	-0.01923	
				3.144	average over 120models	-0.66966	-0.29869	-0.08524	-0.01637	

B

			Derived Delta for Assumed Alpha				Derived Sustainable Average Catch for Assumed Alpha					Y Current --given assumed level of rebuilding			
Nyears	**Time Period**	**Total Catch**	**0.982**	**0.438**	**0.125**	**0.024**	**0.982**	**0.438**	**0.125**	**0.024**	**Obs Ave Catch**	**0.982**	**0.438**	**0.125**	**0.024**
15	2002-2016	925.3	-0.678	-0.302	-0.086	-0.017	-121.8	188.1	76.3	64.0	61.7	-119.6	82.4	9.5	1.5
15		925.3	-0.785	-0.350	-0.100	-0.019	-82.9	277.7	79.3	64.4		-81.4	121.6	9.9	1.5
15		925.3	-0.703	-0.314	-0.089	-0.017	-109.7	203.5	77.0	64.1		-107.7	89.1	9.6	1.5
12	2005-2016	831.4	-0.580	-0.258	-0.074	-0.014	-113.6	245.7	87.1	72.1	69.3	-111.6	107.6	10.9	1.7
12		831.4	-0.743	-0.331	-0.095	-0.018	-65.1	873.0	94.0	73.0		-63.9	382.4	11.7	1.8
12		831.4	-0.536	-0.239	-0.068	-0.013	-142.0	206.0	85.5	71.9		-139.4	90.2	10.7	1.7
12	2002-2013	622.1	-0.643	-0.287	-0.082	-0.016	-66.1	254.3	67.1	54.2	51.8	-64.9	111.4	8.4	1.3
12		622.1	-0.787	-0.351	-0.100	-0.019	-43.7	2067.9	71.8	54.8		-42.9	905.7	9.0	1.3
12		622.1	-0.670	-0.299	-0.085	-0.016	-60.3	304.4	67.9	54.3		-59.2	133.3	8.5	1.3

Table 14.

Table xx Summary of relevant population outputs for varying combinations of Kp and Kd gain parameters by assumed CV level for observation error. The low CV (0.005) assumes almost no observation error in the abundance indices. Effects are averaged over all combinations of r(t) scenarios and harvest scenarios (h(t)) prior to implementation of the control rule.
Simulation failures occur when the population size goes to zero because harvest rates are too high.

Average % of overfishing events					
CV	***Kd***	***Kp=0.25***	***Kp=0.5***	***Kp=0.75***	***Kp=1***
0.005	0	0.171	0.201	0.229	0.282
	1	0.197	0.228	0.249	0.314
	5	0.244	0.254	0.269	0.280
	10	0.217	0.237	0.255	0.281
0.2	0	0.171	0.201	0.234	0.275
	1	0.196	0.231	0.271	0.309
	5	0.247	0.253	0.274	0.292
	10	0.226	0.241	0.258	0.279

Fraction of simulation failures					
CV	***Kd***	***Kp=0.25***	***Kp=0.5***	***Kp=0.75***	***Kp=1***
0.005	0	0.163	0.163	0.153	0.134
	1	0.122	0.112	0.111	0.071
	5	0.000	0.000	0.000	0.000
	10	0.000	0.004	0.010	0.022
0.2	0	0.166	0.164	0.157	0.151
	1	0.126	0.114	0.097	0.082
	5	0.034	0.035	0.029	0.028
	10	0.147	0.162	0.182	0.194

Average Catch					
CV	***Kd***	***Kp=0.25***	***Kp=0.5***	***Kp=0.75***	***Kp=1***
0.005	0	228.6	248.9	270.6	296.5
	1	236.0	254.8	275.3	298.9
	5	256.6	276.3	297.6	320.1
	10	294.4	313.5	332.1	348.2
0.2	0	227.8	248.3	270.6	295.6
	1	235.0	254.5	276.3	298.8
	5	256.6	277.2	297.1	319.4
	10	292.7	314.0	332.2	346.4

Net rate of population change during control period					
CV	***Kd***	***Kp=0.25***	***Kp=0.5***	***Kp=0.75***	***Kp=1***
0.005	0	0.078	0.071	0.061	0.047
	1	0.071	0.063	0.056	0.038
	5	0.058	0.054	0.049	0.043
	10	0.054	0.048	0.041	0.033
0.2	0	0.078	0.071	0.062	0.052
	1	0.072	0.062	0.050	0.038
	5	0.055	0.050	0.042	0.035
	10	0.050	0.044	0.036	0.027

Average CV of Catch					
CV	***Kd***	***Kp=0.25***	***Kp=0.5***	***Kp=0.75***	***Kp=1***
0.005	0	0.068	0.135	0.199	0.259
	1	0.097	0.159	0.219	0.283
	5	0.239	0.281	0.322	0.361
	10	0.401	0.430	0.458	0.483
0.2	0	0.070	0.137	0.203	0.266
	1	0.115	0.176	0.239	0.304
	5	0.368	0.410	0.457	0.503
	10	0.675	0.712	0.737	0.769

Table 15. Summary of derived estimates of catch in 2018 based on the FSD model for alternative values of the gain parameters Kp and Kd. The top table shows the effect of the parameters on estimated catch in mt. The lower table illustrates the effect of the gain parameters on the degree of concordance with historical estimates of observed and predicted catch for the time period 2007 to 2016. Table entries are ratios of the sum of squares difference between observed and predicted to the minimum value.

		Kp								
	122.67	0	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	0	110.3	114.3	115.7	117.1	118.5	120.0	121.4	122.9	124.4
	0.25	111.2	115.3	116.7	118.1	119.5	120.9	122.4	123.9	125.4
	0.5	112.1	116.2	117.6	119.0	120.5	121.9	123.4	124.9	126.4
	0.75	113.0	117.2	118.6	120.0	121.5	122.9	124.4	125.9	127.4
	1	114.0	118.1	119.6	121.0	122.5	123.9	125.4	127.0	128.5
	1.25	114.9	119.1	120.5	122.0	123.5	125.0	126.5	128.0	129.5
	1.5	115.8	120.1	121.5	123.0	124.5	126.0	127.5	129.0	130.6
	1.75	116.8	121.1	122.5	124.0	125.5	127.0	128.6	130.1	131.7
Kd	2	117.8	122.1	123.5	125.0	126.5	128.1	129.6	131.2	132.8
	2.25	118.7	123.1	124.6	126.1	127.6	129.1	130.7	132.3	133.8
	2.5	119.7	124.1	125.6	127.1	128.6	130.2	131.7	133.3	134.9
	2.75	120.7	125.1	126.6	128.1	129.7	131.2	132.8	134.4	136.1
	3	121.7	126.1	127.6	129.2	130.7	132.3	133.9	135.5	137.2
	3.25	122.7	127.2	128.7	130.2	131.8	133.4	135.0	136.6	138.3
	3.5	123.7	128.2	129.8	131.3	132.9	134.5	136.1	137.8	139.4
	3.75	124.7	129.3	130.8	132.4	134.0	135.6	137.2	138.9	140.6
	4	125.7	130.3	131.9	133.5	135.1	136.7	138.4	140.0	141.7
		min (C(2018))=		111.2	max(C(2018))=		141.7			

Ratio of (SSQ-Min(SSQ)) to Minimum SSQ

		Kp								
		0	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	0	0.12	0.13	0.14	0.16	0.19	0.22	0.25	0.30	0.34
	0.25	0.00	0.04	0.07	0.10	0.14	0.19	0.24	0.30	0.37
	0.5	0.13	0.22	0.26	0.31	0.37	0.44	0.51	0.59	0.69
	0.75	0.58	0.71	0.78	0.85	0.93	1.02	1.12	1.23	1.35
	1	1.40	1.61	1.69	1.79	1.90	2.02	2.15	2.30	2.45
	1.25	2.70	2.98	3.10	3.23	3.38	3.53	3.70	3.88	4.08
	1.5	4.56	4.95	5.11	5.28	5.46	5.66	5.88	6.11	6.36
	1.75	7.13	7.64	7.84	8.06	8.29	8.55	8.82	9.11	9.42
Kd	2	10.54	11.20	11.46	11.73	12.03	12.35	12.69	13.05	13.43
	2.25	14.97	15.81	16.14	16.49	16.86	17.26	17.68	18.13	18.60
	2.5	20.63	21.70	22.11	22.55	23.02	23.51	24.03	24.58	25.16
	2.75	27.78	29.13	29.64	30.19	30.76	31.37	32.01	32.69	33.40
	3	36.71	38.40	39.04	39.71	40.42	41.17	41.96	42.79	43.65
	3.25	47.80	49.90	50.69	51.51	52.39	53.30	54.27	55.27	56.33
	3.5	61.46	64.06	65.03	66.04	67.11	68.23	69.41	70.63	71.92
	3.75	78.20	81.41	82.60	83.84	85.15	86.52	87.94	89.44	90.99
	4	98.65	102.60	104.05	105.57	107.16	108.82	110.55	112.36	114.25

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Table 16. Estimated discards by gear type and adjustments for discard mortality rates.

	Discard Estimate (mt)				Fraction by Gear			Adjusted for Discard Mortality Rate			
								0.1	0.76	0.3	
Year	Handline	Trawl	Gill net	Total	Handline	Trawl	Gill net	Handline	Trawl	Gill net	Adj Total
1989	0.00	2.88	2.10	4.97	0.000	0.578	0.422	0.00	2.19	0.63	2.81
1990	0.00	12.09	1.46	13.55	0.000	0.892	0.108	0.00	9.19	0.44	9.63
1991	0.00	6.06	0.87	6.93	0.000	0.875	0.125	0.00	4.61	0.26	4.87
1992	0.00	1.92	0.27	2.19	0.000	0.878	0.122	0.00	1.46	0.08	1.54
1993	0.00	0.63	0.44	1.06	0.000	0.590	0.410	0.00	0.48	0.13	0.61
1994	0.00	2.94	0.22	3.16	0.000	0.930	0.070	0.00	2.23	0.07	2.30
1995	0.00	6.30	0.04	6.34	0.000	0.993	0.007	0.00	4.79	0.01	4.80
1996	0.00	0.52	0.14	0.65	0.000	0.791	0.209	0.00	0.39	0.04	0.43
1997	0.00	1.64	0.00	1.64	0.000	1.000	0.000	0.00	1.24	0.00	1.24
1998	0.00	0.00	0.10	0.10	0.000	0.000	1.000	0.00	0.00	0.03	0.03
1999	0.00	68.85	0.25	69.10	0.000	0.996	0.004	0.00	52.33	0.07	52.40
2000	0.00	11.38	0.49	11.87	0.000	0.958	0.042	0.00	8.65	0.15	8.80
2001	0.00	9.29	0.40	9.68	0.000	0.959	0.041	0.00	7.06	0.12	7.18
2002	0.00	20.20	0.00	20.20	0.000	1.000	0.000	0.00	15.35	0.00	15.35
2003	0.00	15.80	4.35	20.15	0.000	0.784	0.216	0.00	12.01	1.31	13.32
2004	0.02	14.81	0.88	15.71	0.001	0.943	0.056	0.00	11.26	0.26	11.52
2005	0.70	16.90	1.29	18.89	0.037	0.895	0.068	0.07	12.85	0.39	13.30
2006	0.00	19.05	3.40	22.45	0.000	0.849	0.151	0.00	14.48	1.02	15.50
2007	0.08	14.65	2.54	17.27	0.004	0.848	0.147	0.01	11.13	0.76	11.91
2008	0.00	18.87	2.79	21.66	0.000	0.871	0.129	0.00	14.34	0.84	15.18
2009	0.00	16.93	0.92	17.85	0.000	0.949	0.051	0.00	12.87	0.27	13.15
2010	2.52	27.55	4.63	34.69	0.073	0.794	0.134	0.25	20.93	1.39	22.58
2011	0.07	33.56	8.71	42.35	0.002	0.793	0.206	0.01	25.51	2.61	28.13
2012	0.00	43.51	8.68	52.19	0.000	0.834	0.166	0.00	33.07	2.60	35.67
2013	0.20	46.27	9.70	56.18	0.004	0.824	0.173	0.02	35.17	2.91	38.10
2014	0.00	23.95	10.39	34.34	0.000	0.697	0.303	0.00	18.20	3.12	21.32
2015	0.00	22.48	23.82	46.30	0.000	0.485	0.515	0.00	17.08	7.15	24.23
2016	0.00	26.00	21.40	47.40	0.000	0.549	0.451	0.00	19.76	6.42	26.18

Table 17.Estimated total catch with and without adjustment for discard mortality estimates. Rates are defined in Table 16.

Year	*Total Catch (mt)*	*Adjusted total catch (mt)*	*% Change*
1994	24.9	24.1	-3.4%
1995	16.9	15.3	-9.1%
1996	14.0	13.8	-1.6%
1997	15.6	15.3	-2.5%
1998	8.5	8.4	-0.9%
1999	80.6	63.9	-20.7%
2000	22.9	19.9	-13.4%
2001	20.5	18.0	-12.2%
2002	30.2	25.4	-16.0%
2003	36.8	30.0	-18.6%
2004	26.9	22.7	-15.5%
2005	35.7	30.1	-15.6%
2006	36.5	29.6	-19.0%
2007	41.9	36.5	-12.8%
2008	50.3	43.9	-12.9%
2009	62.9	58.2	-7.5%
2010	54.9	42.8	-22.1%
2011	68.1	53.9	-20.9%
2012	87.0	70.5	-19.0%
2013	90.8	72.8	-19.9%
2014	79.3	66.3	-16.4%
2015	108.3	86.2	-20.4%
2016	115.6	94.4	-18.3%

FIGURES

Year	Disards	Landings	Catch
1994	3.16	21.77	24.93
1995	6.34	10.54	16.88
1996	0.65	13.32	13.97
1997	1.64	14.01	15.65
1998	0.10	8.41	8.51
1999	69.08	11.51	80.59
2000	11.87	11.07	22.94
2001	9.68	10.82	20.50
2002	20.20	10.01	30.21
2003	20.15	16.68	36.83
2004	15.71	11.22	26.93
2005	18.89	16.81	35.70
2006	22.45	14.08	36.53
2007	17.27	24.61	41.88
2008	21.66	28.69	50.35
2009	17.85	45.05	62.90
2010	34.68	20.20	54.88
2011	42.34	25.79	68.13
2012	52.18	34.80	86.98
2013	56.16	34.67	90.83
2014	34.33	44.99	79.32
2015	46.28	62.00	108.28
2016	47.39	68.20	115.59

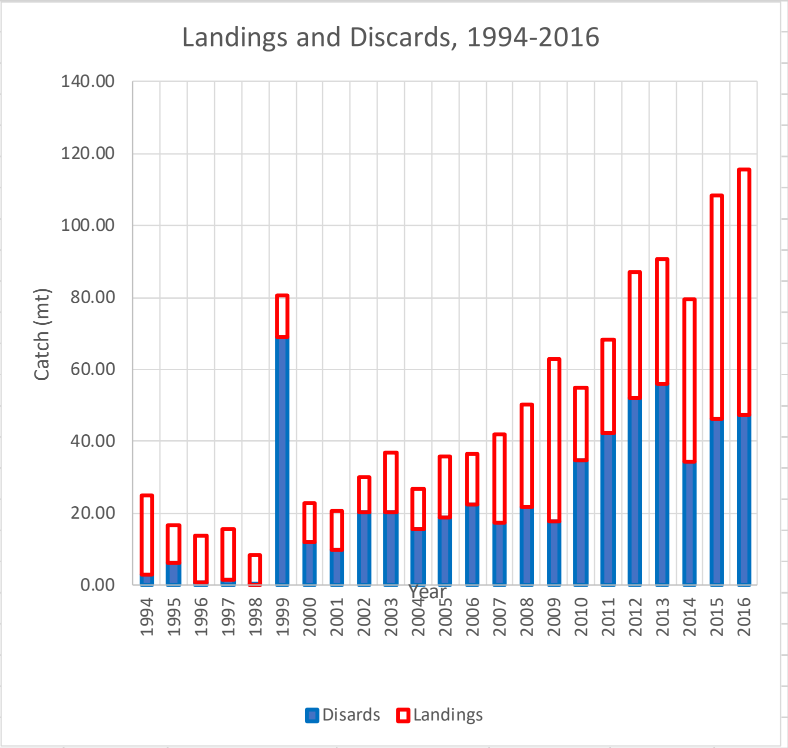

Figure 1. Landings and discards (mt) for Atlantic halibut in US stock area, 1994-2016, used in this assessment.

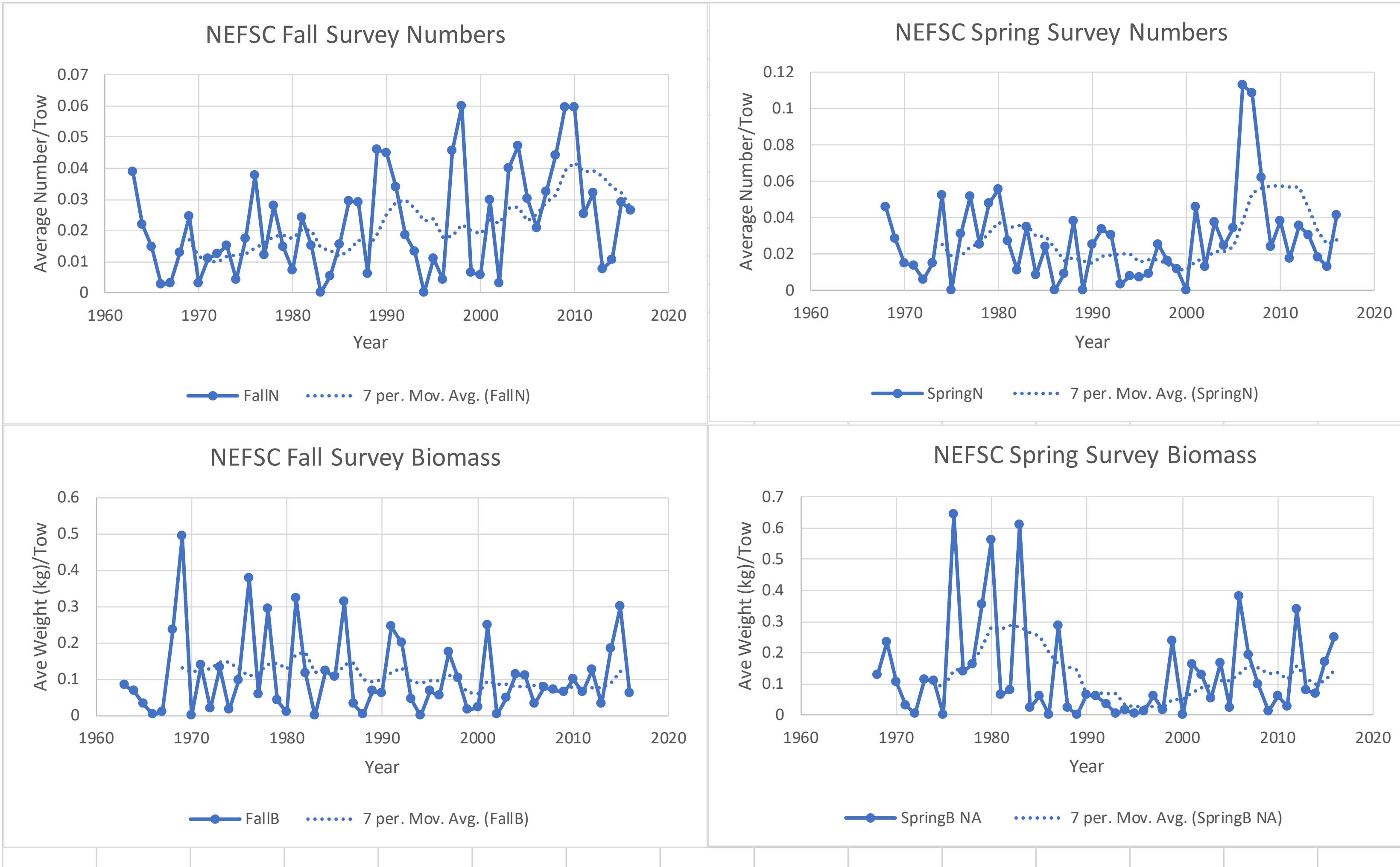

Figure 2. Summary of NEFSC bottom trawl survey indices 1963-2016 for fall and spring surveys expressed in terms of both average numbers per tow and average weight (kg) per tow. A 7 point moving average is used to dampen interannual variability.

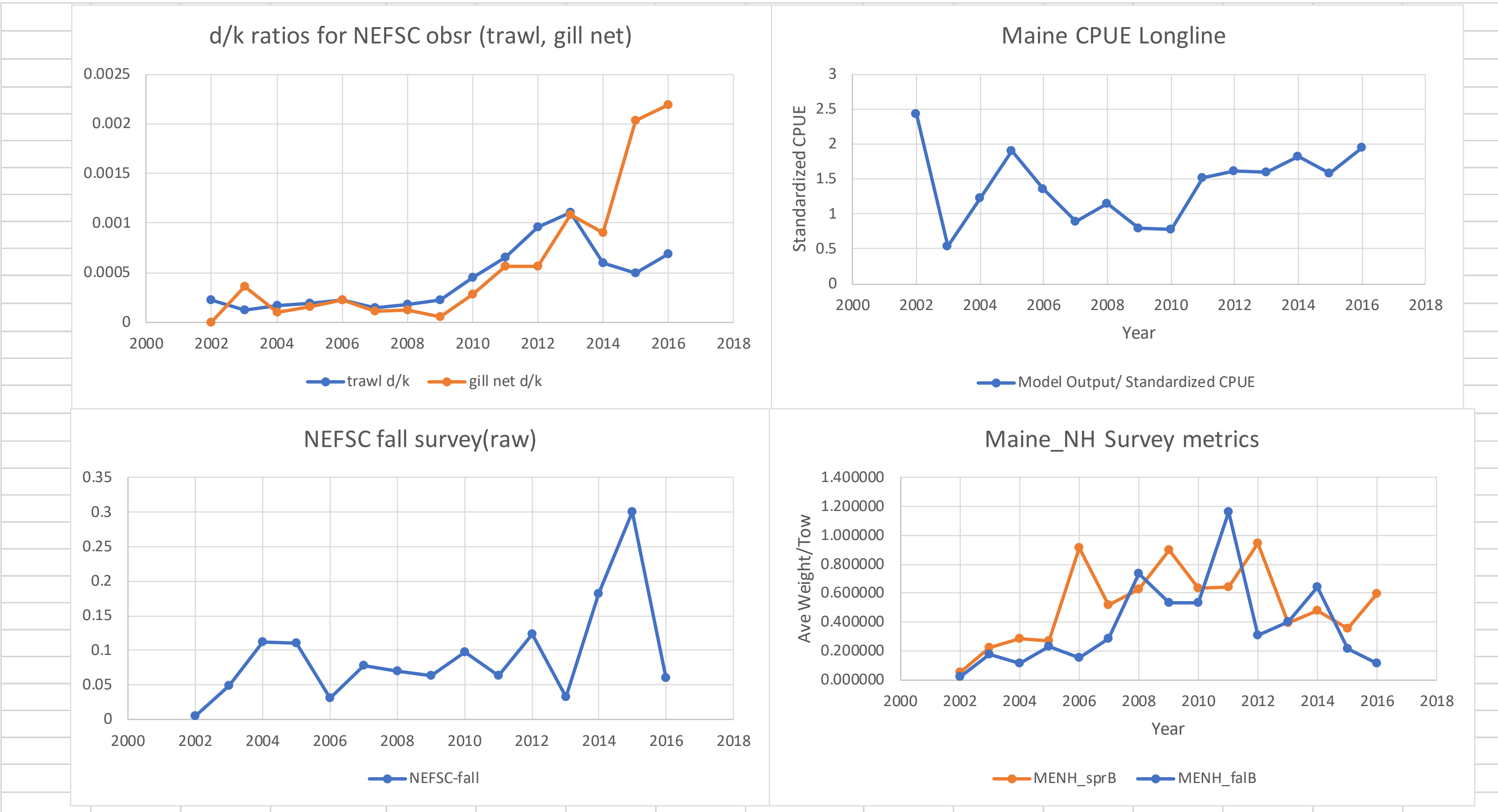

Figure 3. Candidate relative abundance indices considered in Rcrit and FSD models. The Standardized longline CPUE data were obtained from Hansell et al (2017 ms). Results for the Maine-New Hampshire inshore bottom trawl survey were obtained from Sally Sherman, MEDMR. The d/k ratios were obtained from Susan Wigley, NEFSC. NEFSC bottom trawl estimates were obtained from Daniel Hennen, NEFSC. See Appendix 4 for variable definitions.

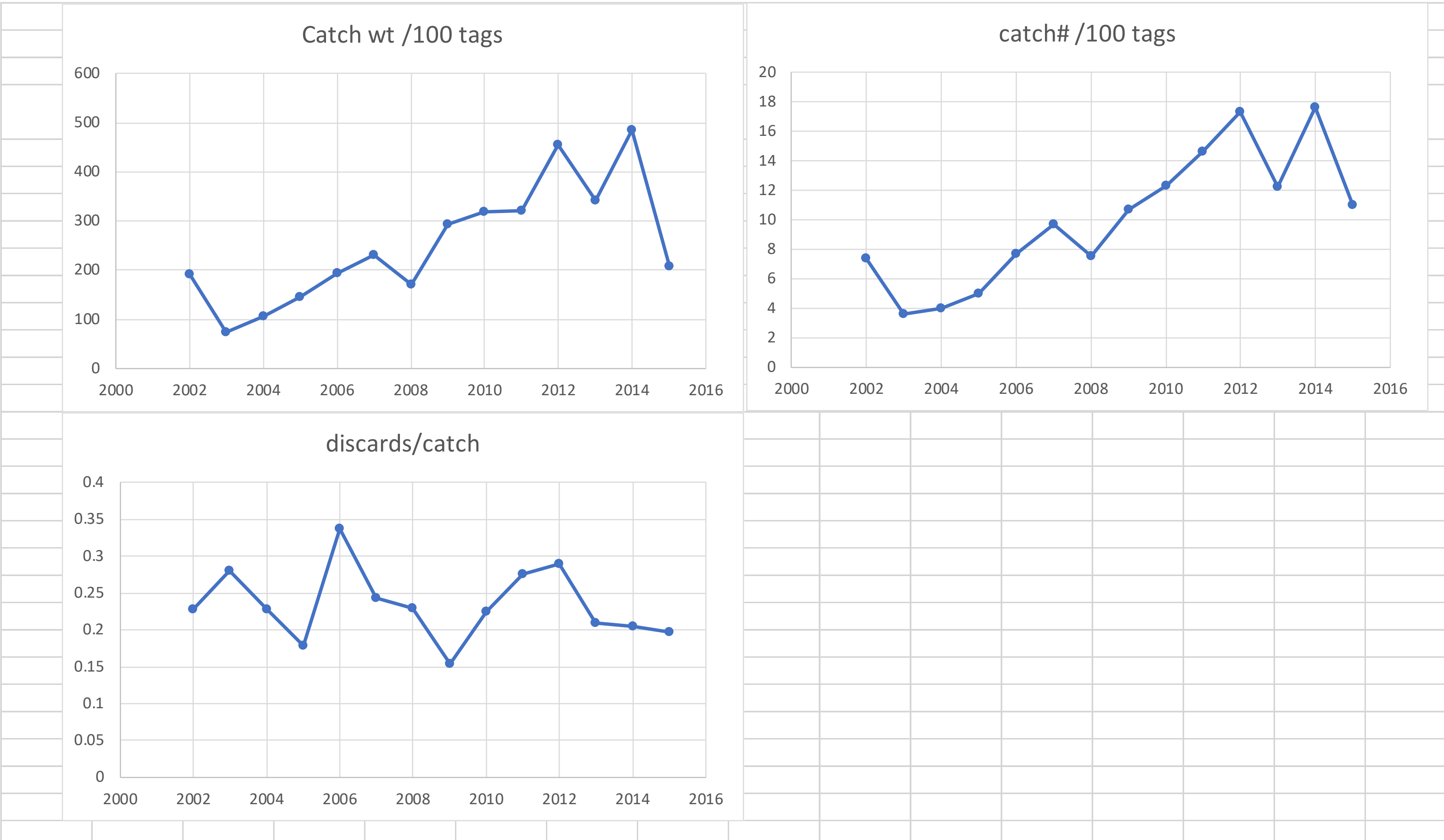

Fig 3.5 Estimates of catch per unit effort based on state data from Maine DMR. Effort is expressed in terms of number of tags issued, and discard to catch ratios were based on fishermen logbooks. Given uncertainties about the data and the availability of a more refined measure of CPUE from Hansell et al. these data were not considered further in this assessment. See Appendix 4 for variable definitions.

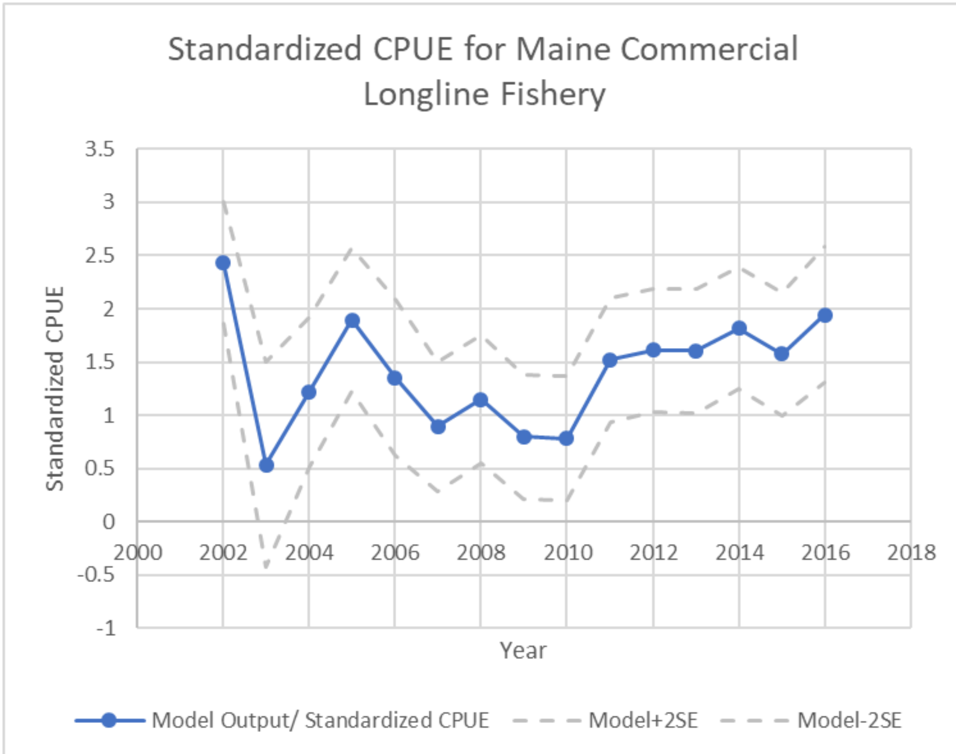

Figure 4. Standardized CPUE from Maine Commercial longline fishery, 2002-2016 provided courtesy of Hansell et al. Estimates and Error bounds are derived from a general linear model analysis.

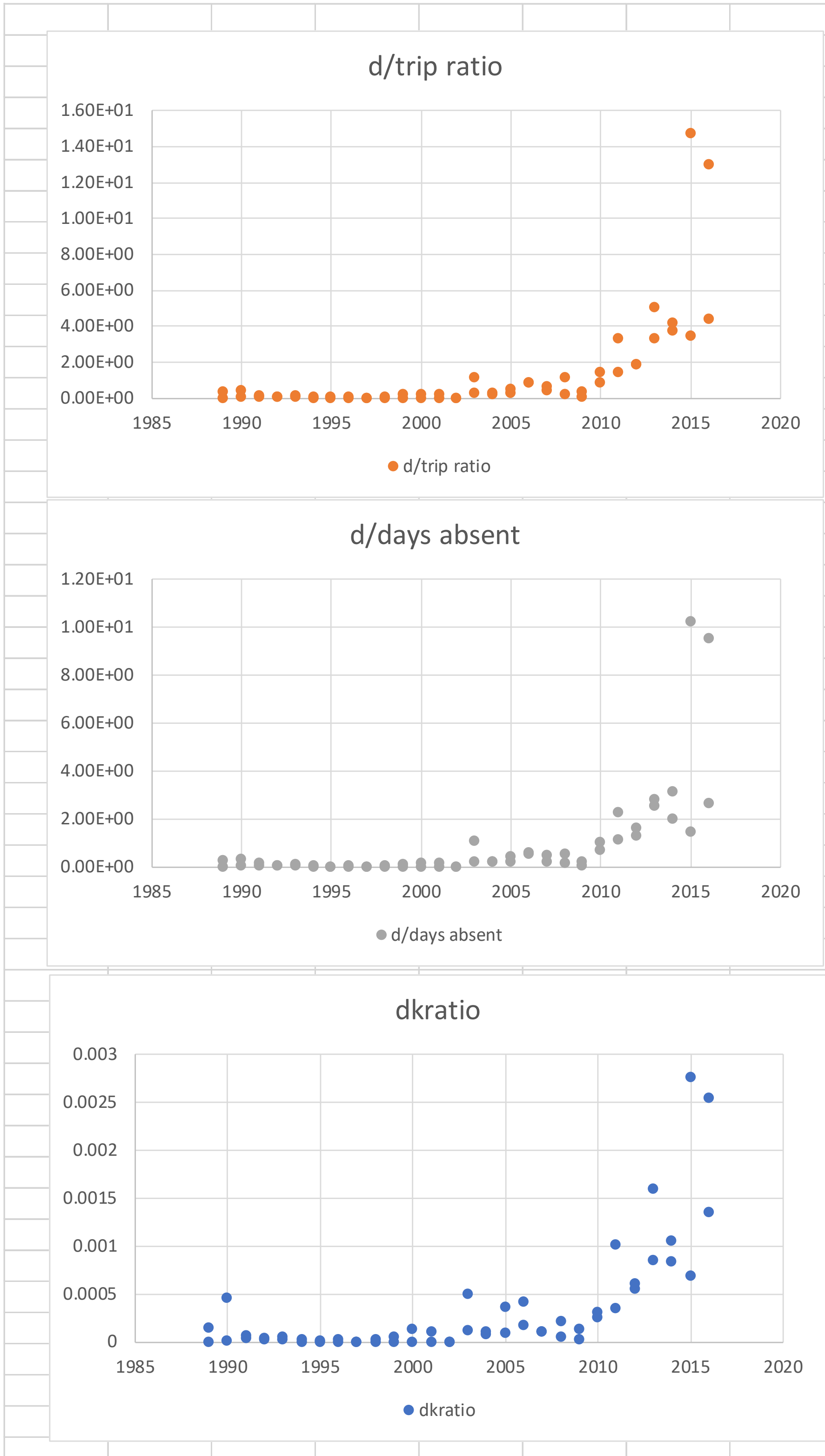

Figure 5. Discard ratios for observed gill net trips from 1989 to 2016 expressed in half year increments. Measures of effort include number of trips, number of days absent and total landed catch. Data courtesy of Susan Wigley, NEFSC

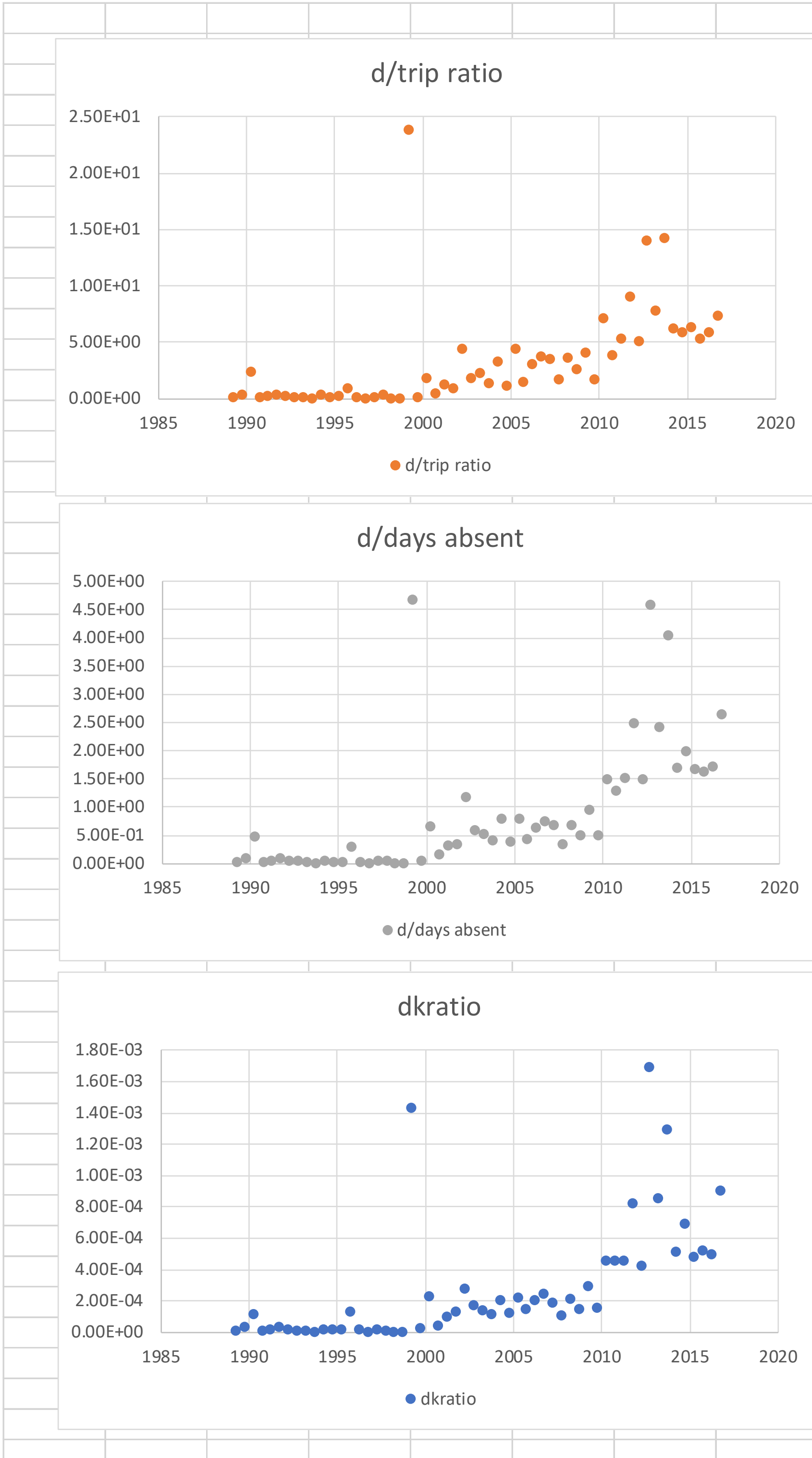

Figure 6. Discard ratios for observed otter trawl trips from 1989 to 2016 expressed in half year increments. Measures of effort include number of trips, number of days absent and total landed catch. Data courtesy of Susan Wigley, NEFSC

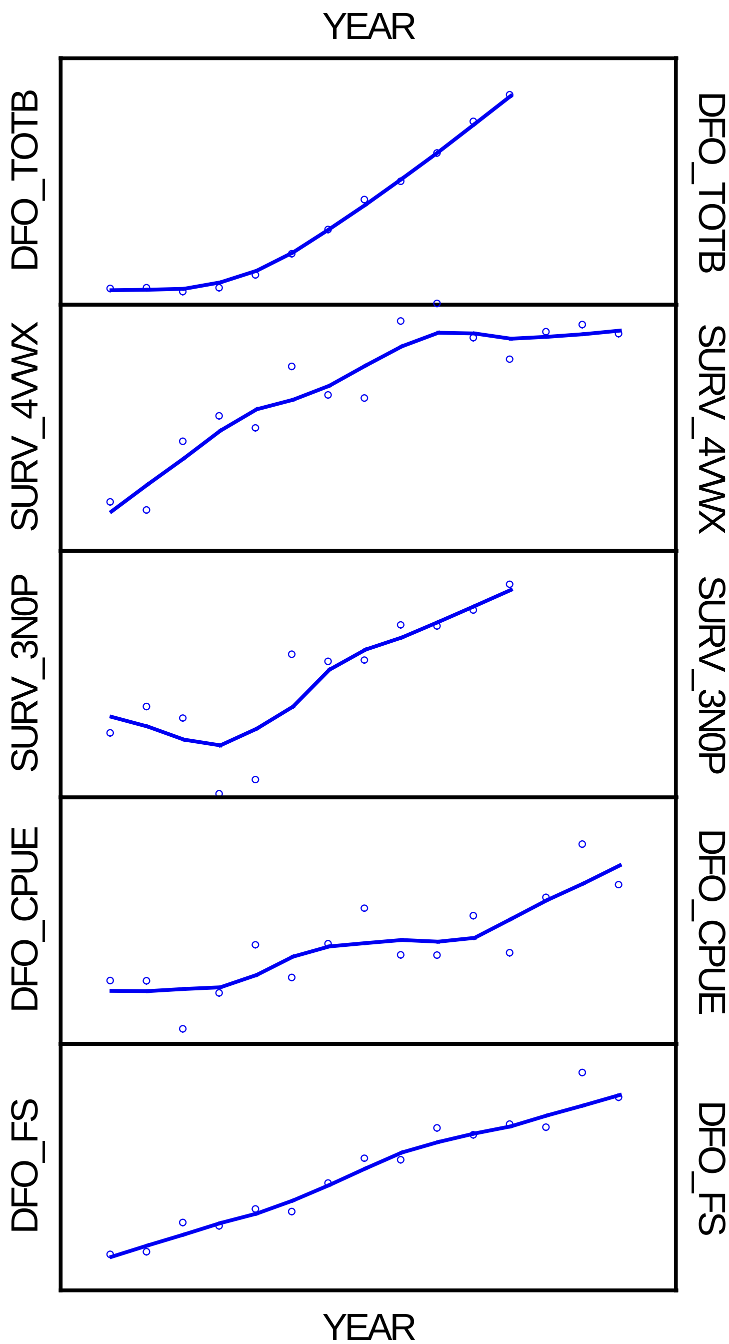

Figure 7. DFO abundance indices 2002-2016. DFO_TOTB is model based estimate of total biomass. Lines represent lowess smooths with tension =0.5. Variable names are DFO_FS, DFO_CPUE, SURV_3NOP, SURV_4VWX. See Appendix 4 for variable definitions.

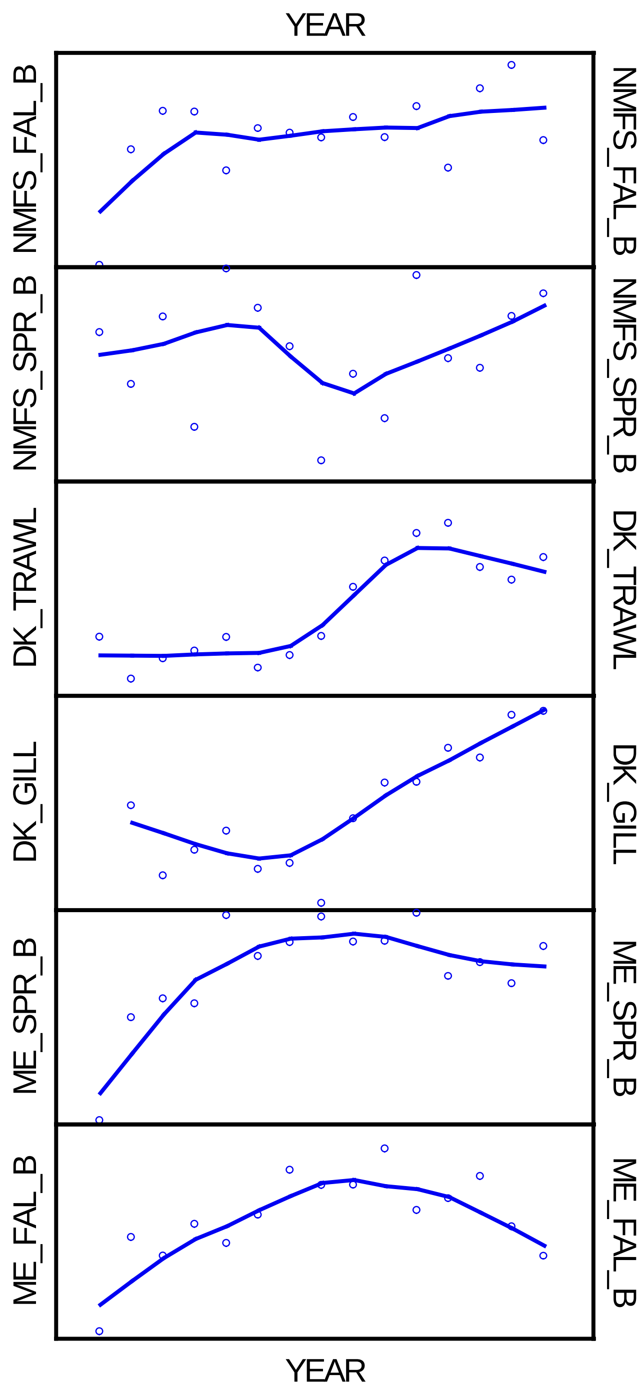

Figure 8. US abundance indices 2002-2016. Lines represent lowess smooths with tension =0.5. Variable names are ME_FAL_B, ME_SPR_B, DK_GILL, DK_TRAWL, NMFS_SPR_B, NMFS_FAL_B. See Appendix 4 for variable definitions.

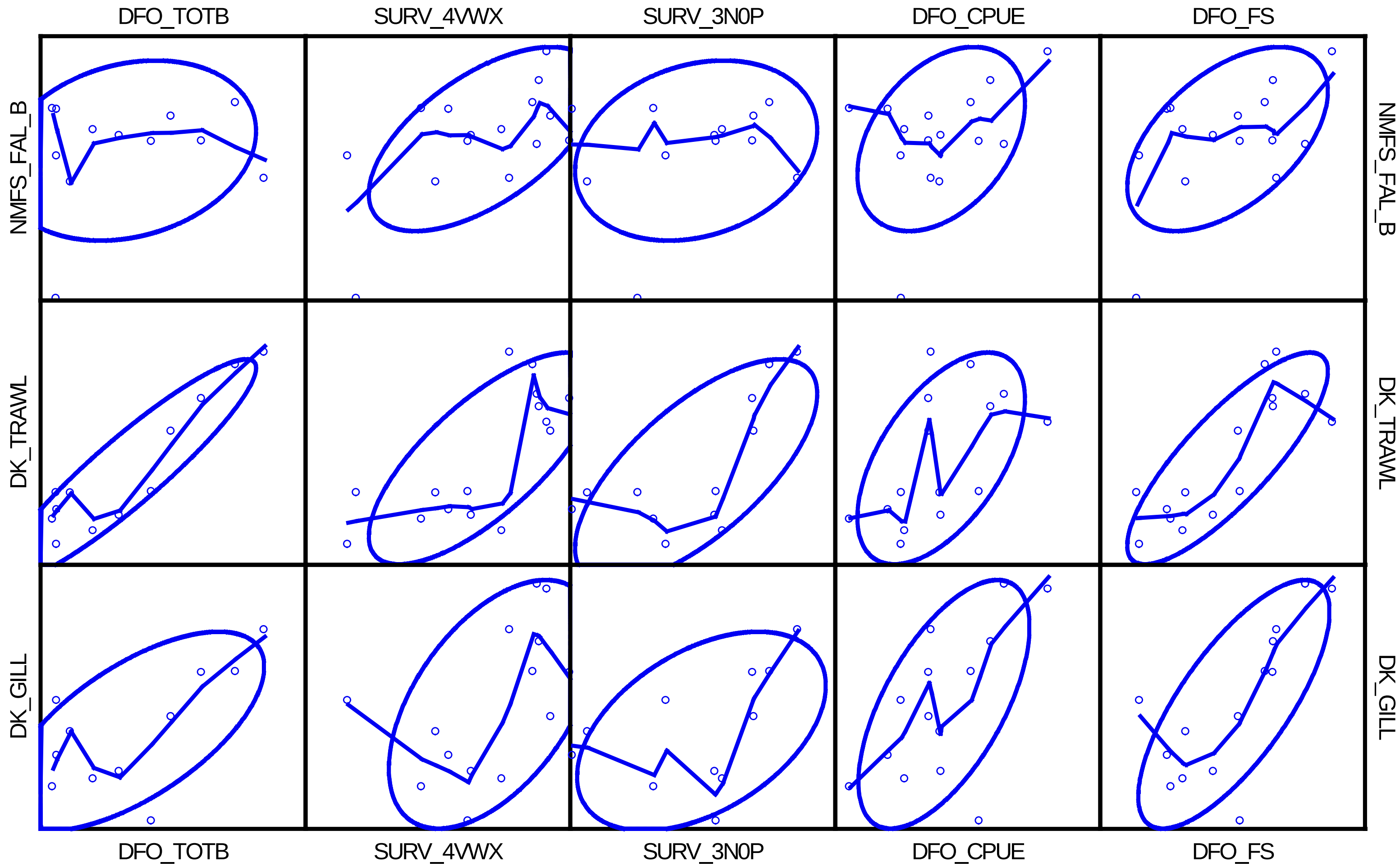

Fig 9. Comparison of DFO and US abundance indices for 2002-2016. Data are smoothed with a lowess mdethod with tension = 0.5. ME_FAL_B, ME_SPR_B, DK_GILL, DK_TRAWL, NMFS_SPR_B, NMFS_FAL_B. DFO_TOTB is model based estimate of total biomass. Variable names are DFO_FS, DFO_CPUE, SURV_3NOP, SURV_4VWX**.** See Appendix 4 for variable definitions.

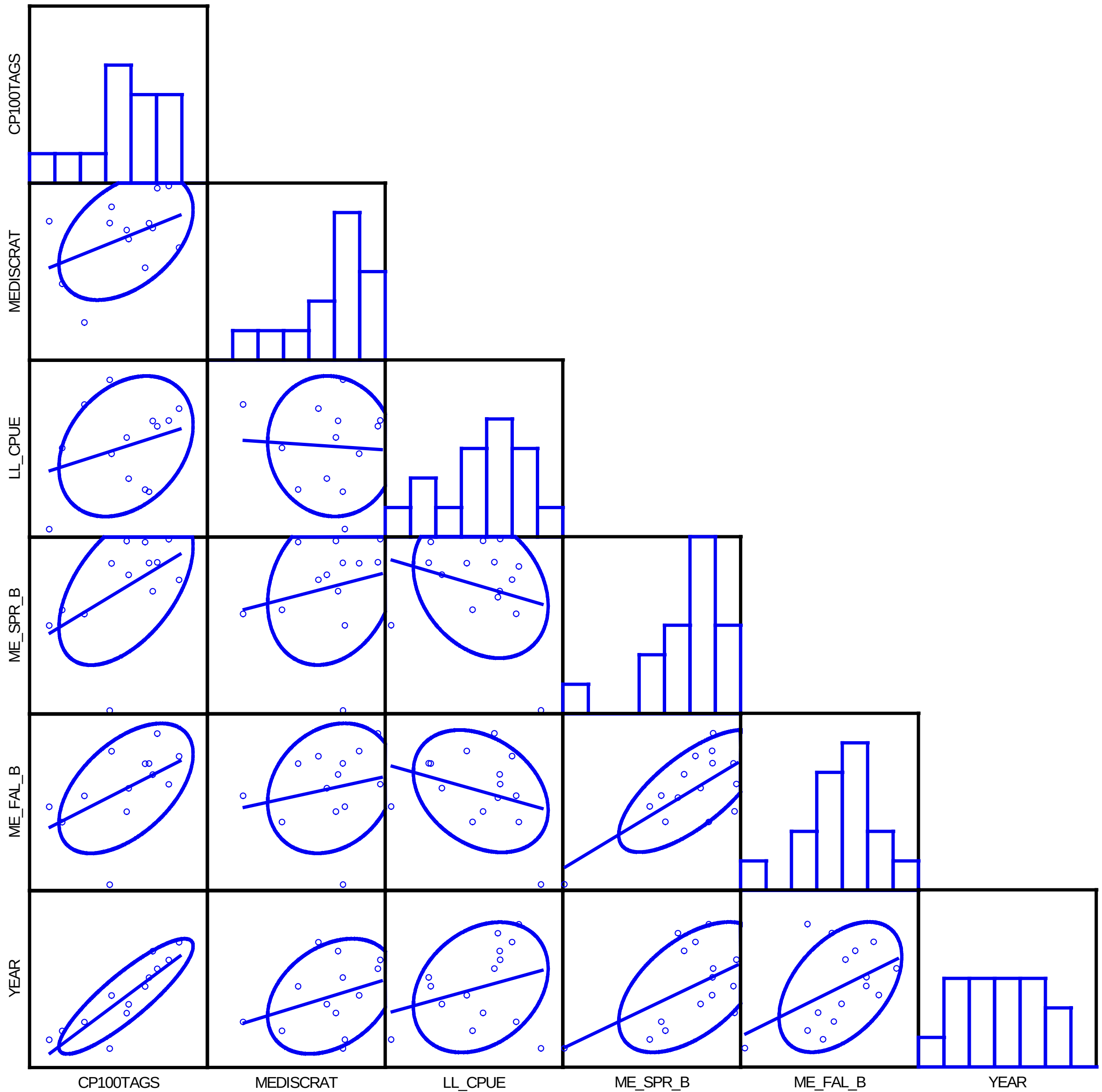

Figure 10. Scatterplot matrix for indices of abundance from Maine surveys and commercial CPUE. Lines represent simple linear regressions. ME_FAL_B, ME_SPR_B, DK_GILL, DK_TRAWL, NMFS_SPR_B, NMFS_FAL_B, LL_CPUE, MEDISCRAT, CP100TAGS. See Appendix 4 for variable definitions.

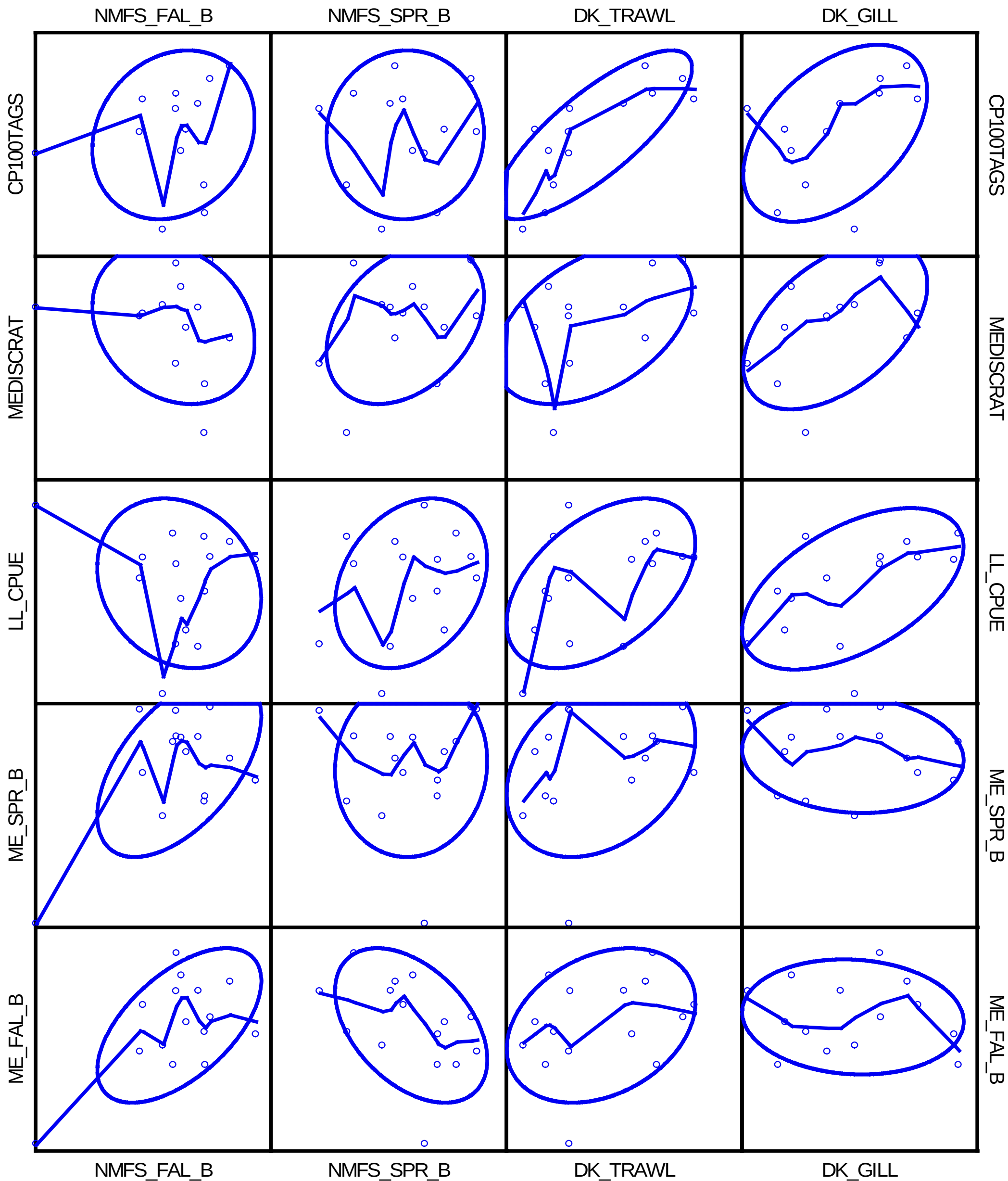

Figure 11. Scatterplot matrix comparison of Maine indices (rows) to NMFS indices. Lines represent lowess smooths with tension =0.5. ME_FAL_B, ME_SPR_B, DK_GILL, DK_TRAWL, NMFS_SPR_B, NMFS_FAL_B, LL_CPUE, MEDISCRAT, CP100TAGS. See Appendix 4 for variable definitions.

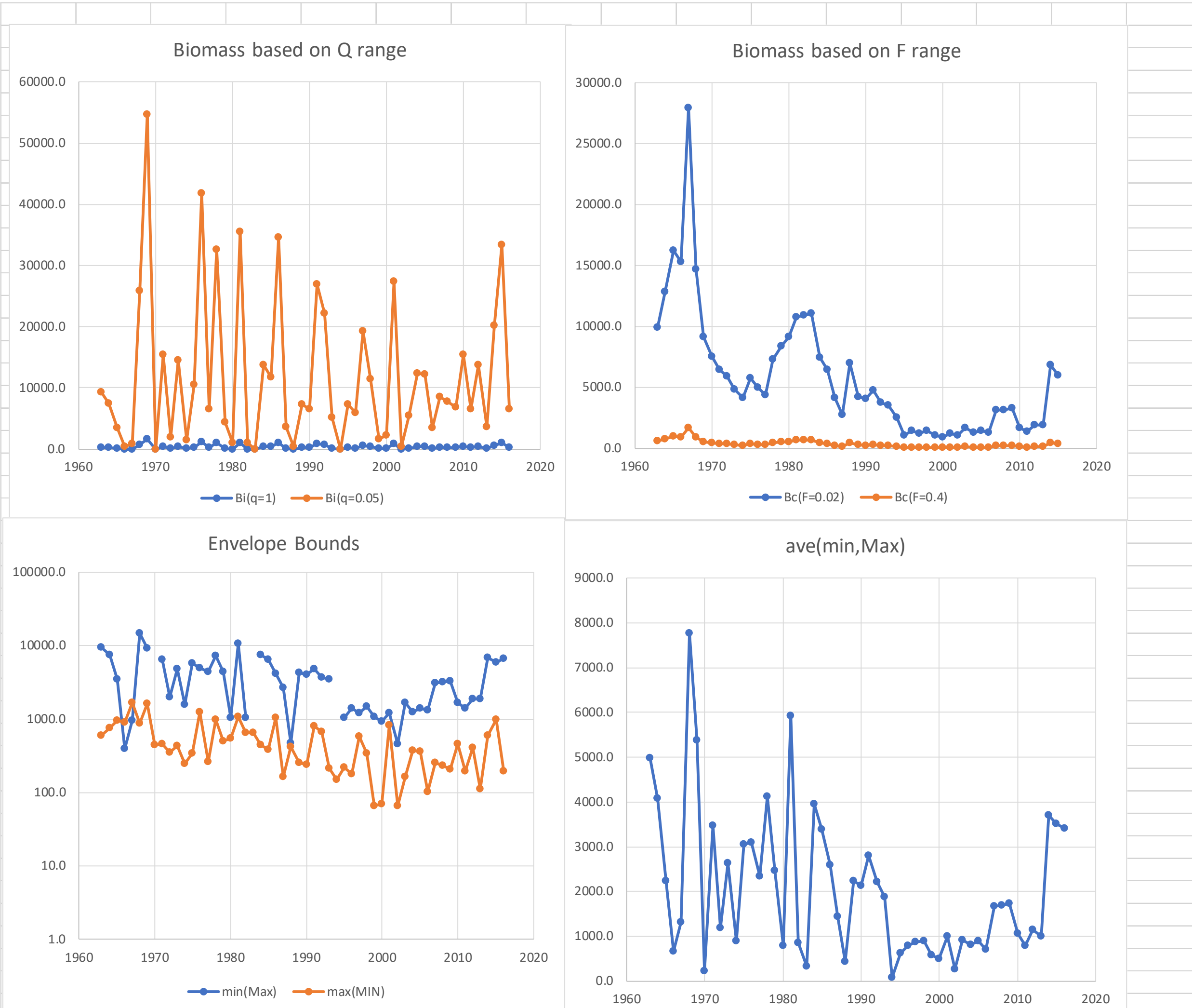

Figure 12. Result of Envelope model analyses of landings and NMFS fall bottom trawl survey estimates. Envelope bounds(lower left plot) represent constrained limits on a log scale. The lower right graph shows the average of the min and max envelope values. Estimates are based on raw survey data.

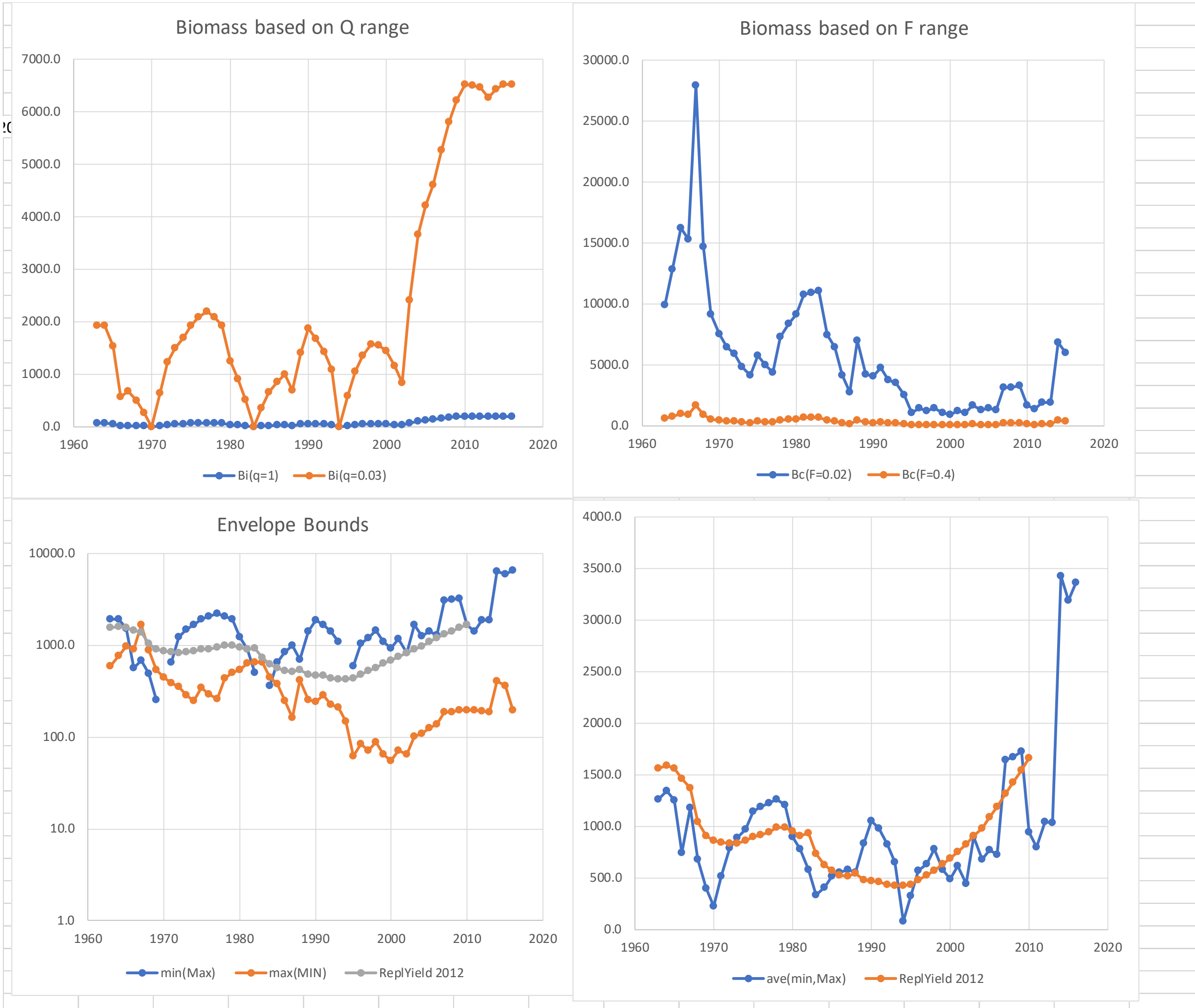

Figure 13. Result of Envelope model analyses of landings and NMFS fall bottom trawl survey estimates. Envelope bounds(lower left plot) represent constrained limits on a log scale.   The lower right graph shows the average of the min and max envelope values. Estimates are based on Kalman smoothed survey data. Biomass estimates from Replacement Yield model (Col and Legault 2012) are provide for reference.

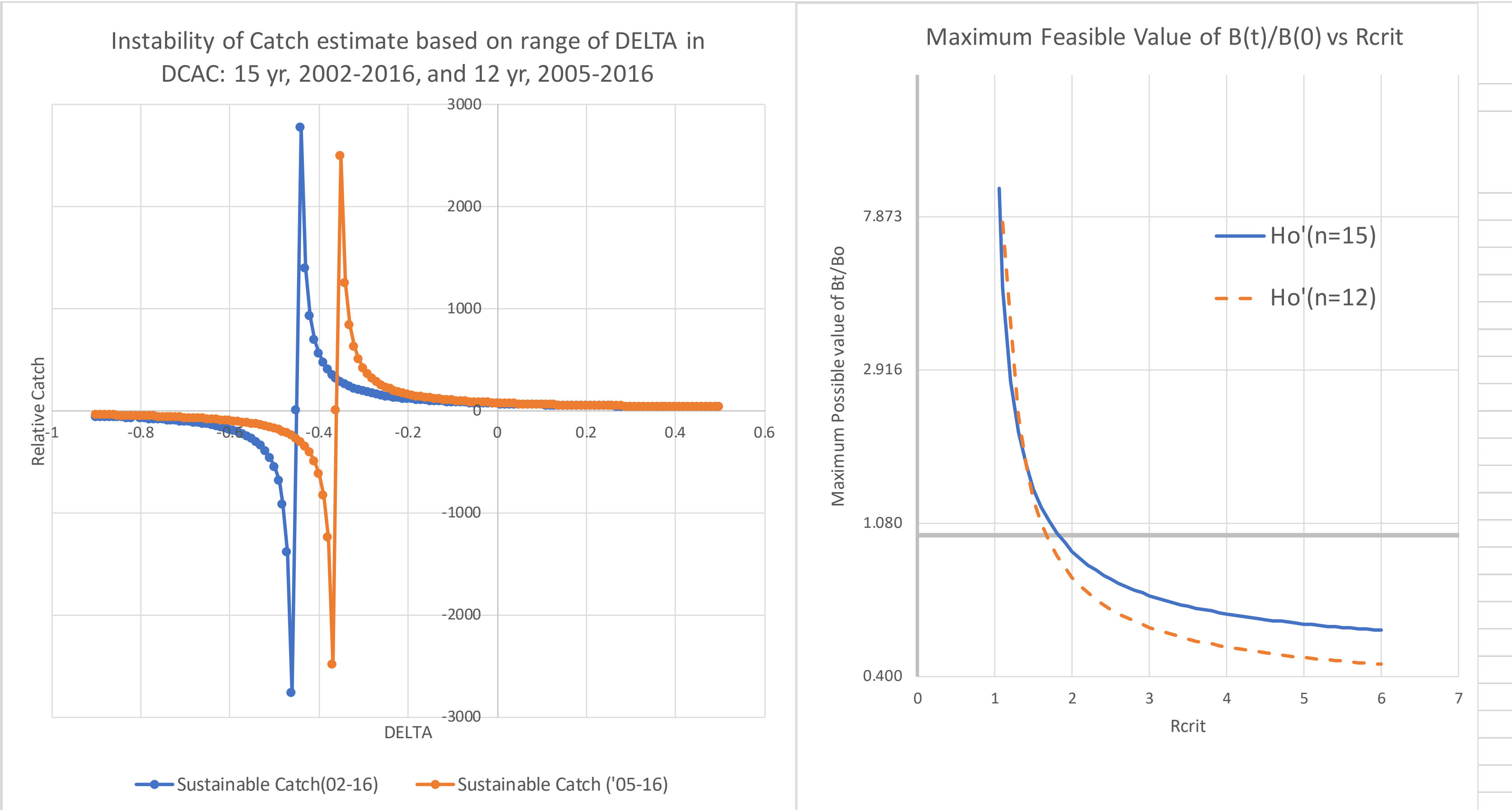

Figure 14. Singularity issues in DCAC for instances where the denominator becomes negative (left plot). The right plot shows the maximum possible value of Bt/B0 for alternative values of Rcrit given 12 or 15 years of catch data.

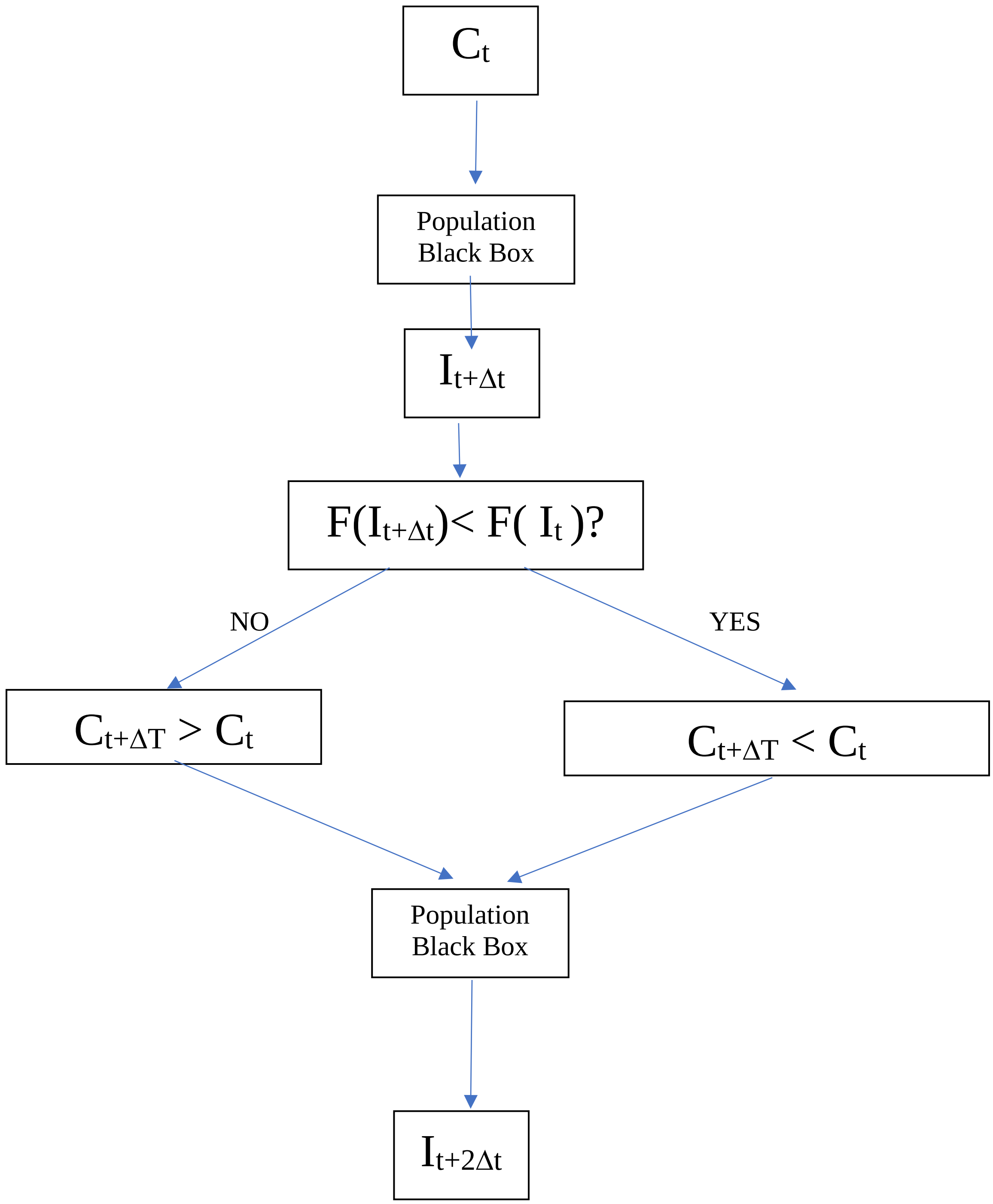

Figure 15. Schematic depiction of the feedback loop used in the FSD model.

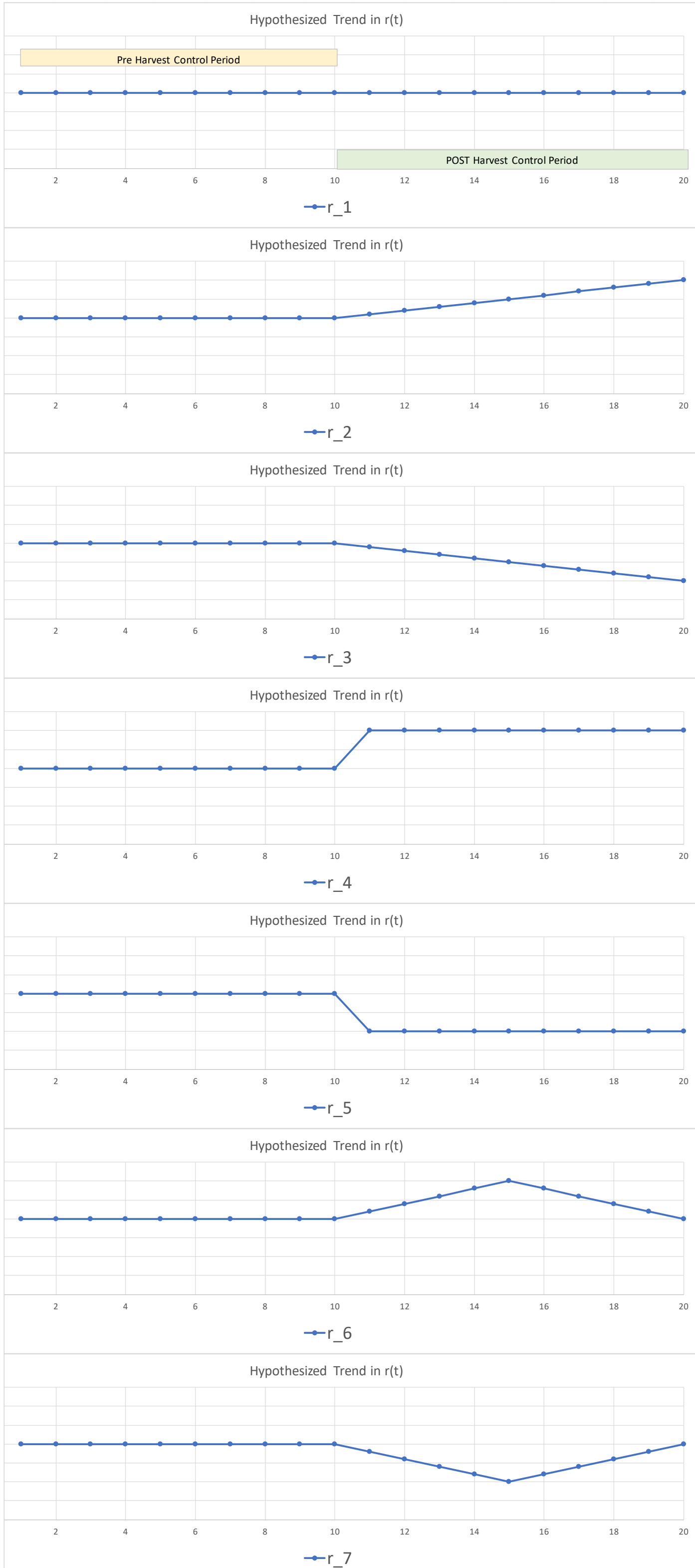

Figure 16. Scenarios for the intrinsic rate of increase r(t) used in the simulation analysis of the FSD model. Note that r(t) is constant during the first ten years, prior to implementation of the FSD control rule.

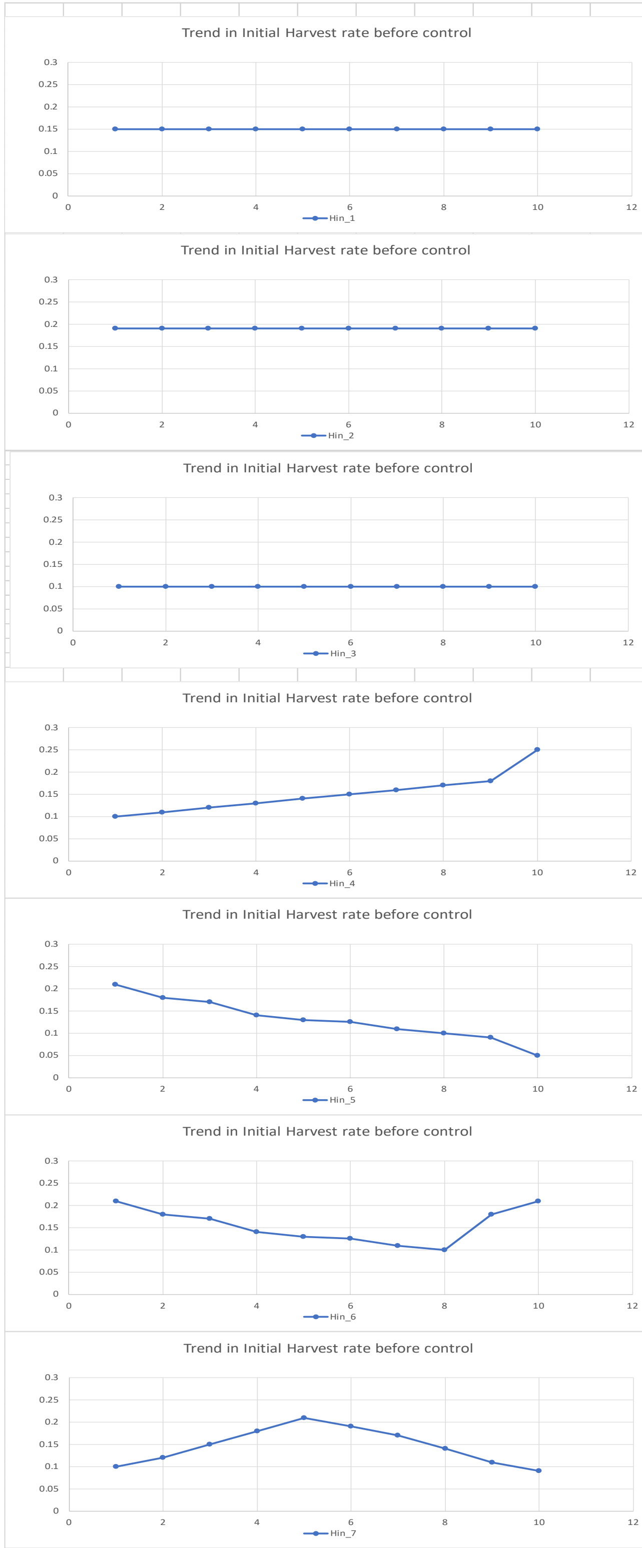

Figure 17. Scenarios for the initial harvest rate h(t) used in the simulation analysis of the FSD model. Note that the harvest rate is used only for the first 10 years. After that, harvest is controlled by the FSD harvest control rule.

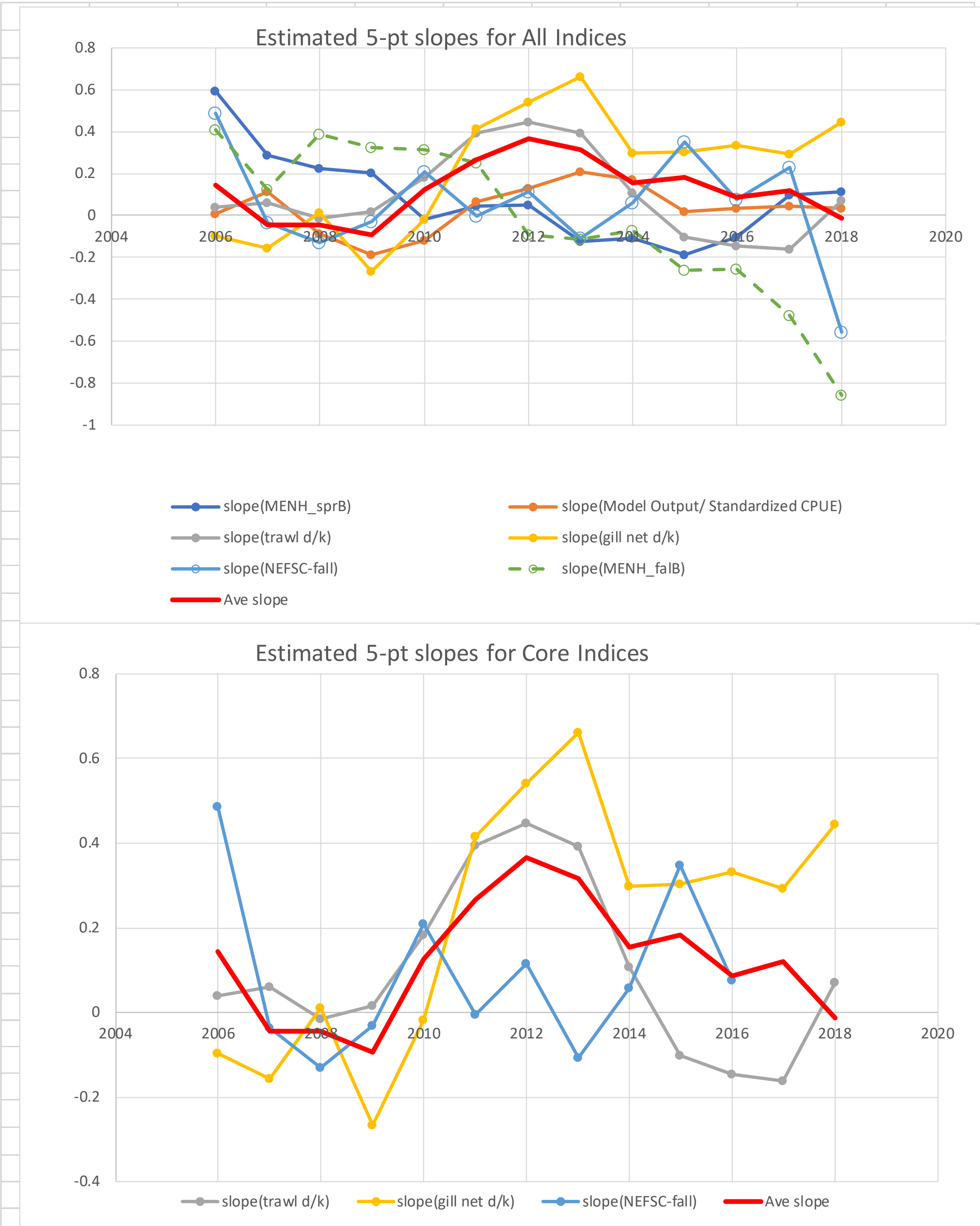

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Figure 18. Trends in abundance indices based on 5 point regressions. Top plot shows full model with 5 indices. Bottom plot shows reduced model using only existing indices.

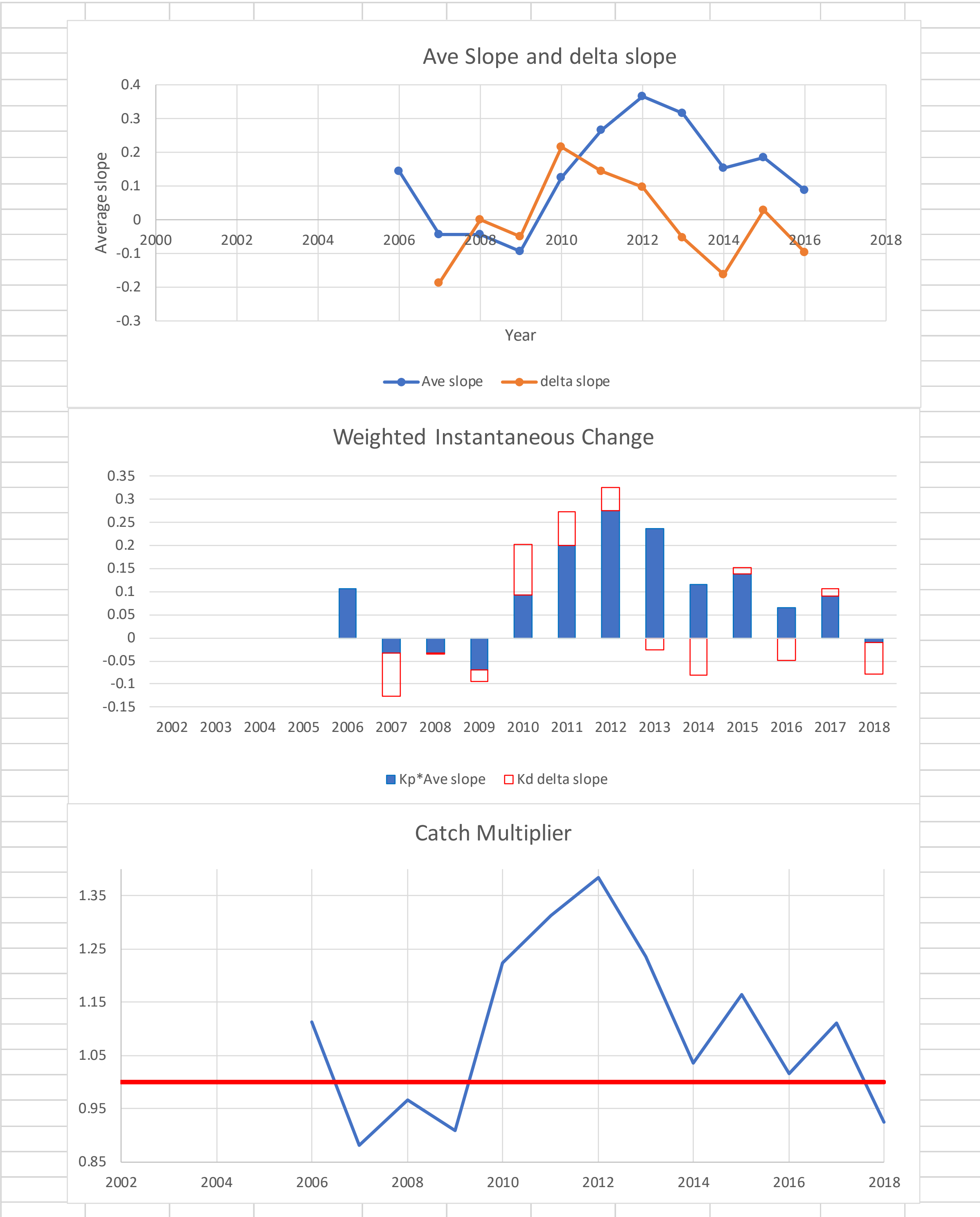

Figure 19. Summary of FSD model results for US Atlantic halibut based on d/k trawl, d/k gill net and NEFSC fall survey abundance indices (See Fig. 18 bottom). Instantaneous rates of change represent Kp and Kd weighted values of the first and second derivative (top figure). The bottom figure show the Catch multiplier used to forecast catch. . The gain parameters for proportional and derivative were set at Kp=0.75 and Kd=0.50, respectively.

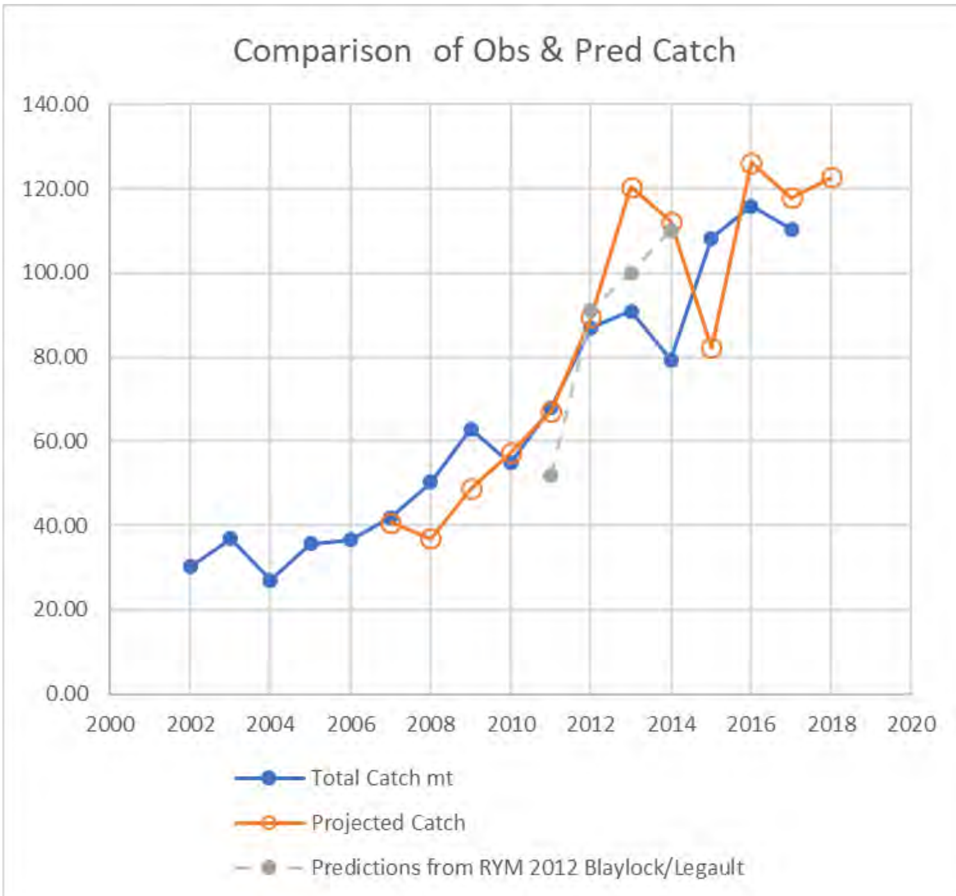

Figure 20. Comparison of observed vs predicted catches based on the FSD model applied to US stock area. Forecasts from RYM application (Blaylock and Legault, 2012) are included for comparison. The gain parameters for proportional and derivative were set at Kp=0.75 and Kd=0.50, respectively.

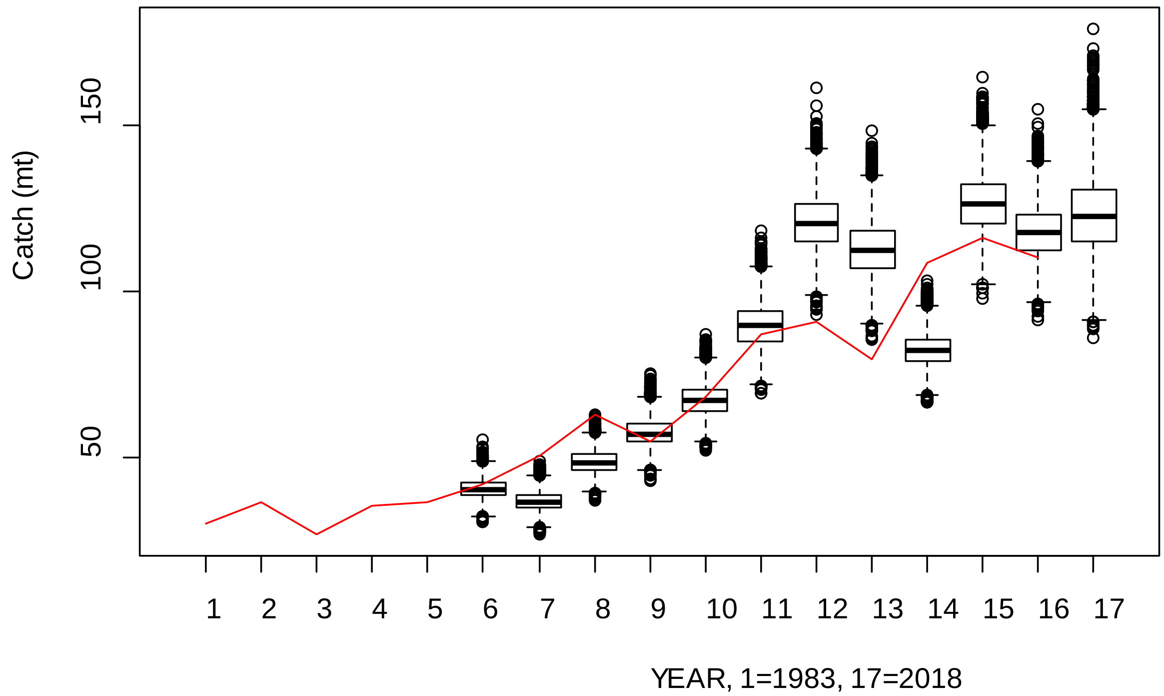

Figure 21. Comparison of observed and predicted distribution of catches for FSD model applied to the US stock area. Uncertainty estimates are based on a parametric bootstrap method described in the text. The gain parameters for proportional and derivative were set at Kp=0.75 and Kd=0.50, respectively.

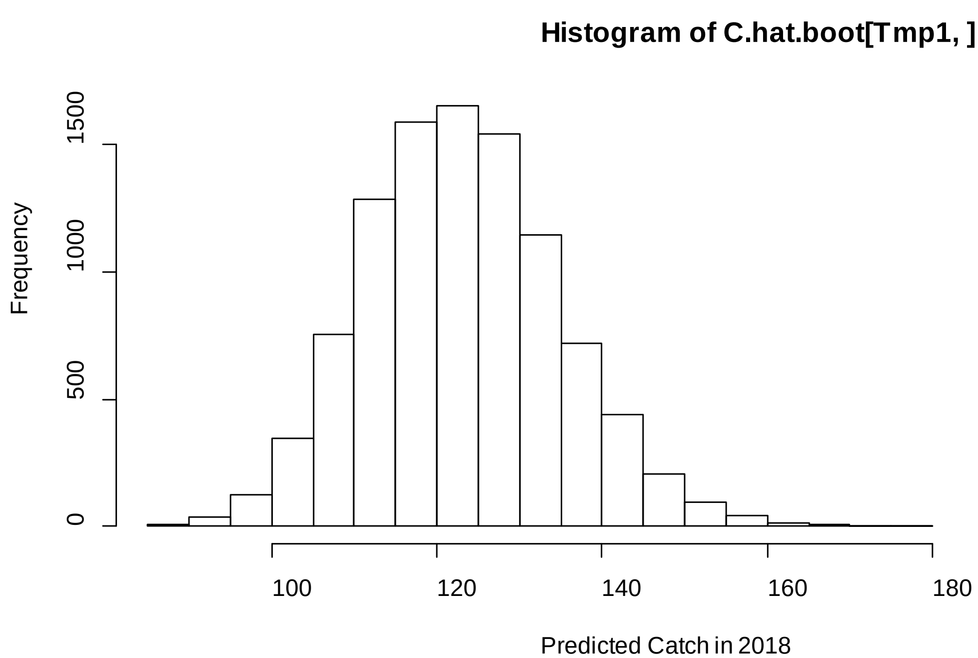

Figure 22. Sampling distribution of predicted catch for 2018 based on parametric bootstrap method with 5000 replications.

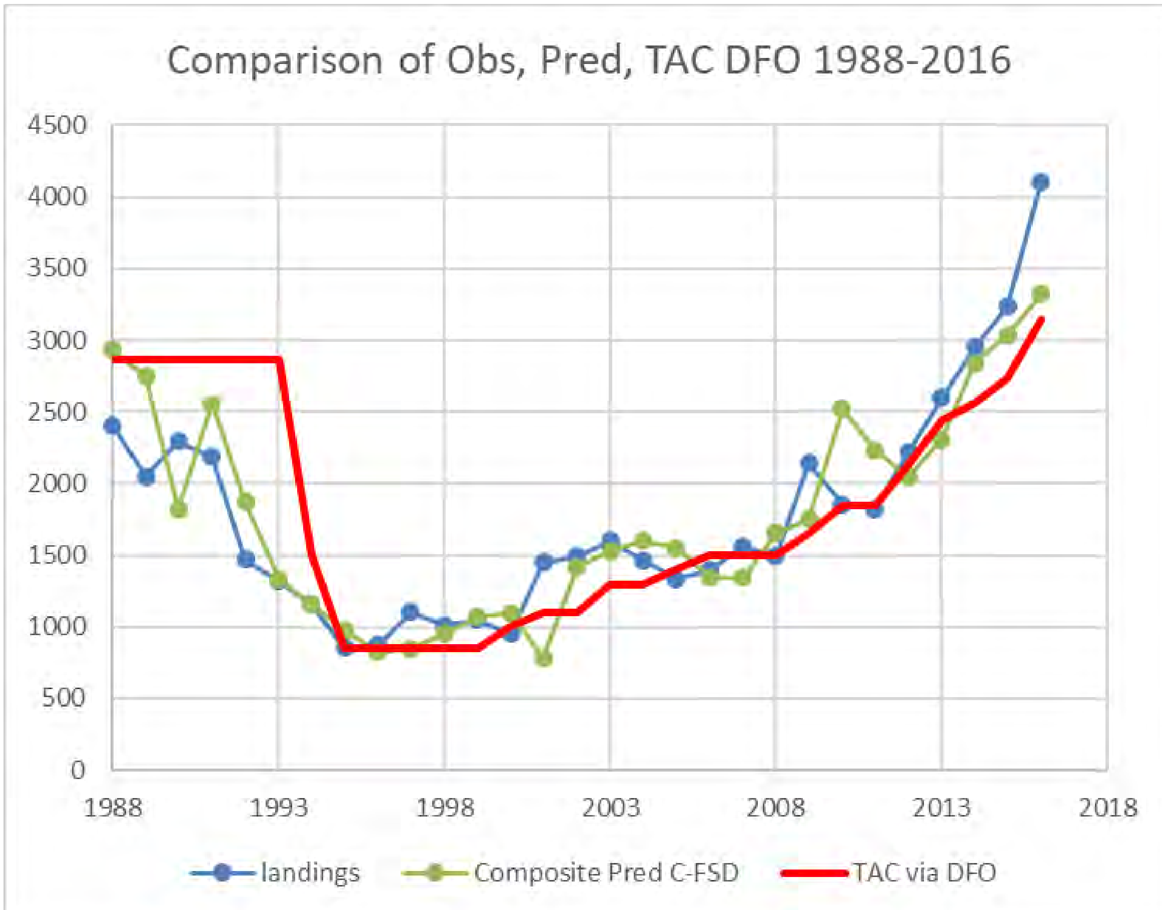

Figure 23. Comparison of FSD prediction with observed landings and TAC for DFO 3NOPs4VWX5Zc stock of Atlantic halibut.

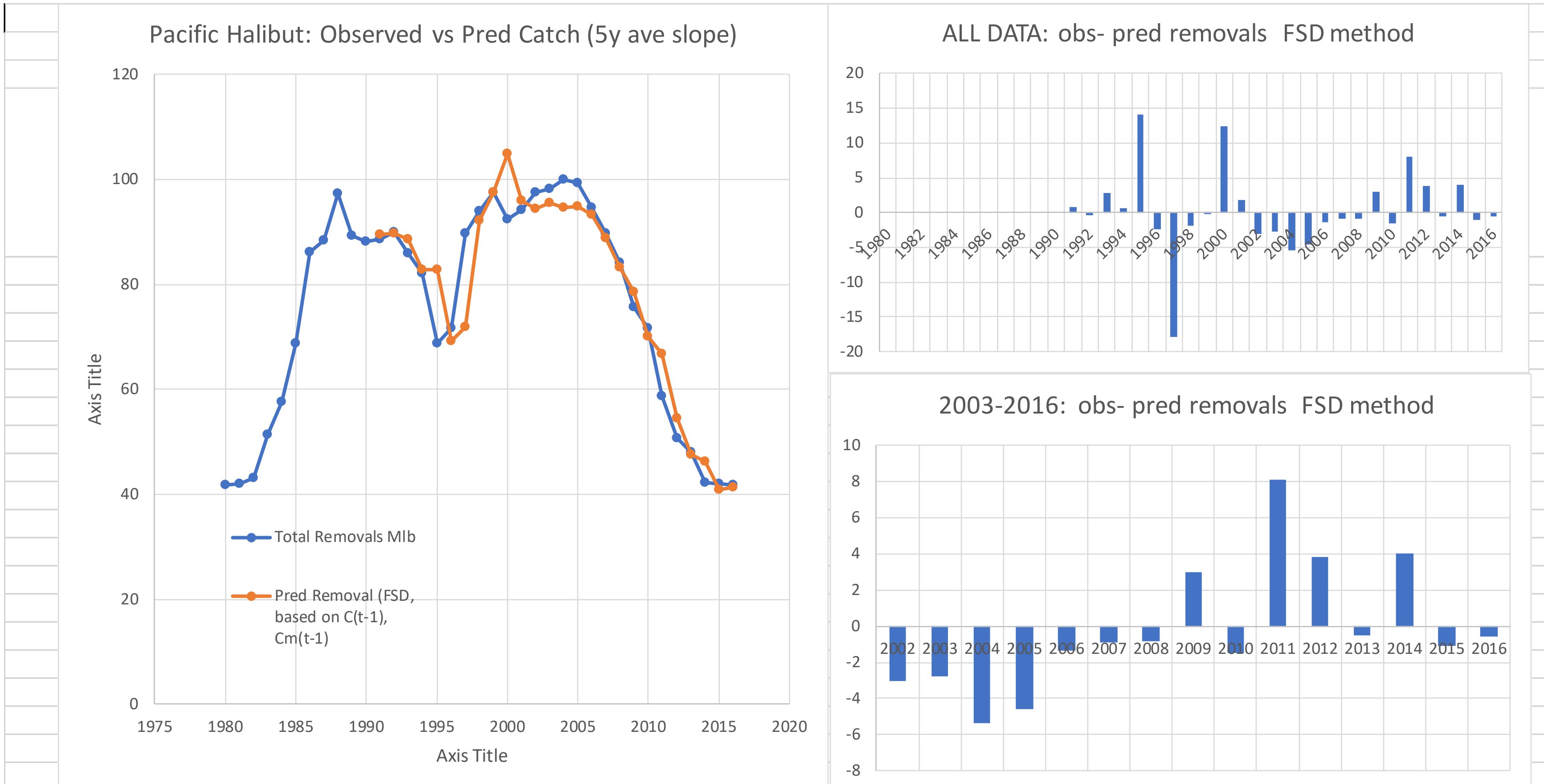

Figure 24. Example application of FSD model to observed catches of IPHC Pacific halibut. Residuals are shown on right hand plots for the full and reduced time series.

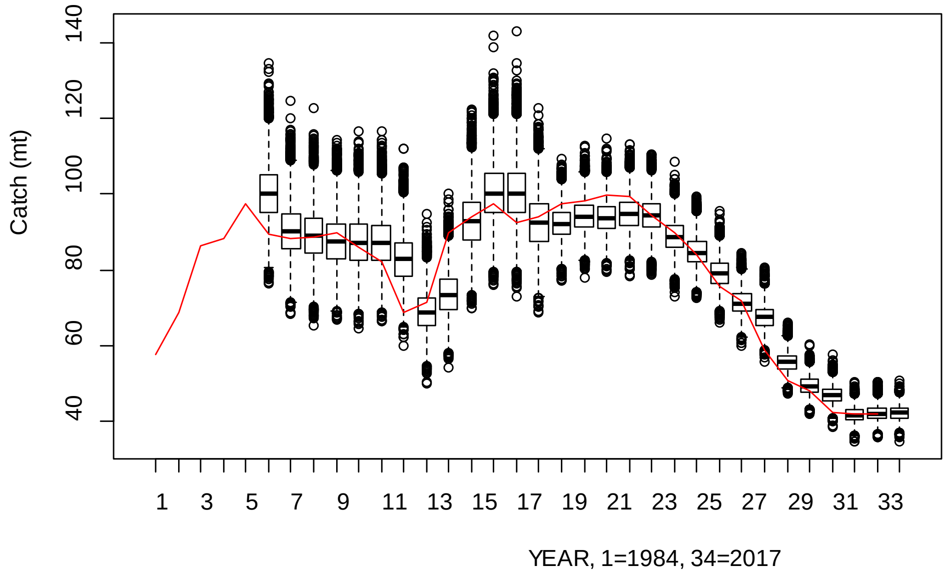

Figure 25. Comparison of observed and predicted catches based on the FSD model with Kp=0.778 and Kd=0.1. Research survey indices were assumed to have a CV=0.2 and Commercial CPUE indices were assumed to have a CV=0.25.

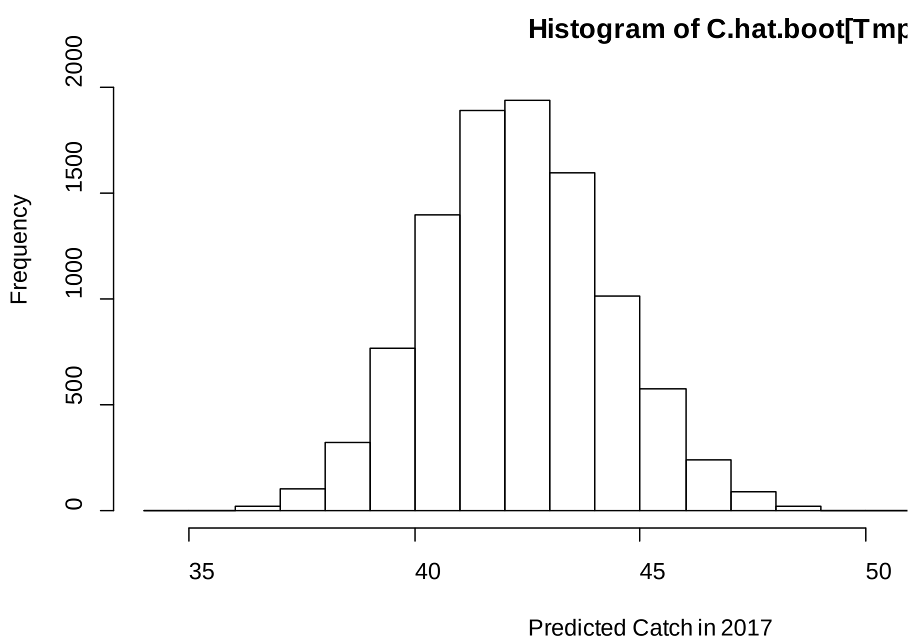

Figure 26. Predicted sampling distribution of estimated total removals in 2017 for Pacific halibut. The FSD model used Kp=0.778 and Kd=0.1. Research survey indices were assumed to have a CV=0.2 and Commercial CPUE indices were assumed to have a CV=0.25

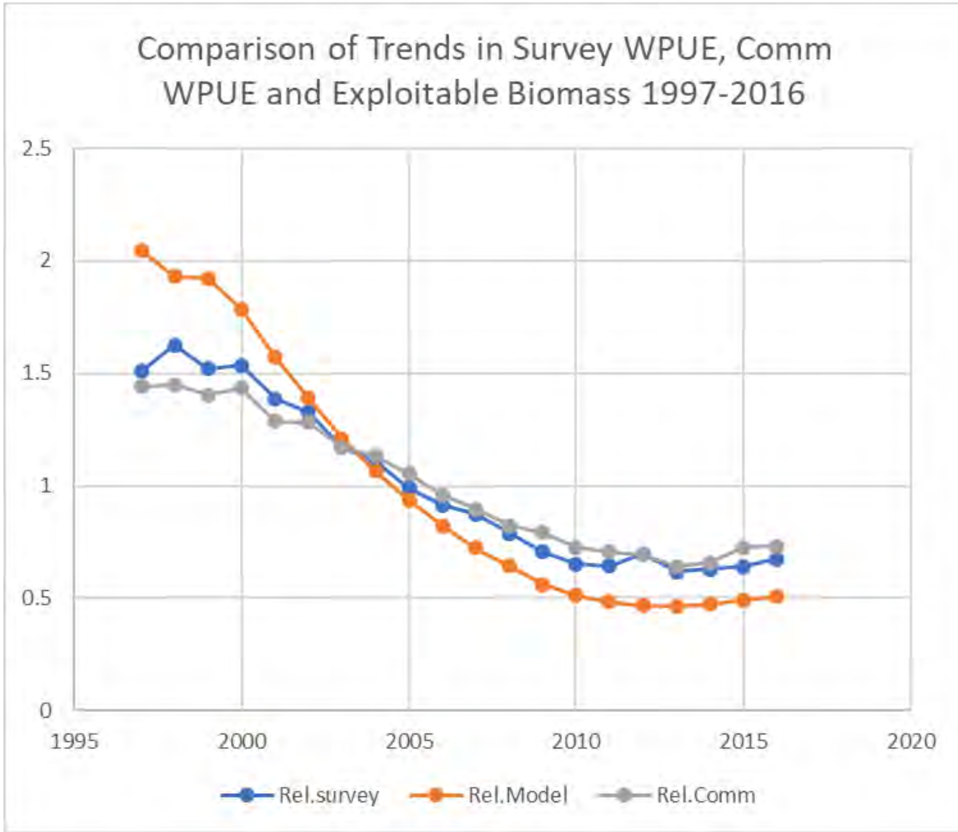

Figure 27. Comparison of relative trends in biomass for IPHC Pacific halibut surveys and modeled biomass. Quantities are expressed as ratio of observed value to its mean for the period 1997-2017. Data were obtained from Stewart(2017) and Stewart and Hicks (2017).

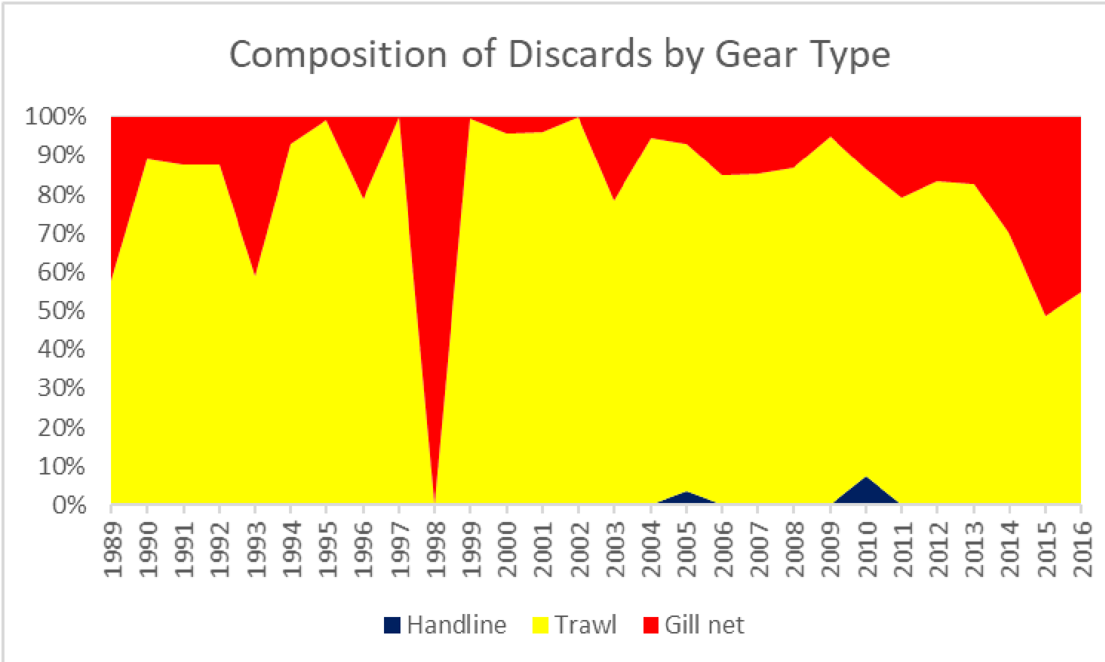

Figure 28. Estimated proportions of discards by gear type, 1989-2016. Estimates are based on an assumed 100% mortality.

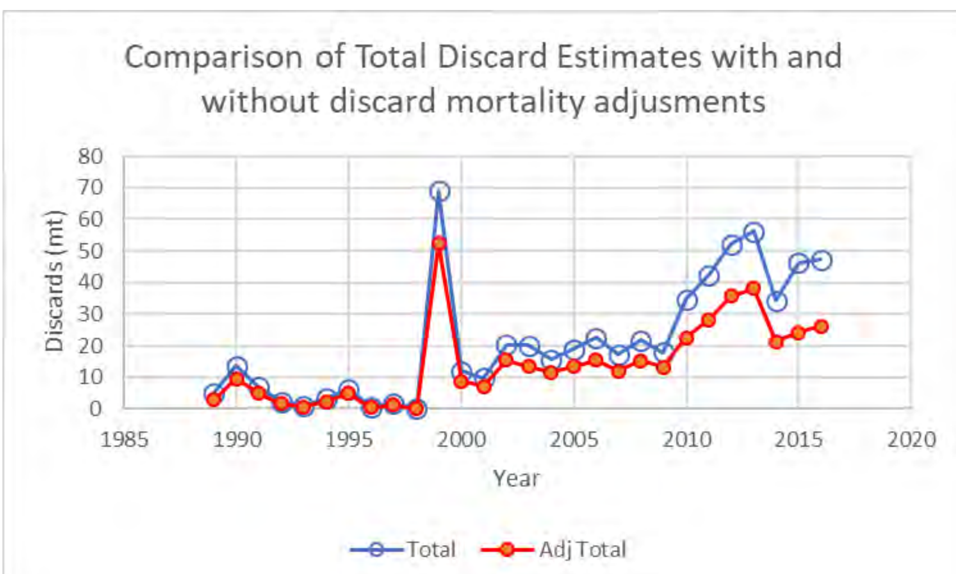

Figure 29. Comparison of total discard estimates based on assumed rates of discard mortality: Trawls 76%, Gill nets 30% and hook gear 10%.

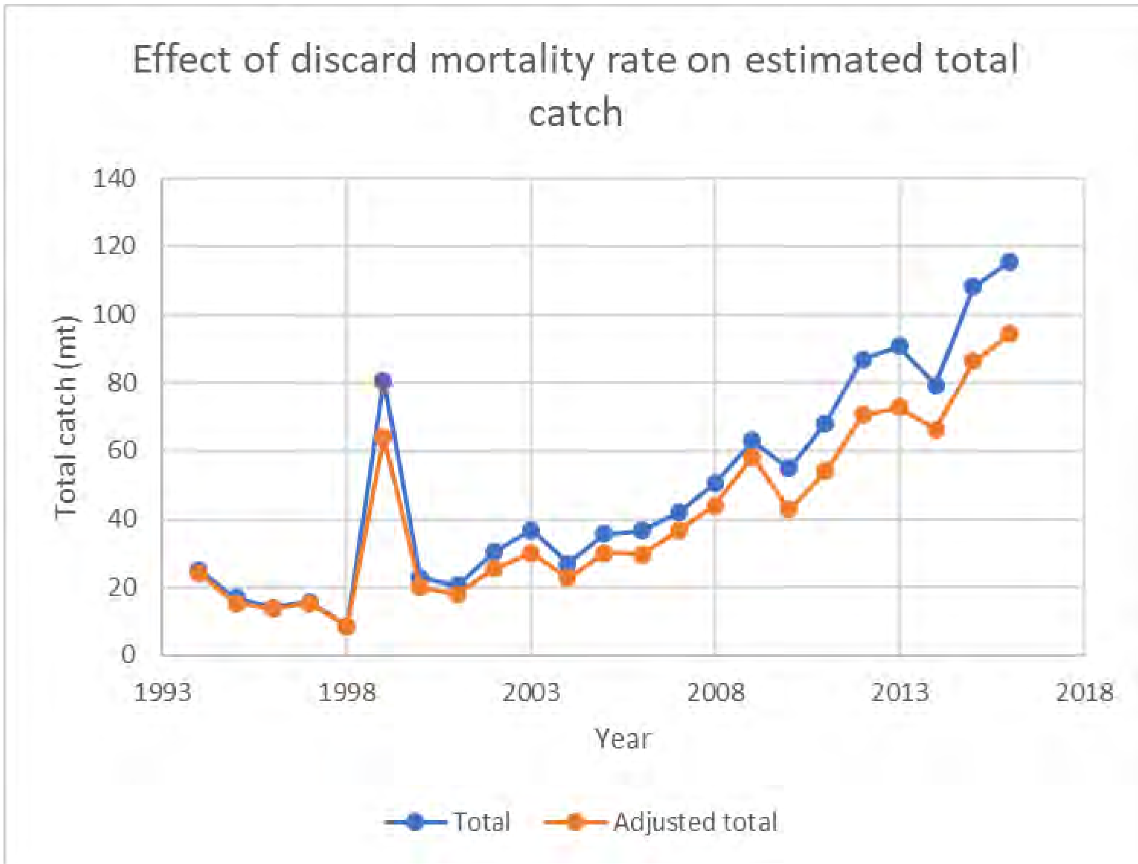

Figure 30. Comparison of total catch estimate based on alternative assumptions about discard mortality. Total assumes 100% mortality, Adjusted total assumes gear specific discard mortality rates of 76% for trawls, 30% for gill nets and 10% for hook gear.

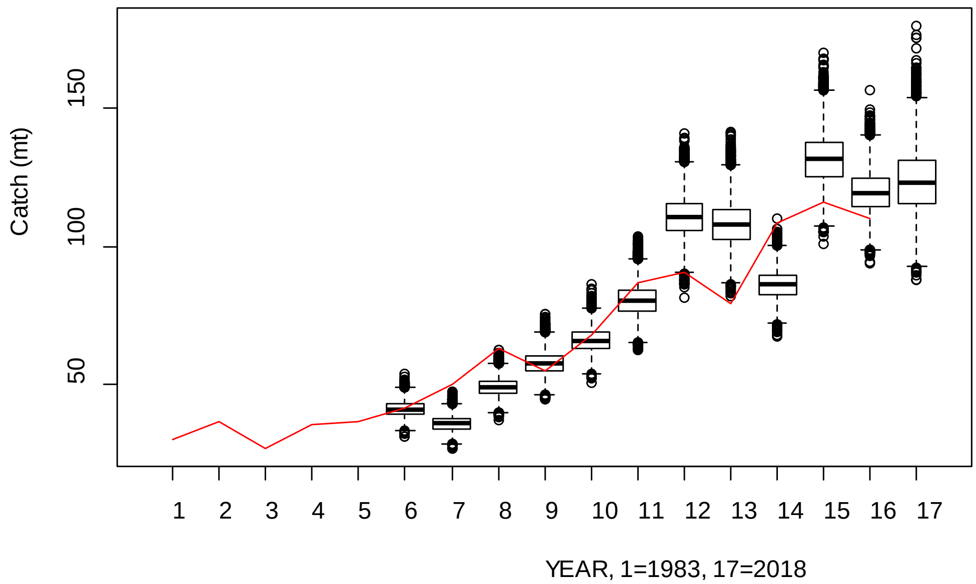

Figure 31. Comparison of observed and predicted distribution of catches for FSD model applied to the US stock **area using total catch to total kept all indices as measures of relative abundance**. Uncertainty estimates are based on a parametric bootstrap method described in the text. The gain parameters for proportional and derivative were set at Kp=0.75 and Kd=0.50, respectively.

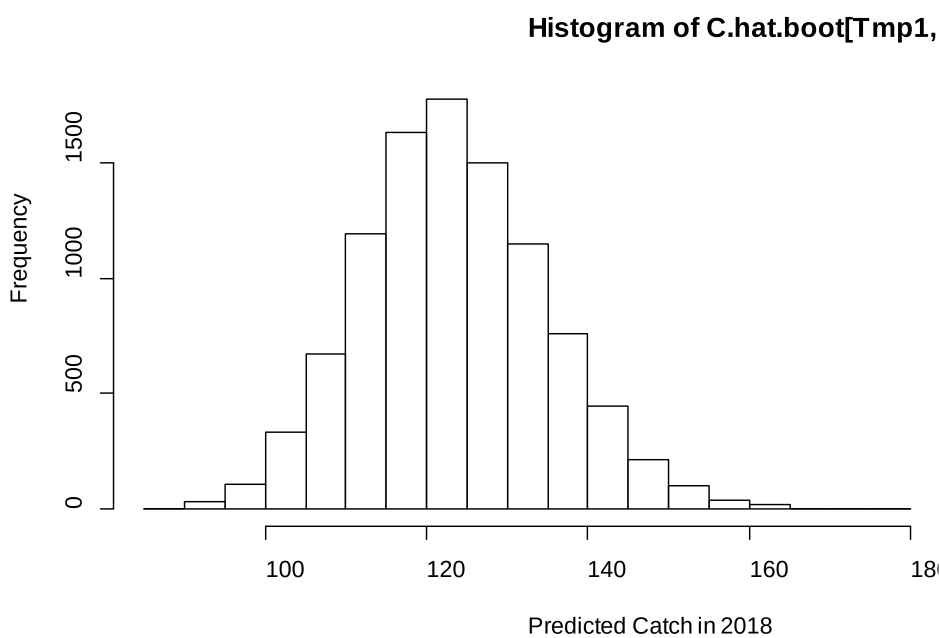

Figure 32. Distribution of forecasted catch for 2018 based on t/k ratio for the US stock area Atlantic halibut. Kp=0.75, Kd=0.5. The model uses t/k ratio for gill nets and trawl trips as measure of relative abundance.

APPENDIX 1. Summary of Input Data considered for use in FSD model for US stock area.

Table 1.1 Summary of average weight per to in the NEFSC bottom trawl survey for fall and spring seasons, 1968-2016.

NEFSC bottom trawl biomass indices (kg/tow)				
Year	Spring B	Spring B_CV	Fall B	Fall B_CV
1963	NA	0	0.0848	0.6024
1964	0	0	0.0669	0.5215
1965	0	0	0.0316	0.5376
1966	0	0	0.0036	1
1967	0	0	0.0086	1
1968	0.1294	0.5851	0.2335	1
1969	0.2363	0.5754	0.4943	0.9433
1970	0.1054	0.7436	0	NA
1971	0.0329	0.7144	0.1393	1
1972	0.0055	1	0.0182	0.8064
1973	0.1129	0.8448	0.1314	0.913
1974	0.1116	0.5555	0.0141	1
1975	0	.	0.0951	0.9542
1976	0.6439	0.9105	0.3775	0.6905
1977	0.1418	0.4812	0.0588	0.699
1978	0.1628	0.7433	0.2943	0.797
1979	0.3565	0.4123	0.04	0.5102
1980	0.5625	0.6764	0.0095	0.7326
1981	0.0659	0.7243	0.3214	0.6741
1982	0.0817	0.7678	0.115	0.862
1983	0.6108	0.5743	0	NA
1984	0.0224	0.8456	0.1237	1
1985	0.063	0.8692	0.1064	1
1986	0	NA	0.3129	0.7392
1987	0.2873	1	0.0328	0.6816
1988	0.0231	1	0.0043	0.9993
1989	0	NA	0.0665	0.6767

NEFSC bottom trawl biomass indices (kg/tow)				
Year	*Spring B*	*Spring B_CV*	*Fall B*	*Fall B_CV*
1990	0.0638	1	0.0596	0.4172
1991	0.0618	0.9497	0.2434	0.829
1992	0.0368	0.6815	0.2007	0.738
1993	0.0058	0.9999	0.0462	0.4607
1994	0.0172	0.9997	0	NA
1995	0.0051	0.7132	0.0661	1.0001
1996	0.0126	0.7075	0.0532	1
1997	0.0626	0.6585	0.1735	0.6996
1998	0.0173	0.6558	0.103	0.5894
1999	0.2394	0.9686	0.0147	0.6154
2000	0	NA	0.0209	1
2001	0.1626	0.8797	0.2474	0.8066
2002	0.128	0.6385	0.0041	1
2003	0.0525	0.9486	0.049	0.5685
2004	0.1676	0.9827	0.1119	0.2902
2005	0.0251	0.6704	0.1105	0.6199
2006	0.383	0.46	0.0312	0.6105
2007	0.1946	0.6034	0.0774	0.6127
2008	0.1005	0.5723	0.0701	0.4966
2009	0.0141	0.4794	0.0633	0.3948
2010	0.0625	0.3045	0.098	0.3592
2011	0.0291	0.667	0.0638	0.4975
2012	0.3418	0.8601	0.1241	0.5256
2013	0.0819	0.5129	0.0331	0.7426
2014	0.0693	0.3737	0.1821	0.5923
2015	0.169	0.5296	0.3011	0.6603
2016	0.2499	0.355	0.0598	0.3691

Table 1.2. Summary of average weight per tow in the Maine-New Hampshire Inshore Survey for fall and spring, 2001 to 2016. Estimates courtesy of Sally Sherman (MEDMR).

Maine-New Hampshire Inshore Survey				
Year	***Spring (kg/tow)***	***CV_spring***	***Fall (kg/tow)***	***CV_fall***
2001	0.49	2.50	0.31	1.32
2002	0.05	1.38	0.08	2.49
2003	0.22	1.16	0.02	0.84
2004	0.29	0.94	0.17	0.83
2005	0.27	0.86	0.12	0.65
2006	0.92	0.90	0.23	0.37
2007	0.52	1.00	0.15	0.88
2008	0.63	1.00	0.28	0.62
2009	0.90	0.75	0.73	0.64
2010	0.63	0.56	0.53	0.92
2011	0.64	0.56	0.53	0.49
2012	0.95	0.55	1.16	0.51
2013	0.39	0.73	0.31	0.45
2014	0.48	1.04	0.40	0.86
2015	0.35	1.62	0.64	1.05
2016	0.59	0.77	0.22	1.49

Table 1.3 Summary of CPUE analyses for Maine logbook data. Standardization model results are courtesy of working paper by Hansell, DeCelles and Cadrin (2017).

Year	Raw CPUE	Model Output/ Standardized CPUE	2 SE for standardized CPUE	Model+2SE	Model-2SE
2002	2.3938	2.4314	0.5691	3.0006	1.8623
2003	0.5306	0.5370	0.9593	1.4963	-0.4223
2004	1.1996	1.2205	0.7039	1.9243	0.5166
2005	1.8928	1.8943	0.6751	2.5694	1.2192
2006	1.3472	1.3562	0.7358	2.0920	0.6204
2007	0.8881	0.8948	0.6098	1.5046	0.2850
2008	1.1387	1.1503	0.6023	1.7527	0.5480
2009	0.7890	0.8009	0.5808	1.3817	0.2201
2010	0.7673	0.7839	0.5832	1.3671	0.2007
2011	1.5123	1.5208	0.5848	2.1056	0.9360
2012	1.5831	1.6115	0.5775	2.1890	1.0340
2013	1.5768	1.6041	0.5787	2.1827	1.0254
2014	1.7945	1.8177	0.5748	2.3926	1.2429
2015	1.5739	1.5739	0.5756	2.1495	0.9984
2016	1.9209	1.9435	0.6355	2.5790	1.3080

Table 1.4. Estimated average **discard to kept all ratios** for observed gill net and trawl fishing trips, 1989-2016, originating from ports in New England (Rhode Island and north). Trips departing from ports in the Mid-Atlantic ports had negligible encounters with halibut over this period.

Discard/kept_all indices										
	gear=100, region=NE						Gear=50, region=NE			
YEAR	***gill net_d/k***	***CV_gill net***	***mean-SE***	***mean+SE***		***YEAR***	***trawl_d/k***	***CV_trawl***	***mean-SE***	***mean+SE***
1989	7.58E-05	0.648	2.66E-05	1.25E-04		1989	0.00002	0.66587	0.00001	0.00003
1990	6.50E-05	0.415	3.80E-05	9.20E-05		1990	0.00007	0.89169	0.00001	0.00014
1991	5.09E-05	0.344	3.34E-05	6.84E-05		1991	0.00002	0.40011	0.00001	0.00003
1992	2.46E-05	0.357	1.58E-05	3.34E-05		1992	0.00001	0.51843	0.00001	0.00002
1993	4.18E-05	0.480	2.17E-05	6.19E-05		1993	0.00000	0.99321	0.00000	0.00001
1994	1.47E-05	0.743	3.78E-06	2.56E-05		1994	0.00001	0.61458	0.00001	0.00002
1995	1.92E-06	1.021	-3.98E-08	3.89E-06		1995	0.00005	0.84180	0.00001	0.00008
1996	5.11E-06	1.064	-3.27E-07	1.05E-05		1996	0.00001	0.67974	0.00000	0.00001
1997	0.00E+00		0.00E+00	0.00E+00		1997	0.00001	0.67339	0.00000	0.00001
1998	7.19E-06	1.013	-9.09E-08	1.45E-05		1998	0.00000		0.00000	0.00000
1999	1.85E-05	0.808	3.55E-06	3.34E-05		1999	0.00101	0.97915	0.00002	0.00200
2000	4.85E-05	0.912	4.26E-06	9.28E-05		2000	0.00011	0.31436	0.00008	0.00014
2001	3.82E-05	1.009	-3.49E-07	7.67E-05		2001	0.00011	0.27023	0.00008	0.00014
2002	0.00E+00		0.00E+00	0.00E+00		2002	0.00022	0.40807	0.00013	0.00032
2003	3.62E-04	0.498	1.82E-04	5.42E-04		2003	0.00012	0.16616	0.00010	0.00015
2004	9.50E-05	0.221	7.41E-05	1.16E-04		2004	0.00017	0.23997	0.00013	0.00021
2005	1.55E-04	0.338	1.02E-04	2.07E-04		2005	0.00019	0.10528	0.00017	0.00020
2006	2.23E-04	0.430	1.27E-04	3.19E-04		2006	0.00022	0.16604	0.00019	0.00026
2007	1.08E-04	0.322	7.29E-05	1.42E-04		2007	0.00015	0.12751	0.00013	0.00016
2008	1.20E-04	0.380	7.47E-05	1.66E-04		2008	0.00017	0.11345	0.00015	0.00019
2009	5.60E-05	0.364	3.56E-05	7.64E-05		2009	0.00023	0.12131	0.00020	0.00025
2010	2.82E-04	0.153	2.39E-04	3.25E-04		2010	0.00045	0.10346	0.00040	0.00050
2011	5.59E-04	0.241	4.24E-04	6.94E-04		2011	0.00065	0.06147	0.00061	0.00069
2012	5.67E-04	0.144	4.86E-04	6.49E-04		2012	0.00096	0.08508	0.00088	0.00104
2013	1.08E-03	0.159	9.10E-04	1.26E-03		2013	0.00110	0.08859	0.00101	0.00120
2014	9.01E-04	0.113	7.99E-04	1.00E-03		2014	0.00059	0.08587	0.00054	0.00065
2015	2.03E-03	0.176	1.67E-03	2.39E-03		2015	0.00050	0.11531	0.00044	0.00056
2016	2.19E-03	0.322	1.49E-03	2.90E-03		2016	0.00068	0.23433	0.00052	0.00084

Table 1.5. Estimated **average total halibut catch (landings +discard) to kept all** ratios for observed gill net and trawl fishing trips, 1989-2016, originating from ports in New England (Rhode Island and north). Trips departing from ports in the Mid-Atlantic ports had negligible encounters with halibut over this period

total catch/kept_all indices										
gear=100, region=NE						Gear=50, region=NE				
YEAR	***gill net_t/k***	***CV_gill net***	***mean-SE***	***mean+SE***		***YEAR***	***trawl_t/k***	***CV_trawl***	***mean-SE***	***mean+SE***
1989	0.0001	0.4948	0.0001	0.0002		1989	0.0002	0.6536	0.0001	0.0003
1990	0.0003	0.3469	0.0002	0.0004		1990	0.0003	0.5359	0.0001	0.0004
1991	0.0003	0.2268	0.0002	0.0003		1991	0.0004	0.3055	0.0003	0.0006
1992	0.0001	0.2631	0.0001	0.0002		1992	0.0006	0.2623	0.0004	0.0007
1993	0.0002	0.3209	0.0001	0.0003		1993	0.0004	0.3417	0.0003	0.0005
1994	0.0001	0.5553	0.0000	0.0001		1994	0.0008	0.2602	0.0006	0.0010
1995	0.0000	1.0207	0.0000	0.0000		1995	0.0008	0.4758	0.0004	0.0012
1996	0.0000	0.8262	0.0000	0.0001		1996	0.0002	0.3312	0.0001	0.0002
1997	0.0000		0.0000	0.0000		1997	0.0001	0.3379	0.0001	0.0002
1998	0.0000	1.0126	0.0000	0.0000		1998	0.0001	0.9919	0.0000	0.0002
1999	0.0000	0.8078	0.0000	0.0000		1999	0.0010	0.9146	0.0001	0.0020
2000	0.0001	0.6977	0.0000	0.0001		2000	0.0002	0.2693	0.0002	0.0003
2001	0.0000	1.0091	0.0000	0.0001		2001	0.0002	0.3038	0.0002	0.0003
2002	0.0000		0.0000	0.0000		2002	0.0003	0.3523	0.0002	0.0004
2003	0.0005	0.4293	0.0003	0.0008		2003	0.0004	0.1332	0.0003	0.0004
2004	0.0002	0.1916	0.0002	0.0002		2004	0.0003	0.1612	0.0003	0.0004
2005	0.0005	0.3640	0.0003	0.0006		2005	0.0004	0.0911	0.0004	0.0004
2006	0.0003	0.3815	0.0002	0.0005		2006	0.0004	0.1285	0.0003	0.0004
2007	0.0002	0.2691	0.0002	0.0003		2007	0.0003	0.1130	0.0003	0.0004
2008	0.0002	0.3584	0.0002	0.0003		2008	0.0004	0.0951	0.0004	0.0005
2009	0.0001	0.4044	0.0001	0.0002		2009	0.0005	0.1029	0.0005	0.0006
2010	0.0004	0.1485	0.0003	0.0005		2010	0.0006	0.0923	0.0006	0.0007
2011	0.0007	0.2017	0.0006	0.0009		2011	0.0009	0.0583	0.0008	0.0009
2012	0.0007	0.1277	0.0006	0.0008		2012	0.0012	0.0767	0.0011	0.0013
2013	0.0015	0.1479	0.0013	0.0017		2013	0.0015	0.0864	0.0014	0.0016
2014	0.0013	0.1040	0.0011	0.0014		2014	0.0009	0.0753	0.0009	0.0010
2015	0.0026	0.1553	0.0022	0.0030		2015	0.0010	0.0917	0.0009	0.0011
2016	0.0028	0.2751	0.0020	0.0036		2016	0.0011	0.1722	0.0009	0.0012

APPENDIX 2. Bootstrap analyses of DFO 3NOPs4WX5Zc

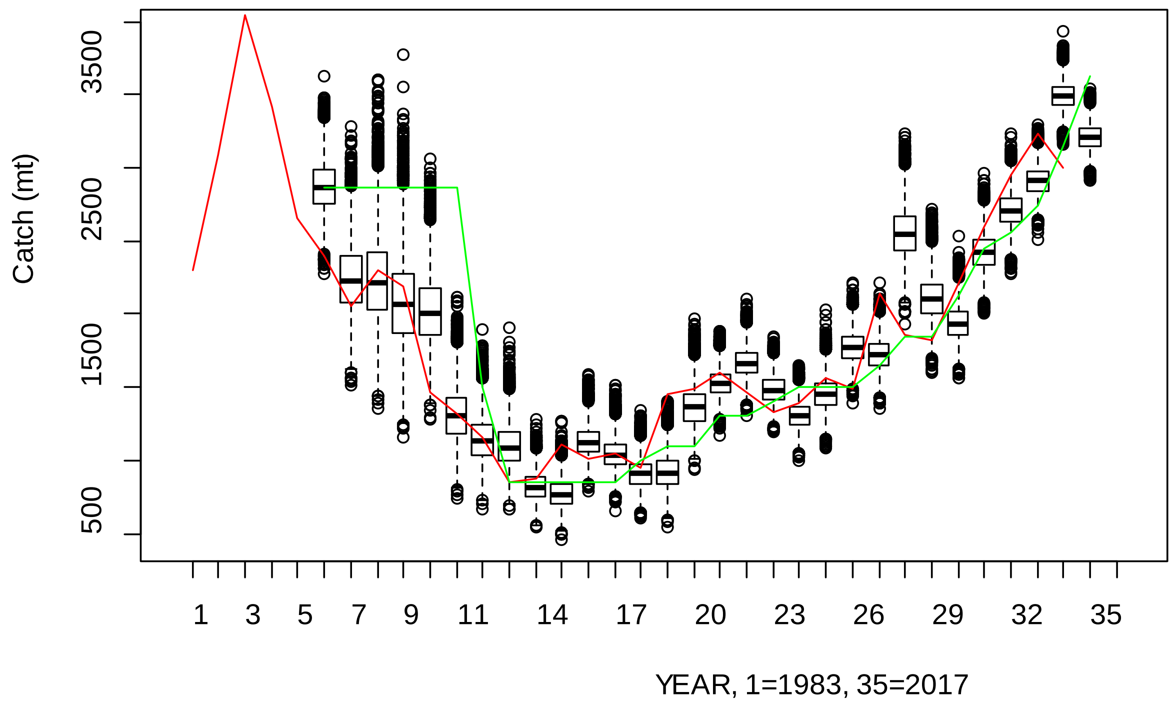

Figure. 2.1 Comparison of observed and predicted distribution of catches for FSD model applied to the DFO 3NOPs4VWX5Zc Uncertainty estimates are based on a parametric bootstrap method described in the text. The gain parameters for proportional and derivative were set at Kp=0.75 and Kd=0.50, respectively. Red line is observed catch. Green line is Canadian TAC.

DFO survey and catch and TAC

1%	5%	10%	25%	50%	75%	90%	95%	99%
3016.2	3070.7	3101.9	3152.2	3211.0	3270.1	3321.4	3355.3	3412.6

Mean=3211.0, CV=0.026

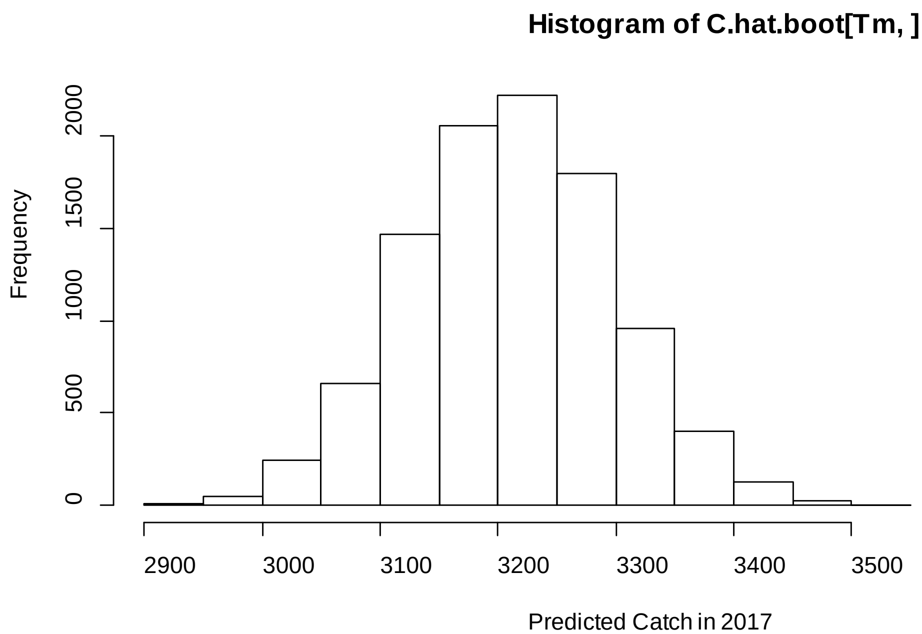

Figure 2.2 Distribution of forecasted catch for 2017. for FSD model applied to the DFO 3NOPs4VWX5Zc Uncertainty estimates are based on a parametric bootstrap method described in the text. The gain parameters for proportional and derivative were set at Kp=0.75 and Kd=0.50, respectively

APPENDIX 3. Comparison of d/k to t/k ratios and implications for assessment.

The following set of graphs and figures represent results of using total halibut catch by weight per weight of total all species combined on observed trips. The t/k ratio was used as a measure of relative abundance instead of the d/k ratio. In general terms the t/k ratio mirrored the d/k ration for both gill nets and trawls (Fig. 3.1 and 3.2)

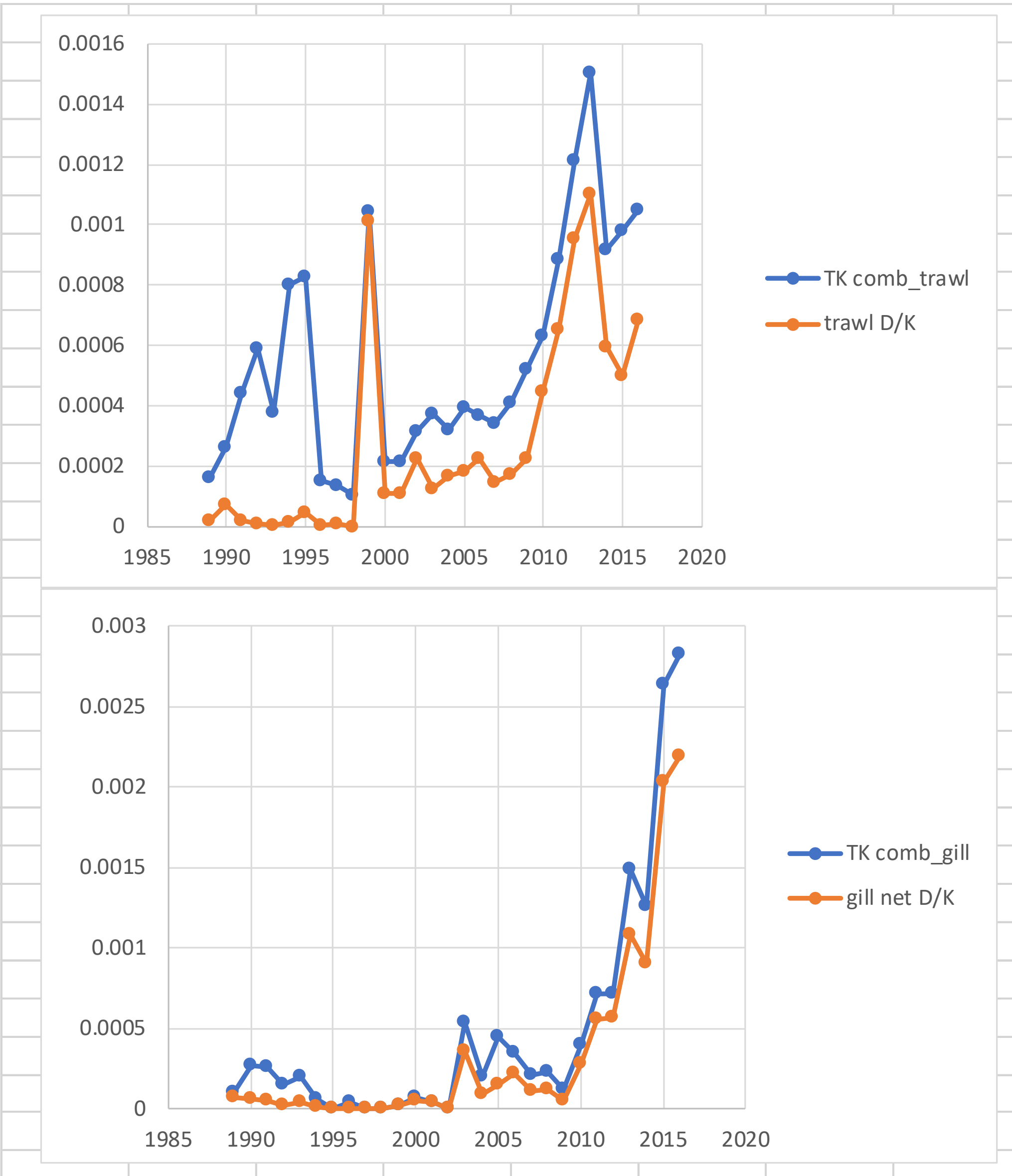

Fig. 3.1 Ratio of discard rates to total catch based on observer data

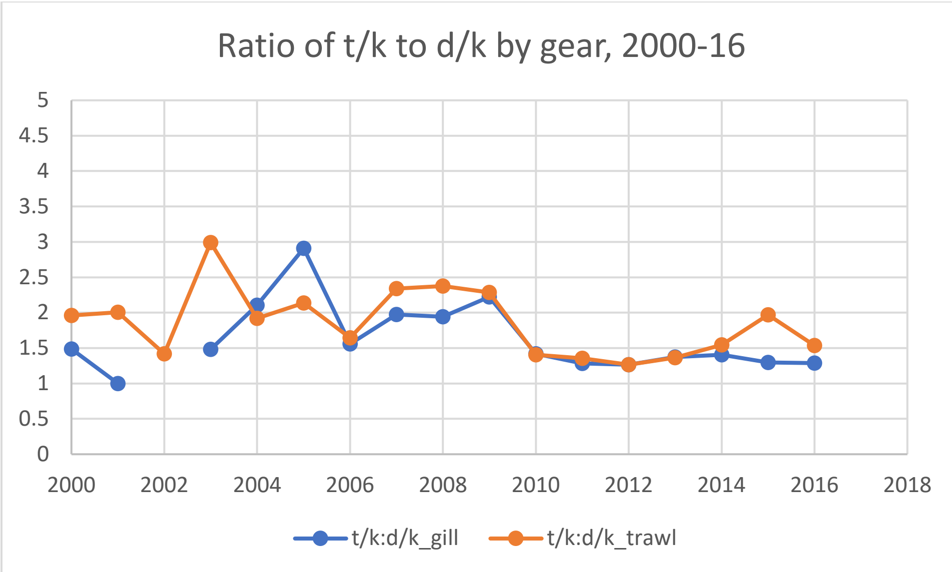

Fig. 3.2 Ratio of t/k to d/k for observed trips on gill net and trawl vessels.

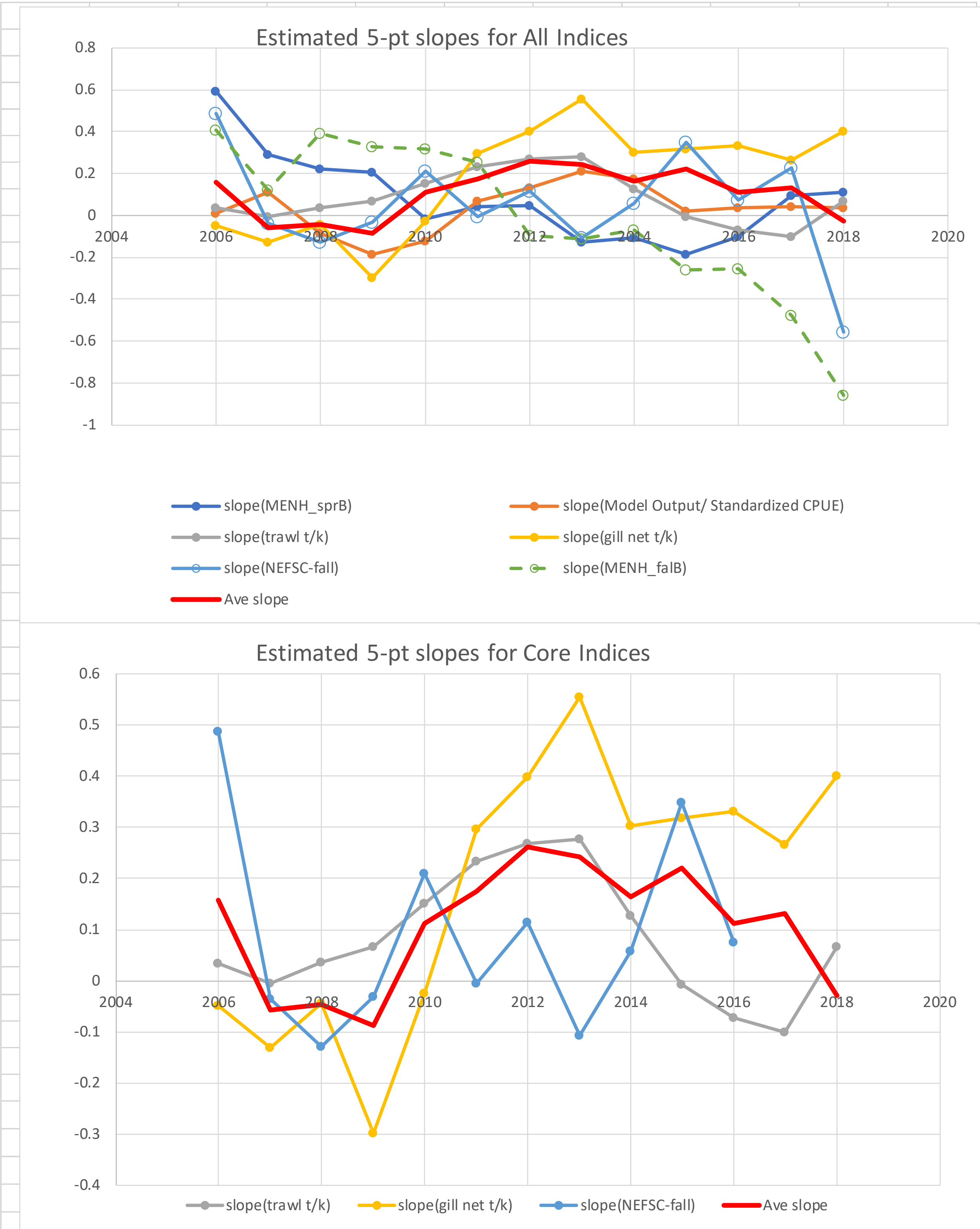

Figure 3.3 Trends in abundance indices based on 5 point regressions. Top plot shows full model with 5 indices. Bottom plot shows reduced model using only existing indices. **Model uses the t/k ratio for gill nets and trawls rather than the d/k ratio as measures of relative abundance**

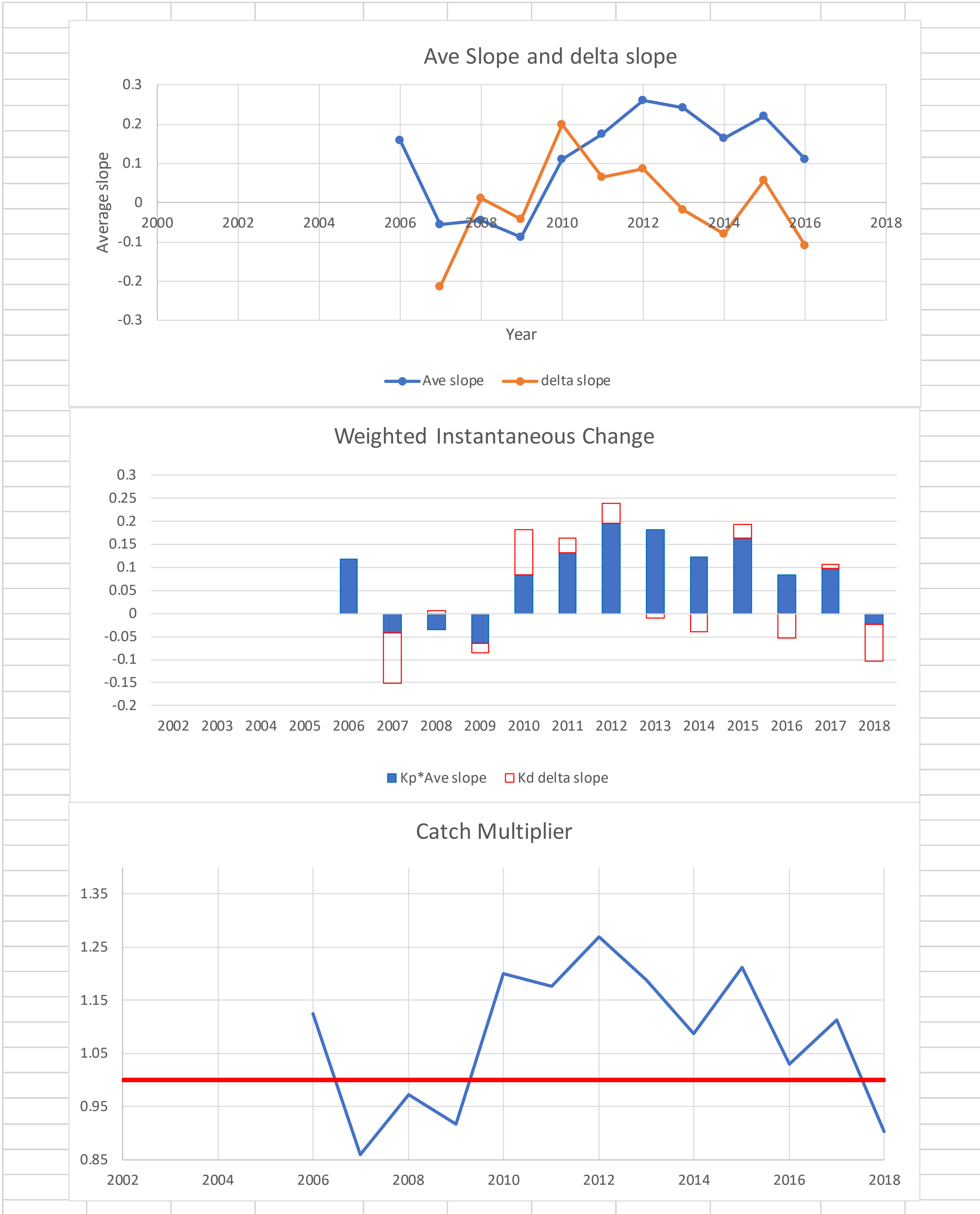

Figure 3.4. Summary of FSD model results for US Atlantic halibut based on d/k trawl, d/k gill net and NEFSC fall survey abundance indices (See Fig. 18 bottom). **Model uses the t/k ratio for gill nets and trawls rather than the d/k ratio as measures of relative abundance** Instantaneous rates of change represent Kp and Kd weighted values of the first and second derivative (top figure). The bottom figure show the Catch multiplier used to forecast catch. . The gain parameters for proportional and derivative were set at Kp=0.75 and Kd=0.50, respectively.

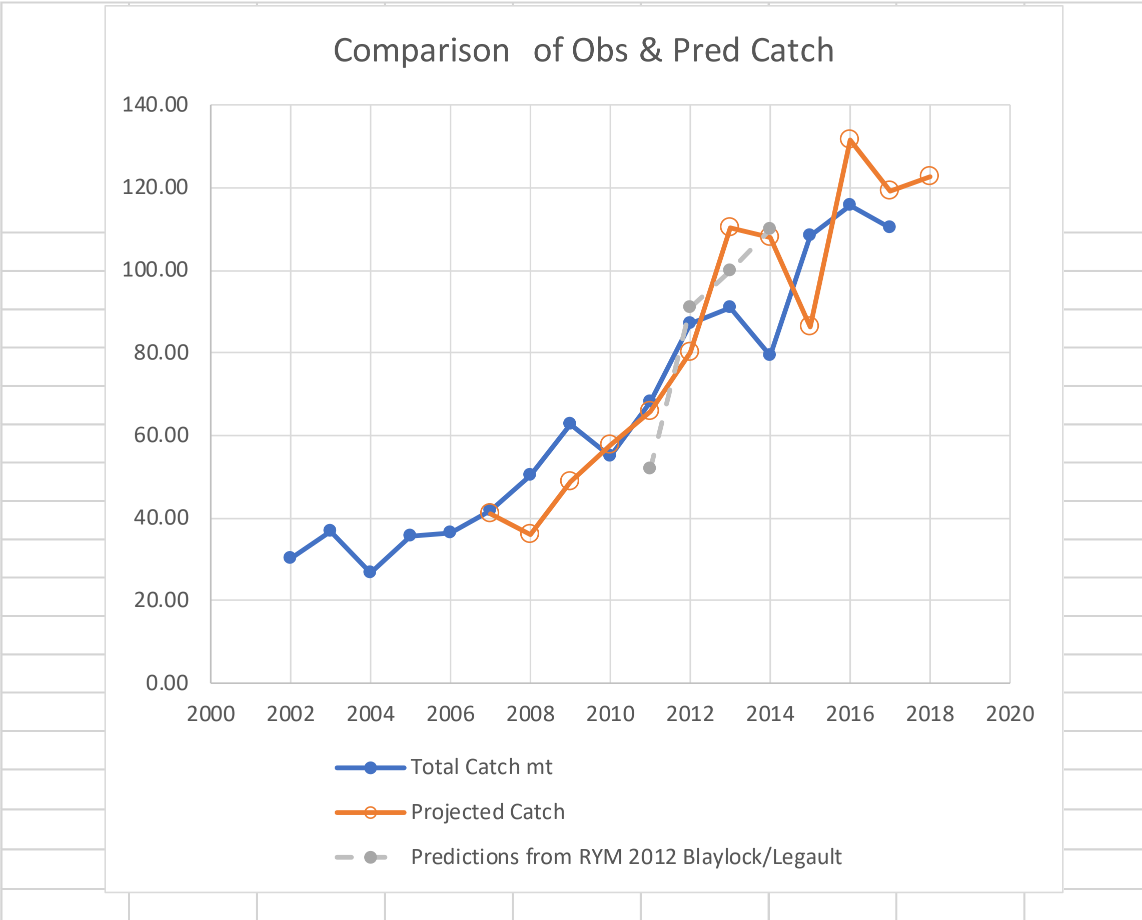

Figure 3.5. Comparison of observed vs predicted catches based on the FSD model applied to US stock area. **Model uses the t/k ratio for gill nets and trawls rather than the d/k ratio as measures of relative abundance**. . Forecasts from RYM application (Blaylock and Legault, 2012) are included for comparison. The gain parameters for proportional and derivative were set at Kp=0.75 and Kd=0.50, respectively.

APPENDIX 4. Summary of variable acronyms used in report.

Variable Name	***Definition***
ME_FAL_B	Average weight per tow in the Maine-New Hampshire bottom trawl survey conducted in Fall, 2001-2016.
ME_SPR_B	Average weight per tow in the Maine-New Hampshire bottom trawl survey conducted in Spring 2001-2016.
DK_GILL	Average ratio of weight of halibut discarded to total weight of all species kept (ie landed) for observed trips on gill net vessels departing from ports in New England Region (Rhode Island and north), 1989-2016.
DK_TRAWL	Average ratio of weight of halibut discarded to total weight of all species kept (ie landed) for observed trips on trawl vessels departing from ports in New England Region (Rhode Island and north), 1989-2016.
TK_GILL	Average ratio of total weight of halibut kept plus discarded to total weight of all species kept (ie landed) for observed trips on gill net vessels departing from ports in New England Region (Rhode Island and north), 1989-2016.
TK_TRAWL	Average ratio of total weight of halibut kept plus discarded to total weight of all species kept (ie landed) for observed trips on trawl vessels departing from ports in New England Region (Rhode Island and north), 1989-2016.
NMFS_SPR_B	Average weight per tow in the Northeast Fisheries Science Center bottom trawl survey conducted in Spring, 1968-2016.
NMFS_FAL_B	Average weight per tow in the Northeast Fisheries Science Center bottom trawl survey conducted in Fall, 1963-2016.
LL_CPUE	Model adjusted estimates of longline fishing catch per unit effort for commercial fishing vessels in Maine, 2002-2016. Based on work of Hansell et al. 2017
MEDISCRAT	Halibut discard rate reported by Maine longline harvesters
CP100TAGS	Total catch of halibut per 100 tags issued by Maine DMR
DFO_FS	Average weight per set for halibut captured in a scientific long line survey conducted jointly by DFO and commercial fishermen, 1998-2016. Fixed stations only. Based on results of GLM.
DFO_CPUE	Average weight per set for halibut reported by commercial fishermen. CI index is just mean and se of all ci sets (600*catchkg/(#hooks)/(DURATION), last reported in data update for 2014 asssessment, 1998-2016
SURV_3NOP	Average number per tow for halibut captured in DFO bottom trawl survey in NAFO area 3NOPs in spring, 1971-2013.
SURV_4VWX	Average number per tow for halibut captured in DFO bottom trawl survey in NAFO area 4VWX in summer,1970-2016
DFO_TOTB	Total biomass estimate derived from analytical model 1970-2013.

2014 TRAC Georges Bank Yellowtail Flounder Diagnostic Review and Empirical Approach Benchmark

SUMMARY –OVERVIEW

A Diagnostic Review and Empirical Approach Benchmark have never been conducted in the TRAC process before. The goal is to explore all sources of data, including those typically not included in stock assessments directly, looking for possible causes of the poor diagnostics in the current VPA for Yellowtail Flounder.

The diagnostic issues from the current assessment can be summarized as: Given the large reductions in catch in recent years, why has the population not responded by increasing abundance and expanding its age structure? The relative fishing mortality rate, computed as the catch divided by any of the three bottom trawl surveys, declined substantially in 1995 and has remained low since. In contrast, the total mortality estimated from the age structure of these same surveys (and confirmed with an independent tagging study) indicated a high and relatively constant level throughout the time series, with perhaps an increase in recent years. These conflicting signals result in a strong retrospective pattern in the current VPA for this stock. Splitting the surveys to alias the source of this conflict initially resolved the retrospective pattern, but the retrospective pattern has returned recently. Additionally, splitting the surveys has resulted in abundance estimates from the VPA which are less than some estimates of the population abundance from independent sources. All three bottom trawl surveys have shown a strong declining trend in recent years despite low catches. Thus, issues to consider as diagnostic problems include: trends in abundance over time, the magnitude of the population, the disparity between trends in F and Z, the lack of expansion in the age structure of the population, the spatial concentration of yellowtail, and the retrospective pattern. These issues are the same ones that led to the 2005 benchmark assessment for this stock.

The Term of Reference for this meeting are:

1) Summarize all available data for Georges Bank yellowtail flounder which can be used to explore possible causes of the poor diagnostics in the current VPA for this stock.

2) Determine which pieces of information are consistent with alternative hypotheses regarding current stock status (e.g., current population is near carrying capacity, current population is near a desired amount, and current population is well below a desired amount).

3) If possible, describe how catch advice could be provided based only on the data (e.g. without relying on a stock assessment model). If feasible, identify and estimate appropriate fishing mortality reference points.

The following summarizes decisions made by the TRAC during the Benchmark.

- **Movement and Distribution** Movement of Georges Bank Yellowtail Flounder outside of stock boundaries is not a likely source for the poor diagnostics in the current VPA formulation.

- **Missing Catch** Examination of the magnitude of change required in the estimated discards or reported landings to explain the amount of missing catch needed to fix the retrospective pattern demonstrated these are unlikely the primary sources of the retrospective pattern.

- There has been a consisten**t aging** of yellowtail that has been verified historically and also recently based on the number of growth marks from tagged and recaptured yellowtail. Issues with age determination do not appear to be a major source of uncertainty in the stock assessment.

- **Natural Mortality** Based on the expected equilibrium age compositions and the range of M values estimated from life history attributes, the TRAC agreed that M =0.2 is likely an underestimate and that an M=0.4 is more consistent with these attributes. *TRAC recommends that the M=0.4 be applied as a sensitivity VPA for the June 1014*

- **Productivity** Several indicators suggest major change in productivity in recent years**.** The most recent survey biomass estimates are among the lowest in the time series and recent recruitment has generally been below average. The Georges Bank Yellowtail Flounder larval index dropped sharply since 2006. Condition factor has been variable but declining since 1998 and fecundity declines with poor condition factor. *TRAC concluded that the stock biomass is low and productivity is poor.*

- **Catchability** Absolute biomass estimates for NEFSC and DFO survey trawl time series will be based on the door spread footprint rather than by the wing spread as done previously. Estimation of biomass based on wing spread is confounded by the herding effect. Empirical estimates of survey efficiency, e.g. whole net efficiency for trawl surveys, should be considered to inform the scale of area swept biomass estimates. Such estimates impose realistic constraints on estimated catchability from the model outputs. *TRAC recommends that door spread swept area biomass estimates be applied in a sensitivity VPA for the June 2014. TRAC also recommends further research to refine estimates of survey gear efficiency.*

- **Absolute Biomass** estimates from surveys or other approaches can be used to inform the plausibility of model estimates, even in cases when the information applies to only part of the stock area. Model results well below the absolute estimates can be used to reject model results, but only when uncertainty in both estimates indicates a real difference. *TRAC agreed that the empirical estimates of biomass should be used to inform and evaluate consistency of VPA biomass estimates*

- There is **gear avoidance** in all surveys. Catchability should always be assumed to be less than one for whole gear. Preliminary analyses indicate there is gear avoidance by yellowtail flounder even during HABCAM surveys, in which catchability has previously been assumed to be 1.0.

- **Biomass Estimation and Exploitation** TRAC agreed to use time series from 1995 forward for interpretation of biomass estimated in the empirical approach. Current biomass will be estimated as the average of the estimated absolute biomass from the NMFS spring and DFO bottom trawl surveys from year *i* and the NMFS autumn bottom trawl survey from year *i-1*. Although these are multi-species surveys, these are the only surveys that sample the entire stock area. A Mass Balance Approach was developed that reconciles time series of survey biomass, catch, survey based total mortality, and individual growth. This approach estimates that M has ranged between 0.8 and 2.0 since 2009. This M represents all losses other than those due to estimated catch. The exploitation rate is calculated as catch/the average of the survey biomasses.

  This method was used to guide the selection of an appropriate harvest rate based on yield per recruit analyses. The target *exploitation rate*, based on the ratio of yield per recruit / total biomass per recruit over a range of M = 0.4 to 1.1, ranged between 0.24-0.27 at $F_{0.1}$ and between 0.22-0.24 at $F_{40\%}$ and is estimated to be = 0.25 (averaged over all 16 values).

- **Catch advice** will be based on the current average biomass described above, the target exploitation rate and qualitative criteria (e.g. is there convincing evidence that the stock is increasing or decreasing; is recent recruitment above or below average, etc.). In the current year *y*, the catch is being set for the next fishing year, *y* +1, without making projections for population dynamics (e.g. catch, survey catch, recruitment, weight at age, selectivity) in year *y*.

Proposal for a Transboundary Resource Assessment Committee Benchmark of the Georges Bank Yellowtail Flounder Empirical Approach

National Marine Fisheries Service
Northeast Fisheries Science Center
Population Dynamics Branch
Woods Hole, MA 02543

January 14, 2014

In December 2013 the Population Dynamics Branch of the Northeast Fisheries Science Center (NEFSC) finalized a proposal to develop an empirical approach for estimating abundance and setting catch limits for Georges Bank yellowtail flounder. The empirical approach will evaluate all relevant data sources with respect to their support for alternative hypotheses on stock status and, if possible, their directional impact on catch advice (Attachment #1). Drafts of the proposal have been considered by scientists within the NEFSC, staff at the Northeast Regional Office (NERO), members and staff of the New England Fishery Management Council (NEFMC), and colleagues at the Department of Fisheries and Oceans (DFO), Canada. Various concerns have been raised about the proposal including questions about the methodology, the process for review, and how it will be used to formulate catch advice. Management advice for this stock is determined by negotiation within the Transboundary Management Guidance Committee (TMGC), a bilateral understanding between the US and Canada and translated into fishery regulations by each country's authorized organizations. As such, it is important to have a mutually acceptable process for convening and vetting the scientific basis for the catch advice. Discussions between scientific staff and NEFSC and DFO have led to a proposal in which the Empirical Approach would be reviewed as a "diagnostic benchmark" within the Transboundary Resource Assessment Committee (TRAC).

Attachment #1 is a general outline of how a TRAC benchmark would be conducted and a discussion of the merits of such an approach. A TRAC Benchmark review would occur April 14th-18th, 2014 in Woods Hole with participation from US and Canadian scientists, academics, interested parties from both countries, and a number of external reviewers selected and supported by both countries. The Terms of Reference (TOR) for the meeting will be restricted to evaluation of information relevant to the estimation of biomass and age composition from various data sources. The TRAC benchmark will not be a forum for introduction of alternative stock assessment models. That review has already taken place at the 2013 International Council for the Exploration of the Seas (ICES) Strategic Initiative for Stock Assessment Methods (SISAM) meeting in Boston. Analyses by leading scientists from around the world demonstrated that further consideration of alternative stock assessment models was unlikely to reveal the underlying causes for the lack of model fit. Lack of fit, presumably due to one or more changes in the data, or assumed or estimated parameters, was a common feature in all models. The SISAM review suggested that stock assessment models were not sufficient to uniquely identify such changes. Instead, a focus on external information would be an appropriate approach to explore problems in model diagnostics and retrospective patterns. The TRAC "diagnostic" benchmark would address these concerns directly but we acknowledge that this departs from the conventional understanding of benchmark assessments.

A diagnostic benchmark assessment through the TRAC will follow well-established and understood conventions for evaluating the scientific basis for catch advice within the US-Canada understanding (Attachment #2) and ensure participation by Canadian colleagues. A diagnostic benchmark also allows for a more thorough external review of the proposed approach and increase the likelihood that it can be used for management. In Attachment #3 we provide draft terms of reference for consideration.

Attachment #1

An Empirical Approach to Setting Catch Limits for Georges Bank Yellowtail Flounder

Problem Statement: The stock assessment for Georges Bank yellowtail flounder suffers from a severe retrospective pattern. Likely causes of the retrospective pattern include misreporting of landings, underestimation of discards, or increases in natural mortality. Unfortunately neither the model nor ancillary evidence is sufficient to distinguish among these competing hypotheses. In the absence of unequivocal evidence, there is no expectation that an update of the current assessment approach will alleviate any of the concerns raised about this assessment. Independent reviews and tests of alternative models by stock assessment scientists at the recent ICES World Conference on Stock Assessment Methods failed to find acceptable alternatives. All of the models suggested that a change in the underlying data or assumed magnitude of natural mortality had occurred, although none of the models could identify a proximate cause. Given the continuing need for stock assessment advice and the likely futility of identifying the perfect model, we propose a new approach that relies heavily on contemporary information. In pursuing this new path, it must be recognized that some of the desirable features of stock assessment models, such as biomass reference points, rebuilding strategies, and forecasting, will be given up. Instead, the approach will focus on a more narrowly defined question of "What is the appropriate level of harvest in the upcoming fishing year?"

Technical Details: There are conflicting signals in the data. Survey trends indicate a rapid increase in the population from the mid 1990s through early 2000s followed by a slower decline. Age distributions from the surveys indicate high total mortality rates throughout the entire time period. Recent tagging studies confirm this high total mortality rate during 2003-2006. Catches have markedly declined in recent years. Dividing the catch time series by the survey time series produces a simple relative fishing mortality rate that shows high values in the 1970s, 1980s, and early 1990s then a sharp decline in 1995 to low levels since then. There is no evidence of a change in natural mortality rate, although fish condition (weight at length) has declined from the early 1990s through recent years. The conflict in the data arises because surveys suggest a high and steady total mortality (Z) despite a large sudden decline in relative fishing mortality (F) in recent years. When natural mortality (M) is assumed to be low and constant the current total mortality (Z) is much greater than F plus M, when in fact Z should exactly equal F plus M.

Proposed Solution: Given the aforementioned concerns, an entirely empirical approach could be used instead. This approach would be based strictly on the data observations: surveys, catch, and any empirical information available. No model would be used beyond Z = F + M.

Instead, the implications of different assumptions regarding recent natural and fishing mortality rate would be explored systematically to demonstrate the potential impact of different catch advice along with notes about the implications of these changes. The proposed method would use as much contemporary information as possible but require that proposed catch levels were logically consistent with the underlying hypotheses used to generate the abundance estimate.

Proposed Process for Georges Bank Yellowtail Flounder Empirical Approach

At its June 2013 meeting, TRAC agreed that a full conventional benchmark for yellowtail flounder was not feasible given the absence of any new data series and that the decision would be reconsidered pending the results of the July 2013 ICES World Conference on Stock Assessment Methods. The ICES Conference subsequently confirmed that none of the models tested provided unequivocal measures of stock abundance. The empirical approach presented here is considered a more complete analysis of the "trends in relative abundance and relative mortality rates derived from survey and fishery data" recommended as part of the benchmark formulation for this stock (Gavaris et al. 2005). However, since this approach is an expansion of the 2005 benchmark, further peer review is warranted. To meet this need we propose to conduct a diagnostic benchmark following the TRAC benchmark review process.

Development of the empirical approach will require close coordination with industry, academic and government partners. Prior to a TRAC integrated peer review, a series of informal meetings will be held with these partners to describe the proposed process and to more fully understand field experiments that may contribute to the formulation of biomass estimates. These meetings will be designed to explore the evidence with the same rigor applied when developing stock assessment models (See Term of Reference 1 in Attachment #3). The scope and timing of these meetings has not been determined but will be dictated by the current schedule of assessments for the Population Dynamics Branch and availability of Canadian colleagues. Following these informal meetings an integrated peer review will be held April 14th-18th, 2014 to examine the data analyses conducted for the empirical approach. Meeting participants will include TRAC members, NEFSC, DFO, and state scientists, academics, Council staff, industry stakeholders and invited external reviewers. The purpose of the peer review diagnostic benchmark is to determine if the empirical approach has correctly evaluated and summarized the available data for Georges Bank yellowtail flounder (See Term of Reference 1 in Attachment #3). One of the most challenging Terms of Reference is TOR 2 in which the consistency of alternative hypotheses will be evaluated. The meeting will address how the empirical approach could be used for catch advice but will not actually derive catch advice (See Term of Reference 3 in Attachment #3).

At the June 2014 TRAC meeting, the recommendations from the diagnostic benchmark meeting will be used to derive catch recommendations. Depending upon the outcome of the benchmark, results will either be considered alone as a basis for catch advice or considered along with the current virtual population analysis (VPA) modeling results and relevant VPA sensitivity runs as have been conducted in the past[1]. The TRAC will synthesize all the available information to provide its recommendation on catch advice to the TMGC.

Gavaris, S., R. O'Boyle, and W. Overholtz. 2005. Proceedings of the Transboundary Resources Assessment Committee (TRAC) Benchmark Review of Stock Assessment Models for the Georges Bank Yellowtail Flounder Stock. TRAC Proceedings 2005/01. 36 p.

[1] An earlier draft document generated some concern regarding how the empirical approach might be used. This is due to the following statements in that draft: *"This would require TRAC rejecting the benchmark assessment model formulations and relying on the benchmark recommendation of using survey and catch information to generate catch advice. Thus, a benchmark would not be required…".* This wording reflects only one possible way in which the TRAC could synthesize all the information according to the benchmark formulation, but is not the only way (as noted by use of the words could and would in this section of the document). Other outcomes include placing more emphasis on the VPA results for catch advice, or using a blended approach of relying on some aspects of the VPA results but not the exact numbers, as has been done by TRAC in the last two years. The expectation is that the empirical approach will more clearly demonstrate the conflicts among the data sources for the Georges Bank yellowtail flounder stock and lead to a better understanding by scientists and managers about why modeling this stock has been so challenging.

Appendix: Technical Details for Proposed Solution

Given the uncertainties described above, current catch data and assumed levels of natural mortality can no longer be used to compute stock size estimates consistent with abundance measures derived from synoptic surveys. A new approach is proposed that relies on analyses of contemporary data and evaluation of alternative hypotheses. These hypotheses will be evaluated with respect to their internal consistency and with respect to their implications for other factors. A mass balance approach will be used to illustrate the implications of alternative estimates of stock size on the likely magnitudes of unreported landings, discard mortality, non-catch mortality, and natural mortality. For parameters that can be bounded but not estimated (e.g. trawl efficiency, post release survival of tagged fish, fraction of stock in Canada, etc.) sensitivity analyses will be used to construct profiles of stock sizes consistent with plausible hypotheses.

Some approaches that may prove useful include

1. Synoptic swept area estimates of abundance from multiple NEFSC and DFO surveys
2. Swept area estimates of abundance over a limited spatial domain, (e.g., 2013 cooperative survey)
3. Gear comparison studies of roller vs. cookie sweep gear conducted under Cooperative Research program
4. Cohort and static catch curves to estimate total Z
5. Long term tagging studies (Wood and Cadrin) to estimate survival rates
6. Short term tagging studies (Peterson estimate by Melgey) to estimate abundance
7. Analyses of condition factor and weights at age as predictors of natural mortality.
8. Sensitivity analyses of potential impacts of mortality from disease (*Ichthyophonus*) or predators (seals?).
9. Seasonal variation in abundance from Cooperative Research/RSA projects.
10. HabCam-based estimates of relative density.

The basic model of abundance would be based on empirical measures of abundance and assumed parameters as follows

$$N = \frac{A_d}{ap_d}\frac{I_t}{e}$$

Where **N** is the estimated total population , $\mathbf{I_t}$ is the index of abundance expressed as numbers or weight per tow, $\mathbf{A_d}$ is the total area within the sampling domain, a is the average area swept per tow, $\mathbf{p_d}$ is the fraction of the total area within the population domain, (*i.e.,* $\mathbf{p_d=A_d/A}$ where **A** is the total area where the stock resides), and **e** is the efficiency of the gear, expressed as probability of capture given encounter.

Some of these parameters are unknown or poorly known. An objective of the evaluation would be to develop realistic empirical bounds on efficiency derived from comparative experiments and to use survey indices to derive estimates of the fraction of total stock within US waters. The uncertainty in the unknown parameters and the sampling variability in the observations would be fully incorporated into overall abundance estimates.

Mortality estimates derived from catch curves and tagging studies would be compared to estimated catches and assumed values of M to create a similar range of population estimates. It is hoped that this piecewise construction of population estimates can be used to identify a range of plausible values for unknown parameters. A mass balance approach will be used to identify the magnitude of missing removals consistent with the swept area biomass estimates and the known removals via landings and discards.

The sampling distribution of population size would be carried through to create a distribution of catches consistent with the population estimates. Several approaches could be used. One approach would be a status quo method that multiplies the estimated abundance by the ratio of catch to relative biomass in recent years. Uncertainty in the estimate of the relative F could be propagated to develop a broad measure of uncertainty in the suitable catch level. Another approach that may be useful is to use an F derived from a yield per recruit analysis. An important aspect of this analysis would be the uncertainty in the discard rate and natural mortality rate. One would focus on predicted magnitude of landings, discards, and natural deaths to gauge their plausibility. Thus, catch advice would not be provided based on a standard assessment approach formula, but rather have to be agreed to by the TRAC (and SSC) given a range of possible quotas and plausible outcomes associated with each possible quota. Feedback from one year to the next in terms of responses in the fishery catch, survey time series, survey age structure, and other pieces of information would be an important component of this approach.

One potential advantage of this approach is that it might give participants a better understanding of the piecewise components of the assessment model. It might also create buy-in and acceptance from constituents who otherwise feel disenfranchised. It is also possible that none of these goals will be achieved, but we do not expect much acceptance from solely pursuing another update or, convening a conventional benchmark.

Attachment #2

Criteria for Evaluation and Modification of TRAC Benchmark Assessments [2]

At the April 2013 TRAC Benchmark meeting the following term of reference was addressed:

"Discuss criteria to determine:
1) When a benchmark assessment should be conducted and
2) What degree of modification is acceptable to make to benchmark model formulation during an update assessment."

The TRAC concluded the following:

"Without new information or modeling approach, requesting a benchmark would not be productive. During a TRAC update, changes to a benchmark model formulation would be presented as a sensitivity run and evaluated to see if a future benchmark would be required based on points outlined below. In all future TRAC assessments, a cumulative summary of changes to the current benchmark model will be included in the assessment research document.

1. Accumulation of data changes result in substantial change in catch advice relative to the benchmark formulation.
2. Change in either data or model results in substantial change in perception of stock size or stock structure.
3. On a regular basis, e.g. every five years, evaluate whether a benchmark review would be justified.
4. New data becomes available, e.g., new survey, that would affect model results.
5. Model results are inconsistent with observations; poor diagnostics.

In a TRAC update, if a sensitivity run suggests that a benchmark is required, the TRAC will present catch advice for both models with rationale as to why the sensitivity run would be preferred in the interim."

[2] *Based on excerpt from :* Claytor R. and L. O'Brien. editors. 2013. Transboundary Resources Assessment Committee Eastern Georges Bank cod benchmark assessment and TRAC Benchmark Criteria Discussion. TRAC Proceedings 2013/x, in review

Attachment #3

Draft Terms of Reference for TRAC Georges Bank Yellowtail Flounder Diagnostic Benchmark 2014

In the 2013 TRAC Status Report (TSR) the following Special Comments were provided:

> *The TRAC acknowledges that the assumptions made about population dynamics in the model do not fully capture the trends in the data. However, the model's conclusion that stock conditions are poor is valid.*
>
> *There is a continued need to conduct research to limit the possible causes for the retrospective bias exhibited in this assessment.*

In response to these comments, the 2014 benchmark meeting is designed to explore all the data available for Georges Bank yellowtail flounder, including data that cannot easily or feasibly be incorporated in a stock assessment model. The purpose of this exploration is to evaluate possible sources of the poor diagnostics exhibited by the current Virtual Population Analysis (VPA). The work to be reviewed during this 2014 benchmark extends the 2005 benchmark assessment which recommended consideration of "trends in relative abundance and relative mortality rates derived from survey and fishery data" (Gavaris et al. 2005). The 2014 diagnostic benchmark will not examine alternative stock assessment models. Such an examination was conducted during the ICES World Conference on Stock Assessment Methods (July 2013, Boston, MA) where no model was found that performed well relative to all the data. As such, the following terms of reference are strictly limited to exploration of the data.

<u>Terms of Reference</u>

1) Summarize all available data for Georges Bank yellowtail flounder which can be used to explore possible causes of the poor diagnostics in the current VPA for this stock.
2) Determine which pieces of information are consistent with alternative hypotheses regarding current stock status (e.g., current population is near carrying capacity, current population is near a desired amount, and current population is well below a desired amount).
3) If possible, describe how catch advice could be provided based only on the data (e.g. without relying on a stock assessment model).

Date of the benchmark meeting: Week of April 14, 2014.

All individuals interested in presenting a working paper for this meeting must contact the US and Canada Co-Chairs no later than February 10, 2014 to indicate their intention to present and to identify their intended topic. Working papers will be due 2 weeks prior to the meeting, so the deadline to submit working papers will be March 28, 2014. Authors must be present at the meeting or via webex to present their working papers. Failure to adhere to these TRAC protocols will result in the working paper being excluded from the meeting agenda. These protocols are designed to allow sufficient time for meeting participants to review the material and to ask questions of the authors during the meeting.

Gavaris, S., R. O'Boyle, and W. Overholtz. 2005. Proceedings of the Transboundary Resources Assessment Committee (TRAC) Benchmark Review of Stock Assessment Models for the Georges Bank Yellowtail Flounder Stock. TRAC Proceedings 2005/01. 36 p.

16 Gulf of Maine - Georges Bank windowpane flounder

Toni Chute

This assessment of the Gulf of Maine - Georges Bank windowpane flounder (Scophthalmus aquosus) stock is an operational update of the 2015 assessment which was based on survey and fishery data through 2014 (NEFSC 2015). Based on the 2015 assessment the stock was overfished, but overfishing was not ocurring. This assessment updates commercial fishery catch data, survey biomass indices, AIM model results, and reference points through 2016.

State of Stock: Based on this updated assessment, the Gulf of Maine - Georges Bank windowpane flounder (*Scophthalmus aquosus*) stock is overfished but overfishing is not occurring (Figures 78-79). Retrospective adjustments were not made to the model results. The mean NEFSC fall bottom trawl survey index from years 2014, 2015 and 2016 (a 3-year moving average is used as a biomass index) was 0.359 kg/tow which is lower than the $B_{Threshold}$ of 1.030 kg/tow. The 2016 relative fishing mortality was estimated to be 0.222 kt per kg/tow which is lower than the F_{MSY} *proxy* of 0.340 kt per kg/tow.

Table 48: Catch and model results table for Gulf of Maine - Georges Bank windowpane flounder. All landings and discard weights are rounded to the nearest metric ton. Biomass index is in units of kg/tow, and relative F is in units of kt per kg/tow (catch in kt per kg/tow of the survey index).

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Data										
Commercial discards	974	329	412	235	180	198	355	215	187	85
Commercial landings	117	46	28	0	0	1	0	0	0	0
Total catch	1,091	376	440	236	180	199	355	215	188	85
Model Results										
Biomass index	0.524	0.448	0.442	0.467	0.433	0.343	0.518	0.535	0.536	0.36
Relative F	2.079	0.849	0.996	0.514	0.416	0.584	0.676	0.393	0.354	0.222

Table 49: Reference points estimated in the 2015 assessment and in the current assessment update. F_{MSY} *proxy* is in units of kt per kg/tow.

	2015	2017
F_{MSY} *proxy*	0.450	0.340 (0.009 - 0.659)
B_{MSY} *proxy* (kg/tow)	1.554	2.060
MSY proxy (mt)	700	700
Overfishing	No	No
Overfished	Yes	Yes

Special Comments:

- What are the most important sources of uncertainty in this stock assessment? Explain, and describe qualitatively how they affect the assessment results (such as estimates of biomass, F, recruitment, and population projections).

  Even though estimated catch has decreased in recent years, the survey index has not shown any resulting increase despite evidence of regular recruitment from survey length frequencies. Since there has been a 'no possession' rule in place since 2010, almost 100% of catch has consisted of estimated discards. These estimates have a higher CV than those for the southern stock but are still fairly low at a mean of 0.124 since 2010 so it is unlikely discards are being poorly estimated. Removals by Canadian fisheries occur from the northern stock area and are not used as a catch component in the model. Using them, especially if they have changed over time, might improve the model fit, which is not as good as the southern stock.

- Does this assessment model have a retrospective pattern? If so, is the pattern minor, or major? (A major retrospective pattern occurs when the adjusted SSB or F_{Full} lies outside of the approximate joint confidence region for SSB and F_{Full}).

  The AIM (An Index Model) model used to estimate status of this stock does not allow estimation of a retrospective pattern.

- Based on this stock assessment, are population projections well determined or uncertain? If this stock is in a rebuilding plan, how do the projections compare to the rebuilding schedule?

  The GARM benchmark indicated that projections should not be made based on discards, so no projections are run for windowpane flounder. Northern windowpane flounder was supposed to be rebuilt by 2017, however the 2008 GARM report states 'Given that current catch is mostly incidental and also given the high uncertainty of index based assessments, it was concluded that it was not appropriate to calculate F rebuild for this stock'.

- Describe any changes that were made to the current stock assessment, beyond incorporating additional years of data and the effect these changes had on the assessment and stock status.

  No changes were made to the Gulf of Maine - Georges Bank windowpane flounder assessment for this update other than the incorporation of 2015 and 2016 NEFSC fall bottom trawl survey data and 2015 and 2016 U.S. commercial landings and discard data.

- If the stock status has changed a lot since the previous assessment, explain why this occurred.

  The stock status of Gulf of Maine - Georges Bank windowpane flounder has not changed since the previous assessment. In 2015, the F status changed from overfishing to no overfishing.

- Provide qualitative statements describing the condition of the stock that relate to stock status.

  Since the year 2000, Gulf of Maine - Georges Bank windowpane flounder has shown decreasing survey indices despite reductions in catch and relative F levels, and the model output replacement ratio for 2016 was only 0.68. The stock was declared overfished in 2007 (the final year of data for GARM 2008) and was scheduled to be rebuilt by 2017, but the stock still remains below the biomass threshold. According to 21.6, windowpane flounder has low *overall climate vulnerability and both males and females are currently showing high condition indices. There are also new recruits regularly present in the fall bottom trawl survey catches.*

- Indicate what data or studies are currently lacking and which would be needed most to improve this stock assessment in the future.

  While the Gulf of Maine - Georges Bank windowpane flounder AIM model fit is reasonable (the relationship between ln(relative F) and ln(replacement ratio), a measure of the relationship between catch and survey index values, has a p-value of 0.11) there may be catches (such as from the Canadian groundfishery on Georges Bank), discards, or incidental mortality unaccounted for in the model. The fit might be improved in the future by estimating additional sources of mortality or removal from the population that may be increasing over recent years. There may also be value in looking carefully at the windowpane stock definitions to see if there might be reason to change them. For the last several years the NEFSC has been collecting otoliths from northern windowpane during the fall survey and we now have several year's worth of ages, enough to explore an age-based model such as ASAP which could provide insight into the population dynamics of northern windowpane.

- Are there other important issues?

  None.

16.1 Reviewer Comments: Gulf of Maine - Georges Bank windowpane flounder

Assessment Recommendation:

The panel concluded that the operational assessment was acceptable as a scientific basis for management advice.

Alternative Assessment Approach:

Not applicable

Status Recommendation:

Based on this updated assessment, the panel agrees with the conclusion that the Gulf of Maine-Georges Bank windowpane flounder stock is overfished but overfishing is not occurring. Since the year 2000, Gulf of Maine-Georges Bank windowpane flounder has shown decreasing survey indices despite reductions in catch and relative F levels. The stock was declared overfished in 2007 (the final year of data for Groundfish Assessment Review Meeting 2008) and was scheduled to be rebuilt by 2017, but the stock still remains below the biomass threshold. Windowpane flounder has low overall climate vulnerability, the larval index has been stable over many years, and both males and females are currently showing high condition indices. There are also new recruits regularly present in the fall bottom trawl survey catches.

Key Sources of Uncertainty:

Even though estimated catch has decreased in recent years, the survey index has not shown any resulting increase despite evidence of regular recruitment from survey length frequencies. There are uncertainties around discard estimates. Removals by Canadian fisheries occur from the Gulf of Maine-Georges Bank stock area and are not used as a catch component in the model. The model fit is notably poor and is worse than in the 2015 operational assessment.

Research Needs:

The panel recommends research focused on estimating additional sources of mortality or removal from the population that may be increasing over recent years. There may also be value in looking carefully at the windowpane stock definitions to see if there might be reason to change them. For the last several years the National Marine Fisheries Service has been collecting otoliths from Gulf of Maine-Georges Bank windowpane during the fall survey and now has several years' worth of ages, enough to explore a statistical catch-at-age model, which could provide insight into the population dynamics of Gulf of Maine-Georges Bank windowpane.

References:

Most recent assessment update:
Northeast Fisheries Science Center. 2015. Operational Assessment of 20 Northeast Groundfish Stocks, updated through 2014. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 15-24; 251 p. Available online at http://nefsc.noaa.gov/publications/crd/crd1524

Most recent benchmark assessment:
Northeast Fisheries Science Center. 2008. Assessment of 19 Northeast Groundfish Stocks through 2007: Report of the 3^{rd} Groundfish Assessment Review Meeting (GARM III), Northeast Fisheries Science Center, Woods Hole, Massachusetts, August 4-8, 2008. US Dep Commer, NOAA FIsheries, Northeast Fish Sci Cent Ref Doc. 08-15; 884 p + xvii.

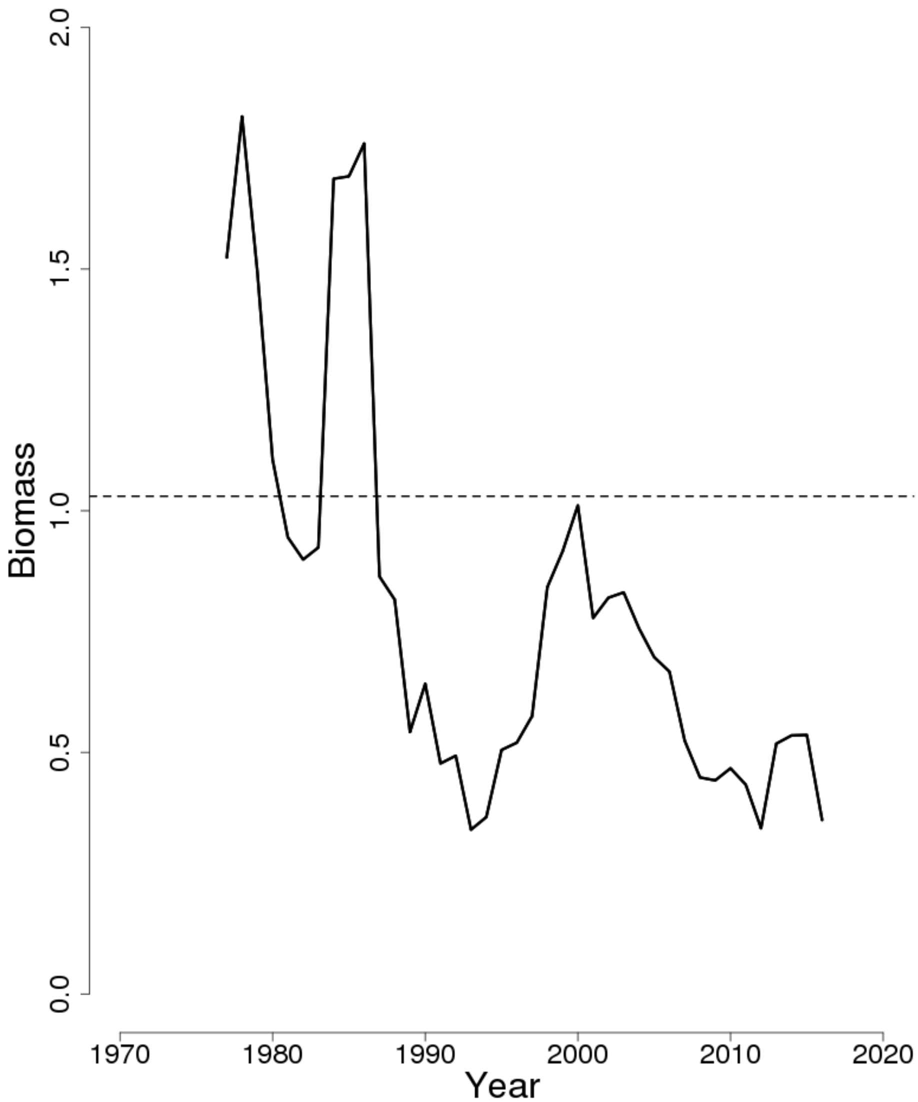

Figure 78: Trends in the biomass index (a 3-year moving average of the NEFSC fall bottom trawl survey index) of Gulf of Maine - Georges Bank windowpane flounder between 1975 and 2016 from the current assessment, and the corresponding $B_{Threshold} = \frac{1}{2}\ B_{MSY}$ *proxy* $=$ 1.030 kg/tow (horizontal dashed line).

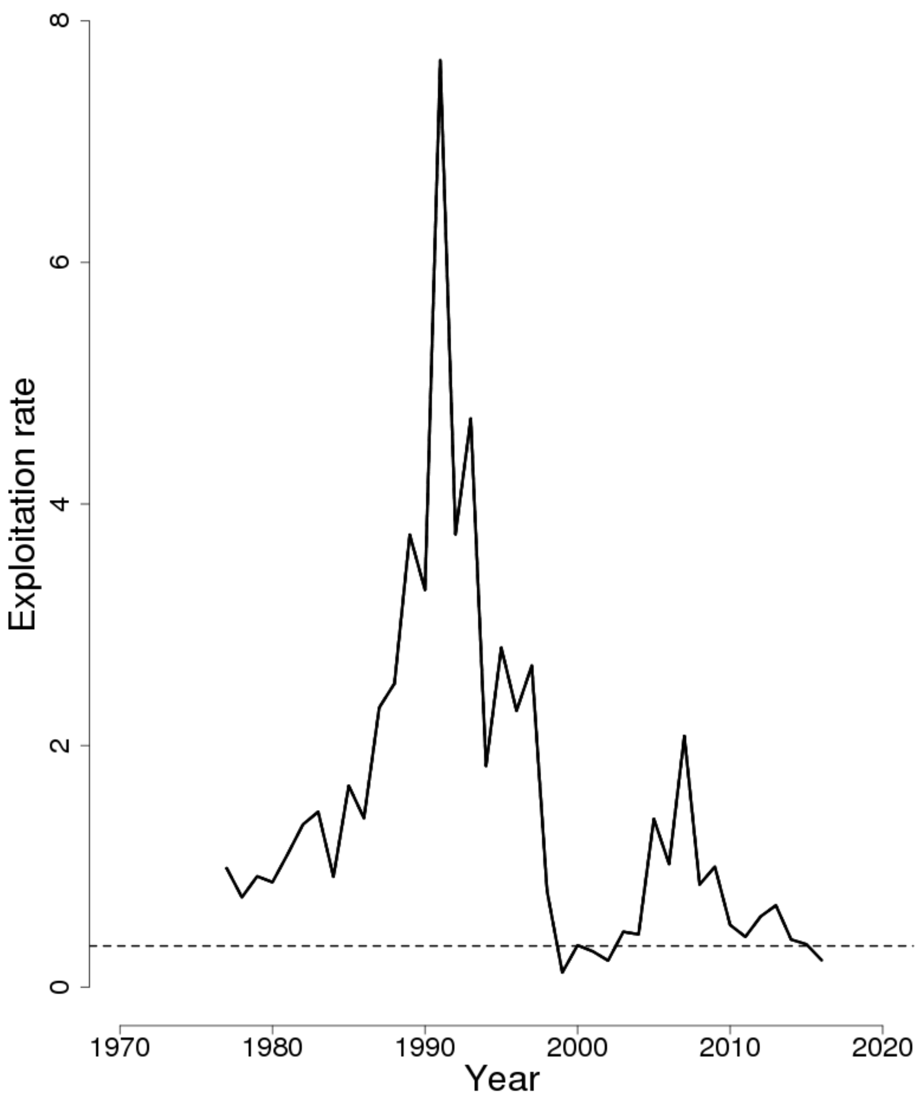

Figure 79: Trends in estimated relative fishing mortality of Gulf of Maine - Georges Bank windowpane flounder between 1975 and 2016 from the current assessment, and the corresponding F_{MSY} *proxy* = 0.34 (horizontal dashed line).

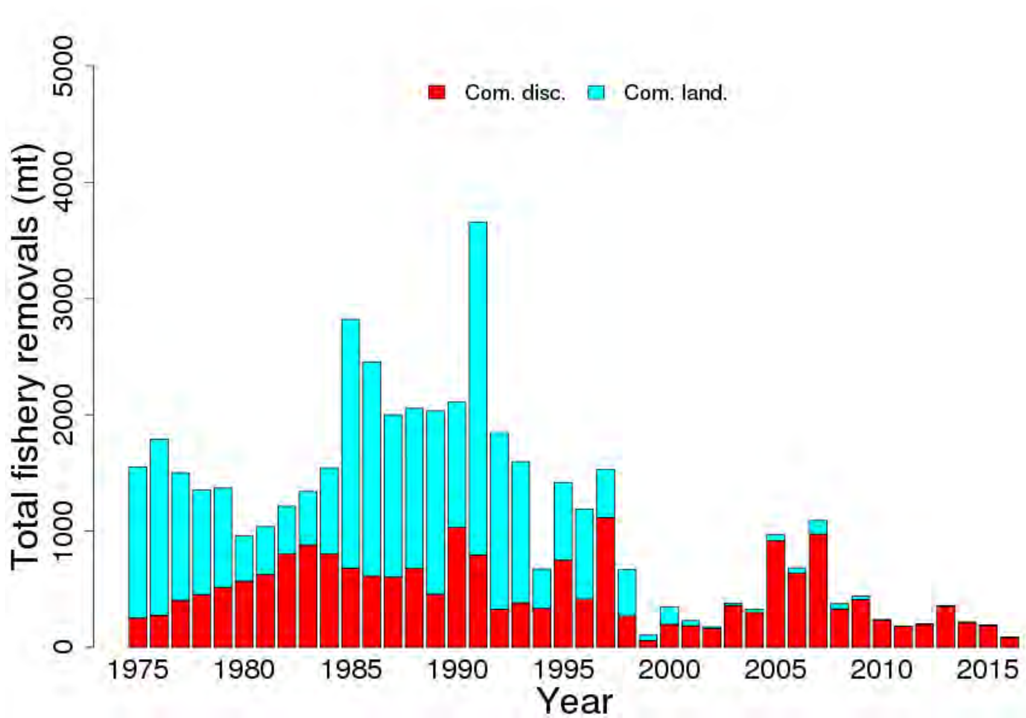

Figure 80: Total catch of Gulf of Maine - Georges Bank windowpane flounder between 1975 and 2016 by disposition (landings and discards).

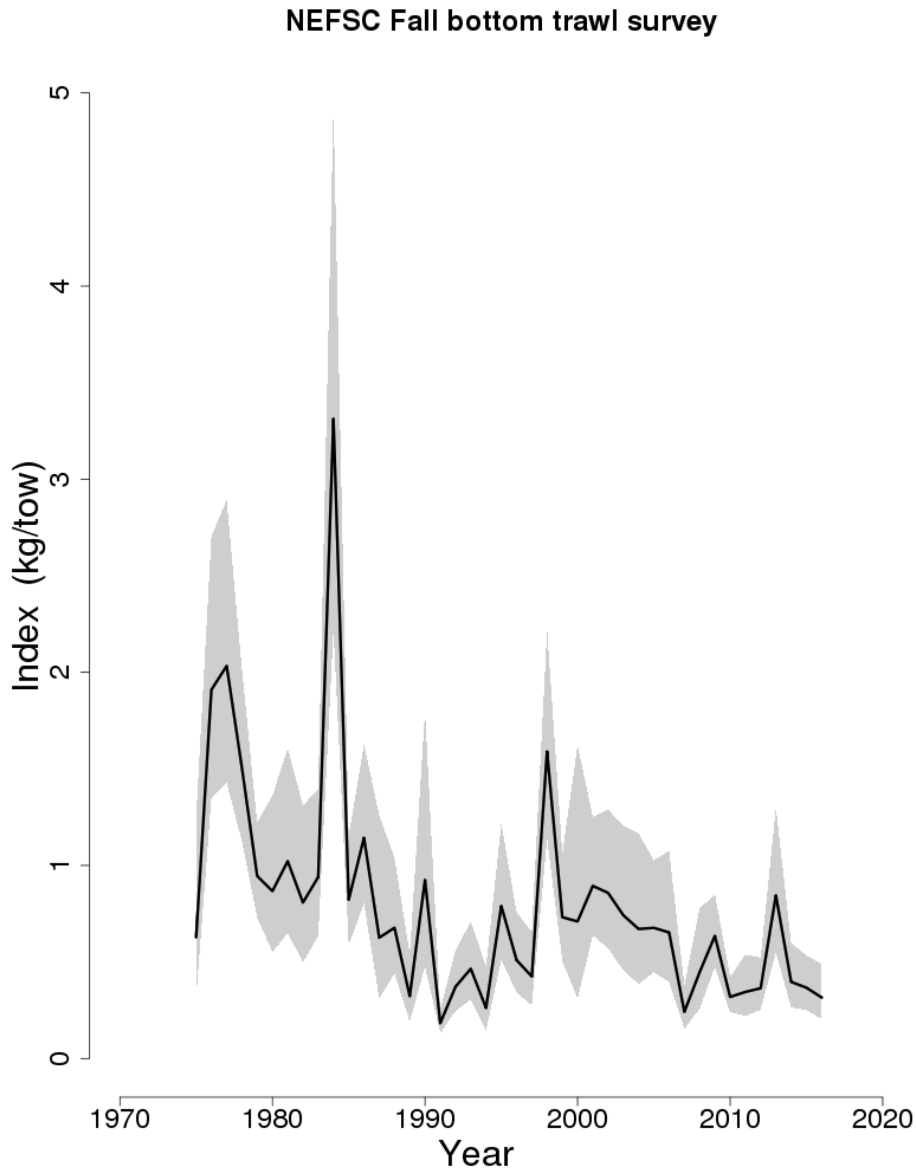

Figure 81: NEFSC fall bottom trawl survey indices in kg/tow for Gulf of Maine - Georges Bank windowpane flounder between 1975 and 2016. The approximate 90% lognormal confidence intervals are shown.

17 Southern New England - mid-Atlantic windowpane flounder

Toni Chute

This assessment of the southern New England - mid-Atlantic windowpane flounder (Scophthalmus aquosus) stock is an operational update of the 2015 assessment which was based on fishery and survey data through 2014 (NEFSC 2015). Based on the 2015 assessment the stock was not overfished, and overfishing was not ocurring. This assessment updates commercial fishery catch data, survey indices of abundance, AIM model results, and reference points through 2016.

State of Stock: Based on this updated assessment, the southern New England - mid-Atlantic windowpane flounder (*Scophthalmus aquosus*) stock is not overfished and overfishing is not occurring (Figures 82-83). Retrospective adjustments were not made to the model results. The mean NEFSC fall bottom trawl survey index from years 2014, 2015, and 2016 (a 3-year moving average is used as a biomass index) was 0.329 (kg/tow) which is higher than the $B_{Threshold}$ of 0.126 (kg/tow). The 2016 relative fishing mortality was estimated to be 1.733 (kt per kg/tow) which is lower than the F_{MSY} *proxy* of 1.918 (kt per kg/tow).

Table 50: Catch and model results table for southern New England - mid-Atlantic windowpane flounder. All landings and discard weights are rounded to the nearest metric ton. Biomass index is in units of kg/tow, and relative F is in units of kt per kg/tow (catch in kt per kg/tow of the survey index).

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Data										
Commercial discards	266	246	405	435	445	701	681	525	516	557
Commercial landings	83	74	53	53	32	29	22	14	22	13
Catch for Assessment	349	321	458	489	477	730	703	539	539	571
Model Results										
Biomass index	0.191	0.204	0.245	0.345	0.435	0.517	0.464	0.413	0.318	0.329
Relative F	1.83	1.572	1.88	1.419	1.103	1.413	1.507	1.308	1.694	1.733

Table 51: Reference points estimated in the 2012 assessment and in the current assessment update. F_{MSY} *proxy* is in units of kt per kg/tow.

	2015	2017
F_{MSY} *proxy*	2.027	1.918 (0.972 - 2.420)
B_{MSY} *proxy* (kg/tow)	0.247	0.253
MSY proxy (mt)	500	500
Overfishing	No	No
Overfished	No	No

Special Comments:

- What are the most important sources of uncertainty in this stock assessment? Explain, and describe qualitatively how they affect the assessment results (such as estimates of biomass, F, recruitment, and population projections).

  Since there has been a 'no posession' rule in place since 2010, commercial windowpane landings have been essentially zero. As a result, in recent years almost 100% of the catch input to the model has been estimated discards. The CVs for these estimates have been small, however, with a mean of 0.93 since 2010, so it is unlikely discards are being severely overestimated or underestimated or the trend over time has been obscured. Discard estimates from the general category scallop fleet (operating largely in the southern stock area) are not included in the model. Using these estimated discards would add about 3% to the catch, but does not change the results of the model.

- Does this assessment model have a retrospective pattern? If so, is the pattern minor, or major? (A major retrospective pattern occurs when the adjusted SSB or F_{Full} lies outside of the approximate joint confidence region for SSB and F_{Full}).

  The AIM (An Index Model) model used to estimate status of this stock does not allow estimation of a retrospective pattern.

- Based on this stock assessment, are population projections well determined or uncertain? If this stock is in a rebuilding plan, how do the projections compare to the rebuilding schedule?

  The GARM benchmark indicated that projections should not be made based on discards, so no projections are run for windowpane flounder.

- Describe any changes that were made to the current stock assessment, beyond incorporating additional years of data and the affect these changes had on the assessment and stock status.

  No changes were made to the southern New England - mid-Atlantic windowpane flounder assessment for this update other than the incorporation of two years of new NEFSC fall bottom trawl survey data and two years of new U.S. commercial landings and discard data (2015 and 2016).

- If the stock status has changed a lot since the previous assessment, explain why this occurred.

  The stock status of southern New England - mid-Atlantic windowpane flounder has not changed since the previous assessment.

- Provide qualitative statements describing the condition of the stock that relate to stock status.

  Since the year 2000, southern New England - mid-Atlantic windowpane flounder has shown increased survey indices and fairly stable catch and relative F levels. There is some noise in the replacement ratio model output, but the 2016 estimate of 0.92, although lower than desired, exceeds the estimates from the previous three years. The stock was declared overfished in 2005 (although the AIM model was not used) and recovered in 2008, so there is a recent history of the stock falling below reference points for biomass, but also having the ability to recover within a fairly short time period. Overfishing was occurring in 2007 (the final year of data used for the 2008 assessment) but has not occurred in the two most recent assessment updates. According to 21.6, windowpane has low overall climate vulnerability and females are currently showing high condition indices.

- Indicate what data or studies are currently lacking and which would be needed most to improve this stock assessment in the future.

  The AIM model fit is presently good with a randomization test indicating the correlation between ln(relative F) and ln(replacement ratio), a measure of the relationship between catch and survey index values, is significant (p = 0.002) so it is not clear what new information would help acheive better results with the AIM model. There has been some ageing work for southern windowpane done at VIMS which we are currently exploring for use in an age-based model such as ASAP which might provide insight into the population dynamics of southern windowpane.

- Are there other important issues?

  None.

17.1 Reviewer Comments: Southern New England - mid-Atlantic windowpane flounder

Assessment Recommendation:

The panel concluded that the operational assessment was acceptable as a scientific basis for management advice.

Alternative Assessment Approach:

Not applicable

Status Recommendation:

Based on this operational assessment, the panel supports the conclusion that the Southern New England-Mid-Atlantic windowpane flounder stock is not overfished and overfishing is not occurring. Since the year 2000, Southern New England-Mid-Atlantic windowpane flounder has shown increased survey indices, fairly stable catch and relative F levels. The stock was declared overfished in 2005 and recovered in 2008, so there is a recent history of the stock falling below reference points for biomass, but also having the ability to recover within a fairly short time period. Overfishing was occurring in 2007 (the final year of data used for the 2008 assessment) but has not occurred in the two most recent assessment updates. Southern New England-Mid-Atlantic windowpane has low overall climate vulnerability and are currently showing high condition indices (only females were analyzed).

Key Sources of Uncertainty:

There is some noise in the replacement ratio model output, but the 2016 estimate exceeds the estimates from the previous three years and is close to 1. Discard estimates from the general category scallop fleet (operating largely in the Southern New England-Mid-Atlantic stock area) are not included in the model. Using these estimated discards would add about 3% to the catch, but does not change the overall results of the model.

Research Needs:

The panel recommends considering incorporation of the ageing work for Southern New England-Mid-Atlantic windowpane done by the Virginia Institute of Marine Science (Northeast Area Monitoring and Assessment Program - NEAMAP) for use in an age-based model. This might provide further insight into the population dynamics of Southern New England-Mid-Atlantic windowpane.

References:

Most recent assessment update:
Northeast Fisheries Science Center. 2012. Assessment or Data Updates of 13 Northeast Groundfish Stocks through 2010. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 12-06; 789 p. Available online at http://nefsc.noaa.gov/publications/

Most recent benchmark assessment:
Northeast Fisheries Science Center. 2008. Assessment of 19 Northeast Groundfish Stocks through 2007: Report of the 3^{rd} Groundfish Assessment Review Meeting (GARM III), Northeast Fisheries Science Center, Woods Hole, MA, August 4-8, 2008. US Dep Commer, NOAA Fisheries, Northeast Fish Sci Cent Ref Doc. 08-15; 884 p.

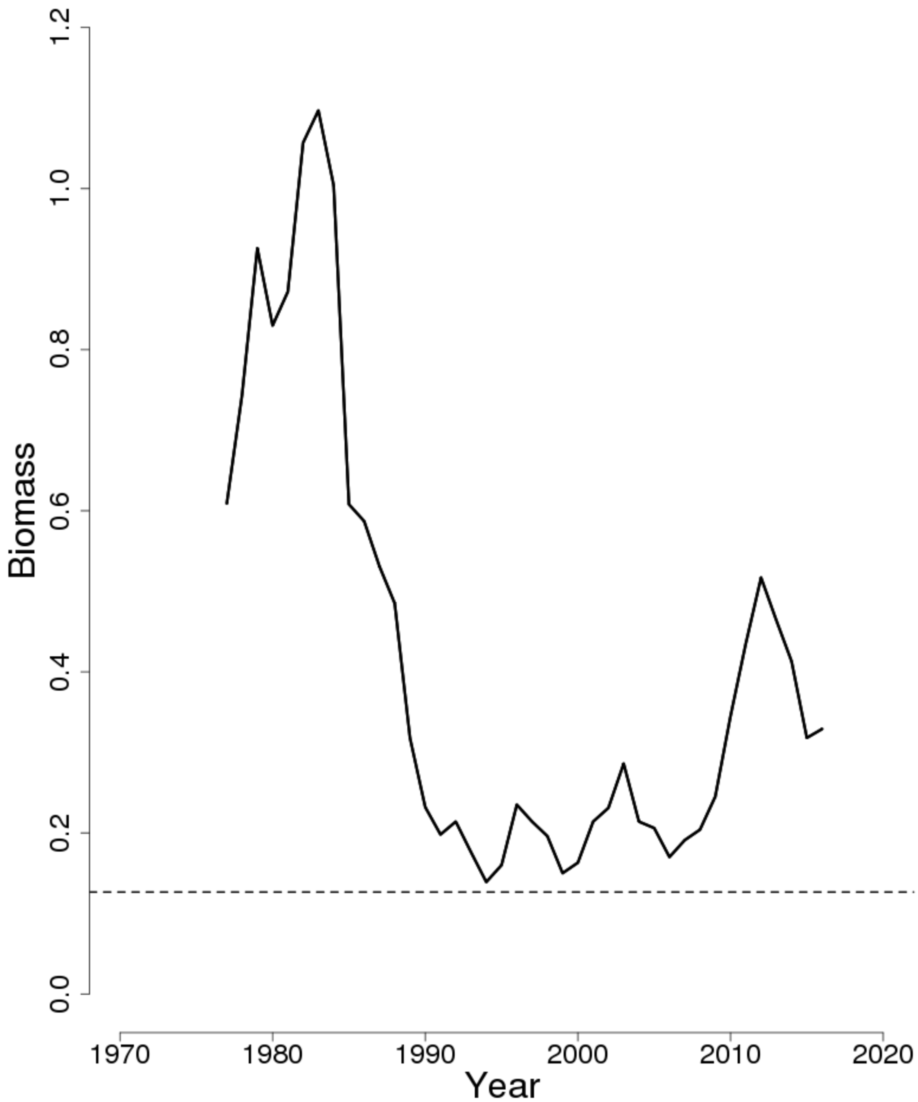

Figure 82: Trends in the biomass index (a 3-year moving average of the NEFSC fall bottom trawl survey index) of southern New England - mid-Atlantic windowpane flounder between 1975 and 2016 from the current assessment, and the corresponding $B_{Threshold} = \frac{1}{2} B_{MSY}$ *proxy* $= 0.126$ kg/tow (horizontal dashed line).

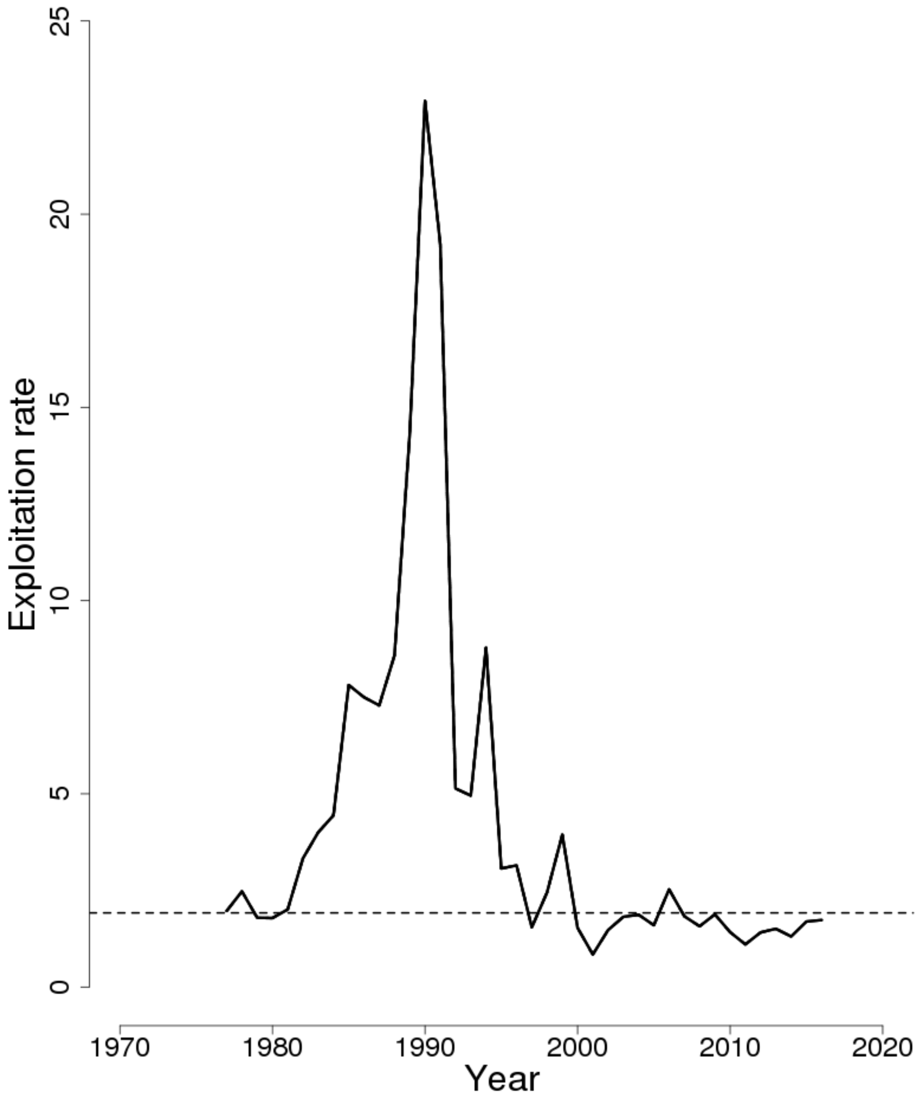

Figure 83: Trends in relative fishing mortality of southern New England - mid-Atlantic windowpane flounder between 1975 and 2016 from the current assessment, and the corresponding F_{MSY} *proxy*=1.918 (horizontal dashed line).

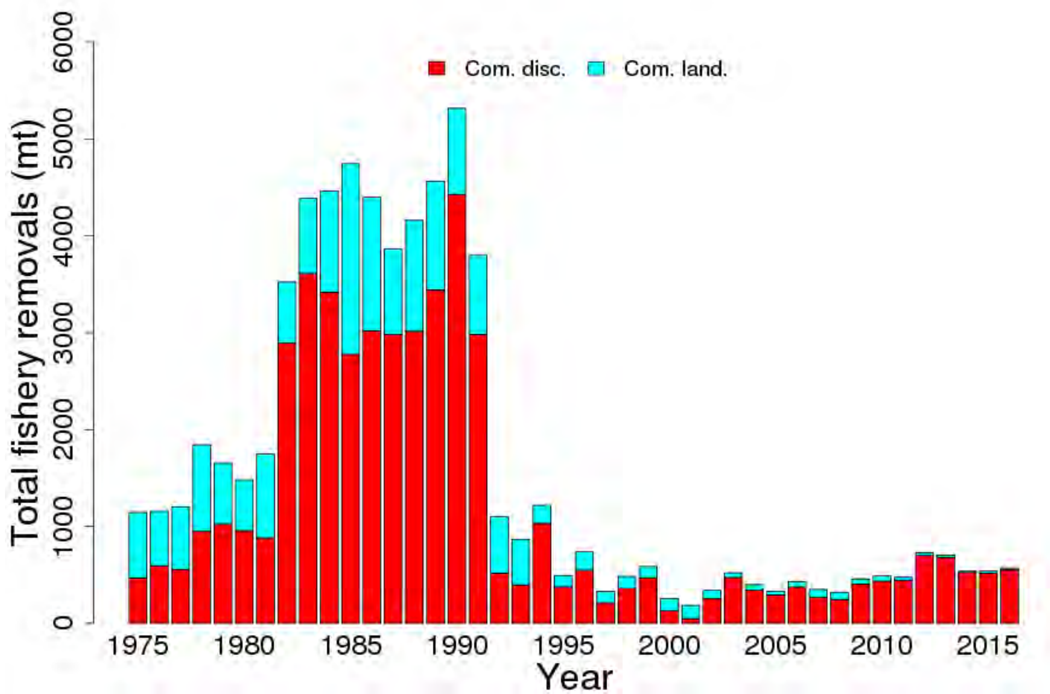

Figure 84: Total catch of southern New England - mid-Atlantic windowpane flounder between 1975 and 2016 by disposition (landings and discards).

NEFSC fall bottom trawl survey

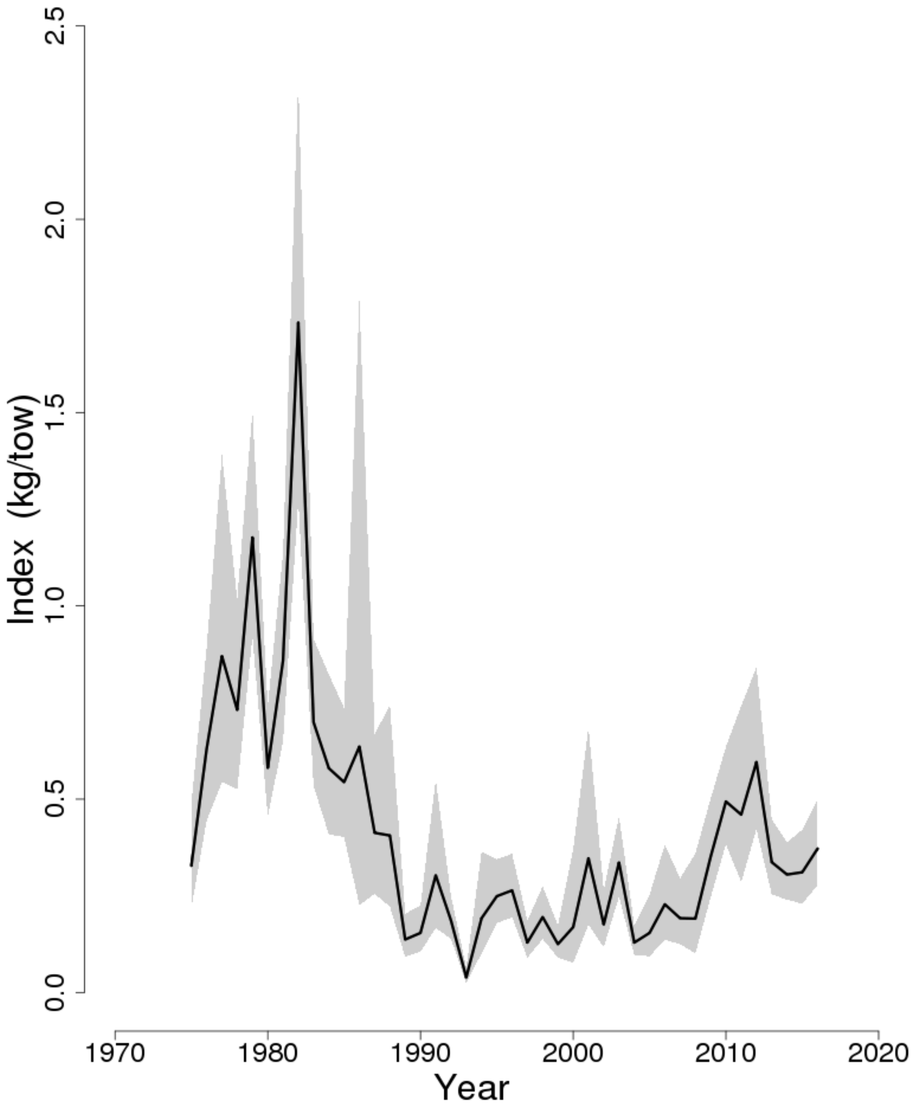

Figure 85: NEFSC fall bottom trawl survey indices in kg/tow for southern New England - mid-Atlantic windowpane flounder between 1975 and 2016. The approximate 90% lognormal confidence intervals are shown.

doi:10.7289/V5/TM-SWFSC-576

NOAA Technical Memorandum NMFS

APRIL 2017

ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2017 FOR U.S. MANAGEMENT IN 2017-18

Kevin T. Hill, Paul R. Crone, and Juan Zwolinski

NOAA-TM-NMFS-SWFSC-576

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
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ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2017 FOR U.S. MANAGEMENT IN 2017-18

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ACRONYMS AND DEFINITIONS

ABC	acceptable biological catch
ALT	1) alternative stock assessment model; 2) German word meaning ‘old’
AT	Acoustic-trawl survey
BC	British Columbia (Canada)
CA	California
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CCA	Central California fishery
CDFW	California Department of Fish and Wildlife
CDFO	Canada Department of Fisheries and Oceans
CICIMAR	Centro Interdisciplinario de Ciencias Marinas
CONAPESCA	National Commission of Aquaculture and Fishing (México)
CPS	Coastal Pelagic Species
CPSAS	Coastal Pelagic Species Advisory Subpanel
CPSMT	Coastal Pelagic Species Management Team
CY	Calendar year
DEPM	Daily egg production method
ENS	Ensenada (México)
FMP	fishery management plan
HG	harvest guideline
INAPESCA	National Fisheries Institute (México)
Model Year	July 1 (year) to June 30 (year+1)
mt	metric tons
mmt	million metric tons
MEXCAL	southern fleet based on ENS, SCA, and CCA fishery data
NMFS	National Marine Fisheries Service
NSP	Northern subpopulation of Pacific sardine, as defined by satellite oceanography data
NOAA	National Oceanic and Atmospheric Administration
ODFW	Oregon Department of Fish and Wildlife
OFL	overfishing limit
OR	Oregon
PNW	northern fleet based on OR, WA, and BC fishery data
PFMC	Pacific Fishery Management Council
SAFE	Stock Assessment and Fishery Evaluation
SCA	Southern California fishery
SCB	Southern California Bight (Pt. Conception, CA to northern Baja California)
SS	Stock Synthesis model
SSB	spawning stock biomass
SSC	Scientific and Statistical Committee
SST	sea surface temperature
STAR	Stock Assessment Review
STAT	Stock Assessment Team
SWFSC	Southwest Fisheries Science Center
TEP	Total egg production
VPA	Virtual Population Analysis
WA	Washington
WDFW	Washington Department of Fish and Wildlife

PREFACE

The Pacific sardine resource is assessed each year in support of the Pacific Fishery Management Council (PFMC) process of stipulating annual harvest specifications for the U.S. fishery. This report serves as a full stock assessment for purposes of advising management for the 2017-18 fishing year. Presently, the assessment/management schedule for Pacific sardine is based on a full assessment conducted every three years, with an update assessment conducted in the interim years. A full stock assessment was conducted in 2014 (Hill et al. 2014; STAR 2014) and update assessments were completed in 2015 and 2016 (Hill et al. 2015, 2016).

Two assessment approaches are presented here, including a survey-based assessment (preferred by the stock assessment team, STAT) and a model-based assessment (alternative, model ALT). The report includes three primary sections: first, a timeline with background information concerning fishery operations and management associated with the Pacific sardine resource (Introduction); second, summaries for various sources of sample data used in the assessments (Data); and third, methods/models used to conduct the assessments (Assessment). The Assessment section includes two parts based on the assessment approach (survey and model). In this context, readers should first consult the section 'Assessment – Acoustic-trawl Survey, Overview,' which serves as the basis of the report, i.e., preferences and justifications regarding the STAT's choice of assessment approach. The two assessment approaches were evaluated at the formal stock assessment review (STAR) in February 2017. Readers should refer to STAR (2017) for details regarding merits and drawbacks of the assessments highlighted during the review, and final decisions from the Panel concerning both short- and long-term recommendations for adopting an assessment approach for advising management in the future. That is, while the survey-based assessment was viewed as the better long-term approach by both the STAT and STAR Panel, the Panel identified a notable shortcoming of the survey-based assessment in the short-term, given the need to forecast stock biomass one full year after the last survey observation. Both the STAT and STAR Panel agreed that the preferred survey-based assessment could be effectively implemented by shifting the fishery start date a few to several months to minimize the time lag between the most recent survey and the official start date of the fishery, e.g., moving the start of the fishery from July 1st to January 1st would accomplish this goal. To summarize, model ALT presently represents the recommended assessment approach to adopt for the upcoming fishing year (2017-18), with a survey-based assessment that accommodates a more workable projection period recommended for subsequent fishing years.

Finally, field, laboratory, and analytical work conducted in support of the ongoing Pacific sardine assessment is the responsibility of the SWFSC and its staff, including: principal investigators (K. T. Hill, P. R. Crone, J. P. Zwolinski); and collaborators (D.A. Demer, E. Dorval, B. J. Macewicz, D. Griffith, and Y. Gu). Principal investigators are responsible for developing assessments, presenting relevant background information, and addressing the merits/drawbacks of the two assessment approaches in the context of meeting the management goal (current estimate of stock biomass each year), which is needed for implementing an established harvest control rule policy for Pacific sardine. An inclusive list of individuals and institutions that have provided information for carrying out the Pacific sardine assessment is presented in Acknowledgements below.

EXECUTIVE SUMMARY

The following Pacific sardine assessment was conducted to inform U.S. fishery management for the cycle that begins July 1, 2017 and ends June 30, 2018. Two assessment approaches were reviewed at the STAR Panel in February 2017: an AT survey-based approach (preferred by the STAT); and a model-based assessment (model ALT). Given forecasting issues highlighted in the review (see STAR 2017 and 'Unresolved Problems and Major Uncertainties' below), the Panel ultimately recommended that management advice be based on model ALT for the 2017-18 fishing year. Model ALT represents the final base model from the February 2017 STAR (Hill et al. 2017, STAR 2017).

Stock

This assessment focuses on the northern subpopulation of Pacific sardine (NSP) that ranges from northern Baja California, México to British Columbia, Canada and extends up to 300 nm offshore. In all past assessments, the default approach has been to assume that all catches landed in ports from Ensenada (ENS) to British Columbia (BC) were from the northern subpopulation. There is now general scientific consensus that catches landed in the Southern California Bight (SCB, i.e., Ensenada and southern California) likely represent a mixture of the southern subpopulation (warm months) and northern subpopulation (cool months) (Felix-Uraga et al. 2004, 2005; Garcia-Morales 2012; Zwolinski et al. 2011; Demer and Zwolinski 2014). Although the ranges of the northern and southern subpopulations can overlap within the SCB, the adult spawning stocks likely move north and south in synchrony each year and do not occupy the same space simultaneously to any significant extent (Garcia-Morales 2012). Satellite oceanography data (Demer and Zwolinski 2014) were used to partition catch data from Ensenada (ENS) and southern California (SCA) ports to exclude both landings and biological compositions attributed to the southern subpopulation.

Catches

The assessment includes sardine landings (mt) from six major fishing regions: Ensenada (ENS), southern California (SCA), central California (CCA), Oregon (OR), Washington (WA), and British Columbia (BC). Landings for each port and for the NSP over the modeled years/seasons follow:

Calendar Yr-Sem	Model Yr-Seas	ENS Total	ENS NSP	SCA Total	SCA NSP	CCA	OR	WA	BC
2005-2	2005-1	37,999.5	4,396.7	16,615.0	1,581.4	7,824.9	44,316.2	6,605.0	3,231.4
2006-1	2005-2	17,600.9	11,214.6	18,290.5	17,117.0	2,032.6	101.7	0.0	0.0
2006-2	2006-1	39,636.0	0.0	18,556.0	5,015.7	15,710.5	35,546.5	4,099.0	1,575.4
2007-1	2006-2	13,981.4	13,320.0	27,546.0	20,567.0	6,013.3	0.0	0.0	0.0
2007-2	2007-1	22,865.5	11,928.2	22,047.2	5,531.2	28,768.8	42,052.3	4,662.5	1,522.3
2008-1	2007-2	23,487.8	15,618.2	25,098.6	24,776.6	2,515.3	0.0	0.0	0.0
2008-2	2008-1	43,378.3	5,930.0	8,979.6	123.6	24,195.7	22,939.9	6,435.2	10,425.0
2009-1	2008-2	25,783.2	20,244.4	10,166.8	9,874.2	11,079.9	0.0	0.0	0.0
2009-2	2009-1	30,128.0	0.0	5,214.1	109.3	13,935.1	21,481.6	8,025.2	15,334.3
2010-1	2009-2	12,989.1	7,904.2	20,333.5	20,333.5	2,908.8	437.1	510.9	421.7
2010-2	2010-1	43,831.8	9,171.2	11,261.2	699.2	1,397.1	20,414.9	11,869.6	21,801.3
2011-1	2010-2	18,513.8	11,588.5	13,192.2	12,958.9	2,720.1	0.1	0.0	0.0
2011-2	2011-1	51,822.6	17,329.6	6,498.9	182.5	7,359.3	11,023.3	8,008.4	20,718.8
2012-1	2011-2	10,534.0	9,026.1	12,648.6	10,491.1	3,672.7	2,873.9	2,931.7	0.0
2012-2	2012-1	48,534.6	0.0	8,620.7	929.9	568.7	39,744.1	32,509.6	19,172.0
2013-1	2012-2	13,609.2	12,827.9	3,101.9	972.8	84.2	149.3	1,421.4	0.0
2013-2	2013-1	37,803.5	0.0	4,997.3	110.3	811.3	27,599.0	29,618.9	0.0
2014-1	2013-2	12,929.7	412.5	1,495.2	809.3	4,403.3	0.0	908.0	0.0
2014-2	2014-1	77,466.3	0.0	1,600.9	0.0	1,830.9	7,788.4	7,428.4	0.0
2015-1	2014-2	14,452.4	0.0	1,543.2	0.0	727.7	2,131.3	62.6	0.0
2015-2	2015-1	18,379.7	0.0	1,514.8	0.0	6.1	0.1	66.1	0.0
2016-1	2015-2	22,647.9	0.0	423.5	184.8	1.1	0.7	0.0	0.0
2016-2	2016-1	23,091.6	0.0	857.5	0.0	10.3	2.7	85.2	0.0

Data and Assessment

The integrated assessment model was developed using Stock Synthesis (SS version 3.24aa), and includes fishery and survey data collected from mid-2005 through 2016. The model is based on a July-June biological year (aka 'model year'), with two semester-based seasons per year (S1=Jul-Dec and S2=Jan-Jun). Catches and biological samples for the fisheries off ENS, SCA, and CCA were pooled into a single MEXCAL fleet (fishery), for which selectivity was modeled separately in each season (S1 and S2). Catches and biological samples from OR, WA, and BC were modeled by season as a single PNW fleet (fishery). A single AT survey index of abundance from ongoing SWFSC surveys (2006-2016) was included in the model.

Model ALT incorporates the following specifications:

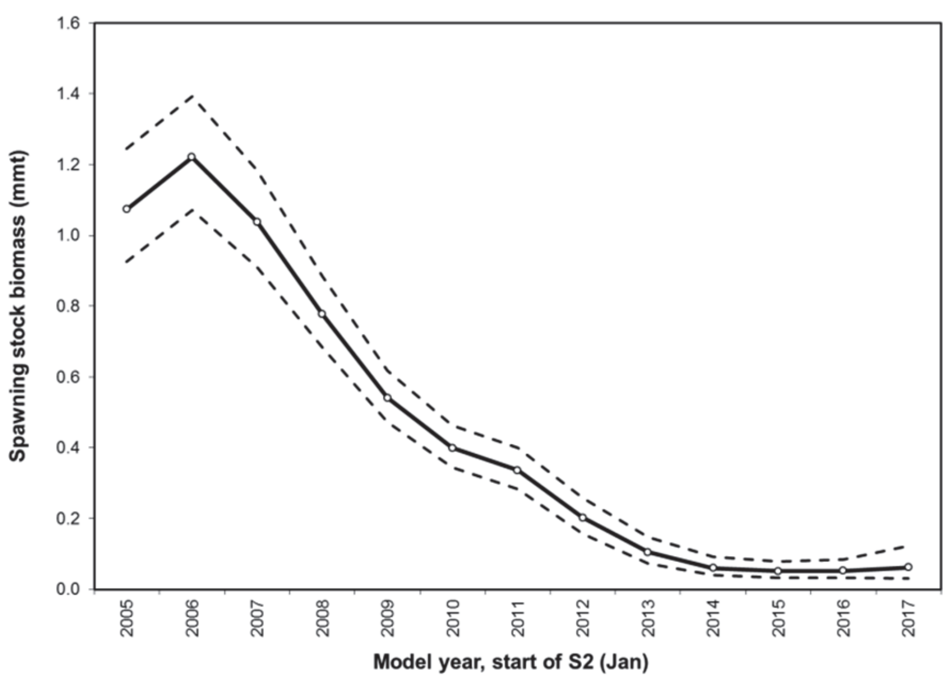
- NSP catches for the MEXCAL fleet computed using an environmental-based optimal habitat index;
- two seasons (semesters, Jul-Dec=S1 and Jan-Jun=S2) for each model year (2005-16);
- sexes were combined;
- maximum age=10, with nine age bins (ages 0-8+);
- two fleets (MEXCAL and PNW), with an annual selectivity pattern for the PNW fleet and seasonal selectivity patterns (S1 and S2) for the MEXCAL fleet;
    - MEXCAL fleet: dome-shaped, age-based selectivity (one parameter per age)
    - PNW fleet: asymptotic, age-based selectivity;
    - age compositions with effective sample sizes calculated by dividing the number of fish sampled by 25 (externally);

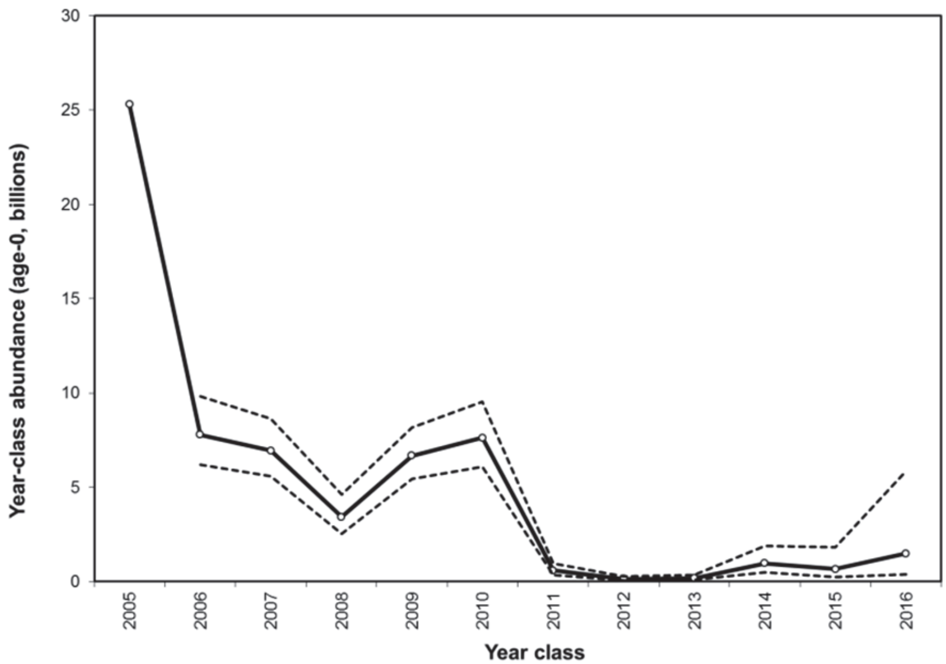
- Beverton-Holt stock-recruitment relationship, with virgin recruitment (R_0), steepness (*h*), and initial equilibrium recruitment offset (R_1) estimated, and average recruitment variability fixed (σ_R=0.75);
- *M* was fixed (0.6 yr^{-1});
- recruitment deviations estimated from 2005-15;
- initial fishing mortality (*F*) was estimated for the MEXCAL_S1 fishery and fixed=0 for MEXCAL_S2 and PNW fisheries;
- single AT survey index of abundance (2006-2013) that includes seasonal (spring and summer) observations in some years, and catchability (*Q*) estimated;
    - o age compositions with effective sample sizes set (externally) to 1 per trawl cluster;
    - o selectivity was assumed to be uniform (fully selected) for age 1+ and zero for age 0; and
- no additional data weighting via variance adjustment factors or lambdas was implemented.

Spawning Stock Biomass and Recruitment

Time series of estimated spawning stock biomass (SSB, mmt) and associated 95% confidence intervals are displayed in the figure and table below. The virgin level of SSB was estimated to be 107,915 mt (0.11 mmt). The SSB has continually declined since 2005-06, reaching historically low levels in recent years (2014-present). The SSB was projected to be 61,684 mt (CV=36%) in January 2018.

Time series of estimated recruitment (age-0, billions) abundance is presented in the figure and table below. The virgin level of recruitment (R_0) was estimated to be 1.52 billion age-0 fish. As indicated for SSB above, recruitment has largely declined since 2005-06, with the exception of a brief period of modest recruitment success from 2009-10. In particular, the 2011-15 year classes have been among the weakest in recent history. A small increase in recruitment was observed in 2016, albeit a highly variable estimate (CV=79%) based on limited data.

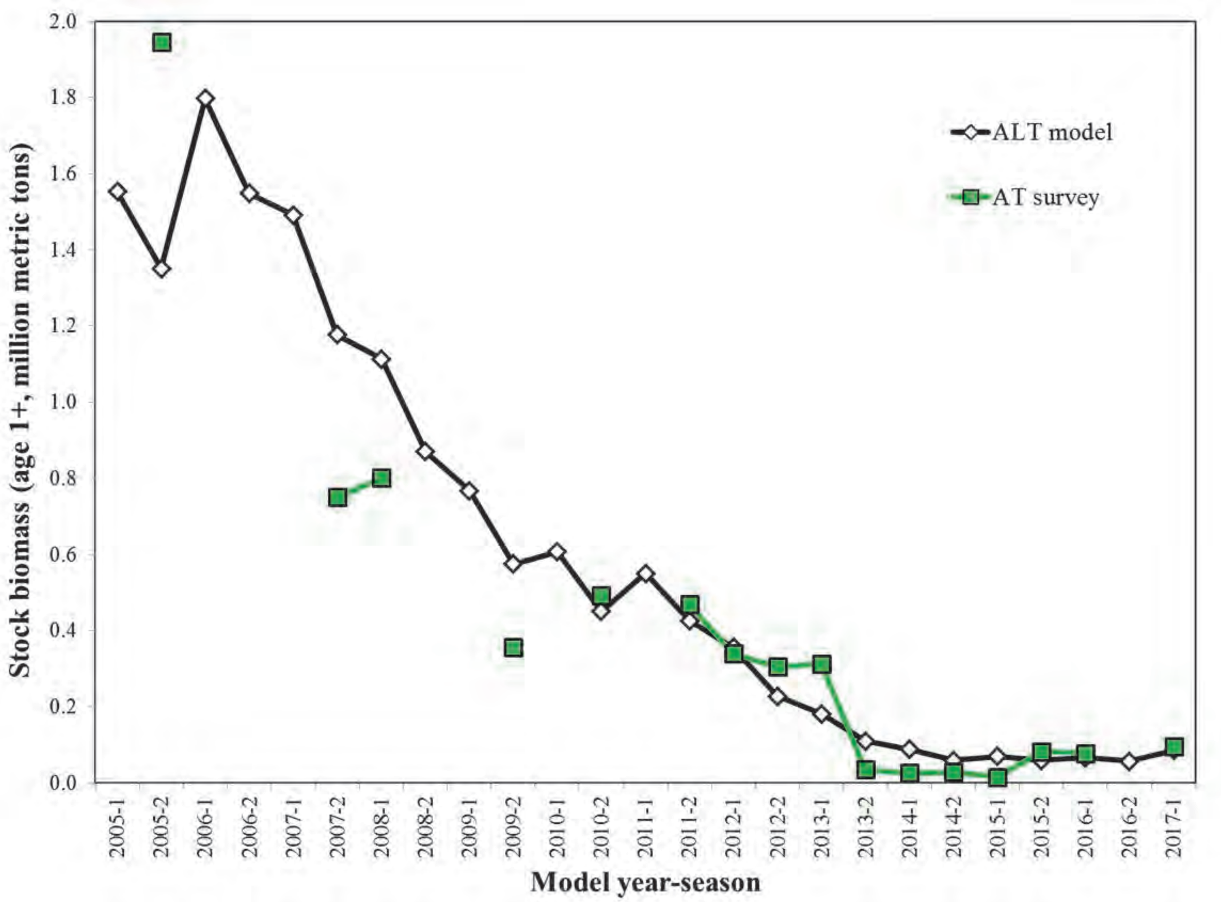




Calendar Yr-Sem	Model Yr-Seas	SSB (mt)	SSB Std Dev	Year class abundance (1000s)	Recruits Std Dev
2005-2	2005-1	---	---	25,280,200	---
2006-1	2005-2	1,073,370	81,231	---	---
2006-2	2006-1	---	---	7,795,940	921,117
2007-1	2006-2	1,220,870	82,137	---	---
2007-2	2007-1	---	---	6,941,430	776,514
2008-1	2007-2	1,038,110	69,463	---	---
2008-2	2008-1	---	---	3,438,450	524,348
2009-1	2008-2	776,752	51,418	---	---
2009-2	2009-1	---	---	6,670,540	698,028
2010-1	2009-2	540,469	36,758	---	---
2010-2	2010-1	---	---	7,626,460	877,556
2011-1	2010-2	399,390	29,801	---	---
2011-2	2011-1	---	---	601,265	152,534
2012-1	2011-2	336,084	29,628	---	---
2012-2	2012-1	---	---	140,769	51,311
2013-1	2012-2	201,813	25,832	---	---
2013-2	2013-1	---	---	185,878	66,165
2014-1	2013-2	104,351	18,784	---	---
2014-2	2014-1	---	---	971,184	337,752
2015-1	2014-2	60,263	13,171	---	---
2015-2	2015-1	---	---	663,664	365,241
2016-1	2015-2	51,186	11,460	---	---
2016-2	2016-1	---	---	1,500,830	1,183,890
2017-1	2016-2	52,353	12,991	---	---

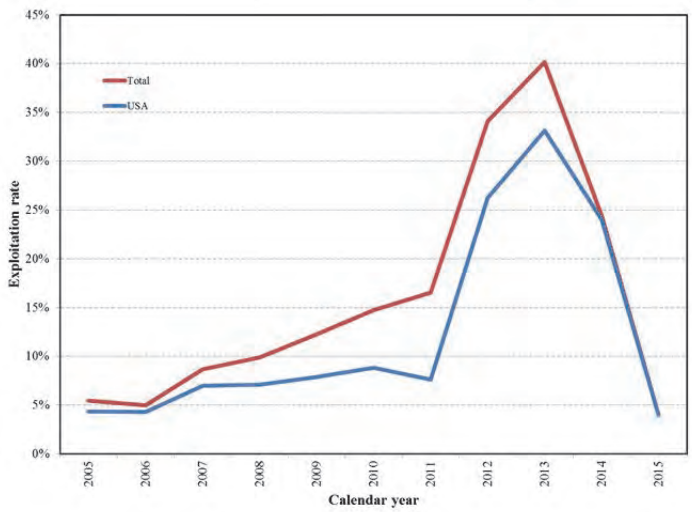
Stock Biomass for PFMC Management in 2017-18

Stock biomass, used for calculating annual harvest specifications, is defined as the sum of the biomass for sardine ages one and older (age 1+) at the start of the management year. Time series of estimated stock biomass (mmt) from model ALT and the AT survey are presented in the figure below. As discussed above for both SSB and recruitment, a similar trend of declining stock biomass has been observed since 2005-06, peaking at 1.8 mmt in 2006, and plateauing at recent historical low levels since 2014. Model ALT stock biomass is projected to be **86,586 mt in July 2017**.



Exploitation Status

Exploitation rate is defined as the calendar year NSP catch divided by the total mid-year biomass (July-1, ages 0+). Based on model ALT estimates, the U.S. exploitation rate has averaged about 11% since 2005, peaking at 33% in 2013. The U.S. and total exploitation rates were <1% in 2016. The U.S. and total exploitation rates for the NSP, calculated from model ALT, are presented in the figure and table below.



Calendar Year	USA	Total
2005	4.4%	5.4%
2006	4.3%	5.0%
2007	7.0%	8.7%
2008	7.1%	9.9%
2009	7.9%	12.2%
2010	8.8%	14.7%
2011	7.6%	16.5%
2012	26.2%	34.1%
2013	33.1%	40.1%
2014	24.0%	24.4%
2015	4.0%	4.0%
2016	0.4%	0.4%

Ecosystem Considerations

Pacific sardine represent an important forage base in the California Current Ecosystem (CCE). At times of high abundance, Pacific sardine can compose a substantial portion of biomass in the CCE. However, periods of low recruitment success driven by prevailing oceanographic conditions can lead to low population abundance over extended periods of time. Readers should consult PFMC (1998), PFMC (2014), and NMFS (2016a,b) for comprehensive information regarding environmental processes generally hypothesized to influence small pelagic species that inhabit the CCE.

Harvest Control Rules

Harvest guideline

The annual harvest guideline (HG) is calculated as follows:

HG = (BIOMASS – CUTOFF) • FRACTION • DISTRIBUTION;

where HG is the total U.S. directed harvest for the period July 2017 to June 2018, BIOMASS is the stock biomass (ages 1+, mt) projected as of July 1, 2017, CUTOFF (150,000 mt) is the lowest level of biomass for which directed harvest is allowed, FRACTION (E_{MSY} bounded 0.05-0.20) is the percentage of biomass above the CUTOFF that can be harvested, and DISTRIBUTION (87%) is the average portion of BIOMASS assumed in U.S. waters. Based on results from model ALT, estimated stock biomass is projected to be below the 150,000 mt threshold and thus, the HG for 2017-18 would be 0 mt.

OFL and ABC

On March 11, 2014, the PFMC adopted the use of CalCOFI sea-surface temperature (SST) data for specifying environmentally-dependent E_{MSY} each year. The E_{MSY} is calculated as,

$$E_{\mathrm{MSY}} = -18.46452+3.25209(T)-0.19723(T^2)+0.0041863(T^3),$$

where T is the three-year running average of CalCOFI SST, and E_{MSY} for OFL and ABC is bounded between 0 to 0.25. Based on the recent warmer conditions in the CCE, the average temperature for 2014-16 increased to 15.9999 °C, resulting in E_{MSY}=0.2251.

Harvest estimates for model ALT are presented in the following table. Estimated stock biomass in July 2017 was **86,586 mt**. The overfishing limit (OFL, 2017-18) associated with that biomass was **16,957 mt**.

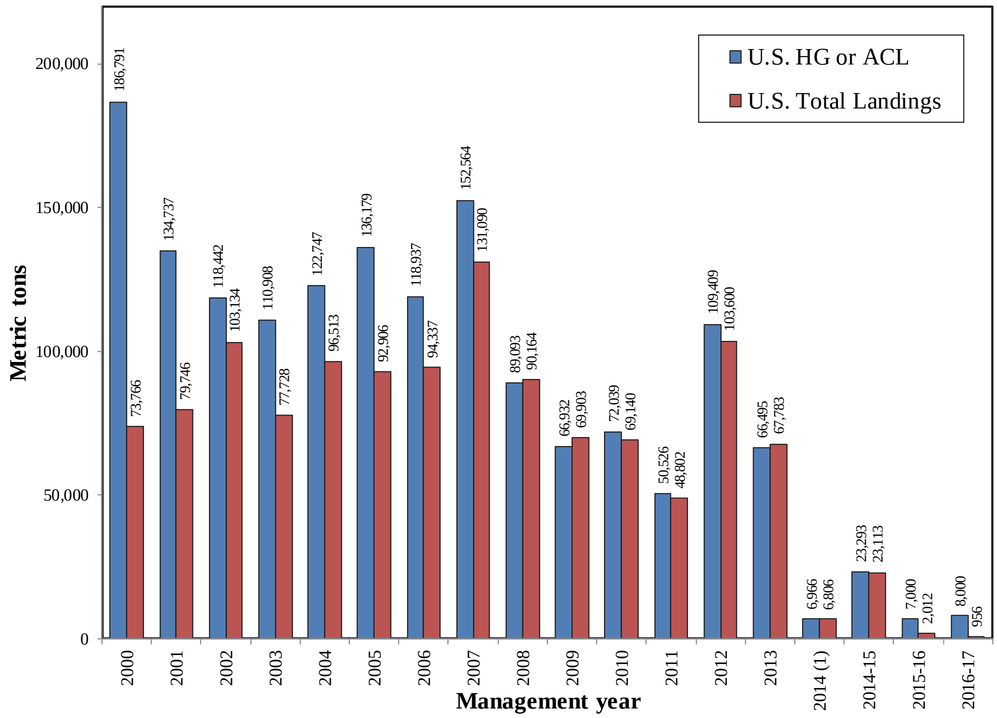
Acceptable biological catches (ABC, 2017-18) for a range of *P-star* values (Tier 1 σ=0.36; Tier 2 σ=0.72) associated with model ALT are presented in the following table.

Harvest control rules for the model-based assessment (model ALT):

Harvest Control Rule Formulas									
OFL = BIOMASS * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
$ABC_{P\text{-}star}$ = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION; where FRACTION is E_{MSY} bounded 0.05 to 0.20									
Harvest Formula Parameters									
BIOMASS (ages 1+, mt)	86,586								
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
ABC $Buffer_{Tier\ 1}$	0.95577	0.91283	0.87048	0.82797	0.78442	0.73861	0.68859	0.63043	0.55314
ABC $Buffer_{Tier\ 2}$	0.91350	0.83326	0.75773	0.68553	0.61531	0.54555	0.47415	0.39744	0.30596
CalCOFI SST (2014-2016)	15.9999								
E_{MSY}	0.225104								
FRACTION	0.200000								
CUTOFF (mt)	150,000								
DISTRIBUTION (U.S.)	0.87								
Harvest Control Rule Values (MT)									
OFL =	**16,957**								
$ABC_{Tier\ 1}$ =	16,207	15,479	14,761	14,040	13,301	12,525	11,676	10,690	9,380
$ABC_{Tier\ 2}$ =	15,490	14,130	12,849	11,625	10,434	9,251	8,040	6,739	5,188
HG =	**0**								

Management Performance

The U.S. HG/ACL values and catches since the onset of federal management are presented in the figure below.



Unresolved Problems and Major Uncertainties

As indicated in the Preface above, the survey-based assessment remains the STAT's preferred approach for advising management regarding Pacific sardine abundance in the future. However, the STAR Panel identified a notable shortcoming of the survey-based assessment that would need to be addressed before adopting this approach for purposes of advising management in the future. Specifically, the issue is related to a need to forecast stock biomass one full year after the last survey observation, i.e., a time lag exists between obtaining the final estimate of stock biomass from the summer AT survey and the start date of the fishery the following year. In particular, it is inherently difficult to reliably estimate the strength of the most recent cohort (age-0 fish) from the previous summer that would be expected to contribute substantially to the age-1+ biomass the following year (e.g., projecting the 2016 year-class size/biomass into July 2017). It is important to note, recent recruitment strength will continue to represent a considerable area of uncertainty, regardless of species or assessment approach (i.e., survey- or model-based), particularly, for coastal pelagic species (e.g., sardine and anchovy) that exhibit highly variable recruitment success in any given year given their high rates of natural mortality. Both the STAT and STAR Panel agreed that uncertainty associated with the forecast needed in the survey-based assessment would be effectively minimized by simply shifting the fishery start date to reduce the time lag between the most recent survey and start date for the fishery (e.g., from July 1st to January 1st).

The STAR Panel ultimately recommended using results from model ALT for sardine management in 2017-18. The Panel identified a number of areas of uncertainty in model ALT, including: 1) best treatment of empirical weight-at-age data from the fisheries and AT survey; 2) treatment of population weight-at-age (time varying vs. time-invariant); 3) use of time-invariant age-length keys to convert AT length compositions to age compositions; 4) selectivity parameterization for the AT survey; 5) lack of empirical justification for increasing natural mortality from 0.4 to 0.6 yr^{-1}; and 6) ongoing concerns about acoustic species identification, target strength estimation, and boundary zone (sea floor, surface, and shore) observations associated with the AT survey (readers should consult sections 3 and 5 in STAR (2017) for further details).

Research and Data Needs

Research and data for improving stock assessments of the Pacific sardine resource in the future address three major areas of need, including AT survey operations, biological data sampling from fisheries, and laboratory-based biology studies (see Research and Data Needs below for further discussion regarding areas of improvement).

INTRODUCTION

Distribution, Migration, Stock Structure, Management Units

Information regarding Pacific sardine (*Sardinops sagax caerulea*) biology and population dynamics is available in Clark and Marr (1955), Ahlstrom (1960), Murphy (1966), MacCall (1979), Leet et al. (2001), as well as references cited below.

The Pacific sardine has at times been the most abundant fish species in the California Current Ecosystem (CCE). When the population is large, it is abundant from the tip of Baja California (23^{o}N latitude) to southeastern Alaska (57^{o}N latitude) and throughout the Gulf of California. Occurrence tends to be seasonal in the northern extent of its range. When abundance was low during the 1960-70s, sardines did not generally occur in significant quantities north of Baja California.

There is a longstanding consensus in the scientific community that sardines off the west coast of North America represent three subpopulations (see review by Smith 2005). A northern subpopulation ('NSP'; northern Baja California to Alaska; Figure 1), a southern subpopulation ('SSP'; outer coastal Baja California to southern California), and a Gulf of California subpopulation were distinguished on the basis of serological techniques (Vrooman 1964) and in studies of oceanography as pertaining to temperature-at-capture (Felix-Uraga et al., 2004, 2005; Garcia-Morales et al. 2012; Demer and Zwolinski 2014). An electrophoretic study (Hedgecock et al. 1989) showed, however, no genetic variation among sardines from central and southern California, the Pacific coast of Baja California, or the Gulf of California. Although the ranges of the northern and southern subpopulations can overlap within the Southern California Bight, the adult spawning stocks likely move north and south in synchrony and do not occupy the same space simultaneously to a significant extent (Garcia-Morales 2012). The northern subpopulation (NSP) is exploited by fisheries off Canada, the U.S., and northern Baja California (Figure 1), and represents the stock included in the CPS Fishery Management Plan (CPS-FMP; PFMC 1998). The 2014 assessment (Hill et al. 2014) addressed the above stock structure hypotheses in a more explicit manner, by partitioning southern (ENS and SCA ports) fishery catches and composition data using an environment-based approach described by Demer and Zwolinski (2014) and in the following sections. The same subpopulation hypothesis is carried forward in the following assessment.

Pacific sardine migrate extensively when abundance is high, moving as far north as British Columbia in the summer and returning to southern California and northern Baja California in the fall. Early tagging studies indicated that the older and larger fish moved farther north (Janssen 1938; Clark & Janssen 1945). Movement patterns were probably complex, and the timing and extent of movement were affected by oceanographic conditions (Hart 1973) and stock biomass levels. During the 1950s to 1970s, a period of reduced stock size and unfavorably cold sea-surface temperatures together likely caused the stock to abandon the northern portion of its range. In recent decades, the combination of increased stock size and warmer sea-surface temperatures resulted in the stock re-occupying areas off Central California, Oregon, Washington, and British Columbia, as well as distant offshore waters off California. During a cooperative U.S.-U.S.S.R. research cruise for jack mackerel in 1991, several tons of sardine were collected 300 nm west of the Southern California Bight (SCB) (Macewicz and Abramenkoff 1993). Resumption of seasonal movement between the southern spawning habitat and the northern feeding habitat has been inferred by presence/absence of size classes in focused regional surveys (Lo et al. 2011) and measured directly using the acoustic-trawl method (Demer et al. 2012).

Life History Features Affecting Management

Pacific sardines may reach 41 cm in length (Eschmeyer et al. 1983), but are seldom longer than 30 cm in fishery catches and survey samples. The heaviest sardine on record weighed 0.323 kg. Oldest recorded age of sardine is 15 years, but fish in California commercial catches are usually younger than five years and fish in the PNW are less than 10 years old. Sardine are typically larger and two to three years older in regions off the Pacific Northwest than observed further south in waters off California. There is evidence for regional variation in size-at-age, with size increasing from south to north and from inshore to offshore (Phillips 1948, Hill 1999). McDaniel et al. (2016) analyzed recent fishery and survey data and found evidence for age-based (as opposed to size-based) movement from inshore to offshore and from south to north.

Historically, sardines fully recruited to the fishery when they were ages three and older (MacCall 1979). Recent fishery data indicate that sardines begin to recruit to the SCA fishery at age zero during the late winter-early spring. Age-dependent availability to the fishery depends upon the location of the fishery, with young fish unlikely to be fully available to fisheries located in the north and older fish less likely to be fully available to fisheries south of Point Conception.

Sardines spawn in loosely aggregated schools in the upper 50 meters of the water column. Sardines are oviparous, multiple-batch spawners, with annual fecundity that is indeterminate, and age- or size-dependent (Macewicz et al. 1996). Spawning of the northern subpopulation typically begins in January off northern Baja California and ends by August off the Pacific Northwest (Oregon, Washington, and Vancouver Island), typically peaking off California in April. Sardine eggs are most abundant at sea-surface temperatures of 13 to 15 ^{o}C, and larvae are most abundant at 13 to 16 ^{o}C. The spatial and seasonal distribution of spawning is influenced by temperature. During warm ocean conditions, the center of sardine spawning shifts northward and spawning extends over a longer period of time (Butler 1987; Ahlstrom 1960; Dorval et al. 2016, 2017). Spawning is typically concentrated in the region offshore and north of Point Conception (Lo et al. 1996, 2005) to areas off San Francisco. However, during April 2015 and 2016 spawning was observed in areas north of Cape Mendocino to central Oregon (Dorval et al. 2016; Dorval et al. 2017 in Appendix A).

Ecosystem Considerations

Pacific sardine represent an important forage base in the California Current Ecosystem (CCE). At times of high abundance, Pacific sardine can compose a substantial portion of biomass in the CCE. However, periods of low recruitment success driven by prevailing oceanographic conditions can lead to low population abundance over extended periods of time. Readers should consult PFMC (1998), PFMC (2014), and NMFS (2016a,b) for comprehensive information regarding environmental processes generally hypothesized to influence small pelagic species that inhabit the CCE.

Abundance, Recruitment, and Population Dynamics

Extreme natural variability is characteristic of clupeid stocks, such as Pacific sardine (Cushing 1971). Estimates of sardine abundance from as early as 300 AD through 1970 have been reconstructed from the deposition of fish scales in sediment cores from the Santa Barbara basin off SCA (Soutar and Issacs 1969, 1974; Baumgartner et al. 1992; McClatchie et al. 2017). Sardine populations existed throughout the period, with abundance varying widely on decadal time scales. Both sardine and anchovy populations tend to vary over periods of roughly 60 years, although sardines have varied more than anchovies. Declines in sardine populations have generally lasted an average of 36 years and recoveries an average of 30 years.

Pacific sardine spawning biomass (age 2+), estimated from virtual population analysis methods, averaged 3.5 mmt from 1932 through 1934, fluctuated from 1.2 to 2.8 mmt over the next ten years, then declined steeply from 1945 to 1965, with some short-term reversals following periods of strong recruitment success (Murphy 1966; MacCall 1979). During the 1960s and 1970s, spawning biomass levels were as low as 10,000 mt (Barnes et al. 1992). The sardine stock began to increase by an average annual rate of 27% in the early 1980s (Barnes et al. 1992).

As exhibited by many members of the small pelagic fish assemblage of the CCE, Pacific sardine recruitment is highly variable, with large fluctuations observed over short timeframes. Analyses of the sardine stock-recruitment relationship have resulted in inconsistent findings, with some studies showing a strong density-dependent relationship (production of young sardine declines at high levels of spawning biomass) and others, concluding no relationship (Clark and Marr 1955; Murphy 1966; MacCall 1979). Jacobson and MacCall (1995) found both density-dependent and environmental factors to be important, as was also agreed during a sardine harvest control rule workshop held in 2013 (PFMC 2013). The current U.S. harvest control rules for sardine couple prevailing SST to exploitation rate (see *Harvest Control Rules* section).

Relevant History of the Fishery and Important Features of the Current Fishery

The sardine fishery was first developed in response to demand for food during World War I. Landings increased rapidly from 1916 to 1936, peaking at over 700,000 mt. Pacific sardine supported the largest fishery in the western hemisphere during the 1930s and 1940s, with landings in Mexico to Canada. The population and fishery soon declined, beginning in the late 1940s and with some short-term reversals, to extremely low levels in the 1970s. There was a southward shift in catch as the fishery collapsed, with landings ceasing in the Pacific Northwest in 1947 through 1948 and in San Francisco, from 1951 through 1952. The San Pedro fishery closed in the mid-1960s. Sardines were primarily reduced to fish meal, oil, and canned food, with small quantities used for bait.

In the early 1980s, sardines were taken incidentally with Pacific and jack mackerel in the SCA mackerel fishery. As sardine continued to increase in abundance, a directed purse-seine fishery was re-established. The incidental fishery for sardines ceased in 1991 when the directed fishery was offered higher quotas. The renewed fishery initiated in ENS and SCA, expanded to CCA, and by the early 2000s, substantial quantities of Pacific sardine were landed at OR, WA, and BC. Volumes have reduced dramatically in the past several years. Harvest by the Mexican (ENS) fishery is not currently regulated by quotas, but there is a minimum legal size limit of 150 mm SL. The Canadian fishery failed to capture sardine in summer 2013, and has been under a moratorium since summer 2015. The U.S. directed fishery has been subject to a moratorium since July 1, 2015.

Recent Management Performance

Management authority for the U.S. Pacific sardine fishery was transferred to the PFMC in January 2000. The Pacific sardine was one of five species included in the federal CPS-FMP (PFMC 1998). The CPS-FMP includes harvest control rules intended to prevent Pacific sardines from being overfished and to maintain relatively high and consistent, long-term catch levels. Harvest control rules for Pacific sardine are described at the end of this report. A thorough description of PFMC management actions for sardines, including HG values, may be found in the most recent CPS SAFE document (PFMC 2014). U.S. harvest specifications and landings since 2000 are displayed in Table 1 and Figure 2. Harvests in major fishing regions from ENS to BC are provided in Table 2 and Figure 3.

ASSESSMENT DATA

Biological Parameters

Stock structure
We presume to model the NSP that, at times, ranges from northern Baja California, México to British Columbia, Canada. As mentioned above, there is general consensus that catches landed in ENS and SCA likely represent a mixture of SSP (during warm months) and NSP (cool months) (Felix-Uraga et al. 2004, 2005; Garcia-Morales 2012; Zwolinski et al. 2011; Demer and Zwolinski 2014) (Figure 1). The approach involves analyzing satellite oceanographic data to objectively partition monthly catches and biological compositions from ENS and SCA ports to exclude data from the SSP (Demer and Zwolinski 2014). This approach was adopted in the 2014 full assessment (Hill et al. 2014; STAR 2014), in the 2015 and 2016 update assessments (Hill et al. 2015, 2016), and is carried forward in the following assessment.

Growth
Analysis of size-at-age from fishery samples (1993-2013) provided no indication of sexual dimorphism related to growth (Figure 4; Hill et al. 2014), so combined sexes were included in the present assessment model with a sex ratio of 50:50.

Past Pacific sardine stock assessments conducted with the CANSAR and ASAP statistical catch-at-age frameworks accounted for growth using empirical weight-at-age time series as fixed model inputs (e.g. Hill et al. 1999; Hill et al. 2006). Stock synthesis models used for management from 2007 through 2016 estimated growth internally using conditional age-at-length compositions and a fixed length-weight relationship (e.g., Hill et al. 2016). Disadvantages to estimating growth internally within the stock assessment include: 1) inability to account for regional differences in age-at-size due to age-based movements (McDaniel et al. 2016); 2) difficulty in modeling cohort-specific growth patterns; 3) potential model interactions between growth estimation and selectivity; and 4) models using conditional age-at-length data are data-heavy, requiring more estimable model parameters than the empirical weight-at-age approach. For these reasons, the model ALT was constructed to bypass growth estimation internally in SS, instead opting for a return to the use of empirical weights-at-age.

Empirical weight-at-age data were included as fixed inputs in model ALT. Fleet- and survey-specific empirical weight-at-age estimates were compiled for each model year and semester. Fishery mean weight-at-age estimates were calculated for seasons with greater than two samples available. Growth patterns were examined by cohort and were smoothed as needed. Specifically, fish of the same cohort were not allowed to shrink in subsequent time steps, and negative deviations were substituted by interpolation. Likewise, missing values were substituted through interpolation. Further details regarding empirical weight-at-age time series for the AT survey are provided in the section 'Fishery-Independent Data \ Acoustic-trawl survey'. All fishery and AT survey weight-at-age vectors are displayed in Figures 5-7. During the STAR Panel (Feb 2017), it was discovered that PNW weight-at-age had not been smoothed by cohort as described above, but instead were input as nominal estimates of weight-at-age. A sensitivity run based on cohort-smoothed PNW data resulted in a negligible impact (<1%) on population estimates, i.e., revised weight-at-age matrix was not included in the final model ALT.

Empirical weight-at-age models require population weight-at-age vectors to convert population number-at-age to biomass-at-age. Model ALT population weight-at-age vectors were derived from the last assessment model (T_2016) after it had been updated with newly available maturity, catch, and survey data (T_2017). Model T_2017 was run once to derive estimates of population weight-at-age at the beginning and middle of each semester. A fecundity*maturity-at-age vector, used to calculate SSB-at-age, was also derived from model T_2017 (see 'Maturity' below). Population- and SSB-at-age vectors are displayed in Figure 8.

Maturity

Maturity was modeled using a fixed vector of fecundity*maturity by age (Figure 8). The vector was derived from the 2016 assessment model after it was updated with newly available information (T_2017). In addition to other data sources, model T_2017 was updated with new parameters for the logistic maturity-at-length function using female sardine sampled from survey trawls conducted from 1994 to 2016 (n=4,561). Reproductive state was primarily established through histological examination, although some immature individuals were simply identified through gross visual inspection. Parameters for the logistic maturity function were estimated using,

$$\text{Maturity} = 1/(1+\exp(slope*L-L_{\text{inflexion}}));$$

where slope = -0.9051 and inflexion = 16.06 cm-SL. Maturity-at-length parameters were fixed in the updated assessment model (T_2017) and fecundity was fixed at 1 egg/gram body weight. Once model T_2017 was run, the fecundity*maturity-at-age vector was extracted for use in the current alternative assessment model (ALT) (Figure 8).

Natural mortality

Age-specific mortality estimates are available for the entire suite of life history stages (Butler et al. 1993). Mortality is high at the egg and yolk sac larvae stages (instantaneous rates in excess of 0.66 d^{-1}). The adult natural mortality rate has been estimated to be M=0.4-0.8 yr^{-1} (Murphy 1966; MacCall 1979) and 0.51 yr^{-1} (Clark and Marr 1955). Zwolinski and Demer (2013) studied natural mortality using trends in abundance from the acoustic-trawl method (ATM) surveys (2006-2011), accounting for fishery removals, and estimated M=0.52 yr^{-1}.

Murphy's (1966) virtual population analysis of the Pacific sardine used M=0.4 yr^{-1} to fit data from the 1930s and 1940s, but M was doubled to 0.8 yr^{-1} from 1950 to 1960 to better fit the trend in CalCOFI egg and larval data (Murphy 1966). Early natural mortality estimates may not be as applicable to the present population, given the significant increase in predator populations since the historic era (Vetter and McClatchie, *in review*). To date, Pacific sardine stock assessments for PFMC management have used M=0.4 yr^{-1}. For reasons explained subsequently, the present alternative assessment (model ALT) was conducted using M=0.6 yr^{-1}. An instantaneous M rate of 0.6 yr^{-1} translates to an annual M rate of 45% of the adult sardine stock dying each year from natural causes. Sensitivities to assumptions regarding M are further explored in this assessment.

Fishery-dependent Data

Overview

Available fishery data include commercial landings and biological samples from six regional fisheries: Ensenada (ENS); Southern California (SCA); Central California (CCA); Oregon (OR); Washington (WA); and British Columbia (BC). Standard biological samples include individual weight (kg), standard length (cm), sex, maturity, and otoliths for age determination (not in all cases). A complete list of available port sample data by fishing region, model year, and season is provided in Table 3.

All fishery catches and compositions were compiled based on the sardine's biological year ('model year') to match the July 1st birth-date assumption used in age assignments. Each model year is labeled with the first of two calendar years spanned (e.g., model year '2005' includes data from July 1, 2005 through June 30, 2006). Further, each model year has two six-month seasons, including 'S1'=Jul-Dec and 'S2'=Jan-Jun. Major fishery regions were pooled to represent a southern 'MEXCAL' fleet (ENS+SCA+CCA) and a northern 'PNW' fleet (OR+WA+BC). The MEXCAL fleet was treated with semester-based selectivities ('MEXCAL_S1' and 'MEXCAL_S2'). Rationale for this fleet design is provided in Hill et al. (2011).

Landings

Ensenada monthly landings from 1993-02 were compiled using the 'Boletín Anual' series previously produced by INAPESCA's Ensenada office (e.g., Garcia and Sánchez 2003). Monthly landings from 2003-14 were taken from CONAPESCA's web archive of Mexican fishery yearbook statistics (CONAPESCA 2015). The ENS monthly landings for 2015-16 were provided by INAPESCA-Ensenada (Concepción Enciso-Enciso, pers. comm.).

California (SCA and CCA) directed commercial landings were obtained from the PacFIN database (2005-2015) and CDFW's 'Wetfish Tables' (2016). Given the California live bait industry is currently the only active sector in the U.S. sardine fishery, live bait landings were also included in this assessment for the first time. California live bait landings are recorded on 'Live Bait Logbooks' provided to the CDFW on a voluntary basis. The CDFW compiles estimates of catch weight based on a conversion of scoop number to kg (Kirk Lynn, CDFW, pers. comm.). Monthly live bait landings were pooled with other commercial catches in the MEXCAL fleet.

Oregon (OR) and Washington (WA) landings (2005-16) were obtained from PacFIN. British Columbia (BC) monthly landing statistics (2005-12) were provided by CDFO (Linnea Flostrand and Jordan Mah, pers. comm.). Sardine were not landed in Canada during 2013-16. The BC landings were pooled with OR and WA as part of the PNW fleet.

Available information concerning bycatch and discard mortality of Pacific sardine, as well as other members of the small pelagic fish assemblage of the California Current Ecosystem, is presented in PFMC (2014). Limited information from observer programs implemented in the past indicated minimal discard of Pacific sardine in the commercial purse seine fishery that targets the small pelagic fish assemblage off the USA Pacific coast.

As stated above, satellite oceanography data were used to characterize ocean climate (SST) within typical fishing zones off Ensenada and Southern California and attribute monthly catch for each fishery to either the southern (SSP) or northern subpopulation (NSP). The NSP landings by model year-season for each fishing region are presented in Table 2 and Figure 3. The current Stock Synthesis model aggregates regional fisheries into a southern 'MEXCAL' fleet and a northern 'PNW' fleet (Figure 1). Landings aggregated by model year-season and fleet are presented in Table 4 and Figure 9.

Age compositions

Age compositions for each fleet and season were the sums of catch-weighted age observations, with monthly landings within each port and season serving as the weighting unit. As indicated above, environmental criteria used to assign landings to subpopulations were also applied to monthly port samples to categorize NSP-based biological compositions.

Age-composition data were partitioned into 9 age bins, representing ages 0 through 8+. Total numbers for ages observed in each fleet-semester stratum were divided by the typical number of fish collected per sampled load (25 fish per sample) to set the sample sizes for compositions included in the assessment model. Seasons with fewer than three samples were excluded from the model. Age compositions were input as proportions. Age-composition time series are presented in Figures 10-12.

Oregon and Washington fishery ages from season 2 (S2, Jan-Jun), were omitted from all models due to inter-laboratory inconsistencies in the application of birth-date criteria during this semester (noting that OR and WA landings and associated samples during S2 are typically trivial). Age data were not available for the BC or ENS fisheries, so PNW and MEXCAL fleet compositions only represent catch-at-age by the OR-WA and CA fisheries, respectively.

Ageing error
Sardine ageing using otolith methods was first described by Walford and Mosher (1943) and extended by Yaremko (1996). Pacific sardines are routinely aged by fishery biologists in CDFW, WDFW, and SWFSC using annuli enumerated in whole sagittae. A birth date of July 1st is assumed when assigning ages.

Ageing-error vectors for fishery data were unchanged from Hill et al. (2011, 2014). Ageing error vectors (SD at true age) were linked to fishery-specific age-composition data (Figure 13). For complete details regarding age-reading data sets, model development and assumptions, see Hill et al. (2011, Appendix 2), as well as Dorval et al. (2013).

Fishery-independent Data

Overview
This assessment uses a single time series of biomass based on the SWFSC's acoustic-trawl (AT) survey. This survey and estimation methods were vetted through a formal methodology review process in February 2011 (PFMC 2011, Simmonds 2011). The AT survey will be reviewed by the PFMC in January 2018.

Acoustic-trawl survey
The AT time series is based on SWFSC surveys conducted along the Pacific coast since 2006 (Cutter and Demer 2008; Zwolinski et al. 2011, 2012, 2014, 2016, Demer et al. 2012, and Zwolinski et al. in preparation). The AT survey and estimation methods were reviewed by a panel of independent experts in February 2011 (PFMC 2011) and the results from these surveys have been included in the assessment since 2011 (Hill et al. 2011, 2012, 2014, 2015, 2016).

Two new AT-based biomass estimates were included in this assessment; one from the spring 2016 survey off central California to Oregon, and the other from the summer 2016 survey spanning San Diego to northern Vancouver Island, Canada. Biomass estimates and associated size distributions from the 2016 surveys are described in the section 'Assessment – Acoustic Trawl Survey' and Zwolinski et al. (in preparation). Biomass estimates from the spring and summer 2016 surveys, 83,037 (CV=0.493) mt and 78,776 (CV=0.539) mt respectively, represent roughly a four-fold increase from those of 2015 (Table 5, Figure 20). The higher AT biomass estimates are consistent with evidence of moderately successful recruitments in 2014 and 2015 (Table 8, Figure 12).

The time series of AT biomass estimates is presented in Table 5 and Figure 20. In order to comply with the model ALT formulation, estimates of abundance at length (Figure 12) were converted into abundance-at-age using seasonal (spring and summer) age-length keys constructed from survey data from 2006 to the present. Age-length keys were constructed for each survey season using the function 'multinom' from the R package 'nnet'. The 'nnet' function fits a multinomial log-linear model using neural networks. The response is a discrete probability distribution of age-at-length. The AT survey biomass estimates (2006-2016) were used as a single time-series, with q being estimated. Age compositions were fit using asymptotic age-selectivity (ages 1+ fully selected; SS age selectivity option 10) which was fixed for the entire time series. Empirical weight-at-age time series (Figure 7) were calculated for every survey using the following process: 1) The AT-derived abundance-at-length was converted to biomass-at-length using a time-invariant length-to-weight relationship. 2) The biomass- and numbers-at-length were converted to biomass-at-age and numbers-at-age, respectively, using the above-mentioned age-length key. 3) mean weights-at-age were calculated by dividing biomass-at-age by the respective numbers-at-age.

Data Sources Considered but not Used

Daily egg production method spawning biomass
Past sardine stock assessments have included a time series of daily egg production method (DEPM) spawning stock biomass (SSB). The time series was included in the assessments as an index of relative female SSB (*Q* estimated) and has always been considered an underestimate of true SSB (Deriso et al. 1996). The DEPM time series has been described in numerous publications and stock assessment reports. The DEPM time series since 2005 is provided in Table 5. The spring 2016 DEPM survey estimate is summarized in Appendix A of this report. It is worth noting that the 2016 estimate of female SSB was only 5,929 mt, the lowest level since mid-1980s. As stated elsewhere, the DEPM series was excluded from model ALT. As indicated in past assessments, exclusion of the DEPM time series continues to have negligible impact on the stock assessment outcome. Nonetheless, DEPM estimates are still considered useful to corroborate/refute results from either the AT survey and/or model ALT (see 'Assessment – Acoustic-trawl survey \ Additional assessment considerations' below).

ASSESSMENT – ACOUSTIC-TRAWL SURVEY

Overview

Current management of the Pacific sardine population inhabiting the California Current of the northeast Pacific Ocean relies on an estimate of stock biomass (age-1+ fish in mt), which is needed for implementing an established harvest control rule policy for this species on an annual basis (see Harvest Control Rules for the 2017-18 Management Cycle below). It is important to note that the stock assessment team (STAT) recommended that the preferred assessment approach for meeting the management goal was to use results from the acoustic-trawl (AT) survey alone, i.e., not results from an integrated population dynamics model (see Preface above). For purposes of conducting the formal stock assessment review (STAR) in February 2017, methods and results from both the survey-based (AT) and model-based (ALT) approaches were presented in the assessment report distributed for review purposes at the meeting. The final assessment report presented here is similar to the review draft, including the STAT's criteria for choosing an assessment approach for advising management of Pacific sardine in the future, as well as data, parameterizations, and results associated with the two assessment approaches.

Merits of AT survey-based assessment
The AT survey employs objective sampling methods based on state of the art echosounder equipment and an expansive data collection design in the field (Zwolinski et al. 2014). Stock assessments since 2011 indicate that the survey produces the strongest signal of Pacific sardine biomass available for assessing absolute abundance of the stock on an annual basis (i.e.,

management goal, see Overview above). The survey design is based on an optimal habitat index (Zwolinski et al. 2011), established catchability ($Q\approx1.0$), and commitment to long-term support. Biomass estimates produced by the survey are primarily subjected to random sampling variability and not affected by uncertainty surrounding poorly understood population processes that must be addressed to varying degrees when fitting population dynamics models, simple or complex.

Drawbacks of model-based assessment

In the context of meeting the management goal, a model-based assessment includes considerable additional uncertainty in recent estimated stock biomass of Pacific sardine, given the need to explicitly model critical stock parameters in the assessment that is unnecessary using a survey-based assessment approach. For example, uncertainty surrounding natural mortality (*M*), recruitment variability (stock-recruitment relationship), biology (longevity, maturity, and growth), and particularly, selectivity, which can substantially influence bottom-line results useful to management. That is, the model-based assessment necessarily includes additional structural and process error, given varying degrees of bias associated with sample data and parameter misspecifications in the model. Further, addressing potential improvements to the AT survey methods and/or design over time (e.g., varying catchability, *Q*) is less straightforward and more problematic in a model-based assessment approach than basing the formal assessment on the estimate of stock biomass produced from the AT survey each year. Finally, including additional sources of data necessarily degrades the influence of the highest quality data available in the integrated model (AT survey abundance index) for determining recent stock biomass.

Additional assessment considerations

Most importantly, employing a survey-based assessment approach requires projecting estimated stock biomass from the AT survey one year (also required for the model-based approach), given the current assessment/review/management schedule. Currently, management stipulations are set roughly one year following the last year of sample data available for assessing the stock. The Pacific sardine stock assessment reviews (STAR) are conducted early in the year (e.g., February 2017) for applying new management stipulations for the upcoming ‘fishing year’ (2017-18). Thus, the AT survey biomass estimated in 2016 needs to be projected one year to summer 2017, see Preface above and Projected Estimates (2016-17) below. Second, the integrated model (e.g., model ALT) should be maintained along with the survey-based assessment to evaluate stock parameters of interest, including the stock-recruitment relationship and recent estimates of recruitment, age/length structure of the population, catches and fishing intensity, etc., as well as to use in the unlikely event that the AT survey is unable to be conducted in a particular year. Finally, if workable in the future, the DEPM time series should be maintained as a complementary index of abundance for corroborating/refuting information generated from the AT survey, as well as to help continually improve the AT survey design (e.g., better understanding of the spawning aggregation/migration/timing in the context of range variability exhibited by the population over time).

Methods

Methods and results for the most recent AT survey cruises conducted in spring and summer 2016 are presented in this report. Methods and sampling designs in the field have been generally similar since the survey was first employed in 2006 (model year 2005), noting that changes to areas surveyed occurred seasonally and annually, given the environmental-based optimal habitat index used to select actual transect lines each year. Readers should consult Zwolinski et al. (2014) and Zwolinski et al. (2016) for survey cruises conducted in past years.

The 2016 surveys were conducted onboard the NOAA Fisheries Survey Vessel (FSV) *Reuben Lasker*. Acoustic data were collected during the day to allow sampling of fish schools aggregated throughout the surface mixed layer. Trawling was conducted during the night to sample fish dispersed near the surface (Mais 1974). The spring survey occurred over 30 days (March 22 to April 22), with transects based on sampling the largest extent of the potential sardine habitat, from north to south. Due to persisting warm conditions in the northeast Pacific Ocean, the sardine potential habitat extended into northern California waters farther north than usual for spring and thus, the survey design was modified to accommodate the expanded habitat (Figure 14). The survey started approximately 10 nm north of Newport, Oregon and progressed south to Bodega Bay, California.

The summer survey occurred over 80 days (June 28 – September 22), and transects spanned the west coast of the U.S. and Canada, from the northern end of Vancouver Island to San Diego (Figure 15). Further details on echosounder calibrations, survey design, and sampling protocols are detailed in Stierhoff et al. (*in preparation*) and Zwolinski et al. (*in preparation*).

Acoustic data from each transect were processed using estimates of sound speed and absorption coefficients calculated with contemporary data from Conductivity-Temperature-Depth (CTD) probes. Echoes from schooling CPS were identified with a semi-automated data processing algorithm as described in Demer et al. (2012). The CPS backscatter was integrated within an observational range of 10 m below the sea surface to the bottom of the surface mixed layer or, if the seabed was shallower, to 3 m above the estimated acoustic dead zone (Demer et al. 2009). The vertically integrated backscatter was averaged along 100-m intervals, and the resulting nautical area backscattering coefficients (s_A; m^2 nm^{-2}) were apportioned based on the proportion of the various CPS found in the nearest trawl cluster. The s_A were converted to biomass and numerical densities using species- and length-specific estimates of weight and individual backscattering properties (see details in Demer et al. 2012 and Zwolinski et al. 2014).

Survey data were post-stratified to account for spatial heterogeneity in sampling effort and sardine density. Total biomass in the survey area was estimated as the sum of the biomasses in each individual stratum. Sampling variance in each stratum was estimated from the inter-transect variance calculated using bootstrap methods (Efron 1981), and total sampling variance was calculated as the sum of the variances across strata (see Demer et al. 2012; Zwolinski et al. 2012; and references therein for details). The 95% confidence intervals (CIs) were estimated as the 0.025 and 0.975 percentiles of the distribution of 1,000 bootstrap biomass estimates. Coefficient of variation (CV) for each of the mean values was obtained by dividing the bootstrapped standard errors by the point estimates (Efron 1981).

For each stratum, estimates of abundance were broken down to 1-cm standard length (SL) classes. These abundance-at-length estimates were obtained by raising the length-frequency distribution from each cluster to the abundance assigned to the respective distribution based on the acoustic backscatter. Age-length keys by season were constructed using age and length data from surveys conducted since 2006. In conjunction with a time-invariant weight-length relationship, the number-at-length estimates from the AT survey were transformed into estimates of number-at-age and biomass-at-age for each year. Mean weight-at-age vectors were constructed by dividing the biomass-at-age vectors by the respective vectors of number-at-age. During the STAR Panel (Feb 2017), the STAT was asked to recompile AT weight-at-age matrices using the cohort-smoothing approach applied to fishery samples (see ‘Biological Parameters \ Growth’). As noted above, and in STAR (2017), results based on this approach were negligibly different (<1% change in biomass, and one likelihood point improvement) and thus, not included in final model ALT.

The management process requires an estimate of stock biomass (age-1+ fish, mt) at the beginning of the fishing year (July 2017). Since the survey occurred in summer 2016 (considered here July 1, 2016 for simplicity), projection of the biomass to 2017, involved 3 steps: 1) estimating age-0 abundance for 2016; 2) accounting for abundance decrease into 2017 due to natural mortality (M); and 3) accounting for biomass increase due to somatic growth. Because age-0 abundance of sardine is not well characterized from the AT survey (see ‘Assessment – Model \ Model Description \ Selectivity’ below), the abundance of this age class in July 2016 was estimated using the stock-recruitment (S-R) relationship from the alternative assessment model, model ALT (see ‘Assessment – Model \ Results \ Stock-recruitment’ below). The SSB input needed for the S-R relationship was obtained by back-calculating the number-at-age estimates for summer 2016 to January 2016 (semester 2 of model year 2015) assuming M=0.3 per semester, followed by conversion into SSB using mean-weight-at-age estimates from the survey and the maturity ogive. The predicted recruitment was then combined accordingly with the vector of other number-at-age estimates from the survey and projected one year into the future assuming M=0.6 yr^{-1} (as assumed in model ALT). The final number-at-age estimates were converted to estimates of biomass-at-age using the estimated mean weight-at-age vector in 2017.

Results

The spring survey totaled 3,850 nm of daytime east-west tracklines and 43 night-time surface trawls resulting in the formation of 18 clusters that were used for species identification and length measurements. The longer summer survey totaled 4,627 nm of daytime east-west tracklines and 121 night-time surface trawls combined into 49 trawl clusters. Post-cruise strata were defined for each survey, considering transect spacing, echoes or catches of CPS, sardine eggs in the Continuous Underway Fish Egg Sampler (CUFES), and the presence of sardine potential habitat (Figures 14 and 16).

In the spring, sardine were primarily concentrated in an area 160 nm long along the coasts of southern Oregon and northern California (Figure 16) and out to 80 nm offshore. Sardine biomass was estimated using 2 strata (Table 6, Figure 16). Stratum 1 contained the largest concentration of CPS backscatter, trawl clusters with sardine, and CUFES samples with sardine eggs (Figures 14 and 16). To the south, stratum 2 contained few adult sardine, no eggs, and relatively low backscatter. Stratum 2 had considerably lower biomass than stratum 1, contributing significantly less to the total biomass in the survey area, which was estimated to be 83,037 mt ($CI_{95\%}$=18,906 to 172,109 mt, CV=49.3 %, Table 6). Globally, the distribution of abundance-at-length estimates had modes at SL=14, 20, and 25 cm (Table 8, Figure 17). The larger-sized cohort was composed of fish age 3 and older, whereas the smaller fish were likely sardine spawned in 2015. The clear separation between the central mode and the two other modes indicates that the central mode encompassed sardine predominantly spawned in 2014.

At the time of the beginning of the summer survey, the sardine potential habitat extended beyond the north of Vancouver Island (Figure 15). Nonetheless, despite the availability of suitable habitat, sardine were only found on the southern end of the Island, around 49 ° N. From there to the south, the stock was highly fragmented and observed in small abundances, except immediately to the north of Point Conception (Figure 15). The entire survey area included an estimated 78,776 mt of Pacific sardine ($CI_{95\%}$=9,538 to 148,287 mt, CV=53.9%, Table 7), with strata 1 and 6 contributing considerably larger biomasses than other strata. The distribution of abundance-at-length estimates had two major modes at 17 and 19 cm, with only minor contributions from other length classes (Table 8, Figure 19). This pattern observed in the length distribution was caused by the disproportionately large abundances observed in strata 1 and 6, which in turn were characterized by a reduced number of clusters. Given the high uncertainty associated with the estimation in these two strata (CV=68.9% and 92.9% for strata 1 and 6, respectively; Table 7), estimated length-at-age of the population was also subject to substantial uncertainty.

Projected Estimates (2016-17)

The projected total estimate of stock biomass (age 1+, mt) for July 2017 from the AT survey was 96,930 mt (Tables 9 and 11). As discussed in Methods above, the projection calculation was based on using number-at-age estimates from the summer 2016 survey (Table 9), along with the recruitment estimate associated with the stock-recruitment relationship in 2016 (from model ALT) discounted for natural mortality (M = 0.6), and finally, converting abundance in numbers to biomass using mean weight-at-age estimates derived from the survey. It is worth noting that this projection is dependent not only on the biomass observed in 2016, but also on the estimated recruitment for 2016. Given the stochastic nature of the past recruitments, it should be expected that a rectification of the 2017 biomass will occur after analysis of the 2017 summer survey. The entire stock biomass time series estimated from the AT survey for 2005-16, including the projected estimate for 2017, is presented in Figure 20. See Appendix 2 in STAR (2017) for additional details regarding biomass projection.

Areas of Improvement for AT Survey

Presently, the AT survey with Q=1.0 is considered to generally provide unbiased measurements of the sardine population (see 'Changes between Last and Current Assessment Model \ Catchability'). Despite this assertion of quality, continued refinement and verification of the survey assumptions will continue in the future. In particular, it is essential that the survey design in the field continues to encompass the entire range of the stock in any given year, as well as expanding areas surveyed by using ancillary sampling tools in situations where the research vessel may have difficulty operating. Combined efforts with state fishery agencies to complement acoustic sampling with optical observations are already underway. Additionally, starting this spring, the SWFSC will begin testing the use of Unmanned Aerial Systems (UAS) to expand its survey capabilities in real time. Besides providing information about the presence of CPS in unnavigable areas, UAS will supplement the use of acoustic sensor to monitor the presence of fish schools near the surface.

Further improvement will continue both in the study of species' target strength (TS), a central parameter to convert acoustic backscatter to numerical densities, and in the improvement of the survey design, particularly in the use of more aggressive adaptive rules that will allow increasing sampling effort in areas with unusually large concentrations of CPS. The use of adaptive sampling procedures will likely reduce the uncertainty of both biomass, species composition, and demography of target species. Also, see 'Assessment Model – Acoustic-trawl Survey / Overview / Additional assessment considerations' above and 'Research and Data Needs' below.

ASSESSMENT – MODEL

History of Modeling Approaches

The population's dynamics and status of Pacific sardine prior to the collapse in the mid-1900s was first modeled by Murphy (1966). MacCall (1979) refined Murphy's virtual population analysis (VPA) model using additional data and prorated portions of Mexican landings to exclude the southern subpopulation. Deriso et al. (1996) modeled the recovering population (1982 forward) using CANSAR, a modification of Deriso's (1985) CAGEAN model. The CANSAR was subsequently modified by Jacobson (Hill et al. 1999) into a *quasi*, two-area model CANSAR-TAM to account for net losses from the core model area. The CANSAR and CANSAR-TAM models were used for annual stock assessments and management advice from 1996 through 2004 (e.g., Hill et al. 1999; Conser et al. 2003). In 2004, a STAR Panel endorsed the use of an Age Structured Assessment Program (ASAP) model for routine assessments. The ASAP model was used for sardine assessment and management advice from 2005 to 2007 (Conser et al. 2003, 2004; Hill et al. 2006a, 2006b). In 2007, a STAR Panel reviewed and endorsed an assessment using Stock Synthesis (SS) 2 (Methot 2005, 2007), and the results were adopted for management in 2008 (Hill et al. 2007), as well as an update for 2009 management (Hill et al. 2008). The sardine model was transitioned to SS version 3.03a in 2009 (Methot 2009) and was again used for an update assessment in 2010 (Hill et al. 2009, 2010). Stock Synthesis version 3.21d was used for the 2011 full assessment (Hill et al. 2011), the 2012 update assessment (Hill et al. 2012), and the 2013 catch-only projection assessment (Hill 2013). The 2014 sardine full assessment (Hill et al. 2014), 2015 update assessment (Hill et al. 2015), and 2016 update assessment (Hill et al. 2016) were based on SS version 3.24s. The 2017 full assessment presented here was based on SS version 3.24aa. SS version 3.24aa corrected errors associated with empirical weight-at-age models having multiple seasons.

Responses to 2014 STAR Panel Recommendations

Many of the following recommendations are based on using an integrated model and not directly applicable to the current assessment, given the survey-based assessment represents the preferred approach for advising management of the Pacific sardine resource in the future. Regardless, brief responses are provided for relevant recommendations in the context of the model-based assessment approach using model ALT.

High priority

A. The assessment would benefit not only from data from Mexico and Canada, but also from joint assessment activities, which would include assessment team members from both countries during assessment development.

Response: Bilateral stock assessment has long been considered a worthwhile goal. However, a more immediate priority is international collaboration to obtain synoptic survey coverage of the northern subpopulation. Synoptic surveys would also simultaneously provide population estimates of the southern subpopulation, as well as other transboundary CPS stocks (i.e., Pacific mackerel, northern anchovy central subpopulation, and jack mackerel). Synoptic CPS surveys are discussed each year at the Trinational Sardine Forum and Mexico-U.S. bilateral meetings.

B. Modify Stock Synthesis so that the standard errors of the logarithms of age-1+ biomass can be reported. These biomasses are used when computing the Overfishing Level, the Acceptable Biological catch, and the Harvest Level, but the CV used when applying the ABC control rule is currently that associated with spawning biomass and not age-1+ biomass.

Response: Requests for this addition to SS have been made in the past, i.e., it is possible that SS ver. 3.0 will include the error estimate associated with estimated stock biomass. André Punt revised an earlier version of SS to produce this output, however, the results were not markedly different than error estimates produced for SSB.

C. Explore models that consider a much longer time-period (e.g. 1931 onwards) to determine whether it is possible to model the entire period and determine whether this leads to a more informative assessment as well as provide a broader context for evaluating changes in productivity.

Response: Fishery managers require advice regarding current and near-future abundance. The STAT considers the above recommendation worthwhile for developing research models, but counterproductive for providing annual management advice.

D. Investigate sensitivity of the assessment to the threshold used in the environmental-based method (currently 50% favorable habitat) to further delineate the southern and northern subpopulations of Pacific sardine. The exploration of sensitivity in the present assessment was limited given time available, but indicated potential sensitivity to this cut-off.

Response: No further work has been conducted to address this recommendation.

E. Compute age-composition data for the ATM survey by multiplying weighted length-frequencies by appropriately constructed age-length keys (i.e. taking account of where the samples were taken).

Response: This recommendation was implemented in model ALT and for the projection model for the AT survey. Methods are described under the Fishery-independent data section above.

F. Investigate alternative approaches for dealing with highly uncertain estimates of recruitment that have an impact on the most recent estimate of age-1+ biomass that is important for management. Possible approaches are outlined in Section 3 of this report.

Response: *No work has been conducted to address this recommendation*.

G. Validation of the environmentally-based stock splitting method should be carried out if management is to be based on separating the northern and southern subpopulations using the habitat model. It may be possible to develop simple discriminant factors to differentiate the two sub-populations by comparing metrics from areas where mixing does not occur. Once statistically significant discriminant metrics (e.g. morphometric, otolith morphology, otolith microstructure, and possibly using more recent developments in genetic methods) have been chosen, these should be applied to samples from areas where mixing may be occurring or where habitat is close to the environmentally-based boundary. This can be used to help set either a threshold or to allocate proportions if mixing is occurring.

Response: Somatic and otolith morphometric analyses were conducted that generally address this recommendation (Felix et al. 2005). The Felix et al. (2005) study complemented a SST-based method published by Felix et al. (2004). Subsequent validation studies have not been undertaken. Genetic methods have been inconclusive.

H. Continue to investigate the merits/drawbacks of model configurations that include age compositions rather than length-composition and conditional age-at-length data, given some evidence for time- and spatially-varying growth.

Response: Model ALT incorporates age compositions, age-based selectivity, and empirical weight-at-age time series.

Medium priority

I. Continue to explore possible additional fishery-independent data sources. However, inclusion of a substantial new data source would likely require review, which would not be easily accomplished during a standard STAR Panel meeting and would likely need to be reviewed during a Council-sponsored Methodology Review.

Response: While other potential fishery-independent data sources may exist for Pacific sardine (e.g., SWFSC juvenile rockfish survey or California's aerial survey), none have been vetted through a Council-sponsored methodology review. The STAT continues to support and promote use of the single, most objective survey tool available for estimating abundance of CPS, i.e., the SWFSC's AT survey.

J. The reasons for the discrepancy between the observed and expected proportions of old fish in the length and age compositions should be explored further. Possible factors to consider in this investigation include ageing error / ageing bias and the way dome-shaped selectivity has been modelled.

Response: Very few sardine older than 6 years of age have been observed in either the fishery or survey samples collected to date. Model ALT has been revised to reduce the maximum age from 15 to 10 and the 'accumulator' age for single binning older fish reduced to age 8+.

K. The Panel continues to support expansion of coast-wide sampling of adult fish for use when estimating parameters in the DEPM method (and when computing biomass from the ATM surveys). It also encourages sampling in waters off Mexico and Canada.

Response: The SWFSC has conducted two surveys per year (spring and summer) since 2012. Summer surveys have typically extended to the northern tip of Vancouver Island, Canada. U.S. survey vessels have not yet had access to Mexican waters and are unlikely to in the near future. INAPESCA recently obtained a new, advanced technology research vessel (BIPO) for surveying the Gulf of California and Baja peninsula. Unfortunately, the BIPO was recently relocated to the Gulf of Mexico and its status for future surveys remains uncertain.

L. Consider spatial models for Pacific sardine that can be used to explore the implications of regional recruitment patterns and region-specific biological parameters. These models could be used to identify critical biological data gaps as well as better represent the latitudinal variation in size-at-age.

Response: No progress has been made toward spatial modeling. Some of the concerns raised regarding regional size-at-age have been accounted for by the use of empirical weight-at-age data and age-based selectivity in model ALT.

M. Consider a model that explicitly models the sex-structure of the population and the catch. An analysis of length-at-age samples did not indicate sexual dimorphism for this stock (see Figure 4a in Hill et al. 2014), so all models presented were combined-sex configurations. Nevertheless, it was felt that a sex-specific model was needed minimally as a sensitivity test to investigate the possibility that accounting for sex will have an impact on stock-assessment results for this resource.

Response: No further work has been conducted to address this recommendation. That is, this exercise is considered a low priority and unwarranted at this time in the ongoing assessment, given no evidence of sex-specific growth has been observed from biological sample information collected to data (see Assessment Data, Biological Parameters, Growth above).

N. Consider a model that has separate fleets for Mexico, California, Oregon-Washington and Canada.

Response: In the past, the STAT has modeled each of these regional fisheries as fleet, which s resulted in an unstable, over-parameterized model. That is, the goal of current model development is to construct a parsimonious assessment model that meets the overriding management objective using/emphasizing the highest quality data available (AT survey abundance time series) in the most straightforward manner (not developed around fine-scale fishery catch and selectivity data).

O. Compare annual length-composition data for the Ensenada fishery that are included in the MEXCAL data sets for the NSP scenario with the corresponding southern California length compositions. Also, compare the annual length composition data for the Oregon-Washington catches with those from the British Columbia fishery. This is particularly important if a future age data/age-based selectivity model scenario is further developed and presented for review.

Response: Ensenada fishery length-composition time series are only available at the semester level, so it is not possible to disaggregate the data (either length or age) to account for contribution of NSP fish. For the last several length-based assessments, the semester *level data were simply down-weighted to account for the NSP catch. The BC fishery length data were not converted to age distributions for model ALT, although this would be theoretically possible to do using an age-length key from the SS model or using data from the OR-WA fisheries. Given the large size of sardines harvested in the BC fishery, this transformation would likely result in skewed age distributions.*

P. Further explore methods to reduce between-reader ageing bias. In particular, consider comparisons among laboratories and assess whether the age-reading protocol can be improved to reduce among-ager variation.

Response: The SWFSC regularly exchanges survey otolith samples with key personnel with the CDFW for double-reading evaluations. However, as noted in Research and Data Needs below, the STAT has suggested more coordination is needed regarding production ageing across multiple laboratories or possibly, more centralized ageing efforts for Pacific sardine, as well as other CPS stocks.

Q. Change the method for allocating area in the DEPM method so that the appropriate area allocation for each point is included in the relevant stratum. Also, apply a method that better accounts for transect-based sampling and correlated observations that reflects the presence of a spawning aggregation.

Response: The DEPM time series is excluded from model ALT.

R. Consider future research on natural mortality. Note that changes to the assumed value for natural mortality may lead to a need for further changes to harvest control rules.

Response: Assessment model ALT has implemented a change in M from 0.4 yr^{-1} *to 0.6* yr^{-1}*. Rationale for the change is provided under: Assessment Data, Biological Parameters, Natural mortality above; Changes between Current and Last Assessment Model, Longevity and natural mortality below; and Natural mortality profile below.*

Low priority

S. Develop a relationship between egg production and fish age that accounts for the duration of spawning, batch fecundity, etc. by age. Using this information in the assessment would require that the stock-recruitment relationship in SS be modified appropriately.

Response: Although the newest version of SS (beta ver. 3.0) has added more flexibility for modeling stock-recruitment dynamics, it is uncertain whether such age-specific details will be available in the future.

Finally, the Panel notes that value of the Small Pelagic Ageing Research Cooperative, which should improve consistency in age-reading methods generally, and in particular for Pacific sardine. Lack of consistency in age estimates was the reason for not using age data for British Columbia.

Response: The SPARC has not met for several years. Canada has no new samples to age, and the majority of existing samples that have been aged are from their summer swept-area trawl survey. The WDFW has aged all samples from the states of Oregon and Washington, but no new samples have been collected since the moratorium. The CDFW and the SWFSC regularly exchange subsamples from the SWFSC's surveys for double reading analysis. Also, see recommendation P above.

Responses to Recent STAR (2017) Panel Requests

During the review in February 2017, additional requests were made during the week-long meeting regarding the proposed survey- and alternative model-based assessments, including evaluating different methods for projecting survey biomass from 2016 to 2017, examining different combinations of data and parameterizations (e.g., growth via empirical weight-at-age matrices and selectivity estimation based on age-vs. length-composition time series) associated with model ALT, and revising outputs and contrasting results across respective models and survey abundance time series. Detailed requests, rationales, and responses associated with sensitivity analysis conducted during the review are presented under Requests made to the STAT during the meeting (STAR 2017).

Changes between Current and Last Assessment Model

Overview

General differences between the current assessment model (ALT) proposed here and the last assessment model (T_2016) used to advise management, as well as model T_2017 that represents an updated T_2016 model are presented in Table 10. Model T_2017 is parameterized similarly as T_2016, with newly available sample information (e.g., catch, composition, and abundance data). As indicated in recent assessments conducted in the past, selectivity estimation continued to result in problematic scaling in model T_2017, with updated length-composition data associated with the AT survey once again resulting in unrealistic estimates of total stock biomass (Figure 21). The AT length-composition time series has continually been poorly fit in the model, with estimated selectivity curves sensitive to even minor additions of new length data. Estimated selectivity of very small, young sardines (6-9 cm, age-0 fish) in the AT survey is low (i.e., in most years, the AT survey does not encounter such sizes/age), so that when small fish are observed occasionally in the survey in limited numbers, selection probabilities translate to implausibly high numbers of young fish present in the population (see STAR 2017). As addressed in past reviews, omitting new length data in the updated assessment alleviated suspect scaling issues (Figure 21) and resulted in a more robust model (e.g., minimized potential for generating retrospective errors generally associated with highly variable terminal estimates of abundance). Given drawbacks of the length-based model above, as well as other data and parameterization considerations noted below (e.g., see Selectivity below), the STAT's proposed model-based assessment in 2017 was model ALT.

In general, model ALT was developed around the most relevant and highest quality source of data available for assessing the status of Pacific sardine, i.e., the focus of model ALT is fitting to the AT survey abundance time series. Finally, it is important to note that model ALT represents the proposed model-based assessment for advising management, but the preferred assessment is a survey-based approach as discussed above (see 'Preface' and 'Assessment – Acoustic-trawl survey \ Overview'). Further details regarding differences/similarities between model ALT and T_2016/T_2017 follow (see accompanying Table 10).

Time period and time step

The modeled timeframe has been shortened by roughly one decade, with the first year in model ALT being 2005, rather than 1993. Time steps in model ALT are treated similarly as in past assessments, being based on two, six-month semester blocks for each fishing year (semester 1=July-December and semester 2=January-June). The need for an extended time period in the model is not supported by the management goal, given that years prior to the start of the AT survey time series provide limited additional information for evaluating terminal stock biomass in the integrated model. Further, although a longer time series of catch may be helpful in a model for accurately determining scale in estimated quantities of interest, estimated trend and scale were not sensitive to changes in start year for model ALT. Finally, Pacific sardine biology (relatively few fish >5 years old observed in fisheries or surveys) further negates the utility of an extended time period in a population dynamics model employed for estimating terminal stock biomass of a short-lived species.

Surveys

Model ALT now includes only an acoustic-trawl survey index of abundance, omitting abundance time series used in past assessments associated with eggs/larvae surveys (daily egg production method – DEPM, and total egg production – TEP). Justification for removing eggs/larvae data from the current model follow: AT survey covers the full range of the stock vs. strictly the spawning aggregation covered by the eggs-larvae surveys; AT survey provides a direct measure of stock biomass vs. an indirect estimate of spawning biomass produced by the eggs/larvae surveys; AT survey provides a snapshot of recent absolute abundance vs. a snapshot of recent relative spawning production generated by the eggs/larvae surveys; and AT survey is based on an efficient survey design that minimizes temporal/sampling biases and maximizes estimate precision vs. much less flexible eggs/larvae surveys that are more prone to sampling biases in the field. Further, shortening the modeled time period necessarily results in omission of the TEP time series, which ended in 2005 (also noting that the TEP method results in a lower quality index of egg production due to lack of adult reproductive parameters). Additionally, the DEPM time series is essentially uninformative in model ALT, which produces similar results with or without inclusion of the eggs/larvae survey. Finally, the AT survey abundance time series in the ALT model is no longer partitioned into independent indices based on spring and summer cruises, but rather, now reflects a single abundance index that, in some years, includes multiple (seasonal) estimates.

Fisheries

Fishery structure in model ALT is similar to past assessments. Three fisheries are included in the model, including two Mexico-California *fleets* separated into semesters (MEXCAL_S1 and MEXCAL_S2) and one *fleet* representing Pacific Northwest fisheries (Canada-WA-OR, PNW). Also, because the California live bait industry currently reflects the only active sector in the U.S. sardine fishery, minor amounts of live bait landings were included in the current assessment based on model ALT.

Longevity and natural mortality

Biology assumptions for Pacific sardine in model ALT have been revised, including decreasing longevity and increasing natural mortality (*M*). Justification for revised assumptions for longevity (15 to 10 years) and *M* (0.4 to 0.6 yr^{-1}) follow: recommended in past assessment reviews; biological parameters are now consistent with observed length and age data collected from the fisheries and surveys (limited numbers of fish >5 years old observed in composition time series since 2000); supportive evidence from mortality studies from AT survey research

(Zwolinski and Demer 2013), as well as from general research addressing underlying correlation between maximum lifespan and mortality (Hoenig 1983); and finally, higher *M* estimates (0.55-0.65 yr^{-1}) were consistent with other estimated parameters associated with the highest priority data in the model, e.g., assumption that AT survey catch rates are applicable to the entire population in any given year (Q≈1), see Natural mortality profile below. Also, see 'Assessment Data \ Biological Parameters \ Natural mortality' above and 'Natural mortality profile' below.

Growth

A matrix of empirical weight-at-age estimates by year/semester is now used in model ALT to translate derived numbers-at-age into biomass-at-age, rather than estimating growth internally in the model as conducted previously in past assessments. Treatment of growth using empirical weight-at-age matrices associated with the fisheries, survey, and population greatly simplifies the overall assessment, while also allowing growth to vary across time and minimizing potential conflicts with selectivity parameterization. Also, see 'Assessment Data \ Biological Parameters \ Growth' above.

Stock-recruitment relationship

Beverton-Holt stock-recruitment (*S*-*R*) parameters are estimated in model ALT, including both virgin recruitment ($\log R_0$) and steepness (*h*), which represents a change from recently conducted assessments that estimated $\log R_0$, but fixed h=0.8. That is, fixing *h* at an assumed higher value in concert with fixed *M* necessarily constrained the model, resulting in relatively optimistic results, given the assumption that productivity remains high at low parent stock size. Finally, general sensitivity analysis during development of model ALT resulted in robust estimates of $\log R_0$ (~14.2) and *h* (~0.36). Also, see 'Model Description \ Stock-recruitment relationship,' 'Results \ Stock-recruitment relationship,' and 'Uncertainty Analyses \ Sensitivity analysis' below.

Selectivity

Selectivity in model ALT is based on age compositions and age-based selectivity, rather than length compositions and length-based selectivity as used in recently conducted past assessments. Primary justification for changing how selectivity is treated in the integrated model is based on the overriding goal to develop a parsimonious model that includes the most efficient parameterizations in the age-structured modeling platform (SS). Further, results from recent assessments have been particularly sensitive to minor changes (updates) to length-composition time series, which has been highlighted as a problematic area over the last few years in the ongoing assessment (Hill et al. 2014, 2015, 2016; STAR 2014). Also, see 'Model Description \ Selectivity' below.

Catchability

Catchability (*Q*) is freely estimated for the AT survey in model ALT, which is a major change from past assessments that have assumed Q=1.0 for the primary index of abundance in the assessment. That is, model ALT illustrates that a critical assumption underlying the survey-based assessment approach (i.e., AT survey methods and design allow efficient sampling within the stock's range in any given year, or Q≈1) is supported using a relatively simple integrated assessment model that includes other ancillary sources of data (e.g., catch and composition data), is based on realistic assumptions/parameterizations (e.g., *M*, growth, and stock-recruitment), is internally consistent (data conflicts are minimized), and generates robust results.

Model Description

Important parameterizations in model ALT are described below. Information for particular parameterizations is also presented under 'Changes between Current and Last Assessment Model' above.

Assessment program with last revision date
In 2014, the stock assessment team (STAT) transitioned from Stock Synthesis (SS) version 3.21d to version 3.24s (Methot 2013, Methot and Wetzel 2013), which was used for all assessments through 2016. In 2017, the SS model received some additional minor revisions and recompiled (version 3.24aa) to accommodate empirical weight-at-age data in a semester-based model. The SS model is comprised of three sub-models: (1) a population dynamics sub-model, where abundance, mortality, and growth patterns are incorporated to create a synthetic representation of the true population; (2) an observation sub-model that defines various processes and filters to derive expected values for different types of data; and (3) a statistical sub-model that quantifies the difference between observed data and their expected values and implements algorithms to search for the set of parameters that maximizes goodness of fit. The modeling framework allows for the full integration of both population size and age structure, with explicit parameterization both spatially and temporally. The model incorporates all relevant sources of variability and estimates goodness of fit in terms of the original data, allowing for final estimates of precision that accurately reflect uncertainty associated with the sources of data used as input in the modeling effort.

Definitions of fleets and areas
Data from major fishing regions are aggregated to represent southern and northern fleets (fisheries). The southern 'MEXCAL' fleet includes data from three major fishing areas at the southern end of the stock's distribution: northern Baja California (Ensenada, Mexico), southern California (Los Angeles to Santa Barbara), and central California (Monterey Bay). Fishing can occur throughout the year in the southern region. However, availability-at-size/age changes due to migration. Selectivity for the southern MEXCAL fleet was therefore modeled separately for seasons 1 and 2 (semesters, S1 and S2).

The 'PNW' fleet (fishery) includes data from the northern range of the stock's distribution, where sardine are typically abundant between late spring and early fall. The PNW fleet includes aggregate data from Oregon, Washington, and Vancouver Island (British Columbia, Canada). The majority of fishing in the northern region typically occurs between July and October (S1).

Likelihood components and model parameters
A complete list of model parameters for model ALT is presented in Table 12. The total objective function was based on the following individual likelihood components: 1) fits to catch time series; 2) fits to the AT survey abundance index; 3) fits to age compositions from the three fleets and AT survey; 4) deviations about the stock-recruitment relationship; and 5) minor contributions from soft-bound penalties associated with particular estimated parameters.

Initial population and fishing conditions

Given the Pacific sardine stock has been exploited since the early 20th Century (i.e., well before the start year used in model ALT), further information is needed to address equilibrium assumptions related to starting population dynamics calculations in the assessment model. One approach is to extend the modeled time period backwards in time to the start of the small pelagic fisheries off the U.S. west coast and in effect, ensure no fishing occurred prior to the start year in the model. In an integrated model, this method can be implemented by: 1) extending the catch time series back in time and confirming that harvest continues to decline generally as the onset of the fishery is approached; or 2) estimating additional parameters regarding initial population and fishing conditions in the model. Given assumptions regarding initial equilibrium for Pacific sardine (a shorter-lived species with relatively high intrinsic rates of increase) are necessarily difficult to support regardless of when the modeled time period begins, as well as the extreme length of an extended catch time series (early 1900s) that would be needed in this case, the approach above was adopted in this assessment, as conducted in all previous assessments to date.

The initial population was defined by estimating 'early' recruitment deviations from 1999-04, i.e., six years prior to the start year in the model. Initial fishing mortality (*F*) was estimated for the MEXCAL_S1 fishery and fixed=0 for MEXCAL_S2 and PNW fisheries, noting that results were robust to different combinations of estimated vs. fixed initial *F* for the three fisheries. In effect, the initial equilibrium age composition in the model is adjusted via application of early recruitment deviations prior to the start year of the model, whereby the model applies the initial *F* level to an equilibrium age composition to get a preliminary number-at-age time series, then applies the recruitment deviations for the specified number of younger ages in this initial vector. If the number of estimated ages in the initial age composition is less than the total number of age groups assumed in the model (as is the case here), then the older ages will retain their equilibrium levels. Because the older ages in the initial age composition will have progressively less information from which to estimate their true deviation, the start of the bias adjustment was set accordingly (see Methot 2013; Methot and Wetzel 2013). Ultimately, this parsimonious approach reflects a non-equilibrium analysis or rather, allows for a relaxed equilibrium assumption of the virgin (unfished) age structure at the start of the model as implied by the assumed natural mortality rate (*M*). Finally, an equilibrium 'offset' from the stock-recruitment relationship was estimated and along with the early recruitment deviation estimates allowed the most flexibility for matching the population age structure to the initial age-composition data at the start of the modeled time period.

Growth

See 'Changes between Current and Last Assessment Model \ Growth' above.

Stock-recruitment relationship

Pacific sardines are believed to have a broad spawning season, beginning in January off northern Baja California and ending by July off the Pacific Northwest. In the semester-based model ALT, spawning stock biomass (SSB) is calculated at the beginning of S2 (January). Recruitment was specified to occur in S1 of the following model year (consistent with the July 1st birth-date assumption). In past assessments, a Ricker stock-recruitment (S-R) relationship had been assumed following Jacobson and MacCall (1995), however, following recommendations from past reviews, a Beverton-Holt S-R has been implemented in all assessments since 2014.

Virgin recruitment (R_0), initial equilibrium recruitment offset (R_1), and steepness (h) were estimated. Following recommendations from past assessments, the estimate of average recruitment variability (σ_R) assumed in the S-R relationship was set to 0.75 since 2014. Recruitment deviations were estimated as separate vectors for the early and main data periods in the overall model. Early recruitment deviations for the initial population were estimated from 1999-04 (six years before the start of the model). A recruitment bias adjustment ramp (Methot and Taylor 2011) was applied to the early period and bias-adjusted recruitment estimated in the main period of the model (Figure 31). Main period recruitment deviations were advanced one year from that used in the last assessment, i.e., estimated from 2005-15 (S2 of each model year), which translates to the 2016 year class being freely estimated (albeit poorly) from the 2016 data available in the model.

It is important to note that there exists little information in the assessment to directly evaluate recent recruitment strength (e.g., absolute numbers of age-0, 6-9 cm fish in the most recent year), with the exception of age data from the southern fisheries, which have caught these juveniles infrequently in past years in low volume during their first semester of life (S1), but in greater amounts during their second semester (MEXCAL_S2). Age-0 recruits are rarely observed in the PNW fishery. Age-0 fish are not typically encountered by the AT survey, except for limited occurrences in particular years and in relatively high numbers observed in one cruise (summer 2015).

Selectivity

Age-composition time series from the MEXCAL and PNW fisheries were modeled using age-based selectivity. The MEXCAL compositions were fit based on each age as a random walk from the previous age, which resulted in domed-shaped selectivity similar to fits from a double-normal selectivity form as used in past assessments, i.e., supporting the assumption that older/larger fish are not generally available to the southern fisheries, both historically and presently. Selectivity for the MEXCAL fleet was estimated by semester (S1 and S2) to better account for both seasonal- and decadal-scale shifts in sardine availability to the southern region. The PNW fishery age compositions were fit using asymptotic selectivity (two-parameter logistic form), given this stock's biology and strong evidence that larger, older sardines typically migrate to more northern feeding habitats each summer. A simple asymptotic selectivity form was used for the AT survey, whereby age-0 fish were assumed to be unavailable and age 1+ fish fully selected. Justifications for a simplified selectivity form for the AT survey follow: the survey is based on sound technical methods and an expansive sampling operation in the field using an optimal habitat index for efficiently encountering all adult fish in the stock (Demer and Zwolinski 2014); observations of age-1 fish in length- and age-composition time series, to some degree, in every year; recognition of some level of ageing bias in the laboratory that may confound explicit interpretation of estimated age compositions, e.g., low probability of selection of age-1 fish in a particular year may be attributed to incorrectly assigned ages for age-0 or age-2 fish; and minor constraints to selectivity estimation, which typically reflects a sensitive parameterization that can substantially impact model results, supports the overriding goal of the assessment, i.e., parsimonious model that is developed around the AT survey abundance index. Finally, in addition to potential biases associated with the trawling and ageing processes, the age-1+ selectivity assumption recognizes the vulnerability of adult sardine with fully-developed swim bladders to echosounder energy in the acoustic sampling process. That is, there are three selectivity components to consider with the acoustic-trawl method: 1) fish availability with regard to the actual area surveyed each year; 2) vulnerability of fish to the acoustic sampling gear; and 3) vulnerability of fish to the mid-water trawl (avoidance and/or extrusion). No evidence exists that sardine with fully-developed swim bladders (i.e., greater than age 0) are missed by the acoustic equipment, further supporting the assumption that age-1+ fish are fully-selected by the survey in any given year.

Catchability
See ‘Changes between Current and Last Assessment Model \ Catchability’ above.

Convergence criteria and status
The iterative process for determining numerical solutions in the model was continued until the difference between successive likelihood estimates was <0.00001. The total likelihood and final gradient estimates for model ALT were 333.256 and 8.97*e*-6, respectively.

Results

The following results pertain to model ALT. Estimates for important parameterizations and derived quantities useful to management are also presented in Tables 10-16.

Parameter estimates and errors
Parameter estimates and standard errors (SE) for model ALT are presented in Table 12.

Growth estimates
Growth parameters were not estimated in model ALT, rather, empirical weight-at-age estimates by year were used to convert estimated numbers into weight of fish for calculating important biomass quantities useful to management (Figures 5-8).

Selectivity estimates and fits to fishery and survey age-composition time series
Age-based selectivity estimates (ogives) for the three fisheries and AT survey are presented in Figure 22. Model fit displays to fishery and AT survey age compositions (including observed and effective sample sizes) and associated Pearson residual plots are presented in Figures 23-26. The fishery (MEXCAL_S1, MEXCAL_S2, and PNW) age-composition time series were fit relatively well in most years, but poor fits were observed in some years, particularly, for the most recent years in the time series (Figures 23-26). Poor fits to the AT survey age-composition time series were indicated in most years (Figure 26). See ‘Uncertainty Analyses / Selectivity analysis’ below.

Fit to survey index of abundance
Model fits to the AT survey abundance index in arithmetic and log scale are presented in Figure 27. The predicted fit to the survey index was generally good (near mean estimates and within error bounds), particularly, for the most recent years of the time series (Figure 27). As illustrated in past assessments, the notable exception in the fitted time series was for the initial survey year 2005 (spring 2006 cruise), which was under-estimated and outside the estimated confidence interval. Estimated catchability (*Q*) for the AT survey was 1.1 (Table 12). Also, see ‘Changes between Current and Last Assessment Model / Catchability’ above.

Stock-recruitment relationship
Recruitment was modeled using a Beverton-Holt stock-recruitment (S-R) relationship (Figure 28). The assumed level of underlying recruitment deviation error was fixed (σ_R=0.75), virgin (unfished) recruitment was estimated (logR_0=14.2), and steepness was estimated (*h*=0.36) (Table 12). Recruitment deviations for the early (1999-04), main (2005-15), and forecast (2016-17) periods in the model are presented in Figure 29). Asymptotic standard errors for recruitment deviations are displayed in Figure 30 and the recruitment bias adjustment plot for early, main, and forecast periods in model ALT is shown in Figure 31.

Population number- and biomass-at-age estimates
Population number-at-age estimates for model ALT are presented in Table 13. On average, age 0-3 fish have comprised roughly 85% of the total number of Pacific sardine in each year from 2005-17. Corresponding estimates of population biomass-at-age, total biomass (age-0+ fish, mt) and stock biomass (age-1+ fish, mt) are shown in Table 14. On average, age 0-3 fish have comprised roughly 65% of the total population biomass in each year from 2005-17.

Spawning stock biomass
Time series of estimated spawning stock biomass (SSB, mmt) and associated 95% confidence intervals are presented in Table 15 and Figure 32. The virgin level of SSB was estimated to be 107,915 mt (0.11 mmt). The SSB has continually declined since 2005-06, reaching historically low levels in recent years (2014-present).

Recruitment
Time series of estimated recruitment (age 0, billions) abundance is presented in Table 15 and Figure 34. The virgin level of recruitment (R_0) was estimated to be 1.52 billion age-0 fish. As indicated for SSB above, recruitment has largely declined since 2005-06, with the exception of a brief period of modest recruitment success from 2009-10. In particular, the 2011-15 year classes have been among the weakest in recent history. A small increase in recruitment was observed in 2016, albeit a highly variable estimate (CV=79%) based on limited data.

Stock biomass for PFMC management
Stock biomass, used for calculating annual harvest specifications, is defined as the sum of the biomass for sardine ages one and older (age 1+) at the start of the management year. Time series of estimated stock biomass (mmt) are presented Table 14 and Figure 33. As discussed above for both SSB and recruitment, a similar trend of declining stock biomass has been observed since 2005-06, plateauing at recent historical low levels since 2014 (roughly 78,000 mt, 0.08 mmt).

Fishing and exploitation rates
Estimated fishing mortality (*F*) time series by fishery are presented in Figure 35. Fishing mortality has been generally less than 0.4 yr^{-1} since 2005-06, with the exception of the PNW fishery in 2005 and from 2012-13, with *F* estimates above 1.0 yr^{-1}.

Exploitation rate is defined as the calendar year northern sub-population (NSP) catch divided by the total mid-year biomass (July 1^{st}, ages 0+). The U.S. and total exploitation rates for the NSP are shown in Figure 36. The U.S. exploitation rate was less than 10% from 2005-11, increased sharply from 2012-14 to over 25%, and dropped again to under 5% recent years. The total exploitation rate time series followed a similar trend, with exploitation rates less than 17% from 2005-11, increasing to 40% by 2013, and decreasing to similar levels as for the U.S. in recent years.

Uncertainty Analyses

Virgin recruitment profile
Virgin recruitment (R_0) profiles are useful for identifying the extent conflicts between data components included in the assessment potentially influence underlying scale in the model (Lee et al. 2014). Components in model ALT include composition (fishery and survey age-composition time series) and abundance (AT survey index of abundance) data. A R_0 profile for model ALT is presented in Figure 37. The profile was conducted over a range of assumed (fixed) R_0 values from 13.5 to 15, with multiple runs at each R_0 level, based on jittering starting values for estimated parameters to ensure model convergence. The profile indicated all sources of data in model ALT were generally consistent, with each component illustrating better fitting models were associated with lower vs. higher assumed levels of R_0. The individual total profile indicates the model ALT configuration (R_0=14.236) appears to have realized a global minimum total likelihood estimate.

Natural mortality profile
Treatment of natural mortality (*M*) in model ALT is discussed above, see 'Longevity and natural mortality.' Uncertainty associated with the assumed (fixed) level of natural mortality in model ALT (M=0.6 yr^{-1}) was also evaluated by profiling across a range of fixed levels of the stock parameter of interest, *M* (Table 16 and Figure 38). The profile was conducted using a range of *M* values from 0.35 to 0.75 yr^{-1}. In the context of the ALT model, models with higher assumed levels of *M* resulted in lower estimates of AT survey catchability (*Q*), and higher terminal estimates of spawning stock biomass and stock biomass. Model fits to most data components, as well as total likelihood estimates indicated slightly better fits to lower estimates of *M*, however, the AT survey index of abundance and MEXCAL_S1 age-composition data indicated better fitting models at higher *M* (Table 16 and Figure 38). The range of recent estimated stock biomass (2014-17) associated with the *M* profile is presented in Figure 38, with terminal year estimates (2017) that ranged from roughly 40,000 mt (M=0.35 yr^{-1}) to 160,000 mt (M=0.75 yr^{-1}).

Retrospective analysis
Retrospective analysis provides another means of examining model properties and characterizing uncertainty. A retrospective analysis was performed for model ALT, whereby data were incrementally removed from the terminal year backwards in time to 2000. Estimated stock biomass time series from this analysis are presented in Figure 39. For the most part, no notable retrospective pattern was indicated by the analysis, i.e., no systematic bias of overestimating biomass in the terminal year was illustrated through sequentially removing data from the model backwards in time. A slight retrospective bias was indicated as data were removed four or more years back in time. It is important to note that some degree of retrospective bias would be expected from a stock assessment of short-lived, productive species like Pacific sardine, given little information is available in the integrated model for estimating recruitment that typically is highly variable in any given year based on immediate oceanographic conditions.

Sensitivity analysis (survey abundance indices, AT survey selectivity, stock-recruitment steepness, data weighting methods, and fishery time-varying selectivity)

Sensitivity analyses were conducted prior and during the review in February that addressed assumptions for survey (AT and DEPM) time series included in the model, AT survey selectivity forms, stock-recruitment (S-R) steepness (*h*), and alternative data weighting approaches for model ALT. Estimates for likelihood components, specific parameters, and derived quantities of interest associated with the models evaluated in sensitivity analysis are presented in Table 17. Estimated stock biomass (age-1+ fish, mt) time series are compared between the different model scenarios in Figure 40. Also, further discussion regarding models evaluated in sensitivity analysis, as well as other configurations investigated during the review are presented in STAR (2017). As illustrated in past assessments, inclusion of the DEPM index of abundance in the model had little influence on results, with nearly identical stock biomass trajectories observed and slightly higher terminal estimate of stock biomass for the model that included both indices of abundance. Basing the AT survey selectivity on a simple (two-parameter logistic) asymptotic form as used for the PNW fishery resulted in generally similar estimated selectivity as the age-1+ fully-selected form used in model ALT, but indicating only partially selected younger ages (i.e., 5% vs. 0%, 25% vs. 100%, and 70% vs. 100% selection for ages 0, 1, and 2, respectively), which resulted in higher estimated stock biomass in the terminal year (approximately 153,000 mt vs. 87,000 mt in model ALT). Fixing S-R steepness at the level assumed in recent assessments (h=0.8) had little effect in the model, with estimated stock biomass in the terminal year equal to roughly 112,00 mt vs. 87,000 mt for model ALT (estimated steepness, h=0.36). Two alternative data weighting approaches ('Francis method' and 'harmonic-mean method' in Stock Synthesis) implemented in model ALT resulted in generally similar findings as the non-weighted baseline model, with slightly higher estimated stock biomass in the terminal year than model ALT; see Francis (2011), Methot and Wetzel 2013, and Punt (in press). Finally, modeling time-varying selectivity for the fisheries resulted in notably better fits to the fishery age-composition time series, with generally similar estimates of derived quantities useful to management as estimated in model ALT (i.e., time invariant selectivity configuration). However, models with time-varying fishery selectivity were inherently less stable, with lack of convergence for many runs or indications of local minima when convergence was realized.

Convergence tests

Convergence properties of model ALT were tested to ensure the model represented an optimal solution. Model ALT was run with a wide range of initial starting values for R_0 (13.1 to 15.1). For each run, phase order for estimating parameter components (e.g., R_0, R_1, steepness, initial F, selectivity, and AT survey Q) was randomized from 1 to 5, and all parameters were jittered by 20% (Table 18). All models converged to the same total negative log likelihood estimate (333.256) and had identical final estimates of R_0 (14.2359). Model ALT appeared to have converged to a global minimum (also, see 'Virgin recruitment profile' above).

Historical analysis

Estimates of stock biomass (age-1+ fish, mt) and recruitment (age-0 fish, billions) for model ALT were compared to recently conducted assessments in Figure 41. Full and updated stock assessments since 2009 (Hill et al. 2009-16) are included in the comparison. Stock biomass and recruitment trends were generally similar, with notable differences in scale between particular years. It is important to note that all previous assessments (since 2009) were structured very similarly (e.g., similar model dimensions, data, assumptions, and parameterizations). Whereas, the newly developed ALT model (2017) reflects a much simpler version of past assessments models (See ‘Changes between Current and Last Assessment Model’ above), necessarily confounding direct comparisons between results from this year’s model with past assessments.

HARVEST CONTROL RULES FOR THE 2017-18 MANAGEMENT CYCLE

Harvest Guideline

The annual harvest guideline (HG) is calculated as follows:

HG = (BIOMASS – CUTOFF) • FRACTION • DISTRIBUTION;

where HG is the total U.S. directed harvest for the period July 2017 to June 2018, BIOMASS is the stock biomass (ages 1+, mt) projected as of July 1, 2017, CUTOFF (150,000 mt) is the lowest level of biomass for which directed harvest is allowed, FRACTION (E_{MSY} bounded 0.05-0.20) is the percentage of biomass above the CUTOFF that can be harvested, and DISTRIBUTION (87%) is the average portion of BIOMASS assumed in U.S. waters. Based on results from model ALT, estimated stock biomass is projected to be below the 150,000 mt threshold and thus, the HG for 2017-18 would be 0 mt. Harvest estimates for model ALT are presented in Table 19.

OFL and ABC

On March 11, 2014, the PFMC adopted the use of CalCOFI sea-surface temperature (SST) data for specifying environmentally-dependent E_{MSY} each year. The E_{MSY} is calculated as,

$$E_{\mathrm{MSY}} = -18.46452+3.25209(T)-0.19723(T^2)+0.0041863(T^3),$$

where T is the three-year running average of CalCOFI SST (Table 20, Figure 42), and E_{MSY} for OFL and ABC is bounded between 0 to 0.25 (Figure 42). Based on the recent warmer conditions in the CCE, the average temperature for 2014-16 increased to 15.9999 °C, resulting in E_{MSY}=0.2251.

Estimated stock biomass in July 2017 for model ALT was **86,586 mt** (Table 19). The overfishing limit (OFL, 2017-18) associated with that biomass was **16,957 mt** (Table 19). Acceptable biological catches (ABC, 2017-18) for a range of *P-star* values (Tier 1 σ=0.36; Tier 2 σ=0.72) associated with model ALT are presented in Table 19.

REGIONAL MANAGEMENT CONSIDERATIONS

Pacific sardine, as well as other species considered in the CPS FMP, are not managed formally on a regional basis within the USA, due primarily to the extensive distribution and annual migration exhibited by these small pelagic stocks. A form of regional (spatial/temporal) management has been adopted for Pacific sardine, whereby seasonal allocations are stipulated in attempts to ensure regional fishing sectors have at least some access to the directed harvest each year (PFMC 2014).

RESEARCH AND DATA NEEDS

Research and data needed for improving stock assessments of the Pacific sardine resource in the future address three major areas that are presented in descending order of importance below.

First and foremost, the most important area of focus should be improvements associated with the highest priority data available for assessing recent stock biomass on an annual basis, namely, the acoustic-trawl (AT) survey index of abundance (see 'Assessment – Acoustic-trawl Survey \ Overview' above). This is the case whether future management will be based directly on the AT survey or via an integrated model. The AT survey methods and design are founded currently on objective scientific bases, however, the need for continual improvement for specific areas include: 1) Target-strength estimation for local species; 2) determine potential biases due to the non-sampling of near-surface waters and shallow regions on the east end of the transects; and 3) implications of the time-lag between acoustic observations and trawl sampling operations (see 'Assessment – Acoustic-trawl Survey \ Areas of Improvement for the AT Survey' above). Additionally, improved relations with neighboring countries that also commercially target the northern sub-population of Pacific sardine (particularly, Mexico) are needed to establish a broader survey boundary than possible presently (e.g., Baja California, Mexico to Vancouver Island, Canada), which would allow stock structure hypotheses for this species to be evaluated more objectively. Finally, long-term support and commitment to the AT survey will benefit more than Pacific sardine alone, given these data represent the highest quality information available for determining recent stock biomass for all members of the small pelagic fish assemblage of the California Current ecosystem, including northern anchovy (northern and central sub-stocks), as well as mackerel populations (e.g., Pacific and jack)—noting that further attention is needed surrounding catchability issues that remain unresolved for these transboundary stocks and the extent to which a species' range in any given year may be outside the survey design's boundaries.

Second, maintaining a high quality (accurate and precise) composition time series, both age and size (length and weight), is critical for either assessment approach, but particularly, for using an integrated model for assessing the status of the stock. Data collection of biological samples by the three state fishery agencies (CDFW, ODFW, and WDFW) is adequate presently, but obtaining such data from Canada and particularly Mexico, has been somewhat problematic in the past. Further, multiple ageing operations are relied on currently, which would benefit from further coordination that ensures samples are efficiently processed in a timely manner and related ageing bias is minimized across laboratories. In this context, a major change that warrants further consideration would be to revisit the merits and drawbacks of using multiple ageing laboratories vs. trying to better centralize ageing operations under a single laboratory.

Third, a schedule should be adopted for conducting biology-related studies for informing critical biological parameters in a model-based assessment. For example, revisiting assumed maturity schedules currently used for Pacific sardine (this is done every year when the DEPM data are processed), as well as periodically evaluating growth parameters applicable to the stock, even though growth is no longer an estimated parameter in the model-based assessment. That is, it is important that data for generally informing biology parameters applicable to the stock continue to be collected and processed according to an efficient schedule that allows both the survey- and particularly, model-based assessment to be updated systematically. For example, an ideal schedule for conducting (coastwide) biology projects related to Pacific sardine would be every 5-7 years.

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TABLES

Table 1. U.S. Pacific sardine harvest specifications and landings (metric tons) since the onset of federal management. U.S. harvest limits and closures are based on total catch, regardless of subpopulation source. Landings for the 2016-17 management year are preliminary and incomplete.

Mgmt Year	U.S. OFL	U.S. ABC	U.S. HG or ACL	U.S. Total Landings	U.S. NSP Landings
2000	n/a	n/a	186,791	73,766	67,691
2001	n/a	n/a	134,737	79,746	57,019
2002	n/a	n/a	118,442	103,134	82,529
2003	n/a	n/a	110,908	77,728	65,692
2004	n/a	n/a	122,747	96,513	78,430
2005	n/a	n/a	136,179	92,906	76,047
2006	n/a	n/a	118,937	94,337	79,623
2007	n/a	n/a	152,564	131,090	107,595
2008	n/a	n/a	89,093	90,164	80,986
2009	n/a	n/a	66,932	69,903	64,506
2010	n/a	n/a	72,039	69,140	58,578
2011	92,767	84,681	50,526	48,802	42,253
2012	154,781	141,289	109,409	103,600	93,751
2013	103,284	94,281	66,495	67,783	60,767
2014 (1)	59,214	54,052	6,966	6,806	6,121
2014-15	39,210	35,792	23,293	23,113	19,969
2015-16	13,227	12,074	7,000	2,012	259
2016-17	23,085	19,236	8,000	*956*	*98*

Table 2. Pacific sardine landings (mt) for major fishing regions off northern Baja California (Ensenada, Mexico), the United States, and British Columbia (Canada). ENS and SCA landings are presented as totals and northern subpopulation (NSP) portions.

Calendar Yr-Sem	Model Yr-Seas	ENS Total	ENS NSP	SCA Total	SCA NSP	CCA	OR	WA	BC
2005-2	2005-1	37,999.5	4,396.7	16,615.0	1,581.4	7,824.9	44,316.2	6,605.0	3,231.4
2006-1	2005-2	17,600.9	11,214.6	18,290.5	17,117.0	2,032.6	101.7	0.0	0.0
2006-2	2006-1	39,636.0	0.0	18,556.0	5,015.7	15,710.5	35,546.5	4,099.0	1,575.4
2007-1	2006-2	13,981.4	13,320.0	27,546.0	20,567.0	6,013.3	0.0	0.0	0.0
2007-2	2007-1	22,865.5	11,928.2	22,047.2	5,531.2	28,768.8	42,052.3	4,662.5	1,522.3
2008-1	2007-2	23,487.8	15,618.2	25,098.6	24,776.6	2,515.3	0.0	0.0	0.0
2008-2	2008-1	43,378.3	5,930.0	8,979.6	123.6	24,195.7	22,939.9	6,435.2	10,425.0
2009-1	2008-2	25,783.2	20,244.4	10,166.8	9,874.2	11,079.9	0.0	0.0	0.0
2009-2	2009-1	30,128.0	0.0	5,214.1	109.3	13,935.1	21,481.6	8,025.2	15,334.3
2010-1	2009-2	12,989.1	7,904.2	20,333.5	20,333.5	2,908.8	437.1	510.9	421.7
2010-2	2010-1	43,831.8	9,171.2	11,261.2	699.2	1,397.1	20,414.9	11,869.6	21,801.3
2011-1	2010-2	18,513.8	11,588.5	13,192.2	12,958.9	2,720.1	0.1	0.0	0.0
2011-2	2011-1	51,822.6	17,329.6	6,498.9	182.5	7,359.3	11,023.3	8,008.4	20,718.8
2012-1	2011-2	10,534.0	9,026.1	12,648.6	10,491.1	3,672.7	2,873.9	2,931.7	0.0
2012-2	2012-1	48,534.6	0.0	8,620.7	929.9	568.7	39,744.1	32,509.6	19,172.0
2013-1	2012-2	13,609.2	12,827.9	3,101.9	972.8	84.2	149.3	1,421.4	0.0
2013-2	2013-1	37,803.5	0.0	4,997.3	110.3	811.3	27,599.0	29,618.9	0.0
2014-1	2013-2	12,929.7	412.5	1,495.2	809.3	4,403.3	0.0	908.0	0.0
2014-2	2014-1	77,466.3	0.0	1,600.9	0.0	1,830.9	7,788.4	7,428.4	0.0
2015-1	2014-2	14,452.4	0.0	1,543.2	0.0	727.7	2,131.3	62.6	0.0
2015-2	2015-1	18,379.7	0.0	1,514.8	0.0	6.1	0.1	66.1	0.0
2016-1	2015-2	22,647.9	0.0	423.5	184.8	1.1	0.7	0.0	0.0
2016-2	2016-1	23,091.6	0.0	857.5	0.0	10.3	2.7	85.2	0.0

Table 3. Pacific sardine length and age samples available for major fishing regions off northern Baja California (Mexico), the United States, and Canada. Samples from model year 2015-1 onward were from incidental catches so were not included in the model.

Calendar Yr-Sem	Model Yr-Seas	ENS Length	ENS Age	SCA Length	SCA Age	CCA Length	CCA Age	OR Length	OR Age	WA Length	WA Age	BC Length	BC Age
2005-2	2005-1	115	0	73	72	24	23	14	14	54	27	65	0
2006-1	2005-2	53	0	67	66	32	31	0	0	0	0	0	0
2006-2	2006-1	46	0	61	61	58	58	12	12	15	15	0	0
2007-1	2006-2	22	0	74	72	47	46	3	3	0	0	0	0
2007-2	2007-1	46	0	72	72	68	68	80	80	10	10	23	0
2008-1	2007-2	43	0	53	53	15	15	0	0	0	0	0	0
2008-2	2008-1	83	0	25	25	30	30	80	80	14	14	229	0
2009-1	2008-2	50	0	20	20	20	20	0	0	0	0	0	0
2009-2	2009-1	0	0	13	12	23	23	82	81	12	12	285	0
2010-1	2009-2	0	0	62	62	37	36	3	1	2	2	2	0
2010-2	2010-1	0	0	25	25	13	13	64	26	8	8	287	0
2011-1	2010-2	0	0	22	21	11	11	0	0	0	0	0	0
2011-2	2011-1	0	0	22	22	22	22	34	33	10	10	362	0
2012-1	2011-2	0	0	48	47	16	16	8	8	8	8	0	0
2012-2	2012-1	0	0	44	41	18	17	83	82	37	37	106	0
2013-1	2012-2	0	0	16	16	2	2	0	0	3	3	0	0
2013-2	2013-1	0	0	39	39	5	5	75	74	66	65	0	0
2014-1	2013-2	0	0	27	26	14	13	0	0	1	1	0	0
2014-2	2014-1	0	0	8	8	6	6	27	27	24	23	0	0
2015-1	2014-2	0	0	18	18	14	14	15	15	1	0	0	0
2015-2	2015-1	0	0	0	0	*2*	*2*	0	0	1	0	0	0
2016-1	2015-2	0	0	*8*	*2*	0	0	*4*	*0*	0	0	0	0
2016-2	2016-1	0	0	*1*	*1*	0	0	*4*	*0*	0	0	0	0

Table 4. Pacific sardine NSP landings (mt) by year-season and SS fleet for model ALT.

Calendar	Model	NSP Catch (model ALT)		
Yr-Sem	Yr-Seas	MEXCAL_S1	MEXCAL_S2	PNW
2005-2	2005-1	13803.0	0.0	54152.6
2006-1	2005-2	0.0	30364.2	101.7
2006-2	2006-1	20726.2	0.0	41220.9
2007-1	2006-2	0.0	39900.3	0.0
2007-2	2007-1	46228.1	0.0	48237.1
2008-1	2007-2	0.0	42910.0	0.0
2008-2	2008-1	30249.2	0.0	39800.1
2009-1	2008-2	0.0	41198.5	0.0
2009-2	2009-1	14044.9	0.0	44841.1
2010-1	2009-2	0.0	31146.5	1369.7
2010-2	2010-1	11274.0	0.0	54085.9
2011-1	2010-2	0.0	27267.6	0.1
2011-2	2011-1	24871.4	0.0	39750.5
2012-1	2011-2	0.0	23189.9	5805.6
2012-2	2012-1	1528.4	0.0	91425.6
2013-1	2012-2	0.0	13884.9	1570.8
2013-2	2013-1	921.6	0.0	57218.0
2014-1	2013-2	0.0	5625.0	908.0
2014-2	2014-1	1830.9	0.0	15216.8
2015-1	2014-2	0.0	727.7	2193.9
2015-2	2015-1	6.1	0.0	66.3
2016-1	2015-2	0.0	185.9	0.7
2016-2	2016-1	10.3	0.0	87.9
2017-1	2016-2	0.0	185.9	0.7
2017-2	2017-1	*10.3*	*0.0*	*87.9*
2018-1	2017-2	*0.0*	*185.9*	*0.7*

Table 5. Fishery-independent indices of Pacific sardine relative abundance. The DEPM time series was not included in model ALT. Complete details regarding calculation of DEPM estimates are provided in Appendix A. In the SS model, indices had a lognormal error structure with units of standard error of log*e*(index). Variances of the observations were available as a CVs, so the SEs were approximated as sqrt(log*e*(1+CV^2)).

Model Yr-Sem	DEPM	S.E. ln(index)	Acoustic	S.E. ln(index)
2005-2	---	---	1,947,063	0.30
2006-1	---	---	---	---
2006-2	198,404	0.30	---	---
2007-1	---	---	---	---
2007-2	66,395	0.27	751,075	0.09
2008-1	---	---	801,000	0.30
2008-2	99,162	0.24	---	---
2009-1	---	---	---	---
2009-2	58,447	0.40	357,006	0.41
2010-1	---		---	---
2010-2	219,386	0.27	493,672	0.30
2011-1	---	---	---	---
2011-2	113,178	0.27	469,480	0.28
2012-1	---	---	340,831	0.33
2012-2	82,182	0.29	305,146	0.24
2013-1	---	---	313,746	0.27
2013-2	---	---	35,339	0.38
2014-1	---	---	26,280	0.63
2014-2	19,376	0.54	29,048	0.29
2015-1	---	---	15,870	0.70
2015-2	5,929	0.54	83,030	0.47
2016-1	---	---	78,770	0.51

Table 6. Pacific sardine biomass by stratum during the spring 2016 survey (see Figures 16 and 17).

Stratum		Transect		Trawls		Sardine		
Number	**Area (n.mi.^{2})**	**Number**	**Distance (n.mi.)**	**CPS clusters**	**Number of sardine**	**Biomass (10^3 tons)**	**95% confidence interval (10^3 tons)**	**CV (%)**
1	13,376	9	2,792	6	13,671	74.65	12.49 - 161.25	51.7
2	8,059	3	459	3	33	8.39	0.08 - 23.65	78.7
1+2	**21,435**	**12**	**3,252**	**9**	**13,704**	**83.04**	**18.91 -172.11**	**49.3**

Table 7. Pacific sardine biomass by stratum during the summer 2016 survey (see Figures 18 and 19).

Stratum		Transect		Trawls		Sardine		
Name	**Area (n.mi.^{2})**	**Number**	**Distance (n.mi.)**	**CPS clusters**	**Number of sardine**	**Biomass (10^3 tons)**	**95% confidence interval (10^3 tons)**	**CV (%)**
1	3,246	5	325	3	4,877	42.62	0.51 - 87.92	68.9
2	7,367	14	730	5	1,692	0.53	0.26 - 0.90	30.8
3	3,304	9	304	1	3,793	6.38	1.61 - 13.61	49.0
4	5,409	9	346	2	3,972	0.34	0.07 - 0.70	57.5
5	3,105	9	287	2	33	0.20	0.00 - 0.43	66.6
6	3,022	8	306	3	8	28.70	0.19 - 83.86	92.9
1+…+6	**25,453**	**54**	**2,298**	**16**	**14,375**	**78.78**	**9.54 – 148.29**	**53.9**

Table 8. Pacific sardine abundance versus standard length for spring and summer 2016 surveys.

	Spring	Summer
Standard length (cm)	**Abundance (millions)**	**Abundance (millions)**
4	0.000	0.000
5	0.000	0.000
6	0.000	11.719
7	0.000	35.156
8	0.000	0.000
9	0.000	11.719
10	0.000	11.719
11	0.051	0.000
12	0.333	11.719
13	40.289	0.453
14	189.427	1.821
15	142.816	11.774
16	32.924	79.878
17	3.658	362.959
18	0.000	195.574
19	44.101	372.646
20	61.907	5.921
21	39.169	0.767
22	11.606	2.620
23	5.513	2.278
24	67.448	4.306
25	101.438	6.286
26	61.341	4.433
27	0.000	0.657
28	0.000	0.000
29	0.000	0.000
30	0.000	0.000

Table 9. The AT survey projection of stock biomass (age 1+, mt) to July 2017. Note that the abundance of age-0 sardine in 2016 is estimated by using the S-R relationship derived from the ALT model. Consequently, the total stock biomass presented here differs from that in Table 7.

Age	Abundance (numbers)	Mean weight (kg)	Biomass (mt)	SSB (mt, January 2016)	Biomass (mt, July 2017)
0	1,254,944,093	0.011	13,563	2,156	NA
1	163,972,918	0.066	10,782	17,095	45,289
2	410,927,780	0.074	30,420	27,439	6,662
3	335,621,177	0.078	26,309	22,515	17,679
4	125,554,639	0.083	10,388	1,763	15,239
5	7,048,585	0.154	1,083	894	10,583
6	3,238,212	0.195	632	697	755
7	2,414,616	0.171	414	366	304
8	1,235,575	0.207	255	52	274
9+	176,923	0.188	33	2,156	146
total	1,254,944,093		93,879	72,976	96,930

Table 10. Model parameterizations and data components for the ALT and T_2016/T_2017 assessment models.

			ASSESSMENT	
			T_2016 / T_2017[a]	**ALT**
PARAMETERIZATIONS		Time period	1993-16 / 1993-17	2005-17
		Surveys	AT, DEPM, TEP	AT
		Fisheries	MEX-CAL, PNW	MEX-CAL, PNW
		Longevity	15 years	10 years
		Natural mortality	Fix (M=0.4)	Fix (M=0.6)
		Growth	Estimated	Emp. weight-at-age
		Stock-recruitment	Beverton-Holt (h fix=0.80)	Beverton-Holt (h est=0.36)
		Selectivity	Length data/Length-based	Age data/Age-based
		Catchability	AT (Q fix=1.0)	AT (Q est=1.1)
DATA COMPONENTS	**Fisheries**	Catch	■	■
		Length comps	■	
		Age comps (cond. age-at-length)	■	
		Age comps (aggregated)		■
		Emp. weight-at-age		■
	Surveys	AT abundance series (spring)	■	
		AT abundance series (summer)	■	
		AT abundance series (annual)		■
		DEPM abundance series	■	
		TEP abundance series	■	
		AT length comps	■	
		AT age comps (cond. age-at-length)	■	
		AT age comps (aggregated)		■
		AT emp. weigth-at-age		■

[a] T_2016 is the last assessment model that was used for management in 2016 and T_2017 is a similarly parameterized model as T_2016, with updated sample information (e.g., catch, abundance, and composition data).

Table 11. Likelihood components and important derived quantities for the AT survey and model ALT.

			ASSESSMENT	
			AT survey[a]	ALT
LIKELIHOODS	Indices	AT survey	na	5.3585
		Subtotal	na	**5.3585**
	Compositions	MEXCAL_S1 age composition	na	50.659
		MEXCAL_S2 age composition	na	75.2038
		PNW age composition	na	89.6647
		AT age composition	na	90.2202
		Subtotal	na	305.748
	Other	**Catch**	na	1.4356E-13
		Recruitment	na	22.148
		Parameter softbounds	na	2.2396E-03
		TOTAL		**333.256**
ESTIMATES		Stock-recruitment ($\ln R_0$)	na	14.2359
		Stock-recruitment (h)	na	0.359
		Spawning stock biomass 2016 (mt)	na	51,187
		Recruitment 2016 (billions of fish)	na	1.50
		Stock biomass peak (mt)	1,947,063	1,798,040
		Stock biomass 2016 (mt)	78,770	66,984
		Stock biomass 2017 (mt)	96,930	86,586

[a] AT survey represents a survey-based assessment and thus, data components, likelihoods, and particular estimated quantities associated with model-based assessments are noted as not applicable (na).

Table 12. Parameter estimates and asymptotic standard errors for model ALT.

					ALT Model	
Parameter	**Phase**	**Min**	**Max**	**Initial**	**Final**	**Std Dev**
NatM_p_1_Fem_GP_1	-3	0.3	0.8	0.6	0.6	_
Wtlen_1_Fem	-3	-3	3	7.5242E-06	7.5242E-06	_
Wtlen_2_Fem	-3	-3	5	3.2332	3.2332	_
SR_LN(R0)	1	3	25	15	14.2359	0.311468
SR_BH_steep	5	0.2	1	0.5	0.359492	0.118458
SR_sigmaR	-3	0	2	0.75	0.75	_
SR_R1_offset	2	-15	15	0	1.82791	0.466138
Early_InitAge_6	_	_	_	_	-0.34461	0.614817
Early_InitAge_5	_	_	_	_	-0.371706	0.556896
Early_InitAge_4	_	_	_	_	-0.350476	0.503177
Early_InitAge_3	_	_	_	_	0.270028	0.419824
Early_InitAge_2	_	_	_	_	1.72383	0.359257
Early_InitAge_1	_	_	_	_	1.20485	0.458441
Main_RecrDev_2005	_	_	_	_	1.36842	0.196122
Main_RecrDev_2006	_	_	_	_	1.24805	0.203673
Main_RecrDev_2007	_	_	_	_	0.557171	0.214939
Main_RecrDev_2008	_	_	_	_	1.24545	0.178846
Main_RecrDev_2009	_	_	_	_	1.42232	0.158794
Main_RecrDev_2010	_	_	_	_	-1.07036	0.238236
Main_RecrDev_2011	_	_	_	_	-2.48923	0.325946
Main_RecrDev_2012	_	_	_	_	-2.08339	0.318891
Main_RecrDev_2013	_	_	_	_	-0.203622	0.328786
Main_RecrDev_2014	_	_	_	_	-0.402663	0.53203
Main_RecrDev_2015	_	_	_	_	0.407849	0.723834
Late_RecrDev_2016	_	_	_	_	0	0.75
ForeRecr_2017	_	_	_	_	0	0.75
InitF_1MEXCAL_S1	1	0	3	1	1.13449	0.638403
InitF_2MEXCAL_S2	-1	0	3	0	0	_
InitF_3PNW	-1	0	3	0	0	_
LnQ_base_5_AT_Survey	4	-3	3	1	0.112508	0.109545
AgeSel_1P_1_MEXCAL_S1	3	-5	9	0.1	2.00011	156.521
AgeSel_1P_2_MEXCAL_S1	3	-5	9	0.1	3.82866	0.897237
AgeSel_1P_3_MEXCAL_S1	3	-5	9	0.1	0.754782	0.16081
AgeSel_1P_4_MEXCAL_S1	3	-5	9	0.1	-1.47545	0.377544
AgeSel_1P_5_MEXCAL_S1	3	-5	9	0.1	-0.232378	0.568367
AgeSel_1P_6_MEXCAL_S1	3	-5	9	0.1	-0.96326	1.35758
AgeSel_1P_7_MEXCAL_S1	3	-5	9	0.1	-0.141954	2.46857
AgeSel_1P_8_MEXCAL_S1	3	-5	9	0.1	-0.363488	4.03621
AgeSel_1P_9_MEXCAL_S1	3	-5	9	0.1	-0.222431	2.8561
AgeSel_1P_10_MEXCAL_S1	-3	-1000	9	-1000	-1000	_
AgeSel_1P_11_MEXCAL_S1	-3	-1000	9	-1000	-1000	_
AgeSel_2P_1_MEXCAL_S2	3	-5	9	0.1	2.00013	156.521
AgeSel_2P_2_MEXCAL_S2	3	-5	9	0.1	0.654966	0.132147
AgeSel_2P_3_MEXCAL_S2	3	-5	9	0.1	-0.983072	0.192291
AgeSel_2P_4_MEXCAL_S2	3	-5	9	0.1	-0.645874	0.345478
AgeSel_2P_5_MEXCAL_S2	3	-5	9	0.1	-0.559952	0.574878
AgeSel_2P_6_MEXCAL_S2	3	-5	9	0.1	0.522301	0.758618
AgeSel_2P_7_MEXCAL_S2	3	-5	9	0.1	-0.225458	1.12833
AgeSel_2P_8_MEXCAL_S2	3	-5	9	0.1	0.575561	1.70181
AgeSel_2P_9_MEXCAL_S2	3	-5	9	0.1	-1.18914	2.61519
AgeSel_2P_10_MEXCAL_S2	-3	-1000	9	-1000	-1000	_
AgeSel_2P_11_MEXCAL_S2	-3	-1000	9	-1000	-1000	_
AgeSel_3P_1_PNW	4	0	10	5	3.3305	0.141048
AgeSel_3P_2_PNW	4	-5	15	1	1.34952	0.118184

Table 13. Pacific sardine northern subpopulation numbers-at-age (1,000s) for model ALT.

		POPULATION NUMBERS-AT-AGE (1,000s of fish)										
Calendar Yr-Sem	Model Yr-Seas	0 (R)	1	2	3	4	5	6	7	8	9	10+
---	VIRG	1,522,530	835,580	458,576	251,672	138,120	75,802	41,601	22,831	12,530	6,877	8,365
---	VIRG	1,127,920	619,013	339,722	186,443	102,322	56,156	30,819	16,914	9,282	5,094	6,197
---	INIT	9,471,400	5,167,970	2,172,350	676,088	325,906	161,385	85,162	45,173	24,212	13,038	15,394
---	INIT	6,976,030	2,932,370	912,624	439,927	217,847	114,956	60,977	32,682	17,600	9,513	11,267
2005-2	2005-1	25,280,200	13,793,900	9,979,490	743,397	197,354	97,998	54,423	45,173	24,212	13,038	15,394
2006-1	2005-2	18,718,100	10,102,900	7,075,340	464,975	96,730	44,328	24,342	20,185	10,819	5,826	6,880
2006-2	2006-1	7,795,940	13,619,600	7,229,740	5,173,750	341,985	71,306	32,583	17,916	14,796	7,982	9,396
2007-1	2006-2	5,773,080	9,948,890	5,165,550	3,611,960	221,018	45,024	20,504	11,275	9,313	5,025	5,916
2007-2	2007-1	6,941,430	4,159,010	6,984,530	3,750,530	2,647,740	162,751	33,017	15,067	8,233	6,869	8,098
2008-1	2007-2	5,137,670	2,965,460	4,744,780	2,609,500	1,731,130	105,008	21,253	9,709	5,309	4,432	5,227
2008-2	2008-1	3,438,450	3,597,170	1,970,640	3,374,960	1,892,400	1,266,940	76,212	15,489	6,986	3,898	7,143
2009-1	2008-2	2,544,700	2,550,370	1,324,670	2,371,340	1,273,930	848,174	50,952	10,370	4,681	2,613	4,791
2009-2	2009-1	6,670,540	1,762,310	1,659,490	934,848	1,712,600	930,131	613,133	37,015	7,420	3,431	5,476
2010-1	2009-2	4,937,750	1,263,350	1,140,470	652,745	1,124,630	602,265	396,061	23,932	4,800	2,221	3,545
2010-2	2010-1	7,626,460	3,408,910	817,087	802,803	469,993	816,828	432,492	285,855	17,000	3,497	4,239
2011-1	2010-2	5,645,060	2,444,320	559,601	542,548	284,432	479,373	252,632	167,077	9,941	2,046	2,481
2011-2	2011-1	601,265	4,023,340	1,680,890	403,175	396,103	208,962	350,170	185,066	121,328	7,320	3,350
2012-1	2011-2	444,929	2,848,070	1,120,170	270,780	238,540	122,408	204,220	108,050	70,887	4,279	1,959
2012-2	2012-1	140,769	315,290	1,936,510	801,651	194,075	168,094	85,001	142,115	74,431	49,615	4,390
2013-1	2012-2	104,215	231,500	1,362,700	451,255	72,965	55,223	27,406	45,728	23,945	15,962	1,412
2013-2	2013-1	185,878	70,714	144,810	946,436	320,789	51,985	38,680	19,310	31,584	17,068	12,507
2014-1	2013-2	137,617	51,726	101,981	572,195	144,595	21,269	15,613	7,784	12,732	6,881	5,043
2014-2	2014-1	971,184	91,842	31,340	70,019	405,399	103,393	14,937	11,045	5,378	9,133	8,664
2015-1	2014-2	718,601	64,707	20,696	47,281	248,427	61,942	8,914	6,601	3,217	5,466	5,188
2015-2	2015-1	663,664	523,398	46,386	15,110	34,284	176,655	43,609	6,277	4,630	2,270	7,535
2016-1	2015-2	491,652	387,681	34,350	11,187	25,365	130,671	32,256	4,643	3,424	1,679	5,573
2016-2	2016-1	1,500,830	363,179	285,616	25,394	8,279	18,779	96,701	23,876	3,435	2,536	5,372
2017-1	2016-2	1,111,830	269,003	211,485	18,792	6,117	13,869	71,412	17,632	2,536	1,873	3,967
2017-2	2017-1	1,033,840	821,675	198,356	156,399	13,908	4,529	10,265	52,864	13,045	1,878	4,326

Table 14. Pacific sardine northern subpopulation biomass-at-age for model ALT.

		POPULATION BIOMASS-AT-AGE (mt)											SUMMARY BIOMASS	
Calendar Yr-Sem	Model Yr-Seas	0	1	2	3	4	5	6	7	8	9	10+	Ages 0+	Ages 1+
---	VIRG	11,419	39,189	35,081	26,174	17,583	11,052	6,656	3,897	2,237	1,267	1,619	156,173	144,754
---	VIRG	36,883	38,193	30,813	21,665	14,028	8,614	5,107	2,958	1,686	950	1,205	162,101	125,218
---	INIT	71,036	242,378	166,185	70,313	41,488	23,530	13,626	7,711	4,322	2,402	2,980	645,970	574,934
---	INIT	228,116	180,927	82,775	51,120	29,867	17,634	10,104	5,716	3,196	1,774	2,190	613,420	385,304
2005-2	2005-1	189,602	646,934	763,431	77,313	25,123	14,288	8,708	7,711	4,322	2,402	2,980	1,742,813	1,553,212
2006-1	2005-2	612,082	623,349	641,733	54,030	13,262	6,800	4,034	3,530	1,965	1,087	1,337	1,963,208	1,351,127
2006-2	2006-1	58,470	638,759	553,075	538,070	43,535	10,396	5,213	3,058	2,641	1,470	1,819	1,856,507	1,798,037
2007-1	2006-2	188,780	613,847	468,515	419,710	30,302	6,907	3,397	1,972	1,691	937	1,150	1,737,207	1,548,428
2007-2	2007-1	52,061	195,058	534,317	390,055	337,057	23,729	5,283	2,572	1,470	1,265	1,568	1,544,434	1,492,373
2008-1	2007-2	168,002	182,969	430,352	303,224	237,338	16,108	3,522	1,698	964	826	1,016	1,346,019	1,178,017
2008-2	2008-1	25,788	168,707	150,754	350,996	240,903	184,720	12,194	2,644	1,247	718	1,383	1,140,054	1,114,265
2009-1	2008-2	83,212	157,358	120,148	275,550	174,656	130,110	8,443	1,814	850	487	931	953,558	870,346
2009-2	2009-1	50,029	82,652	126,951	97,224	218,014	135,613	98,101	6,319	1,324	632	1,060	817,920	767,891
2010-1	2009-2	161,464	77,949	103,441	75,849	154,187	92,387	65,627	4,186	872	414	689	737,065	575,600
2010-2	2010-1	57,198	159,878	62,507	83,492	59,830	119,094	69,199	48,795	3,034	644	821	664,492	607,294
2011-1	2010-2	184,593	150,815	50,756	63,044	38,996	73,536	41,861	29,222	1,805	382	482	635,491	450,898
2011-2	2011-1	4,509	188,695	128,588	41,930	50,424	30,467	56,027	31,591	21,657	1,348	648	555,885	551,375
2012-1	2011-2	14,549	175,726	101,599	31,465	32,704	18,777	33,839	18,898	12,873	798	381	441,610	427,060
2012-2	2012-1	1,056	14,787	148,143	83,372	24,706	24,508	13,600	24,259	13,286	9,139	850	357,706	356,650
2013-1	2012-2	3,408	14,284	123,597	52,436	10,004	8,471	4,541	7,998	4,348	2,977	275	232,338	228,930
2013-2	2013-1	1,394	3,317	11,078	98,429	40,836	7,579	6,189	3,296	5,638	3,144	2,421	183,322	181,928
2014-1	2013-2	4,500	3,192	9,250	66,489	19,824	3,263	2,587	1,361	2,312	1,283	980	115,041	110,541
2014-2	2014-1	7,284	4,307	2,398	7,282	51,607	15,075	2,390	1,885	960	1,682	1,677	96,548	89,264
2015-1	2014-2	23,498	3,992	1,877	5,494	34,059	9,502	1,477	1,154	584	1,019	1,009	83,667	60,169
2015-2	2015-1	4,977	24,547	3,548	1,571	4,364	25,756	6,977	1,072	826	418	1,459	75,518	70,540
2016-1	2015-2	16,077	23,920	3,116	1,300	3,478	20,045	5,345	812	622	313	1,083	76,110	60,033
2016-2	2016-1	11,256	17,033	21,850	2,641	1,054	2,738	15,472	4,076	613	467	1,040	78,240	66,983
2017-1	2016-2	36,357	16,597	19,182	2,184	839	2,128	11,833	3,084	461	349	771	93,784	57,427
2017-2	2017-1	7,754	38,537	15,174	16,265	1,771	660	1,642	9,024	2,329	346	837	94,339	**86,586**

Table 15. Spawning stock biomass (SSB) and recruitment (Recruits) estimates and asymptotic standard errors for model ALT. SSB estimates were calculated at the beginning of Season 2 of each model year (January). Recruits were age-0 fish calculated at the beginning of each model year (July).

Model Yr-Seas	SSB (mt)	SSB Std Dev	Recruits (1000s)	Recruits Std Dev
VIRG-1	---	---	1,522,550	474,216
VIRG-2	107,915	33,611	---	---
INIT-1	---	---	9,471,460	4,375,370
INIT-2	324,262	89,816	---	---
2005-1	---	---	25,280,200	---
2005-2	1,073,370	81,231	---	---
2006-1	---	---	7,795,940	921,117
2006-2	1,220,870	82,137	---	---
2007-1	---	---	6,941,430	776,514
2007-2	1,038,110	69,463	---	---
2008-1	---	---	3,438,450	524,348
2008-2	776,752	51,418	---	---
2009-1	---	---	6,670,540	698,028
2009-2	540,469	36,758	---	---
2010-1	---	---	7,626,460	877,556
2010-2	399,390	29,801	---	---
2011-1	---	---	601,265	152,534
2011-2	336,084	29,628	---	---
2012-1	---	---	140,769	51,311
2012-2	201,813	25,832	---	---
2013-1	---	---	185,878	66,165
2013-2	104,351	18,784	---	---
2014-1	---	---	971,184	337,752
2014-2	60,263	13,171	---	---
2015-1	---	---	663,664	365,241
2015-2	51,186	11,460	---	---
2016-1	---	---	1,500,830	1,183,890
2016-2	52,353	12,991	---	---

Table 16. Natural mortality (M=0.35-0.75 yr^{-1}) profile with associated important likelihood (L), parameter (Q), and derived quantity (terminal spawning stock biomass and stock biomass) estimates for model ALT.

Likelihoods / Estimates	Natural mortality (*M*)								
	0.35	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**
AT survey abundance index (*L*)	4.3	4.6	4.9	5.2	5.3	5.4	5.3	5.2	4.9
AT age composition (*L*)	87.0	87.3	87.9	88.6	89.4	90.2	91.0	92.3	92.3
Total (*L*)	325.7	327.6	329.0	330.3	331.7	333.3	334.7	337.2	339.6
AT catchability (*Q*)	2.4	2.1	1.8	1.6	1.3	1.1	0.9	0.7	0.6
Spawning stock biomass 2016 (mt)	26,936	29,921	34,156	39,152	45,083	52,354	59,621	74,587	93,362
Stock biomass 2017 (mt)	42,078	46,536	54,134	63,099	73,676	86,586	99,469	126,021	160,447

Table 17. Estimates for likelihood components, specific parameters, and derived quantities of interest for models evaluated in sensitivity analysis. Models are defined in footnote below.

			MODEL[a]					
			ALT	ALT_AT+DEPM	ALT_AT SELEX=LOGISTIC	ALT_h=0.8	ALT_FDW	ALT_HMDW
LIKELIHOODS	Indices	AT survey	5.36	6.12	10.48	5.38	5.99	6.19
		DEPM	na	12.55	na	na	na	na
		Subtotal	**5.36**	**18.67**	**10.48**	**5.38**	**5.36**	**6.19**
	Compositions	MEXCAL_S1 age composition	50.66	49.92	51.23	50.56	13.51	11.12
		MEXCAL_S2 age composition	75.20	74.02	67.68	75.78	16.60	9.14
		PNW age composition	89.66	92.34	94.82	89.11	28.14	22.85
		AT age composition	90.22	90.52	63.86	90.40	44.92	38.18
		Subtotal	**305.74**	**306.80**	**277.59**	**305.85**	**103.17**	**81.29**
	Other	**Catch**	<1	<1	<1	<1	<1	<1
		Recruitment	22.15	21.44	23.18	23.08	15.09	14.03
		Parameter softbounds	<1	<1	<1	<1	<1	<1
		TOTAL	**333.26**	**346.91**	**311.25**	**334.31**	**123.62**	**101.51**
ESTIMATES		Stock-recruitment ($\ln R_0$)	14.24	14.35	14.42	14.54	14.48	14.52
		Stock-recruitment (h)	0.36	0.37	0.39	0.80	0.35	0.35
		Spawning stock biomass 2016 (mt)	51,187	63,756	46,348	54,462	60,144	61,514
		Recruitment 2016 (billions of fish)	1.50	1.77	1.20	2.31	1.80	1.34
		Stock biomass peak (mt)	1,798,040	1,663,290	1,798,040	1,821,590	1,770,560	1,778,130
		Stock biomass 2016 (mt)	66,984	80,475	145,099	73,389	85,472	61,514
		Stock biomass 2017 (mt)	86,586	102,574	153,020	112,494	108,924	112,534

[a] Models are as follows: ALT is baseline model; ALT_DEPM is model ALT (including DEPM index of abundance); ALT_AT SELEX=LOGISTIC is model ALT (including 2-parameter logistic selectivity for the AT survey); ALT_h=0.8 is model ALT (including steepness fixed, h=0.8); ALT_FDW is model ALT (including Francis data weighting method); and ALT_HMDW is model ALT (including harmonic mean data weighting method).

Table 18. Convergence tests for model ALT, where randomized phase orders and 20% initial parameter jittering were applied to a range (13.2-15.1) of initial starting values of R_0.

	PHASE ORDER BY COMPONENT						RESULTS	
Initial R_0	R_0	R_1	B-H (h)	Init F	ln(Q)	Selectivity	Final R_0	Total -log(L)
13.2	1	5	2	1	3	4	14.2359	333.256
13.3	3	1	4	3	2	5	14.2359	333.256
13.4	2	4	1	2	5	3	14.2359	333.256
13.5	4	5	3	4	1	2	14.2359	333.256
13.6	5	2	4	5	3	1	14.2359	333.256
13.7	5	1	2	5	4	3	14.2359	333.256
13.8	3	5	2	3	4	1	14.2359	333.256
13.9	2	3	5	2	1	4	14.2359	333.256
14.0	1	3	2	1	5	4	14.2359	333.256
14.1	4	1	3	4	2	5	14.2359	333.256
14.2	2	3	4	2	5	1	14.2359	333.256
14.3	4	2	3	4	1	5	14.2359	333.256
14.4	1	3	2	1	4	5	14.2359	333.256
14.5	5	3	4	5	2	1	14.2359	333.256
14.6	3	1	5	3	4	2	14.2359	333.256
14.7	3	1	5	3	4	2	14.2359	333.256
14.8	2	3	1	2	5	4	14.2359	333.256
14.9	5	4	3	5	2	1	14.2359	333.256
15.0	1	5	2	1	3	4	14.2359	333.256
15.1	4	1	5	4	2	3	14.2359	333.256

Table 19. Harvest control rules for the model-based assessment (model ALT).

Harvest Control Rule Formulas									
OFL = BIOMASS * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
$ABC_{P\text{-}star}$ = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION; where FRACTION is E_{MSY} bounded 0.05 to 0.20									
Harvest Formula Parameters									
BIOMASS (ages 1+, mt)	86,586								
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
ABC $Buffer_{Tier 1}$	0.95577	0.91283	0.87048	0.82797	0.78442	0.73861	0.68859	0.63043	0.55314
ABC $Buffer_{Tier 2}$	0.91350	0.83326	0.75773	0.68553	0.61531	0.54555	0.47415	0.39744	0.30596
CalCOFI SST (2014-2016)	15.9999								
E_{MSY}	0.225104								
FRACTION	0.200000								
CUTOFF (mt)	150,000								
DISTRIBUTION (U.S.)	0.87								
Harvest Control Rule Values (MT)									
OFL =	**16,957**								
$ABC_{Tier 1}$ =	16,207	15,479	14,761	14,040	13,301	12,525	11,676	10,690	9,380
$ABC_{Tier 2}$ =	15,490	14,130	12,849	11,625	10,434	9,251	8,040	6,739	5,188
HG =	**0**								

Table 20. CalCOFI annual and three-year average sea surface temperatures (SST, °C) since 1984. Three-year average SST is used to calculate E_{MSY} in the harvest control rules.

Calendar year	CalCOFI annual SST (°C)	CalCOFI 3-yr average SST (°C)
1984	16.3533	---
1985	15.7605	---
1986	15.9823	16.0320
1987	16.2973	16.0134
1988	15.7851	16.0216
1989	15.4632	15.8485
1990	15.9946	15.7476
1991	15.7998	15.7525
1992	16.7028	16.1657
1993	16.4182	16.3069
1994	16.4762	16.5324
1995	15.9241	16.2729
1996	16.3252	16.2419
1997	16.6950	16.3148
1998	16.7719	16.5973
1999	15.2843	16.2504
2000	15.7907	15.9490
2001	15.5535	15.5429
2002	14.9414	15.4285
2003	16.0328	15.5092
2004	15.8849	15.6197
2005	15.4585	15.7920
2006	15.9157	15.7530
2007	15.1543	15.5095
2008	15.2724	15.4475
2009	15.3583	15.2617
2010	15.5520	15.3942
2011	15.5618	15.4907
2012	15.2939	15.4692
2013	14.9097	15.2551
2014	14.1932	14.7989
2015	17.4765	15.5265
2016	16.3299	15.9999

FIGURES

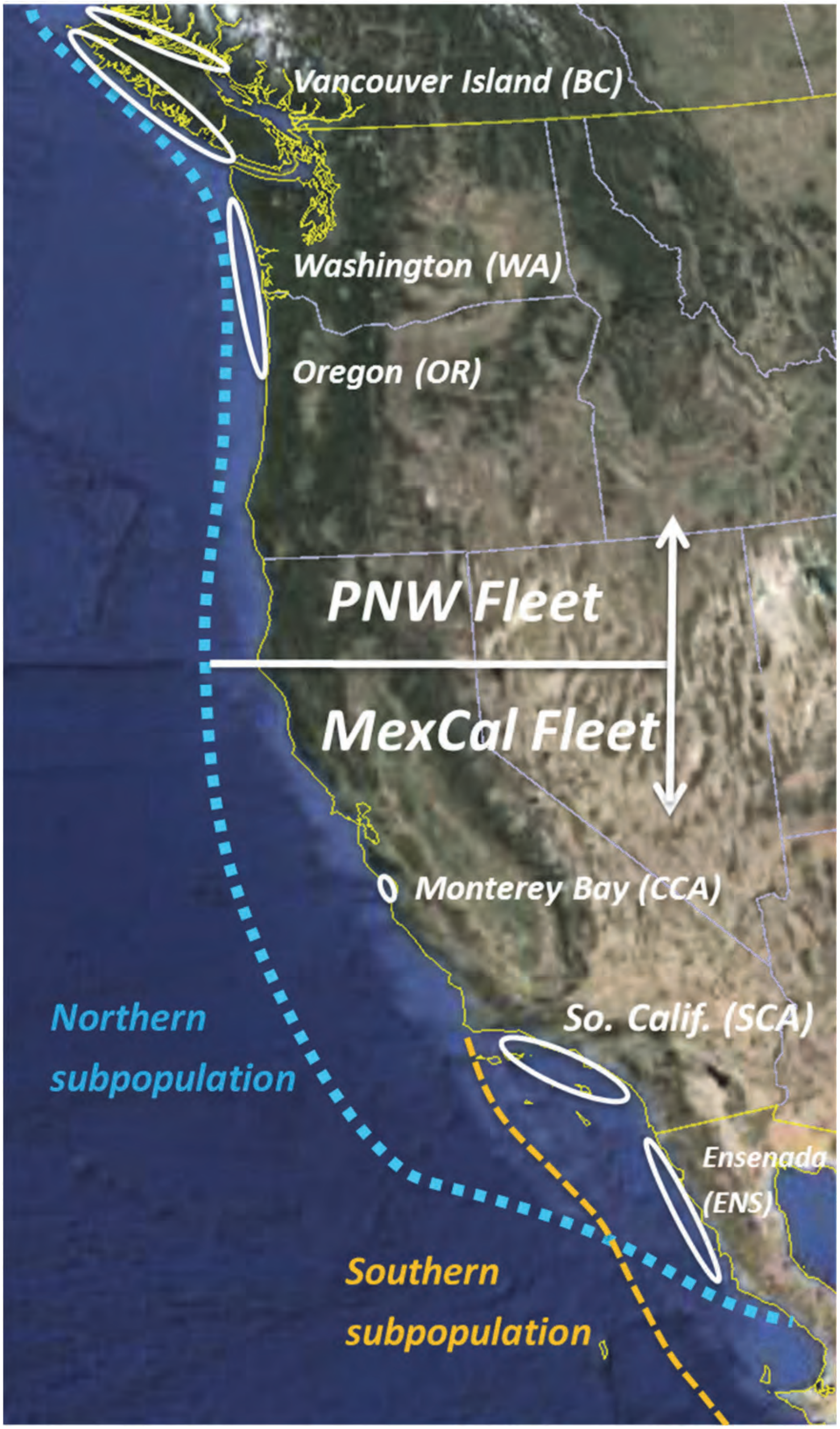


Figure 1. Distribution of the northern subpopulation of Pacific sardine, primary commercial fishing areas, and modeled fleets.

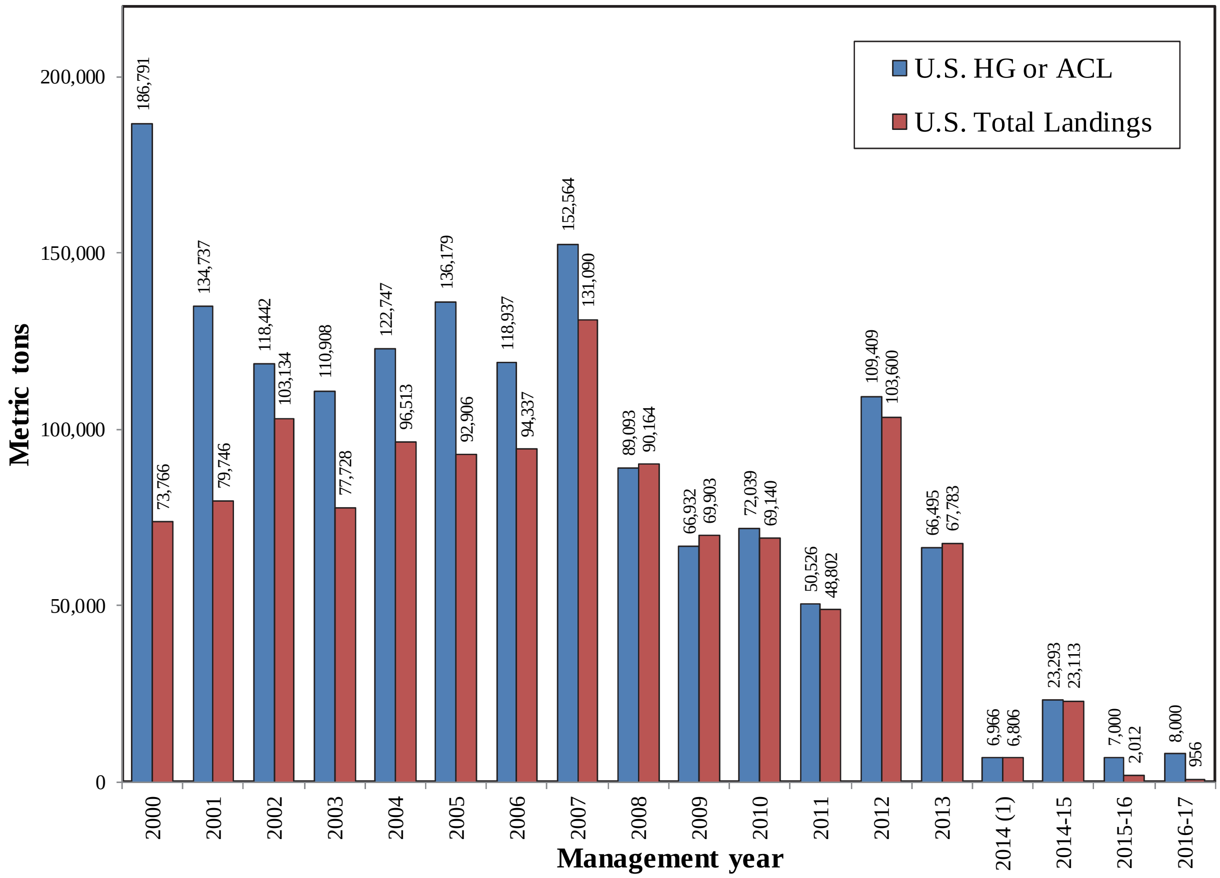


Figure 2. U.S. Pacific sardine harvest guidelines or acceptable catch limits and landings since the onset of federal management.

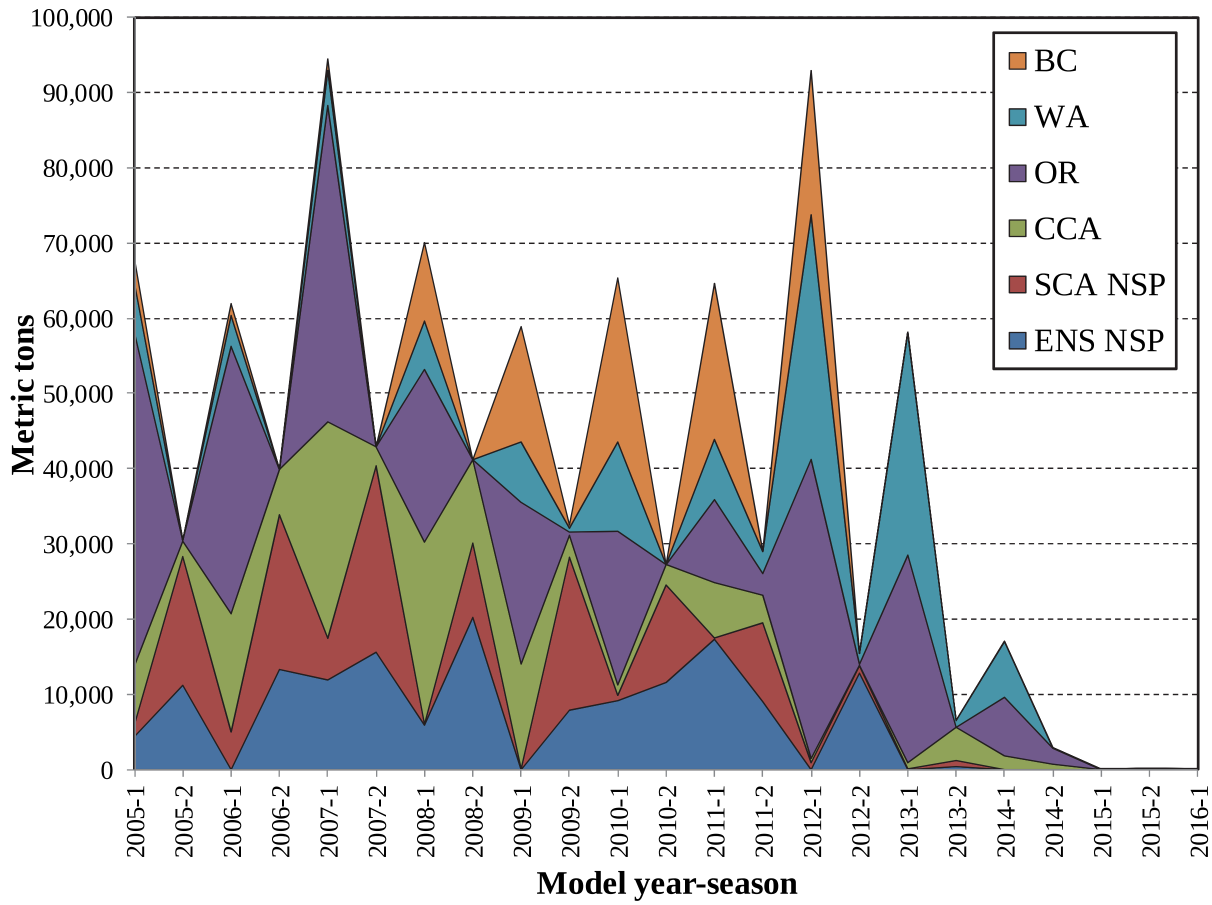


Figure 3. Pacific sardine NSP landings (mt) by major fishing region.

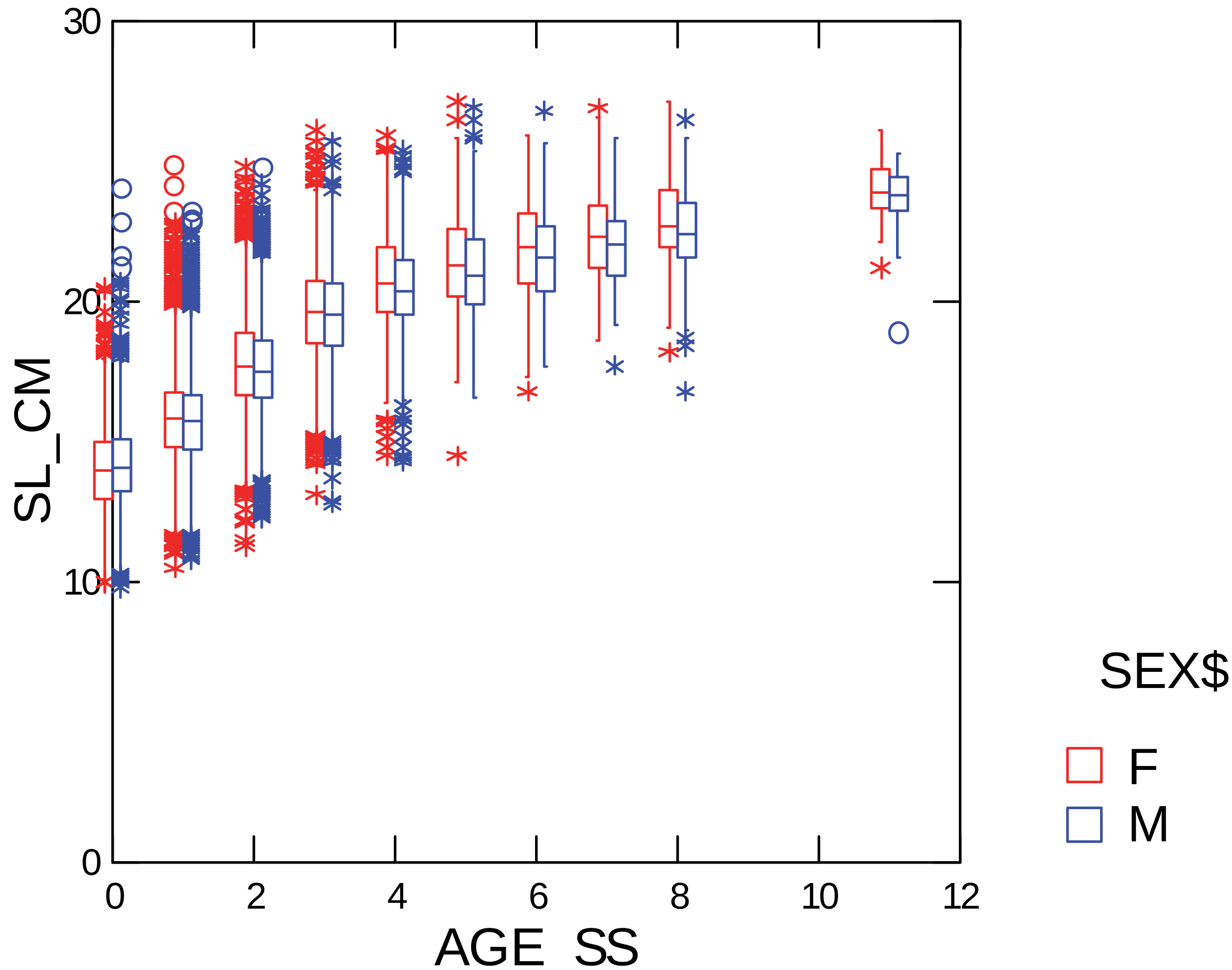


Figure 4. Length-at-age by sex from NSP fishery samples (1993-2013; Hill et al. 2014), indicating lack of sexually dimorphic growth. Box symbols indicate median and quartile ranges for the raw data.

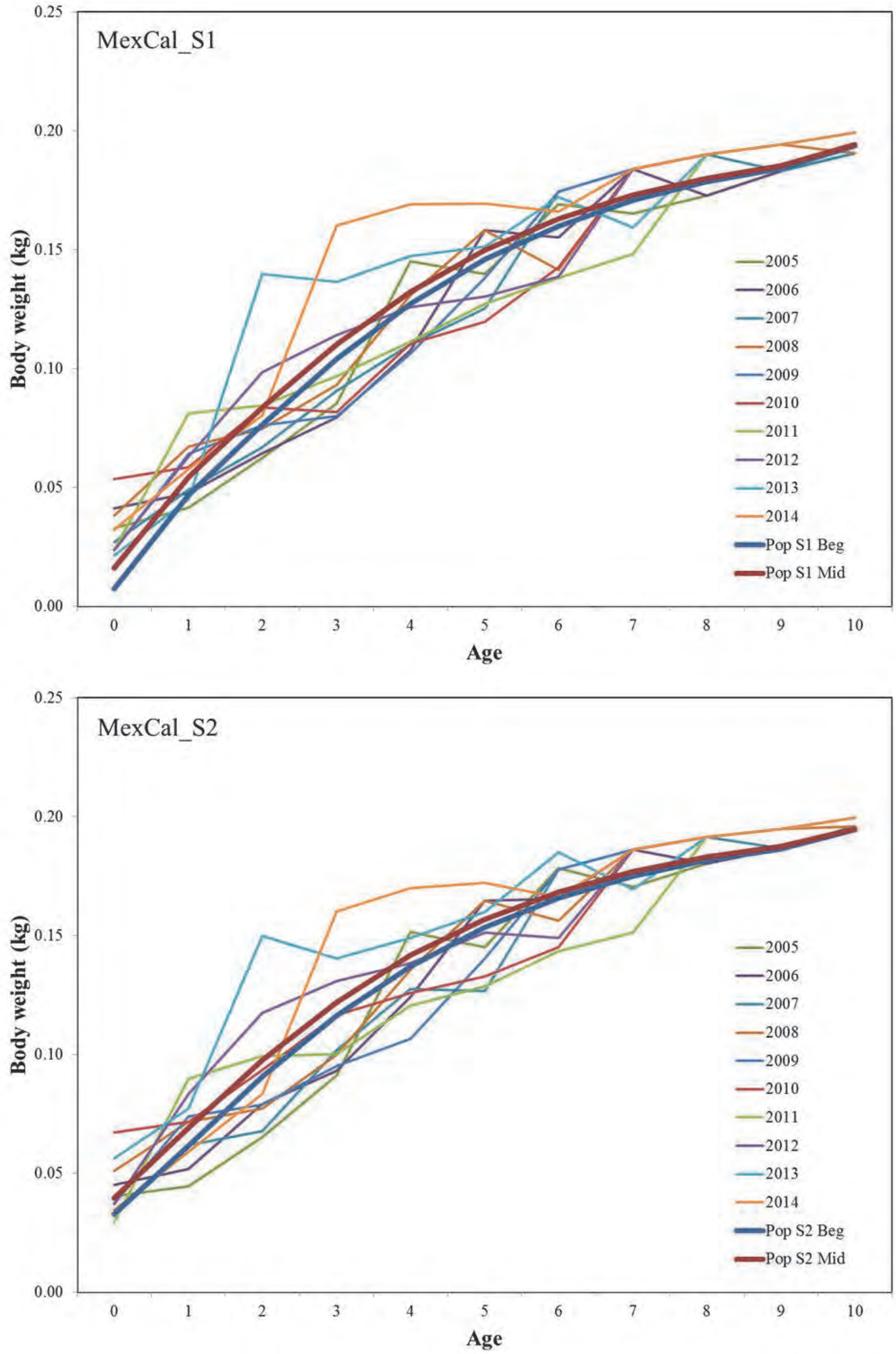
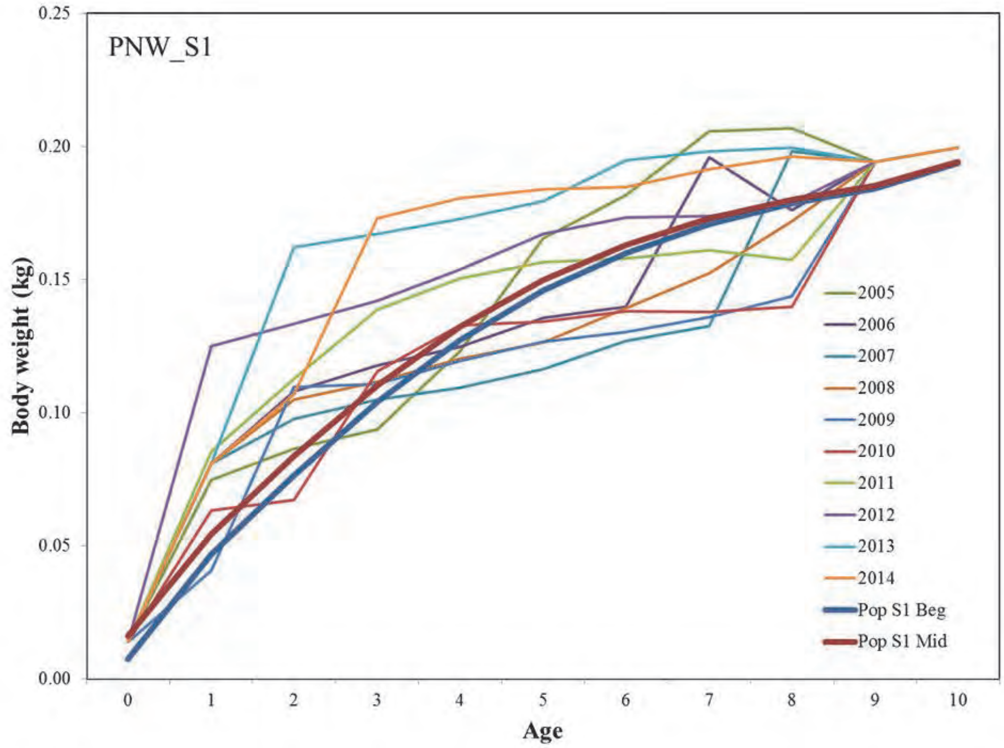


Figure 5. Empirical weight-at-age time series for the MEXCAL fleet in seasons 1 and 2.



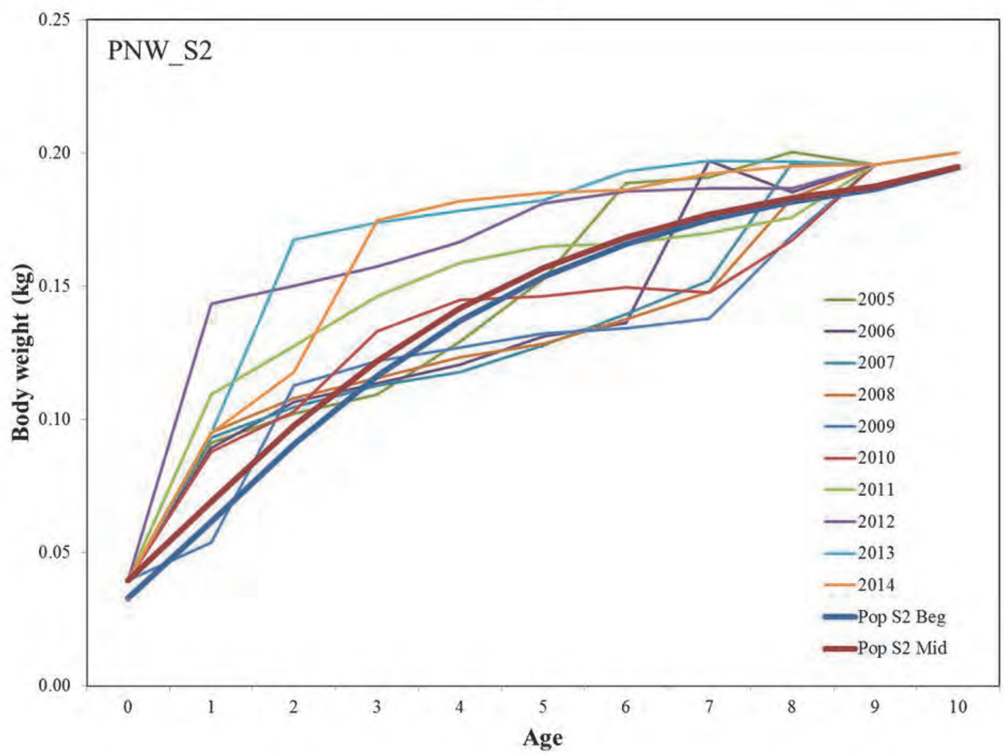


Figure 6. Empirical weight-at-age time series for the PNW fleet in seasons 1 and 2.

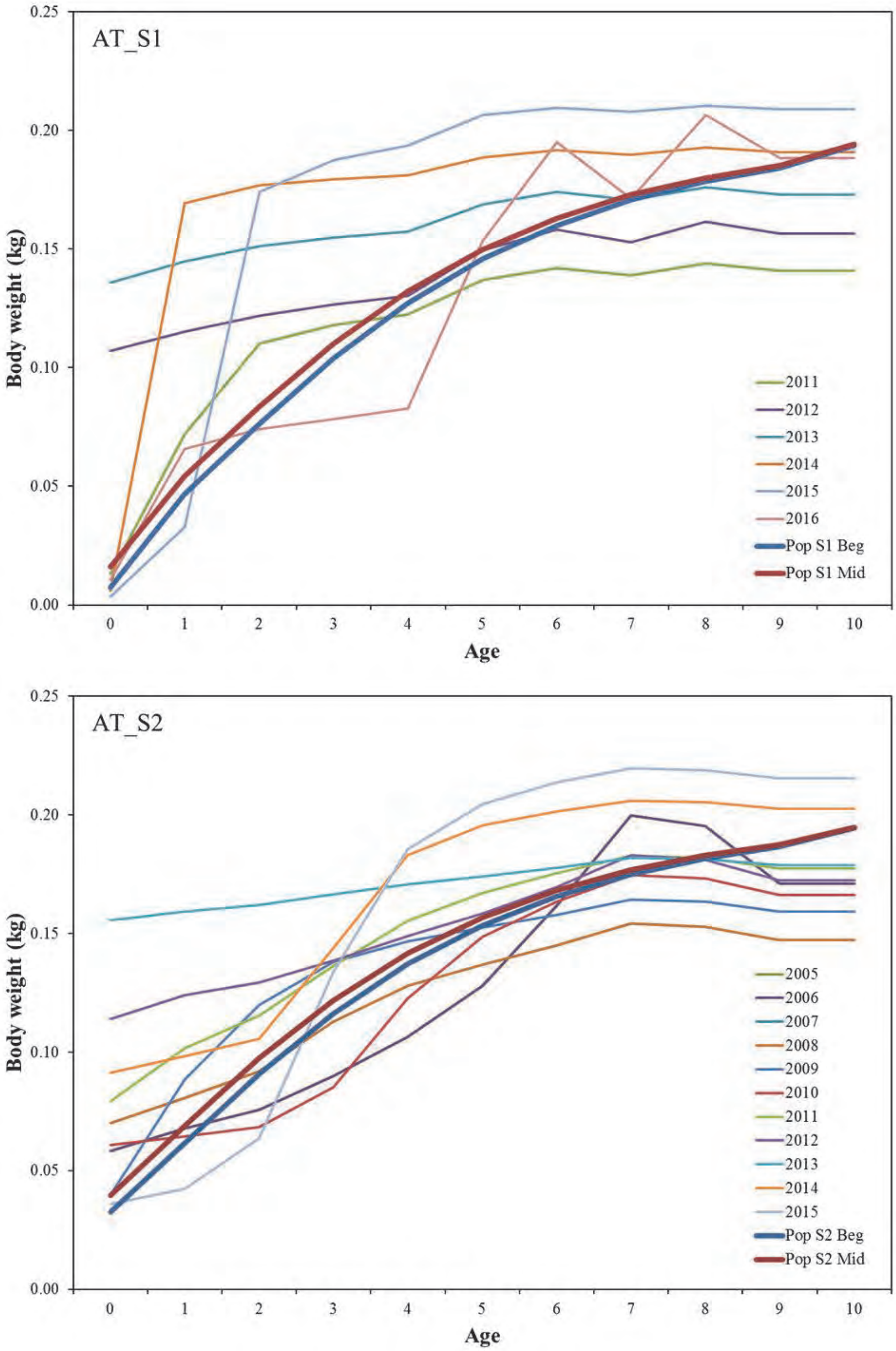


Figure 7. Empirical weight-at-age time series for the AT survey in seasons 1 and 2.

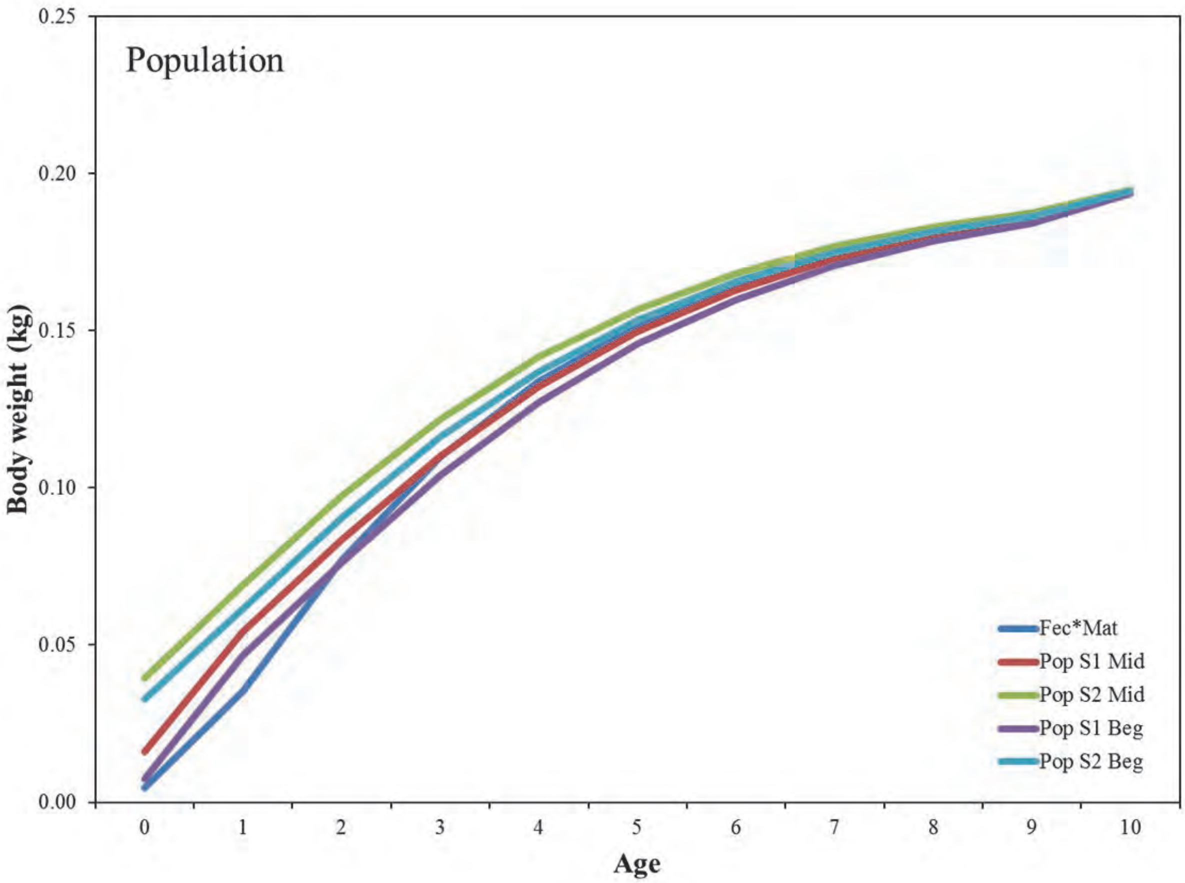


Figure 8. Population body weights-at-age and SSB-at-age applied in model ALT. Population body weights-at-age are provided at the beginning and middle of seasons 1 and 2, and fecundity*maturity-at-age is used to calculate SSB at the beginning of season 2.

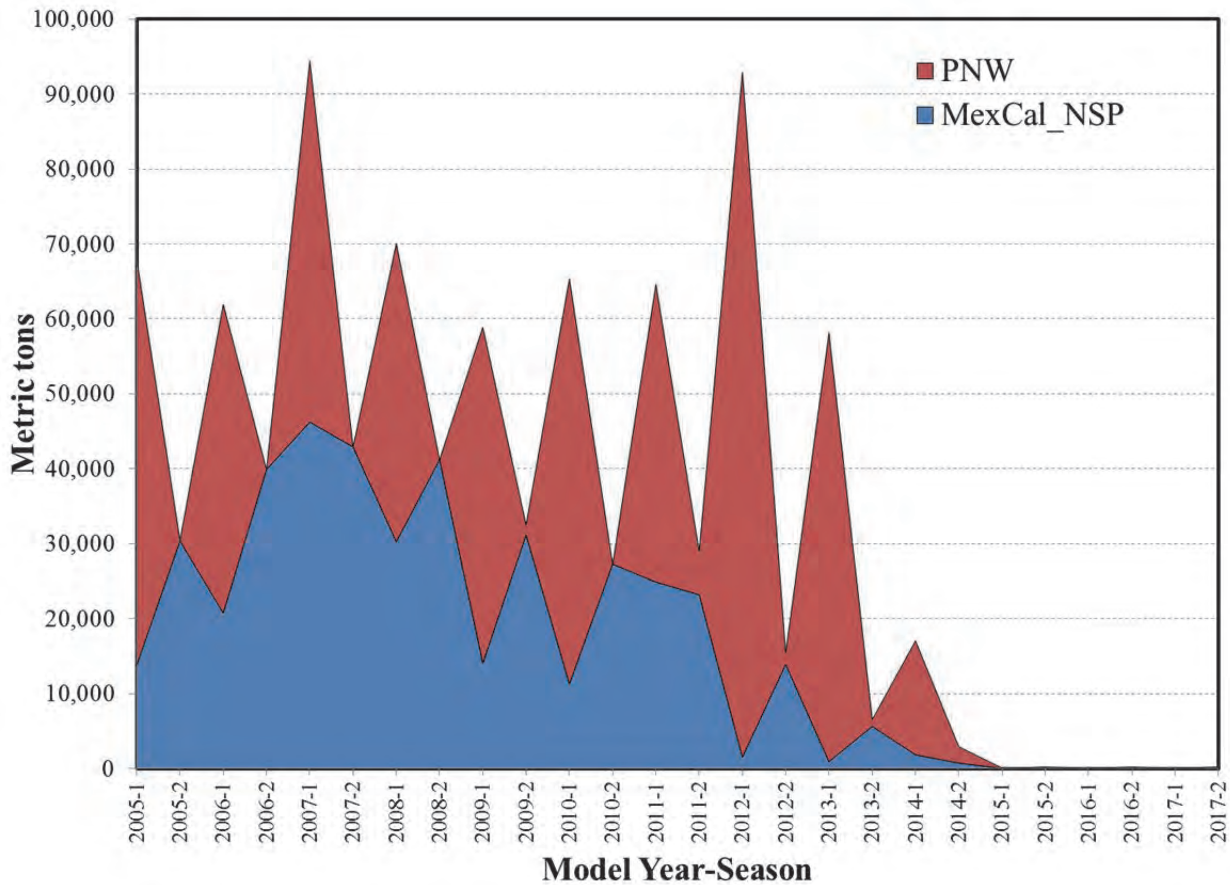


Figure 9. Pacific sardine NSP landings (mt) by fleet, model year and semester as used in model ALT.

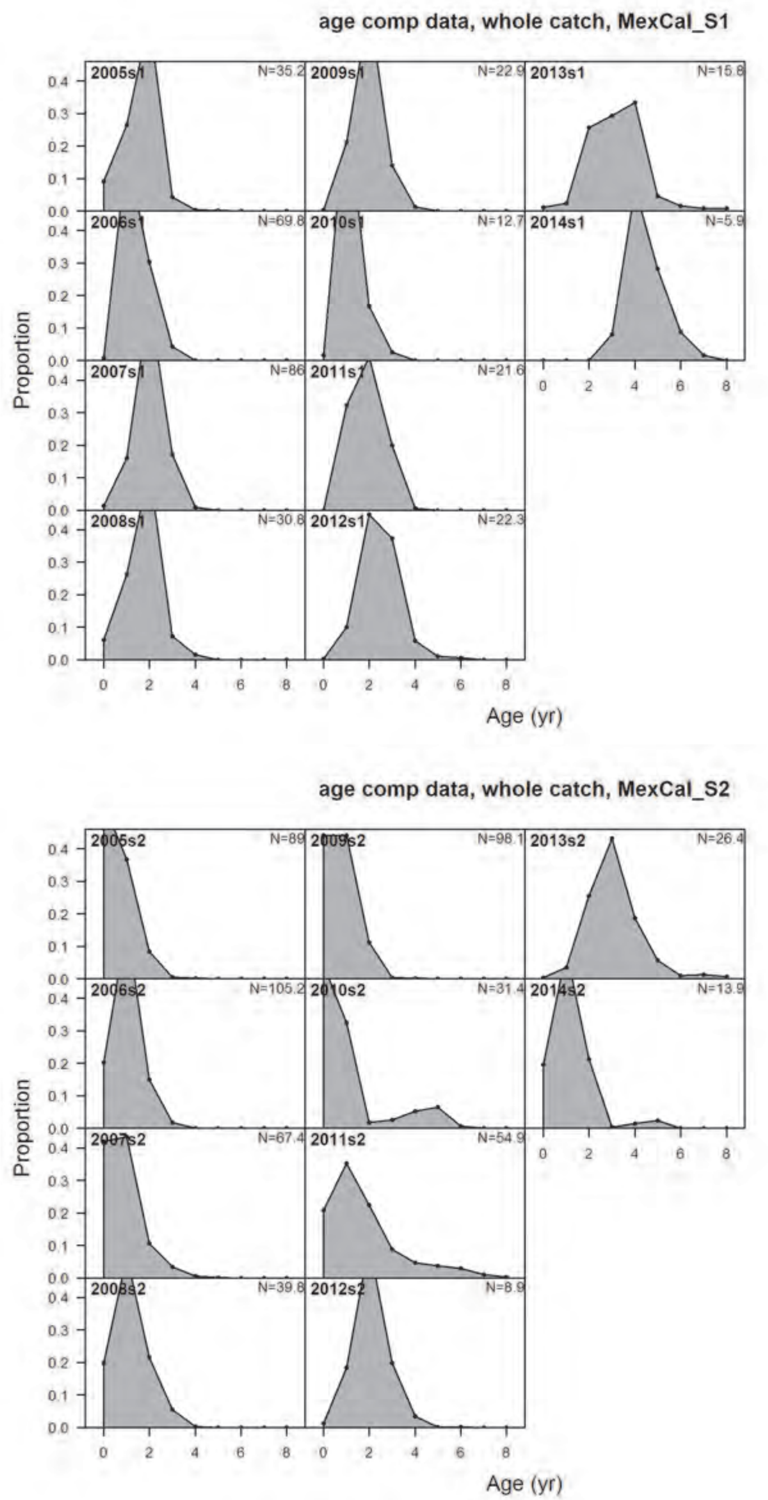


Figure 10. Age composition time series for the MEXCAL fleet in seasons 1 (upper) and 2 (lower). N represents input sample sizes.

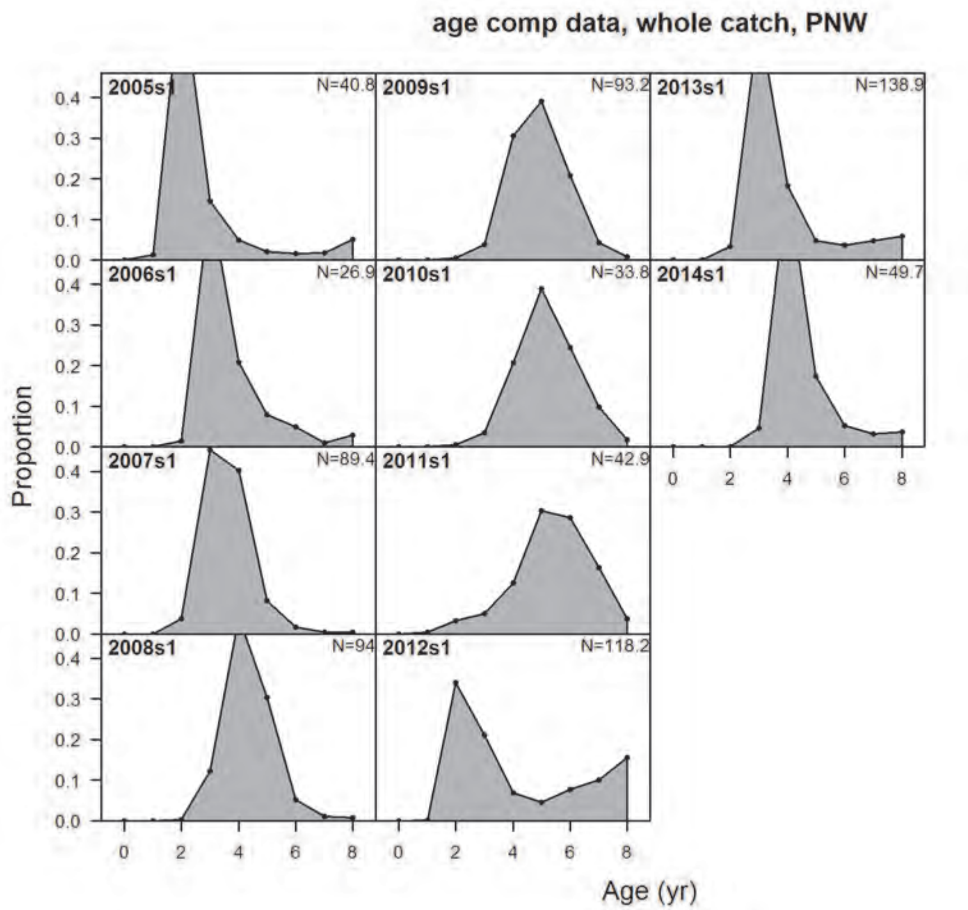


Figure 11. Age composition time series for the PNW fleet in season 1. N represents input sample sizes.

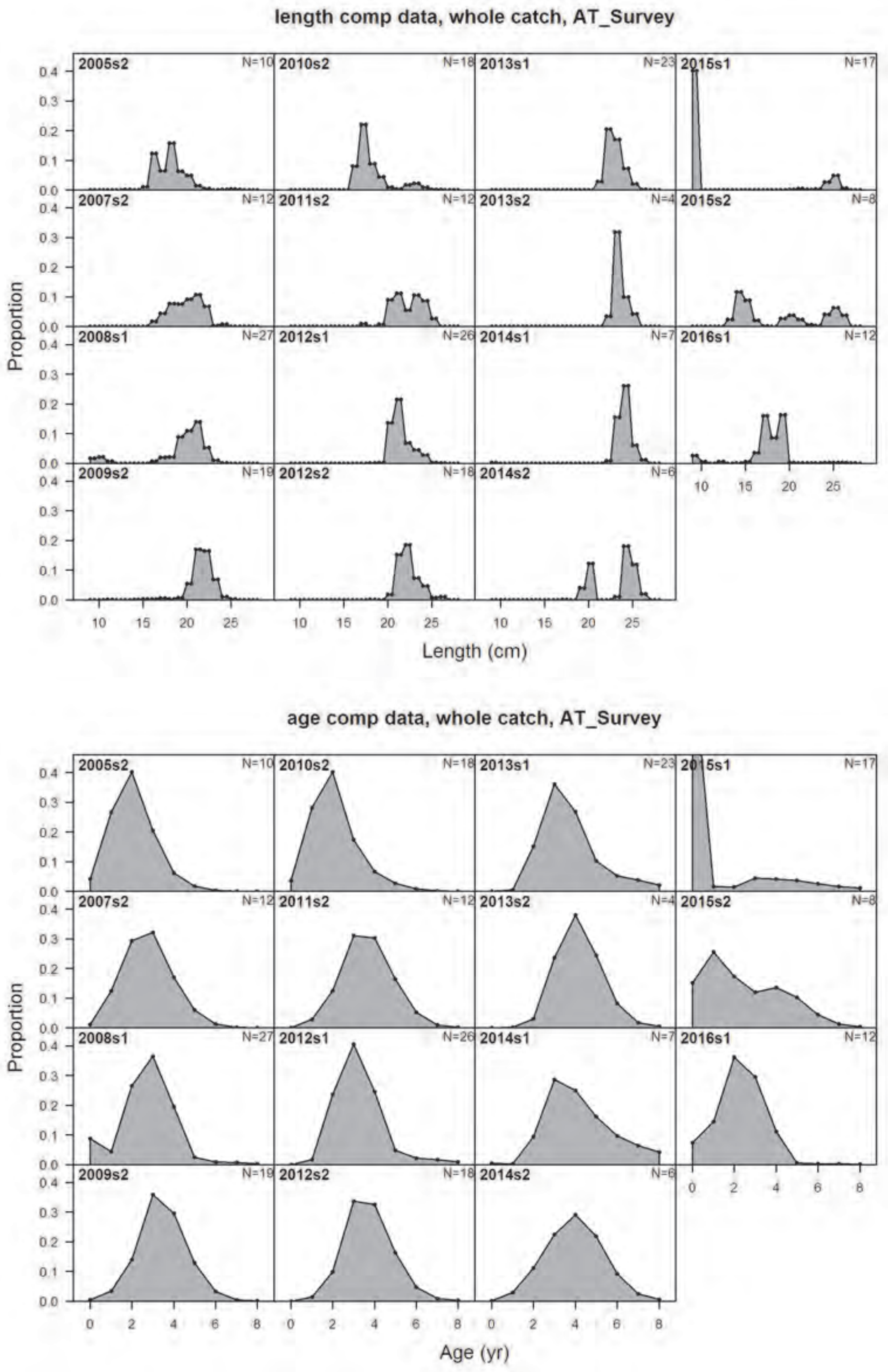


Figure 12. Length- (upper panel) and age-composition (lower panel) time series for the AT survey. N represents input sample sizes.

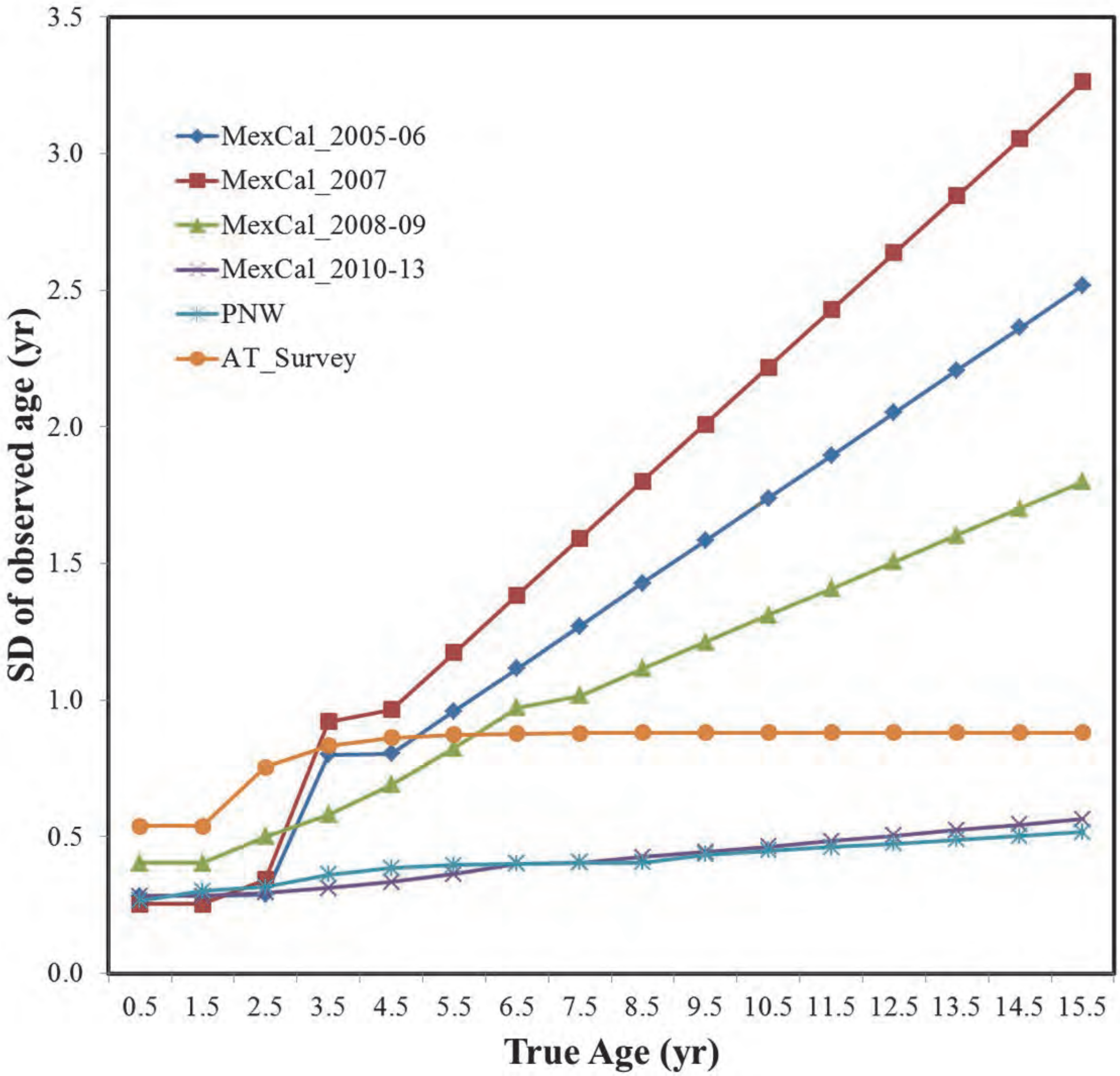


Figure 13. Laboratory- and year-specific ageing errors applied in model ALT.

Figure 14. Results from the AT survey for spring 2016. Acoustic backscatter (s_A, m^2 n.mi.^{2}) from coastal pelagic fish species (CPS) superimposed on the distribution of potential sardine habitat (dashed lines) defined at the mid-period of the survey (left); acoustic proportions of CPS in trawl clusters, including northern anchovy (*Engraulis mordax*), Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*)(middle); and density (eggs min^{-1}) of sardine eggs from the continuous underway fish egg sampler (right).

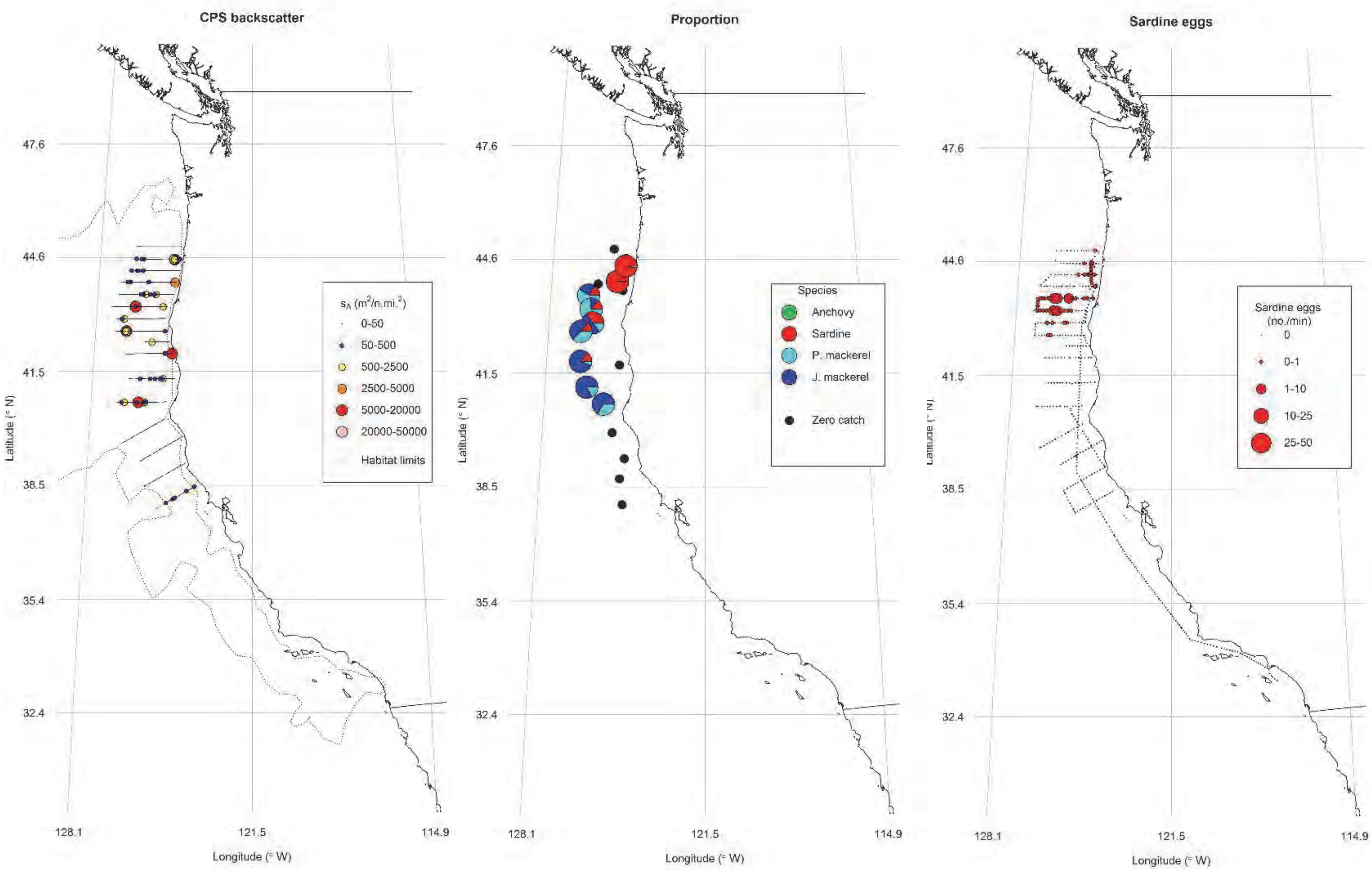


Figure 15. Results from the AT survey for summer 2016. Acoustic backscatter (s_A, m^2 $n.mi.^2$) from coastal pelagic fish species (CPS; left); acoustic proportions of CPS in trawl clusters (right), including northern anchovy (*Engraulis mordax*), Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), and Pacific herring (*Clupea pallasii*). Egg samples are not shown because the primary spawning period for sardine is during spring.

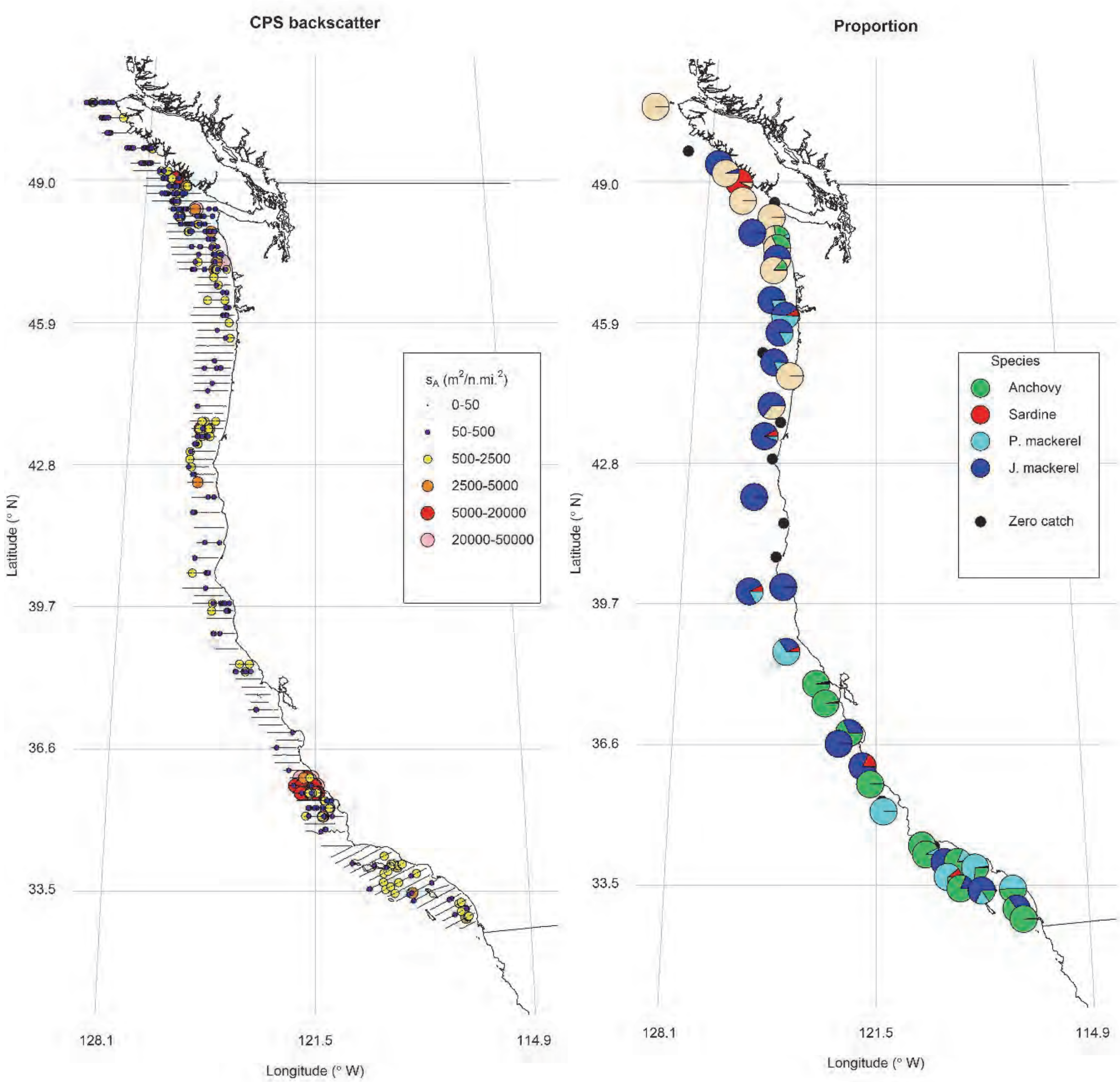


Figure 16. Sardine biomass densities versus stratum (Table 6) estimated in the AT survey for spring 2016. The red numbers represent the locations of trawl clusters with at least one sardine.

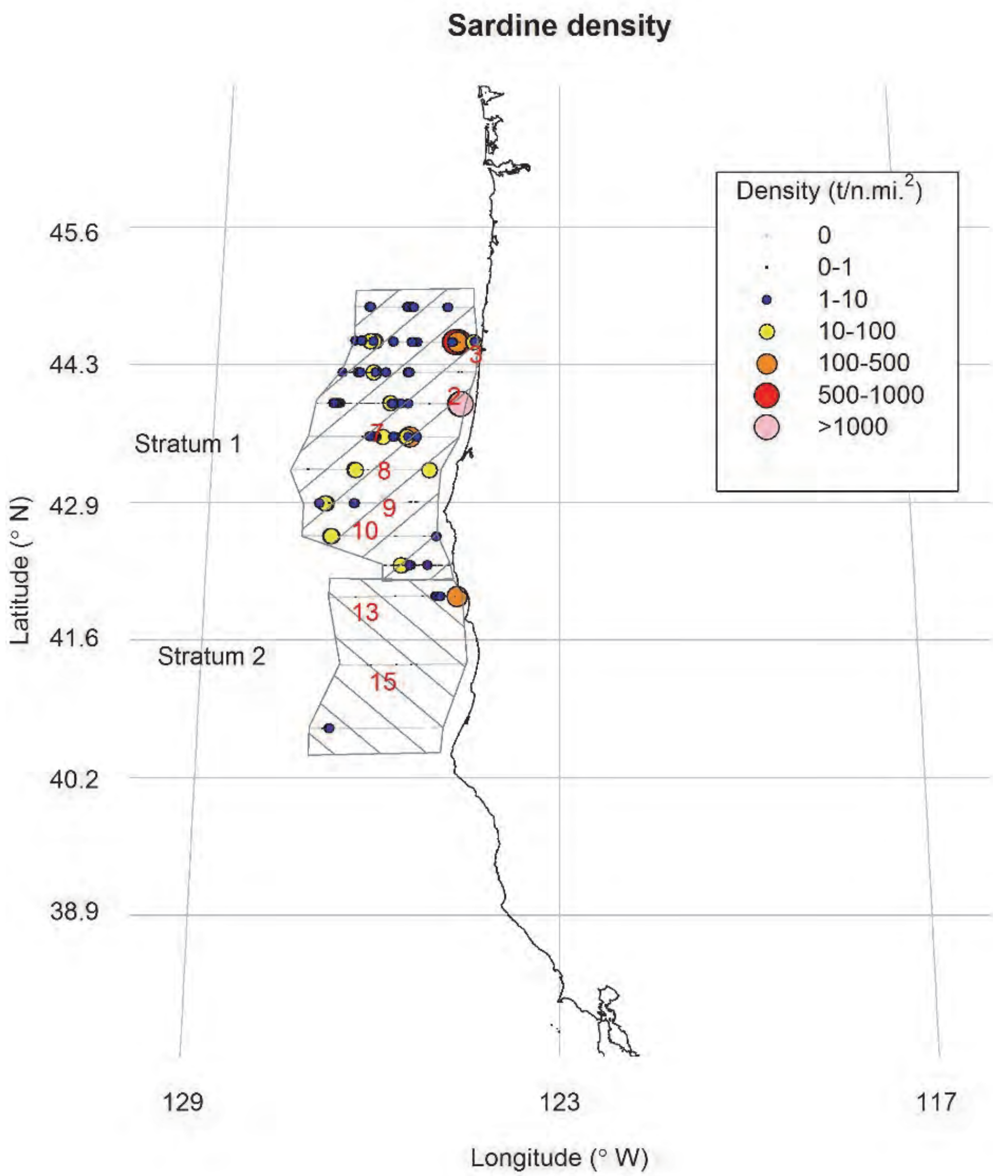


Figure 17. Estimated sardine abundance by length-class for the entire survey area and for the two strata (Figure 16) for the AT survey in spring 2016. The corresponding number of sardine sampled in each stratum is provided in Table 6.

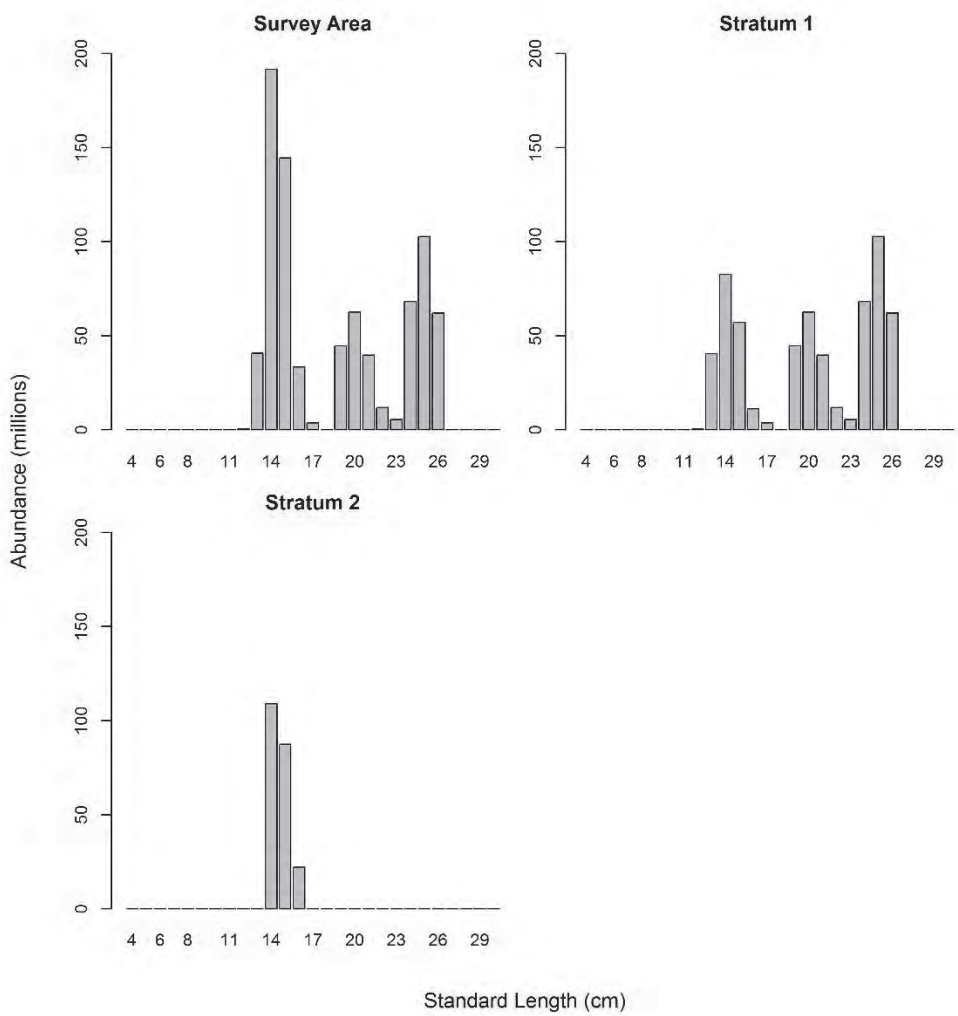


Figure 18. Sardine biomass densities versus stratum (Table 7) estimated in the AT survey for summer 2016. Numbers in red represent the locations of trawl clusters with at least one sardine.

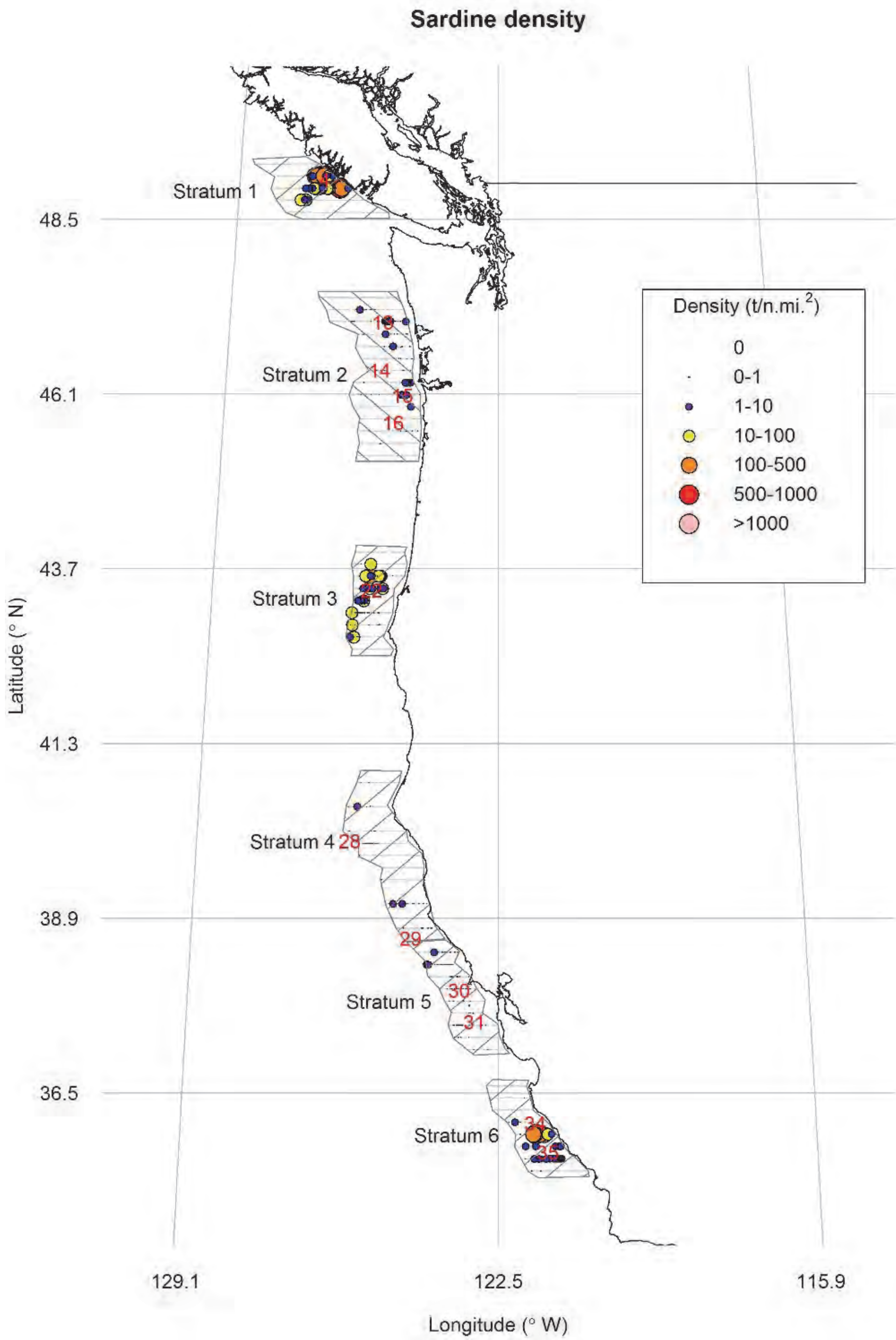
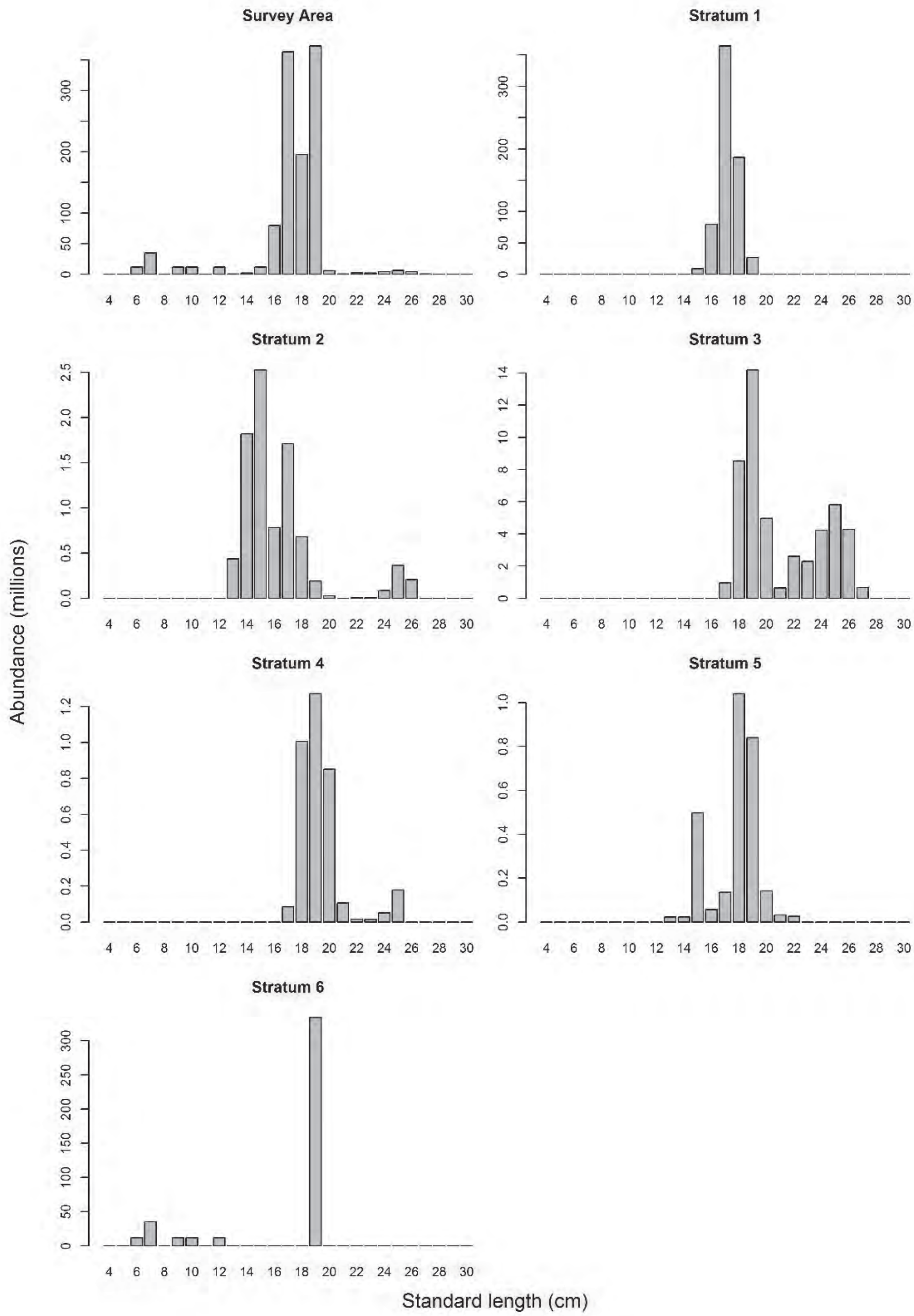


Figure 19. Estimated sardine abundance by length-class for the entire survey area and for the six strata (Figure 18) in the AT survey in summer 2016. The corresponding number of sardine sampled in each stratum is provided in Table 7.



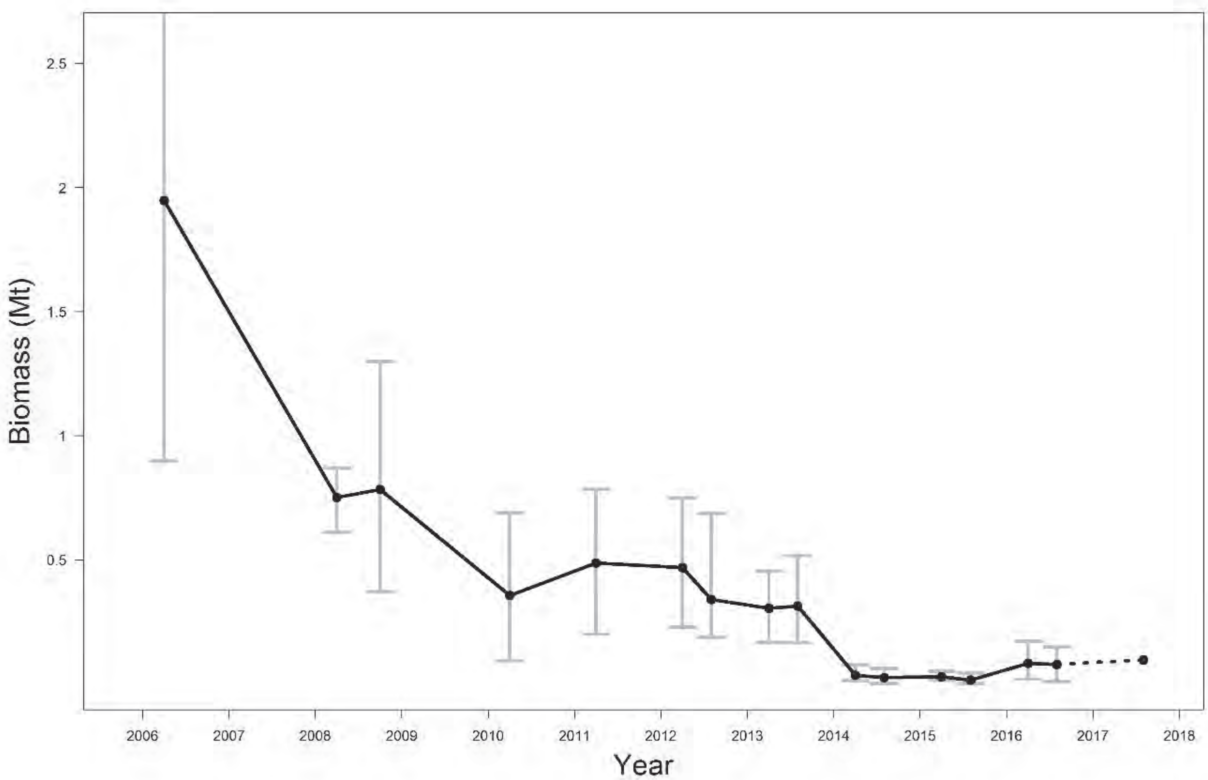


Figure 20. Time-series of Pacific sardine biomass with respective 95% confidence intervals as estimated by acoustic-trawl (AT) surveys. The biomass in July 2017 was projected based on the summer 2016 AT biomass and the expected recruitment using the ALT model's S-R relationship.

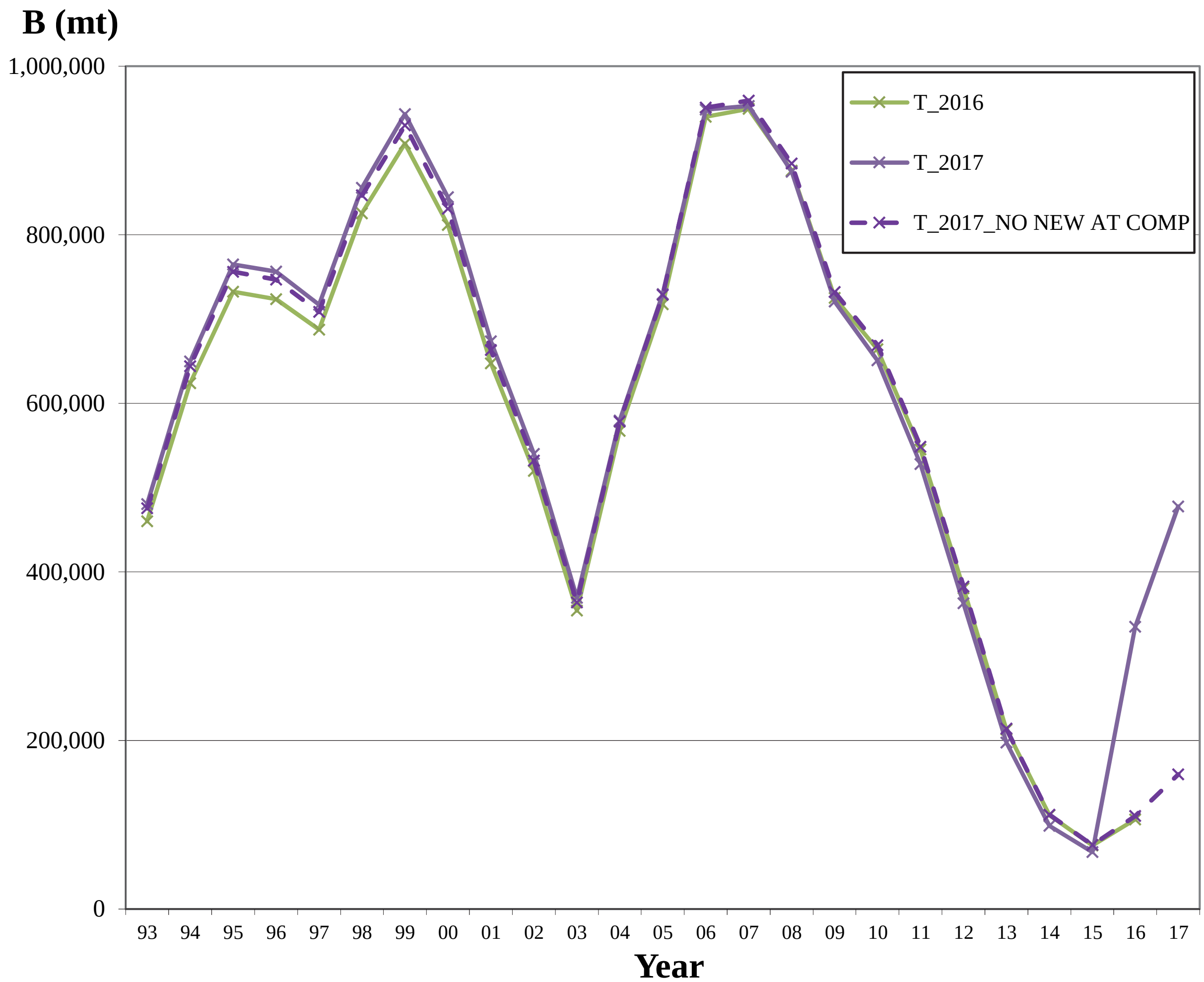


Figure 21. Estimated stock biomass (age 1+ fish, mt) time series for the 2016 update model (T_2016), the update model with 2016 AT biomass and length compositions (T_2017), and the update model with no new AT length compositions.

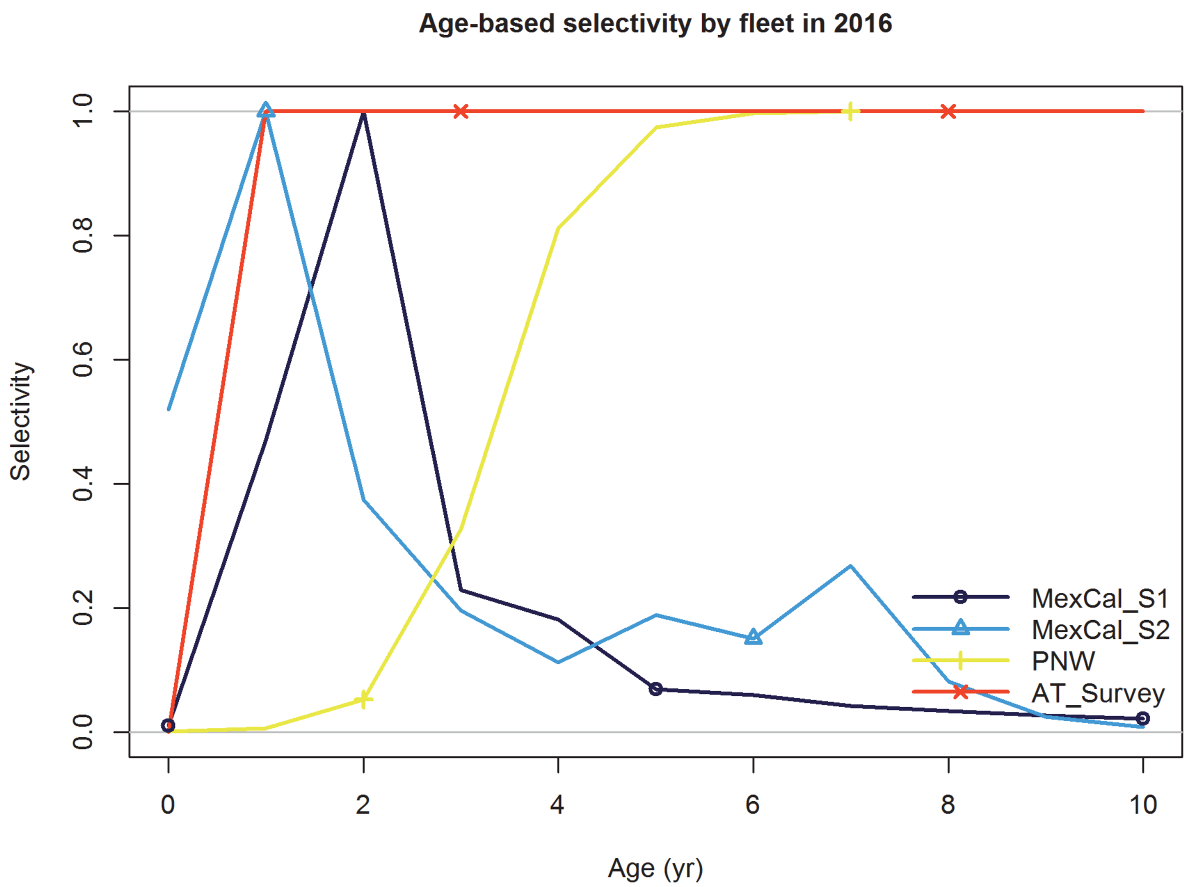


Figure 22. Age-selectivity patterns for model ALT.

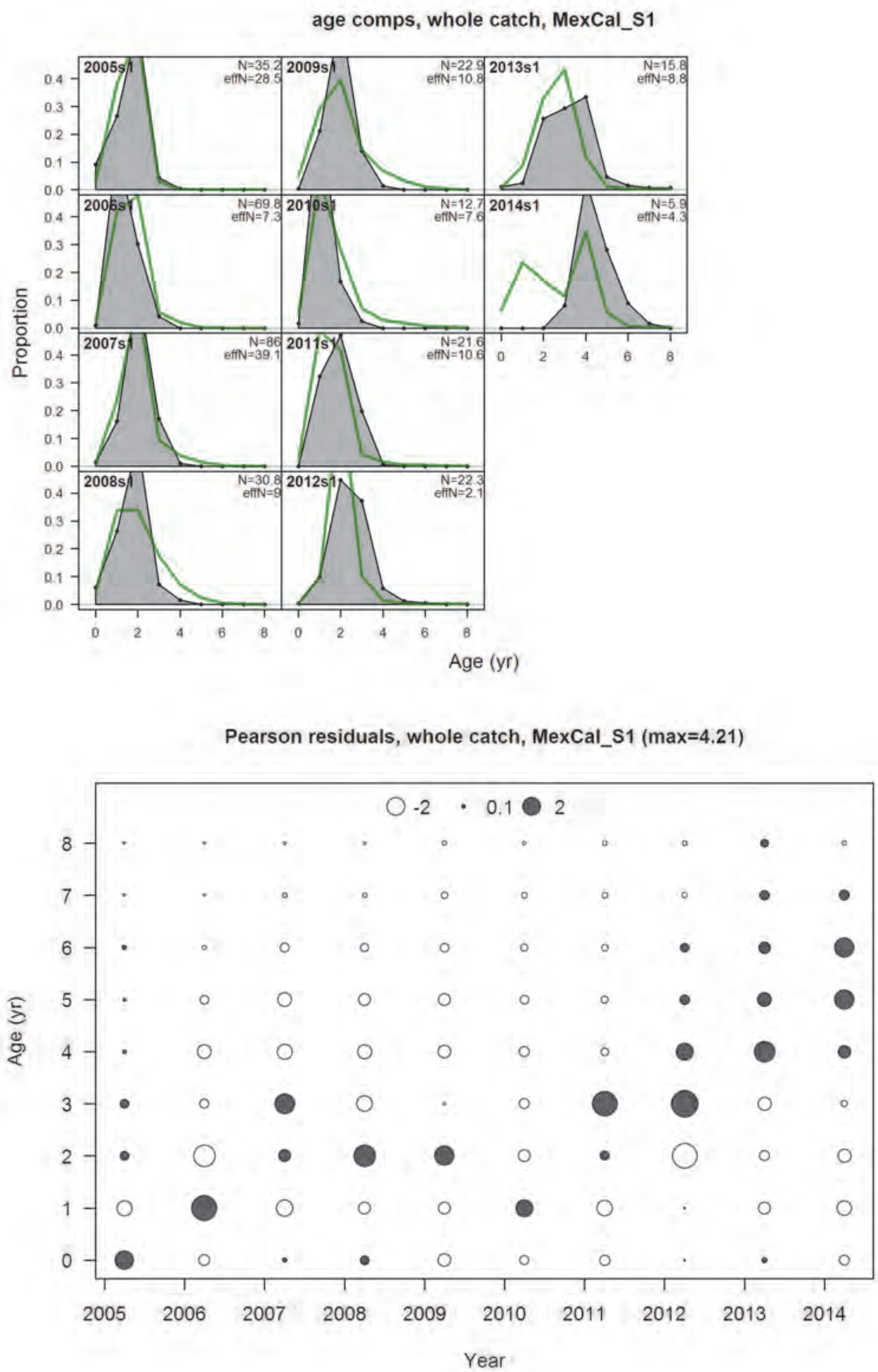
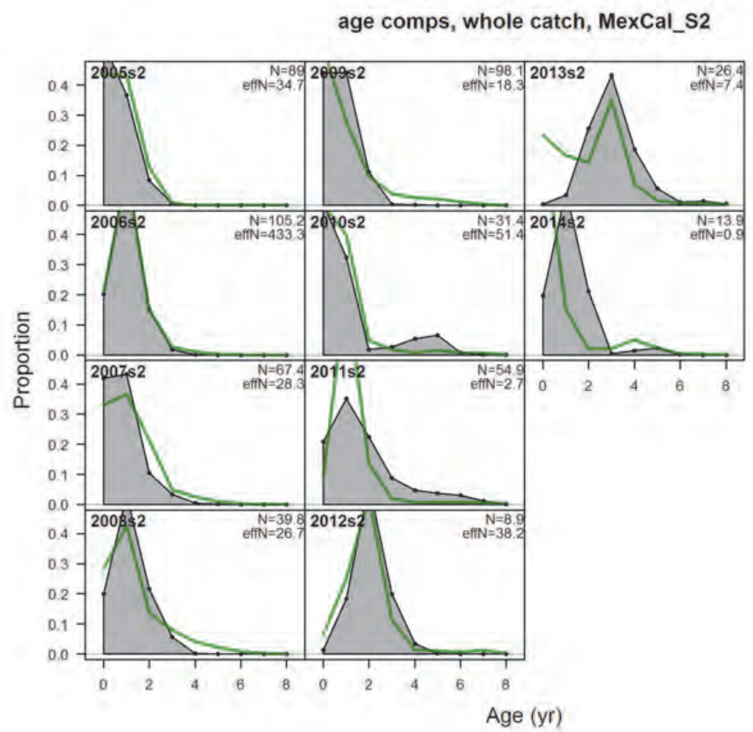


Figure 23. . Fit to age-composition time series and residual plot for the MEXCAL_S1 fleet in model ALT. N represents input sample sizes and effN is the effective sample size given overall statistical fit in the model.



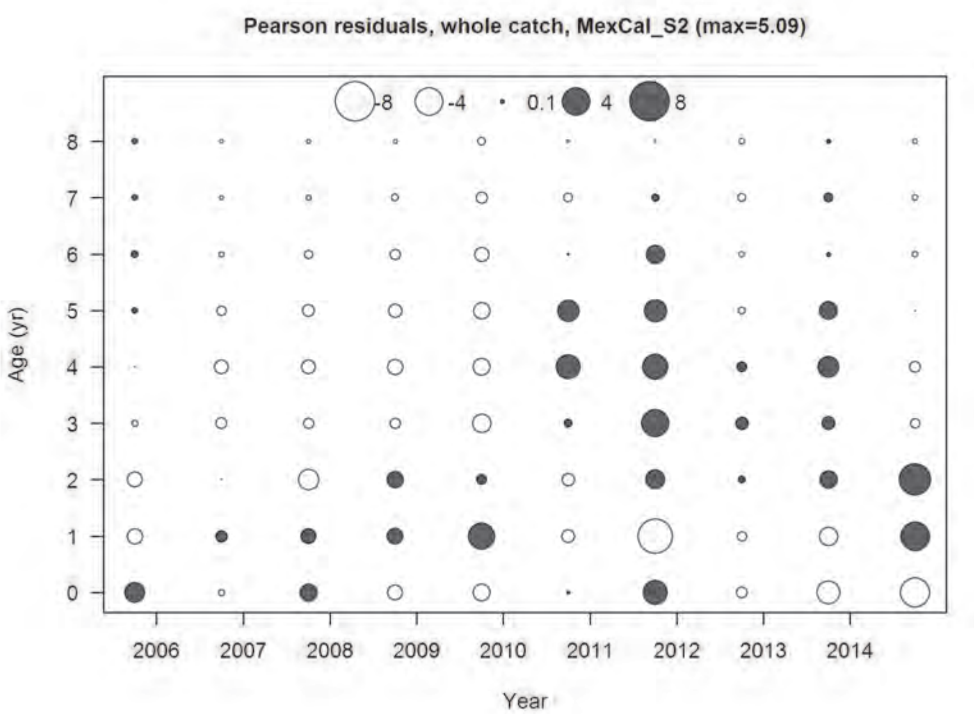


Figure 24. Fit to age-composition time series and residual plot for the MEXCAL_S2 fleet in model ALT. N represents input sample sizes and effN is the effective sample size given overall statistical fit in the model.

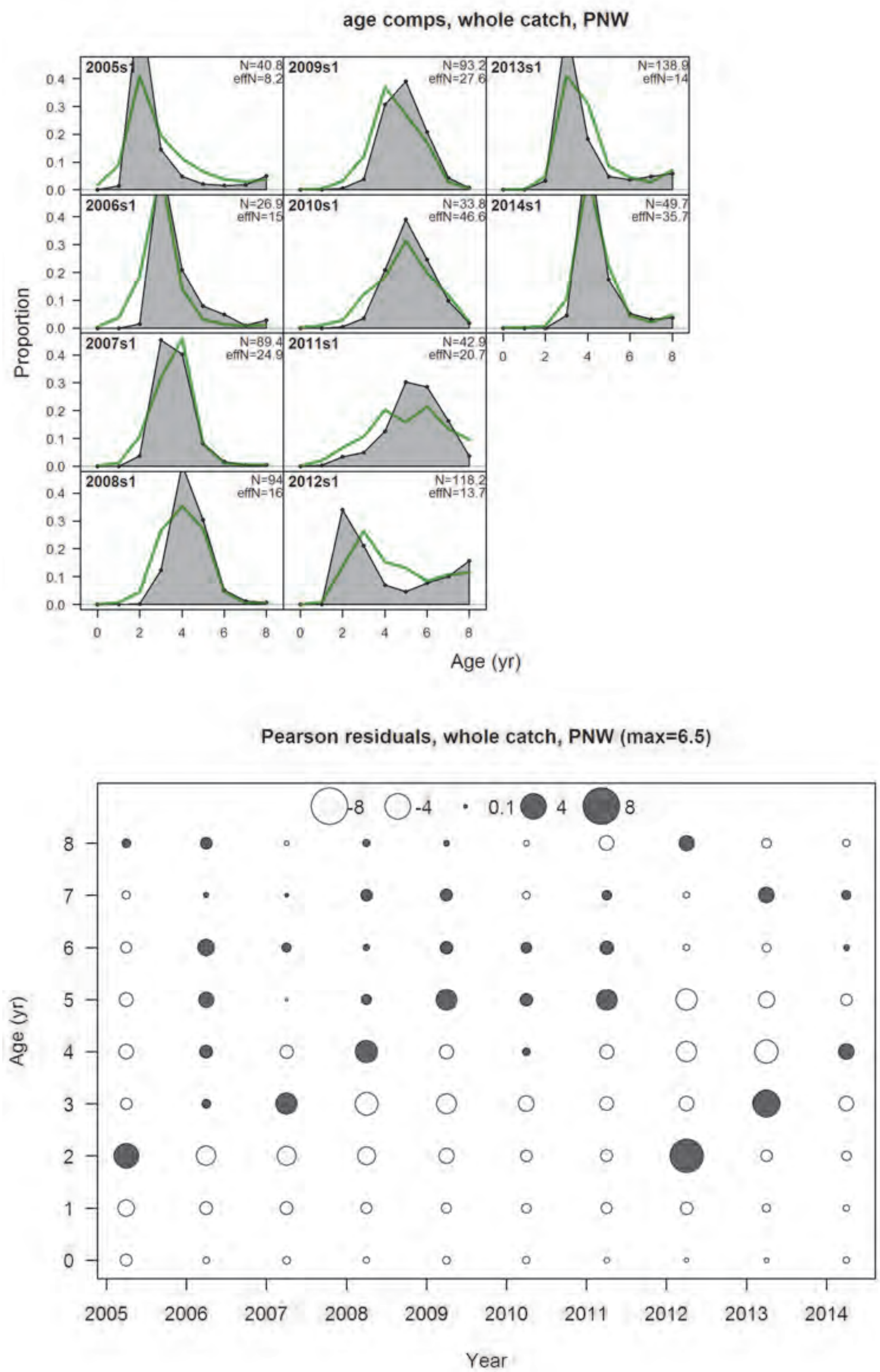
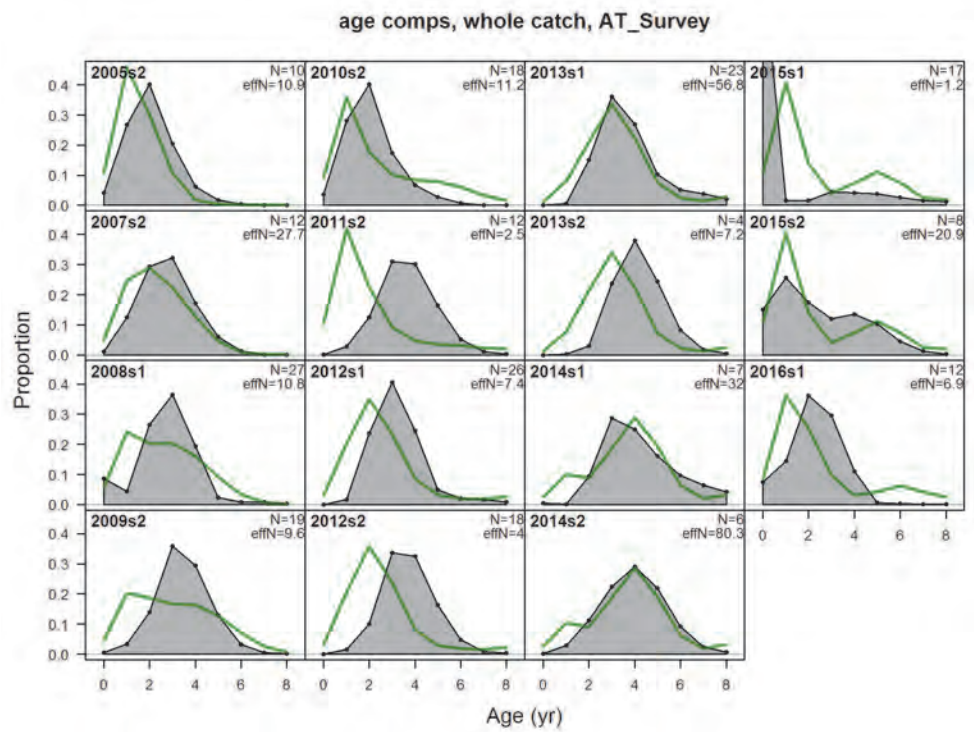


Figure 25. Fit to age-composition time series and residual plot for the PNW fleet in model ALT. N represents input sample sizes and effN is the effective sample size given overall statistical fit in the model.



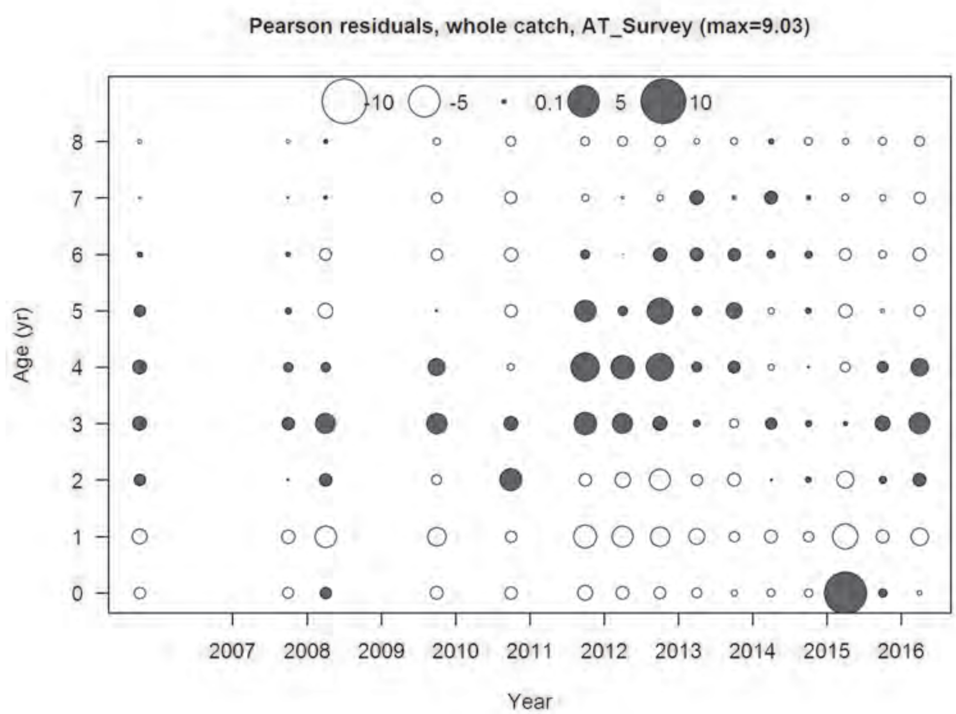


Figure 26. Fit to age-composition time series and residual plot for the AT survey for model ALT. N represents input sample sizes and effN is the effective sample size given overall statistical fit in the model.

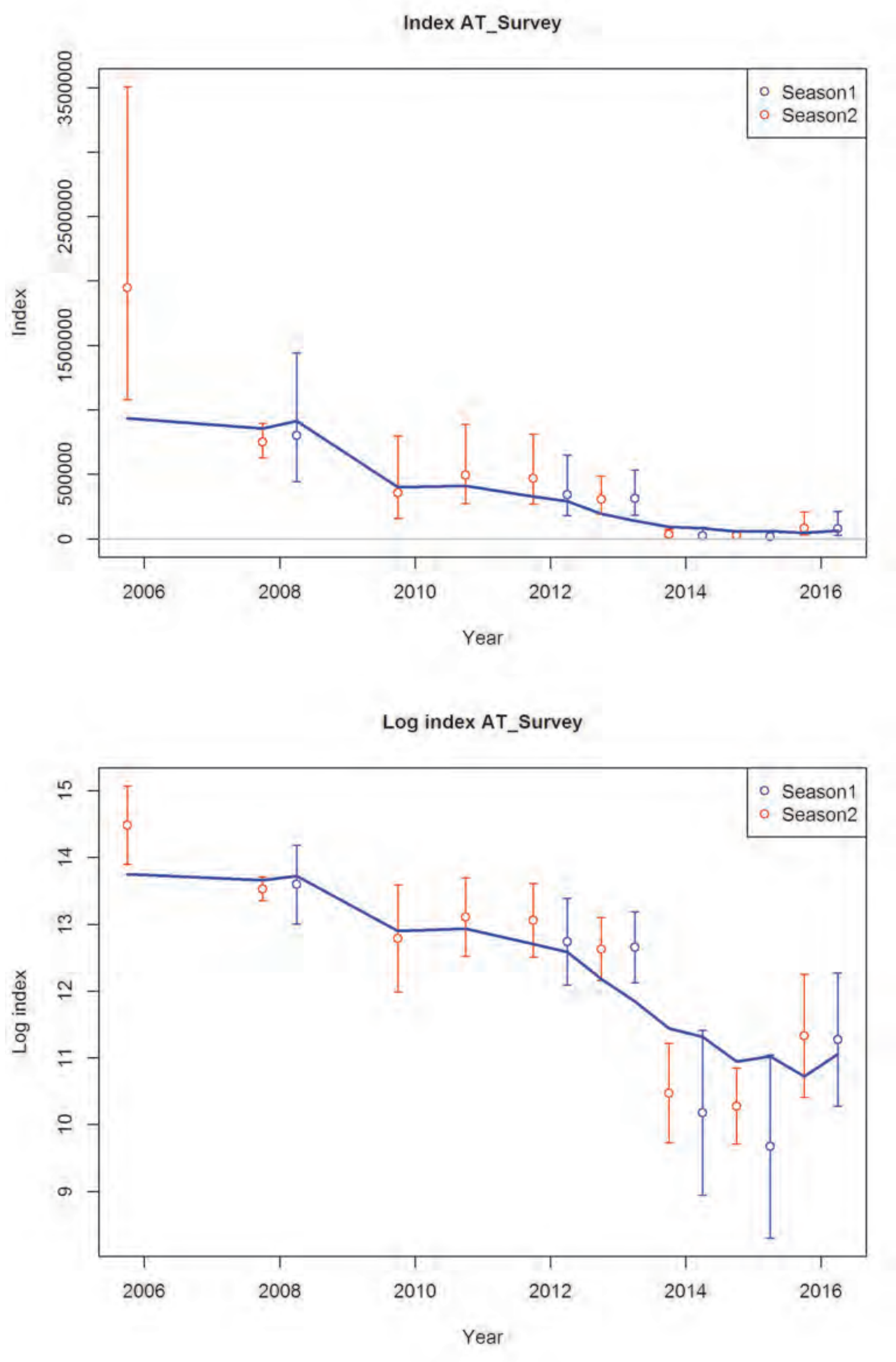


Figure 27. Fit to the AT survey abundance index in arithmetic (upper panel) and log (lower panel) scales for model ALT. *Q*=1.1 (estimated).

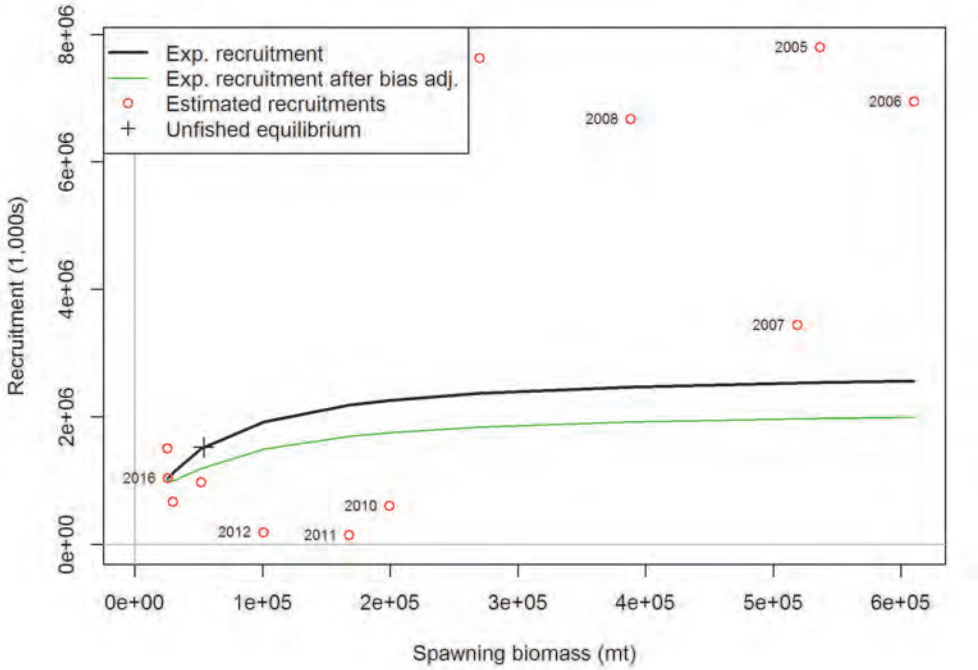


Figure 28. Estimated stock-recruitment (Beverton-Holt) relationship for model ALT. Steepness is estimated (h=0.36). Year labels represent year of SSB producing the subsequent year class.

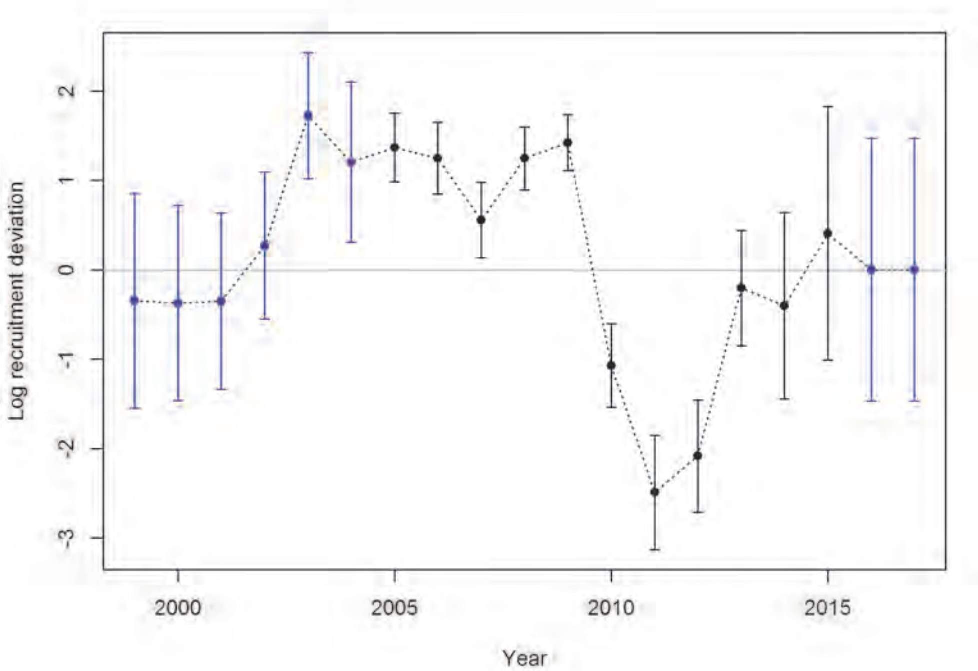


Figure 29. Recruitment deviations and standard errors (σ_R = 0.75) for model ALT. Year labels represent year of SSB producing the subsequent year class.

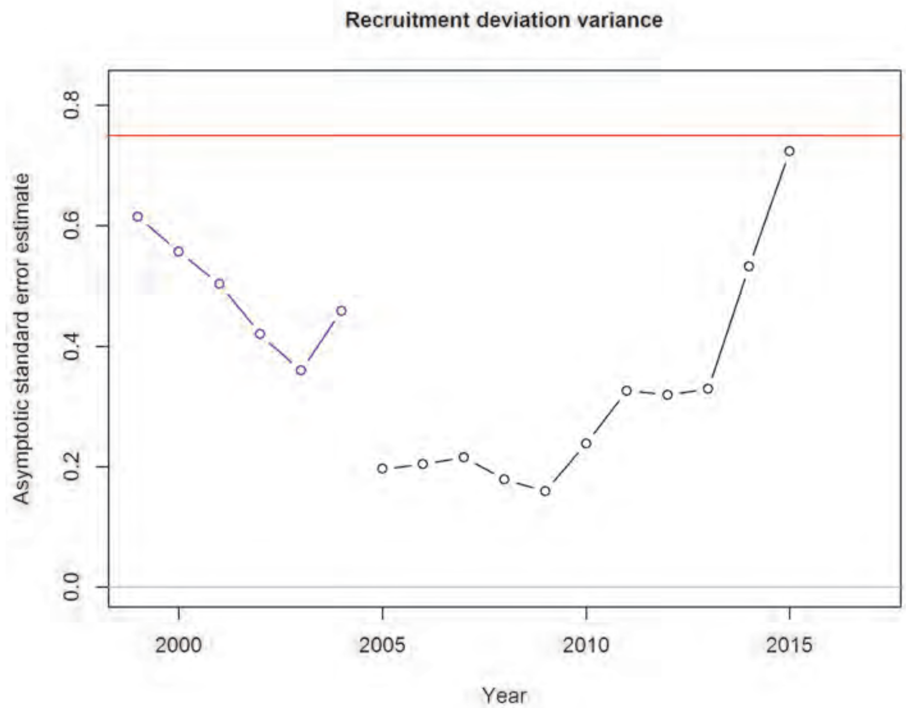


Figure 30. Asymptotic standard errors for estimated recruitment deviations for model ALT.

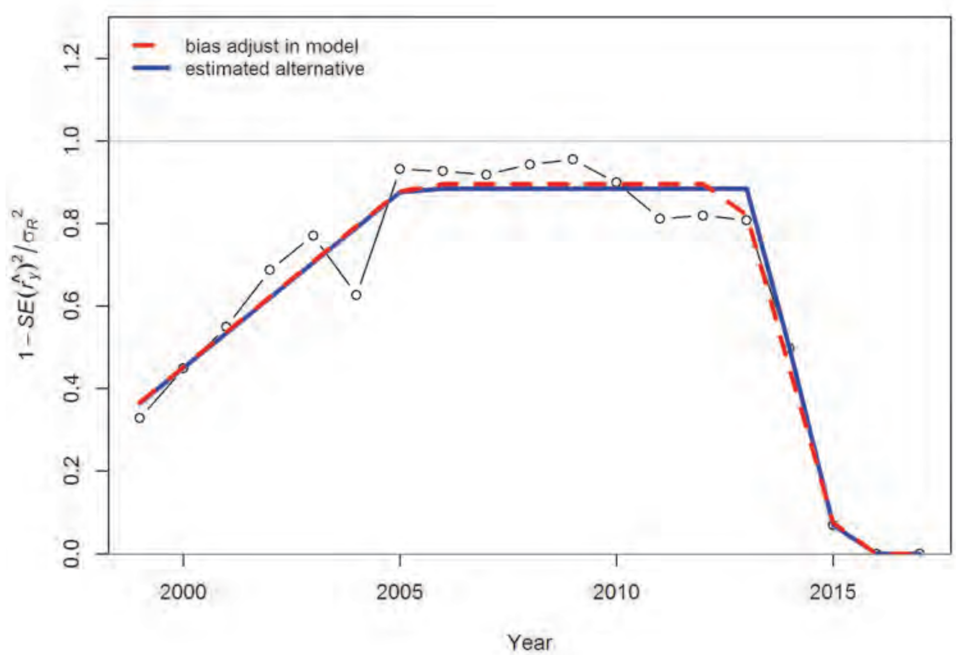


Figure 31. Recruitment bias adjustment plot for early, main, and forecast periods in model ALT.

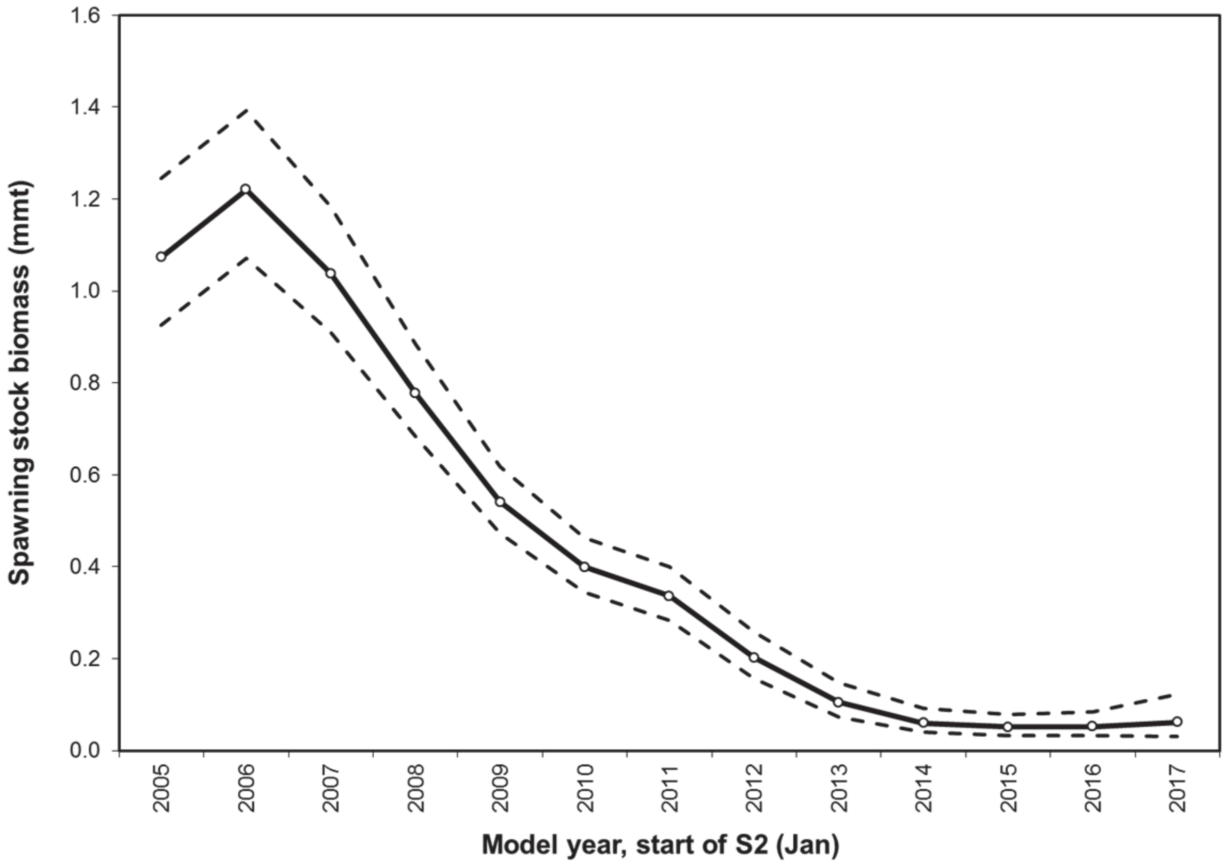


Figure 32. Spawning stock biomass time series (±95% CI) for model ALT.

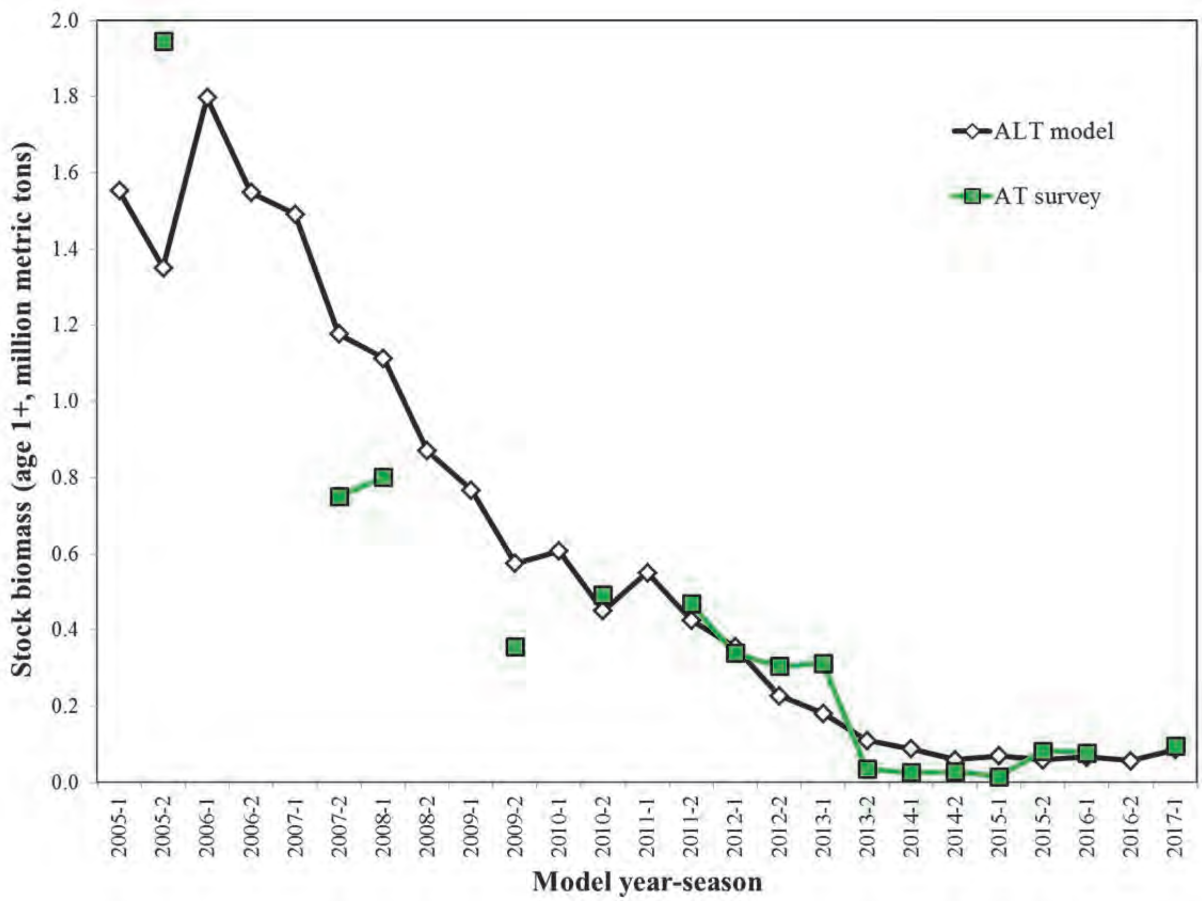


Figure 33. Estimated stock biomass (age 1+ fish, mt) time series for the AT survey and model ALT.

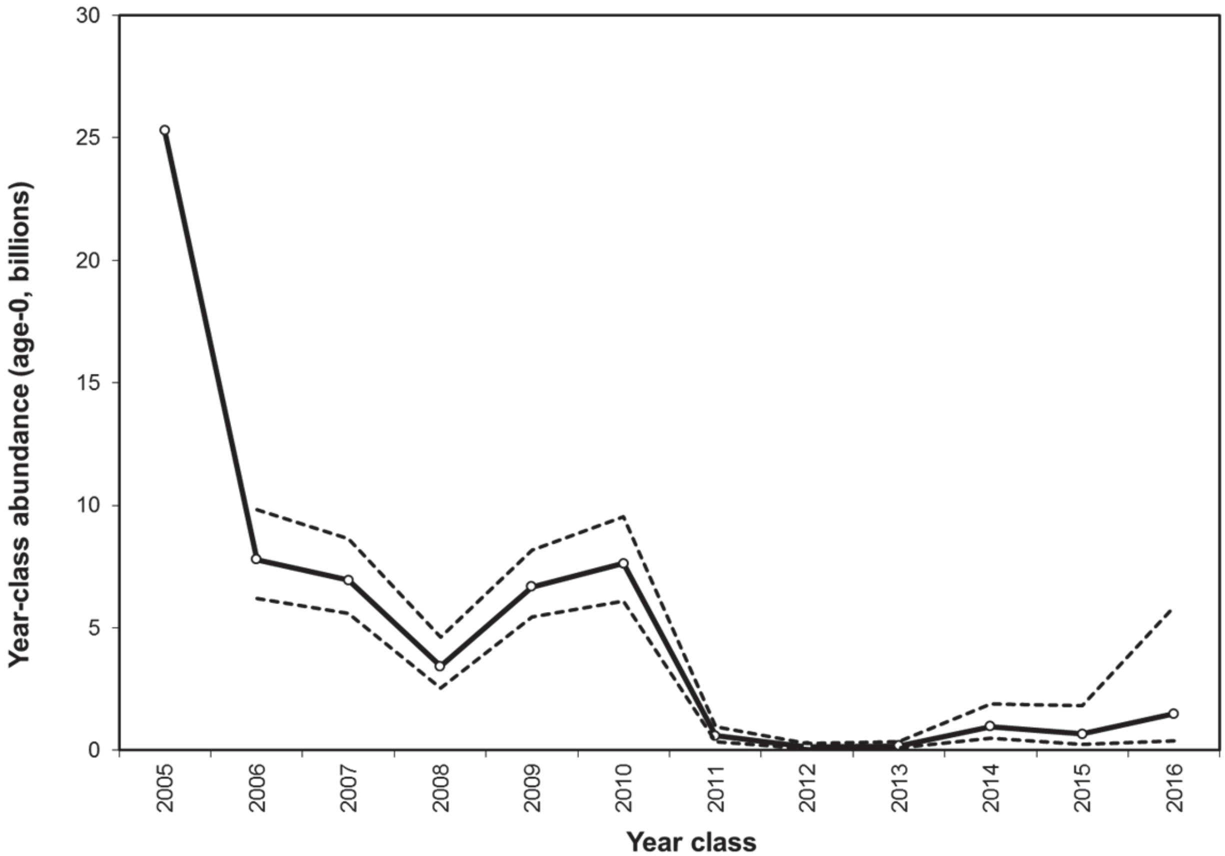


Figure 34. Recruit (age-0 fish, billions) abundance time series (±95% CI) for model ALT.

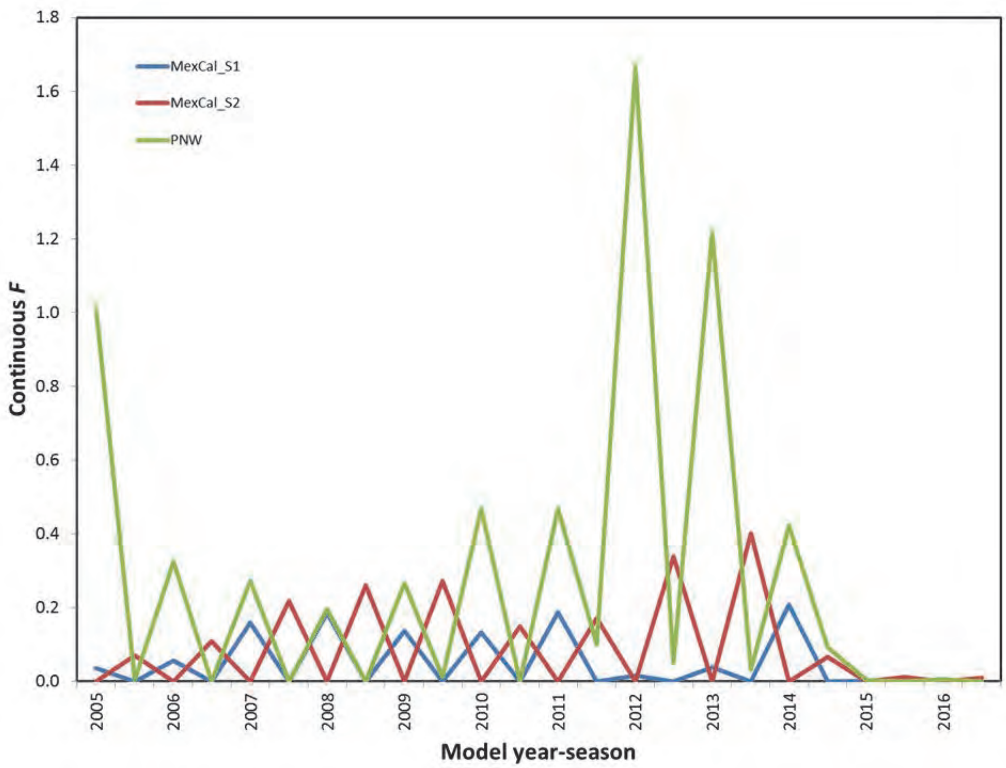


Figure 35. Instantaneous fishing mortality (apical *F*) time series for model ALT. Note that high *F* values for the PNW fleet reflect rates for fishes ages 6 and older.

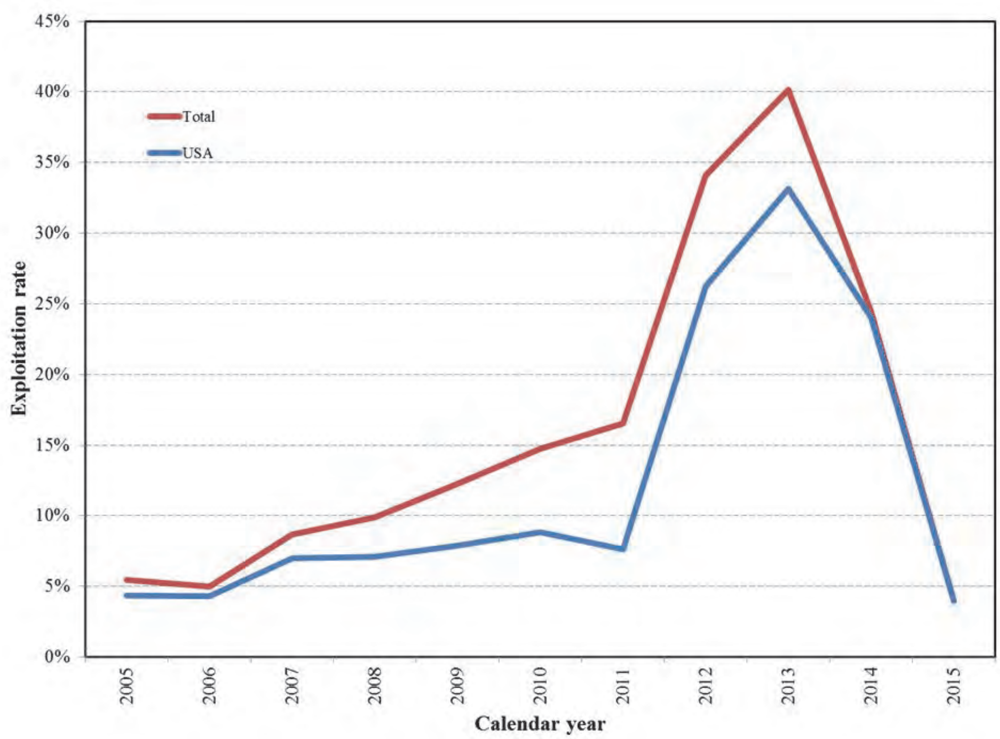


Figure 36. Annual exploitation rate (CY landings / July total biomass) for model ALT.

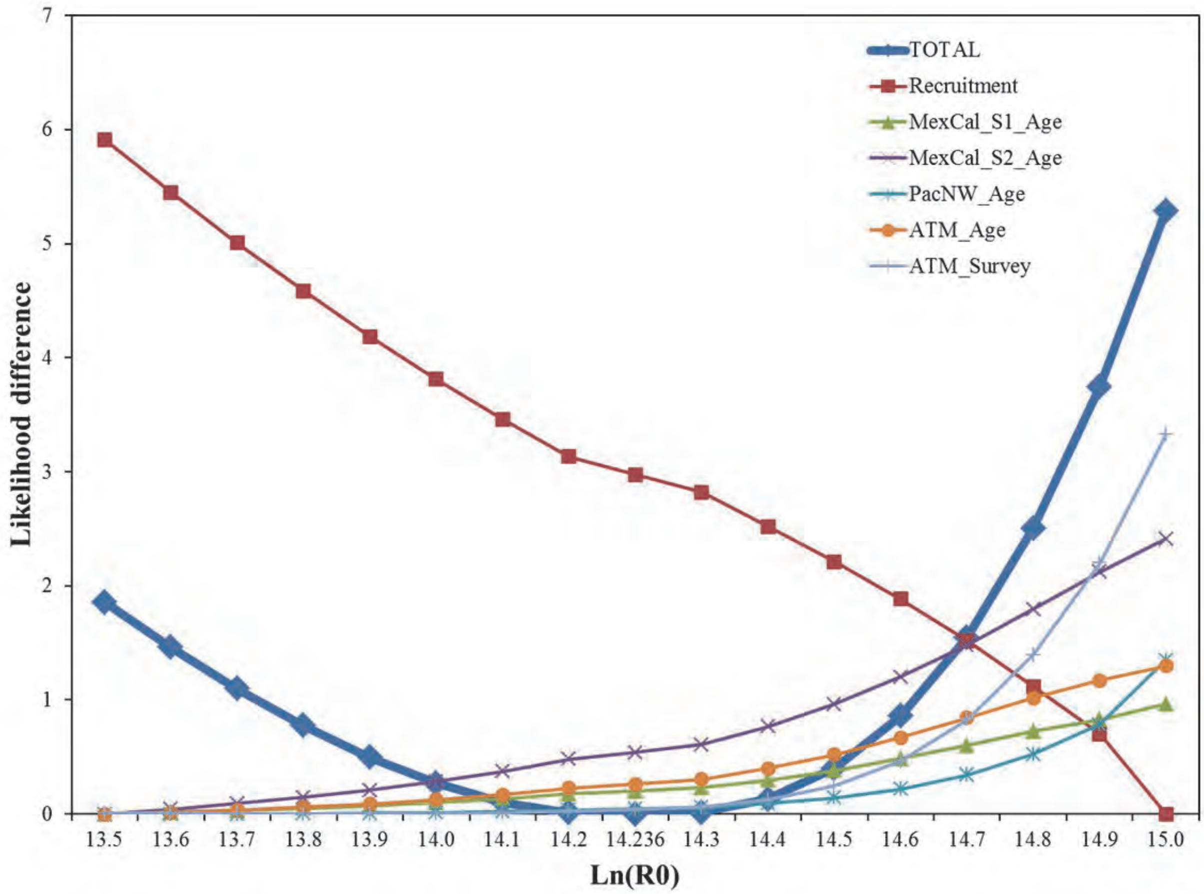
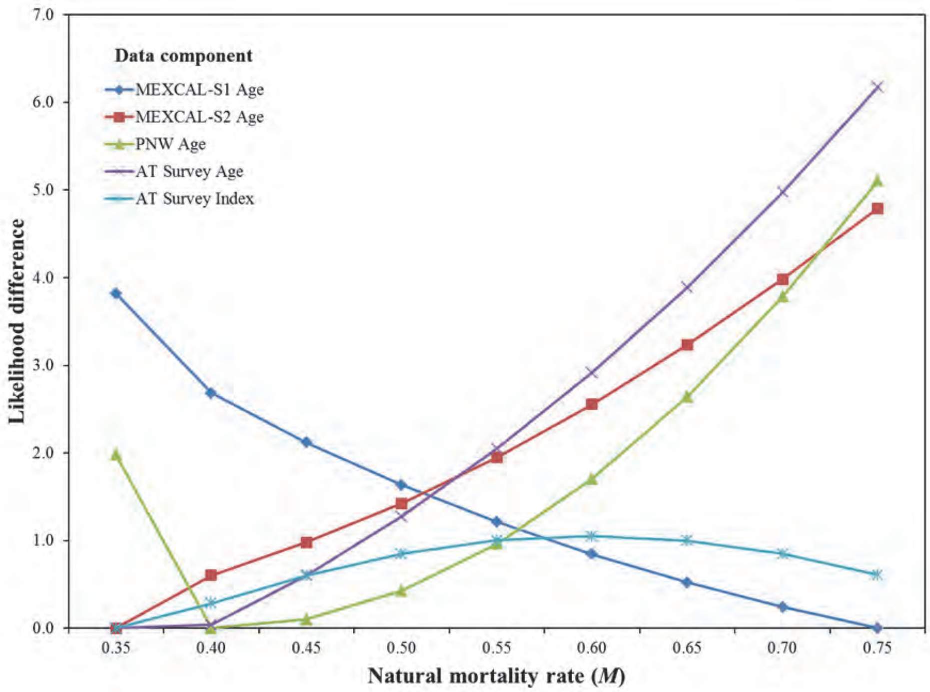


Figure 37. Virgin recruitment (logR_0) profile and associated difference in likelihood estimates for data components, recruitment, and total in model ALT.



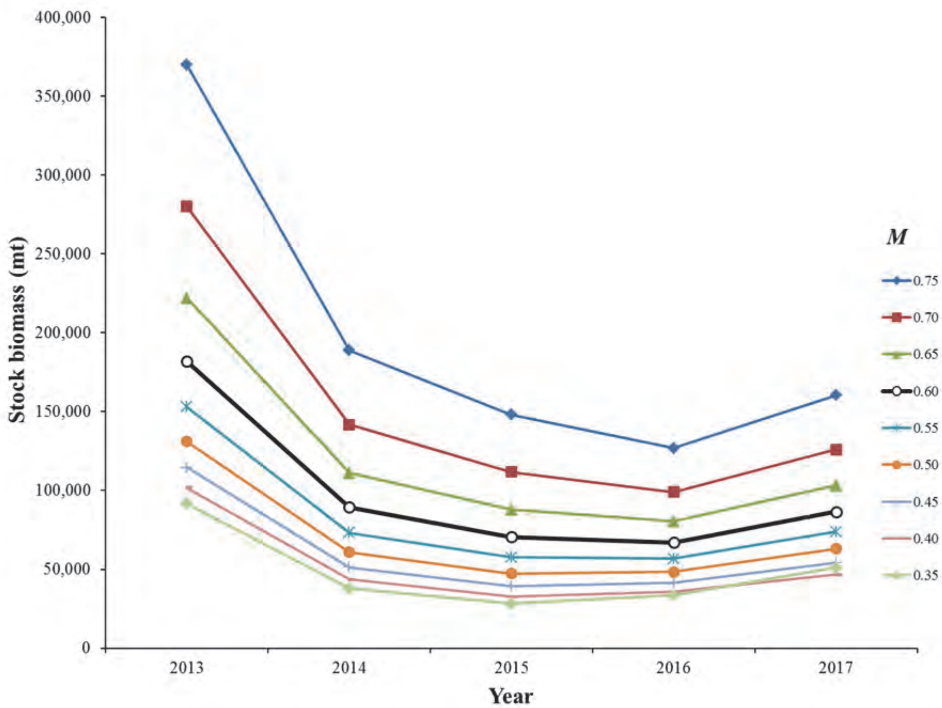


Figure 38. Likelihood differences (upper) and estimated stock biomass (age 1+, mt) for recent years (2014-17) (lower) associated with a range of fixed natural mortality values (M=0.35-0.75 yr^{-1}).

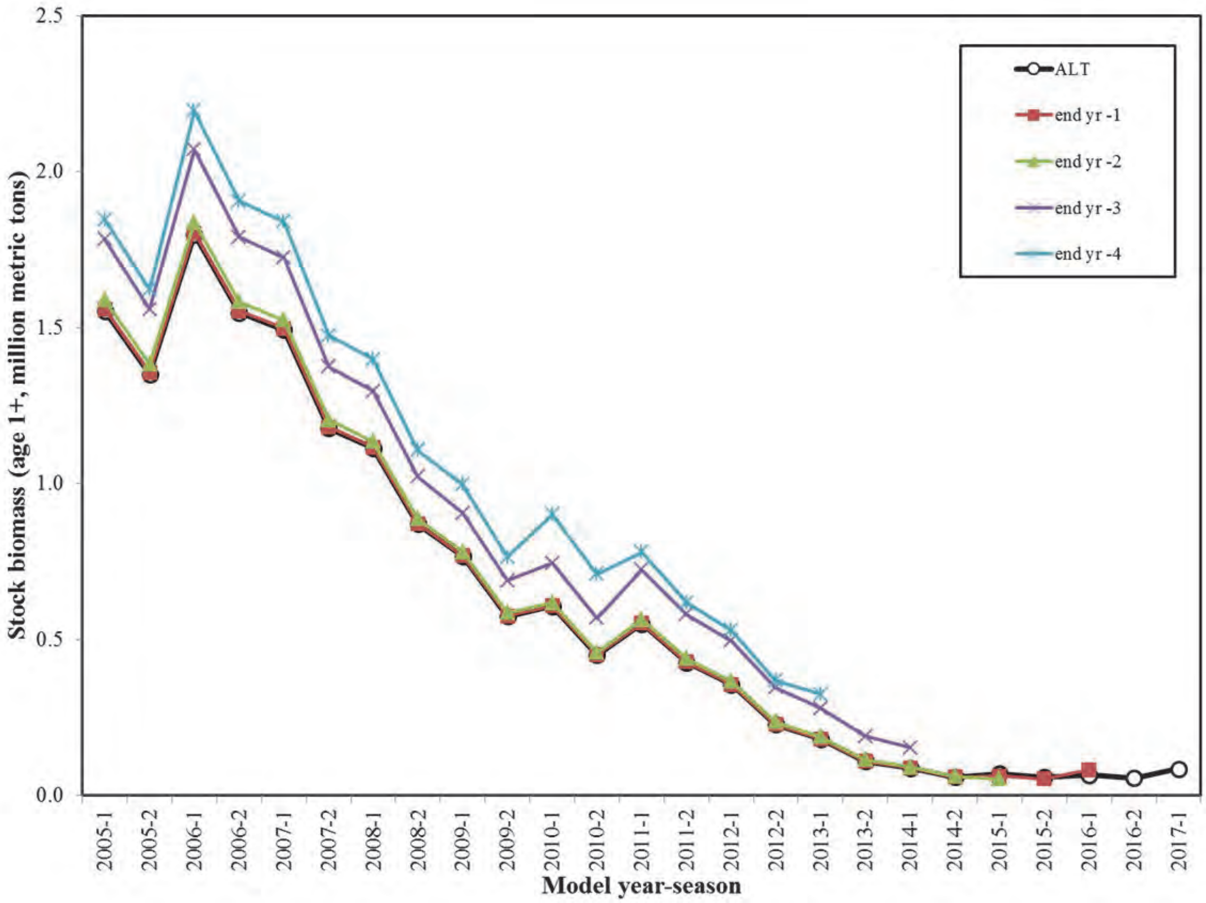


Figure 39. Retrospective analyses of stock biomass (age 1+) for model ALT.

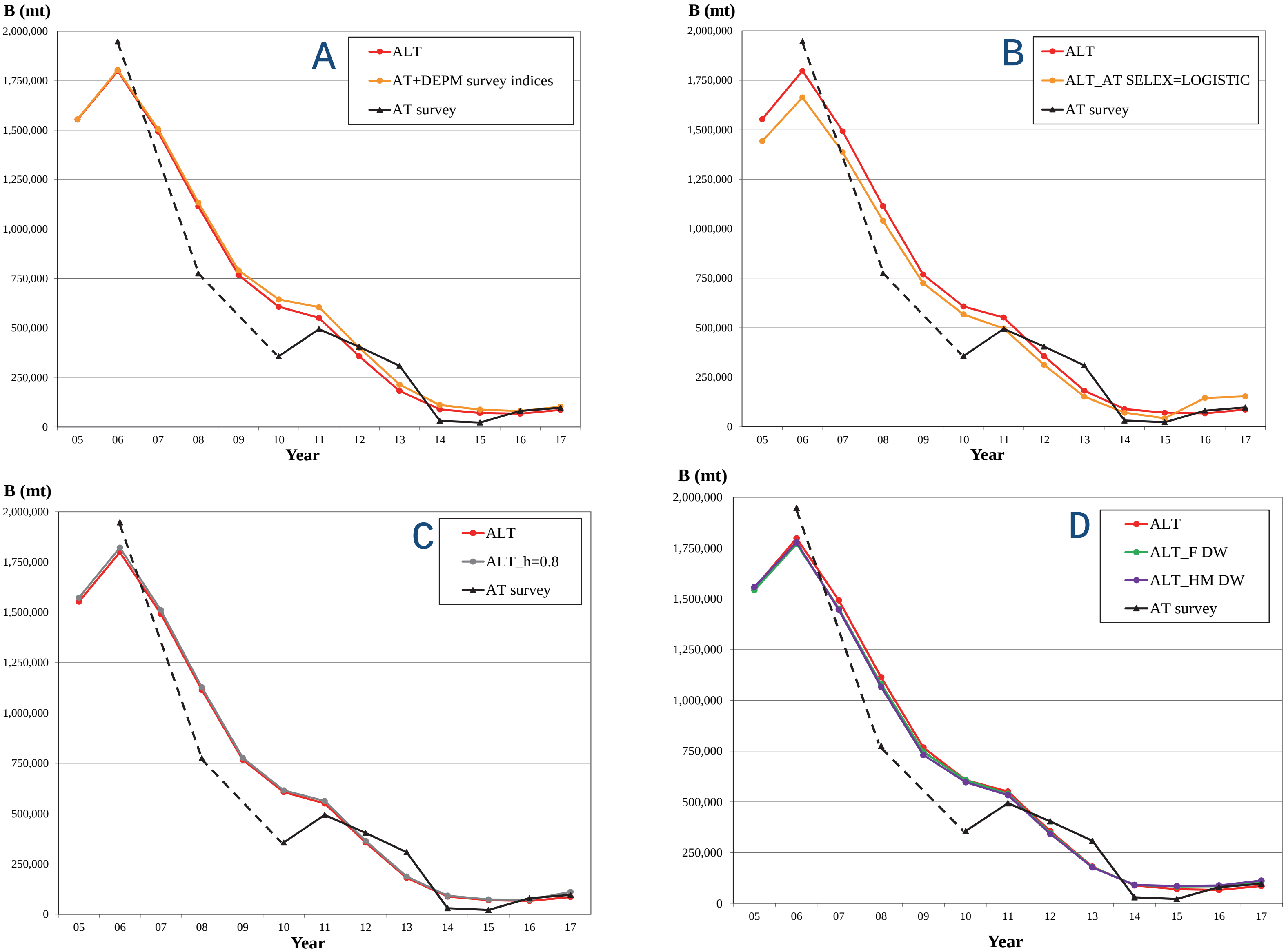


Figure 40. Estimated stock biomass (age-1+ fish, mt) time series associated with sensitivity analysis for model ALT: A) model ALT vs. model ALT (including DEPM abundance index); B) model ALT vs. model ALT (including 2-parameter logistic selectivity for the AT survey); C) model ALT vs. model ALT (including steepness fixed, *h*=0.8); and D) model ALT vs. model ALT (including Francis and harmonic mean data weighting methods). The estimated stock biomass time series for the AT survey is also presented in each display.

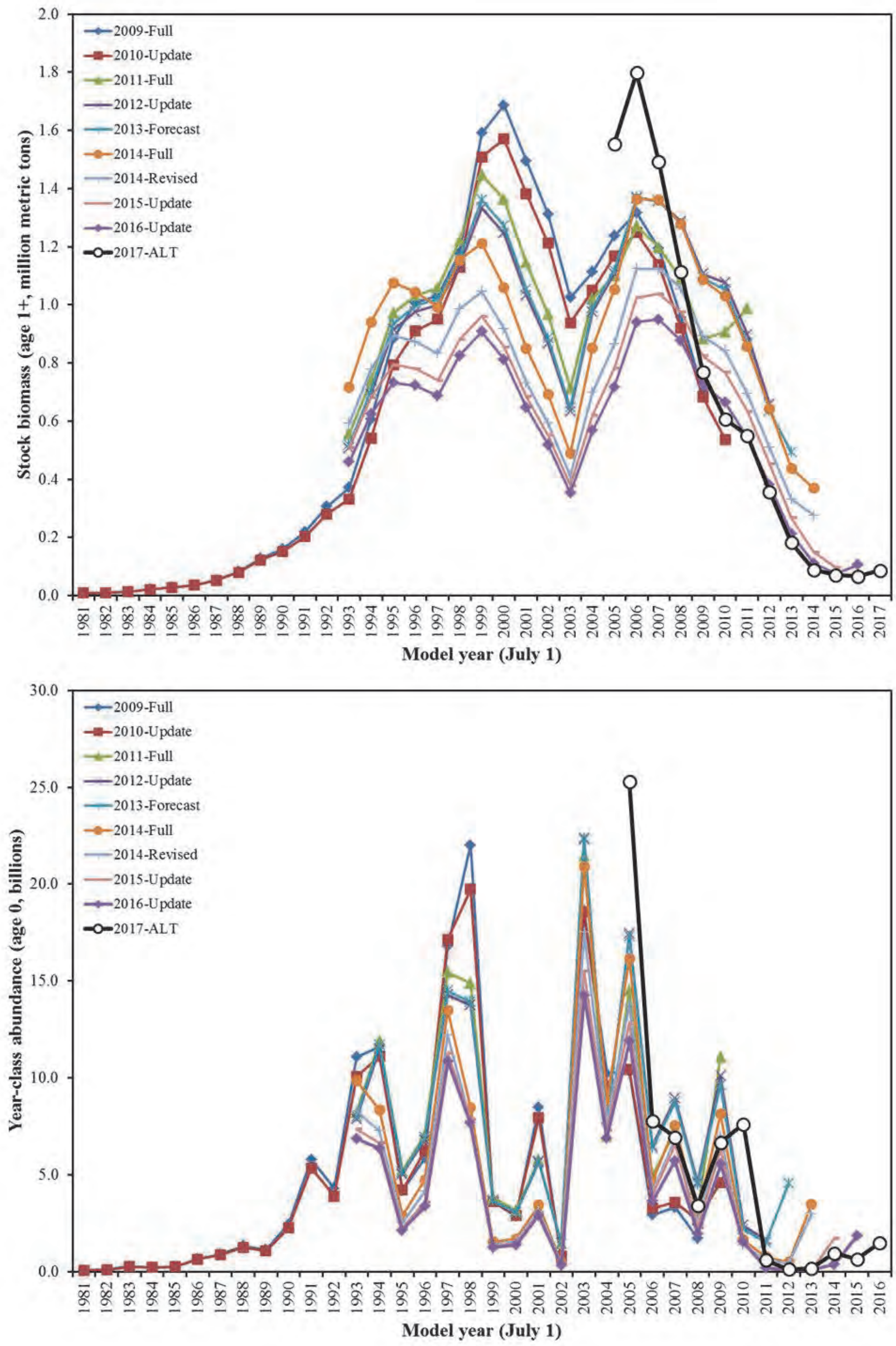


Figure 41. Estimated stock biomass (age 1+ fish, mt, upper panel) and recruitment (lower panel) time series for model ALT and past assessment model used for management.

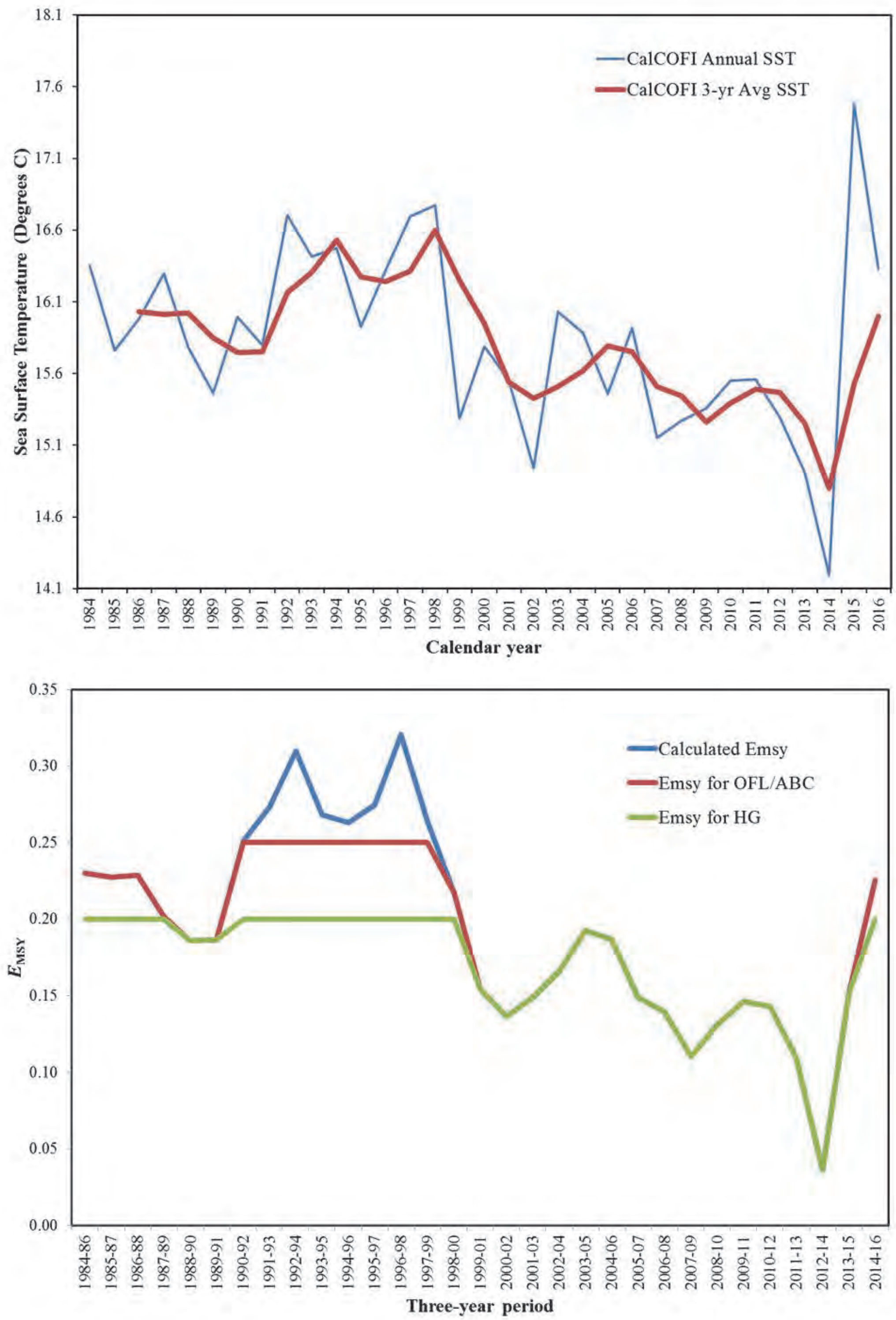


Figure 42. CalCOFI sea surface temperatures (SST, °C, upper panel) and calculated E_{MSY} values (lower panel).

APPENDICES

APPENDIX A

SPAWNING BIOMASS OF PACIFIC SARDINE (*SARDINOPS SAGAX*) ESTIMATED FROM THE DAILY EGG PRODUCTION METHOD OFF THE U.S. WEST COAST IN 2016 (SUMMARY)

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[1]Southwest Fisheries Science Center, La Jolla Laboratory
[2]Ocean Associates contractor at Southwest Fisheries Science Center

From 1994 to 2013 DEPM and TEP estimates of SSB were based on SWFSC ship-based surveys conducted each April between San Diego and San Francisco, California (i.e. standard DEPM area), although in some years the surveys were extended as far north as Washington. In 2015 the survey was mostly north of the standard DEPM area and in 2016 it was completely north of this region. Therefore, in both years the SSB estimate was based on the whole DEPM survey area. The DEPM index of female SSB is used when data for eggs, larvae and adult daily-specific fecundity are available from the survey. The total egg production (TEP) index of SSB is used when survey-specific adult reproductive data are unavailable. The DEPM and TEP series have been used for sardine stock assessment since the 1990s, and the surveys and estimation method were reviewed by a STAR Panel in May 2009. Both time series are treated as indices of relative SSB, with catchability coefficients (q) being estimated (Figure 1).

In 2016 the SWFSC conducted the sardine DEPM biomass survey aboard the NOAA ship *Rueben Lasker* (March 22 – April 22) from about Lincoln Beach, Oregon (44.85°N) to north of Muir Beach, California (ending at 37.84°N on CalCOFI line 56.7) (Figure 1). The spring CalCOFI survey was conducted on the NOAA Ship *Bell M. Shimada* (April 1 – April 22) from San Diego to San Francisco Bay. However, data from the CalCOFI survey were not used because no trawling was conducted. Further, during CalCOFI no eggs were collected from CalVET tows, one egg was caught in Bongo tows, and no larvae were collected in both nets (Table 1). Consequently, only data from the DEPM survey on the *Lasker* were included in the estimation of spawning biomass of Pacific sardine. The DEPM survey from the *Lasker* employed all the usual methods for estimating sardine SSB (Lo et al. 2010), but sampling was performed outside of the standard DEPM area (Figure 1).

The 2016 sardine DEPM survey was initially designed with thirty five distinct transects in which eighteen were compulsory and seventeen were adaptive, covering the area from Newport, Oregon to Point Conception, California. The compulsory transects were positioned at forty nautical mile intervals and when adaptive transects were occupied, the spacing between transects was reduced to twenty nautical miles. Similar to the 2015 survey, the Zwolinski et al. (2011)'s habitat model forecast for April 2016 was used to determine potential optimal habitat of sardine and sampling frame of the survey. Since the northern extent of the population was not known, the ship traveled northward and began sampling on the second compulsory line (located at 43.9°N) from the northern most pre-determined transect. Because Pacific sardine eggs were encountered during operations on this transect, the ship continued sampling north until no eggs were encountered, which extended the last northern line to a position just off Lincoln Beach, Oregon. Hence, the whole DEPM survey area was located between 44.85°N and 37.84°N (Figure 1) and effectively occupied 11 compulsory and 5 adaptive lines from the north to the south. Transect spacing was reduced, as much as 20 nautical mile, whenever sardine eggs, larvae or fish were encountered. In areas with no observed eggs, fish or larvae, transect spacing was increased as much as forty nautical miles to save time and cover a broader area of the coast.

The 2016 DEPM index area for the entire survey (44.85°N latitude to CalCOFI line 56.7) was 133,489 km^2 (Figure 1). The egg production (P_0) estimate was 0.54/0.05m^2/day (CV = 0.56) in the high egg-density region and 0.07/0.05 m^2/day (CV = 0.58) for the whole survey area. These areas were computed after a 2.5 nautical mile expansion (i.e. half of the distance between CUFES samples) from survey line or station (see Dorval et al. 2017). Female spawning biomass for the whole survey area was taken as the sum of female spawning biomasses in Regions 1 and 2 (Table 2). The female spawning biomass (sum) and total spawning biomass for the DEPM whole survey area were estimated to be 5,929 mt (CV = 0.58) and 9,536 mt (CV = 0.59), respectively (Table 2).

Adult reproductive parameters for the 2016 whole survey area are presented in Table 3. The estimated daily-specific fecundity was 20.07 (number of eggs/population weight (g)/day) using the following estimates of reproductive parameters from 71 mature females collected from 6 positive trawls: mean batch fecundity (F) was 34,327 eggs/batch (CV = 0.15), fraction spawning (S) was 0.145 females spawning per day (CV = 0.20), mean female fish weight (W_f) was 148.03 g (CV = 0.098), and sex ratio of females by weight (R) was 0.598 (CV = 0.13). Since 2005, trawling has been conducted randomly or at CalCOFI stations, which resulted in sampling adult sardines in both high (Region 1) and low (Region 2) sardine egg-density areas. During the 2016 survey, 3 tows were positive for mature female sardines in Region 1 and 3 in Region 2. Additionally, during the survey one tow caught solely males and nine tows caught only immature sardines (Dorval et al. 2016). Further, batch fecundity was predicted from a regression model using data collected from the 2016 survey.

In SS, the DEPM series was taken to represent female SSB (length selectivity option ’30’) in the middle of S2 (April). Since 2009, the time series of spawning biomass was replaced by female spawning biomass for years when sufficient trawl samples were available and the total egg production for other years as inputs to the stock assessment of Pacific sardine. The 2016 DEPM estimate is much lower than in the previous few years (Tables 2 & 3; Figure 1), potentially due to: 1) continuing decline in spawning stock biomass since 2011; 2) the shift of the high egg-density area to off Oregon, a less suitable spring spawning habitat; and 3) the trawl catches were mostly dominated by young, small and immature sardines which were not producing eggs.

Table 1. Number of positive tows of sardine eggs from CalVET, yolk-sac larvae from CalVET and Bongo, eggs from CUFES and positive sardine trawls[a] in Region 1 (high, eggs/min ≥ 0.2), Region 2 (low, eggs/min < 0.2) for the *Reuben Lasker* Sardine DEPM survey in spring 2016 and the *Bell M. Shimada* CalCOFI survey. The *Lasker* whole DEPM survey area (133,488 km^2, between latitudes 44.85°N and 37.84°N) from about Lincoln Beach, Oregon to CalCOFI line 56.7 (Muir Beach, California) was all north of the standard DEPM area (CalCOFI line 60.0 to 95.0).

Gear	Tows and Sampling type	CalCOFI	DEPM		
		April 1-22, 2016 *Bell M. Shimada*	March 26 – April 22, 2016 *Reuben Lasker*		
			Region 1	Region 2	Whole
CalVET (Pairovet)	Total tows	87	18	43	61
	Total positive tows	0	10	6	16
	Positive egg tows	0	10	2	12
	Eggs	0	31	41	72
	Positive larvae tows	0	2	5	7
	Yolk sac larvae	0	9	32	41
BONGO	Total tows	101	9	47	56
	Total positive tows	3	3	21	24
	Positive egg tows[b]	1	2	4	6
	Eggs[b]	1	21	67	88
	Positive larvae tows	2	3	21	24
	Yolk sac larvae	0	149	371	520
CUFES	Total samples	577	60	274	334
	Positive samples	9	39	15	54
	Eggs	15	448	32	480
Trawl	Total tows	n/a	6	35	41
	Total positive tows		3	13	16
	Total sardine		212	276	488
	Female sardine		105	107	212
	Area in km^2	354,032	12,778	120,710	133,488

[a] All sardines were captured at night; 10 trawls in Region 2 caught only male or immature sardines.
[b] Egg data from the Bongo net are not used in the daily egg production (P_0) estimation.
[c] Total sardine were those sampled and measured: including males, females, and those of unknown sex
[d] Female sardine were those sampled and measured: including mature and immature.

Table 2. The spawning biomass related parameters: daily egg production/0.05m^2 (P_0),daily mortality rate (z), survey area (km^2), two daily specific fecundities: (RSF/W), and (SF/W); s. biomass, female spawning biomass, total egg production (TEP) and sea surface temperature for 1986, 1987, 1994, 2004, 2005 and 2007-2016.

Calendar Year	Month	Region	[1]P_0/0.05m^2 (cv)	Z (CV)	[2]RSF/W based on S_1	[3]RSF/W based on S_{12}	[3]FS/W based on S_{12}	[4]Area (km^2)	[5]S. biomass (cv)	S. biomass females (cv)	S. biomass females (Sum of R1andR2) (cv)	Total egg production (TEP)	Mean temperature (°C) for positive eggs	Mean temperature (°C) from Calvet
1986	Aug.	[6]S	1.48(1)	1.59(0.5)	38.31	43.96	72.84	6478	4362 (1.00)	2632 (1)		9587.44		
		N	0.32(0.25)		8.9	13.34	23.89	5333	2558 (0.33)	1429 (0.28)		1706.56		
		whole	0.95(0.84)		23.61	29.89	49.97	11811	7767 (0.87)	4491 (0.86)	4061 (0.66)	11220.45	18.7	18.5
1987	July	1	1.11(0.51)	0.66(0.4)	38.79	37.86	57.05	22259	13050 (0.58)	8661 (0.56)		24707.49		
		2	0					15443	0	0		0		
		whole	0.66(0.51)		38.79	37.86	57.05	37702	13143 (0.58)	8723 (0.56)	8661 (0.56)	25637.36	18.9	18.1
1994	April	1	0.42(0.21)	0.12(0.91)	11.57	11.42	21.27	174880	128664 (0.30)	69065 (0.30)		73449.6		
		2	0(0)	-				205295	0	0		0		
		whole	0.193(0.21)		11.57	11.42	21.27	380175	128531 (0.31)	68994 (0.30)	69065 (0.30)	73373.775	14.3	14.7
2004	April	1	3.92(0.23)	0.25(0.04)	27.03	26.2	42.37	68204	204118 (0.27)	126209 (0.26)		267359.68		
		2	0.16(0.43)		-	-	-	252416	30833 (0.45)	19065 (0.44)		40386.56		
		whole	0.96(0.24)		27.03	26.2	42.37	320620	234958 (0.28)	145297 (0.27)	145274 (0.23)	307795.2	13.4	13.7
2005	April	1	8.14(0.4)	0.58(0.2)	31.49	25.6	46.52	46203	293863 (0.45)	161685 (0.42)		376092.42		
		2	0.53(0.69)		3.76	3.2	7.37	207417	686168 (0.86)	298258 (0.89)		109931.01		
		whole	1.92(0.42)		15.67	12.89	27.11	253620	755657 (0.52)	359209 (0.50)	459943 (0.60)	486950.4	14.21	14.1
2007	April	1	1.32(0.2)	0.13(0.36)	12.06	13.37	27.54	142403	281128 (0.42)	136485 (0.36)		187971.96		
		2	0.56(0.46)		24.48	23.41	38.94	213756	102998 (0.67)	61919 (0.62)		119703.36		
		whole	0.86(0.26)		15.68	16.17	31.52	356159	380601 (0.39)	195279 (0.36)	198404 (0.31)	306296.74	13.7	13.6
2008	April	1	1.45(0.18)	0.13(0.29)	57.4	53.89	68.54	53514	29798 (0.20)	22642 (0.19)		77595.3		
		2	0.202(0.32)		13.84	12.6	22.57	244435	78359 (0.45)	43753 (0.42)		49375.87		
		whole	0.43(0.21)		21.82	20.31	32.2	297949	126148 (0.40)	79576 (0.35)	66395 (0.28)	128118.07	13.1	13.1
2009	April	1	1.76(0.22)	0.25(0.19)	19.50	20.37	36.12	74966	129520 (0.31)	73048 (0.29)		131940.16		
		2	0.15(0.27)		14.25	14.34	22.97	199929	41816 (0.38)	26114 (0.38)		29989.35		
		whole	0.59(0.22)		17.01	17.53	29.11	274895	185084 (0.28)	111444 (0.27)	99162 (0.24)	162188.05	13.6	13.5

Continue
Table 2

Calendar Year	Month	Region	[1]P0/0.05m2 (cv)	Z (CV)	[2]RSF/Wb ased on S_1	[3]RSF/W based on S_{12}	[3]FS/W based on S_{12}	[4]Area (km^2)	[5]S. biomass (cv)	S. biomass females (cv)	S. biomass females (Sum of R1andR2) (cv)	Total egg production (TEP)	Mean temper-ature (°C) for positive eggs	Mean temper-ature (°C) from Calvet
2010	April	1	1.70(0.22)	0.33(0.23)	21.08	24.02	51.56	27462	38875 (0.44)	18111 (0.39)		46685.4		
		2	0.22(0.42)		14.55	16.20	26.65	244311	66345 (0.58)	40336 (0.58)		53748.42		
		whole	0.36(0.29)		16.08	18.07	31.49	271773	108280 (0.46)	62131 (0.46)	58447 (0.42)	97838.28	13.7	13.9
2011	April	1	5.57(0.24)	0.51(0.14)	19.03	24.26	41.16	41878	192332 (0.31)	113340 (0.30)		233260.5		
		2	0.487(0.33)		11.40	14.67	25.04	272603	181016 (0.48)	106046 (0.49)		132757.7		
		whole	1.16(0.26)		14.85	19.04	32.40	314481	383286 (0.32)	225155 (0.32)	219386 (0.28)	364798.0	13.5	13.6
2012	April	1	5.28 (0.27)	0.66(0.11)	17.76	19.25	42.17	32322	177289 (0.37)	80930 (0.33)		170660.16		
		2	0.24 (0.27)		15.34	14.67	35.52	238669	78102 (0.60)	32248 (0.46)		57280.56		
		whole	0.84 (0.27)		16.14	16.14	37.65	270991	282110 (0.43)	120902 (0.36)	113178 (0.27)	227632.44	13.57	13.3
2013	April	1	5.47 (0.29)	0.64(0.16)	32.35	27.41	47.91	29176	116455 (0.40)	66633 (0.36)		159592.72		
		2	0.27 (0.44)		13.20	24.71	39.00	112221	24547 (0.48)	15549 (0.49)		30299.67		
		whole	1.34 (0.299)		26.22	26.22	44.70	141397	144880 (0.36)	84972 (0.33)	82182 (0.30)	198471.98	13.51	13.47
2014	April	1	--	--	--	--	--	--	--	--	--	--		
		2	--	--	0	23.70	42.28		--	--	--	--		
		whole	--	--	0	23.70	42.28	160305	--	--	--	--	--	14.51
2015	April	1	1.71 (0.71)	1.095(0.15)	37.42	21.38	47.75	8814	14087 (0.79)	6308 (0.74)		15071.9		
		2	0.09 (0.73)		0	12.07	23.46	172436	25408 (0.76)	13068 (0.78)		15329.6		
		whole	0.17 (0.72)		25.62	18.09	37.28	181250	33412 (0.74)	16207 (0.74)	19376 (0.58)	30395.6	12.02	12.64
2016	April	1	0.54 (0.56)	0.64 (0.22)	17.5	20.53	30.20	12778	6738 (0.60)	4581 (0.72)		6918		
		2	0.02 (0.81)		24.11	20.72	39.39	120710	2563 (0.82)	1348 (0.82)		2654		
		whole	0.07 (0.58)		20.07	20.07	33.56	133488	9536 (0.59)	5703 (0.62)	5929 (0.58)	9571	11.99	12.38

1: P_0 for the whole is the weighted average with area as the weight.

2. The estimates of adult parameters for the whole area were unstratified and RSF/W was based on original S_1 data of day-1 spawning females. For 2004, 27.03 was based on sex ratio= 0.618 while past biomass used RSF/W of 21.86 based on sex ratio = 0.5.(Lo et al. 2008).

3. The estimates of adult parameters for the whole area were unstratified. Batch fecundity was estimated with error term. For 1987 and 1994, estimates were based on S_1 using data of day-1 spawning females. For 2004, all trawls were in Region 1 and value was applied to Region 2.

4. Region 1 area is based: in 2015, on CUFES ≥ 0.3 eggs/min; in 2004-2013, on CUFES ≥1 eggs/min; and prior to 1997, from CalVET tows with eggs/0.05m^2 >0.

5: For the spawning biomass, the estimate for the whole area uses unstratified adult parameters.

6. Within southern and northern area, the survey area was stratified as Region 1 (eggs/0.05m2>0 with embedded zero) and Region 2 (zero eggs).

Table 3. Pacific sardine female adult parameters for surveys conducted in the standard daily egg production method (DEPM) sampling area off California during 1994-2014 (1994 includes females from off Mexico) and off northern California and Oregon in 2015-2016.

		1994	1997	2001	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Midpoint date of survey		22-Apr	25-Mar	1-May	21-Apr	25-Apr	13-Apr	2-May	24-Apr	16-Apr	27-Apr	20-Apr	8-Apr	19-Apr	25-Apr	26-Apr	14-Apr	7-Apr
Positive collections date range		04/15-05/07	03/12-04/06	05/01-05/02	04/18-04/23	04/22-04/27	03/31-04/24	05/01-05/07	04/19-04/30	04/13-04/27	04/17-05/06	04/12-04/27	03/23-04/25	04/08-04/28	04/18-05/03	04/25-05/03	04/01-04/17	3/27-04/18
N collections with mature females		37	4	2	6	16	14	7	14	12	29	17	30	16	15	3	4	6
N collection within Region 1		19	4	2	6	16	6	2	8	4	15	3	14	8	8	3	2	3
Average surface temperature (°C) at collection locations		14.36	14.28	12.95	12.75	13.59	14.18	14.43	13.6	12.4	12.93	13.62	13.12	13.18	13.65	12.96	12.54	12.38
Female fraction	**R**	0.538	0.592	0.677	0.385	0.618	0.469	0.451	0.515	0.631	0.602	0.574	0.587	0.429	0.586	0.560	0.485	0.598
Average mature female weight (grams):																		
with ovary	W_f	82.53	127.76	79.08	159.25	166.99	65.34	67.41	81.62	102.21	112.40	129.51	127.59	141.36	138.17	155.82	192.21	148.03
without ovary	W_{of}	79.33	119.64	75.17	147.86	156.29	63.11	64.32	77.93	97.67	106.93	121.34	119.38	131.58	129.76	146.35	178.26	140.22
Average batch fecundity[a] (oocytes)	**F**	24283	42002	22456	54403	55711	17662	18474	21760	29802	29790	39304	38369	38681	41339	46124	60916	34327
Relative batch fecundity (oocytes/g)		294	329	284	342	334	270	274	267	292	265	303	301	274	299	296	317	232
N mature females analyzed		583	77	9	23	290	175	86	203	187	467	313	244	126	121	7	25	71
N active mature females		327	77	9	23	290	148	72	187	177	463	310	244	125	119	7	25	71
Spawning fraction of mature females[b]	**S**	0.074	0.133	0.111	0.174	0.131	0.124	0.0698	0.114	0.1186	0.1098	0.1038	0.1078	0.1376	0.149	0.143	0.118	0.145
Spawning fraction of active females[c]	S_a	0.131	0.133	0.111	0.174	0.131	0.155	0.083	0.134	0.1187	0.1108	0.1048	0.1078	0.1388	0.153	0.143	0.118	0.145
Daily specific fecundity	$\frac{RSF}{W}$	11.7	25.94	21.3	22.91	27.04	15.67	8.62	15.68	21.82	17.53	18.07	19.04	16.14	26.22	23.70	18.09	20.07

[a] 1994-2001 estimates were calculated using F_b = -10858 + 439.53 W_{of} (Macewicz et al. 1996), 2004 used $F_b = 356.46W_{of}$. (Lo and Macewicz 2004), 2005 used F_b = -6085 + 376.28 W_{of} (Lo and Macewicz 2006), 2006 used F_b = -396 + 293.39 W_{of} (Lo et al. 2007a), 2007 used $F_b = 279.23W_{of}$ (Lo et al. 2007b), 2008 used $F_b = 305.14W_{of}$ (Lo et al. 2008), 2009 used $F_b = -4598 + 326.78W_{of} + e$ (Lo et al. 2009), 2010 used $F_b = 5136 + 287.37W_{of} + e$ (Lo et al. 2010), 2011 used $F_b = -2252 + 347.6W_{of} + e$ (Lo et al. 2011), 2012 used $F_b = -12724 + 402.3W_{of} + e$ (Lo et al. 2013), 2013 used $F_b = -9759 + 404.24W_{of} + e$ (Dorval et al. 2014), 2014 used equation from 2013, 2015 used $F_b = -5112 + 365.85W_{of} + e$, and 2016 used $F_b = 12708 + 167.83W_{of} + e$,.

[b] Mature females include females that are active and those that are postbreeding (incapable of further spawning this season). S_1 was used for years prior to 2009 and S_{12} was used staring 2009.

[c] Active mature females are capable of spawning and have ovaries containing oocytes with yolk or postovulatory follicles less than 60 hours old.

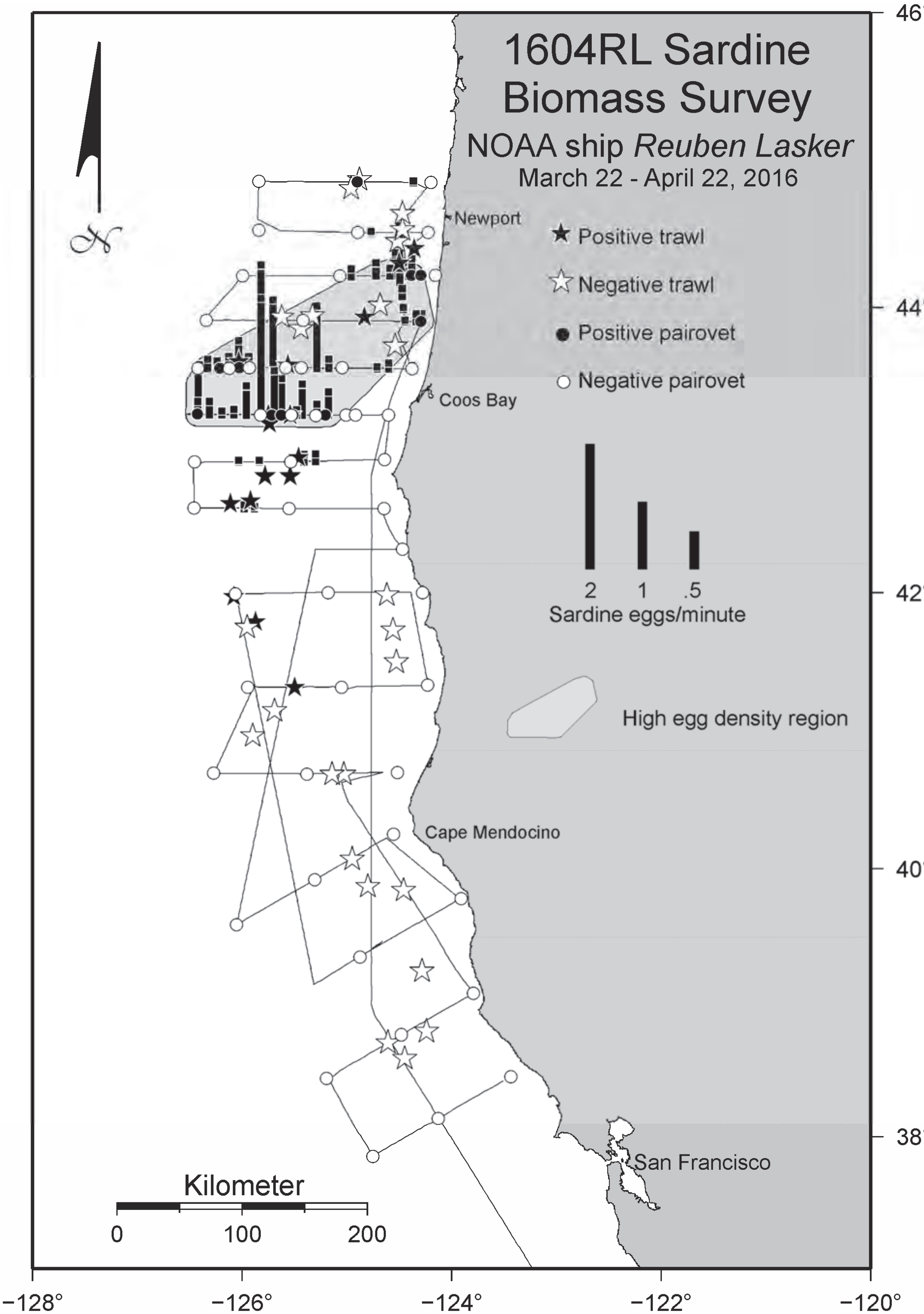

Figure 1. DEPM survey area and location of CalVET (Pairovet) and bongo tows, CUFES, and trawl locations during the 2016 survey aboard the NOAA ship *Reuben H. Lasker*.

APPENDIX B

SS INPUT FILES FOR MODEL ALT

STARTER.SS

```
# Pacific sardine stock assessment (2017-18)
# P.R. Crone, K.T. Hill, J.P. Zwolinski (Nov 2016)
# Model ALT: number of fisheries = 3 / surveys = 1 / time-step = semester / biological distributions = age /
          selectivity = age-based / growth = emp. WAA
# SS model (ver. 3.24s)
# Starter file
#
ALT.dat
ALT.ctl
0 # 0=use init values in control file; 1=use ss3.par
1 # Run display detail (0,1,2)
2 # Detailed age-structured reports in REPORT.SSO: (0,1,2)
1 # Write detailed checkup.sso file (0,1)
3 # Write parm values to ParmTrace.sso (0=no,1=good,active; 2=good,all; 3=every_iter,all_parms; 4=every,active)
2 # Write to cumreport.sso (0=no, 1=like&timeseries, 2=add survey fits)
0 # Include prior_like for non-estimated parameters (0,1)
1 # Use soft boundaries to aid convergence: (0,1)
1 # Number of datafiles to produce: 1st is input, 2nd is estimates, 3rd and higher are bootstrap
10 # Turn off estimation for parameters entering after this phase
10 # MCeval burn interval
2 # MCeval thin interval
0.05 # Jitter initial parm value by this fraction
-1 # Min yr for sdreport outputs (-1 for styr)
-2 # Max yr for sdreport outputs (-1 for endyr; -2 for endyr+Nforecastyrs
0 # N individual STD years
# Vector of year values
0.00001 # Final convergence criteria (e.g., 1.0e-05)
0 # Retrospective year relative to end year (e.g. -4)
1 # Min age for calc of summary biomass
1 # Depletion basis:  denom is: 0=skip; 1=rel X*B0; 2=rel X*Bmsy; 3=rel X*B_styr
1 # Fraction (X) for depletion denominator (e.g. 0.4)
4 # SPR_report_basis: 0=skip; 1=(1-SPR)/(1-SPR_tgt); 2=(1-SPR)/(1-SPR_MSY); 3=(1-SPR)/(1-SPR_Btarget); 4=rawSPR
4 # F_report_units: 0=skip; 1=exploitation(Bio); 2=exploitation(Num); 3=sum(Frates); 4=true F for range of ages
0 8 # Min and max age over which average F will be calculated with F_reporting=4
2 # F_report_basis: 0=raw; 1=F/Fspr; 2=F/Fmsy ; 3=F/Fbtgt
999 # End of file
```

FORECAST.SS

```
# Pacific sardine stock assessment (2017-18)
# P.R. Crone, K.T. Hill, J.P. Zwolinski (Nov 2016)
# Model ALT: number of fisheries = 3 / surveys = 1 / time-step = semester / biological distributions = age /
          selectivity = age-based / growth = emp. WAA
# SS model (ver. 3.24s)
# Forecast file
#
# Note: for all year entries except rebuilder, enter either: actual year, -999 for styr, 0 for endyr, neg number
          for relative endyr
1 #_Benchmarks: 0=skip, 1=calc F_spr,F_btgt,F_msy
2 #_MSY: 1= set to F(SPR), 2=calc F(MSY), 3=set to F(Btgt), 4=set to F(endyr)
0.4 #_SPR target (e.g., 0.40)
0.4 #_Biomass target (e.g., 0.40)
# Bmark_years: beg_bio, end_bio, beg_selex, end_selex, beg_relF, end_relF (enter actual year, or values of 0 or
          -integer to be rel. endyr)
0 0 0 0 0 0
1 # Bmark_relF_basis: 1 = use year range; 2 = set relF same as forecast below
1 # Forecast: 0=none; 1=F(SPR); 2=F(MSY) 3=F(Btgt); 4=Ave F (uses first-last relF yrs); 5=input annual F scalar
1 # N forecast years
0 # F scalar (only used for Do_Forecast==5)
# Fcast_years: beg_selex, end_selex, beg_relF, end_relF  (enter actual year, or values of 0 or -integer to be
          rel. endyr)
0 0 0 0
1 # Control rule method (1=catch=f(SSB) west coast, 2=F=f(SSB) )
0.5 # Control rule Biomass level for constant F (as frac of Bzero, e.g. 0.40); (Must be > the no F level below)
0.1 # Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10)
0.75 # Control rule target as fraction of Flimit (e.g. 0.75)
3 # N forecast loops
3 # First forecast loop with stochastic recruitment
0 # Forecast loop control #3 (reserved for future bells&whistles)
```

```
0 # Forecast loop control #4 (reserved for future bells&whistles)
0 # Forecast loop control #5 (reserved for future bells&whistles)
2020 # FirstYear for caps and allocations (should be after years with fixed inputs)
0 # Stddev of log(realized catch/target catch) in forecast (set value>0.0 to cause active impl_error)
0 # Do West Coast gfish rebuilder output (0/1)
0 # Rebuilder: first year catch could have been set to zero (Ydecl)(-1 to set to 1999)
0 # Rebuilder: year for current age structure (Yinit) (-1 to set to endyear+1)
1 # Fleet relative F: 1=use first-last alloc year, 2=read seas(row) x fleet(col) below
# Note: fleet allocation is used directly as average F if Do_Forecast=4
2 # Basis for forecast catch tuning and for forecast catch caps and allocation: 2=deadbio, 3=retainbio,
          5=deadnum, 6=retainnum
# Conditional input if relative F option=2
# Fleet relative F: rows are seasons, columns are fleets
# Fleet: MEXCAL_S1 MEXCAL_S2 PNW
# 0 0 0 # S1
# 0 0 0 # S2
# Max total catch by fleet (-1 to have no max): must enter value for each fleet
-1 -1 -1
# Max total catch by area (-1 to have no max): must enter value for each fleet
-1
# Fleet assignment to allocation group (enter group ID# for each fleet, 0 for not included in an alloc group)
0 0 0
# Conditional on >1 allocation group
# Allocation fraction for each of: 0 allocation groups
# No allocation groups
6 # Number of forecast catch levels to input (or else calculate catch from forecast F)
2 # Basis for input forecast catch: 2=dead catch, 3=retained catch, 99 = input Hrate(F) with units that are from
          fishery units
# Input fixed catch values
# Year Season Fleet Catch/F
2017   1  1    10.30
2017   2  1    0.00
2017   1  2    0.00
2017   2  2    185.87
2017   1  3    87.90
2017   2  3    0.70
999 # End of file
```

ALT.DAT

```
# Pacific sardine stock assessment (2017-18)
# P.R. Crone, K.T. Hill, J.P. Zwolinski (Nov 2016)
# Model ALT: number of fisheries = 3 / surveys = 1 / time-step = semester / biological distributions = age /
          selectivity = age-based / growth = emp. WAA
# SS model (ver. 3.24s)
# Data file
#
2005 # Start year (July 1993)
2016 # End year (ADVANCED ONE YEAR; FORECAST=2017-18)
2 # N_seasons
6 6 # Months per season (2 semesters per fishing year)
2 # Spawning season (Spring semester)
3 # N_fleets
2 # N_surveys
1 # N_areas
MEXCAL_S1%MEXCAL_S2%PNW%DEPM%AT_Survey
0.5 0.5 0.5 0.58 0.75 # Survey timing in season
1 1 1 1 1 # Area assignments for each fishery/survey
1 1 1 # Units of catch: 1=biomass, 2=number
0.05 0.05 0.05 # SE of log(catch), only used for initial equilibrium catch and for Fmethod=2-3
1 # N_genders
10 # N_ages
1000 0 0 # Initial equilibrium catch for each fishery
48 # N_lines of catch to read
# Catch biomass(mt): columns are fisheries, year, season
# LANDINGS
827.51  0.00    0.00    1993    1
0.00    11679.31        0.00    1993    2
8940.33 0.00    0.00    1994    1
0.00    40439.57        0.00    1994    2
6048.30 0.00    22.68   1995    1
0.00    26820.27        0.00    1995    2
12038.89   0.00 0.00    1996    1
0.00    19489.95        43.54   1996    2
13018.20   0.00 27.22   1997    1
0.00    24916.29        0.82    1997    2
```

```
19062.67	0.00	488.25	1998	1
0.00	63812.26	74.39	1998	2
15060.75	0.00	725.20	1999	1
0.00	58889.27	429.59	1999	2
23750.08	0.00	15586.16	2000	1
0.00	35341.42	2336.90	2000	2
11607.29	0.00	22545.99	2001	1
0.00	41513.06	3136.84	2001	2
16644.36	0.00	35525.69	2002	1
0.00	36906.76	597.29	2002	2
10410.67	0.00	37242.26	2003	1
0.00	22672.97	2618.43	2003	2
17143.09	0.00	46730.80	2004	1
0.00	25890.59	1016.32	2004	2
13802.99	0.00	54152.62	2005	1
0.00	30364.20	101.70	2005	2
20726.23	0.00	41220.90	2006	1
0.00	39900.28	0.00	2006	2
46228.11	0.00	48237.10	2007	1
0.00	42910.05	0.00	2007	2
30249.18	0.00	39800.10	2008	1
0.00	41198.49	0.00	2008	2
14044.87	0.00	44841.15	2009	1
0.00	31146.46	1369.73	2009	2
11273.97	0.00	54085.91	2010	1
0.00	27267.62	0.09	2010	2
24871.40	0.00	39750.49	2011	1
0.00	23189.90	5805.63	2011	2
1528.37	0.00	91425.63	2012	1
0.00	13884.90	1570.78	2012	2
921.56	0.00	57217.96	2013	1
0.00	5625.03	908.01	2013	2
1830.92	0.00	15216.82	2014	1
0.00	727.71	2193.87	2014	2
6.13	0.00	66.28	2015	1
0.00	185.87	0.70	2015	2
10.30	0.00	87.90	2016	1
0.00	185.87	0.70	2016	2	# Repeat of 2015-2
# 10.30	0.00	87.90	2017	1	(PLACED IN FORECAST)
# 0.00	185.87	0.70	2017	2	(PLACED IN FORECAST)
#
27 #_N_cpue_and_surveyabundance_observations
#_Units:  0=numbers; 1=biomass; 2=F
#_Errtype:  -1=normal; 0=lognormal; >0=T
#_Fleet Units Errtype
1 1 0 # MEXCAL_S1
2 1 0 # MEXCAL_S2
3 1 0 # PNW
4 1 0 # DEPM
5 1 0 # ATM
# Year season index obs error
1993	2	4	69065	0.29	# DEPM_9404
2003	2	4	145274	0.23	# DEPM_0404
2004	2	4	459943	0.55	# DEPM_0504
2006	2	4	198404	0.30	# DEPM_0704
2007	2	4	66395	0.27	# DEPM_0804
2008	2	4	99162	0.24	# DEPM_0905
2009	2	4	58447	0.40	# DEPM_1004
2010	2	4	219386	0.27	# DEPM_1104
2011	2	4	113178	0.27	# DEPM_1204
2012	2	4	82182	0.29	# DEPM_1304
# 2013	2	4	(No est.)	# DEPM_1404
2014	2	4	19376	0.54	# DEPM_1504
2015	2	4	5929	0.54	# DEPM_1604
#
2005	2	5	1947063	0.30	# ATM_0604
2007	2	5	751075	0.09	# ATM_0804
2009	2	5	357006	0.41	# ATM_1004
2010	2	5	493672	0.30	# ATM_1104
2011	2	5	469480	0.28	# ATM_1204
2012	2	5	305146	0.24	# ATM_1304
2013	2	5	35339	0.38	# ATM_1404
2014	2	5	29048	0.29	# ATM_1504
2015	2	5	83030	0.47	# ATM_1604
#
2008	1	5	801000	0.30	# ATM_0807
```

```
2012    1  5    340831  0.33    # ATM_1207
2013    1  5    313746  0.27    # ATM_1307
2014    1  5    26280   0.63    # ATM_1407
2015    1  5    15870   0.70    # ATM_1507
2016    1  5    78770   0.51    # ATM_1607
#
0 # N_fleets with discard
# Discard units: 1=same_as_catch units (bio/num), 2=fraction, 3=numbers
# Discard error type: >0 for DF of T-dist(read CV below), 0 for normal with CV, -1 for normal with se, -2 for
          lognormal
# Fleet discard units and error type
0 # N_discard obs
# Year season index obs error
#
0 # N_meanbodywt obs
100 # DF for_meanbodywt t-distribution likelihood
#
2 # Length bin method: 1=use databins; 2=generate from binwidth,min,max below; 3=read vector
0.5 # Bin width for population size composition
8 # Minimum size in the population (lower edge of first bin and size at age 0)
30 # Maximum size in the population (lower edge of last bin)
-0.0001 # Composition tail compression
0.0001 # Add to composition
0 # Combine males into females at or below this bin number
39 # N_length bins
9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5 16 16.5 17 17.5 18 18.5 19 19.5 20 20.5 21 21.5 22 22.5 23
          23.5 24 24.5 25 25.5 26 26.5 27 27.5 28
89 # N_length obs
# Year Season Fleet/Survey Gender Part Nsamp Datavector(female-male)
1993    1  1    0       0       2.72    0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.01470588     0.00000000
                0.14705882     0.23529412     0.19117647     0.20588235     0.13235294     0.05882353
                0.01470588     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
1994    1  1    0       0       13.74   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00192997     0.01865635
                0.04117263     0.08430434     0.07591361     0.07404029     0.08683868     0.12757807
                0.09884957     0.10926901     0.11878046     0.08880898     0.05178937     0.00695027
                0.01026562     0.00365034     0.00060123     0.00000000     0.00060123     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
1995    1  1    0       0       4.80    0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00833333     0.00000000     0.00833333     0.00833333     0.01666667
                0.07500000     0.08333333     0.05833333     0.20833333     0.13333333     0.21666667
                0.08333333     0.06666667     0.01666667     0.00833333     0.00833333     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
1996    1  1    0       0       59.54   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00034806     0.00058009
                0.00219937     0.00576503     0.00957964     0.02611018     0.04050980     0.05620072
                0.08282782     0.13533238     0.15435462     0.17604004     0.13254345     0.08564194
                0.05547979     0.02087313     0.00993156     0.00286865     0.00069611     0.00023204
                0.00062219     0.00000000     0.00000000     0.00042114     0.00042114     0.00000000
                0.00042114     0.00000000     0.00000000     0.00000000
1997    1  1    0       0       54.96   0.00161047     0.00000000     0.00000000     0.00000000     0.00000000
                0.00070613     0.00190931     0.00249531     0.00157254     0.00740264     0.02034422
                0.02746041     0.02356657     0.03226502     0.04920364     0.05812807     0.09131547
                0.12217437     0.17851369     0.16690609     0.10823880     0.06410378     0.02256286
                0.00874199     0.00479242     0.00070613     0.00249531     0.00176969     0.00030895
                0.00070613     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
1998    1  1    0       0       61.82   0.00000000     0.00013950     0.00000000     0.00054913     0.00217145
                0.00754043     0.02660605     0.06328062     0.09928446     0.12017588     0.11452861
                0.10222652     0.08662035     0.08022393     0.05559320     0.04519876     0.03979356
                0.03720684     0.02689637     0.02425384     0.01374267     0.01309129     0.01455336
                0.00735521     0.00736115     0.00379924     0.00202174     0.00182034     0.00226600
                0.00169950     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
1999    1  1    0       0       8.45    0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00970931     0.02427327     0.05825584     0.09709307
                0.13107564     0.18600867     0.21698374     0.07874420     0.08045604     0.05037072
                0.03313752     0.01627580     0.00727624     0.00325516     0.00229776     0.00229776
                0.00153184     0.00038296     0.00019148     0.00038296     0.00000000     0.00000000
```

```
                0.00000000    0.00000000    0.00000000    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000
2000   1 1      0      0      19.31  0.00000000    0.00000000    0.00000000    0.00000000    0.00000000
                0.00000000    0.00214444    0.00687013    0.00236284    0.00816075    0.01610311
                0.02362844    0.03736871    0.07557145    0.12782502    0.17187176    0.18629126
                0.17216776    0.08516998    0.03492402    0.01434741    0.01172984    0.01007111
                0.00731811    0.00463296    0.00036867    0.00000000    0.00000000    0.00107222
                0.00000000    0.00000000    0.00000000    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000
2001   1 1      0      0      26.92  0.00299140    0.00273498    0.01506817    0.03187710    0.04628212
                0.02810027    0.01845921    0.01980049    0.02094225    0.00689629    0.00233494
                0.00009139    0.00702992    0.01724077    0.03944303    0.04010245    0.05293178
                0.06963658    0.06813359    0.03349161    0.02422864    0.01998817    0.02567865
                0.04374940    0.06629584    0.11235528    0.07962582    0.03629326    0.02802019
                0.01335362    0.01339213    0.00843442    0.00307756    0.00191866    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000
2002   1 1      0      0      46.96  0.00000000    0.00000000    0.00000000    0.00000000    0.00000000
                0.00058534    0.00000000    0.00000000    0.00427117    0.00856097    0.01383827
                0.02882084    0.07292346    0.10667321    0.12477102    0.13591949    0.17905045
                0.12960308    0.09350153    0.04093142    0.02615243    0.01065275    0.00566682
                0.00430140    0.00526596    0.00146460    0.00420899    0.00225146    0.00000000
                0.00000000    0.00000000    0.00058534    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000
2003   1 1      0      0      13.15  0.00000000    0.00169262    0.00451718    0.01608292    0.06021648
                0.12408570    0.08347189    0.05346355    0.04403720    0.02879712    0.01144579
                0.02279141    0.01563165    0.02462320    0.02606885    0.03942352    0.05607711
                0.07024577    0.06869371    0.06366968    0.04343752    0.04937621    0.04233675
                0.02762563    0.01033400    0.00851117    0.00243153    0.00091182    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000
2004   1 1      0      0      32.30  0.00000000    0.00000000    0.00000000    0.00024514    0.00024514
                0.00073543    0.00205767    0.00283243    0.00824157    0.00988930    0.04485433
                0.11745533    0.20110987    0.16552816    0.14517069    0.11552133    0.08888914
                0.04629335    0.01857389    0.01104107    0.00756468    0.00443794    0.00243413
                0.00239788    0.00000806    0.00000201    0.00000000    0.00223572    0.00000000
                0.00000000    0.00223572    0.00000000    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000
2005   1 1      0      0      28.75  0.00000000    0.00000000    0.00071949    0.00143897    0.00653511
                0.01157153    0.01384485    0.01309843    0.02798175    0.05168794    0.07930643
                0.09237886    0.07490876    0.08847601    0.11085534    0.15343903    0.10619562
                0.07417982    0.03501566    0.02276698    0.01374071    0.01125064    0.00258153
                0.00246207    0.00002240    0.00056560    0.00000000    0.00113119    0.00056560
                0.00000000    0.00271410    0.00056560    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000
2006   1 1      0      0      70.00  0.00000000    0.00000000    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000817    0.00139593    0.00370309    0.01051305    0.02830085
                0.08812453    0.16038481    0.17472994    0.15633215    0.13757842    0.10032027
                0.06327177    0.03845569    0.02449167    0.00528078    0.00445611    0.00132639
                0.00033160    0.00033160    0.00033160    0.00033160    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000
2007   1 1      0      0      69.87  0.00164969    0.00247453    0.00329937    0.00264684    0.00076071
                0.00094036    0.00106112    0.00505987    0.00726599    0.01044510    0.02075499
                0.03448703    0.06756079    0.10788447    0.15231813    0.18353671    0.15746569
                0.11193402    0.06189772    0.03095113    0.01131497    0.00936246    0.00448928
                0.00070277    0.00070277    0.00049491    0.00111500    0.00082484    0.00181466
                0.00164969    0.00164969    0.00115478    0.00032994    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000
2008   1 1      0      0      27.00  0.00000000    0.00001951    0.00001951    0.00007805    0.00007805
                0.00025365    0.00812568    0.01322437    0.01507600    0.01012736    0.00703638
                0.00222432    0.00815459    0.03743973    0.10519409    0.17673635    0.17069402
                0.16753307    0.13252684    0.05969125    0.02792098    0.01779568    0.00494964
                0.01433373    0.00739166    0.00899568    0.00066448    0.00187718    0.00005853
                0.00177962    0.00000000    0.00000000    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000
2009   1 1      0      0      23.00  0.00000000    0.00000000    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000    0.00000000    0.00718480
                0.00659772    0.02510462    0.00834218    0.03988813    0.13822895    0.30734108
                0.28332180    0.12859970    0.04820622    0.00544034    0.00174446    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000
2010   1 1      0      0      13.00  0.00000000    0.00000000    0.00000000    0.00000000    0.00000000
                0.00000000    0.00000000    0.00000000    0.00000000    0.00307692    0.00000000
                0.02153846    0.11076923    0.30153846    0.28615385    0.22153846    0.02153846
                0.01846154    0.00307692    0.00307692    0.00615385    0.00307692    0.00000000
```

```
              0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000
2011   1  1   0       0      22.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00550160     0.02270543     0.10592845     0.30705434
              0.33715847     0.16548304     0.03472523     0.01524281     0.00344984     0.00000000
              0.00000000     0.00275080     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000
2012   1  1   0       0      22.96  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.02288534
              0.01634667     0.02615468     0.01307734     0.00326933     0.00980800     0.02916482
              0.07258330     0.10858359     0.14709358     0.12463433     0.14112953     0.13635974
              0.07152817     0.05732066     0.01399447     0.00048164     0.00372320     0.00186160
              0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000
2013   1  1   0       0      16.00  0.00000000     0.00000000     0.00074231     0.00148463     0.00222694
              0.00296925     0.00371157     0.00519619     0.00222694     0.00074231     0.00074231
              0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00148463
              0.00148463     0.00234205     0.02328286     0.02859415     0.05945618     0.04296925
              0.10566584     0.17808666     0.26589605     0.13284417     0.08507572     0.04410319
              0.00867218     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000
2014   1  1   0       0      6.00   0.00000000     0.00000000     0.00000000     0.00000000     0.00000895
              0.00000000     0.00000000     0.00000000     0.00000895     0.00003133     0.00003581
              0.00001790     0.00000448     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.01599821     0.03999552     0.18397941     0.34396598     0.31996419
              0.07199194     0.01599821     0.00799910     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000
# 2015 1 1 (Was used, but small sample size, incidental landings, omit)
2015   1  -1  0       0      1.00   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.04000000     0.00000000     0.12000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.04000000     0.24000000     0.16000000     0.28000000     0.12000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000
# 2016 1 1 (Not available)
#
1993   2  2   0       0      80.83  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00000000     0.00024233     0.00140226     0.00726413     0.02974873     0.06247855
              0.09739572     0.09557449     0.07134655     0.06703480     0.08193713     0.10366195
              0.11143525     0.10144129     0.05447251     0.03973350     0.02527592     0.01453475
              0.00850628     0.00787906     0.00345701     0.00250677     0.00214831     0.00346978
              0.00312588     0.00135054     0.00021661     0.00128376     0.00093526     0.00000000
              0.00014086     0.00000000     0.00000000     0.00000000
1994   2  2   0       0      206.08 0.00000000     0.00000000     0.00000000     0.00000000     0.00145457
              0.00504078     0.00606898     0.00700771     0.01410691     0.02242621     0.04034287
              0.06906816     0.09654861     0.11238178     0.12955228     0.13501642     0.11091489
              0.09320556     0.05899874     0.04552064     0.02495894     0.01511850     0.00540478
              0.00359894     0.00066879     0.00092576     0.00026691     0.00000000     0.00012087
              0.00000000     0.00029208     0.00069722     0.00000000     0.00000000     0.00000000
              0.00029208     0.00000000     0.00000000     0.00000000
1995   2  2   0       0      42.30  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
              0.00483005     0.00181639     0.00978760     0.01443863     0.02041858     0.02632739
              0.03677194     0.05949842     0.09049866     0.10561619     0.13138787     0.11886270
              0.11101527     0.07941884     0.07368271     0.04314995     0.03412017     0.01538229
              0.01735834     0.00323563     0.00100235     0.00056203     0.00000000     0.00040900
              0.00000000     0.00000000     0.00000000     0.00040900     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000
1996   2  2   0       0      31.69  0.00000000     0.00000000     0.00000001     0.00000006     0.00208698
              0.00474184     0.01105977     0.01641602     0.03848093     0.04640019     0.05225376
              0.07284165     0.06293899     0.03267289     0.02526977     0.03481597     0.04474040
              0.05224002     0.05002577     0.07588550     0.07647282     0.09283255     0.08189359
              0.05770817     0.02553826     0.01572120     0.00742768     0.00448802     0.00253262
              0.00168842     0.00168842     0.00168842     0.00168842     0.00238407     0.00337683
              0.00000000     0.00000000     0.00000000     0.00000000
1997   2  2   0       0      39.04  0.00116688     0.00116688     0.01283567     0.01168079     0.01911496
              0.00995550     0.00463359     0.00836094     0.02093227     0.01412310     0.04077870
              0.04592240     0.05486011     0.07529587     0.08758462     0.06419613     0.05883337
              0.06624342     0.04634799     0.03228601     0.03351542     0.03099222     0.05453763
              0.05713365     0.05113369     0.04096875     0.03221245     0.01144112     0.00765009
              0.00308468     0.00057263     0.00023650     0.00020197     0.00000000     0.00000000
              0.00000000     0.00000000     0.00000000     0.00000000
```

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1998    2  2    0       0       62.89  0.00000000     0.00052375     0.00292399     0.00531268     0.00807976
                0.00892394     0.01445008     0.04007347     0.04947419     0.06018640     0.07160912
                0.08430841     0.09930662     0.11026781     0.09545976     0.09022715     0.07892527
                0.06308014     0.02943892     0.02494755     0.01733738     0.01275855     0.01065188
                0.00689855     0.00555941     0.00337949     0.00283313     0.00163188     0.00071536
                0.00040797     0.00030739     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
1999    2  2    0       0       45.97  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00373364     0.01858885     0.06092482     0.10283009
                0.13630227     0.17321851     0.15257482     0.12476550     0.08514671     0.05049129
                0.03310700     0.02304860     0.01857073     0.01262764     0.00349994     0.00042741
                0.00014219     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2000    2  2    0       0       42.47  0.00000000     0.00000000     0.00000000     0.00007818     0.00031273
                0.00695721     0.00948363     0.02298990     0.03958827     0.04929372     0.07791587
                0.10364298     0.10939476     0.07624154     0.05471634     0.05940971     0.08000407
                0.07736515     0.05906656     0.05988523     0.04314596     0.04274591     0.01443181
                0.01154905     0.00083513     0.00000000     0.00086812     0.00007818     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2001    2  2    0       0       57.78  0.00000000     0.00000000     0.00114442     0.01008725     0.02360642
                0.04515338     0.06577894     0.08827063     0.10528246     0.11005028     0.08543740
                0.06257413     0.06371308     0.05222215     0.02452615     0.02527951     0.02070571
                0.02867169     0.04446623     0.05499618     0.03036332     0.02717653     0.01354428
                0.00784013     0.00561628     0.00208727     0.00069576     0.00069576     0.00000000
                0.00000000     0.00001467     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2002    2  2    0       0       55.61  0.00000000     0.00000000     0.00000000     0.00037996     0.00113988
                0.00189980     0.00264471     0.00378459     0.00573358     0.00469099     0.00904018
                0.02153204     0.04856377     0.08579611     0.12189739     0.13011447     0.12668342
                0.09525103     0.04868384     0.03776127     0.05061458     0.05005716     0.04759173
                0.04675377     0.02437622     0.01196384     0.00688184     0.00781155     0.00573013
                0.00095678     0.00080336     0.00086203     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2003    2  2    0       0       74.37  0.00000000     0.00000000     0.00002333     0.00737407     0.03796815
                0.06330862     0.06164288     0.08781023     0.13955871     0.16815734     0.12204441
                0.08096378     0.04889651     0.02406924     0.01538764     0.01563158     0.01102487
                0.01358790     0.01561320     0.02270900     0.01540512     0.01581931     0.00585443
                0.00228531     0.00198207     0.00690423     0.00409315     0.00215683     0.00243203
                0.00283737     0.00324271     0.00081068     0.00040534     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2004    2  2    0       0       81.35  0.00000000     0.00000000     0.00000000     0.00000000     0.00093783
                0.00153447     0.00348067     0.00686443     0.02125242     0.03295020     0.06153444
                0.10844211     0.11494040     0.12997977     0.12299243     0.09934347     0.09079576
                0.07490959     0.06642619     0.03379681     0.01274994     0.00944827     0.00238726
                0.00082184     0.00068687     0.00101954     0.00203739     0.00000000     0.00066788
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2005    2  2    0       0       69.54  0.00003323     0.00016617     0.00198183     0.00724287     0.02546488
                0.03423464     0.04343134     0.05161252     0.08921533     0.10317372     0.11440362
                0.10395214     0.11260776     0.08466520     0.06700801     0.04312203     0.03875394
                0.02639734     0.01505989     0.01090155     0.00709011     0.00530332     0.00273073
                0.00352497     0.00253710     0.00095835     0.00156157     0.00078078     0.00027632
                0.00048453     0.00064604     0.00035514     0.00032302     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2006    2  2    0       0       79.01  0.00000000     0.00000000     0.00000000     0.00007155     0.00193274
                0.00448013     0.00870836     0.01190914     0.02276871     0.02245554     0.05508678
                0.08312489     0.10950482     0.11508847     0.11718795     0.09778619     0.08344183
                0.07797438     0.05950222     0.04982304     0.02853562     0.01769640     0.00778031
                0.00668425     0.00192038     0.00407420     0.00371857     0.00243818     0.00184306
                0.00148743     0.00148743     0.00148743     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2007    2  2    0       0       53.13  0.00000000     0.00000000     0.00056916     0.00458294     0.01523107
                0.01624194     0.03828270     0.07429633     0.10589583     0.11936676     0.13445629
                0.09028317     0.08948056     0.09093413     0.06813034     0.04676708     0.03148477
                0.01534756     0.01102726     0.00991497     0.00445812     0.00594738     0.00799020
                0.00561403     0.00666222     0.00305137     0.00193240     0.00055948     0.00018649
                0.00055948     0.00018649     0.00018649     0.00037299     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2008    2  2    0       0       39.53  0.00130827     0.00130827     0.00261985     0.00174435     0.00820997
                0.01240801     0.02192600     0.03724275     0.03155898     0.02949098     0.03131780
                0.04421268     0.06406849     0.11119877     0.13321561     0.12895909     0.08889473
                0.07252151     0.05604855     0.05270723     0.02472053     0.01390128     0.00841632
                0.00910891     0.00492096     0.00313298     0.00174435     0.00198249     0.00043609
                0.00067422     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
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                0.00000000     0.00000000     0.00000000     0.00000000
2009   2  2     0       0      99.00  0.00000000     0.00000000     0.00000000     0.00033110     0.00098937
                0.00364222     0.01526663     0.04815485     0.10491762     0.15225861     0.16727933
                0.14395945     0.12763433     0.09200956     0.07251219     0.03921100     0.01392598
                0.00964499     0.00259569     0.00164641     0.00095708     0.00053046     0.00065827
                0.00089258     0.00090368     0.00000000     0.00000000     0.00007860     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2010   2  2     0       0      32.96  0.00000000     0.00000000     0.00000000     0.00000329     0.00000986
                0.00000000     0.01533814     0.03545198     0.07505310     0.08012643     0.16082054
                0.16409807     0.14395429     0.08121932     0.03649645     0.02499783     0.00880498
                0.00803841     0.00505031     0.00646200     0.00190905     0.00326271     0.00879883
                0.01489032     0.03181114     0.02910381     0.02842698     0.01759765     0.00812199
                0.00744516     0.00067683     0.00135367     0.00067683     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2011   2  2     0       0      56.28  0.00000000     0.00000000     0.00000000     0.00000000     0.00042055
                0.00393862     0.02649871     0.07254863     0.07899923     0.06480918     0.05727363
                0.04957664     0.04043675     0.05008019     0.04620495     0.05065969     0.03636937
                0.04610942     0.04153957     0.06936597     0.04808470     0.04969147     0.03341529
                0.02532542     0.01673552     0.02905829     0.02593557     0.02224027     0.00818459
                0.00324890     0.00108297     0.00216593     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2012   2  2     0       0      9.00   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00634863     0.00634863     0.01904590     0.03809180     0.01904590     0.08292541
                0.10792675     0.13008930     0.15627021     0.07814954     0.12219678     0.07438000
                0.05428802     0.04833258     0.04339435     0.00937866     0.00227252     0.00151501
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2013   2  2     0       0      28.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00026894     0.00287596     0.00971450     0.00404500     0.00323817     0.00206913
                0.00296922     0.00360037     0.00476941     0.01809207     0.02177791     0.03006646
                0.03606958     0.07238448     0.17035400     0.25213401     0.20643699     0.09677617
                0.03764854     0.01076876     0.00506478     0.00634317     0.00253239     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2014   2  2     0       0      14.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00334979     0.01674895     0.03014811     0.05359663     0.08400949
                0.11768389     0.12398933     0.17300721     0.21933638     0.08066685     0.04959071
                0.00700984     0.00119060     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00718278     0.00850714     0.01678294
                0.00122678     0.00597259     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
# 2015 2 2 (Not available)
#
1999   1  3     0       0      3.04   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000095
                0.00000095     0.00000285     0.00001236     0.04484245     0.07472347     0.07472918
                0.13447410     0.15869488     0.13446554     0.05976204     0.04482153     0.02422648
                0.04642701     0.03714674     0.03716576     0.02788359     0.03717908     0.03919457
                0.00929548     0.00000666     0.00000285     0.01494051     0.00000000     0.00000095
                0.00000000     0.00000000     0.00000000     0.00000000
1999   2  3     0       0      4.24   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.01886792     0.01886792
                0.02830189     0.16981132     0.17924528     0.20754717     0.16981132     0.11320755
                0.04716981     0.02830189     0.00943396     0.00943396     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2000   1  3     0       0      63.93  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00003375     0.00006482     0.00000000     0.00003375     0.00000000
                0.00003375     0.00000000     0.00000000     0.00063677     0.00308924     0.01570860
                0.02898601     0.03823612     0.05495875     0.06093348     0.06560425     0.07664897
                0.09104633     0.12502336     0.11358864     0.11316074     0.07608888     0.06753608
                0.03163643     0.01814741     0.01018023     0.00428843     0.00365138     0.00060061
                0.00003107     0.00003970     0.00000000     0.00001246
2000   2  3     0       0      10.72  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000026     0.00012460     0.00000000     0.00000000
                0.00000026     0.00000000     0.00000026     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.02350879     0.02375825     0.08315347     0.13179081
                0.15417981     0.17881393     0.13080486     0.14894118     0.07718786     0.03579353
                0.00003091     0.01189510     0.00000951     0.00000449     0.00000106     0.00000079
                0.00000000     0.00000000     0.00000000     0.00000026
2001   1  3     0       0      78.15  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00087005     0.00156608     0.00121806
                0.00115894     0.00060192     0.00046425     0.00000000     0.00046425     0.00000000
```

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                0.00000002     0.00261835     0.01024098     0.02323570     0.07467192     0.16300429
                0.17738632     0.16996193     0.12669923     0.09158078     0.06693893     0.04293152
                0.02073142     0.01275755     0.00758599     0.00156533     0.00158897     0.00011092
                0.00004628     0.00000000     0.00000000     0.00000002
2001   2  3     0      0       26.76  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00048288     0.00048288
                0.00000053     0.00000000     0.00000000     0.00000000     0.00367294     0.00879451
                0.04010952     0.09046219     0.18199439     0.21660795     0.19187645     0.13186477
                0.06604471     0.04323092     0.01074198     0.00880089     0.00289994     0.00048341
                0.00096629     0.00048288     0.00000000     0.00000000
2002   1  3     0      0       172.79 0.00000000     0.00000000     0.00000000     0.00000313     0.00000626
                0.00000626     0.00000626     0.00000313     0.00000938     0.00000626     0.00001363
                0.00000313     0.00062473     0.00031198     0.00094645     0.00136169     0.00143519
                0.00317196     0.00361648     0.00444832     0.00536365     0.00421846     0.01381946
                0.03565991     0.11857744     0.20342331     0.21914500     0.14683906     0.11571644
                0.06020604     0.03543252     0.01287390     0.00777273     0.00240956     0.00164771
                0.00033310     0.00054432     0.00001901     0.00002414
2002   2  3     0      0       8.44   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00312357
                0.00000000     0.00000000     0.00624714     0.00937071     0.00937295     0.01249428
                0.01249652     0.05221134     0.13789484     0.06785376     0.17431751     0.21008191
                0.06999081     0.08758723     0.05631804     0.06875428     0.00938411     0.00624714
                0.00312580     0.00312357     0.00000000     0.00000446
2003   1  3     0      0       145.33 0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000397     0.00000000     0.00000397     0.00000397     0.00081444     0.00403192
                0.00514471     0.00338591     0.00141363     0.00001985     0.00029674     0.00455528
                0.01661655     0.03216569     0.04716668     0.06356196     0.04611645     0.05368928
                0.06537740     0.06742541     0.07208935     0.12367128     0.12474048     0.10239500
                0.07361669     0.04797912     0.02147233     0.01095014     0.00687007     0.00305615
                0.00071418     0.00062688     0.00001260     0.00001191
2003   2  3     0      0       16.88  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00068529
                0.01626167     0.03183805     0.07470549     0.17346083     0.15096679     0.24561041
                0.16554308     0.08604058     0.03407916     0.01027932     0.00915877     0.00137058
                0.00000000     0.00000000     0.00000000     0.00000000
2004   1  3     0      0       93.35  0.00001567     0.00001567     0.00000000     0.00000000     0.00056254
                0.00028127     0.00056254     0.00142204     0.00609585     0.00738530     0.00901487
                0.00780880     0.00880757     0.00314547     0.01122084     0.01449783     0.04081487
                0.03735165     0.03390459     0.02231370     0.02555715     0.01629821     0.02816169
                0.02899177     0.05840626     0.06057283     0.09562618     0.08453840     0.14026268
                0.09805984     0.07524450     0.03709070     0.02707205     0.01236191     0.00425655
                0.00131717     0.00055007     0.00017067     0.00024033
2004   2  3     0      0       7.88   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.02131378     0.05692221     0.15080485
                0.27920147     0.24587915     0.15038613     0.02495166     0.02063744     0.00998066
                0.00499033     0.00000000     0.00499033     0.00499033     0.00000000     0.00499033
                0.00998066     0.00000000     0.00998066     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2005   1  3     0      0       67.68  0.00000000     0.00000000     0.00000000     0.00000000     0.00000553
                0.00001355     0.00159531     0.00039392     0.00002710     0.00004066     0.00020755
                0.00020258     0.00270103     0.02291847     0.05924987     0.09616749     0.20727817
                0.18328761     0.12443673     0.05097571     0.01877167     0.01515760     0.00998755
                0.00942919     0.01080600     0.01225695     0.01347518     0.01909393     0.02824136
                0.03110144     0.04082612     0.02108261     0.01447999     0.00282130     0.00249264
                0.00027437     0.00014659     0.00002710     0.00002710
2006   1  3     0      0       27.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00385525
                0.01151585     0.04782390     0.16295078     0.33602885     0.24986185     0.11243519
                0.01737664     0.00466226     0.00994350     0.00193035     0.00122605     0.00686819
                0.00826354     0.01135211     0.00487000     0.00864962     0.00000000     0.00000000
                0.00038607     0.00000000     0.00000000     0.00000000
2006   2  3     0      0       3.00   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.01333333     0.00000000     0.06666667     0.06666667     0.20000000     0.16000000
                0.09333333     0.09333333     0.05333333     0.02666667     0.05333333     0.00000000
                0.08000000     0.04000000     0.02666667     0.02666667     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2007   1  3     0      0       87.86  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000737     0.00000000     0.00000000     0.00000000     0.00000000
```

```
                0.00000000     0.00000000     0.00000000     0.00001639     0.00061942     0.00255561
                0.01442330     0.07011329     0.13161223     0.21359514     0.23707687     0.18219854
                0.07245245     0.02287642     0.01307278     0.00799927     0.00556329     0.00684479
                0.00802636     0.00410422     0.00215245     0.00214591     0.00115543     0.00071927
                0.00011042     0.00050099     0.00001250     0.00004528
2008   1  3     0      0       129.64  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00004054     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00041928     0.00000000     0.00000000     0.00058332
                0.00460794     0.03193930     0.06132653     0.11715864     0.14270701     0.15921219
                0.11117985     0.07109068     0.04339494     0.04764464     0.06409722     0.06209469
                0.04086420     0.02147774     0.01039633     0.00450936     0.00253737     0.00106315
                0.00059479     0.00056213     0.00027694     0.00022122
2009   1  3     0      0       159.41  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000722     0.00000000     0.00000000     0.00000000     0.00000000
                0.00036834     0.00036834     0.00000722     0.00002165     0.00000722     0.00001443
                0.00385185     0.02385351     0.05630274     0.13546005     0.16896254     0.15574778
                0.09681599     0.06985591     0.04410210     0.07537644     0.06582272     0.05197468
                0.02553117     0.01450460     0.00584005     0.00330284     0.00143161     0.00023704
                0.00012583     0.00002508     0.00004879     0.00003229
2009   2  3     0      0       4.33    0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.01398663     0.00000000     0.00000000     0.00000000     0.00000000
                0.00640983     0.00764838     0.05363834     0.07792424     0.18996976     0.18962297
                0.20269211     0.13261832     0.06086833     0.03818737     0.01244710     0.00622355
                0.00776308     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2010   1  3     0      0       158.60  0.00000000     0.00000000     0.00000000     0.00000000     0.00001429
                0.00001429     0.00001429     0.00001429     0.00001429     0.00001429     0.00044699
                0.00000000     0.00000121     0.00000000     0.00182244     0.00202608     0.00164970
                0.00257329     0.00747769     0.02929572     0.09131722     0.14271426     0.15874857
                0.10985279     0.08726802     0.06754262     0.09067348     0.07714994     0.06213060
                0.03582122     0.02020100     0.00620373     0.00350799     0.00107204     0.00019082
                0.00002417     0.00005373     0.00002859     0.00012036
2011   1  3     0      0       209.70  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00003151     0.00000000     0.00000000     0.00001309     0.00000000
                0.00098545     0.00003928     0.00059179     0.00017022     0.00011007     0.00198926
                0.00187005     0.00458734     0.00621298     0.01733638     0.02663686     0.09056926
                0.12766615     0.12250119     0.08001007     0.12016808     0.12573893     0.10839274
                0.08486996     0.04554796     0.01977992     0.00882012     0.00339068     0.00107283
                0.00055389     0.00018109     0.00013134     0.00003151
2011   2  3     0      0       15.00   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.01595748     0.06102858     0.09574485     0.11202126     0.10134751     0.10393621
                0.08544319     0.15735814     0.12312026     0.10388306     0.02943256     0.00803189
                0.00269502     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2012   1  3     0      0       119.96  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00039374     0.01042668     0.04536653     0.10833995     0.15991690     0.16908725
                0.11185223     0.10350004     0.12242207     0.10086189     0.04285995     0.01986392
                0.00450227     0.00011357     0.00000000     0.00000000     0.00049302     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2012   2  3     0      0       3.00    0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.04000000     0.06666667     0.36000000
                0.28000000     0.10666667     0.06666667     0.05333333     0.01333333     0.01333333
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2013   1  3     0      0       141.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00031076     0.00826635     0.04840622     0.18377225
                0.25546424     0.23831458     0.13242000     0.07340381     0.03383920     0.01716330
                0.00642818     0.00176975     0.00044137     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2013   2  3     0      0       1.20    0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.03333333     0.06666667     0.23333333     0.46666667     0.16666667     0.03333333
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2014   1  3     0      0       50.88   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
```

```
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00486853
               0.03420662     0.14943202     0.25345626     0.29136535     0.16668853     0.06801615
               0.02262697     0.00535488     0.00398470     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000
2014   2  3   0       0       15.92  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00518691
               0.01580589     0.14519508     0.26636975     0.32264050     0.18093404     0.04798212
               0.01321244     0.00007982     0.00000000     0.00259345     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000
# 2015 1 3 (Was used, but small sample size, incidental landings, omit)
2015   1  -3  0       0       1.00   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.04000000     0.00000000
               0.04000000     0.00000000     0.00000000     0.00000000     0.04000000     0.00000000
               0.00000000     0.00000000     0.16000000     0.16000000     0.24000000     0.24000000
               0.08000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000
# 2015 2 3 (Not available)
# 2016 1 3 (Not available)
#
2005   2  5   0       0       10.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00270862     0.00270862     0.00000000
               0.00000000     0.01100873     0.01100873     0.12353364     0.12353364     0.06453880
               0.06453880     0.15773170     0.15773170     0.06426980     0.06426980     0.05009669
               0.05009669     0.01516183     0.01516183     0.00505394     0.00505394     0.00000000
               0.00000000     0.00168465     0.00168465     0.00336930     0.00336930     0.00168465
               0.00000000     0.00000000     0.00000000     0.00000000
2007   2  5   0       0       12.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.01871052     0.01871052     0.04456086
               0.04456086     0.07885461     0.07885461     0.07720993     0.07720993     0.09196321
               0.09196321     0.10803940     0.10803940     0.06881783     0.06881783     0.00321240
               0.00321240     0.00825866     0.00825866     0.00037258     0.00037258     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000
2009   2  5   0       0       19.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00071913
               0.00071913     0.00036184     0.00036184     0.00000000     0.00000000     0.00121512
               0.00121512     0.00265337     0.00265337     0.00332081     0.00332081     0.00555546
               0.00555546     0.00224440     0.00224440     0.00833426     0.00833426     0.05506318
               0.05506318     0.17107802     0.17107802     0.16580872     0.16580872     0.06954074
               0.06954074     0.01153821     0.01153821     0.00243023     0.00243023     0.00027301
               0.00000000     0.00000000     0.00000000     0.00000000
2010   2  5   0       0       18.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000449     0.00000449     0.00000000     0.00000000     0.00000000
               0.00000000     0.00015121     0.00015121     0.08020558     0.08020558     0.22135962
               0.22135962     0.08918809     0.08918809     0.04535153     0.04535153     0.00957193
               0.00957193     0.00287216     0.00287216     0.01710648     0.01710648     0.02239309
               0.02239309     0.00960401     0.00960401     0.00139900     0.00139900     0.00158562
               0.00000000     0.00000000     0.00000000     0.00000000
2011   2  5   0       0       12.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00966230
               0.00966230     0.00000000     0.00000000     0.00874343     0.00874343     0.09109599
               0.09109599     0.11348639     0.11348639     0.05587484     0.05587484     0.10595060
               0.10595060     0.08715280     0.08715280     0.02797210     0.02797210     0.00006153
               0.00006153     0.00000000     0.00000000     0.00000000
2012   2  5   0       0       18.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00087027     0.00087027     0.00043514     0.00043514     0.01933857
               0.01933857     0.15265050     0.15265050     0.18642185     0.18642185     0.07407997
               0.07407997     0.04749947     0.04749947     0.00758276     0.00758276     0.01112147
               0.01112147     0.00000000     0.00000000     0.00000000
2013   2  5   0       0       4.00   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.03553942     0.03553942     0.32050317
               0.32050317     0.10057675     0.10057675     0.04338066     0.04338066     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000
2014   2  5   0       0       6.00   0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
               0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00195881
```

```
                0.00195881     0.00000000     0.00000000     0.04068968     0.04068968     0.12361069
                0.12361069     0.00000000     0.00000000     0.00000000     0.00000000     0.01110877
                0.01110877     0.18187444     0.18187444     0.12041276     0.12041276     0.02034484
                0.02034484     0.00000000     0.00000000     0.00000000
2015   2  5     0       0      8.00    0.00000000     0.00000000     0.00000000     0.00000000     0.00003149
                0.00003149     0.00020758     0.00020758     0.02511719     0.02511719     0.11809357
                0.11809357     0.08903510     0.08903510     0.02052566     0.02052566     0.00228070
                0.00228070     0.00000000     0.00000000     0.02749376     0.02749376     0.03859413
                0.03859413     0.02441912     0.02441912     0.00723552     0.00723552     0.00343672
                0.00343672     0.04204884     0.04204884     0.06323913     0.06323913     0.03824149
                0.03824149     0.00000000     0.00000000     0.00000000
#
2008   1  5     0       0      27.00  0.01700544     0.01700544     0.02210707     0.02210707     0.00680218
                0.00680218     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00680218     0.00680218     0.02009720
                0.02009720     0.02164783     0.02164783     0.08951514     0.08951514     0.10939327
                0.10939327     0.14029251     0.14029251     0.05385909     0.05385909     0.01118376
                0.01118376     0.00129435     0.00129435     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000
2012   1  5     0       0      26.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00035481     0.00035481     0.00193496     0.00193496     0.13636929
                0.13636929     0.21595031     0.21595031     0.06930702     0.06930702     0.04528789
                0.04528789     0.02760803     0.02760803     0.00294741     0.00294741     0.00024028
                0.00024028     0.00000000     0.00000000     0.00000000
2013   1  5     0       0      23.00  0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00002651
                0.00002651     0.02839681     0.02839681     0.20512511     0.20512511     0.17157365
                0.17157365     0.07299605     0.07299605     0.02026224     0.02026224     0.00161961
                0.00161961     0.00000000     0.00000000     0.00000000
2014   1  5     0       0      7.00   0.00204979     0.00204979     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000369
                0.00000369     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00903077     0.00903077     0.15522242
                0.15522242     0.26099332     0.26099332     0.06138772     0.06138772     0.01131228
                0.01131228     0.00000000     0.00000000     0.00000000
2015   1  5     0       0      17.00  0.40403690     0.40403690     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000380     0.00000380     0.00000000
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000     0.00187125
                0.00187125     0.00561487     0.00561487     0.00192622     0.00192622     0.00374361
                0.00374361     0.02701399     0.02701399     0.04906669     0.04906669     0.00666849
                0.00666849     0.00005418     0.00005418     0.00000000
2016   1  5     0       0      12.00   0.02582573     0.02582573     0.00516515     0.00516515     0.00000000
                0.00000000     0.00516515     0.00516515     0.00019948     0.00019948     0.00080251
                0.00080251     0.00518937     0.00518937     0.03520717     0.03520717     0.15997810
                0.15997810     0.08620133     0.08620133     0.16424753     0.16424753     0.00260972
                0.00260972     0.00033790     0.00033790     0.00115483     0.00115483     0.00100394
                0.00100394     0.00189810     0.00189810     0.00277042     0.00277042     0.00195391
                0.00195391     0.00028966     0.00028966     0.00000000
#
9 # N_age bins

0 1 2 3 4 5 6 7 8

6  # N_ageerror definitions

#
0.5     1.5     2.5     3.5     4.5     5.5     6.5     7.5     8.5     9.5     10.5 # 1_CA_1981-06
0.2832  0.2832  0.289   0.8009  0.8038  0.9597  1.1156  1.2715  1.4274  1.5833  1.7392 # 1_CA_1981-06
0.5     1.5     2.5     3.5     4.5     5.5     6.5     7.5     8.5     9.5     10.5 # 2_CA_2007
0.2539  0.2539  0.3434  0.9205  0.9653  1.1743  1.3832  1.5922  1.8011  2.0101  2.219 # 2_CA_2007
0.5     1.5     2.5     3.5     4.5     5.5     6.5     7.5     8.5     9.5     10.5 # 3_CA_2008-09
0.4032  0.4032  0.4995  0.58    0.6902  0.8246  0.9727  1.0165  1.1144  1.2123  1.3102 # 3_CA_2008-09
0.5     1.5     2.5     3.5     4.5     5.5     6.5     7.5     8.5     9.5     10.5 # 4_CA_2010-13
0.2825  0.2825  0.2955  0.3125  0.3347  0.3637  0.4017  0.4046  0.4245  0.4445  0.4645 # 4_CA_2010-13
0.5     1.5     2.5     3.5     4.5     5.5     6.5     7.5     8.5     9.5     10.5 # 5_ORWA_all
0.26655 0.30145 0.3149  0.3615  0.3847  0.3961  0.4018  0.4047  0.4061  0.4352  0.4487 # 5_ORWA_all
0.5     1.5     2.5     3.5     4.5     5.5     6.5     7.5     8.5     9.5     10.5 # 6_CalCOFI_C
0.5386  0.5386  0.7547  0.8341  0.8634  0.8741  0.8781  0.8796  0.8801  0.8801  0.8801 # 6_CalCOFI_C
#
75 # N_age composition obs
```

```
3 # Length bin method: 1=poplenbins, 2=datalenbins, 3=lengths
-1 # Combine males into females at or below this bin number
# Age comps (CAAL)
# Year Season Fleet/Survey Gender Part Ageerr Lbin_lo Lbin_hi Nsamp datavector(female-male)
1993    1  1    0       0       1       -1      -1      2.72    0.00000000     0.00000000     0.11764706
                0.76470588     0.10294118     0.01470588     0.00000000     0.00000000     0.00000000
1994    1  1    0       0       1       -1  -1  11.76  0.02233392     0.46921325     0.31997955     0.15950127
                0.02897201     0.00000000     0.00000000     0.00000000     0.00000000
1995    1  1    0       0       1       -1  -1  4.76   0.11764706     0.56302521     0.25210084     0.06722689
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
1996    1  1    0       0       1       -1  -1  89.28  0.00000000     0.05567822     0.57869148     0.31936116
                0.04119642     0.00460375     0.00000000     0.00046897     0.00000000
1997    1  1    0       0       1       -1  -1  54.92  0.00393055     0.41526377     0.48143507     0.08999595
                0.00760341     0.00177125     0.00000000     0.00000000     0.00000000
1998    1  1    0       0       1       -1  -1  75.32  0.08752419     0.65178011     0.20556040     0.02738368
                0.02185746     0.00530475     0.00058942     0.00000000     0.00000000
1999    1  1    0       0       1       -1  -1  6.96   0.12068966     0.51724138     0.35632184     0.00574713
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
2000    1  1    0       0       1       -1  -1  22.64  0.05612282     0.21594669     0.47409550     0.23739199
                0.01419224     0.00225076     0.00000000     0.00000000     0.00000000
2001    1  1    0       0       1       -1  -1  37.24  0.19498424     0.24032396     0.10821490     0.29193947
                0.11194383     0.03989310     0.00899338     0.00370711     0.00000000
2002    1  1    0       0       1       -1  -1  30.32  0.17079894     0.53308456     0.23318285     0.04302452
                0.01864624     0.00126289     0.00000000     0.00000000     0.00000000
2003    1  1    0       0       1       -1  -1  17.76  0.56513500     0.22899483     0.18990839     0.01273176
                0.00323001     0.00000000     0.00000000     0.00000000     0.00000000
2004    1  1    0       0       1       -1  -1  33.52  0.00300111     0.90375628     0.06959324     0.00743078
                0.01147566     0.00000000     0.00474293     0.00000000     0.00000000
2005    1  1    0       0       1       -1  -1  35.24  0.09102697     0.26552164     0.59466314     0.04284618
                0.00412282     0.00121284     0.00060642     0.00000000     0.00000000
2006    1  1    0       0       1       -1  -1  69.76  0.00908783     0.64539166     0.30295669     0.04256381
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
2007    1  1    0       0       2       -1  -1  86.00  0.01357889     0.16055166     0.64593872     0.17061145
                0.00931929     0.00000000     0.00000000     0.00000000     0.00000000
2008    1  1    0       0       3       -1  -1  30.84  0.06153622     0.26350954     0.58776778     0.07218948
                0.01499698     0.00000000     0.00000000     0.00000000     0.00000000
2009    1  1    0       0       3       -1  -1  22.88  0.00349661     0.21120316     0.63114846     0.14041369
                0.01373808     0.00000000     0.00000000     0.00000000     0.00000000
2010    1  1    0       0       4       -1  -1  12.68  0.01577287     0.79179811     0.16719243     0.02523659
                0.00000000     0.00000000     0.00000000     0.00000000     0.00000000
2011    1  1    0       0       4       -1  -1  21.64  0.00000000     0.32278273     0.47187076     0.19905465
                0.00629186     0.00000000     0.00000000     0.00000000     0.00000000
2012    1  1    0       0       4       -1  -1  22.32  0.00335775     0.10053293     0.44773547     0.37325638
                0.05790999     0.01147166     0.00573583     0.00000000     0.00000000
2013    1  1    0       0       4       -1  -1  15.84  0.01132400     0.02443363     0.25675788     0.29354382
                0.33484537     0.04608165     0.01688430     0.00806468     0.00806468
2014    1  1    0       0       4       -1  -1  5.92   0.00009926     0.00000451     0.00000451     0.08063643
                0.53220043     0.28222750     0.08870007     0.01612729     0.00000000
# 2015 1 1 (Was used in lt comps, but small sample size/incidental landings, omit)
# 2016 1 1 (Not available)
#
1993    2  2    0       0       1       -1  -1  30.44  0.21106902     0.38434172     0.30704382     0.06010656
                0.02088125     0.01089044     0.00566720     0.00000000     0.00000000
1994    2  2    0       0       1       -1  -1  120.96 0.36945499     0.45924059     0.11019804     0.05280057
                0.00706495     0.00093579     0.00030505     0.00000000     0.00000000
1995    2  2    0       0       1       -1  -1  58.84  0.24589769     0.44769841     0.28115147     0.02299743
                0.00194198     0.00031302     0.00000000     0.00000000     0.00000000
1996    2  2    0       0       1       -1  -1  45.92  0.29892120     0.35526509     0.28407353     0.05385728
                0.00380762     0.00407529     0.00000000     0.00000000     0.00000000
1997    2  2    0       0       1       -1  -1  47.44  0.16769604     0.44927048     0.17462436     0.14077280
                0.05754727     0.00731508     0.00277398     0.00000000     0.00000000
1998    2  2    0       0       1       -1  -1  72.48  0.26761762     0.47815789     0.21604073     0.02580353
                0.00936489     0.00301533     0.00000000     0.00000000     0.00000000
1999    2  2    0       0       1       -1  -1  55.32  0.27314763     0.51943459     0.18108008     0.01831521
                0.00686090     0.00095133     0.00021026     0.00000000     0.00000000
2000    2  2    0       0       1       -1  -1  48.04  0.27341328     0.37293108     0.27881477     0.06382949
                0.01091465     0.00000000     0.00000000     0.00009674     0.00000000
2001    2  2    0       0       1       -1  -1  71.04  0.67276346     0.18270578     0.09872123     0.03669650
                0.00653717     0.00257586     0.00000000     0.00000000     0.00000000
2002    2  2    0       0       1       -1  -1  76.48  0.18899176     0.59397851     0.16841782     0.03741263
                0.00773647     0.00329546     0.00008367     0.00000000     0.00008367
2003    2  2    0       0       1       -1  -1  74.64  0.83351604     0.04116990     0.06930792     0.03300254
                0.01468797     0.00389736     0.00353461     0.00088365     0.00000000
2004    2  2    0       0       1       -1  -1  59.16  0.04238489     0.87005119     0.07242785     0.01265237
                0.00145970     0.00102400     0.00000000     0.00000000     0.00000000
2005    2  2    0       0       1       -1  -1  89.04  0.53994582     0.36702223     0.08416083     0.00500806
```

```
                 0.00132284     0.00090732     0.00072560     0.00045366     0.00045366
2006   2  2      0        0      1        -1   -1  105.16 0.20172661     0.63015996     0.15000726     0.01740041
                 0.00070577     0.00000000     0.00000000     0.00000000     0.00000000
2007   2  2      0        0      2        -1   -1  67.44  0.42021952     0.43386305     0.10589809     0.03396340
                 0.00544372     0.00061223     0.00000000     0.00000000     0.00000000
2008   2  2      0        0      3        -1   -1  39.76  0.19862191     0.52834154     0.21532639     0.05558720
                 0.00212296     0.00000000     0.00000000     0.00000000     0.00000000
2009   2  2      0        0      3        -1   -1  98.08  0.44090117     0.44149224     0.11209083     0.00372405
                 0.00179171     0.00000000     0.00000000     0.00000000     0.00000000
2010   2  2      0        0      4        -1   -1  31.40  0.50304830     0.32470002     0.01757707     0.02625377
                 0.05345083     0.06594583     0.00763583     0.00069417     0.00069417
2011   2  2      0        0      4        -1   -1  54.88  0.20910019     0.35249163     0.22419952     0.08833225
                 0.04648802     0.03648118     0.03009719     0.01083858     0.00197145
2012   2  2      0        0      4        -1   -1  8.92   0.01286056     0.18465132     0.56709595     0.19900628
                 0.03408414     0.00153450     0.00076725     0.00000000     0.00000000
2013   2  2      0        0      4        -1   -1  26.40  0.00400245     0.03541231     0.25560467     0.43215639
                 0.18609710     0.05679863     0.01021883     0.01366366     0.00604596
2014   2  2      0        0      4        -1   -1  13.88  0.19601085     0.54781269     0.21272334     0.00361995
                 0.01478894     0.02384416     0.00120007     0.00000000     0.00000000
# 2015 2 2 (Small sample size, omit)
#
1999   1  3      0        0      5        -1   -1  2.96   0.00000000     0.00000000     0.59151581     0.20074375
                 0.04758623     0.12952271     0.03063150     0.00000000     0.00000000
2000   1  3      0        0      5        -1   -1  66.64  0.00000000     0.00661920     0.20664268     0.39154056
                 0.21333728     0.10964756     0.05159158     0.01292370     0.00769745
2001   1  3      0        0      5        -1   -1  81.28  0.00000000     0.01319829     0.09882524     0.43321579
                 0.28807345     0.09650734     0.05247704     0.01444472     0.00325813
2002   1  3      0        0      5        -1   -1  110.32 0.00000000     0.00376606     0.02888569     0.14173143
                 0.37497785     0.24597782     0.11747427     0.05690067     0.03028621
2003   1  3      0        0      5        -1   -1  92.32  0.00000000     0.02102307     0.16425121     0.15811910
                 0.10310171     0.18273199     0.16023280     0.09892235     0.11161776
2004   1  3      0        0      5        -1   -1  66.56  0.00000000     0.18029041     0.09935404     0.14911095
                 0.11148963     0.14727065     0.15776410     0.06809703     0.08662319
2005   1  3      0        0      5        -1   -1  40.84  0.00000000     0.01355483     0.68729690     0.14494663
                 0.04909713     0.02077143     0.01635392     0.01781254     0.05016661
2006   1  3      0        0      5        -1   -1  26.92  0.00000000     0.00000000     0.01497099     0.60873284
                 0.20905176     0.07984672     0.04903877     0.00985519     0.02850373
2007   1  3      0        0      5        -1   -1  89.40  0.00000000     0.00000000     0.03684181     0.45391632
                 0.40243125     0.08105161     0.01657055     0.00464352     0.00454494
2008   1  3      0        0      5        -1   -1  94.00  0.00000000     0.00000000     0.00238411     0.12188750
                 0.50241139     0.30400027     0.05113905     0.01114247     0.00703520
2009   1  3      0        0      5        -1   -1  93.24  0.00000000     0.00000000     0.00497725     0.03834955
                 0.30673956     0.39095629     0.20858215     0.04278986     0.00760533
2010   1  3      0        0      5        -1   -1  33.76  0.00000000     0.00000000     0.00486375     0.03556323
                 0.20782114     0.39064640     0.24531203     0.09814472     0.01764872
2011   1  3      0        0      5        -1   -1  42.88  0.00000000     0.00357123     0.03311394     0.04935194
                 0.12486830     0.30299646     0.28571874     0.16388915     0.03649023
2012   1  3      0        0      5        -1   -1  118.24 0.00000000     0.00058319     0.34026869     0.21053451
                 0.06934004     0.04548403     0.07671303     0.10090398     0.15617254
2013   1  3      0        0      5        -1   -1  138.92 0.00000000     0.00000000     0.03331987     0.59242727
                 0.18326590     0.04825943     0.03647473     0.04773246     0.05852034
2014   1  3      0        0      5        -1   -1  49.68  0.00000000     0.00000000     0.00000000     0.04583663
                 0.65905889     0.17432845     0.05249064     0.03186569     0.03641970
# 2015 1 3 (Not available)
# 2016 1 3 (Not available)
2008   1  5      0        0      6        -1       -1      27      0.08731171     0.04380052     0.26575501
                 0.36538608     0.19445315     0.02418848     0.00829887     0.00773572     0.00307052
                 #_ATM_0807
2012   1  5      0        0      6        -1       -1      26      0.00001520     0.01677598     0.23653229
                 0.40645653     0.24558422     0.04880821     0.02070141     0.01687986     0.00824632
                 #_ATM_1207
2013   1  5      0        0      6        -1       -1      23      0.00000100     0.00499673     0.15131654
                 0.36165968     0.26882845     0.10206614     0.05161105     0.03794263     0.02157775
                 #_ATM_1307
2014   1  5      0        0      6        -1       -1      7       0.00401556     0.00178747     0.09319014
                 0.28674884     0.25004562     0.16133568     0.09638624     0.06409438     0.04239605
                 #_ATM_1407
2015   1  5      0        0      6        -1       -1      17      0.79121499     0.01653593     0.01533798
                 0.04501253     0.04114013     0.03734153     0.02580894     0.01569317     0.01191480
                 #_ATM_1507
2016   1  5      0        0      6        -1       -1      12      0.07423564     0.14454549     0.36224125
                 0.29585694     0.11067899     0.00621347     0.00285455     0.00212853     0.00124515
                 #_ATM_1607
2005   2  5      0        0      6        -1       -1      10      0.04097055     0.26719664     0.40185645
                 0.20502934     0.06231908     0.01777227     0.00392903     0.00072135     0.00020532
                 #_ATM_0604
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2007    2  5    0       0       6       -1      -1      12      0.01096180      0.12544972      0.29386586
                0.32190324      0.17145667      0.06094926      0.01307678      0.00178334      0.00055332
                #_ATM_0804
2009    2  5    0       0       6       -1      -1      19      0.00481952      0.03387770      0.13939793
                0.35867340      0.29524038      0.12936332      0.03219387      0.00494117      0.00149270
                #_ATM_1004
2010    2  5    0       0       6       -1      -1      18      0.03694126      0.28170239      0.40268130
                0.17414783      0.06689676      0.02781991      0.00788978      0.00149273      0.00042807
                #_ATM_1104
2011    2  5    0       0       6       -1      -1      12      0.00125332      0.02871729      0.12482482
                0.31089259      0.30276895      0.16512145      0.05264767      0.01074155      0.00303233
                #_ATM_1204
2012    2  5    0       0       6       -1      -1      18      0.00021479      0.01468604      0.09973243
                0.33734389      0.32554332      0.16291630      0.04769501      0.00923904      0.00262919
                #_ATM_1304
2013    2  5    0       0       6       -1      -1      4       0.00001100      0.00230515      0.03046514
                0.23762094      0.37986376      0.24421439      0.08331543      0.01732321      0.00488095
                #_ATM_1404
2014    2  5    0       0       6       -1      -1      6       0.00096497      0.02929461      0.11198702
                0.22449596      0.29105970      0.21911163      0.09227308      0.02431374      0.00649928
                #_ATM_1504
2015    2  5    0       0       6       -1      -1      8       0.15162306      0.25553182      0.17387315
                0.11993204      0.13544885      0.10271864      0.04501109      0.01254897      0.00331238
                #_ATM_1604
#
75 # N_mean_length-at-age_obs_ (Not used)
# Year Season Fleet/Survey Gender Part Ageerr Nsamp datavector(female-male) Nfish (female-male)
1993    1  1    0       0       1       2.72    -1.0    -1.0    18.0    18.8    19.3    -1.0    -1.0    -1.0    -1.0
                0.00    0.00    0.32    2.08    0.28    0.00    0.00    0.00    0.00
1994    1  1    0       0       1       11.76   17.8    17.2    18.4    18.9    20.6    -1.0    -1.0    -1.0    -1.0
                0.32    5.32    3.80    2.00    0.32    0.00    0.00    0.00    0.00
1995    1  1    0       0       1       4.76    15.0    18.1    17.2    19.0    -1.0    -1.0    -1.0    -1.0    -1.0
                0.56    2.68    1.20    0.32    0.00    0.00    0.00    0.00    0.00
1996    1  1    0       0       1       89.28   -1.0    17.5    18.5    19.2    19.6    21.6    -1.0    -1.0    -1.0
                0.00    5.12    52.28   27.72   3.68    0.44    0.00    0.00    0.00
1997    1  1    0       0       1       54.96   12.3    16.4    18.3    19.6    21.6    -1.0    -1.0    -1.0    -1.0
                0.16    25.80   24.68   3.92    0.32    0.00    0.00    0.00    0.00
1998    1  1    0       0       1       75.32   12.7    14.5    17.0    19.6    21.0    21.9    -1.0    -1.0    -1.0
                3.56    53.52   14.84   1.76    1.24    0.36    0.00    0.00    0.00
1999    1  1    0       0       1       6.96    13.7    15.1    15.7    -1.0    -1.0    -1.0    -1.0    -1.0    -1.0
                0.84    3.60    2.48    0.00    0.00    0.00    0.00    0.00    0.00
2000    1  1    0       0       1       22.64   14.1    16.7    17.1    17.1    18.1    -1.0    -1.0    -1.0    -1.0
                1.08    3.92    10.64   6.56    0.36    0.00    0.00    0.00    0.00
2001    1  1    0       0       1       37.24   11.6    17.3    17.5    21.3    22.1    23.3    23.5    23.8    -1.0
                8.36    7.68    4.28    10.68   4.24    1.52    0.36    0.12    0.00
2002    1  1    0       0       1       30.32   16.1    16.3    17.6    18.4    21.6    -1.0    -1.0    -1.0    -1.0
                5.36    16.48   6.84    1.16    0.44    0.00    0.00    0.00    0.00
2003    1  1    0       0       1       17.76   12.0    16.9    18.2    20.0    -1.0    -1.0    -1.0    -1.0    -1.0
                8.56    4.48    4.36    0.32    0.00    0.00    0.00    0.00    0.00
2004    1  1    0       0       1       33.52   13.9    15.6    16.9    18.5    22.1    -1.0    -1.0    -1.0    -1.0
                0.16    30.12   2.72    0.20    0.24    0.00    0.00    0.00    0.00
2005    1  1    0       0       1       35.24   13.4    14.3    16.4    18.3    21.8    -1.0    -1.0    -1.0    -1.0
                4.72    12.56   16.48   1.20    0.16    0.00    0.00    0.00    0.00
2006    1  1    0       0       1       69.76   14.5    15.4    16.9    18.2    -1.0    -1.0    -1.0    -1.0    -1.0
                0.92    47.36   18.60   2.88    0.00    0.00    0.00    0.00    0.00
2007    1  1    0       0       2       86.00   12.9    15.2    16.7    19.1    20.5    -1.0    -1.0    -1.0    -1.0
                2.24    16.16   52.00   14.80   0.80    0.00    0.00    0.00    0.00
2008    1  1    0       0       3       30.84   14.1    16.9    17.4    18.9    21.2    -1.0    -1.0    -1.0    -1.0
                1.60    8.56    18.08   2.24    0.36    0.00    0.00    0.00    0.00
2009    1  1    0       0       3       22.88   -1.0    16.4    17.4    17.9    19.5    -1.0    -1.0    -1.0    -1.0
                0.00    5.40    13.20   3.92    0.28    0.00    0.00    0.00    0.00
2010    1  1    0       0       4       12.68   15.8    16.0    18.2    17.8    -1.0    -1.0    -1.0    -1.0    -1.0
                0.20    10.04   2.12    0.32    0.00    0.00    0.00    0.00    0.00
2011    1  1    0       0       4       21.64   -1.0    17.4    17.7    19.4    20.9    -1.0    -1.0    -1.0    -1.0
                0.00    5.64    10.76   5.12    0.12    0.00    0.00    0.00    0.00
2012    1  1    0       0       4       22.32   -1.0    16.4    18.9    19.9    20.7    21.3    22.6    -1.0    -1.0
                0.00    1.60    10.44   8.52    1.36    0.24    0.12    0.00    0.00
2013    1  1    0       0       4       8.84    11.5    14.0    20.7    21.1    21.8    22.3    22.9    -1.0    -1.0
                0.60    0.52    1.32    2.56    3.04    0.60    0.12    0.00    0.00
2014    1  1    0       0       4       5.92    13.9    -1.0    -1.0    22.6    22.8    22.8    22.8    -1.0    -1.0
                0.88    0.00    0.00    0.40    2.64    1.40    0.44    0.00    0.00
1993    2  2    0       0       1       30.44   15.8    17.5    18.4    20.6    22.1    23.6    24.5    -1.0    -1.0
                6.44    11.52   9.24    1.96    0.72    0.40    0.16    0.00    0.00
1994    2  2    0       0       1       120.96  17.9    17.2    18.7    19.7    20.6    22.1    -1.0    -1.0    -1.0
                47.44   54.28   12.08   6.24    0.76    0.12    0.00    0.00    0.00
1995    2  2    0       0       1       58.84   15.5    18.3    17.3    19.3    20.5    -1.0    -1.0    -1.0    -1.0
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			13.20	29.12	14.96	1.36	0.16	0.00	0.00	0.00	0.00				
1996	2	2	0	0	1	45.92	13.9	17.9	18.5	19.2	22.2	22.7	-1.0	-1.0	-1.0
			14.00	15.16	13.80	2.60	0.16	0.20	0.00	0.00	0.00				
1997	2	2	0	0	1	47.44	13.2	16.6	19.5	21.0	21.7	22.2	23.8	-1.0	-1.0
			8.36	15.04	9.64	9.84	3.76	0.64	0.16	0.00	0.00				
1998	2	2	0	0	1	72.48	13.4	15.1	17.1	19.6	21.0	21.9	-1.0	-1.0	-1.0
			23.24	33.12	13.80	1.52	0.60	0.20	0.00	0.00	0.00				
1999	2	2	0	0	1	55.32	15.0	15.3	16.0	17.6	21.6	-1.0	-1.0	-1.0	-1.0
			16.72	26.68	10.44	1.04	0.36	0.00	0.00	0.00	0.00				
2000	2	2	0	0	1	48.04	14.1	17.1	17.2	17.6	20.7	-1.0	-1.0	-1.0	-1.0
			13.04	19.12	12.76	2.60	0.48	0.00	0.00	0.00	0.00				
2001	2	2	0	0	1	71.08	13.1	17.5	18.0	21.4	22.5	23.3	-1.0	-1.0	-1.0
			49.64	13.44	5.28	2.20	0.40	0.12	0.00	0.00	0.00				
2002	2	2	0	0	1	76.48	16.5	16.7	17.8	18.9	21.7	22.8	-1.0	-1.0	-1.0
			12.88	43.52	14.92	3.92	0.92	0.24	0.00	0.00	0.00				
2003	2	2	0	0	1	74.64	13.4	16.9	18.5	20.9	22.1	21.9	23.9	-1.0	-1.0
			63.08	2.76	4.60	2.16	1.24	0.40	0.32	0.00	0.00				
2004	2	2	0	0	1	59.16	14.2	16.0	17.6	19.7	-1.0	-1.0	-1.0	-1.0	-1.0
			3.32	50.76	4.36	0.60	0.00	0.00	0.00	0.00	0.00				
2005	2	2	0	0	1	89.04	14.4	14.8	16.9	19.2	21.8	23.4	24.6	-1.0	-1.0
			44.68	31.32	11.56	0.80	0.16	0.16	0.20	0.00	0.00				
2006	2	2	0	0	1	105.16	14.9	15.8	18.2	19.3	21.2	-1.0	-1.0	-1.0	-1.0
			17.08	61.52	23.04	3.40	0.12	0.00	0.00	0.00	0.00				
2007	2	2	0	0	2	67.44	13.4	16.3	17.3	20.1	21.7	21.4	-1.0	-1.0	-1.0
			22.96	27.76	10.64	5.12	0.84	0.12	0.00	0.00	0.00				
2008	2	2	0	0	3	39.76	15.2	17.2	17.6	19.0	21.8	-1.0	-1.0	-1.0	-1.0
			7.16	21.88	8.44	2.08	0.20	0.00	0.00	0.00	0.00				
2009	2	2	0	0	3	98.08	14.2	17.3	17.6	18.0	20.1	-1.0	-1.0	-1.0	-1.0
			49.52	37.36	10.56	0.48	0.16	0.00	0.00	0.00	0.00				
2010	2	2	0	0	4	31.40	16.6	16.9	19.1	20.8	21.5	22.1	23.0	-1.0	-1.0
			13.84	7.96	0.68	1.52	3.08	3.80	0.44	0.00	0.00				
2011	2	2	0	0	4	54.88	13.4	18.1	18.2	19.8	21.0	21.7	22.1	23.0	-1.0
			9.40	18.92	14.96	5.24	2.44	2.08	1.28	0.48	0.00				
2012	2	2	0	0	4	8.92	-1.0	18.2	19.1	20.1	20.9	-1.0	-1.0	-1.0	-1.0
			0.00	1.36	4.72	2.32	0.32	0.00	0.00	0.00	0.00				
2013	2	2	0	0	4	26.40	16.0	17.5	20.9	21.8	22.4	22.8	24.5	23.6	-1.0
			0.28	1.80	6.24	11.28	4.84	1.52	0.16	0.20	0.00				
2014	2	2	0	0	4	13.88	14.0	16.0	17.5	-1.0	23.2	23.3	-1.0	-1.0	-1.0
			2.32	7.36	2.56	0.00	0.40	1.12	0.00	0.00	0.00				
1999	1	3	0	0	5	2.96	-1.0	-1.0	17.8	19.7	21.0	22.5	-1.0	-1.0	-1.0
			0.00	0.00	1.56	0.60	0.20	0.52	0.00	0.00	0.00				
2000	1	3	0	0	5	66.64	-1.0	19.9	19.1	20.7	21.5	22.1	22.6	22.7	22.1
			0.00	0.44	12.40	25.16	14.76	8.16	4.00	1.12	0.60				
2001	1	3	0	0	5	81.28	-1.0	16.3	20.4	20.8	21.2	22.1	22.8	22.6	23.4
			0.00	1.76	8.68	34.96	22.88	7.56	4.08	1.12	0.24				
2002	1	3	0	0	5	110.32	-1.0	19.5	20.7	21.7	22.0	22.3	22.8	23.2	23.5
			0.00	0.96	4.28	15.36	39.76	26.68	12.80	6.64	3.84				
2003	1	3	0	0	5	92.32	-1.0	18.9	19.6	20.4	21.8	22.5	22.7	22.9	23.6
			0.00	1.80	15.12	14.40	10.40	17.80	14.88	8.08	9.84				
2004	1	3	0	0	5	66.56	-1.0	16.9	19.7	21.2	22.5	23.1	23.4	23.5	23.6
			0.00	18.80	8.80	9.76	6.44	7.64	8.04	3.12	3.96				
2005	1	3	0	0	5	40.84	-1.0	17.0	17.5	19.7	21.3	22.6	23.3	24.0	24.1
			0.00	0.96	22.12	5.48	2.72	1.76	1.52	1.64	4.64				
2006	1	3	0	0	5	26.92	-1.0	-1.0	19.1	19.5	19.8	21.5	22.6	23.5	24.0
			0.00	0.00	0.48	17.64	5.40	1.80	0.76	0.32	0.52				
2007	1	3	0	0	5	89.40	-1.0	-1.0	18.6	19.3	19.7	20.1	21.7	22.7	24.4
			0.00	0.00	3.00	38.36	37.80	7.76	1.68	0.40	0.40				
2008	1	3	0	0	5	94.00	-1.0	-1.0	18.5	19.2	19.9	20.3	21.0	21.8	22.8
			0.00	0.00	0.24	11.76	45.96	29.12	5.24	1.08	0.60				
2009	1	3	0	0	5	93.24	-1.0	-1.0	19.1	19.1	19.5	19.9	20.3	21.0	21.8
			0.00	0.00	0.64	4.16	28.68	35.48	19.56	4.00	0.72				
2010	1	3	0	0	5	33.76	-1.0	-1.0	16.4	19.9	19.9	20.0	20.2	20.3	21.0
			0.00	0.00	0.16	1.12	6.88	13.04	8.40	3.48	0.68				
2011	1	3	0	0	5	42.88	-1.0	17.4	19.0	20.0	20.7	20.9	21.0	21.1	20.3
			0.00	0.12	1.24	2.12	5.16	13.08	12.60	7.04	1.52				
2012	1	3	0	0	5	118.24	-1.0	19.9	19.8	20.1	20.8	21.4	21.7	21.8	21.9
			0.00	0.12	41.72	25.04	8.12	5.44	8.92	11.76	17.12				
2013	1	3	0	0	5	138.92	-1.0	-1.0	20.7	20.9	21.1	21.3	22.0	22.2	22.2
			0.00	0.00	4.24	80.44	26.12	6.80	5.52	6.96	8.84				
2014	1	3	0	0	5	49.68	-1.0	-1.0	-1.0	21.9	22.0	22.0	22.1	22.7	22.8
			0.00	0.00	0.00	2.40	32.68	8.64	2.60	1.60	1.76				
2008	1	5	0	0	6	28.56	10.2	-1.0	20.0	20.8	21.6	22.1	-1.0	-1.0	-1.0
			1.08	0.00	3.24	12.48	11.08	0.60	0.00	0.00	0.00				
2012	1	5	0	0	6	23.16	-1.0	20.4	20.8	21.1	22.0	23.1	23.7	23.8	23.9
			0.00	0.36	6.00	7.00	3.28	2.40	1.60	1.60	0.92				
2013	1	5	0	0	6	14.16	-1.0	-1.0	22.3	22.4	22.4	23.7	24.2	23.8	24.3

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                0.00   0.00   3.88   6.48   1.60   1.00   0.80   0.16   0.24
2014   1  5     0      0      6      8.48   -1.0   18.7   23.5   23.7   23.7   24.2   25.0   -1.0   -1.0
                0.00   0.12   2.40   3.96   1.40   0.20   0.24   0.00   0.00
2015   1  5     0      0      6      7.44   7.2           21.4   22.8   24.6   25.1   25.2   25.0   -1.0
                -1.0   3.36   0.20   0.16   0.60   2.12   0.76   0.12   0.00   0.00
2016   1  5     0      0      6      10.44  -1.0   17.1   21.4   22.8   24.6   25.1   24.5   25.6   -1.0
                0.00   2.04   4.28   2.32   0.76   0.76   0.12   0.12   0.00
2005   2  5     0      0      6      11.56  16.3   17.8   18.9   19.0   21.2   -1.0   -1.0   -1.0   -1.0
                0.44   1.80   6.40   2.44   0.36   0.00   0.00   0.00   0.00
2007   2  5     0      0      6      18.2   -1.0   17.7   19.2   21.4   21.7   21.6   -1.0   -1.0   -1.0
                0.00   0.12   2.64   11.80  3.00   0.60   0.00   0.00   0.00
2009   2  5     0      0      6      34.72  -1.0   17.0   20.0   21.8   22.1   22.3   22.9   24.3   -1.0
                0.00   0.68   0.84   7.88   15.60  8.00   1.56   0.12   0.00
2010   2  5     0      0      6      30.64  17.7   17.8   18.6   21.0   22.8   23.0   23.2   23.1   -1.0
                0.20   7.16   8.00   3.84   5.72   3.96   1.52   0.24   0.00
2011   2  5     0      0      6      13.68  -1.0   20.3   20.7   21.8   22.9   23.6   23.3   23.3   -1.0
                0.00   1.16   4.48   2.20   2.44   1.88   1.28   0.24   0.00
2012   2  5     0      0      6      8.68   -1.0   -1.0   21.6   21.8   22.2   23.3   23.7   24.3   23.9
                0.00   0.00   1.84   3.76   1.20   0.52   0.64   0.36   0.32
2013   2  5     0      0      6      0.64   -1.0   -1.0   23.1   23.3   23.2   -1.0   -1.0   -1.0   -1.0
                0.00   0.00   0.24   0.20   0.16   0.00   0.00   0.00   0.00
2014   2  5     0      0      6      2.44   19.0   18.7   24.1   24.1   24.3   24.6   25.0   -1.0   -1.0
                0.12   0.12   0.20   0.24   0.80   0.72   0.16   0.00   0.00
2015   2  5     0      0      6      4.28   14.4   21.4   22.8   24.6   25.1   20.0   -1.0   -1.0   -1.0
                4.08   2.44   0.56   0.32   0.48   0.16   0.00   0.00   0.00
#
0 # N_environment variables
0 # N_environment obs
0 # N_sizefreq methods to read in
0 # No tag data
0 # No morph composition data
999 # End of file
```

WTATAGE.SS

```
184  #_user_must_replace_this_value_with_number_of_lines_with_wtatage_below

10 # maxage

# if yr=-yr, then fill remaining years for that seas, growpattern, gender, fleet

# fleet 0 contains begin season pop WT

# fleet -1 contains mid season pop WT

# fleet -2 contains maturity*fecundity

#yr seas gender growpattern birthseas fleet  0 1 2 3 4 5 6 7 8 9 10

-1993  2  1    1      1      -2     0.0046 0.0354 0.0773 0.1100 0.1339 0.1515 0.1644 0.1739 0.1808 0.1858
               0.1939 #_fecundity*maturity from T_2017_abbrev with Bev's new ogive
-1993  1  1    1      1      -1     0.0161 0.0542 0.0837 0.1103 0.1323 0.1497 0.1630 0.1729 0.1801 0.1854
               0.1941 #_Popn S1 Mid-season from T_2017_abbrev
-1993  2  1    1      1      -1     0.0396 0.0691 0.0975 0.1219 0.1416 0.1568 0.1683 0.1768 0.1830 0.1875
               0.1948 #_Popn S2 Mid-season from T_2017_abbrev
-1993  1  1    1      1      0      0.0075 0.0469 0.0765 0.1040 0.1273 0.1458 0.1600 0.1707 0.1785 0.1842
               0.1936 #_Popn S1 Beg-season from T_2017_abbrev
-1993  2  1    1      1      0      0.0327 0.0617 0.0907 0.1162 0.1371 0.1534 0.1657 0.1749 0.1816 0.1865
               0.1944 #_Popn S2 Beg-season from T_2017_abbrev
1993   1  1    1      1      1      0.0210 0.0362 0.0771 0.0620 0.0744 0.0886 0.1959 0.2205 0.2113 0.1831
               0.1906 #_MexCal_S1_Sem1
1994   1  1    1      1      1      0.0210 0.0723 0.0885 0.0996 0.1278 0.1508 0.1777 0.1959 0.2205 0.2113
               0.1906 #_MexCal_S1_Sem1
1995   1  1    1      1      1      0.0429 0.0581 0.0848 0.0885 0.1117 0.1355 0.1547 0.1788 0.1959 0.2205
               0.2113 #_MexCal_S1_Sem1
1996   1  1    1      1      1      0.0210 0.0825 0.0977 0.1098 0.1173 0.1288 0.1547 0.1652 0.1798 0.1959
               0.2205 #_MexCal_S1_Sem1
1997   1  1    1      1      1      0.0340 0.0598 0.0844 0.1043 0.1361 0.1600 0.1574 0.1652 0.1728 0.1831
               0.1959 #_MexCal_S1_Sem1
1998   1  1    1      1      1      0.0260 0.0446 0.0743 0.1086 0.1289 0.1450 0.1626 0.1721 0.1728 0.1831
               0.1906 #_MexCal_S1_Sem1
1999   1  1    1      1      1      0.0330 0.0487 0.0550 0.0792 0.1346 0.1355 0.1547 0.1652 0.1728 0.1831
               0.1906 #_MexCal_S1_Sem1
2000   1  1    1      1      1      0.0393 0.0658 0.0720 0.0712 0.0889 0.1606 0.1547 0.1652 0.1728 0.1831
               0.1906 #_MexCal_S1_Sem1
2001   1  1    1      1      1      0.0210 0.0772 0.0959 0.1325 0.1513 0.1218 0.1866 0.1633 0.1728 0.1831
```

```
                0.1906  #_MexCal_S1_Sem1
2002    1  1    1       1       1       0.0630  0.0668  0.0868  0.0958  0.1405  0.1556  0.1547  0.1866  0.1728  0.1831
                0.1906  #_MexCal_S1_Sem1
2003    1  1    1       1       1       0.0219  0.0734  0.0945  0.1191  0.1267  0.1476  0.1685  0.1652  0.1866  0.1831
                0.1906  #_MexCal_S1_Sem1
2004    1  1    1       1       1       0.0383  0.0530  0.0753  0.0952  0.1295  0.1512  0.1547  0.1652  0.1728  0.1866
                0.1906  #_MexCal_S1_Sem1
2005    1  1    1       1       1       0.0329  0.0416  0.0623  0.0852  0.1450  0.1398  0.1692  0.1652  0.1728  0.1831
                0.1906  #_MexCal_S1_Sem1
2006    1  1    1       1       1       0.0411  0.0477  0.0645  0.0795  0.1077  0.1581  0.1552  0.1840  0.1728  0.1831
                0.1906  #_MexCal_S1_Sem1
2007    1  1    1       1       1       0.0270  0.0490  0.0670  0.0906  0.1103  0.1253  0.1743  0.1840  0.1901  0.1831
                0.1906  #_MexCal_S1_Sem1
2008    1  1    1       1       1       0.0380  0.0671  0.0747  0.0931  0.1307  0.1581  0.1415  0.1840  0.1901  0.1941
                0.1906  #_MexCal_S1_Sem1
2009    1  1    1       1       1       0.0237  0.0642  0.0762  0.0800  0.1064  0.1380  0.1743  0.1840  0.1901  0.1941
                0.1992  #_MexCal_S1_Sem1
2010    1  1    1       1       1       0.0534  0.0585  0.0836  0.0818  0.1105  0.1197  0.1427  0.1840  0.1901  0.1941
                0.1992  #_MexCal_S1_Sem1
2011    1  1    1       1       1       0.0237  0.0812  0.0845  0.0967  0.1113  0.1272  0.1381  0.1481  0.1901  0.1941
                0.1992  #_MexCal_S1_Sem1
2012    1  1    1       1       1       0.0237  0.0630  0.0984  0.1141  0.1257  0.1302  0.1387  0.1840  0.1901  0.1941
                0.1992  #_MexCal_S1_Sem1
2013    1  1    1       1       1       0.0214  0.0452  0.1398  0.1365  0.1473  0.1512  0.1723  0.1592  0.1901  0.1941
                0.1992  #_MexCal_S1_Sem1
-2014   1  1    1       1       1       0.0323  0.0577  0.0803  0.1601  0.1690  0.1693  0.1659  0.1840  0.1901  0.1941
                0.1992  #_MexCal_S1_Sem1
1993    2  1    1       1       1       0.0210  0.0362  0.0771  0.0620  0.0744  0.0886  0.1959  0.2205  0.2113  0.1831
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
1994    2  1    1       1       1       0.0210  0.0723  0.0885  0.0996  0.1278  0.1508  0.1777  0.1959  0.2205  0.2113
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
1995    2  1    1       1       1       0.0429  0.0581  0.0848  0.0885  0.1117  0.1355  0.1547  0.1788  0.1959  0.2205
                0.2113  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
1996    2  1    1       1       1       0.0210  0.0825  0.0977  0.1098  0.1173  0.1288  0.1547  0.1652  0.1798  0.1959
                0.2205  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
1997    2  1    1       1       1       0.0340  0.0598  0.0844  0.1043  0.1361  0.1600  0.1574  0.1652  0.1728  0.1831
                0.1959  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
1998    2  1    1       1       1       0.0260  0.0446  0.0743  0.1086  0.1289  0.1450  0.1626  0.1721  0.1728  0.1831
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
1999    2  1    1       1       1       0.0330  0.0487  0.0550  0.0792  0.1346  0.1355  0.1547  0.1652  0.1728  0.1831
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2000    2  1    1       1       1       0.0393  0.0658  0.0720  0.0712  0.0889  0.1606  0.1547  0.1652  0.1728  0.1831
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2001    2  1    1       1       1       0.0210  0.0772  0.0959  0.1325  0.1513  0.1218  0.1866  0.1633  0.1728  0.1831
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2002    2  1    1       1       1       0.0630  0.0668  0.0868  0.0958  0.1405  0.1556  0.1547  0.1866  0.1728  0.1831
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2003    2  1    1       1       1       0.0219  0.0734  0.0945  0.1191  0.1267  0.1476  0.1685  0.1652  0.1866  0.1831
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2004    2  1    1       1       1       0.0383  0.0530  0.0753  0.0952  0.1295  0.1512  0.1547  0.1652  0.1728  0.1866
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2005    2  1    1       1       1       0.0329  0.0416  0.0623  0.0852  0.1450  0.1398  0.1692  0.1652  0.1728  0.1831
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2006    2  1    1       1       1       0.0411  0.0477  0.0645  0.0795  0.1077  0.1581  0.1552  0.1840  0.1728  0.1831
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2007    2  1    1       1       1       0.0270  0.0490  0.0670  0.0906  0.1103  0.1253  0.1743  0.1840  0.1901  0.1831
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2008    2  1    1       1       1       0.0380  0.0671  0.0747  0.0931  0.1307  0.1581  0.1415  0.1840  0.1901  0.1941
                0.1906  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2009    2  1    1       1       1       0.0237  0.0642  0.0762  0.0800  0.1064  0.1380  0.1743  0.1840  0.1901  0.1941
                0.1992  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2010    2  1    1       1       1       0.0534  0.0585  0.0836  0.0818  0.1105  0.1197  0.1427  0.1840  0.1901  0.1941
                0.1992  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2011    2  1    1       1       1       0.0237  0.0812  0.0845  0.0967  0.1113  0.1272  0.1381  0.1481  0.1901  0.1941
                0.1992  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2012    2  1    1       1       1       0.0237  0.0630  0.0984  0.1141  0.1257  0.1302  0.1387  0.1840  0.1901  0.1941
                0.1992  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
2013    2  1    1       1       1       0.0214  0.0452  0.1398  0.1365  0.1473  0.1512  0.1723  0.1592  0.1901  0.1941
                0.1992  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
-2014   2  1    1       1       1       0.0323  0.0577  0.0803  0.1601  0.1690  0.1693  0.1659  0.1840  0.1901  0.1941
                0.1992  #_MexCal_S1_Sem2_(same_as_MexCal_S2)
1993    1  1    1       1       2       0.0520  0.0724  0.0866  0.1240  0.1488  0.1772  0.1959  0.2205  0.2043  0.1866
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
1994    1  1    1       1       2       0.0440  0.0723  0.0885  0.0996  0.1317  0.1527  0.1782  0.1959  0.2205  0.2043
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
1995    1  1    1       1       2       0.0493  0.0628  0.0973  0.0885  0.1238  0.1417  0.1559  0.1793  0.1959  0.2205
```

```
                0.2043  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
1996    1  1    1       1       2       0.0354 0.0835 0.1010  0.1230  0.1588  0.1431  0.1559  0.1706  0.1803  0.1959
                0.2205  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
1997    1  1    1       1       2       0.0393 0.0616 0.1008  0.1256  0.1406  0.1613  0.1718  0.1706  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
1998    1  1    1       1       2       0.0338 0.0496 0.0743  0.1216  0.1322  0.1498  0.1639  0.1724  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
1999    1  1    1       1       2       0.0474 0.0498 0.0581  0.0840  0.1476  0.1417  0.1559  0.1706  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2000    1  1    1       1       2       0.0582 0.0808 0.1022  0.0781  0.1053  0.1736  0.1559  0.1706  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2001    1  1    1       1       2       0.0311 0.0820 0.0958  0.1365  0.1535  0.1382  0.1866  0.1706  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2002    1  1    1       1       2       0.0682 0.0807 0.1030  0.1113  0.1441  0.1578  0.1559  0.1866  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2003    1  1    1       1       2       0.0315 0.0744 0.0949  0.1243  0.1422  0.1511  0.1791  0.1706  0.1866  0.1866
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2004    1  1    1       1       2       0.0390 0.0576 0.0763  0.1103  0.1347  0.1602  0.1559  0.1706  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2005    1  1    1       1       2       0.0403 0.0445 0.0653  0.0913  0.1516  0.1450  0.1782  0.1706  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2006    1  1    1       1       2       0.0451 0.0518 0.0793  0.0931  0.1240  0.1647  0.1655  0.1860  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2007    1  1    1       1       2       0.0326 0.0619 0.0678  0.1019  0.1274  0.1267  0.1777  0.1860  0.1913  0.1866
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2008    1  1    1       1       2       0.0511 0.0716 0.0773  0.0997  0.1356  0.1647  0.1563  0.1860  0.1913  0.1947
                0.1959  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2009    1  1    1       1       2       0.0372 0.0739 0.0790  0.0952  0.1065  0.1403  0.1777  0.1860  0.1913  0.1947
                0.1995  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2010    1  1    1       1       2       0.0673 0.0715 0.0934  0.1166  0.1258  0.1329  0.1451  0.1860  0.1913  0.1947
                0.1995  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2011    1  1    1       1       2       0.0296 0.0898 0.0993  0.1000  0.1205  0.1286  0.1433  0.1512  0.1913  0.1947
                0.1995  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2012    1  1    1       1       2       0.0370 0.0833 0.1175  0.1307  0.1385  0.1513  0.1490  0.1860  0.1913  0.1947
                0.1995  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
2013    1  1    1       1       2       0.0563 0.0773 0.1499  0.1402  0.1489  0.1599  0.1850  0.1694  0.1913  0.1947
                0.1995  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
-2014   1  1    1       1       2       0.0344 0.0591 0.0833  0.1601  0.1700  0.1721  0.0830  0.1860  0.1913  0.1947
                0.1995  #_MexCal_S2_Sem1_(same_as_MexCal_S1)
1993    2  1    1       1       2       0.0520  0.0724  0.0866  0.1240  0.1488  0.1772  0.1959  0.2205  0.2043  0.1866
                0.1959  #_MexCal_S2_Sem2
1994    2  1    1       1       2       0.0440  0.0723  0.0885  0.0996  0.1317  0.1527  0.1782  0.1959  0.2205  0.2043
                0.1959  #_MexCal_S2_Sem2
1995    2  1    1       1       2       0.0493  0.0628  0.0973  0.0885  0.1238  0.1417  0.1559  0.1793  0.1959  0.2205
                0.2043  #_MexCal_S2_Sem2
1996    2  1    1       1       2       0.0354  0.0835  0.1010  0.1230  0.1588  0.1431  0.1559  0.1706  0.1803  0.1959
                0.2205  #_MexCal_S2_Sem2
1997    2  1    1       1       2       0.0393  0.0616  0.1008  0.1256  0.1406  0.1613  0.1718  0.1706  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem2
1998    2  1    1       1       2       0.0338  0.0496  0.0743  0.1216  0.1322  0.1498  0.1639  0.1724  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem2
1999    2  1    1       1       2       0.0474  0.0498  0.0581  0.0840  0.1476  0.1417  0.1559  0.1706  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem2
2000    2  1    1       1       2       0.0582  0.0808  0.1022  0.0781  0.1053  0.1736  0.1559  0.1706  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem2
2001    2  1    1       1       2       0.0311  0.0820  0.0958  0.1365  0.1535  0.1382  0.1866  0.1706  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem2
2002    2  1    1       1       2       0.0682  0.0807  0.1030  0.1113  0.1441  0.1578  0.1559  0.1866  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem2
2003    2  1    1       1       2       0.0315  0.0744  0.0949  0.1243  0.1422  0.1511  0.1791  0.1706  0.1866  0.1866
                0.1959  #_MexCal_S2_Sem2
2004    2  1    1       1       2       0.0390  0.0576  0.0763  0.1103  0.1347  0.1602  0.1559  0.1706  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem2
2005    2  1    1       1       2       0.0403  0.0445  0.0653  0.0913  0.1516  0.1450  0.1782  0.1706  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem2
2006    2  1    1       1       2       0.0451  0.0518  0.0793  0.0931  0.1240  0.1647  0.1655  0.1860  0.1803  0.1866
                0.1959  #_MexCal_S2_Sem2
2007    2  1    1       1       2       0.0326  0.0619  0.0678  0.1019  0.1274  0.1267  0.1777  0.1860  0.1913  0.1866
                0.1959  #_MexCal_S2_Sem2
2008    2  1    1       1       2       0.0511  0.0716  0.0773  0.0997  0.1356  0.1647  0.1563  0.1860  0.1913  0.1947
                0.1959  #_MexCal_S2_Sem2
2009    2  1    1       1       2       0.0372  0.0739  0.0790  0.0952  0.1065  0.1403  0.1777  0.1860  0.1913  0.1947
                0.1995  #_MexCal_S2_Sem2
2010    2  1    1       1       2       0.0673  0.0715  0.0934  0.1166  0.1258  0.1329  0.1451  0.1860  0.1913  0.1947
                0.1995  #_MexCal_S2_Sem2
2011    2  1    1       1       2       0.0296  0.0898  0.0993  0.1000  0.1205  0.1286  0.1433  0.1512  0.1913  0.1947
```

0.1995 #_MexCal_S2_Sem2
2012 2 1 1 1 2 0.0370 0.0833 0.1175 0.1307 0.1385 0.1513 0.1490 0.1860 0.1913 0.1947
0.1995 #_MexCal_S2_Sem2
2013 2 1 1 1 2 0.0563 0.0773 0.1499 0.1402 0.1489 0.1599 0.1850 0.1694 0.1913 0.1947
0.1995 #_MexCal_S2_Sem2
-2014 2 1 1 1 2 0.0344 0.0591 0.0833 0.1601 0.1700 0.1721 0.1659 0.1860 0.1913 0.1947
0.1995 #_MexCal_S2_Sem2
1993 1 1 1 1 3 0.0138 0.0809 0.1067 0.1283 0.1477 0.1638 0.1760 0.1846 0.1904 0.1943
0.1996 #_PacNW_Sem1
1994 1 1 1 1 3 0.0138 0.0809 0.1067 0.1283 0.1477 0.1638 0.1760 0.1846 0.1904 0.1943
0.1996 #_PacNW_Sem1
1995 1 1 1 1 3 0.0138 0.0809 0.1067 0.1283 0.1477 0.1638 0.1760 0.1846 0.1904 0.1943
0.1996 #_PacNW_Sem1
1996 1 1 1 1 3 0.0138 0.0809 0.1067 0.1283 0.1477 0.1638 0.1760 0.1846 0.1904 0.1943
0.1996 #_PacNW_Sem1
1997 1 1 1 1 3 0.0138 0.0809 0.1067 0.1283 0.1477 0.1638 0.1760 0.1846 0.1904 0.1943
0.1996 #_PacNW_Sem1
1998 1 1 1 1 3 0.0138 0.0809 0.1067 0.1283 0.1477 0.1638 0.1760 0.1846 0.1904 0.1943
0.1996 #_PacNW_Sem1
1999 1 1 1 1 3 0.0138 0.0809 0.0869 0.1270 0.1568 0.1826 0.1760 0.1846 0.1904 0.1943
0.1996 #_PacNW_Sem1
2000 1 1 1 1 3 0.0138 0.1440 0.1193 0.1530 0.1685 0.1798 0.1883 0.1957 0.2040 0.1943
0.1996 #_PacNW_Sem1
2001 1 1 1 1 3 0.0138 0.0735 0.1403 0.1480 0.1570 0.1741 0.1902 0.1862 0.1982 0.1943
0.1996 #_PacNW_Sem1
2002 1 1 1 1 3 0.0138 0.1256 0.1505 0.1714 0.1782 0.1881 0.2005 0.2089 0.2151 0.1943
0.1996 #_PacNW_Sem1
2003 1 1 1 1 3 0.0138 0.1094 0.1236 0.1386 0.1670 0.1855 0.1933 0.1973 0.2124 0.1943
0.1996 #_PacNW_Sem1
2004 1 1 1 1 3 0.0138 0.0734 0.1235 0.1547 0.1834 0.1998 0.2063 0.2105 0.2151 0.1943
0.1996 #_PacNW_Sem1
2005 1 1 1 1 3 0.0138 0.0747 0.0864 0.0938 0.1229 0.1655 0.1816 0.2058 0.2067 0.1943
0.1996 #_PacNW_Sem1
2006 1 1 1 1 3 0.0138 0.0809 0.1080 0.1176 0.1247 0.1355 0.1397 0.1959 0.1762 0.1943
0.1996 #_PacNW_Sem1
2007 1 1 1 1 3 0.0138 0.0809 0.0977 0.1050 0.1093 0.1163 0.1269 0.1324 0.1980 0.1943
0.1996 #_PacNW_Sem1
2008 1 1 1 1 3 0.0138 0.0809 0.1050 0.1116 0.1202 0.1264 0.1392 0.1522 0.1718 0.1943
0.1996 #_PacNW_Sem1
2009 1 1 1 1 3 0.0138 0.0405 0.1095 0.1108 0.1194 0.1267 0.1304 0.1359 0.1436 0.1943
0.1996 #_PacNW_Sem1
2010 1 1 1 1 3 0.0138 0.0632 0.0673 0.1156 0.1328 0.1341 0.1380 0.1379 0.1399 0.1943
0.1996 #_PacNW_Sem1
2011 1 1 1 1 3 0.0138 0.0853 0.1127 0.1386 0.1505 0.1565 0.1580 0.1609 0.1575 0.1943
0.1996 #_PacNW_Sem1
2012 1 1 1 1 3 0.0138 0.1250 0.1334 0.1421 0.1536 0.1671 0.1733 0.1737 0.1790 0.1943
0.1996 #_PacNW_Sem1
2013 1 1 1 1 3 0.0138 0.0809 0.1621 0.1670 0.1728 0.1795 0.1949 0.1980 0.1994 0.1943
0.1996 #_PacNW_Sem1
-2014 1 1 1 1 3 0.0138 0.0809 0.1067 0.1730 0.1805 0.1838 0.1846 0.1915 0.1961 0.1943
0.1996 #_PacNW_Sem1
1993 2 1 1 1 3 0.0396 0.0947 0.1178 0.1383 0.1562 0.1704 0.1807 0.1878 0.1926 0.1957
0.2000 #_PacNW_Sem2
1994 2 1 1 1 3 0.0396 0.0947 0.1178 0.1383 0.1562 0.1704 0.1807 0.1878 0.1926 0.1957
0.2000 #_PacNW_Sem2
1995 2 1 1 1 3 0.0396 0.0947 0.1178 0.1383 0.1562 0.1704 0.1807 0.1878 0.1926 0.1957
0.2000 #_PacNW_Sem2
1996 2 1 1 1 3 0.0396 0.0947 0.1178 0.1383 0.1562 0.1704 0.1807 0.1878 0.1926 0.1957
0.2000 #_PacNW_Sem2
1997 2 1 1 1 3 0.0396 0.0947 0.1178 0.1383 0.1562 0.1704 0.1807 0.1878 0.1926 0.1957
0.2000 #_PacNW_Sem2
1998 2 1 1 1 3 0.0396 0.0947 0.1178 0.1383 0.1562 0.1704 0.1807 0.1878 0.1926 0.1957
0.2000 #_PacNW_Sem2
1999 2 1 1 1 3 0.0396 0.1001 0.1199 0.1478 0.1683 0.1855 0.1807 0.1878 0.1926 0.1957
0.2000 #_PacNW_Sem2
2000 2 1 1 1 3 0.0396 0.1422 0.1336 0.1550 0.1713 0.1850 0.1873 0.1969 0.1991 0.1957
0.2000 #_PacNW_Sem2
2001 2 1 1 1 3 0.0396 0.1120 0.1559 0.1631 0.1725 0.1873 0.1996 0.2007 0.1962 0.1957
0.2000 #_PacNW_Sem2
2002 2 1 1 1 3 0.0396 0.1246 0.1446 0.1692 0.1819 0.1907 0.1989 0.2107 0.2047 0.1957
0.2000 #_PacNW_Sem2
2003 2 1 1 1 3 0.0396 0.1165 0.1392 0.1610 0.1834 0.1959 0.2019 0.2062 0.2034 0.1957
0.2000 #_PacNW_Sem2
2004 2 1 1 1 3 0.0396 0.0799 0.1086 0.1388 0.1745 0.1907 0.2060 0.2086 0.2047 0.1957
0.2000 #_PacNW_Sem2
2005 2 1 1 1 3 0.0396 0.0913 0.1020 0.1092 0.1292 0.1526 0.1887 0.1910 0.2005 0.1957

```
         0.2000  #_PacNW_Sem2
2006    2  1    1       1       3       0.0396  0.0893  0.1065  0.1135  0.1205  0.1312  0.1361  0.1969  0.1853  0.1957
         0.2000  #_PacNW_Sem2
2007    2  1    1       1       3       0.0396  0.0930  0.1046  0.1126  0.1178  0.1278  0.1395  0.1521  0.1961  0.1957
         0.2000  #_PacNW_Sem2
2008    2  1    1       1       3       0.0396  0.0952  0.1079  0.1155  0.1234  0.1284  0.1376  0.1479  0.1830  0.1957
         0.2000  #_PacNW_Sem2
2009    2  1    1       1       3       0.0396  0.0539  0.1126  0.1218  0.1268  0.1323  0.1341  0.1379  0.1689  0.1957
         0.2000  #_PacNW_Sem2
2010    2  1    1       1       3       0.0396  0.0879  0.1029  0.1331  0.1447  0.1461  0.1495  0.1477  0.1671  0.1957
         0.2000  #_PacNW_Sem2
2011    2  1    1       1       3       0.0396  0.1094  0.1274  0.1461  0.1588  0.1649  0.1659  0.1699  0.1759  0.1957
         0.2000  #_PacNW_Sem2
2012    2  1    1       1       3       0.0396  0.1435  0.1502  0.1574  0.1666  0.1810  0.1857  0.1866  0.1866  0.1957
         0.2000  #_PacNW_Sem2
2013    2  1    1       1       3       0.0396  0.0947  0.1675  0.1738  0.1783  0.1821  0.1932  0.1971  0.1968  0.1957
         0.2000  #_PacNW_Sem2
-2014   2  1    1       1       3       0.0396  0.0947  0.1178  0.1747  0.1819  0.1851  0.1862  0.1922  0.1952  0.1957
         0.2000  #_PacNW_Sem2
1993    1  1    1       1       5       0.0125  0.0461  0.0839  0.1173  0.1434  0.1622  0.1754  0.1843  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
1994    1  1    1       1       5       0.0125  0.0461  0.0839  0.1173  0.1434  0.1622  0.1754  0.1843  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
1995    1  1    1       1       5       0.0125  0.0461  0.0839  0.1173  0.1434  0.1622  0.1754  0.1843  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
1996    1  1    1       1       5       0.0125  0.0461  0.0839  0.1173  0.1434  0.1622  0.1754  0.1843  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
1997    1  1    1       1       5       0.0125  0.0461  0.0839  0.1173  0.1434  0.1622  0.1754  0.1843  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
1998    1  1    1       1       5       0.0125  0.0461  0.0839  0.1173  0.1434  0.1622  0.1754  0.1843  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
1999    1  1    1       1       5       0.0125  0.0461  0.0839  0.1173  0.1434  0.1622  0.1754  0.1843  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
2000    1  1    1       1       5       0.0125  0.0461  0.0839  0.1173  0.1434  0.1622  0.1754  0.1843  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
2001    1  1    1       1       5       0.0125  0.0461  0.0839  0.1173  0.1434  0.1622  0.1754  0.1843  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
2002    1  1    1       1       5       0.0125  0.0461  0.0839  0.1173  0.1434  0.1622  0.1754  0.1843  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
2003    1  1    1       1       5       0.0125  0.0461  0.0839  0.1173  0.1434  0.1622  0.1754  0.1843  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
2004    1  1    1       1       5       0.0125  0.0688  0.1243  0.1380  0.1640  0.1737  0.1850  0.1914  0.1921  0.1942
         0.1995  #_ATM_Survey_Sem1
2005    1  1    1       1       5       0.0125  0.0445  0.0734  0.1278  0.1443  0.1676  0.1778  0.1920  0.2003  0.1942
         0.1995  #_ATM_Survey_Sem1
2006    1  1    1       1       5       0.0125  0.0563  0.0750  0.0817  0.1313  0.1506  0.1754  0.1843  0.1923  0.2003
         0.1995  #_ATM_Survey_Sem1
2007    1  1    1       1       5       0.0125  0.0451  0.0705  0.0969  0.0996  0.1348  0.1569  0.1843  0.1903  0.1942
         0.2003  #_ATM_Survey_Sem1
2008    1  1    1       1       5       0.0134  0.0461  0.1040  0.1153  0.1181  0.1221  0.1383  0.1843  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
2009    1  1    1       1       5       0.0125  0.0446  0.0890  0.1182  0.1257  0.1264  0.1368  0.1547  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
2010    1  1    1       1       5       0.0125  0.0480  0.0708  0.1088  0.1348  0.1368  0.1402  0.1463  0.1903  0.1942
         0.1995  #_ATM_Survey_Sem1
2011    1  1    1       1       5       0.0131  0.0720  0.1101  0.1179  0.1224  0.1369  0.1419  0.1389  0.1440  0.1410
         0.1410  #_ATM_Survey_Sem1
2012    1  1    1       1       5       0.1071  0.1152  0.1220  0.1265  0.1302  0.1496  0.1581  0.1528  0.1615  0.1564
         0.1564  #_ATM_Survey_Sem1
2013    1  1    1       1       5       0.1358  0.1449  0.1513  0.1548  0.1574  0.1689  0.1740  0.1708  0.1761  0.1730
         0.1730  #_ATM_Survey_Sem1
2014    1  1    1       1       5       0.0061  0.1694  0.1768  0.1794  0.1812  0.1885  0.1916  0.1897  0.1930  0.1910
         0.1910  #_ATM_Survey_Sem1
2015    1  1    1       1       5       0.0036  0.0329  0.1741  0.1874  0.1937  0.2066  0.2095  0.2078  0.2105  0.2089
         0.2089  #_ATM_Survey_Sem1
-2016   1  1    1       1       5       0.0108  0.0658  0.0740  0.0784  0.0827  0.1536  0.1951  0.1713  0.2065  0.1883
         0.1883  #_ATM_Survey_Sem1
1993    2  1    1       1       5       0.0283  0.0651  0.1015  0.1313  0.1536  0.1694  0.1803  0.1876  0.1924  0.1956
         0.1999  #_ATM_Survey_Sem2
1994    2  1    1       1       5       0.0283  0.0651  0.1015  0.1313  0.1536  0.1694  0.1803  0.1876  0.1924  0.1956
         0.1999  #_ATM_Survey_Sem2
1995    2  1    1       1       5       0.0283  0.0651  0.1015  0.1313  0.1536  0.1694  0.1803  0.1876  0.1924  0.1956
         0.1999  #_ATM_Survey_Sem2
1996    2  1    1       1       5       0.0283  0.0651  0.1015  0.1313  0.1536  0.1694  0.1803  0.1876  0.1924  0.1956
         0.1999  #_ATM_Survey_Sem2
1997    2  1    1       1       5       0.0283  0.0651  0.1015  0.1313  0.1536  0.1694  0.1803  0.1876  0.1924  0.1956
```

```
                0.1999  #_ATM_Survey_Sem2
1998    2  1    1       1       5       0.0283  0.0651  0.1015  0.1313  0.1536  0.1694  0.1803  0.1876  0.1924  0.1956
                0.1999  #_ATM_Survey_Sem2
1999    2  1    1       1       5       0.0283  0.0651  0.1015  0.1313  0.1536  0.1694  0.1803  0.1876  0.1924  0.1956
                0.1999  #_ATM_Survey_Sem2
2000    2  1    1       1       5       0.0283  0.0651  0.1015  0.1313  0.1536  0.1694  0.1803  0.1876  0.1924  0.1956
                0.1999  #_ATM_Survey_Sem2
2001    2  1    1       1       5       0.0283  0.0651  0.1015  0.1313  0.1536  0.1694  0.1803  0.1876  0.1924  0.1956
                0.1999  #_ATM_Survey_Sem2
2002    2  1    1       1       5       0.0283  0.0651  0.1015  0.1313  0.1536  0.1694  0.1803  0.1876  0.1924  0.1956
                0.1999  #_ATM_Survey_Sem2
2003    2  1    1       1       5       0.0665  0.1150  0.1349  0.1622  0.1729  0.1781  0.1825  0.1917  0.1924  0.1956
                0.1999  #_ATM_Survey_Sem2
2004    2  1    1       1       5       0.0250  0.0711  0.1261  0.1411  0.1658  0.1745  0.1919  0.2003  0.1924  0.1956
                0.1999  #_ATM_Survey_Sem2
2005    2  1    1       1       5       0.0584  0.0677  0.0756  0.0899  0.1063  0.1281  0.1616  0.1998  0.1952  0.1709
                0.1709  #_ATM_Survey_Sem2
2006    2  1    1       1       5       0.0584  0.0677  0.0756  0.0899  0.1063  0.1281  0.1616  0.1998  0.1952  0.1709
                0.1709  #_ATM_Survey_Sem2
2007    2  1    1       1       5       0.0702  0.0806  0.0920  0.1128  0.1279  0.1369  0.1451  0.1542  0.1529  0.1471
                0.1471  #_ATM_Survey_Sem2
2008    2  1    1       1       5       0.0702  0.0806  0.0920  0.1128  0.1279  0.1369  0.1451  0.1542  0.1529  0.1471
                0.1471  #_ATM_Survey_Sem2
2009    2  1    1       1       5       0.0399  0.0884  0.1197  0.1381  0.1467  0.1524  0.1579  0.1642  0.1633  0.1593
                0.1593  #_ATM_Survey_Sem2
2010    2  1    1       1       5       0.0609  0.0644  0.0684  0.0851  0.1228  0.1485  0.1635  0.1745  0.1731  0.1663
                0.1663  #_ATM_Survey_Sem2
2011    2  1    1       1       5       0.0792  0.1016  0.1154  0.1364  0.1554  0.1669  0.1755  0.1827  0.1818  0.1773
                0.1773  #_ATM_Survey_Sem2
2012    2  1    1       1       5       0.1141  0.1239  0.1294  0.1386  0.1489  0.1585  0.1694  0.1830  0.1811  0.1724
                0.1724  #_ATM_Survey_Sem2
2013    2  1    1       1       5       0.1556  0.1593  0.1619  0.1664  0.1707  0.1742  0.1778  0.1819  0.1813  0.1787
                0.1787  #_ATM_Survey_Sem2
2014    2  1    1       1       5       0.0914  0.0984  0.1055  0.1438  0.1829  0.1955  0.2015  0.2058  0.2052  0.2026
                0.2026  #_ATM_Survey_Sem2
-2015   2  1    1       1       5       0.0359  0.0424  0.0638  0.1338  0.1855  0.2045  0.2137  0.2196  0.2189  0.2153
                0.2153  #_ATM_Survey_Sem2
```

ALT.CTL

```
# Pacific sardine stock assessment (2017-18)
# P.R. Crone, K.T. Hill, J.P. Zwolinski (Nov 2016)
# Model ALT: number of fisheries = 3 / surveys = 1 / time-step = semester / biological distributions = age /
          selectivity = age-based / growth = emp. WAA
# SS model (ver. 3.24s)
# Control file
#
1 #_N_growth patterns
1 # N_Morphs within growth pattern
# Cond 1 # Morph between/within SD ratio (no read if N_morphs=1)
# Cond 1 # Vector morphdist (-1 for first value gives normal approximation)
1 # N_recruitment assignments (overrides GP*area*season parameter values)
0 # Recruitment interaction requested
# GP season area for each recruitment assignment
1 1 1
# Cond 0 # N_movement_definitions goes here if N_areas >1
# Cond 1 # First age that moves (real age at begin of season, not integer) also conditioned on Do_migration >0
# Cond 1 1 1 2 4 10 # Example move definition for seas=1, morph=1, source=1 dest=2, age1=4, age2=10
3 # N_block patterns
3 7 5 # N_blocks per pattern
# Begin and end years of blocks (pattern 1)
2005 2005 2006 2011 2010 2014 # MEXCAL_S1
# Begin and end years of blocks (pattern 2)
2005 2005 2006 2009 2010 2010 2011 2011 2012 2012 2013 2013 2014 2017 # ATM
# Begin and end years of blocks (pattern 3)
2005 2012 2013 2013 2014 2014 2015 2015 2016 2017 # ATM
0.5 # Fraction female
0 # Natural mortality type: 0=1 Parm, 1=N_breakpoints, 2=Lorenzen, 3=agespecific, 4=age-specific with season
          interpolation
# No additional input for M_type=0 (read 1 parametr per morph)
1 # Growth model: 1=vonBert with L1&L2, 2=Richards with L1&L2, 3=age_speciific_K, 4=not implemented
0.5 # Growth_age for_L1
999 #_Growth_age for_L2 (999=use Linf)
0 # SD add to LAA (set to 0.1 for SS2 V1.x compatibility)
0 # CV_growth pattern: (0) CV=f(LAA), (1) CV=F(A), (2) SD=F(LAA), (3) SD=F(A), (4) log(SD)=F(A)
5 # Maturity_option: 1=length logistic, 2=age logistic, 3=read age-maturity matrix by growth pattern, 4=read
```

```
          age-fecundity, 5=read fecundity/wt from wtatage.ss
# Placeholder for empirical age-maturity by growth pattern
0 # First mature age
1 # Fecundity option:(1) eggs=Wt*(a+b*Wt),(2) eggs=a*L^b,(3) eggs=a*Wt^b, (4) eggs=a+b*L, (5)eggs=a+b*W
0 # Hermaphroditism option: 0=none, 1=age-specific
1 # Parameter offset approach: 1=none, 2=Mortality, growth, CV_growth as offset from female-GP1, 3=like SS2 V1.x
1 # Env/block/dev adjust method: 1=standard, 2=logistic transform keeps in base parm bounds, 3=standard w/ no
          bound check
# Growth parameters
# LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev block block_Fxn
0.3 0.8 0.6 0 -1 99 -3 0 0 0 0 0 0 0 # NatM_p_1_Fem_GP_1
3 15 10 0 -1 99 -3 0 0 0 0 0 0 0 # LAA_min_Fem_GP_1
20 30 25 0 -1 99 -3 0 0 0 0 0 0 0 # LAA_max_Fem_GP_1
0.05 0.99 0.4 0 -1 99 -3 0 0 0 0 0 0 0 # VonBert_K_Fem_GP_1
0.05 0.5 0.14 0 -1 99 -3 0 0 0 0 0 0 0 # CV_young_Fem_GP_1
0.01 0.1 0.05 0 -1 99 -3 0 0 0 0 0 0 0 # CV_old_Fem_GP_1
-3 3 7.5242e-006 0 -1 99 -3 0 0 0 0 0 0 0 # WtLt_1_Fem
-3 5 3.233205 0 -1 99 -3 0 0 0 0 0 0 0 # WtLt_2_Fem
9 19 15.44 0 -1 99 -3 0 0 0 0 0 0 0 # Mat50%_Fem
-20 3 -0.89252 0 -1 99 -3 0 0 0 0 0 0 0 # Mat_slope_Fem
0 10 1 0 -1 99 -3 0 0 0 0 0 0 0 # Eggs/kg_inter_Fem
-1 5 0 0 -1 99 -3 0 0 0 0 0 0 0 # Eggs/kg_slope_wt_Fem
-4 4 0 0 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_GP_1
-4 4 1 0 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_Area_1
-4 4 1 0 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_Seas_1
-4 4 0 0 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_Seas_2
1 1 1 0 -1 99 -3 0 0 0 0 0 0 0 # Cohort Growth_Dev
#
# Cond 0  # Custom MG-env_setup (0/1)
# Cond -2 2 0 0 -1 99 -2 # Placeholder when no MG-env parameters
# Custom MG-block_setup (0/1)
# Cond No MG parm trends
# Seasonal effects on biology parameter
0 0 0 0 0 0 0 0 0 0 # femwtlt1, femwtlt2, mat1, mat2, fec1, fec2, malewtlt1, malewtlt2, L1, K
# Cond -2 2 0 0 -1 99 -2 # Placeholder when no seasonal MG parameters
# Cond -4 # MGparm_dev Phase
#
# Spawner-recruit (SR) parameters
3 # SR function: 1=Null, 2=Ricker (2 parm), 3=std_B-H (2 parm), 4=S-CAA, 5=Hockey stick, 6=flat-top_B-H,
          7=Survival_3Parm
# LO HI INIT PRIOR PR_type SD PHASE
3 25 15 0 -1 99 1 # SR_R0
0.2 1 0.5 0 -1 99 5 # SR_steepness
0 2 0.75 0 -1 99 -3 # SR_sigmaR
-5 5 0 0 -1 99 -3 # SR_env link
-15 15 0 0 -1 99 2 # SR_R1_offset
0 0 0 0 -1 99 -3 # SR_autocorr
0 # SR_env link
0 # SR_env target: 0=none, 1=devs, 2=R0, 3=steepness
1 # Do recdev:  0=none, 1=devvector, 2=simple deviations
2005 # First year of main rec_devs (early devs can preceed this era) (was 1993 in 2016 assessment)
2015 # Last year of main rec_devs (forecast devs start in following year) (was 2014 in 2016 assessment)
1 # Rec_dev phase
#
1 # Read 13 advanced options (0/1)
-6 # Rec_dev early start: 0=none (neg value makes relative to rec_dev)
2 # Rec_dev early phase
0 # Forecast rec phase (includes late rec): 0 value sets to maxphase+1
1 # Lambda for Forecast rec likelihood occurring before endyr+1
#
1994.7 # Last early_yr nobias adjustment in MPD (was 1984 in 2016 assessment)
2005.2 # First yr fullbias adjustment in_MPD (was 1993 in 2016 assessment)
2012.8 # Last yr fullbias adjustment in MPD (was 2011 in 2016 assessment)
2015.2 # First recent_yr nobias adjustment in MPD (was 2015 in 2016 assessment)
0.8956 # Max bias adjustment in_MPD (-1 to override ramp and set bias adjustment=1.0 for all estimated rec_devs)
0 # Period of cycles in recruitment (N_parms read below)
-5 # Min rec_dev
5 # Max rec_dev
0 # Read rec_devs
# End of advanced SR options
#
# Placeholder for full parameter lines for recruitment cycles
# Read specified rec_devs
# Yr Input_value
#
# Fishing mortality (F) parameters
```

```
0.1 # F ballpark for tuning early phases
-2006 # F ballpark year (neg value to disable)
3 # F method: 1=Pope, 2=instant F, 3=hybrid
4 # Max F or harvest rate (depends on F method)
# No additional F input needed for F method 1
# If F method=2 then read overall start F value, overall phase, N_detailed inputs to read
# If F method=3 then read N_iterations for tuning for F method=3
10 # N_iterations for tuning F (F method=3 only, e.g., 3-7)
#
# Initial F parameters
# LO HI INIT PRIOR PR_type SD PHASE
0 3 1 0 -1 99 1 # Init F_MEXCAL_S1
0 3 0 0 -1 99 -1 # Init F_MEXCAL_S2
0 3 0 0 -1 99 -1 # Init F_PNW
#
# Catchability (Q) parameters
# Den_dep: 0=off and survey is proportional to abundance, 1=add parameter for non-linearity
# Env_var: 0=off, 1 = add parameter for env effect on Q
# Extra_SE: 0=off, 1 = add parameter for additive constant to input SE in ln space
# Q_type: <0=mirror, 0=median_float, 1=mean_float, 2=estimate parameter for ln(Q), 3=parameter with random_dev,
          4=parameter with random walk, 5=mean unbiased float assigned to parameter
#         <0=mirror
#         0=Q floats as a scaling factor (no variance bias adjustment is taken into account)
#         1=Q floats as scaling factor (variance bias adjustment is used) ** recommended option **
#         2=Q is a parameter (variance bias adjustment is NOT used, so produces same result as option=0)
#         3=parameter with random_dev
#         4=parameter with random walk
#         5=mean unbiased float assigned to parameter
# Note: a new option will be created to include bias adjustment in the parameter approach
# Den-dep  Env-var  Extra_SE  Q_type
0 0 0 0 # MEXCAL_S1
0 0 0 0 # MEXCAL_S2
0 0 0 0 # PNW
0 0 0 2 # DEPM
0 0 0 2 # AT
#
# Cond # If Q has random component then 0=read one parameter for each fleet with random Q, 1=read a parameter
          for each year of index
# Q parameters (if any)
# LO HI INIT PRIOR PR_type SD PHASE
-3 3 1 0 -1 99 4 # Q_DEPM
-3 3 1 0 -1 99 4 # Q_AT
#
# Size selectivity types
# Pattern Discard Male Special
0 0 0 0 # MEXCAL_S1
0 0 0 0 # MEXCAL_S2
0 0 0 0 # PNW
30 0 0 0 # DEPM
0 0 0 0 # ATM
#
# Age selectivity types
# Pattern Discard Male Special
17 0 0 10 # MEXCAL_S1
17 0 0 10 # MEXCAL_S2
12 0 0 0 # PNW
0 0 0 0 # DEPM
10 0 0 0 # AT
#
# Age selectivity
# LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
# MEXCAL_S1 (age-specific, random walk)
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-0
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-1
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-2
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-3
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-4
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-5
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-6
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-7
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-8
-1000 9        -1000  -1      -1      99   -3  0 0 0 0 0 0 0 # Age-9
-1000 9        -1000  -1      -1      99   -3  0 0 0 0 0 0 0 # Age-10
#
# MEXCAL_S2 (age-specific, random walk)
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-0
```

```
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-1
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-2
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-3
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-4
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-5
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-6
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-7
-5    9        0.1    -1      -1      99   3  0 0 0 0 0 0 0 # Age-8
-1000 9        -1000  -1      -1      99   -3  0 0 0 0 0 0 0 # Age-9
-1000 9        -1000  -1      -1      99   -3  0 0 0 0 0 0 0 # Age-10
#
# PacNW (asymptotic)
0 10 5 0 -1 99 4 0 0 0 0 0 0 0 # AgeSel_P1_PacNW
-5 15 1 0 -1 99 4 0 0 0 0 0 0 0 # AgeSel_P2_PacNW
#
# DEPM (SSB) - No parameter lines
#
# ATM (Asymptotic option 10, no parameter lines)
#
# Cond: Custom sel-env setup (0/1)
# Cond: Env_fxns setup
# 1 # Cond: Custom sel-blk setup (0/1)
#
# 1 # Cond: Selectivity parameter trends
# 4 # Cond: Selectivity parm_dev phase
# 2 # Cond: Env/Block/Dev_adjustment method: 1=standard, 2=logistic trans to keep in base parameter bounds,
          3=standard with no bound check
#
# Tag loss and Tag reporting parameters
0 # Tag custom:  0=no read, 1=read if tags exist
# Cond -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0  # Placeholder if no parameters
#
1 # Variance adjustments
# Fleet/Survey: 1 2 3 4 5
0.000000  0.000000    0.000000       0.000000       0.000000 # add_to_survey_CV
0.000000  0.000000    0.000000       0.000000       0.000000 # add_to_discard_stddev
0.000000  0.000000    0.000000       0.000000       0.000000 # add_to_bodywt_CV
1.000000    1.000000    1.000000    1.000000    1.000000 # mult_by_lencomp_N
1.000000    1.000000    1.000000    1.000000    1.000000 # mult_by_agecomp_N
1.000000    1.000000    1.000000    1.000000    1.000000 # mult_by_size-at-age_N
#
1 # Max lambda phase
1 # SD_offset
#
17 # Number of changes to make to default Lambdas (default value=1)
# Like_comp codes: 1=survey, 2=discard, 3=mean_wt, 4=length, 5=age, 6=size-freq, 7=size_age, 8=catch,
#                  9=initial equilibrium catch, 10=rec_dev, 11=parameter_prior, 12=parameter_dev,
#                  13=crash penalty, 14=morph composition; 15=tag composition, 16=tag neg_bin
# Like_comp fleet/survey  phase  value  size-freq_method
1 4 1 0 1 # DEPM
1 5 1 1 1 # ATM
4 1 1 0 1 # MEXCAL_S1 (length)
4 2 1 0 1 # MEXCAL_S2 (length)
4 3 1 0 1 # PNW (length)
4 5 1 0 1 # ATM (length)
5 1 1 1 1 # MEXCAL_S1 (age)
5 2 1 1 1 # MEXCAL_S2 (age)
5 3 1 1 1 # PNW (age)
5 5 1 1 1 # ATM (age)
7 1 1 0 1 # MEXCAL_S1 (Mean LAA)
7 2 1 0 1 # MEXCAL_S2 (Mean LAA)
7 3 1 0 1 # PNW (Mean LAA)
7 5 1 0 1 # ATM (Mean LAA)
9 1 1 0 1 # Initial equilibrium catch (MEXCAL_S1)
9 2 1 0 1 # Initial equilibrium catch (MEXCAL_S2)
9 3 1 0 1 # Initial equilibrium catch (PNW)
#
0 # Read specs for more SD reporting (0/1)
# 0 1 -1 5 1 5 1 -1 5 # Placeholder for selectivity type, lt/age, year, N_selectivity bins, growth pattern,
          N_growth ages, natage_area (-1 for all), natage_yr, N_natages
# Placeholder for vector of selectivity bins to be reported
# Placeholder for vector of growth ages to be reported
# Placeholder for vector of natage ages to be reported
999 # End of file
```

Appendix C

PFMC Scientific Peer Reviews and Advisory Body Reports.

Pacific Sardine
STAR Panel Meeting Report

NOAA / Southwest Fisheries Science Center
La Jolla, California
February 21-23, 2017

STAR Panel Members:
André Punt (Chair), Scientific and Statistical Committee (SSC), Univ. of Washington
Will Satterthwaite, SSC, Southwest Fisheries Science Center
Evelyn Brown, SSC, Lummi Natural Resources, LIBC
Jon Vølstad, Center for Independent Experts (CIE)
Gary Melvin, Center for Independent Experts (CIE)

Pacific Fishery Management Council (Council) Representatives:
Kerry Griffin, Council Staff
Diane Pleschner-Steele, CPSAS Advisor to STAR Panel
Lorna Wargo, CPSMT Advisor to STAR Panel

Pacific Sardine Stock Assessment Team:
Kevin Hill, NOAA / SWFSC
Paul Crone, NOAA / SWFSC
Juan Zwolinski, NOAA / SWFSC

1) Overview

The Pacific Sardine Stock Assessment and Review (STAR) Panel (Panel) met at the Southwest Fisheries Science Center (SWFSC), La Jolla, CA from February 21-23, 2017 to review a draft assessment by the Stock Assessment Team (STAT) for the northern subpopulation of Pacific Sardine. Introductions were made (see list of attendees, Appendix 1), and the agenda was adopted. A draft assessment document and background materials were provided to the Panel in advance of the meeting on a Council FTP site.

Drs. Paul Crone, Kevin Hill, and Juan Zwolinski presented the assessment methodology. Paul Crone first outlined the assessment philosophy, which focused on selecting an approach that made most use of the data source considered by the STAT to be most objective, i.e. the Acoustic Trawl Method (ATM) survey. The STAT provided results for two assessment approaches: (a) use of the summer 2016 ATM survey estimate and associated age-composition projected to 1 July 2017, and (b) a model-based assessment that provides an estimate of age 1+ biomass on 1 July 2017.

Juan Zwolinski described the survey-based method for estimating age 1+ biomass on 1 July 2017, which involved estimating numbers-at-age on 1 July 2016 from the summer 2016 ATM survey from numbers-at-length using an age-length key that pooled data over multiple summer surveys, and projecting these numbers forward accounting for natural mortality and growth, and adding the estimated recruitment for 2016. The recruitment for 2016 was based on the stock-recruitment relationship estimated by model ALT, and the spawning stock biomass for 2016 was estimated by back-projecting the summer 2016 numbers-at-age to 1 January 2016.

Kevin Hill and Paul Crone described the data on which the model-based assessment was based, as well the results from a draft assessment utilizing the Stock Synthesis Assessment Tool, Version 3.24aa. Model ALT differed from the model on which the 2016 update assessment was based by starting the assessment in 2005 rather than 1993, excluding the Daily Egg Production Method (DEPM) and Total Egg Production (TEP) indices, estimating rather than pre-specifying stock-recruitment steepness, pre-specifying weight-at-age rather than estimating it within the assessment, assuming that selectivity for the ATM survey is zero for age 0 and uniform for age 1 and older, estimating survey catchability (Q), assuming that selectivity is age- rather than length-based, modelling ages 0-10+yr rather than ages 0-15+yr, assuming natural mortality (*M*) is 0.6yr^{-1} rather than 0.4yr^{-1} for all age classes and fitting the catch and ATM survey age-composition data (rather than the associated length-composition data). Unlike the 2016 and earlier assessments, model ALT included additional live bait landings, which generally reflected a minor contribution to the total landings in California. However, model ALT did not include biological composition data from the live bait catches, given this fishery sector had not been regularly sampled in the past, with samples being available for only the most recent year of the time period modelled in the assessment.

The review and subsequent explorations of the assessment through sensitivity analyses were motivated primarily by the need for the survey-based method to provide an estimate of age 1+ biomass and its CV, to better understand the rationale for the changes made to the model on which the last full assessment was based that led to model ALT, and to identify the best approach for providing an estimate of age 1+ biomass on 1 July 2017. The Panel had several comments and concerns regarding the ATM survey methodology and ways in which estimates of close-to-absolute abundance can be obtained. However, this was not a review of the ATM survey, since a second Council-sponsored ATM methodology review is planned for early 2018. Therefore, comments regarding the ATM survey and how estimates of abundance from that survey are constructed are reflected primarily in the Research Recommendations section of the report.

The STAR Panel thanked the STAT for their hard work and willingness to respond to Panel requests, and the staff at the SWFSC La Jolla laboratory for their usual exceptional support and provisioning during the STAR meeting.

2) <u>Day 1 requests made to the STAT during the meeting – Tuesday, February 21</u>

Request 1: Provide documentation on the procedures used to calculate the survey age-composition data, including how age-length and age-biomass keys are constructed.

Rationale: These calculations are critical to projecting biomass after accounting for natural mortality, somatic growth, and recruitment; but the draft assessment document did not describe these calculations in sufficient detail for them to be reproduced. In addition, the age-compositions for the ATM survey in model ALT were computed using the method.

Response: Dr. Zwolinski presented written documentation and figures. The function "multinom" from the R package "nnet" fits a multinomial log-linear model using neural networks. The response is a discrete probability distribution (see Fig. 1). It is simpler to use than the alternative (sequential logistic models), and it provides a smoother transition between classes than an empirical age-at-length key. The age and lengths used for constructing the age-length key were from surveys from 2004 to the present. Due to the assumption of a July first date and its effect on ageing, the STAT built a season-specific age-length key using data pooled across time, separately for spring/summer.

The Panel agreed that aggregation across years is not appropriate if some length classes represent multiple ages, which is the case for Pacific sardine. Moreover, substantial spatial and temporal variation occurs in size-at-age, and merging the data from several years creates bias in annual estimates of age compositions of varying magnitude and direction.

Request 2: Provide full specification, including equations, of the calculations used to 1) project from the ATM survey biomass estimate to the estimated age-1+ biomass on July 1 of the following fishing year, and 2) calculate the uncertainty associated with that biomass estimate.

Rationale: The projection calculations need to be reproducible. Management advice (Overfishing Level OFL, Acceptable Biological Catch ABC, and Harvest Guideline HG) for Pacific sardine requires an estimate of age 1+ biomass (OFL, ABC, HG) and its uncertainty (ABC) on July 1, 2017.

Response: For 1), Dr. Zwolinksi walked the Panel through a spreadsheet that made these calculations and the Panel agreed that the calculations were sensible, conditional on the age-weight key. For 2), assuming independence of age 1 and age 2+ biomass, the total variance was calculated by summing the respective variances. This calculation is negatively biased because it ignores uncertainty in age-composition and weight-at-age. It was noted that the resultant coefficient of variation (CV) for age 1+biomass is lower than the CV for either component (age 1 versus age 2+) due to their assumed independence.

Request 3: Plot cohort-specific rather than year-specific growth curves (weight-at-age) for the ATM survey and overlay raw data/information on sample sizes. Make it clear which values are estimated versus inferred. Do this for the fisheries data as well.

Rationale: Cohort-specific curves are easier to interpret as growth trajectories than year-specific curves. It is important to understand how much data drives these estimates, and to understand the consequences of applying the same age-length key for all years with survey data to calculate the weight-at-age and age-composition for the ATM survey.

Response: Dr. Hill presented tables including sample sizes and estimated means for each cohort-season-age combination. The tables were formatted to highlight entries that were inferred versus estimated. Dr. Hill calculated means whenever 3 or more samples were available. However, these means were sometimes overwritten based on the assumption that animals did not shrink. The ATM data showed substantial variation in weight-at-age across years (Fig. 2), and possibly increasing size-at-age in recent years. The MexCal catch data appeared less variable overall, and it was noted that fishery sample sizes were generally larger than the ATM sample sizes. The smoothing was not applied to the PNW catch.

The Panel noted that the adopted method ended up discarding data for cohorts with unusually large mean sizes for (for example) age-0 fish by not allowing "shrinkage", whereas it may have been the age-0 means that were anomalous rather than the means calculated for older ages. The Panel also noted that in many cases, the sample sizes were very small. The weight-at-age key used within the survey-based projection did not exclude "shrinkage". Using the weight-at-age key in model ALT produced an imperceptible difference in model-estimated age 1+ biomass.

Request 4: Verify that model ALT was run with ATM survey selectivity set equal to 0 for age-0 fish. Contact Dr. Rick Methot to better understand how selectivity is being modeled under the chosen selectivity option in SS.

Rationale: The model outputs appear to indicate that the model predicts non-zero catches of age-0 fish despite the intent to specify selectivity to be zero on age-0 fish. This may have significant unintended consequences for the likelihood calculations.

Response: This question was not fully resolved. It appears that Stock Synthesis predicts some catch of nominal "age 0" even given selectivity of zero on true age-0 fish because aging error leads to the expectation that some age-1 fish will be caught and mis-categorized as age 0. Further, model runs revealed that the model was unable to converge if aging error was set to zero or made very small, but reductions in the specified aging error led to the expected reduction in the predicted age-0 catch. It was noted that surveys likely include a mix of age-1 fish mis-categorized as age-0, as well as fish that are truly age 0.

Dr. Methot also noted that Stock Synthesis had not been as thoroughly debugged for semester-based models as for strictly annual models.

See also Requests 5, 8, and 9.

Request 5: Re-run model ALT with age 0 fish removed from the input file for the ATM survey.

Rationale: Similar to Request 4, the model likelihood should not be influenced by data on age-0 fish if it is assumed selectivity on age-0 fish is zero, but the model appears to be generating non-zero predictions and comparing these against the input data.

Response: The model still predicted catch of age-0 fish in this scenario. This is consistent with the explanation suggested for this pattern under Request 4.

Request 6: Report the CV of the estimate of terminal biomass based on changes in how the compositional data are weighted.

Rationale: The weighting of composition data appeared to have little effect on the point estimate of biomass, but it is important to understand implications of alternative weighting schemes for uncertainty as well.

Response: Data weighting increased the CV by 2-3%. The base model had a CV of approximately 36%, Francis-weighting led to a CV of approximately 38%, and harmonic mean weighting led to a CV of about 39%.

Request 7: Show more outputs from T_2017 and T_2017_No_New_AT_Comp.
Rationale: These outputs would help the Panel evaluate the reasons for proposing a move away from a strict update of the previously accepted model structure, i.e. identify problems with a strict update that the new model structure addresses.
Response: Selectivity curves for the spring and summer ATM surveys were noticeably different depending on whether the two most recent survey length-compositions were included in the assessment or not (Fig. 3). These models appeared to yield acceptable fits to abundance indices, but the fits to observed length-compositions were poor. It appears that the model estimates very low selectivity on small fish for the summer survey (since selectivity does not vary across years, and very few small fish are encountered most years) such that when small fish are encountered, they are expanded to a very large number. During Panel discussion, it was noted that this unexpected behavior should not happen if selectivity were forced to be the same for the spring and summer surveys.

<u>**Day 2 requests made to the STAT during the meeting – Wednesday, February 22**</u>
Request 8: Develop a model in which selectivity for age-0 animals in the survey is time-varying.
Rationale: The availability of age-0 animals to the survey seems to be highly variable among years, but influential on the results. A selectivity function in which age-0 selectivity varies among years should "discount" the influence of occasional catches of age-0 animals.
Response: A model was presented that assumed essentially full selection on age-1+ animals, and time-varying age-0 selectivity. The model estimated nearly zero selectivity on age-0 fish in all years except 2015, when estimated selectivity on age-0 fish was nearly 1.0 (atypically large pulse of small/young fish observed in summer 2015). Fits to composition data were similar to those for model ALT, except that the spike of age-0 fish in 2015 was captured better. The estimate of age 1+biomass on 1 July, 2017 for this model was 77,845 t.

Request 9: Run a variant of model ALT in which the age-composition data are assigned to a new fleet (6) that has logistic selectivity (estimated separately for the spring and summer periods).
Rationale: Selectivity for the ATM survey is assumed to be uniform on animals aged 1 and older so age-composition data are not required for this survey. The selectivity pattern for the trawl component of the survey is not uniform on age-1+ animals (some age-0 animals are caught) and it may be possible to represent this using a logistic selectivity function.
Response: This model performed generally similar to a logistic formulation applied to the ATM survey for both age-composition and as an abundance index, but it misses the summer 2016 ATM survey estimate of biomass from above whereas the logistic fits that estimate closely. However, the logistic model had a negative log-likelihood of approximately 311, compared to 305 for this variant, and 333 for model ALT. Thus, both a model with logistic ATM selectivity and a model that assumed 1+ selectivity for ATM survey estimates and logistic selectivity for the associated age-composition data fit the data somewhat better than model ALT.

Request 10: Conduct a retrospective evaluation of how well alternative assessment methods can predict the biomass from the summer ATM surveys. For each year Y for which there is a summer ATM survey estimate for year Y and year Y+1, report predictions of year Y+1 biomass based on

(a) the estimate of biomass from the results of the ATM survey during summer of year Y, (b) the estimate of biomass based on applying the projection method to the results from the ATM survey in summer of year Y, and (c) model ALT based on data through year Y.
Rationale: The Panel wished to understand which method was able to predict the ATM survey estimate of biomass most accurately.
Response: The STAT provided results for the three selected approaches as well estimates of age 1+ biomass obtained by projecting the actual assessments used for 2012, 2013, 2014 and 2015 forward ("Past assessment" in Fig. 4) and estimates of age 1+ biomass obtained by projecting the model used for 2014, 2015 and 2016 management advice ("2014 formulation"). Model ALT generally came closest to predicting the survey biomass estimate the following year, doing so by a substantial margin for 2014. "Past assessment" was usually the worst. Model ALT had the lowest residual variance. Relative errors were a CV of 1.07 for Model ALT, 1.26 for the 2014 model formulation, 1.50 for the last survey without projection, 1.62 for the values adopted in management specifications, and 1.70 for projections from the previous ATM survey (see Appendix 2 for the specifications for the method).

Day 3 requests made to the STAT during the meeting – Thursday, February 23
Request 11: Develop a method for estimating recruitment solely from ATM data, explain how these recruitment estimates could be used to project forward from an ATM biomass estimate, and then add results for that method to the retrospective comparison described in Request 10.
Rationale: During discussion of Request 10, it was clear that much of the concern regarding the currently proposed method of projecting from the survey was its dependence on model ALT for stock-recruitment estimates for conducting the projection, resulting in its dependence on the same assumptions the STAT was hoping to avoid by moving away from an integrated assessment. It was pointed out that it could be possible to develop estimates of age 1 biomass on 1 July, 2017 strictly from the ATM data.
Response: The STAT modified the survey projection method so that projected biomass of 1-year-olds was the average over the most recent five years (see Appendix 2 for details). As desired, this approach was not tied to the model ALT. However, the residual standard deviation for this approach ("Survey projection 2"), while better than "Survey projection", was still worse than Model ALT and the 2014 model formulation (1.45) (Fig. 4).

3) Technical Merits and/or Deficiencies of the Assessment

Alternative assessment approaches
The Panel considered four ways to estimate age 1+ biomass on 1 July 2017: (a) use the estimate of biomass from the summer 2016 ATM survey, (b) project the estimate of biomass from the summer 2016 ATM survey to 1 July 2017 using the 'survey projection' model (or an alternative approach), (c) model ALT, and (d) the model on which the 2014-16 assessments were based. The Panel had concerns with, and comments on, all of these methods:

- Assuming that the 1 July 2017 biomass equals the estimate of biomass from the summer 2016 ATM survey ignores mortality (from natural causes and from fishing), growth and recruitment from July 2016 to July 2017. However, this method is simple to implement because it does not rely on a model, nor does it rely on estimates of age composition for which sample sizes are low.
- Projecting the biomass from the 2016 ATM survey to 1 July 2017 accounts for mortality, growth and recruitment from July 2016 to July 2017. However, the approach used to

convert from length composition to age composition is incorrect, and the method used to derive the CV of age 2+ biomass does not allow for uncertainty in population age composition, projected weight-at-age and maturity-at-age. In addition, the method relies heavily on model ALT because approximately half of the age 1+ biomass on 1 July 2017 consists of age-1 animals, i.e. the estimate of this biomass is based to a substantial extent on the stock-recruitment function from model ALT. Finally, the value for M of 0.6yr^{-1} has no clear justification. The version of the projection model provided initially to the Panel did not account for catches so it could not be applied were the targeted sardine fishery to be re-opened, and does not account for the limited catches during 2016.

- Model ALT has several of the problems associated with the 'survey projection' model, i.e. the age-composition data are based on a year-invariant age-length key, and the basis for M=0.6yr^{-1} lacks strong empirical justification (and indeed likelihood profiles indicate some support for lower M than the value adopted for model ALT). In addition, the model presented to the Panel predicted age-0 catch in the ATM survey even though it is assumed that age-0 animals are not selected during the ATM survey. It appears that the model predictions of age-0 animals in the ATM survey are actually model-predicted numbers of age-1 animals that are predicted to be mis-read as age-0 animals. However, examination of the ATM survey length-frequencies suggests that that some age-0 animals (or animals that were spawning earlier in the year) are encountered during the surveys (Fig. 5). Model ALT estimates Q to be 1.1, which is unlikely given some sardine are not available to the survey owing to being inshore of the survey area.
- The model on which the 2014-16 assessments were based was approved for management by the 2014 STAR Panel. However, that assessment had some undesirable features, including extreme sensitivity to the occurrence of small (<~15cm fish) in the ATM surveys, poor fits to the length-composition and survey data, and sensitivity to the initial values for the parameters (i.e. local minima). These sensitivities and the resultant high uncertainty about population scale were noted in previous reviews.

The Panel explored alternatives to the current selectivity formulation to better understand why model ALT was predicting age-0 catch when selectivity for age-0 fish was set to zero. It was noted that the results are generally robust to assuming that selectivity is a logistic function of length (but that implies that some age-1+ animals are not available to the ATM survey), allowing for time-varying age-0 selectivity, and estimating a separate selectivity pattern for ATM survey age-composition data.

The Panel noted that the 'survey projection' model and model ALT both rely on the samples from the ATM surveys to compute weight-at-age and survey age-composition data. The samples sizes for age from each survey are very small (16 – 1,051), which means that estimates of, for example, weight-at-age are highly uncertain. The procedure of ensuring that weight-at-age for a cohort does not decline over time seems intuitively correct. However, if the estimated mean weight of young fish in a cohort is anomalously high or low due to sampling errors (owing to small samples), it can impact the weight-at-age of that cohort for all subsequent ages.

Model ALT estimated steepness rather than fixing it equal to 0.8. The results were not sensitive to fixing versus estimating steepness, but the estimate of 0.36 was low.

Selection of an assessment approach

The Panel considered the merits of the various approaches. It concluded that:

- The approach on which 2014-16 management was based exhibited undesirable assessment diagnostics, and produced extremely high estimates of recruitment when large numbers of small fish were observed in the ATM survey length-frequencies. The approach also performed poorly in retrospective analysis (Fig. 4)[1]. The Panel and STAT agreed that this approach should not be used for 2017 management.
- The survey projection method (and the modified version, "Survey projection 2") seems a viable and defensible way to estimate age 1+ biomass using the ATM survey results, especially if the method could be modified to not use the results from model ALT. However, as currently formulated, this method performs no better than assuming that the age 1+ biomass in July 2017 equals the survey estimate of biomass for summer 2016 (Fig. 4). Thus, while viable, this approach requires further development and review prior to adoption.
- Estimating the biomass on 1 July of year Y+1 based on the ATM survey estimate for year Y is simple, but the Panel was concerned that this method ignored catches during year Y and may lead to additional risk. Thus, the basic approach is viable, but needs additional testing prior to adoption.

Given the current management approach that requires an estimate of age-1 biomass at the start of July, the Panel and STAT agreed that model ALT was the best approach at present for conducting an assessment for the northern subpopulation of Pacific sardine, notwithstanding the concerns listed above. The results from the assessment are robust to changes to how selectivity is modelled, the value for steepness and data weighting, but there were several concerns with this model that could not be resolved during the Panel meeting. Assuming uniform selectivity leads to lower estimates of current 1+ biomass, but this assumption reflects the expectation that all fish in the survey area are vulnerable to detection during an acoustic survey.

The final model (model ALT) incorporates the following specifications:
- catches for the MexCal fleet computed using the environmentally-based method;
- two seasons (semesters, Jul-Dec=S1 and Jan-Jun=S2) for each assessment year from 2005 to 2016;
- sexes were combined; ages 0-10+.
- two fisheries (MexCal and PacNW fleets), with an annual selectivity pattern for the PacNW fleet and seasonal selectivity patterns (S1 and S2) for the MexCal fleet;
    - MexCal fleet: age-based selectivity (one parameter per age)
    - PacNW fleet: asymptotic age-based selectivity;
    - age-compositions with effective sample sizes calculated by dividing the number of fish sampled by 25 (externally) and lambda weighting=1 (internally);
- Beverton-Holt stock-recruitment relationship with "steepness" estimated;
- *M* was fixed (0.6 yr^{-1});
- recruitment deviations estimated from 2005-2015;
- virgin recruitment estimated, and σ_R fixed at 0.75;
- initial *F*s estimated for the MexCal S1 fleet and assumed to be 0 for the other fleets;

[1] Care needs to be taken interpreting Fig. 4 given the low number of years involved and the fact the observed 1+ biomass is subject to considerable sampling error.

- ATM survey biomass 2006-2013, partitioned into two (spring and summer) surveys, with Q estimated;
    - age-compositions with effective sample sizes set to 1 per cluster (externally);
    - selectivity is assumed to be uniform (fully-selected) above age 1 and zero for age 0.

The estimate of age 1+ biomass on 1 July 2017 from model ALT is 86,586t (CV 0.363). Model ALT indicates that age 1+ biomass has rebuilt close to that in 2014, owing to a substantial increase in biomass based on the indices from the survey (Fig. 6). The estimate of age 1+ biomass is less than the estimate of age 1+ biomass on 1 July 2016 from the 2016 stock assessment (106,137t). This is a consequence of the change in assessment methodology, in particular that selectivity for the ATM survey is assumed to be uniform for fish aged 1 and older (assuming that selectivity is logistic in model ALT increases the estimate of 1+ biomass from 86,586t to 153,020t).

Future directions

The STAT strongly supports that management advice for Pacific sardine be based on the estimates of biomass from the ATM survey rather than a projection model or an integrated assessment. The Panel notes the following ways in which management could be based on the ATM survey results.

- Change the start-date of the fishery so that the time between conducting the survey and implementation of harvest regulations is minimized.
- Use Management Strategy Evaluation to evaluate the risk to the stock of basing management actions on an estimate of biomass that could be a year old at the start of the fishing season (if the fishery start date is unchanged). Review of an updated MSE would likely not require a Methodology Panel, but could instead be conducted by the SSC.

The Panel notes that there may be benefits to attempting to use both the spring and summer ATM surveys as the basis for an ATM survey-only approach and that moving to an assessment approach that relies on the most recent ATM survey (or two) may be compromised by reductions in ship time and/or problems conducting the survey. It agrees with the STAT that there is value in continuing to collect biological data and to update model ALT even if management moves to an ATM survey-only approach.

4) Areas of Disagreement

There were no major areas of disagreement between the STAT and Panel, nor among members of the Panel.

5) Unresolved Problems and Major Uncertainties

The core issues for stock assessments continue to be related to the temporal and spatial scale of the surveys and insufficient sample sizes of age-length for sardine in the ATM survey. The ability of a single boat following fixed transects along the entire sardine NSP region over a single period to sufficiently observe and sample a highly mobile schooling fish that exhibits high variability in recruitment, migratory patterns and timing, school structure, and depth distribution remains a core challenge. The relatively small sample size of sardine for biological analysis remains a concern related to acoustic expansions, population model estimates, and projection forecasts that depend on age composition and size-at-age information. A solution may require more resources than SWFSC has at its disposal so that will require Council action; resolution of this issue is outside of the ability of the Panel to address.

The Panel identified concerns with all of the proposed assessment approaches as highlighted in Section 3 of this report. In relation to model ALT, the Panel was unable to fully resolve the issue of observations of age-0 animals in the ATM survey age compositions, and how to compute age-composition and weight-at-age for the ATM survey.

6) Issues raised by the CPSMT and CPSAS representatives during the meeting

a) CPSMT issues

The CPSMT (MT) representative appreciates the substantial efforts by the STAT and the constructive Panel discussion, and offers the following comments.

The STAT proposed the ATM survey as the preferred approach over an integrated model for estimating sardine biomass. However, because the ATM survey at this time does not better estimate biomass projected to the start of the 2017-18 fishing year, the integrated model (Model ALT) was ultimately recommended. The MT representative agrees this was a reasonable approach to meet management requirements for a July 1, 2017 biomass estimate, but nevertheless also supports further consideration for shifting to the ATM survey to estimate biomass. The MT representative notes that issues of spatial and temporal coverage, and sample size remain for the survey. This has implications for the model ALT as well.

The review noted problems associated with some very small sample sizes produced by the trawl component of the ATM survey. Given that fish captured in trawls informs the species composition of the acoustic signals, as well as providing biological data, additional effort is required to refine and improve trawling operations. Additionally, more of the fish (particularly during the summer survey) that are collected need to be processed for ageing. The MT representative notes small sample size was flagged as a concern in the last full update conducted in 2014 and strongly supports the Panel recommendation that the SWFSC conduct analyses to estimate optimal sample size and to refine the survey methodology.

The lack of nearshore coverage by the ATM survey persists. Research needs to be conducted to explore possible approaches for surveying this area. Collaborative projects with industry should be encouraged to leverage their expertise. Further, emphasis should be placed on ensuring that the survey has sufficient sea-days to effectively cover the entire west coast irrespective of whether the ATM survey is used within a model or if the ATM survey is to be considered the preferred approach to inform the biomass estimate for management. The current plan to reduce the number of sea-days from 80 in 2016 to 50 in 2017 is concerning. The 50-day summer survey planned for 2017 does not include the area south of Monterey. If distance between transects were increased, the survey could possibly be extended to Point Conception, which would still not include the Southern California Bight. Fewer days at sea and the corresponding likely decrease in number of trawls also reduces the data upon which to base species composition and to produce biological data.

An MSE to evaluate the effects of using the ATM biomass estimate to inform the following year's harvest control rules is proposed as a high research priority (G). If the MSE were to find the one-year lag does create unacceptable outcomes one approach would be to develop an improved projection model. Another proposed fix would be to move the fishing year start date. While possible, the MT representative would like to highlight that the start date was adjusted beginning in 2014 to afford the STAT more time between the conclusion of field seasons and the deadline for STAR review of stock assessments. More significantly, shifting the start date can raise management issues because embedded in it is the period-based catch allocation scheme. Selecting an existing allocation period start date (January 1, July 1 and September 1) is perhaps more straightforward and would not necessarily require substantial analysis. Selecting any other starting point would likely necessitate an analysis of impacts and therefore more time to implement (i.e. two to three Council meetings). How to best accomplish aligning a shift to using only an ATM survey-derived biomass estimate with a change to the fishing year will require additional deliberation.

b) CPSAS issues

The CPSAS representative commends the Panel and STAT for their extensive and thoughtful body of work throughout the 2017 sardine STAR panel. Unfortunately, the 2017 sardine assessment again encountered the same difficulties observed in previous STAR panels. Most of the unresolved problems and major uncertainties listed in the 2011 and 2014 STAR panel reports still exist.

Earlier panels pointed out significant scaling issues. The 2017 assessment also encountered issues with ageing, notably an age-length key that was deemed incorrect. One persistent problem is the very small sample size for biological composition data obtained during ATM surveys and other sampling; another is the high variability in length-at-age observed in sardine year-to-year. As pointed out during the meeting, an age/length key averaged over seasons is not valid; it ignores differential cohort strengths. This presents a major problem in model projections, and adds another layer of uncertainty considering the current time lag between field surveys and the development of either ATM survey-based or model-based management advice for the fishery.

Assigning July 1 as the standardized birth date for sardine also presents problems, particularly in light of recent year ocean conditions that have precipitated sardine spawning earlier in the year, too early to be observed in April DEPM surveys, and producing age-0 fish assumed too small to be captured in ATM surveys. Yet an abundance of small fish exists! In fact, the 2015 summer ATM survey did encounter a spike of very small fish. A record number of pelagic juvenile sardines (and anchovies) also was found in the 2015 juvenile rockfish cruise. However, the length-composition data for the small fish were omitted from the assessment model in 2015 because the biomass estimate produced was “unrealistic.”

Ironically, none of the approaches considered at this STAR panel meeting found adequate evidence of recruitment in 2016 to boost the stock assessment “number” in 2017. In fact, the projected biomass estimate for 2017 is lower than 2016 at a time that sardines are increasing in abundance, apparently coast-wide, but certainly in California. The current report attributed this to a change in assessment methodology.

Fishermen from the Pacific Northwest and California who attended the STAR panel meeting reported that they have observed an abundance of 3-6 inch fish for the past couple of years, particularly in live bait catches. California fishermen delivered samples of these fish to the SWFSC and California Department of Fish and Wildlife (CDFW). But while the 2016 draft stock assessment did include a small number of live bait catches (now the only active non-treaty fishery for sardine on the West Coast), the corresponding biological-composition data were not aged and hence included in the assessment.

In the opinion of the fishermen, an opinion shared by this CPSAS representative, none of the four approaches considered during the panel meeting accurately reflect the biomass of sardine now in the ocean. The Panel also voiced concerns with all the methods presented; those concerns are reflected in the body of this report under **Technical Merits and/or Deficiencies of the assessment.**

The CPSAS representative highlights major concerns, including:

- The STAT now recommends the ATM survey as the most objective survey method. However, ATM surveys at present do not capture fish in the upper water column, nor a large biomass of young fish (sizes 3 inches and up) that fishermen have observed in nearshore waters since late 2014; this biomass is largely inside ATM survey tracks. But the ATM survey is assigned a catchability quotient (Q) of 1 nonetheless, meaning it "sees" all the fish. The Q for Model ALT, which is based largely on ATM survey data, is estimated at 1.1, which the STAR Panel report calls into question, given for example the unquantified volume of fish in nearshore waters.
- The summer 2016 ATM survey reported a fourfold increase in age 1+ biomass, but the biomass estimate produced is substantially lower than the estimate used for management in 2016. The STAR panel found fault with the methodology used to project the 2016 biomass to 2017. So do we – but using the 2016 ATM biomass estimate without adjusting for recruitment ignores reality.
- In addition, the proposal to simply use the biomass estimate from the summer ATM survey directly, to avoid uncertainty in model assumptions, could bypass surveying a substantial portion of the biomass if/when cruises are shortened, or disrupted. For example, the 2017 summer survey schedule is only 50 days, down from 80 days in 2016. This means the survey may not extend much below San Francisco, which will miss a substantial portion of California's historical fishing grounds.
- Also, a proposal to change the fishing season start date to more closely follow the survey, thus avoiding the need to project recruitment, is not as simple as it sounds. The current seasonal structure is tied to an allocation framework that would require serious discussion and analysis before any change could be implemented.
- At the end of the day, the STAR panel cautiously recommended proceeding with Model ALT, as the "least-worst" way to produce the age 1+ biomass estimate and CV required for management in 2017. The CPSAS hopes the SSC and Council will acknowledge all the caveats, and recognize that this is a "stop-gap" approach until the ATM methodology review can be accomplished in 2018, along with further review and improvement of Model ALT input and assumptions and potential review of other assessment indices.
- The CPSAS representative again voices concern that stock assessments appear to be gravitating toward one independent index measuring one point in time, based on ATM surveys. We strongly encourage a continuation of multiple surveys as each survey type has strengths and weaknesses. Other fishery-independent research, i.e. the juvenile rockfish survey, was informative in 2016 and should be approved to provide information for future sardine stock assessments, as this could serve as another indicator of recruitment.
- Clearly the small sample size and inadequate biological composition data are causing serious problems in assessing the sardine (and anchovy) resource. Industry has offered to help collect data, and we hope this offer will be acted upon in a way that such information can be incorporated into future stock assessments.

- As we have noted in the past, industry wants to see a sustainable resource (to the degree that environmental conditions will allow) that is in no danger of being overfished. Current sardine stock assessments and harvest policy are very precautionary. We sincerely hope that going forward we can develop a truly collaborative research program for the CPS complex.

Other recommendations:

- Please work collaboratively with industry to resolve persistent data deficiencies, including assessing the nearshore, upper water column, and the need for substantial increase in sample size and biological composition data for sardine (and other CPS), particularly ageing.
- Recognize that the 2017 assessment is "déjà vu all over again" and most of the unresolved problems and major uncertainties listed in the 2011 and 2014 STAR panel reports still exist.
- Prior panel, SSC, CPSMT and CPSAS reports have recommended a methods review of the ATM survey ASAP as a high priority research and data need. We continue to emphasize this need, and further recommend that such review also encompass review of Model ALT and other potential data collection options, including the juvenile rockfish survey, CDFW/CWPA aerial survey and any other promising data collection prospects available by the time of the scheduled ATM review in January 2018.
- We also support the STAT high-priority recommendation to address: "*technical issues related to echosounder deployment and associated signal interpretation (e.g., uncertainty surrounding species-specific target strength [TS], sonar bias related to backscatter uncertainty, and areas of the upper water column that potentially are not capable of being surveyed*)."

Dr. Zwolinski noted that target strength is currently based on "similar" fish, not Coastal Pelagic Species (CPS) found in the California Current. The STAT and Panel recognized that incorrect target strength could result in both over or under-estimation of biomass

Finally, the CPSAS representative points out that improving survey and assessment methodology to accurately reflect abundance of sardine (and other CPS) is absolutely essential: the future of the industry hangs in the balance.

7) Research Recommendations

High priority

A. Conduct an analysis of effect of fish sample size on the uncertainty in the ATM biomass estimates and model outputs. Use this information to re-evaluate and revise the sampling strategy for size and age data that includes target sample sizes for strata
B. The clusters (the Primary Sampling Units, PSUs) with age-length data should be grouped into spatial strata (post-strata, or collapsed post-strata used in ATM biomass estimators). The variance in estimates of age-length compositions can then be estimated by bootstrapping of PSUs, where age-length keys are constructed for each bootstrap replicate. The sub-sample size of fish within clusters that are measured for lengths should be increased, and length-stratified age-sampling should be implemented. This approach would likely increase coverage of age samples per length class and reduce data gaps.

C. The survey projection method should be developed further. Specifically, the survey age-composition should be based on annual age-length keys, and the uncertainty associated with population age-composition, weight-at-age and maturity-at-age needs to be quantified and included in the calculation of CVs. A bootstrapping procedure could be used to quantify the uncertainty associated with population age-composition and projected weight-at-age. Uncertainty in weight-at-age could also be evaluated using a retrospective analysis in which the difference between observed and predicted weight-at-age for past years was calculated. Ultimately, improved estimates of weight-at-age and measures of precision of such estimates could be obtained by fitting a model to the empirical data on weight-at-age.
D. The methods for estimating 1 July age 1+ biomass based on the results of the ATM survey during the previous year currently use only the results of the summer survey. Improved precision is likely if the results from the spring and summer surveys were combined. This may become more important if the number of days for surveying is reduced in future. Consideration should be given to fish born after 1 July.
E. Investigate alternative approaches for dealing with highly uncertain estimates of recruitment that have an impact on the most recent estimate of age-1+ biomass that is important for management.
F. Modify Stock Synthesis so that the standard errors of the logarithms of age-1+ biomass can be reported. These biomasses are used when computing OFLs, ABCs and HGs, but the CV used when applying the ABC control rule is currently that associated with spawning biomass and not age-1+ biomass.
G. The approach of basing OFLs, ABCs and HGs for a year on the biomass estimate from the ATM survey for the previous year should be examined using MSE so the anticipated effects of larger CVs and a possible time-lag between when the survey was conducted and when catch limits are implemented on risk, catch and catch variation statistics can be quantified.
H. The assessment would benefit not only from data from Mexico and Canada, but also from joint assessment activities, which would include assessment team members from both countries during assessment development.
I. The assessment would benefit from the availability of estimates of 1+ biomass that include quantification of the biomass inshore of the survey area and in the upper water column.
J. It is unclear how the habitat model is applied to determine survey design. Is this an *ad hoc* decision or is there a formal procedure? The next Panel should be provided with comprehensive documentation on how the habitat model is applied.
K. Consider future research on natural mortality. Note that changes to the assumed value for natural mortality may lead to a need for further changes to harvest control rules.
L. Explore the potential of collaborative efforts to increase sample sizes and/or gather data relevant to quantifying effects of ship avoidance, problems sampling near-surface schools, and currently unsampled nearshore areas.
M. Reduce aging error and bias by coordinating and standardizing aging techniques and performing an aging exchange (double blind reading) to validate aging and estimate error. Standardization might include establishing a standard "birth month" and criteria for establishing the presence of an outer annuli. If this has already been established, identify labs, years, or sample lots where there is deviation from the criteria. The outcome of comparative studies should be provided with every assessment.

Medium priority

N. Continue to explore possible additional fishery-independent data sources such as the SWFSC juvenile rockfish survey and the CDFW/CWPA cooperative efforts (additional sampling and aerial surveys). Inclusion of a substantial new data source would likely require review, which would not be easily accomplished during a standard STAR Panel meeting and would likely need to be reviewed during a Council-sponsored Methodology Review.

O. Consider spatial models for Pacific sardine that can be used to explore the implications of regional recruitment patterns and region-specific biological parameters. These models could be used to identify critical biological data gaps as well as better represent the latitudinal variation in size-at-age; this should include an analysis of age-structure on the mean distribution of sardine in terms of inshore-offshore (especially if industry partner-derived data were available).

P. Consider a model that has separate fleets for Mexico, California, Oregon-Washington and Canada.

Q. Compare annual length-composition data for the Ensenada fishery that are included in the MexCal data sets for the northern sub-population with the corresponding southern California length compositions. Also, compare the annual length-composition data for the Oregon-Washington catches with those from the British Columbia fishery. This is particularly important if a future age data/age-based selectivity model scenario is further developed and presented for review.

Low priority

R. Consider a model that explicitly models the sex-structure of the population and the catch.

S. Develop a relationship between egg production and fish age that accounts for the duration of spawning, batch fecundity, etc. by age. Using this information in the assessment would require that the stock-recruitment relationship in SS be modified appropriately.

T. Change the method for allocating area in the DEPM method so that the appropriate area allocation for each point is included in the relevant stratum. Also, apply a method that better accounts for transect-based sampling and correlated observations that reflects the presence of a spawning aggregation.

Recommendations that should be addressed during the 2018 review of the ATM survey

A. In relation to the habitat model
    a. Investigate sensitivity of the assessment to the threshold used in the environmental-based method (currently 50% favourable habitat) to further delineate the southern and northern subpopulations of Pacific sardine.
    b. Further validate the environmentally-based stock splitting method. The habitat model used to develop the survey plan and assign catches to subpopulation seems to adequately predict the spawning/egg distribution in the CalCOFI core DEPM region, but eggs were observed where they were not expected in northern California, Oregon and Washington during one of the two years when the survey extended north. It may be possible to develop simple discriminant factors to differentiate the two sub-populations by comparing metrics from areas where mixing does not occur. Once statistically significant discriminant metrics (e.g. morphometric, otolith morphology, otolith micro-structure, and possibly using more recent developments in genetic methods) have been chosen, these should be

applied to samples from areas where mixing may be occurring or where habitat is close to the environmentally-based boundary. This can be used to help set either a threshold or to allocate proportions if mixing is occurring.

c. Consider including environmental covariates in model-based approaches that would account quantitatively for environmental effects on distribution and biomass. The expertise from a survey of fishermen could be extremely useful in identifying covariates that impact the distribution of clusters.

B. The SWFSC plans to examine ship avoidance using aerial drone sampling; there is an ongoing significant effort by Institute of Marine Research in Norway to understand the same issue using sonar, and the SWFSC acoustics team should communicate and coordinate with those researchers.

C. The effect of population size affecting the number and spacing of school clusters likely affects the probability of acoustic detection in a non-linear way; this could create a negatively biased estimate at low population levels and potentially a non-detection threshold below which the stock size cannot be reliably assessed. A simulation exercise should be conducted using the current, decreased and increased survey effort over a range of simulated population distribution scenarios to explore this.

D. The consequences of the time delay and difference in diurnal period of the acoustic surveys versus trawling need to be understood; validation or additional research is critical to ensure that the fish caught in the trawls from the night time scattering layer share the same species, age and size structure as the fish ensonified in the daytime clusters.

E. The ATM survey design and estimation methods need to be more precisely specified. A document must be provided to the ATM review (and future assessment STAR Panels) that:
   - delineates the survey area (sampling frame);
   - specifies the spatial stratification (if any) and transect spacing within strata planned in advance (true stratification);
   - specifies the rule for stopping a transect (offshore boundary);
   - specifies the rules for conducting trawls to determine species composition;
   - specifies the rule for adaptive sampling (including the stopping rule); and
   - specifies rules for post-stratification, and in particular how density observations are taken into account in post-stratification. Alternative post-stratification without taking into account density should be considered.

References

Venables,W.N. and D.B. Ripley, B.D., 2002. Modern Applied Statistics with S, 4th ed. Springer-Verlag, New York.

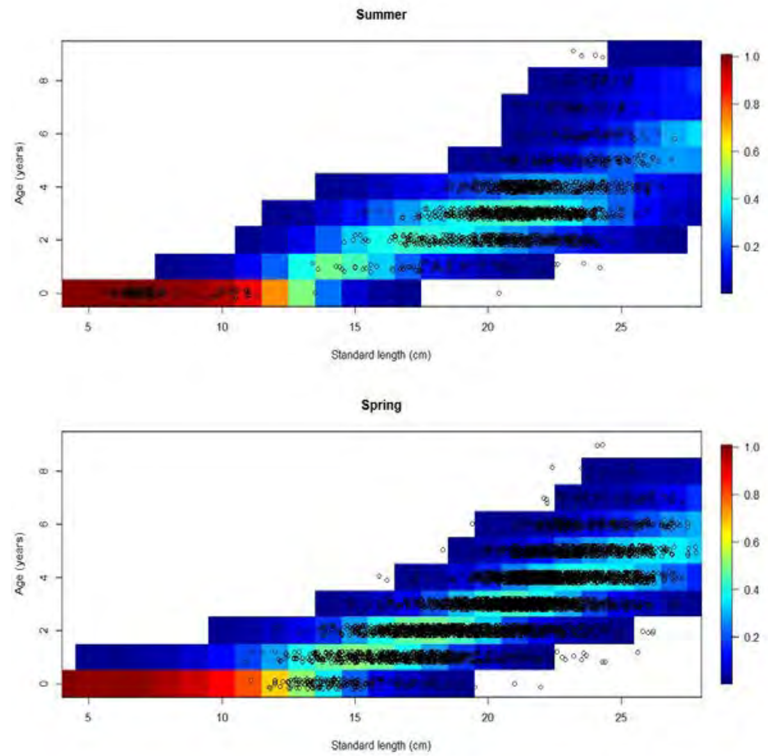

Fig. 1. Age-length key constructed using age and length information from sardine collected during Spring (upper panel) and Summer (lower panel) ATM surveys from 2004 to the present. The colored surface in the background is the multinomial surface $P(x = i|length)$ for $i \in \{0,1, \dots ,8,9+\}$ fit using the *multinom* function available in the *nnet* package for R (Venables and Ripley, 2002). The points in the foreground represent the pairs of data used to fit the model.

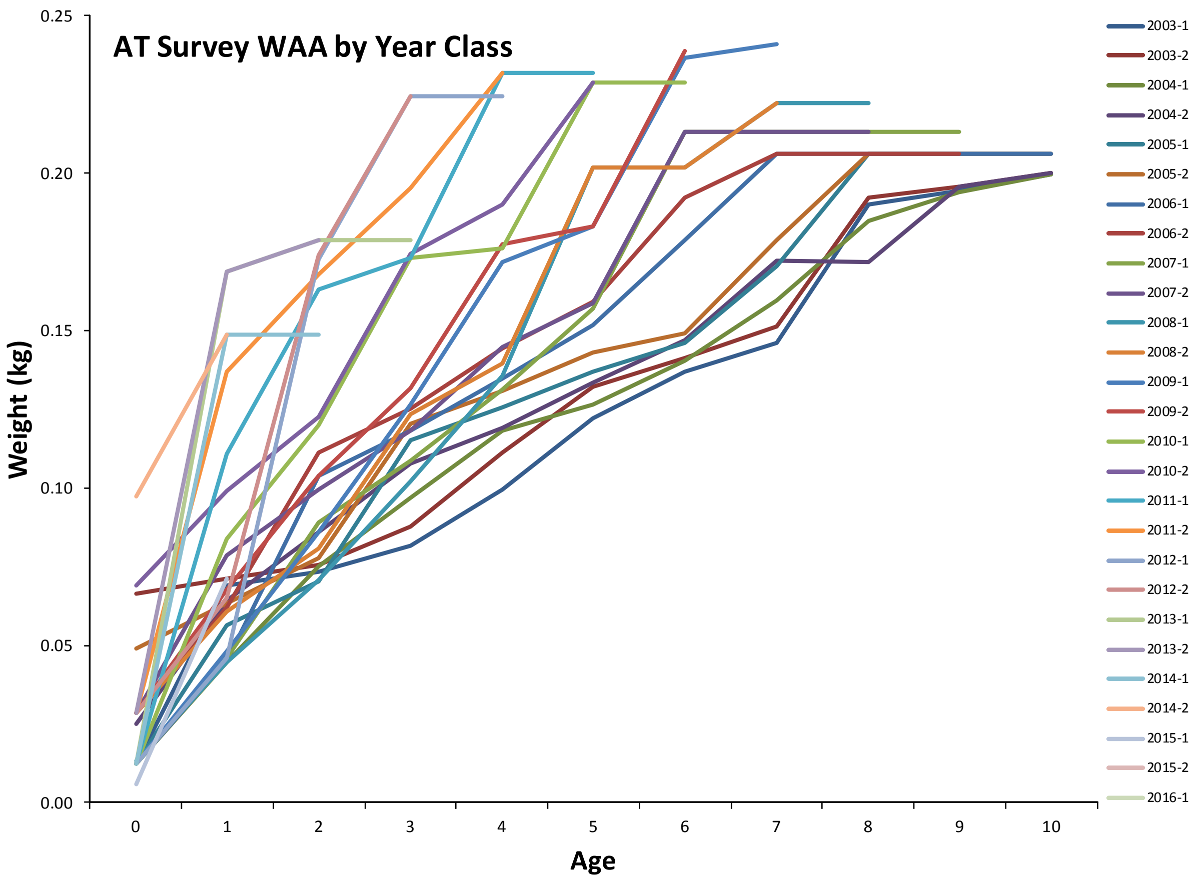

Fig. 2. Weight-at-age by cohort for the ATM survey.

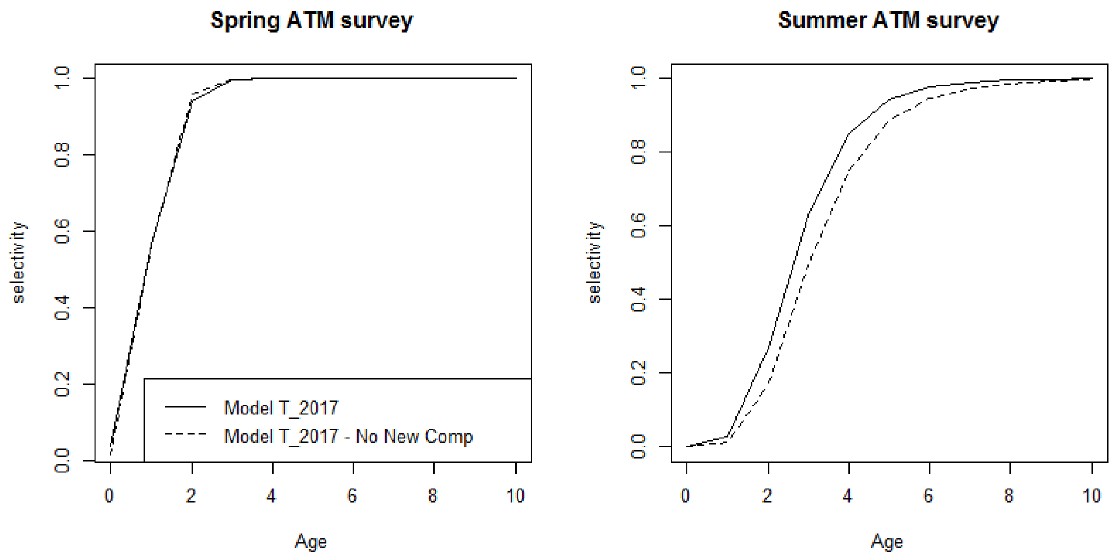

Fig. 3. ATM survey selectivity for the spring and summer surveys from Model T2017 and a variant of that model in which the last two ATM length-compostions are dropped from the model.

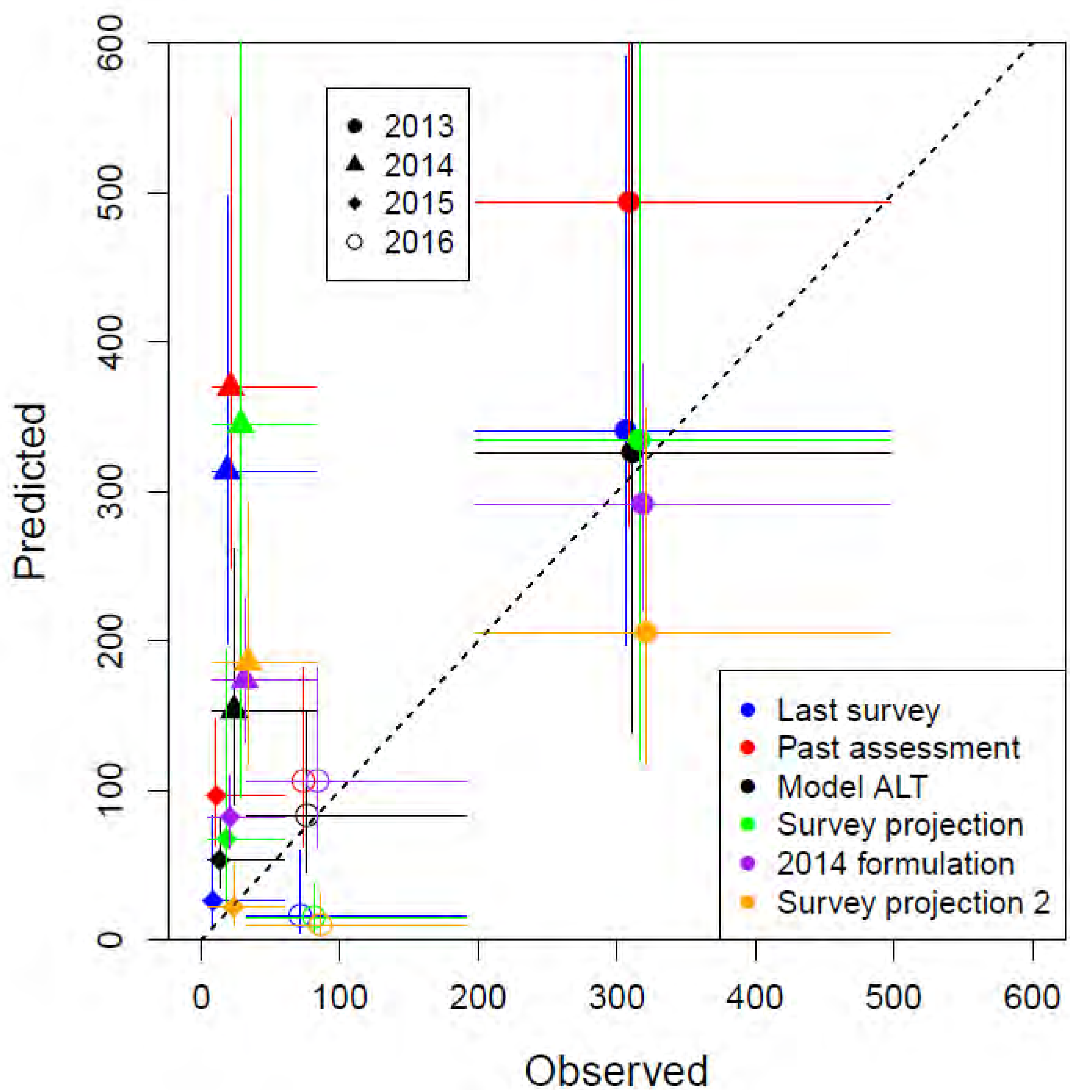

Fig. 4. Observed (x-axis values, ATM survey biomass estimates) and model-predicted (y-axis values) biomass on 1 July of each of 2013, 2014, 2015 and 2016. The observed values are the summer ATM survey estimates. The lines indicate 90% confidence intervals under the assumption of log-normal error. The x-axis values are jittered for ease of presentation.

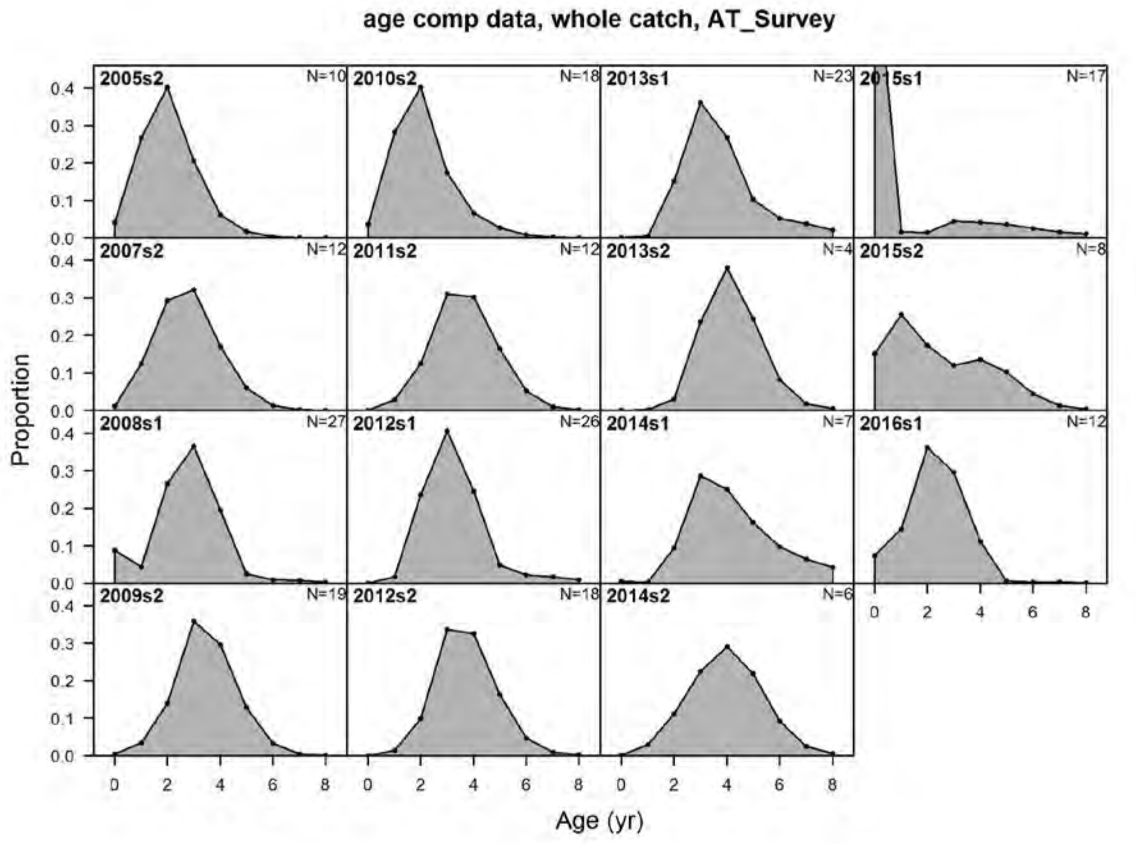

Fig. 5. The ATM survey age-compostion data.

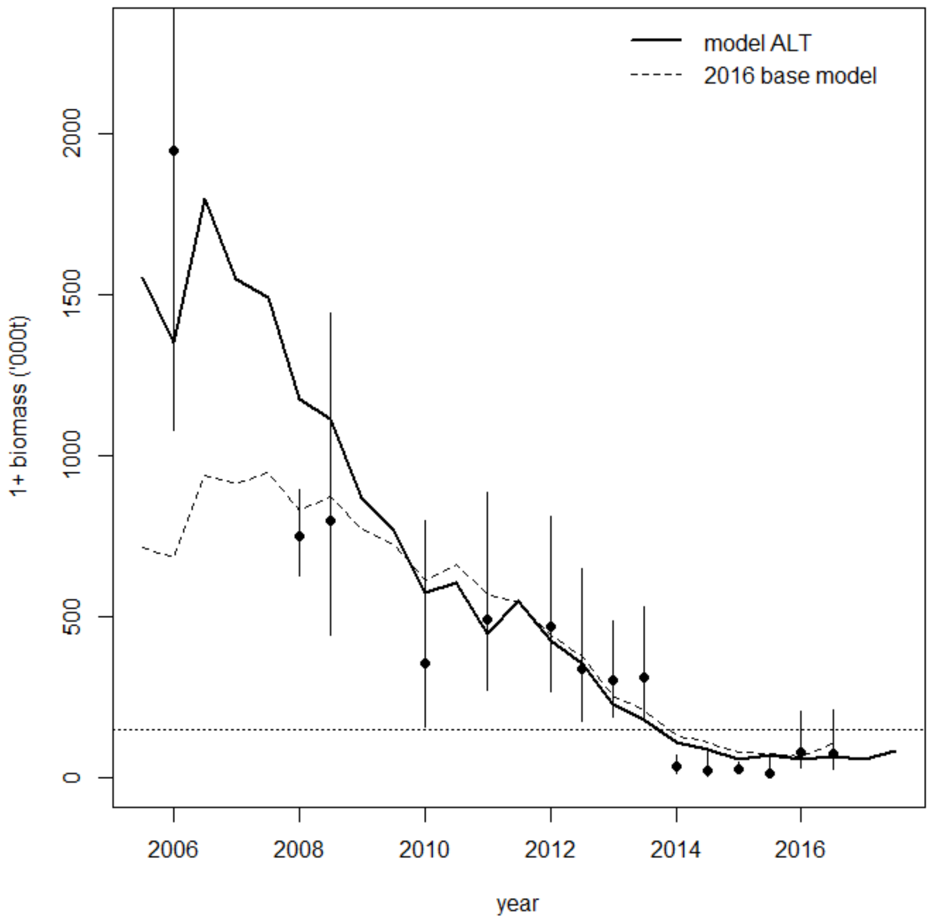

Fig. 6. Time-trajectories of 1+ biomass from model ALT and the 2016 base model. The ATM survey estimates of biomass and their 95% confidence intervals are indicates by the dots and the vertical bars, respectively.

Appendix 1
2017 Pacific Sardine STAR Panel Meeting Attendees

STAR Panel Members:
André Punt (Chair), Scientific and Statistical Committee (SSC), Univ. of Washington
Will Satterthwaite, SSC, Southwest Fisheries Science Center
Evelyn Brown, SSC, Lummi Natural Resources, LIBC
Jon Vølstad, Center for Independent Experts (CIE)
Gary Melvin, Center for Independent Experts (CIE)

Pacific Fishery Management Council (Council) Representatives:
Kerry Griffin, Council Staff
Diane Pleschner-Steele, CPSAS Advisor to STAR Panel
Lorna Wargo, CPSMT Advisor to STAR Panel

Pacific Sardine Stock Assessment Team:
Kevin Hill, NOAA / SWFSC
Paul Crone, NOAA / SWFSC
Juan Zwolinski, NOAA / SWFSC

Other Attendees
Dale Sweetnam, SWFSC
Alan Sarich, CPSMT/Quinault Indian Nation
Emmanis Dorval, SWFSC
Chelsea Protasio, CPSMT/CDFW
Kirk Lynn, CPSMT/CDFW
Ed Weber, SWFSC
Josh Lindsay, NMFS WCR
Erin Kincaid, Oceana
Al Carter, Ocean Gold
Jason Dunn, Everingham Bros Bait
Nick Jurlin, F/V Eileen
Neil Guglielmo, F/V Trionfo
Andrew Richards, Commercial
Hui-Hua Lee, SWFSC
Bev Macewicz, SWFSC
Chenying Gao, Student
Steven Teo, SWFSC
Kevin T.R. Piner, SWFSC
Andy Blair, Commercial
Jamie Ashley, F/V Provider
John Budrick, CDFW
Steve Crooke, CPSAS
Gilly Lyons, Pew Trusts

<u>Acronyms</u>
CDFW – California Department of Fish and Wildlife
CPSAS - Coastal Pelagic Species Advisory Subpanel
CIE – Council on Independent Experts
CPSMT - Coastal Pelagic Species Management Team
CWPA – California Wetfish Producers Association
SSC - Scientific and Statistical Committee
SWFSC - Southwest Fisheries Science Center (National Oceanic and Atmospheric Administration)
WCR – West Coast Region

Appendix 2
Projection of summer AT biomass 1 year into the future (Juan Zwolinski)

Given a vector of abundance-at-age from a summer survey during year *t* $\hat{\mathbf{a}}_{\mathrm{t}} = [\hat{a}_{0t}, a_{1t}, \ldots, a_{9+t}]$, with ages 0 through 9 and above, and where $\hat{a}_{0t}$ is the expected abundance of age-0 sardine estimated in one of the two possible ways described below, the abundance of sardine age 1 and older (zge-1+) at year *t+1* can be estimated by $\hat{\mathbf{a}}_{t+1} = \hat{\mathbf{a}}_{\mathrm{t}} \times e^{-(M+F)}$, where M and F are natural and fishing instantaneous mortality coefficients relative to one year, respectively. The corresponding biomass is obtained by the pointwise product $\hat{\mathbf{a}}_{\mathrm{t+1}} \times \mathbf{w}_{\mathrm{t}}$, where the empirical mean weight-at-age $\mathbf{w}_t = [w_{1t}, \ldots, w_{9+t}]$ is estimated from the survey during year *t*. If fishing mortality is expressed in catch, then $\hat{\boldsymbol{a}}_{t+1}$ can be approximated by $\hat{\boldsymbol{a}}_{t+1} = (\,\hat{\mathbf{a}}_t \times e^{-(M/2)} - \mathbf{c}_t) \times e^{-(M/2)}$, where $\hat{\boldsymbol{c}}_t = [c_{0t}, c_{1t}, \ldots, c_{9+t}]$ is the expected catch in numbers per age class.

Estimating a_{0t}

Summer AT surveys are not reliable estimators of the abundance of age-0 sardine at time *t* ($a_{0\mathrm{t}}$). Therefore, any projection of biomass from a survey at year *t* to year *t+1* requires a_{0t} to be estimated. Assuming that no fishing occurs for age-0 sardine, the expected age-0 abundance $\hat{a}_0$ can be estimated as the mean of the implied age-0 abundances calculated from *n* surveys such that:

$$E[a_0] = \hat{a}_0 = \frac{1}{\mathrm{n}} \sum_n a_1 \times e^M \, .$$

Alternatively, a_{0t} can be estimated using the stock-recruitment relationship from the most recent assessment. In order to do so, the abundance $\boldsymbol{a}_t = [a_{1t}, \ldots, a_{9+t}]$ from the summer survey has to be regressed 6 months and converted into spawning stock biomass (SSB) at *t-0.5*. Using empirical mean weight-at-age in winter $\mathbf{w}_{\mathrm{t-0.5}} = [w_{0t-0.5}, \ldots, w_{8+t}]$, and the vector of proportions of mature fish per age class $\mathbf{s}_{\mathrm{t-0.5}} = [s_{0t-0.5}, \ldots, s_{8+t}]$, $\mathrm{SSB}_{t\text{-}0.5}$ is obtained by the sum of the pointwise-product $\mathbf{a}_{\mathrm{t-0.5}} \times \mathbf{w}_{\mathrm{t-0.5}} \times \mathbf{s}_{\mathrm{t-0.5}}$, where $\mathbf{a}_{\mathrm{t-0.5}}$ can be calculated by $\hat{\mathbf{a}}_{\mathrm{t-0.5}} = \hat{\mathbf{a}}_{\mathrm{t}} \times e^{(M+F)/2}$ in case F is reasonably known. If fishing is expressed in catch, then $\hat{\mathbf{a}}_{\mathrm{t-0.5}} = (\,\hat{\mathbf{a}}_{\mathrm{t}} \times e^{(M/4)} + \mathbf{c}_{\mathbf{t-0.5}}) \times e^{(M/4)}$. There, $\mathbf{c}_{\mathbf{t-0.5}}$ is the vector of catch-at-age that occurred in the 6 months prior to the survey.

Center for Independent Experts (CIE) Independent Peer Review Report of the Pacific Sardine Stock Assessment

Southwest Fisheries Science Center (SWFSC)

La Jolla, CA, February 21-23, 2017

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Executive Summary

In the US, the Pacific sardine is currently a limited entry fishery managed by the Pacific Fishery Management Council using a Harvest Control Rule where the total allowable catch for a given year is based on a forward projection estimate of age 1+ biomass (mt) from the prior year assessment. The main objective of this STAR review was to evaluate two proposed alternative assessment methods for giving quota advice for 2017: (1) the Acoustic-Trawl Method (ATM) survey, which is preferred by the SWFSC stock assessment team, and (2) Model ALT which is implemented using the Stock Synthesis Model. An alternative ATM survey projection method was also considered during the review. The relatively parsimonious Model ALT reduced the parameter space compared to a standard implementation of Stock Synthesis by estimating several parameters external to the model using empirical data, and by fixing parameters. The performance of several assessment methods under the current HCR was compared based on their ability to predict a current ATM survey estimate of age 1+ biomass in the prior year´s assessment. The ATM survey method is considered to provide the most reliable estimate of the current year 1+ biomass, but the survey methods are not sufficiently documented to assess the accuracy of the estimate, and have several issues that could lead to bias in the absolute biomass estimates and associated variance. Although the ATM survey itself will be reviewed in 2018, and was not a focus of this review, all assessment methods rely heavily on survey estimate of absolute biomass of age 1+ fish. Therefore, I discuss some possible sources of bias in this review, and provide some recommendations for reducing such biases. It is well known from the literature that post-stratification based on density values observed during the survey, as was done in the ATM survey, can result in negative bias in variance estimates. The variance estimation by bootstrapping for the ATM survey also treats the transects within post-strata as simple random. This is common practice in analysis of systematically spaced transects, and is conservative since it will likely overestimate the variance for evenly spaced transects. However, in the ATM survey the handling of the adaptive component results in variable transect spacing (unequal inclusion probability) in some post-strata, which can bias the variance estimates in unknown directions when this is ignored in the analysis. The use of seasonal fixed age-length keys based on multi-year trawl survey data from 2006 can also yield biases with varying magnitude and directions in estimates of age-compositions, and will cause negative bias in variance estimates for age-compositions, and therefore estimates of age 1+ biomass. The assumption that the ATM method provides unbiased absolute biomass estimates assumes that target strength is known, and ignores vessel avoidance, incomplete survey coverage and other factors that can cause bias. Also, as revealed during this review the current forward projection method for the ATM survey method does not perform well. As currently formulated, this method performs no better than assuming no change and applying the survey estimate of age 1+ biomass in 2016 as an estimate also for age 1+ biomass in July 2017. Thus, while viable, this approach requires further development and review prior to adoption. The review panel considered Model ALT method to perform best for the current management advice that relies on a projection estimate of 1+ biomass for 2017, even though several errors in the model were discovered during the review. Major sources of uncertainty for stock assessments under the current HCR, regardless of method, is related to highly variable recruitment, growth, and uncertainty in natural mortality, *M*. Accuracy of assessments is also highly influenced by the temporal and spatial coverage of the ATM survey, the post-stratification used for estimation, insufficient sample sizes of age-length, and the use of fixed age-length keys. The assumption of multinomial distribution of numbers at age in the ATM survey method and the ALT model is likely to be unrealistic given the highly-clustered trawl sampling, causing additional errors.

Background

The National Marine Fisheries Service's (NMFS) Office of Science and Technology coordinates and manages a contract providing external expertise through the Center for Independent Experts (CIE) to conduct independent peer reviews of NMFS scientific projects. Background material and reports (Appendix A) for the review was provided by the NMFS project contact two weeks prior to the review. A Statement of Work (Annex B) is established by the NMFS Project Contact and Contracting Officer's Technical Representative, and reviewed by the CIE for compliance with their policy for providing independent expertise that can provide impartial and independent peer review without conflicts of interest.

CIE reviewers are selected by the CIE Steering Committee and CIE Coordination Team to conduct the independent peer review of NMFS science in compliance with the predetermined Terms of Reference (ToRs) of the peer review. Each CIE reviewer is contracted to deliver an independent peer review report to be approved by the CIE Steering Committee. Further information on the CIE process can be obtained from www.ciereviews.org.

This independent reviewer was requested by the Center of Independent Exerts to participate in a stock assessment review (STAR) panel to conduct independent peer review of the 2016 draft assessment by the Stock Assessment Team (STAT) for the northern subpopulation of Pacific Sardine. The STAR Panel (Appendix C), including the two CIE Reviewers, are responsible for determining if a stock assessment or technical analysis is sufficiently complete. It is their responsibility to identify assessments that cannot be reviewed or completed for any reason.

1. Description of the Reviewer's Role in the Review Activities

A peer review meeting was held at the Southwest Fisheries Science Center (SWFSC) in La Jolla, California, from February 21-24 to review a draft assessment by the Stock Assessment Team (STAT) for the northern subpopulation of Pacific Sardine. The Stock Assessment Review (STAR) panel consisted of three members of the Scientific and Statistical Committee (SSC): Dr. André Punt (University of Washington, Chair), Dr. Will Satterthwaite (SWFSC), and Dr. Evelyn Brown (Lummi Natural Resources), and two reviewers from the Center for Independent Experts (CIE): Dr. Jon Vølstad (Norway), and Dr. Gary Melvin (Canada). The STAR panel was expertly chaired by Andre Punt.

My input in the review was particularly related to statistical survey sampling methods and propagation of errors in input data through the assessment modeling that provides biomass estimates for quota advice. I have long experience and expertise in the design, analysis, and execution of fishery-independent surveys for use in stock assessments, and have experience with demersal and mid-water trawl surveys, acoustic-trawl surveys of pelagic fishes, and in the use of aerial surveys. I also have expertise in the application of fish stock assessment methods, particularly length/age-structured modeling approaches. For comments related to technical aspects of acoustic survey methods I defer to fellow CIE reviewer Gary Melvin who specializes in acoustic methods.

By way of background, I am chief scientist and leader of the Fishery Dynamics research group at Institute of Marine Research, Bergen, Norway. My education includes a bachelor with double majors in mathematics and biology, a master degree in Fishery Biology incl. management, and a Ph.D. in quantitative fisheries biology (biometrics) from University of Bergen, Norway. My PhD studies included research as a visiting scholar at Northeast Fisheries Science Center, Woods Hole, and graduate courses in mathematical statistics at University of Bergen and at the Department of Biomathematics (now department of Statistics), Oxford University (UK), as a British Council Scholar. My dissertation was on survey design and analysis of abundance surveys. I have more than 25 years of international research experience in statistical survey methods, quantitative fisheries biology, and statistical ecology from academia, national institutes, and private industry. My research primarily focuses on the development and optimization of statistical survey techniques for assessment of fisheries resources and the environment, and the quantification of uncertainty in stock assessments.

My preparations in advance of the peer review meeting included a review of background material and reports (Appendix A) provided by the SWFSC Project Contact Dr. Dale Sweetnam (SWFSC) via email on February 7 via link to ftp-site. This was a very effective way of distributing the extensive material. All the presentations (see below) were added to the ftp site during the review meeting.

A series of very informative power point presentations were given during the review meeting by the SWFSC Stock Assessment Team. My fellow peer reviewers and I asked questions during the presentations and participated in the panel discussions on validity, results, recommendations, and conclusions. Will Satterthwaite (SSC, SWFSC) acted as rapporteur.

Drs. Paul Crone, Kevin Hill, and Juan Zwolinski presented the assessment methodology. Two alternative assessment approaches were presented:

1. Direct use of the summer 2016 Acoustic Trawl Method (ATM) survey estimate and associated age-composition projected to 1 July 2017, which is the method preferred by SWFSC, and

2. Model ALT which is a model-based assessment that provides an estimate of age 1+ biomass on 1 July 2017 based on a modified more parsimonious Stock Synthesis model where many parameters are estimated externally from empirical data.

Juan Zwolinski described the survey-based method for estimating age 1+ biomass on 1 July 2017 that involved:

- estimating numbers-at-age on 1 July 2016 from the summer 2016 ATM survey from numbers-at-length using an age-length key that pooled data over multiple summer surveys, and
- projecting these numbers forward accounting for natural mortality and growth, and adding the estimated recruitment for 2016. The recruitment for 2016 was based on the stock-recruitment relationship estimated by model ALT, and the spawning stock biomass for 2016 was estimated by back-projecting the summer 2016 numbers-at-age to 1 January 2016.

Kevin Hill and Paul Crone described the data on which the model-based assessment was based, as well the results from a draft assessment utilizing the Stock Synthesis Assessment Tool, Version 3.24aa. Model ALT differed from the model on which the 2016 update assessment was based by:

- starting the assessment in 2005 rather than 1993,
- excluding the Daily Egg Production Method (DEPM) and Total Egg Production (TEP) indices,
- estimating rather than pre-specifying stock-recruitment steepness,
- pre-specifying weight-at-age rather than estimating it within the assessment,
- assuming selectivity for the ATM survey to be zero for age 0 and uniform for age 1 and older,
- estimating survey catchability (Q), assuming selectivity to be age- rather than length-based,
- modelling ages 0-10+yr rather than ages 0-15+yr, assuming natural mortality (M) is 0.6yr-1 rather than 0.4yr-1 for all age classes and fitting the catch and ATM survey age-composition data (rather than the associated length-composition data).

Unlike the 2016 and earlier assessments, model ALT included additional live bait landings, which generally reflected a minor contribution to the total landings in California in the past. However, model ALT did not include biological composition data from the live bait catches, given this fishery sector had not been regularly sampled in the past, with samples being available for only the most recent year of the time series modelled in the assessment.

The review and request by the STAR panel for additional analysis during the meeting were motivated primarily by the need to better understand the rationale for model ALT, and to identify the best approach for providing a projection of age 1+ biomass on 1 July 2017 that is currently required by management. The Panel had several comments and concerns regarding the ATM survey methodology and ways in which estimates of close-to-absolute abundance can be obtained. However, this was not a review of the ATM survey, since a second Council-sponsored ATM methodology review is planned for early 2018. Therefore, comments in the Panel Report regarding the ATM survey and how estimates of abundance from that survey are constructed are reflected primarily in the Research Recommendations section of the report. However, since both assessment methods considered in the review strongly depends on the ATM survey, I have made several comments in the next section, and in section (3).

2. Findings by ToR

The bibliography list (Appendix A) and the Statement of Work (Appendix B) describe the documents reviewed and review activities, respectively, as part of an independent peer review completed for the Center for Independent Experts (CIE).

2.1. Acoustic Trawl Method (ATM) Survey Assessment

In the assessment approach based on the ATM survey two methods are used to project the current (2016) estimate of age 1+ biomass to an estimate of age1 biomass for 2017. The preferred approach in the Draft Stock Assessment Document projecting the biomass from the 2016 ATM survey to 1 July 2017 accounting for mortality, growth and recruitment from July 2016 to July 2017. However, the approach used to convert from length composition to age composition is incorrect, and the method used to derive the CV of age 2+ biomass does not allow for uncertainty in population age composition, projected weight-at-age and maturity-at-age. In addition, the method relies heavily on model ALT because approximately half of the age 1+ biomass on 1 July 2017 consists of age-1 animals, i.e. the estimate of this biomass is based to a substantial extent on the stock-recruitment function from model ALT. Finally, the value for M of 0.6yr-1 has no clear justification. The version of the projection model provided initially to the Panel did not account for catches so it could not be applied were the targeted sardine fishery to be re-opened, and does not account for the limited catches during 2016. An alternative assessment based on the ATM survey proposed during the review meeting assume that the 1 July 2017 biomass equals the estimate of biomass from the summer 2016 ATM survey. This “projection” ignores mortality (from natural causes and from fishing), growth and recruitment from July 2016 to July 2017. However, this method is simple to implement because it does not rely on a model, nor does it rely on highly uncertain recruitment estimates and estimates of age composition for which sample sizes are low.

The Panel had several comments and concerns regarding the ATM survey methodology and ways in which estimates of close-to-absolute abundance can be obtained. In a prior CIE review in 2011, it was concluded that there are no major problems with acoustic technique and methodology and it was the best that could be used at that time. Although this is not a review of the ATM survey, since a second Council-sponsored

ATM methodology review is planned for early 2018, I have several comments in section (3) since the ATM survey results are critical input to all assessment models being evaluated.

2.2. Model ALT Assessment

The final model (model ALT) incorporates the following specifications:

- catches for the MexCal fleet computed using the environmentally-based method;
- two seasons (semesters, Jul-Dec=S1 and Jan-Jun=S2) for each assessment year from 2005 to 2016;
- sexes were combined; ages 0-10+.
- two fisheries (MexCal and PacNW fleets), with an annual selectivity pattern for the PacNW fleet and seasonal selectivity patterns (S1 and S2) for the MexCal fleet;
  - MexCal fleet: age-based selectivity (one parameter per age)
  - PacNW fleet: asymptotic age-based selectivity;
  - age-compositions with effective sample sizes calculated by dividing the number of fish sampled by 25 (externally) and lambda weighting=1 (internally);
- Beverton-Holt stock-recruitment relationship with "steepness" estimated;
- *M* was fixed (0.6 yr^{-1});
- recruitment deviations estimated from 2005-2015;
- virgin recruitment estimated, and σ_R fixed at 0.75;
- initial *F*s estimated for the MexCal S1 fleet and assumed to be 0 for the other fleets;
- ATM survey biomass 2006-2013, partitioned into two (spring and summer) surveys, with Q estimated;
  - age-compositions with effective sample sizes set to 1 per cluster (externally);
  - selectivity is assumed to be uniform (fully-selected) above age 1 and zero for age 0.

The estimate of age 1+ biomass on 1 July 2017 from model ALT is 86,586t (CV 0.363). Model ALT indicates that age 1+ biomass has rebuilt close to that in 2014, owing to a substantial increase in biomass based on the indices from the survey.

Model ALT has several of the problems associated with the 'survey projection' model, i.e. the age-composition data are based on a year-invariant age-length key, and the basis for M=0.6yr-1 lacks strong empirical justification (and indeed likelihood profiles indicate some support for lower M than the value adopted for model ALT). In addition, the model presented to the Panel predicted age-0 catch in the ATM survey even though it is assumed that age-0 animals are not selected during the ATM survey. It appears that Stock Synthesis with the ALT parametrization predicts some catch of nominal "age 0" even when the selectivity is set to zero for age-0 fish. The STAR review panel requested several additional model runs to gain insights, because aging error could result in some age-1 fish in catches being misclassified as age 0. Furthermore, model runs revealed that the model was unable to converge if aging error was set to zero or made very small, but reductions in the specified aging error led to the expected reduction in the predicted age-0 catch. It was noted that surveys likely include a mix of age-1 fish misclassified as age-0, as well as fish that are truly age 0. Dr. Methot has also noted that Stock Synthesis had not been as thoroughly debugged for semester-based models as for strictly annual models

2.3. Evaluating the Performance of Assessment Approaches

The performance of several assessment methods under the current HCR was compared based on their ability to predict a current ATM survey estimate of age 1+ biomass in the prior year´s assessment. The

STAR review considered four methods:

a) ATM survey method using the 1+ biomass estimate from the prior year as is,
   i. This assumption ignores mortality (from natural causes and from fishing), growth and recruitment from July 2016 to July 2017.
b) ATM survey method projecting the biomass from the prior summer ATM survey estimate using the 'survey projection' model (or an alternative approach),
c) Model ALT assessment and projection, and for comparison,
d) the assessment model and projection on which the 2014-16 estimates of biomass were based.

Results are provided in Fig. 4 from the STAR Panel.

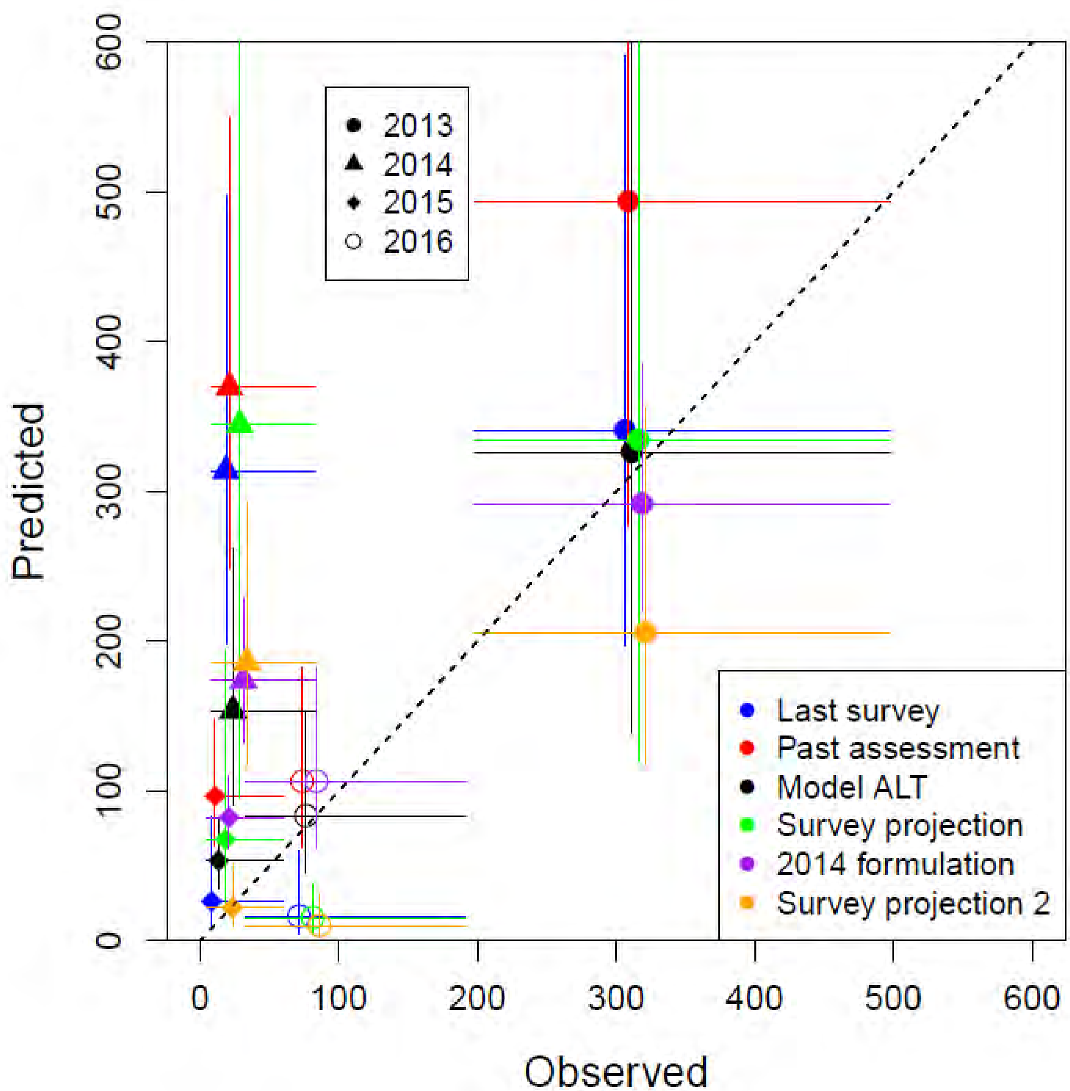

Fig. 4. (From Final Report of Sardine STAR Panel). Observed (x-axis values, ATM survey biomass estimates) and model-predicted (y-axis values) biomass on 1 July of each of 2013, 2014, 2015 and 2016. The observed values are the summer ATM survey estimates. The lines indicate 90% confidence intervals under the assumption of log-normal error. The x-axis values are jittered for ease of presentation.

The Panel had concerns with these methods. The ATM survey is considered to provide the most reliable estimate of the current year 1+ biomass, but the survey design and analysis methods are not sufficiently documented to assess the accuracy of the estimate, and have several issues that could lead to bias in the absolute biomass estimates and associated variance. Projecting the biomass from the 2016 ATM survey to 1 July 2017 (Method b) accounts for mortality, growth and recruitment from July 2016 to July 2017. However, the approach used to convert from length composition to age composition using fixed seasonal age-length keys based on data since 2006 is incorrect, and the method used to derive the CV of age 2+ biomass does not allow for uncertainty in population age composition, projected weight-at-age and maturity-at-age. In addition, the estimate of this biomass is based to a substantial extent on the stock-recruitment function from model ALT. Finally, the value for M of 0.6yr-1 has no clear justification.

Model ALT (Method c) has several of the problems associated with the 'survey projection' model, i.e. the age-composition data are based on a fixed age-length key, and the basis for M=0.6yr-1 lacks strong empirical justification. In addition, the model presented to the Panel predicted age-0 catch in the ATM survey even though it is assumed that age-0 animals are not selected during the ATM survey. Also, Model ALT estimates Q to be 1.1, which is unlikely given some sardine are not available to the survey owing to being inshore of the survey area.

The model (d) on which the 2014-16 assessments were based was approved for management by the 2014 STAR Panel. However, that assessment had some undesirable features, including extreme sensitivity to the occurrence of small (<~15cm fish) in the ATM surveys, poor fits to the length-composition and survey data, and sensitivity to the initial values for the parameters (i.e. local minima). These sensitivities and the resultant high uncertainty about population scale were noted in previous reviews.

The Panel explored alternatives to the current selectivity formulation to better understand why model ALT was predicting age-0 catch when selectivity for age-0 fish was set to zero. It was noted that the results are generally robust to the assumption that selectivity is a logistic function of length, allowing for time-varying age-0 selectivity, and estimating a separate selectivity pattern for ATM survey age-composition data.

The Panel noted that the 'survey projection' model and model ALT both rely on the samples from the ATM surveys to compute weight-at-age and survey age-composition data. These estimates are highly uncertain since the samples sizes for age from each survey are very small (16 – 1,051 fish; and VERY few trawl clusters which are the primary sampling units for the age-comps).

3. Conclusions and Recommendations

The SWFSC assessment scientists (STAT) did an outstanding job presenting the assessment results, and were very helpful throughout the review meeting by providing additional analysis upon request and answering questions related to the panel's interpretation of the available data and results. The panel members had broad and complimentary expertise that covered all the review subjects. The effectiveness of the review process was substantially enhanced by the expert leadership of the chair, Andre Punt, and the panel greatly benefited from the input from the Pacific Fishery Management Council, and representatives from the fishing industry. One criticism I have is that the stock assessment report and material provided that formed the basis for the review provided insufficient details to fully assess the quality of the input-data and model specification. I recognize that the stock assessment scientists responsible for the report may have had insufficient time to fully document the methods.

The STAR panel cautiously recommended proceeding with Model ALT, as the "least-worst" way to produce the age 1+ biomass estimate and CV required for management in 2017. Given the current

HCR, the Panel and STAT agreed that model ALT was the best approach at present for conducting an assessment for the northern subpopulation of Pacific sardine, notwithstanding the concerns listed above.   The alternative assessment approaches provided more uncertain predictions of age 1+ biomass July 1, 2017:

- The approach on which 2014-16 management was based exhibited undesirable assessment diagnostics, and produced extremely high estimates of recruitment when large numbers of small fish were observed in the ATM survey length-frequencies. The approach also performed poorly in retrospective analysis (Fig. 4). The Panel and STAT agreed that this approach should not be used for 2017 management.
- The survey projection method (and the modified version, "Survey projection 2") seems a viable and defensible way to estimate age 1+ biomass using the ATM survey results, especially if the method could be modified to not use the results from model ALT. However, as currently formulated, this method performs no better than assuming the age 1+ biomass in July 2017 equals the survey estimate of biomass for summer 2016 (Fig. 4). Thus, while viable, this approach requires further development and review prior to adoption.
- Estimating the biomass on 1 July of year Y+1 based on the ATM survey estimate for year Y is simple, but the Panel was concerned that this method ignored catches during year Y and may lead to additional risk. Thus, the basic approach is viable, but needs additional testing prior to adoption.

I agree fully with these recommendations in the STAR review report on how management could be based on the ATM survey results:

- Change the start-date of the fishery so that the time between conducting the survey and implementation of harvest regulations is minimized.
- Use Management Strategy Evaluation to evaluate the risk to the stock of basing management actions on an estimate of biomass that could be a year old at the start of the fishing season (if the fishery start date is unchanged). Review of an updated MSE would likely not require a Methodology Panel, but could instead be conducted by the SSC.

As the review Panel noted, there may be benefits in using both the spring and summer ATM surveys as the basis for the assessment. Relying an ATM survey based assessment approach that relies on an estimate for the current year may be compromised by proposed reductions in ship time and/or problems conducting the survey. Also, as pointed out by the STAT there is value in continuing to collect biological data and to update model ALT even if management moves to an ATM survey-only approach.

In the following section, I have some more comments on the STM survey, and recommendations for future documentation and analysis.

Acoustic Trawl Method Survey

The systematic design for acoustic-trawl survey is robust for covering Pacific sardine with varying patchiness and areas of occupancy, provided that the spatial coverage E-W and N-S is adequate. The acoustic survey transect design is systematic with a close to regular spacing of transects allocated in advance, and adaptive component with reduced transect spacing in some areas of expected high abundance. Abundance and biomass is estimated by treating transects as simple random samples within post-strata, and the variance is estimated by bootstrap with equal selection probability of transects. However, based on provided material, documents, and discussions during this review it is apparent that the ATM survey is not based on probabilistic sampling design where every transect (primary sampling unit, PSU) has a known probability of being selected. The adaptive sampling component where additional acoustic transects are added in areas with observed high density of Pacific sardines is not well documented, and appears to be ad-hoc. The post-stratification of transects used in the estimating abundance and biomass by age class takes are based on sampling intensity (spacing of transects) and measured density. The grouping of transects with low density into separate strata is inappropriate and likely to cause bias in the variance estimates. Also, even though SWFSC staff argued that transects within all post-strata have equal spacing (and selection probability), this is not documented and is contradicted by figures presented during the review showing post-strata and acoustic transects.

Before the upcoming 2018 review of the ATM survey, it is strongly recommended that SWFSC specify the survey design and estimation methods in sufficient details. A document should be provided to the ATM review (and future assessment STAR Panels) that:

- delineates the annual survey area (sampling frame);
- specifies the spatial stratification (if any) and transect spacing within strata planned (true stratification);
- specifies the rule for stopping a transect (offshore boundary);
- specifies the rules for conducting trawls to determine species composition;
- specifies the rule for adaptive sampling (including the start and stopping rule); and
- specifies rules for post-stratification, and how density observations are considered in post-stratification.
- alternative post-stratification without considering density should be considered.

It is particularly important that the sampling frame covers the area of occupancy, that allocation of transects be based on probabilistic methods and that biases be minimized. The systematic allocation of transects with random start, and known selection probabilities, provides unbiased estimates of means and totals provided that the estimators apply weights that consider the probabilities of selection. However, systematic sampling precludes unbiased analytical variance estimates, and if the systematic survey is treated as simple random the estimated variance is likely to be biased upwards (Cochran, 1977). The systematic transect survey can also be considered a stratified sampling design with 1 PSU (transect) in each spatial stratum. A common approach to approximate the variances in estimates of means and totals in systematic designs is to group neighboring strata to yield a pseudo design with more than one PSU per stratum that is treated as it were the actual design (Wolter, 1985; Dunn and Harrison, 1993, Korn and Graubard, 1999). The variance and the relative standard error (RSE) (Jessen, 1978) is then estimated under the assumption of simple random sampling within the collapsed strata (Fuller, 2009). See Nøttestad et al. (2017) for an application for trawl sampling of mackerel.

The sardine habitat model based on remotely sensed SST, chlorophyll, and sea-surface gradient (Zwolinski et al. 2011) is currently used to (1) develop the sampling frame, and (2) assign catches to subpopulation but not to allocate sampling effort within the survey area, which is based on an ad-hoc adaptive sampling with denser spacing of transects in areas with high density of sardine. One reason for this adaptive component, with use of post-stratification in the analysis, instead of stratifying in advance (true stratification) on habitat is that the habitat is very dynamic even within the time period of the surveys. It is strongly recommended that the best available models be used for sample allocation, and that any real-time adaptive component be conducted using methods that minimizes bias (see for example, Harbitz et al. 2009; Thomposon and Seber 2009).

Assuming we have defined the sampling frame using a model, allocation based on the model will only affect precision, and even a relatively crude model that can identify areas with higher than average density will likely give better precision than equal spacing throughout the survey area. The habitat model predicts probabilities of capture for broad categories of habitat (e.g., "optimal", "good", "unsuitable" habitat). This is fine for defining the sampling frame but for sample allocation/stratification, the distribution of model predictions should be used to create strata that are most similar within. Alternative model approaches should also be considered for stratification. Ed Weber (SWFSC) is currently working with a sardine habitat model based on a ROMS model (Wang and Chao 2004) coupled with a biological model known as CoSiNE (Carbon, Silicate, Nitrogen Ecosystem model Chai et al., 2002; Liu and Chai, 2009). He demonstrated the model to me after the review meeting. Based on simulations of historic surveys he is testing if stratification based on modeled habitat could improve the precision of acoustic surveys. Using modeled data for stratification, and to allocate more transects (with known probability) to strata that are expected to have high density and variance, instead of satellite data, appears to have a several advantages. It is mechanistic, at least to the level of secondary production. It does not suffer from data gaps due to cloud cover. It could potentially be projected into the future for short periods.

Clearly, the changes in spatial distributions over time, both horizontally and vertically, may introduce biases in acoustic indices of abundance of changing magnitudes and directions. Such biases can be caused by vessel avoidance, acoustic shadowing and depth dependent acoustic target strength (Skaret et al., 2005; Løland et al., 2007; Hjellvik et al., 2008). Random sampling errors in acoustic survey indices of abundance due to spatial sampling has been shown to be the main source of uncertainty in acoustic measurements of abundance (Rose et al. 2000). Løland et al. (2007) investigated several additional sources of error in acoustic survey estimates of the Norwegian Spring Spawning herring stock in the wintering area. They did, however, conclude that acoustic sampling error (variation among transects) was the largest contributor to the total uncertainty of the estimate. The ATM surveys at present do not capture fish in the upper water column, and appears to miss a large biomass of young fish (sizes 3 inches and up) that fishermen have observed in nearshore waters since late 2014; this biomass is largely inside ATM survey tracks. The SWFSC plans to examine ship avoidance using aerial drone sampling. There is an ongoing significant effort by Institute of Marine Research in Norway to understand the same issue using sonar, and the SWFSC acoustics team should communicate and coordinate with those researchers. The possible bias due to not detecting fish that are near the surface by acoustics could be investigated using sonar. This is currently being done in acoustic-trawl surveys for herring by Institute of Marine Research, Norway, and is addressed in a large effort to reduce uncertainty in stock assessments (REDUS project: www.redus.no).

Trawl sampling and the estimation of age-compositions

The current practice of treating data on numbers-at-age from the trawl survey as multinomial is problematic because the trawl samples are clustered, and age-samples are subsamples from trawl hauls. This is likely to result in cluster effects, resulting in correlation among age-groups (see ICES 2016a,b, 2017, and Aanes and Vølstad 2016). It is recommended that the age-data be evaluated. Ideally, it would be possible to run bootstrap resampling on the PSUs to create replicated Model ALT runs that reflect the complexity in input data. See the Norwegian Spring-spawning Herring case study under the REDUS project in ICES WKCOSTBEN (ICES 2017) for an example where the more complex error structure in input data is accounted for. The statistical assessment model XSAM (developed by Sondre Aanes, Norwegian Computing Centre) has been chosen for the assessment of Norwegian Spring Spawning Herring by ICES Benchmark assessments (2016a,b) because it can take into account the complex error structure in input-data in age-based assessment.

It is further recommended that the level of biological sub-sampling and data collections at each trawl station (or clusters of trawl stations) be evaluated through simulations to see how subsample size at the trawl stations affects the precision in estimates of numbers at age through age-length keys for the combined acoustic-trawl survey. The effective sample size for estimating age is likely to be driven by the number of transects and trawl stations sampled, and may be little affected by the sub-sample sizes of fish that are aged at each trawl station. Stewart and Hamel (2014) and Aanes and Vølstad (2015) have shown that it is sufficient to collect ~10-20 ages from each station to estimate the age distribution and that higher numbers of age-samples will only marginally improve the precision in estimates of age-composition, since the variance is driven by the number of PSUs sampled (number of trawl stations). Results in Nøttestad et al. (2017) show that for Atlantic mackerel the collections of extra length samples within trawl stations, and trawl stations with length-only samples can increased the precision in the estimates of abundance indices at age for age groups that occur in low proportions.

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Appendix 2: Copy of Statement of Work

Statement of Work
National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS)
Center for Independent Experts (CIE) Program External Independent Peer Review

STAR Panel Review of the 2017-2018 Pacific Sardine Stock Assessment

February 21-24, 2017

Background

The National Marine Fisheries Service (NMFS) is mandated by the Magnuson-Stevens Fishery Conservation and Management Act, Endangered Species Act, and Marine Mammal Protection Act to conserve, protect, and manage our nation's marine living resources based upon the best scientific information available (BSIA). NMFS science products, including scientific advice, are often controversial and may require timely scientific peer reviews that are strictly independent of all outside influences. A formal external process for independent expert reviews of the agency's scientific products and programs ensures their credibility. Therefore, external scientific peer reviews have been and continue to be essential to strengthening scientific quality assurance for fishery conservation and management actions.

Scientific peer review is defined as the organized review process where one or more qualified experts review scientific information to ensure quality and credibility. These expert(s) must conduct their peer review impartially, objectively, and without conflicts of interest. Each reviewer must also be independent from the development of the science, without influence from any position that the agency or constituent groups may have. Furthermore, the Office of Management and Budget (OMB), authorized by the Information Quality Act, requires all federal agencies to conduct peer reviews of highly influential and controversial science before dissemination, and that peer reviewers must be deemed qualified based on the OMB Peer Review Bulletin standards.
(http://www.cio.noaa.gov/services_programs/pdfs/OMB_Peer_Review_Bulletin_m05-03.pdf).
Further information on the CIE program may be obtained from www.ciereviews.org.

Scope

The CIE reviewers will serve on a Stock Assessment Review (STAR) Panel and will be expected to participate in the review of Pacific sardine stock assessment. The Pacific sardine stock is assessed regularly (currently, every 1-2 years) by SWFSC scientists, and the Pacific Fishery Management Council (PFMC) uses the resulting biomass estimate to establish an annual harvest guideline (quota). The stock assessment data and model are formally reviewed by a Stock Assessment Review (STAR) Panel once every three years, with a coastal pelagic species subcommittee of the SSC reviewing updates in interim years. Independent peer review is required by the PFMC review process. The STAR Panel will review draft stock assessment documents and any other pertinent information for Pacific sardine, work with the stock assessment teams to make necessary revisions, and produce a STAR Panel report for use by the PFMC and other interested persons for developing management recommendations for the fishery. The PFMC's Terms of Reference (ToRs) for the STAR Panel review are attached in Appendix 1. The tentative agenda of the Panel review meeting is attached in Appendix 2. Finally, a Panel summary report template is attached as Appendix 3.

Requirements

Two CIE reviewers shall participate during a panel review meeting in La Jolla, California during 21-24 February, and shall conduct impartial and independent peer review accordance with the SoW and ToRs herein. The CIE reviewers shall have the expertise as listed in the following descending order of importance:

- The CIE reviewer shall have expertise in the design and execution of fishery-independent surveys for use in stock assessments, preferably with coastal pelagic fishes

- The CIE reviewer shall have expertise in the application of fish stock assessment methods, particularly, length/age-structured modeling approaches, e.g., 'forward-simulation' models (such as Stock Synthesis, SS) and it is desirable to have familiarity in 'backward-simulation' models (such as Virtual Population Analysis, VPA).
- The CIE reviewer shall have expertise in the life history strategies and population dynamics of coastal pelagic fishes.
- It is desirable for the CIE reviewer to be familiar with the design and application of fisheries underwater acoustic technology to estimate fish abundance for stock assessment.
- It is desirable for the CIE reviewer to be familiar with the design and application of aerial surveys to estimate fish abundance for stock assessment.

The CIE reviewer's duties shall not exceed a maximum of 14 days to complete all work tasks of the peer review process.

Tasks for reviewers

- Review the following background materials and reports prior to the review meeting: *Two weeks before the peer review, the NMFS Project Contact will send by electronic mail or make available at an FTP site to the CIE reviewers all necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE on where to send documents. The CIE reviewers shall read all documents in preparation for the peer review, for example:*

    - *Recent stock assessment documents since 2013;*
    - *STAR Panel- and SSC-related documents pertaining to reviews of past assessments;*
    - *CIE-related summary reports pertaining to past assessments; and*
    - *Miscellaneous documents, such as ToR, logistical considerations.*

Pre-review documents will be provided up to two weeks before the peer review. Any delays in submission of pre-review documents for the CIE peer review will result in delays with the CIE peer review process, including a SoW modification to the schedule of milestones and deliverables. Furthermore, the CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein.

- Attend and participate in the panel review meeting
    - The meeting will consist of presentations by NOAA and other scientists, stock assessment authors and others to facilitate the review, to provide any additional information required by the reviewers, and to answer any questions from reviewers
- After the review meeting, reviewers shall conduct an independent peer review in accordance with the requirements specified in this SOW, OMB guidelines, and TORs, in adherence with the required formatting and content guidelines; reviewers are not required to reach a consensus
- Each reviewer may assist the Chair of the meeting with contributions to the summary report, if required by the TORs
- Deliver their reports to the Government according to the specified milestone dates

Foreign National Security Clearance

When reviewers participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign National Security Clearance approval for reviewers who are non-US citizens. For this reason, the reviewers shall provide requested information (e.g., first and last name, contact information, gender, birth date, passport number, country of passport, travel dates, country of citizenship, country of current residence, and home country) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/ and http://deemedexports.noaa.gov/compliance_access_control_procedures/noaa-foreign-national-registration-system.html. The contractor is required to use all appropriate methods to safeguard Personally Identifiable Information (PII).

Place of Performance

The place of performance shall be at the contractor's facilities, and at the Southwest Fisheries Science Center in La Jolla, California.

Period of Performance

The period of performance shall be from the time of award through April 30, 2017. Each reviewer's duties shall not exceed 14 days to complete all required tasks.

Schedule of Milestones and Deliverables:

The contractor shall complete the tasks and deliverables in accordance with the following schedule.

No later than January 24, 2017	CIE sends reviewers contact information to the COTR, who then sends this to the NMFS Project Contact
No later than February 7, 2017	NMFS Project Contact sends the CIE Reviewers the pre-review documents
February 21-24, 2017	The reviewers participate and conduct an independent peer review during the panel review meeting
March 10, 2017	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
March 31, 2017	CIE submits CIE independent peer review reports to the COTR
April 7, 2017	The COTR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Applicable Performance Standards

The acceptance of the contract deliverables shall be based on three performance standards: (1) The reports shall be completed in accordance with the required formatting and content (2) The reports shall address each TOR as specified (3) The reports shall be delivered as specified in the schedule of milestones and deliverables.

Travel

All travel expenses shall be reimbursable in accordance with Federal Travel Regulations (http://www.gsa.gov/portal/content/104790). International travel is authorized for this contract. Travel is not to exceed $10,000.

Restricted or Limited Use of Data

The contractors may be required to sign and adhere to a non-disclosure agreement.

Peer Review Report Requirements

1. The report must be prefaced with an Executive Summary providing a concise summary of the findings and recommendations, and specify whether or not the science reviewed is the best scientific information available.

2. The report must contain a background section, description of the individual reviewers' roles in the review activities, summary of findings for each TOR in which the weaknesses and strengths are described, and conclusions and recommendations in accordance with the TORs.

   a. Reviewers must describe in their own words the review activities completed during the panel review meeting, including a brief summary of findings, of the science, conclusions, and recommendations.

   b. Reviewers should discuss their independent views on each TOR even if these were consistent with those of other panelists, but especially where there were divergent views.

   c. Reviewers should elaborate on any points raised in the summary report that they believe might require further clarification.

   d. Reviewers shall provide a critique of the NMFS review process, including suggestions for improvements of both process and products.

   e. The report shall be a stand-alone document for others to understand the weaknesses and strengths of the science reviewed, regardless of whether or not they read the summary report. The report shall represent the peer review of each TOR, and shall not simply repeat the contents of the summary report.

3. The report shall include the following appendices:

   Appendix 1: Bibliography of materials provided for review
   Appendix 2: A copy of this Statement of Work
   Appendix 3: Panel membership or other pertinent information from the panel review meeting.

Appendix 1: Terms of Reference for the Peer Review of the Pacific sardine stock assessment

The CIE reviewers are one of the four equal members of the STAR panel. The principal responsibilities of the STAR Panel are to review stock assessment data inputs, analytical models, and to provide complete STAR Panel reports.

Along with the entire STAR Panel, the CIE Reviewer's duties include:

1. Reviewing draft stock assessment and other pertinent information (e.g.; previous assessments and STAR Panel reports);
2. Working with STAT Teams to ensure assessments are reviewed as needed;
3. Documenting meeting discussions;
4. Reviewing summaries of stock status (prepared by STAT Teams) for inclusion in the Stock Assessment and Fishery Evaluation (SAFE) document;
5. Recommending alternative methods and/or modifications of proposed methods, as appropriate during the STAR Panel meeting, and;
6. The STAR Panel's terms of reference concern technical aspects of stock assessment work. The STAR Panel should strive for a risk neutral approach in its reports and deliberations.

The STAR Panel, including the CIE Reviewers, are responsible for determining if a stock assessment or technical analysis is sufficiently complete. It is their responsibility to identify assessments that cannot be reviewed or completed for any reason. The decision that an assessment is complete should be made by Panel consensus. If agreement cannot be reached, then the nature of the disagreement must be described in the Panels' and CIE Reviewer's reports.

The review solely concerns technical aspects of stock assessment. It is therefore important that the Panel strive for a risk neutral perspective in its reports and deliberations. Assessment results based on model scenarios that have a flawed technical basis, or are questionable on other grounds, should be identified by the Panel and excluded from the set upon which management advice is to be developed. The STAR Panel should comment on the degree to which the accepted model scenarios describe and quantify the major sources of uncertainty Confidence intervals of indices and model outputs, as well as other measures of uncertainty that could affect management decisions, should be provided in completed stock assessments and the reports prepared by STAR Panels.

Recommendations and requests to the STAT Team for additional or revised analyses must be clear, explicit, and in writing. A written summary of discussion on significant technical points and lists of all STAR Panel recommendations and requests to the STAT Team are required in the STAR Panel's report. This should be completed (at least in draft form) prior to the end of the meeting. It is the chair and Panel's responsibility to carry out any follow-up review of work that is required.

Appendix 2: DRAFT AGENDA: CPS STAR PANEL

Tuesday, 21 February

08h30	Call to Order and Administrative Matters	
	Introductions	Punt
	Facilites, e-mail, network, etc.	Sweetnam
	Work plan and Terms of Reference	Griffin
	Report Outline and Appointment of Rapporteurs	Punt
09h00	Pacific Sardine survey-based assessment presentation	Hill/Crone
10h00	Break	
10h30	Pacific Sardine model-based assessment presentation	Hill/Crone
11h30	Acoustic and trawl survey	Zwolinski
12h00	Bayesian estimates of spawning fraction	Dorval
12h30	Lunch	
13h30	Pacific Sardine assessment presentation (continue)	Hill/Crone
14h30	Panel discussion and analysis requests	Panel
15h00	Break	
15h30	Public comments and general issues	
17h00	Adjourn	

Wednesday, 22 February

08h00. Assessment Team Responses	Hill/Crone
10h30 Break	
11h00. Discussion and STAR Panel requests	Panel
12h30 Lunch	
13h30 Report drafting	Panel
15h00 Break	
15h30 Assessment Team Responses	Hill/Crone
16h30 Discussion and STAR Panel requests	
17h00 Adjourn	

Thursday, 23 February

08h00. Assessment Team Responses	Hill/Crone
10h30 Break	
11h00. Discussion and STAR Panel requests	Panel
12h30 Lunch	
13h30 Report drafting	Panel
15h00 Break	
15h30 Assessment Team Responses	Hill/Crone
16h30 Discussion and STAR Panel requests	
17h00 Adjourn	

Friday, 24 February

08h00. Assessment Team Responses	Hill/Crone
10h30 Break	
11h00. Discussion and STAR Panel requests	Panel
12h30 Lunch	
13h30 Finalize STAR Panel Report	Panel
15h00 Break	
15h30 Finalize STAR Panel Report	Panel
17h00 Adjourn	

Appendix 3: STAR Panel Summary Report (Template)

- Names and affiliations of STAR Panel members

- List of analyses requested by the STAR Panel, the rationale for each request, and a brief summary the STAT responses to each request

- Comments on the technical merits and/or deficiencies in the assessment and recommendations for remedies

- Explanation of areas of disagreement regarding STAR Panel recommendations
    - Among STAR Panel members (including concerns raised by the CPSMT and CPSAS representatives)
    - Between the STAR Panel and STAT Team

- Unresolved problems and major uncertainties, e.g., any special issues that complicate scientific assessment, questions about the best model scenario, etc.

- Management, data or fishery issues raised by the public and CPSMT and CPSAS representatives during the STAR Panel

- Prioritized recommendations for future research and data collection

Appendix 3: Panel membership or other pertinent information from the panel review meeting

STAR Panel Members:
André Punt (Chair), Scientific and Statistical Committee (SSC), Univ. of Washington
Will Satterthwaite, SSC, Southwest Fisheries Science Center
Evelyn Brown, SSC, Lummi Natural Resources, LIBC
Jon Vølstad, Center for Independent Experts (CIE)
Gary Melvin, Center for Independent Experts (CIE)

Pacific Fishery Management Council (Council) Representatives:
Kerry Griffin, Council Staff
Diane Pleschner-Steele, CPSAS Advisor to STAR Panel
Lorna Wargo, CPSMT Advisor to STAR Panel

Pacific Sardine Stock Assessment Team:
Kevin Hill, NOAA / SWFSC
Paul Crone, NOAA / SWFSC
Juan Zwolinski, NOAA / SWFSC

Other Attendees
Dale Sweetnam, SWFSC
Alan Sarich, CPSMT/Quinault Indian Nation
Emmanis Dorval, SWFSC
Chelsea Protasio, CPSMT/CDFW
Kirk Lynn, CPSMT/CDFW
Ed Weber, SWFSC
Josh Lindsay, NMFS WCR
Erin Kincaid, Oceana
Al Carter, Ocean Gold
Jason Dunn, Everingham Bros Bait
Nick Jurlin, F/V Eileen
Neil Guglielmo, F/V Trionfo
Andrew Richards, Commercial
Hui-Hua Lee, SWFSC
Bev Macewicz, SWFSC
Chenying Gao, Student
Steven Teo, SWFSC
Kevin Piner, SWFSC
Andy Blair, Commercial
Jamie Ashley, F/V Provider
John Budrick, CDFW
Steve Crooke, CPSAS
Gilly Lyons, Pew Trusts

CDFW – California Department of Fish and Wildlife
CPSAS - Coastal Pelagic Species Advisory Subpanel
CIE – Council on Independent Experts
CPSMT - Coastal Pelagic Species Management Team
CWPA – California Wetfish Producers Association

SSC - Scientific and Statistical Committee (of the Pacific Fishery Management Council)
SWFSC - Southwest Fisheries Science Center (National Oceanic and Atmospheric Administration)
WCR – West Coast Region

CIE Reviewer's Report on the STAR Panel Review of the 2017-2018 Pacific Sardine Stock Assessment

Gary D. Melvin[1]

Prepared for:

Center for Independent Experts (CIE)

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Executive Summary

The review of the 2017-2018 Pacific Sardine Stock Assessment developed by the Southwest Fisheries Science Center (SWFSC) STAT team was conducted by a STAR Panel, at the SWFSC Torrey Pines Court Laboratory, La Jolla, CA, from 21-24 February 2017. The main objectives of the Panel were to review two new approaches to the assessment of the Northern subpopulation of Pacific sardine (NSP): the first is the acoustic trawl method which was approved by a 2011 STAR Panel to provide an estimate of absolute abundance of the NSP, and the second a revised/modified model based assessment using Stock Synthesis model Version 3.24aa with a single index of abundance. Previous assessment approaches (e.g., T_2016 update) were also examined but not really considered to provide advice on the 2017 1+ biomass.

The assessment document and all background material necessary to conduct the Panel Review was made available almost two weeks in advance, allowing plenty of time to prepare for the meeting. In general, the Panel review adhered to the agenda provided to Panel members prior to the meeting, although the Chair was flexible and allowed diversion into other subject areas when they were relevant to the discussion. Several Panel requests for additional information or clarification of procedures were made to the technical team over the first 3 days. These requests were fulfilled promptly and to the satisfaction of the Panel. Much of the success of the Panel Review can be attributed to the technical team who did an excellent job of summarizing the information and providing the available data to address the issues at hand. The Chair kept the group focused on the topic being addressed, while at the same time allowing everyone, including observers, to express their views or contribute their expert opinion. A number of the attendees also provided valuable input during the course of the meeting.

The Panel concluded that neither of the two assessment approaches presented at the 2017 Pacific Sardine stock assessment was fully acceptable. The Acoustic-Trawl survey, while all agreed was likely the better approach, did not provide a reasonable mechanism to project the 1+ biomass forward approximately 1 year to July 1, required by management. On the other hand, the model-based approach had its own issues with the treatment age 0 in the model that were not fully resolved during the review. However, the Panel concluded that based on the available information the model-based was the better approach to provide the required estimate of biomass for management of the NSP Pacific sardine resource.

Many of the issues associated with the spatial-temporal distribution of fish and sample size, identified by the last review, continue to plague the 2017 sardine assessment. The Panel again raised concerns about the survey coverage, especially in light of the fishing industry's reports of large quantities of sardines in the nearshore water not surveyed by the research vessel. The limited amount of sampling conducted by the survey vessel and the samples available for ageing in

some years was a major surprise and concern for the Panel. Development of an age length key and estimating age distribution from such few samples is problematic. Furthermore, the use of a multi-year age length key due to the lack of sufficient samples is generally frowned upon by those involved in age structured assessments. Both the distribution of sardines and sample size need to be addressed in the near future.

There is an excellent opportunity to resolve some of the issues associated with coverage and sampling. During the meeting, there were several offers from the fishing industry to assist the STAT with improving the survey coverage to areas not covered by the large vessel and to work with the survey vessel to collect additional samples. These opportunities should be explored by the STAT, and if feasible, a coordinated program developed to ensure the efficient use of vessel time and effort, as well as the integration of industry-collected data into the assessment process.

The Panel was informed that the survey vessel time for the summer survey will be reduced from the current 80 days to 50 days in 2018. This represents a significant reduction in survey time and will at a minimum increase the variance of the biomass estimates and likely impact (reduce) the survey coverage and sampling time. This is another reason to explore collaboration with the fishing industry. The effects of this change/reduction in vessel time need to be evaluated if they are to continue into the future.

The Panel’s report, to some extent summarized in this report, represents the consensus view of the STAR Panel Review of the 2017-2018 Pacific Sardine Stock Assessment and I fully concur with its content, recommendations, and conclusions. Overall, there were no major areas of disagreement between the STAT and Panel, nor among members of the Panel.

1.0 BACKGROUND

The National Marine Fisheries Service (NMFS) is mandated by the Magnuson-Stevens Fishery Conservation and Management Act, Endangered Species Act, and Marine Mammal Protection Act to conserve, protect, and manage our nation's marine living resources based upon the best scientific information available (BSIA). Under this mandate the NMFS (Office of Science and Technology) coordinates and manages a contract for providing external expertise through the Center for Independent Experts (CIE) to conduct independent peer-reviews of NMFS scientific projects. The CIE reviewers are selected by the CIE Steering Committee and the CIE Coordination Team to conduct the independent peer review of the NMFS science in compliance with the predetermined Terms of Reference (TORs) for the peer review. In this case the "Terms of Reference for the groundfish and coastal pelagic species stock assessment review process for 2017-2018", provided as background material for the meeting, describes objectives and the roles and responsibilities of the participants. Two CIE reviewers served on a five-person Stock Assessment and Review (STAR) Panel, Chaired by Andre Punt, to review the 2017-2018 Pacific Sardine Stock Assessment. The Statement of Work (SoW) described in Appendix I identified the roles, responsibilities and reporting structure for the CIE reviewer. The reviewers are chosen on their expertise to provide an impartial, independent peer review without conflicts of interest, report on methods, outcomes and recommendations of the stock assessment review.

The Pacific sardine stock is assessed regularly (currently, every 1-2 years) by SWFSC scientists and the Pacific Fishery Management Council (PFMC) uses the resulting biomass estimate to establish an annual harvest guideline (quota). The stock assessment data and models are formally reviewed by a Stock Assessment Review (STAR) Panel once every three years, with a coastal pelagic species subcommittee of the SSC reviewing updates in interim years. Independent peer review is required by the PFMC review process. The STAR Panel reviews draft stock assessment documents and any other pertinent information for Pacific sardine, works with the stock assessment (STAT) team to make necessary revisions, and produces a STAR Panel report for use by the PFMC and other interested persons for developing management recommendations for the fishery.

Each CIE reviewer is contracted to participate in the STAR Panel review meeting and to deliver an independent peer-review report to be approved by the CIE Steering Committee. This report, although generally consistent with, and similar to the STAR Panel report, is independent of the Panel report.

The specific tasks of the CIE Reviewers are to (See details in the SOW – Appendix 1):

- Review the background materials and reports prior to the review meeting
- Attend and participate in the panel review meeting
- After the review meeting, reviewers shall conduct an independent peer review in accordance with the requirements specified in this SOW, OMB guidelines, and TORs
- Assist the Chair of the meeting with contributions to the summary report, if required by the TORs
- Deliver their reports to the Government according to the specified milestone dates

1.1 Overview

A Pacific Sardine Stock Assessment and Review (STAR) Panel (Panel) was convened to review a draft assessment by the Stock Assessment Team (STAT) for the Northern Subpopulation of Pacific Sardine at the Southwest Fisheries Science Center, La Jolla, CA from February 21-24, 2017. The structure, responsibilities, goals, objectives and reporting requirements were defined under the terms of reference for the groundfish and coastal pelagic species stock assessment review process for 2017-18. In essence, the Panel reviewed three approaches for providing advice to management; two new assessment approaches and the default of updating the previous assessment. A list of attendees and the agenda are provided in the Appendices. It should be noted that because the CIE reviewer report is a standalone document, several sections of this report contain text that has been extracted almost verbatim from the STAR Panel report as the reviewer contributed to the document and feels it provides a good overview of the process and discussions.

Stock assessment team members, Drs. Paul Crone, Kevin Hill, and Juan Zwolinski presented a general overview of the assessment methodology for each of the different assessment approaches. Paul Crone first outlined the assessment history and philosophy, then moved on to focus on selecting an approach that was considered by the STAT to be most objective, i.e. the Acoustic Trawl Method (ATM) survey. In addition, because of the management schedule and fishing year, there is a requirement to provide the age 1+ biomass on July 1, 2017. The STAT provided results for two assessment approaches: (a) use of the summer 2016 Acoustic-Trawl method (ATM) survey biomass estimate and associated age-composition projected to 1 July 2017, and (b) a model-based assessment (ALT) that provides an estimate of age 1+ biomass on 1 July 2017. Both were considered as viable options for estimating biomass.

Dr. Juan Zwolinski provided a general overview of the spring (March/April) and the summer (July/September) acoustic-trawl surveys; the former concentrated in the southern USA, and the latter had broad coverage from California to Canada. Methodologies were discussed, however, because an ATM methodology review is scheduled for January 2018, only in general terms. Much of this survey approach had been reviewed and approved by a STAR Panel Review in 2011. He also described the survey-based method for estimating/projecting the age 1+ biomass on 1 July 2017. The method involved estimating numbers-at-age on 1 July 2016 from the summer 2016 ATM survey from numbers-at-length using an age-length key (pooled data over multiple summer surveys), and projecting these numbers forward under natural mortality, growth, and adding the estimated recruitment for 2016. Recruitment for 2016 was based on the stock-recruitment relationship estimated from ALT model outputs. The spawning stock biomass for 2016 was estimated by back-projecting the summer 2016 numbers-at-age to 1 January 2016.

Kevin Hill and Paul Crone presented the data on the model-based assessment, as well the results from a draft assessment utilizing the Stock Synthesis Assessment Tool, Version 3.24aa. The major differences in Model ALT from the model on which the 2016 update assessment (T_2016) were starting the assessment in 2005 rather than 1993, excluding the Daily Egg Production Method (DEPM) and Total Egg Production (TEP) indices, estimating rather than pre-specifying stock-recruitment steepness, pre-specifying weight-at-age rather than estimating it within the assessment, assuming that selectivity for the ATM survey is zero for age 0 and uniform for age 1 and older, estimating survey catchability (Q), assuming that selectivity is age- rather than length-based, modelling ages 0-10yr rather than ages 0-15yr, assuming natural mortality (*M*) is $0.6yr^{-1}$ rather than $0.4yr^{-1}$ for all age classes and fitting the catch and ATM survey age-composition data (rather than the associated length-composition data). Unlike the 2016 and earlier assessments, the model ALT included additional live bait landings, which generally reflected a minor contribution to the total landings in California and was the only active sector in the US sardine fishery. However, model ALT did not include biological composition data from the live bait catches, given this fishery sector had not been regularly sampled in the past. Samples were available for only the most recent year of the time series modelled in the assessment.

The review and subsequent explorations of the assessment through sensitivity analyses were motivated primarily by the need for the survey-based method to provide an estimate of age 1+ biomass and its CV, to better understand the rationale for the changes made to the model on which the last full assessment was based that led to model ALT. The Panel had several comments and concerns regarding the ATM survey methodology and ways in which estimates of close-to-absolute abundance can be obtained. However, it was stressed throughout the meeting that this was not a review of the ATM survey, since an ATM methodology review is planned in early 2018. Therefore, comments regarding the ATM survey and how estimates of abundance from that survey are constructed are reflected primarily in the Research Recommendations section of the report.

In the end, the Panel was not fully satisfied with either of the approaches used to estimate the age 1+ biomass on July 1, 2017. The ATM had problems with the approach used to project almost a year forward and the ALT model with the treatment age 0 in the model. These issues are discussed in more detail below; however, the Panel concluded that the ALT model was the better available approach to provide the required estimate of biomass for management of the NSP Pacific sardine resource.

The STAR Panel and the CIE reviewers thank the STAT for their hard work and willingness to respond to Panel requests, and the staff at the SWFSC La Jolla laboratory for their usual exceptional support and provisioning during the STAR meeting.

1.2 Goals and Objectives:

The specific goals and objectives for the 2017 Pacific Sardine Stock Assessment Review are those defined in the of groundfish and CPS STAR process document as follows:

1) ensure that stock assessments represent the best scientific information available and facilitate the use of this information by the Council to adopt OFLs, ABCs, ACLs, harvest guidelines (HGs), and annual catch targets (ACTs);
2) meet the mandates of the Magnuson-Stevens Fisheries Conservation and Management Act (MSA) and other legal requirements
3) follow a detailed calendar and fulfill explicit responsibilities for all participants to produce required reports and outcomes;
4) provide an independent external review of stock assessments;
5) increase understanding and acceptance of stock assessments and peer reviews by all members of the Council family;
6) identify research needed to improve assessments, reviews, and fishery management in the future; and
7) use assessment and review resources effectively and efficiently.

It is important to note that the following report to the CIE reflects my independent opinions and views on the issues and questions identified in the terms of reference, statement of work, and the above goals and objectives. The report is, however, generally consistent with the recommendations and conclusions of the other panel members and CIE reviewers. Overall, there was general consensus among the panel members with no identifiable areas of disagreement.

2.0 Description of the individual reviewers' Role

The CIE reviewers essentially served two roles on the STAR Panel Review of the 2017-2018 Pacific Sardine Stock Assessment. First, to participate as a full panel member in the review of the practices and procedures involved in the proposed assessment methods/approaches, and second to provide an independent review of the methodology and process.

To meet these requirements for the assessment of the Pacific sardine resource in 2017 a reviewer must have achieved recognition in several fisheries related fields. In this context, I am considered an expert in the assessment of small pelagic fish stocks, fisheries acoustics as applied to assessment of small and large pelagics, and their application to the management of the stocks. Currently, I am a senior Research Scientist with the Canadian Department of Fisheries and Oceans responsible for the research and assessment of large and small pelagic fish species. In addition, I am the scientist responsible for the acoustic program in my region of Canada and I have spent more than 25 years as the lead for small pelagic stock assessment program. I have a B.Sc., M.Sc., and PhD in fisheries related fields and have served on several international stock assessment review groups. Between 2010 and 2014, I was the Chair of the ICES North Sea Technical Review working group which provided quality control for all North Sea fish stocks assessed by ICES. Recently I was appointed Chair of the ICCAT western Bluefin tuna assessment working group.

My primary role was to participate in the 2017 Review as an informed expert and to contribute to the discussions and recommendations put forward by the STAT and the STAR Panel. Prior to the meeting, the stock assessment document was provided by the STAT team along with numerous background reports/documents on the fishery, methods, outputs and recommendations. The majority were read before the meeting so that well informed questions and discussions could be undertaken. Once the meeting began, my main focus was to be on the acoustic aspect of the assessment methodology; however, we were informed that because there will be a methodology review of the Acoustic –Trawl survey approach in January of 2018, much of the discussion will be deferred until. The meeting was still open to discussion on this subject, but most issues would be identified for investigation at the 2018 review.

Thereafter my focus shifted to the other areas of the review, participating in the discussions on the model-based assessment, major issues such as ageing, changes in mortality, the projection of biomass to July 1, 2017, the conclusions/

recommendations of the STAR Panel, contributions to the Panel Report and the preparation of an independent reviewer's report.

3.0 Summary of Findings for each term of Reference:

The summary presented below is an overview of the review and is generally consistent with the observations and results found in the STAR Panel Review Report. However, in several sections the text has been enhanced or is more inclusive to elaborate on specific issues. Prior to discussing the outcomes of the review associated with each TOR, I would like to make a few general comments regarding the documentation and the presentations. The stock assessment team (STAT) provided a good overview of the methodology and approaches described in the assessment document (Hill et al., 2017). The presentations by individual members of the team were informative and coherent. However, there were a number of cases where insufficient details were provided in the methods section of the assessment document for the Panel members to have a clear understanding about what or how something was done. This resulted in several extended discussions on the issue that could have been resolved with a few additional sentences in the assessment document. The STAT was very helpful in providing the details or the source of the details to the Panel where clarification was requested. Of particular concern were biological sampling protocols and the post stratification and analytical approaches used in the acoustic biomass estimation. Both involved extended discussions to clarify several areas of uncertainty.

The STAT team prepared and presented two new assessment approaches to the STAR Panel for review; One based on the outputs from an Acoustic-Trawl survey (ATM) as an absolute estimate of abundance, and the other an integrated model based method (SS3) to estimate biomass (ALT). Both methods were found to have merit but the former was obviously preferred by the STAT. The option to simply update the previous assessment (T_2016 to T2017) was not really being proposed or considered, although it was approved for management of resource by the 2014 STAR Panel. This was due to some undesirable features, such as extreme sensitivity to the occurrence of small fish in the ATM surveys, poor fits to the length-composition and survey data, as well as sensitivity to initial values for the parameters.

Although acoustic technology plays an extremely important role in the assessment, discussion on much of the acoustic methodology and assumptions was deferred. The Panel was informed that an acoustic methods meeting was scheduled for January of 2018 and that issues could, and should, be identified, but that detailed discussion of the issue would be postponed until the methods meeting. The assumption that the ATM was an acceptable approach was based on the 2011 Acoustic-Trawl Survey Method for Coastal Pelagic Species- Report of Methodology Review Panel Meeting, conclusions that: “Overall, the Panel is satisfied that the design of the acoustic-trawl surveys, as well as the methods of data collection and analysis are adequate for the provision of advice on the abundance of Pacific sardine, jack mackerel, and Pacific mackerel, subject to caveats, in particular related to the survey areas and distributions of the stocks at the times of surveying. The Panel concluded that estimates from the acoustic-trawl surveys can be included in the 2011 Pacific sardine stock assessment as “absolute estimates”.

Finally, there was a preconceived, or biased, preference of which model approach was preferred by the STAT team. While most of the Panel agreed that the simplest approach was likely the better, the text of the document only identified the merits of a survey-based assessment and the drawbacks of a model-based assessment. This somewhat unbalanced overview was discussed early during the meeting and the team agreed to provide a more balanced overview in the assessment document. Ironically, in the end, it was the model-based approach (ALT) that was selected to provide the advice to management for 2017.

One constraint in the process was the necessity for the approach to provide a mechanism for projecting a biomass estimate for the start of the fishing year, in this case 1 July 2017. As happened in this review, the STAT and the STAR Panel agreed that the ATM was the better and simpler approach for providing estimates of biomass, but because of the issues associated with the projection method proposed for the ATM the panel was left with no alternative but to recommend the use of the ALT model to provide advice to management. Both approaches provided similar biomass estimates. Several methods to provide a suitable projection approach for the ATM were investigated during the meeting but none were deemed acceptable. Alternative approaches to resolve this problem are proposed in the STAR Panel report recommendations.

The role of the STAR Panel is to conduct a detailed technical evaluation of a full stock assessment to advance the best available scientific information to the Council. The specific responsibilities of the STAR panel are to:

1) Review draft stock assessment documents, data inputs, and analytical models, along with other pertinent information (e.g., previous assessments and STAR panel reports, when available);

2) Discuss the technical merits and deficiencies of the input data and analytical methods during the open review panel meeting, work with the STATs to correct deficiencies, and, when possible, suggest new tools or analyses to improve future assessments; and

3) Develop STAR panel reports for all reviewed species to document meeting discussion and recommendations.

3.1 Review draft stock assessment documents, data inputs, and analytical models

Approximately two weeks before the STAR Panel meeting access to a web-site containing the draft Pacific Sardine Assessment Document and background material was granted. This was an excellent source on material from which to prepare for the actual review meeting. At the meeting, the SWFSC assessment team provided a good overview of the assessment approaches and the logic for their preference. Details were provided on each approach, survey design, analytical methods, and results during the meeting. This information greatly assisted the Review Panel in their review of assessment approach. When the Panel requested for a more detailed explanation or additional analysis the team generally provided the information the next day. The Panel and the CIE reviewers appreciated their efforts and acknowledge the extensive research effort to evaluate factors that may affect or bias outputs. The documented and presented information was sufficient to conduct the STAR Panel Review of the assessment and generally represents the best scientific information available at the moment. The ATM methodology Review to be held in 2018 will hopefully resolve the issues and recommendations associated with this assessment approach.

In general, the Panel review adhered to the agenda provided to attendees prior to the meeting. However, some flexibility was permitted by the chair when the discussion led into an area to be discussed later that was helpful to address the issue on-hand. Each CIE Reviewer participated in the discussion and review of the specific topics identified in the agenda and made a significant contribution to the Panel's draft summary report. The review chair collated the draft text and completed the Panel report with input from all Panel members. The review can be divided into 4 broad topics; the overview, acoustic-trawl surveys, the integrated assessment model (ALT), and conclusions/recommendations, each of which are discussed below.

3.2 Discuss the technical merits and deficiencies of the input data and analytical methods during the open review panel meeting.

The STAR Panel report provides a detailed summary of the Panel's views on the merits and deficiencies of both assessment approaches as well as suggestions to evaluated and potentially correct these deficiencies. Over the 3-day meeting, most areas of uncertainty or concern were addressed and where possible additional information or data reruns were requested to improve the Panel's understanding of procedures and processes (Section 3.3.1).

In addition, specific issues were raised and are identified below.

3.2.1 Acoustic Trawl Method (ATM) survey.

There were a number of merits and deficiencies identified during the 2017 Star Panel Review for the Acoustic Trawl Method survey. Both the STAT and the STAR Panel agreed that the ATM likely provided the better approach to assess the NSP Pacific sardine stock in term of biomass. Unfortunately, the proposed approach to project the stock forward by about 1 year was deemed circular and performed poorly to other projection methods tested during the meeting. While the detailed discussion of the acoustic methods were deferred until the 2018 methods review, several areas of weakness in the survey approach were discussed (survey coverage, biological sampling, stratification, and ageing). Factors such as TS were not investigated but could have had a significant impact on the estimated biomass (assumed to be absolute). Herein lies another example of where some additional detail in the documentation could have helped. Target strength is a function of fish length and usually expressed in terms of total length for pelagic species. Yet, the length measured during the survey was standard length. Although not requested during the meeting, a simple statement indicating the TS equation was correct for length measurement would have clarified what was actually done.

Survey Coverage:

Survey coverage has been, and continues to be, a major issue for both the spring and summer acoustic surveys in that they do not provide complete coverage of the seasonal distribution of the species. Each year the fishing industry (Captains and representatives) reports a varying amount of Pacific sardine in the inshore waters not covered by the AT surveys. According to the industry representatives present at this year's Panel, large amounts of sardines were observed inshore over the last two years during the time of the survey that would not be accounted for by the survey. If these observations can be confirmed and quantified, it would complete the survey coverage, and likely increase the 1+ biomass of the Northern Pacific stock. Even the 2011 Panel Review, which acknowledged that the survey was adequate to provide an absolute biomass estimate for the area covered, suggested that methods be explored to obtain information, particularly on the inshore and to a lesser extent on the offshore areas.

From a personal point of view, this is an excellent opportunity for the STAT team and the SWFSC to explore collaboration opportunities for surveying with the fishing industry. A major challenge for the larger research vessels is the minimum depth restrictions, imposed for safety reasons, limiting how close to shore the vessel can survey. Fishermen are general very familiar with local conditions and could, assuming a coordinated effort, provide coverage of those areas not covered by the survey vessel, thus eliminating the continuous uncertainty associated with what is and isn't in the inshore waters during the survey. Furthermore, there appears to be a sincere interest by the fishing industry to collaborate with the STAT team on surveying.

Another deficiency not directly related to spatial coverage, but the scope of the technology used to survey, is the amount of sardines distributed in the acoustic surface dead zone (10-15m below the surface). Currently, the surveys are conducted with hull mounted acoustic echo-sounders that can only detect fish directly under the vessel. Pacific sardines are commonly found very near the surface, thus any fish occurring in the dead zone would go undetected and would likely avoid the vessel, especially during the day. Recommendations have been made in previous reviews to investigate this section of the water column using sonar technology; however, no new information was presented at the review. The recommendation to use drone technology to address these and other areas of uncertainty are to be encouraged but they should not occur at the expense of more conventional technologies (e.g., sonar and aerial surveys).

Biological Sampling:

Biological Sampling appears to be another deficiency of the ATM. The current practice of surveying during the day and fishing during the night was again questioned. The assumption that fish present during the day are the same fish caught and occur with the same species composition (representative) is a major source of uncertainty. It should also be noted that a large number of the sets (Trawls) contain 0 catches (up to 50% in some years). Combine that with the pooling of sets into clusters and the actual sample size decreases substantially.

For this survey, the Primary Sampling Unit (PSU) is a cluster of sets undertaken in a general area. How the locations of the sets are determined is another area of uncertainty. It was curious to note that some clusters (multiple sets) occurred in areas where no fish were observed and no fish were caught. It was explained that because fishing occurred at night that fishing stations may or may not be in areas with fish. Given that the purpose of sampling is to determine species and size composition of the acoustic targets, fishing in areas without fish for multiple sets is somewhat futile. This practice of fishing for the sake of fishing also appears to be an inefficient use of precious vessel time. Better use of fishing time needs to be addressed and may help to improve biological sampling.

The species composition data from the sets are used to apportion the acoustic backscatter into species backscatter and subsequently into species specific biomass. Efforts should be made to improve (increase) biological sampling and reduce the uncertainty. This is another area where collaboration with the fishing industry could benefit both science and the industry. Working with the fishing industry could remove some of the uncertainty associated with day surveying and night sampling if fishing vessels were used to confirm acoustic targets. Purse seines are generally non-size selective and in many cases the entire school can be caught, permitting additional sampling with an actual biomass estimate. Additional samples would also be available for ageing.

Ageing:

The Panel discussed a number of issues associated with the number of samples aged and the development of age-length keys related to both assessment approaches being reviewed. Probably most surprising to the Panel was the limited number of otoliths collected for a given AT survey. The number of fish sampled for age ranged from 16 to 1,051 per year, but were generally less than 500, especially in the most recent years. The explanation provided by the STAT was that samples were difficult to collect during the survey as the biomass was low. The Panel expressed concern about the application of so few ages to age length keys and the implication of this on the age and weight at length used for the models. Of particular concern was the practice of pooling samples from several years to create a generic ALK that was applied to the length distributions. Most fishery scientists frown (a must not do) upon this practice as it removes the effects of all inter-annual or density dependent growth variability. The generic ALK will also have an impact on all age-related factors associated with the assessment. Several unusual patterns were noted in the weight at age figures for a number of years. The only real solution is to increase the number of samples collected and to increase the number of otoliths retained for ageing so that sufficient otoliths are collected to generate an annual ALK. This is another area that should be explored where collaboration/coordination with the fishing industry could benefit both the resource and the analysis. Fishing vessels could be utilized to sample fish during the survey or to supplement low samples in specific areas where research samples are limited.

Post survey stratification:

The method used to post stratify the AT survey into stratum was unclear in the assessment report and caused several members of the Panel to express their concern about using the presence and density of fish to post stratify the survey area. A fair amount of discussion ensued on the approach, sampling design and the potential bias of using the latter two criteria to stratify the survey observations. Eventually, the actual procedure for increasing the intensity (spacing) of transects was explained and the Panel felt more comfortable with the approach. However, there were still uncertainties associated with how things were done and what triggered a change in transect spacing. This issue will be dealt with further by the second CIE Reviewer and under the recommendations that should be addressed at the upcoming review of ATM scheduled for early 2018. Recommendation E states that the ATM survey design and estimation methods need to be more precisely specified.

3.2.2 Model-based assessment

The second assessment approach reviewed by the Panel was the model-based assessment (ALT) utilizing Version 3.24aa of the Stock Synthesis Assessment Toolbox to evaluate the status of the NSP of Pacific sardine stock. This model differs significantly in configuration and input parameters from the model used to update the assessment in 2016. Consequently, the requirement for a STAR Panel review. Changes include starting the model in 2005 (previously 1993) and excluding the Daily Egg Production Method (DEPM) and Total Egg Production (TEP) indices. Stock recruitment steepness and weight-at-age was pre-defined with the assumption that selectivity of the AT survey being 0 for age 0 and uniform for all other ages. Catchability was estimated under an age-based rather than a length-based model, ages modeled were reduced from 15 to 10 years and natural mortality increased from 0.4 to 0.6. Given that there is no directed fishery on the NSP resource so landings from the small live bait catches were included for 2015 and 2016 for the first time.

It was evident from the assessment document and presentations that the STAT team preferred the survey based method over the model-based approach to the assessment. The challenge for the preferred approach was to project forward almost a year from the last survey to the beginning of the management year. Thus, one of the key drivers in the review was to explore the method proposed by the STAT to estimate age 1+ biomass and its associated CV on July 1, 2017 from the ATM. If the proposed method was unacceptable then the Panel must identify the best approach to achieve and estimate biomass for management purposes.

Several inconsistencies, especially for age 0 were noted by the Panel in the outputs of the ALT model. A significant amount of time was spent on resolving issues associated with the ALT model. It appears that the seasonal option in the modelling (SS3) toolbox had not been fully tested and that it was producing unusual outputs related to the Age 0 fish. Several requests were made to the STAT team to try to resolve/understand these problems. Although not fully resolved to the satisfaction of the Panel, a work around process was established and projections for the 1+ biomass was available for the ALT model. Several approaches to estimate age 1+ biomass were explored by the Panel and are described below.

The first was to assume that the 1 July 2017 biomass equals the estimate of biomass from the summer 2016 ATM survey; simply ignoring mortality (natural causes and fishing), growth and recruitment from July 2016 to July 2017. This method was considered as the simplest approach and the easiest to implement because it does not rely on a model or estimates of age composition for which sample sizes are low.

The second approach was to project the biomass from the 2016 ATM survey to 1 July 2017 taking into account mortality, growth and recruitment between July 2016 and July 2017. Unfortunately, the approach used to convert from length-composition to age-composition was incorrect, and the method used to derive the CV of age 2+biomass did not allow for uncertainty in the population age-composition, projected weight-at-age and maturity-at-age. In addition, the method relied heavily on model ALT because approximately half of the age 1+ biomass on 1 July 2017 consisted of age-1 animals. As such, the estimate of biomass is based to a substantial extent on the stock-recruitment function from model ALT. Finally, the value for M of 0.6yr-1 has no clear justification. The version of the projection model provided initially to the Panel did not account for catches, meaning that the procedure could not be applied in the future when the targeted sardine fishery re-opened. Furthermore, it did not account for the limited catches during 2016.

The third approach was to use the ALT model projections. The ALT Model has similar problems associated with the ‘survey projection’ model, i.e. the age-composition data are based on a year-invariant age-length key, and the basis for M=0.6yr-1 lacks strong empirical justification (and indeed likelihood profiles indicate some support for lower M than the value adopted for model ALT). In addition, the model presented to the Panel predicted age 0 catch in the ATM survey even though it is assumed that age-0 animals are not selected during the ATM survey. It appears that the model predictions of age-0 animals in the ATM survey are actually model-predicted numbers of age-1 animals that are predicted to be mis-read as age-0 animals. However, examination of the ATM survey length-frequencies suggests that that some age-0 animals (or animals that were spawning earlier in the year) are encountered during the surveys. The Model ALT also estimates Q to be 1.1, which is unlikely given some sardine are not available to the survey owing to being inshore of the survey area.

Finally, projections from the previous assessment model were examined. The model on which the 2014-16 assessments were based was approved for management by the 2014 STAR Panel. However, that assessment had some undesirable features, including extreme sensitivity to the occurrence of small (<~15cm fish) in the ATM surveys, poor fits to the length-composition and survey data, and sensitivity to initial values for the parameters (i.e. local minima) as noted in previous reviews. The Panel explored alternatives to the current selectivity formulation to better understand why model ALT was predicting age 0 catch when selectivity for age-0 fish was set to zero. It was noted that the results were generally robust assuming that selectivity is a logistic function of length (but that implies that some age-1+ animals are not available to the ATM survey), allowing for time-varying age 0 selectivity, and estimating a separate selectivity pattern for ATM survey age-composition data.

The Panel noted that the 'survey projection' model and model ALT both rely on the samples from the ATM surveys to compute weight-at-age and survey age-composition data. The sample sizes for age from each survey were very small which means that estimates of, for example, weight-at-age are highly uncertain. The procedure of ensuring that weight-at-age for a cohort does not decline over time seems intuitively correct. However, if the estimated mean weight of young fish in a cohort is anomalously high owing to small samples, it can impact the weight-at-age of that cohort for all subsequent ages. When Model ALT steepness was estimated rather than fixing it equal to 0.8, the results were not sensitive to fixing versus estimating steepness, but the estimate of 0.36 was low.

In the end the Panel considered four ways to meet the management requirement to estimate age 1+ biomass on 1 July 2017: (1) the simple approach of using the of biomass estimate from the summer 2016 ATM survey without projecting forward, (2) projecting biomass from the 2016 ATM survey (summer) to 1 July 2017 using the proposed 'survey projection' model (and/or an alternative approach), (3) model ALT, and (4) the model on which the 2014-16 assessments were based. The Panel concluded that although neither method was fully acceptable that option 3, the ALT model, was likely the best available approach to meet the management needs.

3.3 Develop STAR panel reports for all reviewed species to document meeting discussion and recommendations.

This section summarizes the discussion and recommendations that form an integral part of the STAR Panel report. As a full member of the panel, I made a significant contribution to the preparation and editing of the final report. Consequently, I see no merit in rewording the sections related to requests for additional information, the recommendations and conclusions of the STAR panel report so I have extracted the appropriate sections and included them in my report. Although I fully agree with the content, there are a few areas where I have enhanced the text to complement that contained in the Panel report.

3.3.1 Requests made to the STAT (Taken Directly from the STAR Panel Report)

Day 1– Tuesday, February 21:

***Request 1*:** Provide documentation on the procedures used to calculate the survey age-composition data, including how age-length and age-biomass keys are constructed.

Rationale: These calculations are critical to projecting biomass after accounting for natural mortality, somatic growth, and recruitment; but the draft assessment document did not describe these calculations in sufficient detail for them to be reproduced. In addition, the age-compositions for the ATM survey in model ALT were computed using the method.

Response: Dr. Zwolinski presented written documentation and figures. The function "multinom" from the R package "nnet" fits a multinomial log-linear model using neural networks. The response is a discrete probability distribution (see Fig. 1). It is simpler to use than the alternative (sequential logistic models), and it provides a smoother transition between classes than an empirical age-at-length key. The age and lengths used for constructing the age-length key were from surveys from 2004 to the present. Due to the assumption of a July first date and its effect on ageing, the STAT built a season-specific age-length key using data pooled across time separately for spring/summer.
The Panel agreed that aggregation across years is not appropriate if some length-classes represent multiple ages, which is the case for Pacific sardine. Moreover, substantial spatial and temporal variation occurs in size-at-age, and smoothing this out by merging the data from several years creates bias in annual estimates of age compositions of varying magnitude and direction.

Request 2: Provide full specification, including equations, of the calculations used to 1) project from the ATM survey biomass estimate to the estimated age 1+ biomass on July 1 of the following fishing year, and 2) calculate the uncertainty associated with that biomass estimate.

Rationale: The projection calculations need to be reproducible. Management advice (Overfishing Level OFL, Acceptable Biological Catch ABC, and Harvest Guideline HG) for Pacific sardine requires an estimate of age 1+ biomass (OFL, ABC, HG) and its uncertainty (ABC) on July 1, 2017.

Response: For 1), Dr. Zwolinksi walked the Panel through a spreadsheet that made these calculations and the Panel agreed that the calculations were sensible, conditional on the age-weight key. For 2), assuming independence of age- 1 and age- 2+ biomass, the total variance was calculated by summing the respective variances. This calculation is negatively biased because it ignores uncertainty in age-composition and weight-at-age. It was noted that the resultant coefficient of variation (CV) for age 1+biomass is lower than the CV for either component (age- 1 versus age- 2+) due to their assumed independence.

Request 3: Plot cohort-specific rather than year-specific growth curves (weight-at-age) for the ATM survey and overlay raw data/information on sample sizes. Make it clear which values are estimated versus inferred. Do this for the fisheries data as well.

Rationale: Cohort-specific curves are easier to interpret as growth trajectories than year-specific curves. It is important to understand how much data drives these estimates, and to understand the consequences of applying the same age-length key for all years with survey data to calculate the weight-at-age and age-composition for the ATM survey.

Response: Dr. Hill presented tables including sample sizes and estimated means for each cohort-season-age combination. The tables were formatted to highlight entries that were inferred versus estimated. Dr. Hill calculated means whenever three or more samples were available. However, these means were sometimes overwritten based on the assumption that animals did not shrink. The ATM data showed substantial variation in weight-at-age across years (Fig. 2), and possibly increasing size-at-age in recent years. The MexCal catch data appeared less variable overall, and it was noted that fishery sample sizes were generally larger than the ATM sample sizes. An error was discovered in the weight-at-age data for the PNW catch, which could not be resolved during the Panel meeting.

The Panel noted that the adopted method ended up discarding data for cohorts with unusually large mean sizes for age-0 fish by not allowing "shrinkage", whereas it may have been the age-0 means that were anomalous rather than the means calculated for older ages. The Panel also noted that in many cases, the sample sizes were very small. The weight-at-age key used within the survey-based projection did not exclude "shrinkage". Using the weight-at-age key in model ALT produced an imperceptible difference in model-estimated age 1+ biomass.

Request 4: Verify that model ALT was run with ATM survey selectivity set equal to 0 for age-0 fish. Contact Dr. Rick Methot to better understand how selectivity is being modeled under the chosen selectivity option in SS.

Rationale: The model outputs appear to indicate that the model predicts non-zero catches of age-0 fish despite the intent to specify selectivity to be 0 zero on age-0 fish. This may have significant unintended consequences for the likelihood calculations.

Response: This question was not fully resolved. It appears that Stock Synthesis predicts some catch of nominal "age- 0" even given selectivity of zero on true age-0 fish because aging error leads to the expectation that some age-1 fish will be caught and miscategorized as age- 0. Further model runs revealed that the model "blew up" if aging error was set to zero or made

very small, but reductions in the specified aging error led to the expected reduction in the predicted age-0 catch. It was noted that surveys likely include a mix of age-1 fish miscategorized as age-0, as well as fish that are truly age-0.
Dr. Methot also noted that Stock Synthesis had not been as thoroughly debugged for semester-based models as for strictly annual models.
See also Requests 5, 8, and 9.

Request 5: Re-run model ALT with age- 0 fish removed from the input file for the ATM survey.

Rationale: Similar to Request 4, the model likelihood should not be influenced by data on age-0 fish if it is assumed selectivity on age-0 fish is zero, but the model appears to be generating non-zero predictions and comparing these against the input data.

Response: The model still predicted catch of age-0 fish in this scenario. This is consistent with the explanation suggested for this pattern under Request 4.

Request 6: Report the CV of the estimate of terminal biomass based on changes in how the compositional data are weighted.

Rationale: The weighting of compositional data appeared to have little effect on the point estimate of biomass, but it is important to understand implications of alternative weighting schemes for uncertainty as well.

Response: Data weighting increased the CV by 2-3%. The base model had a CV of approximately 36%, Francis-weighting led to a CV of approximately 38%, and harmonic mean weighting led to a CV of about 39%.

Request 7: Show more outputs from T_2017 and T_2017_No_New_AT _Comp

Rationale: These outputs would help the Panel evaluate the reasons for proposing a move away from a strict update of the previously accepted model structure, i.e. identify problems with a strict update that the new model structure addresses.

Response: Selectivity curves for the spring and summer ATM surveys were noticeably different depending on whether the two most recent survey length-compositions were included in the assessment or not (Fig. 3). These models appeared to yield acceptable fits to abundance indices, but the fits to observed length-compositions were poor. It appears that the model estimates very low selectivity on small fish for the summer survey (since selectivity does not vary across years, and very few small fish are encountered most years) such that when small fish are encountered, they are expanded to a very large number. During Panel discussion, it was noted that this unexpected behavior should not happen if selectivity were forced to be the same for the spring and summer surveys.

Day 2 – Wednesday, February 22

Request 8: Develop a model in which selectivity for age-0 animals in the survey is time-varying.

Rationale: The availability of age-0 animals to the survey seems to be highly variable among years, but influential on the results. A selectivity function in which age-0 selectivity varies among years should “discount” the influence of occasional catches of age-0 animals.

Response: A model was presented that assumed essentially full selection on age-1+ animals, and time-varying age-0 selectivity. The model estimated nearly zero selectivity on age-0 fish in all years except 2015, when estimated selectivity on age-0 fish was nearly 1.0. Fits to compositional data were similar to those for model ALT, except that the spike of age-0 fish in 2015 was captured better. The estimate of age 1+biomass on 1 July, 2017 for this model was 77,845 t.

Request 9: Run a variant of model ALT in which the age-compositions are assigned to a new fleet (6) that has logistic selectivity (estimated separately for the spring and summer periods).

Rationale: Selectivity for the ATM survey is assumed to be uniform on animals aged 1 and older so age-composition data are not required for this survey. The selectivity pattern for the trawl component of the survey is not uniform on age-1+ animals (some age-0 animals are caught) and it may be possible to represent this using a logistic selectivity function.

Response: This model performed generally similarly to a double-logistic formulation applied to the ATM survey for both age-composition and as an abundance index, but it misses the summer 2016 ATM survey estimate of biomass from above, whereas the double-logistic fits that estimate closely. The double-logistic model had a negative log-likelihood of approximately 311, compared to 305 for this variant and 333 for model ALT. Thus, both a model with logistic ATM selectivity and a model that assumed 1+ selectivity for ATM survey estimates and logistic selectivity for the associated age-composition data fit the data somewhat better than model ALT.

Request 10: Conduct a retrospective evaluation of how well alternative assessment methods can predict the biomass from the summer ATM surveys. For each year Y for which there is a summer ATM survey estimate for year Y and year Y+1, report predictions of year Y+1 biomass based on (a) the estimate of biomass from the results of the ATM survey during summer of year Y, (b) the estimate of biomass based on applying the projection method to the results from the ATM survey in summer of year Y, and (c) model ALT based on data through year Y.

Rationale: The Panel wished to understand which method was able to predict the ATM survey estimate of biomass most accurately.

Response: The STAT provided results for the three selected approaches as well as the estimates of age 1+ biomass obtained by projecting the actual assessments used for 2012, 2013, 2014 and 2015 forward ("Past assessments" in Fig. 4) and estimates of age 1+ biomass obtained by projecting the model used for 2014, 2015 and 2016 management advice ("2014 formulation"). Model ALT generally came closest to predicting the survey biomass estimate the following year, doing so by a substantial margin for 2014. "Past assessment" was usually the worst. Model ALT had the lowest residual variance. Relative errors were a CV of 1.07 for Model ALT, 1.26 for the 2014 model on which 2014, 2015 and 2016 management advice was based on formulation, 1.50 for the last survey without projection, 1.62 for the values adopted in management specifications, and 1.70 for projections from the past previous ATM survey (see Appendix 2 for the specifications for the method).

Day 3 – Thursday, February 23

Request 11: Develop a method for estimating recruitment solely from ATM data, explain how these recruitment estimates could be used to project forward from an ATM biomass estimate, and then add results for that method to the retrospective comparison described in Request 10.

Rationale: During discussion of Request 10, it was clear that much of the concern regarding the currently proposed method of projecting from the survey was its dependence on model ALT for inputs, resulting in its dependence on the same assumptions the STAT was hoping to avoid by moving away from an integrated assessment. It was pointed out that it could be possible to develop estimates of age 1 biomass on 1 July, 2017 strictly from the ATM data.

Response: The STAT modified the survey projection method so that projected biomass of 1-year-olds was the average over the most recent five years. As desired, this approach was not tied to the model ALT. However, the residual standard deviation for this approach ("Survey projection 2"), while better than "Survey projection", was still worse than Model ALT and the 2014 model formulation (1.45) (Fig. 4).

4.0 Recommendation and Conclusions

One of the primary objectives of the stock assessment process and the STAR Panel Review was to provide advice to management on 2017-2018 NSP Pacific sardine resource using the best available information/data. The Panel reviewed multiple options, described above and concluded for 2017 that, given the current management approach requires an estimate of age-1 biomass at the start of July, model ALT was the best approach at present for conducting this assessment notwithstanding the concerns listed above. The results from the assessment are robust to changes in how selectivity is modelled, the value for steepness and data weighting, but there were several concerns with this model that could not be resolved during the Panel meeting. Assuming uniform selectivity leads to lower estimates of current 1+ biomass, but this assumption reflects the expectation that all fish in the survey area are vulnerable to detection during an acoustic survey.

The STAT strongly recommends that management advice for Pacific sardine be based on the estimates of biomass from the ATM survey rather than a projection model or an integrated assessment. The STAR Panel is in general agreement with this approach and notes the following ways in which management could be based on the ATM survey results given the July 1 biomass estimate requirement. The first would be to change the start-date of the fishery so that the time between conducting the survey and the implementation of harvest regulations is minimized. And, secondly to use Management Strategy Evaluation to evaluate the risk to the stock of basing management actions on an estimate of biomass that could be a year old at the start of the fishing season (if the fishery start date is unchanged). Review of an updated MSE would likely not require a Methodology Panel, but could instead be conducted by the SSC.

The Panel further notes that there may be benefits to attempting to use both the spring and summer ATM surveys as the basis for an ATM survey-only approach and that moving to an assessment approach that relies on the most recent ATM survey (or two) may be compromised by reductions in ship time and/or problems conducting the survey. From the CIE Reviewer perspective, the reduction of vessel time will have implications for the AT survey and at a minimum will increase the variance estimates of biomass and the uncertainty about survey coverage.

The Panel agrees with the STAT that there is value in continuing to collect biological data and to update model ALT even if management moves to an ATM survey-only approach.

4.1 Research Recommendations:

The Panel identified a number of research recommendations that have been prioritized in three categories: High, medium and low.

High priority

A. Conduct an analysis of effect of fish sample size on the uncertainty in the ATM biomass estimates and model outputs. Use this information to re-evaluate and revise the sampling strategy for size and age data that includes target sample sizes for strata.
B. The clusters (the Primary Sampling Units, PSUs) with age-length data should be grouped into spatial strata (post-strata, or collapsed post-strata used in ATM biomass estimators). The variance in estimates of age-length compositions can then be estimated by bootstrapping of PSUs, where age-length keys are constructed for each bootstrap replicate. The sub-sample size of fish within clusters that are measured for lengths should be increased, and length-stratified age-sampling should be implemented. This approach would likely increase coverage of age samples per length class and reduce data gaps.
C. The survey projection method should be developed further. Specifically, the survey age-composition should be based on annual age-length keys, and the uncertainty associated with population age-composition, weight-at-age and maturity-at-age needs to be quantified and included in the calculation of CVs. A bootstrapping procedure could be used to quantify the uncertainty associated with population age-composition and projected weight-at-age. Uncertainty in weight-at-age could also be evaluated using a retrospective analysis in which the difference between observed and predicted weight-at-age for past years was calculated. Ultimately, improved estimates of weight-at-age and measures of precision of such estimates could be obtained by fitting a model to the empirical data on weight-at-age.
D. The methods for estimating 1 July age 1+ biomass based on the results of the ATM survey during the previous year currently use only the results of the summer survey. Improved precision is likely if the results from the spring and summer surveys were combined. This may become more important if the number of days for surveying is reduced in the future. Consideration should be given to fish born after 1 July.
E. Investigate alternative approaches for dealing with highly uncertain estimates of recruitment that have an impact on the most recent estimate of age-1+ biomass that is important for management.
F. Modify Stock Synthesis so that the standard errors of the logarithms of age-1+ biomass can be reported. These biomasses are used when computing OFLs, ABCs and HGs, but the CV used when applying the ABC control rule is currently that associated with spawning biomass and not age-1+ biomass.
G. The approach of basing OFLs, ABCs and HGs for a year on the biomass estimate from the ATM survey for the previous year should be examined using MSE so the anticipated effects of larger CVs and a possible time-lag

between when the survey was conducted and when catch limits are implemented on risk, catch and catch variation statistics can be quantified.

H. The assessment would benefit not only from data from Mexico and Canada, but also from joint assessment activities, which would include assessment team members from both countries during assessment development.
I. The assessment would benefit from the availability of estimates of 1+ biomass that include quantification of the biomass inshore of the survey area and in the upper water column.
J. It is unclear how the habitat model is applied to determine survey design. Is this an *ad hoc* decision or is there a formal procedure? The next Panel should be provided with comprehensive documentation on how the habitat model is applied.
K. Consider future research on natural mortality. Note that changes to the assumed value for natural mortality may lead to a need for further changes to harvest control rules.
L. Explore the potential of collaborative efforts to increase sample sizes and/or gather data relevant to quantifying effects of ship avoidance, problems sampling near-surface schools, and currently un-sampled nearshore areas.
M. Reduce aging error and bias by coordinating and standardizing aging techniques and performing an aging exchange (double blind reading) to validate aging and estimate error. Standardization might include establishing a standard “birth month” and criteria for establishing the presence of an outer annuli. If this has already been established, identify labs, years, or sample lots where there is deviation from the criteria. The outcome of comparative studies should be provided with every assessment.

Medium priority

N. Continue to explore possible additional fishery-independent data sources such as the SWFSC juvenile rockfish survey and the CDFW/CWPA cooperative efforts (additional sampling and aerial surveys). Inclusion of a substantial new data source would likely require review, which would not be easily accomplished during a standard STAR Panel meeting and would likely need to be reviewed during a Council-sponsored Methodology Review.
O. Consider spatial models for Pacific sardine that can be used to explore the implications of regional recruitment patterns and region-specific biological parameters. These models could be used to identify critical biological data gaps as well as better represent the latitudinal variation in size-at-age; this should include an analysis of age-structure on the mean distribution of sardine in terms of inshore-offshore (especially if industry partner-derived data were available).
P. Consider a model that has separate fleets for Mexico, California, Oregon-Washington and Canada.

Q. Compare annual length-composition data for the Ensenada fishery that are included in the MexCal data sets for the northern sub-population with the corresponding southern California length compositions. Also, compare the annual length-composition data for the Oregon-Washington catches with those from the British Columbia fishery. This is particularly important if a future age data/age-based selectivity model scenario is further developed and presented for review.

Low priority

R. Consider a model that explicitly models the sex-structure of the population and the catch.
S. Develop a relationship between egg production and fish age that accounts for the duration of spawning, batch fecundity, etc., by age. Using this information in the assessment would require that the stock-recruitment relationship in SS be modified appropriately.
T. Change the method for allocating area in the DEPM method so that the appropriate area allocation for each point is included in the relevant stratum. Also, apply a method that better accounts for transect-based sampling and correlated observations that reflects the presence of a spawning aggregation.

4.2 Recommendations that should be addressed during the 2018 review of the ATM survey

The Panel was informed that a methodology review of the ATM approach was scheduled for January 2018. Because of this, a number of issues and detailed discussions regarding this approach were deferred until the review. However, the Panel did make several recommendations, listed below, that should be considered for the 2018 review.

A. In relation to the habitat model:

a. Investigate sensitivity of the assessment to the threshold used in the environmental-based method (currently 50% favourable habitat) to further delineate the southern and northern subpopulations of Pacific sardine.
b. Further validate the environmentally-based stock splitting method. The habitat model used to develop the survey plan and assign catches to subpopulation seems to adequately predict the spawning/egg distribution in the CalCOFI core DEPM region, but eggs were observed where they were not expected in northern California, Oregon and Washington during one of the two years when the survey extended north. It may be possible to develop simple discriminant factors to differentiate the two sub-populations by comparing metrics from areas where mixing does not occur. Once statistically significant discriminant metrics (e.g. morphometric, otolith morphology, otolith micro-structure, and possibly using more recent developments in genetic methods) have been chosen,

these should be applied to samples from areas where mixing may be occurring or where habitat is close to the environmentally-based boundary. This can be used to help set either a threshold or to allocate proportions if mixing is occurring.

c. Consider including environmental covariates in model-based approaches that would account quantitatively for environmental effects on distribution and biomass. The expertise from a survey of fishermen could be extremely useful in identifying covariates that impact the distribution of clusters.

B. The SWFSC plans to examine ship avoidance using aerial drone sampling; there is an ongoing significant effort by Institute of Marine Research in Norway to understand the same issue using sonar, and the SWFSC acoustics team should communicate and coordinate with those researchers.

C. The effect of population size affecting the number and spacing of school clusters likely affects the probability of acoustic detection in a non-linear way; this could create a negatively biased estimate at low population levels and potentially a non-detection threshold below which the stock size cannot be reliably assessed. A simulation exercise should be conducted using the current, decreased and increased survey effort over a range of simulated population distribution scenarios to explore this.

D. The consequences of the time delay and difference in diurnal period of the acoustic surveys versus trawling need to be understood; validation or additional research is critical to ensure that the fish caught in the trawls from the night time scattering layer share the same species, age and size structure as the fish ensonified in the daytime clusters.

E. The ATM survey design and estimation methods need to be more precisely specified. A document must be provided to the ATM review (and future assessment STAR Panels) that:

- delineates the survey area (sampling frame);
- specifies the spatial stratification (if any) and transect spacing within strata planned in advance (true stratification);
- specifies the rule for stopping a transect (offshore boundary);
- specifies the rules for conducting trawls to determine species composition;
- specifies the rule for adaptive sampling (including the stopping rule); and
- specifies rules for post-stratification, and in particular how density observations are taken into account in post-stratification. Alternative post-stratification without taking into account density should be considered.

DISCLAIMER

The information in this report has been provided for review purposes only. The author makes no representation, express or implied, as to the accuracy of the information and accepts no liability whatsoever for either its use or any reliance placed on it.

Appendix I: Background material

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Appendix II: Statement of Work for Dr. Gary Melvin

Statement of Work
National Oceanic and
Atmospheric Administration
(NOAA) National Marine Fisheries
Service (NMFS)
Center for Independent
Experts (CIE) Program
External Independent
Peer Review
STAR Panel Review of the 2017-2018 Pacific Sardine
Stock Assessment
February 21-24, 2017

Background

The National Marine Fisheries Service (NMFS) is mandated by the Magnuson-Stevens Fishery Conservation and Management Act, Endangered Species Act, and Marine Mammal Protection Act to conserve, protect, and manage our nation's marine living resources based upon the best scientific information available (BSIA). NMFS science products, including scientific advice, are often controversial and may require timely scientific peer reviews that are strictly independent of all outside influences. A formal external process for independent expert reviews of the agency's scientific products and programs ensures their credibility. Therefore, external scientific peer reviews have been and continue to be essential to strengthening scientific quality assurance for fishery conservation and management actions.
Scientific peer review is defined as the organized review process where one or more qualified experts review scientific information to ensure quality and credibility. These expert(s) must conduct their peer review impartially, objectively, and without conflicts of interest. Each reviewer must also be independent from the development of the science, without influence from any position that the agency or constituent groups may have. Furthermore, the Office of Management and Budget (OMB), authorized by the Information Quality Act, requires all federal agencies to conduct peer reviews of highly influential and controversial science before dissemination, and that peer reviewers must be deemed qualified based on the OMB Peer Review Bulletin standards.
(http://www.cio.noaa.gov/services_programs/pdfs/OMB_Peer_Review_Bulletin_m05-03.pdf).
Further information on the CIE program may be obtained from www.ciereviews.org.

Scope

The CIE reviewers will serve on a Stock Assessment Review (STAR) Panel and will be expected to participate in the review of Pacific sardine stock assessment. The Pacific sardine stock is assessed regularly (currently, every 1-2 years) by SWFSC scientists, and the Pacific Fishery Management Council (PFMC) uses the resulting biomass estimate to establish an annual harvest guideline (quota). The stock assessment data and model are formally reviewed by a Stock Assessment Review (STAR) Panel once every three years, with a coastal pelagic species subcommittee of the SSC reviewing updates in interim years. Independent peer review is required by the PFMC review process. The STAR Panel will review draft stock assessment documents and any other pertinent information for Pacific sardine, work with the stock assessment teams to make necessary revisions, and produce a STAR Panel report for use by the PFMC and other interested persons for developing management recommendations for the fishery. The PFMC's Terms of Reference (ToRs) for the STAR Panel review are attached in Appendix 1. The tentative agenda of the Panel review meeting is attached in Appendix 2. Finally, a Panel summary report template is attached as Appendix 3.

Requirements

Two CIE reviewers shall participate during a panel review meeting in La Jolla, California during 21-24 February, and shall conduct impartial and independent peer review accordance with the SoW and ToRs herein. The CIE reviewers shall have the expertise as listed in the following descending order of importance:

- The CIE reviewer shall have expertise in the design and execution of fishery-independent surveys for use in stock assessments, preferably with coastal pelagic fishes.
- The CIE reviewer shall have expertise in the application of fish stock assessment methods, particularly, length/age-structured modeling approaches, e.g., ‘forward-simulation’ models (such as Stock Synthesis, SS) and it is desirable to have familiarity in ‘backward-simulation’ models (such as Virtual Population Analysis, VPA).
- The CIE reviewer shall have expertise in the life history strategies and population dynamics of coastal pelagic fishes.
- It is desirable for the CIE reviewer to be familiar with the design and application of fisheries underwater acoustic technology to estimate fish abundance for stock assessment.
- It is desirable for the CIE reviewer to be familiar with the design and application of aerial surveys to estimate fish abundance for stock assessment.

The CIE reviewer's duties shall not exceed a maximum of 14 days to complete all work tasks of the peer review process.

Tasks for reviewers

- Review the following background materials and reports prior to the review meeting: *Two weeks before the peer review, the NMFS Project Contact will send by electronic mail or make available at an FTP site to the CIE reviewers all necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE on where to send documents. The CIE reviewers shall read all documents in preparation for the peer review, for example:*

- *Recent stock assessment documents since 2013;*
    - *STAR Panel- and SSC-related documents pertaining to reviews of past assessments;*
    - *CIE-related summary reports pertaining to past assessments; and*
    - *Miscellaneous documents, such as ToR, logistical considerations.*

Pre-review documents will be provided up to two weeks before the peer review. Any delays in submission of pre-review documents for the CIE peer review will result in delays with the CIE peer review process, including a SoW modification to the schedule of milestones and deliverables. Furthermore, the CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein.

- Attend and participate in the panel review meeting • The meeting will consist of presentations by NOAA and other scientists, stock assessment authors and others to facilitate the review, to provide any additional information required by the reviewers, and to answer any questions from reviewers

    - After the review meeting, reviewers shall conduct an independent peer review in accordance with the requirements specified in this SOW, OMB guidelines, and TORs, in adherence with the required formatting and content guidelines; reviewers are not required to reach a consensus
- Each reviewer may assist the Chair of the meeting with contributions to the summary report, if required by the TORs
- Deliver their reports to the Government according to the specified milestone dates

Foreign National Security Clearance

When reviewers participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign

National Security Clearance approval for reviewers who are non-US citizens. For this reason, the reviewers shall provide requested information (e.g., first and last name, contact information, gender, birth date, passport number, country of passport, travel dates, country of citizenship, country of current residence, and home country) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/ and http://deemedexports.noaa.gov/compliance_access_control_procedures/noaa-foreign-national-registration- system.html. The contractor is required to use all appropriate methods to safeguard Personally Identifiable Information (PII).

Place of Performance

The place of performance shall be at the contractor's facilities, and at the Southwest Fisheries Science Center in La Jolla, California.

Period of Performance

The period of performance shall be from the time of award through April 30, 2017. Each reviewer's duties shall not exceed 14 days to complete all required tasks.

Schedule of Milestones and Deliverables

The contractor shall complete the tasks and deliverables in accordance with the following schedule.

No later than January 24, 2017	CIE sends reviewers contact information to the COTR, who then sends this to the NMFS Project Contact
No later than February 7, 2017	NMFS Project Contact sends the CIE Reviewers the pre-review documents
February 21-24, 2017	The reviewers participate and conduct an independent peer review during the panel review meeting
March 10, 2017	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
March 31, 2017	CIE submits CIE independent peer review reports to the COTR
April 7, 2017	The COTR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Applicable Performance Standards

The acceptance of the contract deliverables shall be based on three performance standards:
(1) The reports shall be completed in accordance with the required formatting and content (2) The reports shall address each TOR as specified (3) The reports shall be delivered as specified in the schedule of milestones and deliverables.

Travel

All travel expenses shall be reimbursable in accordance with Federal Travel Regulations (http://www.gsa.gov/portal/content/104790). International travel is authorized for this contract. Travel is not to exceed $10,000.

Restricted or Limited Use of Data

The contractors may be required to sign and adhere to a non-disclosure agreement.

Annex I: Review Panel Agenda

Revised AGENDA

2017 Pacific Sardine Stock Assessment Review

Southwest Fisheries Science Center
8901 La Jolla Shores Dr., La Jolla, CA 92037
La Jolla, CA 92037
858-334-2800

This is a public meeting, and time for public comment may be provided at the discretion of the meeting Chair. This is a work session for the primary purpose of reviewing the current Pacific sardine stock assessment, under the Pacific Fishery Management Council's (Council) terms of reference for the CPS stock assessment reviews. The Stock Assessment Review Panel will review the assessment and produce a report to the full SSC, in advance of the April 2017 Council meeting in Sacramento, California. The assessment will be used for setting sardine harvest specifications and management measures for the July 1, 2017 – June 30, 2018 fishery.

TUESDAY, FEBRUARY 21, 2017 – 10 A.M.

A. Call to Order, Introductions, Approval of Agenda — André Punt, Chair
(10 a.m., 15 minutes)

B. Terms of Reference for CPS Stock Assessment Review Process — Kerry Griffin
(10:15 a.m., 15 minutes)

C. Pacific Sardine Stock Assessment Team Presentation Overview — Paul Crone, Kevin Hill
(10:30 a.m., 15 minutes)

D. Acoustic-Trawl Survey — Juan Zwolinski
(10:45 a.m., 45 minutes)

E. Pacific Sardine Stock Assessment Team Presentation — Kevin Hill, Paul Crone
(11:30 p.m., 1 hour 30 minutes)

LUNCH
(1 p.m. – 3p.m., 2 hours)

NOTE: The Pacific Room is needed for another purpose from 1 p.m. until 3 p.m. The STAR Panel and attendees can move to Stenella Meeting room during this time.

E. Pacific Sardine Stock Assessment Team Presentation (continued if needed) Kevin Hill
(3:00 p.m., 30 minutes) Paul Crone

F. Discussion and Requests Panel
(3:30 p.m., 1 hour 30 minutes)

WEDNESDAY FEBRUARY 22, 2017

G. Work Session – STAT and STAR Panel All
(8 a.m., 2 hours)

H. Public Comment
(10 a.m., 0.5 hours)

I. Response to Requests Kevin Hill
(10:30 a.m., 1.5 hours)

LUNCH

J. Initial Report Writing and STAT Work Session Panel
(1 p.m., 2.5 hours)

K. Discussion and Requests Panel
(3:30 p.m., 1 hour)

L. Public Comment André Punt
(4:30 p.m., 0.5 hours)

THURSDAY FEBRUARY 23, 2017

M. Response to Requests Kevin Hill
(8 a.m., 2 hours)

BREAK

N. Discussion and Requests Panel
(10:30 a.m., 1.5 hours)

LUNCH

O. Response to Requests Kevin Hill
(1 p.m., 1 hour)

P. Public Comment
(2 p.m., 0.5 hours)

BREAK

Q. Report Writing and STAT Work Session
(3 p.m., 2 hours)

FRIDAY FEBRUARY 24, 2017

R. Response to Comments (If Necessary) — Kevin Hill
(8 a.m., 1 hour)

S. Discussion – Next Steps and Deadlines — André Punt
(9 a.m., 1 hour) — Kerry Griffin

BREAK

T. Finalize Report Assignments — André Punt
(10:30 a.m., 1.5 hours)

U. Work Session as Necessary and Meeting Wrap Up — André Punt
(12:00 p.m.)

ADJOURN

Appendix III: List of Participants

STAR Panel Members:
André Punt (Chair), Scientific and Statistical Committee (SSC), Univ. of Washington
Will Satterthwaite, SSC, Southwest Fisheries Science Center
Evelyn Brown, SSC, Lummi Natural Resources, LIBC
Jon Vølstad, Center for Independent Experts (CIE)
Gary Melvin, Center for Independent Experts (CIE)

Pacific Fishery Management Council (Council) Representatives:
Kerry Griffin, Council Staff
Diane Pleschner-Steele, CPSAS Advisor to STAR Panel
Lorna Wargo, CPSMT Advisor to STAR Panel

Pacific Sardine Stock Assessment Team:
Kevin Hill, NOAA / SWFSC
Paul Crone, NOAA / SWFSC
Juan Zwolinski, NOAA / SWFSC

Other Attendees
Dale Sweetnam, SWFSC
Alan Sarich, CPSMT/Quinault Indian Nation
Emmanis Dorval, SWFSC
Chelsea Protasio, CPSMT/CDFW
Kirk Lynn, CPSMT/CDFW
Ed Weber, SWFSC
Josh Lindsay, NMFS WCR
Erin Kincaid, Oceana
Al Carter, Ocean Gold
Jason Dunn, Everingham Bros Bait
Nick Jurlin, F/V Eileen
Neil Guglielmo, F/V Trionfo
Andrew Richards, Commercial
Hui-Hua Lee, SWFSC
Bev Macewicz, SWFSC
Chenying Gao, Student
Steven Teo, SWFSC
Kevin Piner, SWFSC
Andy Blair, Commercial
Jamie Ashley, F/V Provider
John Budrick, CDFW
Steve Crooke, CPSAS
Gilly Lyons, Pew Trusts

Agenda Item G.5.b
Supplemental SSC Report
April, 2017

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON FINAL ACTION ON SARDINE ASSESSMENT, SPECIFICATIONS, AND MANAGEMENT MEASURES

The Scientific and Statistical Committee (SSC) reviewed the 2017 stock assessment of the northern subpopulation of Pacific sardine. Drs. Kevin Hill and Paul Crone (Southwest Fisheries Science Center) presented the results of the stock assessment and Dr. André Punt (SSC) provided an overview of the Stock Assessment Review (STAR) Panel report. The SSC appreciates the effort put forth by the stock assessment team to improve the assessment model in response to previous full and update assessment concerns.

The SSC endorses the 2017 Pacific sardine base case assessment model (termed model ALT in the assessment document) as the best available science for use in managing the northern subpopulation of Pacific sardine. The base case model uses an integrated assessment approach to estimate age-1+ biomass at the start of the 2017/2018 fishing year (July 1, 2017). This model is more stable, shows improved fit to recent surveys, and has improved retrospective patterns and thus is an improvement over the 2014 full assessment model and subsequent update assessments. Major differences include starting the assessment in 2005 rather than 1993, excluding the Daily Egg Production Method and Total Egg Production indices, and changing model specifications for natural mortality, weight-at-age, survey selectivity, catchability, and steepness of the stock-recruitment relationship.

There is no direct information on the size of the 2016 year-class, so it is estimated from the stock-recruitment relationship. As a result, there is considerable uncertainty associated with the estimate of age-1+ biomass in 2017. A substantial proportion of total biomass will be from that incoming cohort of uncertain size, especially when the stock size is estimated to be low, as it is presently. There are additional key uncertainties associated with natural mortality, weight-at-age, survey selectivity, and catchability.

The estimate for total age-1+ biomass on July 1, 2017, is 86,586 mt. The SSC recommends an overfishing limit (OFL) of 16,957 mt and that the base model be considered a category 1 assessment with a default sigma (σ) of 0.36 to be used in determining the acceptable biological catch.

The SSC reiterates that the assessment and OFL are only for the northern subpopulation of Pacific sardine, although some portion of the U.S. catch in each year is likely from the southern subpopulation.

There may be benefits to the survey-based approach advocated by the stock assessment team, and the planned early 2018 review of this survey could provide further information on the suitability of this approach. There would be less uncertainty in the calculation of the OFL when using a survey-based approach if the time-lag between conducting the survey and the start of the fishing year was minimized. Further evaluation of a survey-based assessment approach through a management strategy evaluation would be beneficial.

PFMC
04/08/17

COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON FINAL ACTION ON SARDINE ASSESSMENT, SPECIFICATIONS, AND MANAGEMENT MEASURES

The Coastal Pelagic Species Management Team (CPSMT), Coastal Pelagic Species Advisory Subpanel (CPSAS) and Scientific and Statistical Committee (SSC) jointly received a presentation from Drs. Kevin Hill and Paul Crone concerning the Pacific sardine full stock assessment conducted in 2017. The CPSMT recommends that the Pacific Fishery Management Council (Council) adopt the Alternative Stock Assessment (ALT) model within the full assessment for management of the 2017-2018 sardine fishery (Agenda Item G.5.a, Stock Assessment Report). The age 1^+ biomass estimated from this assessment for July 1, 2017 is 86,586 metric tons (mt).

Similar to the 2016-2017 biomass estimate of 106,137 mt, the 2017-2018 biomass estimate of 86,586 mt is below the CUTOFF value of 150,000 mt. Accordingly, the Fishery Management Plan dictates a closure of the primary directed fishery for Pacific sardine for the upcoming fishing year (July 1, 2017 - June 30, 2018). This closure, however, does not preclude the allowance for incidental catch in other CPS and non-CPS fisheries as well as directed live bait, recreational and tribal harvest fisheries.

Harvest Specifications for 2017-2018
Table 1 (below) contains the overfishing limit (OFL) and a range of acceptable biological catch (ABC) values based on various P* (probability of overfishing) values. The CPSMT recommends use of a P* value of 0.40, consistent with previous sardine management specifications. The SSC designated the 2017 assessment as a Tier 1. The P* value of 0.40 applied to the 2016-2017 OFL of 16,957 mt, using a Tier 1 sigma of 0.36, produces an acceptable biological catch (ABC) of 15,479 mt.

During the 2015-2016 fishing season, the CPSMT evaluated the potential needs for incidental allowances for other CPS fisheries when the primary directed sardine season is closed (April 2015 Agenda item G.1.b, Supplemental CPSMT Report). That evaluation considered the historical levels of incidental sardine catch under a range of species and fishery dynamics. Consistent with that evaluation, the CPSMT again recommends an annual catch limit (ACL) of 8,000 mt (Table 2) to allow other fisheries to proceed. The CPSMT also recommends the same accountability measures as 2016-2017, presented following Table 2.

The Quinault Indian Nation request of 800 mt, the live bait fishery, and other minimal sources of mortality, such as recreational take, will be accounted for against the ACL. Coastwide incidental non-tribal landings for the 2016-2017 season through March 30, 2017 total 358 mt, while the Quinault Indian Nation reports 85 mt.

Table 1. Pacific sardine harvest formula parameters for 2017-2018.

Harvest Control Rule Formulas									
OFL = BIOMASS * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
$ABC_{P\text{-}star}$ = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION; where FRACTION is E_{MSY} bounded 0.05 to 0.20									
Harvest Formula Parameters									
BIOMASS (ages 1+, mt)	86,586								
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
ABC $Buffer_{Tier 1}$	0.95577	0.91283	0.87048	0.82797	0.78442	0.73861	0.68859	0.63043	0.55314
ABC $Buffer_{Tier 2}$	0.91350	0.83326	0.75773	0.68553	0.61531	0.54555	0.47415	0.39744	0.30596
CalCOFI SST (2014-2016)	15.9999								
E_{MSY}	0.225104								
FRACTION	0.200000								
CUTOFF (mt)	150,000								
DISTRIBUTION (U.S.)	0.87								
Harvest Control Rule Values (MT)									
OFL =	**16,957**								
$ABC_{Tier 1}$ =	16,207	15,479	14,761	14,040	13,301	12,525	11,676	10,690	9,380
$ABC_{Tier 2}$ =	15,490	14,130	12,849	11,625	10,434	9,251	8,040	6,739	5,188
HG =	**0**								

Table 2. 2017-2018 Calculated OFL, ABC and CPSMT-Recommended ACL.

Biomass	86,586 mt
OFL	16,957 mt
P* buffer	0.4
$ABC_{0.4}$	15,479 mt
ACL	8,000 mt

List of CPSMT-Recommended Accountability Measures

The following would be automatic in season actions for CPS fisheries:

- An incidental per landing allowance of 40 percent Pacific sardine in non-treaty CPS fisheries until a total of 2,000 mt of Pacific sardine are landed.
- When the 2,000 mt is achieved the incidental per landing allowance would be reduced to 20 percent until a total of 5,000 mt of Pacific sardine have been landed.
- When 5,000 mt have been landed, the incidental per landing allowance would be reduced to 10 percent for the remainder of the 2017-2018 fishing year.

A 2 mt incidental per landing allowance in non-CPS fisheries.

PFMC
04/09/17

COASTAL PELAGIC SPECIES ADVISORY SUBPANEL REPORT ON FINAL ACTION ON SARDINE ASSESSMENT, SPECIFICATIONS, AND MANAGEMENT MEASURES

The Coastal Pelagic Species Advisory Subpanel (CPSAS) heard a presentation by Dr. Kevin Hill on the Assessment of the Pacific Sardine Resource in 2017 for U.S. Management in 2017-18 (Agenda Item G.5.a, Stock Assessment Report), given at the Science and Statistical Committee (SSC) meeting. CPSAS members also heard a summary review of the Pacific Sardine Stock Assessment Review (STAR) Panel Meeting Report (Agenda Item G.5.a, STAR Panel Report) by Dr. Andre Punt. CPSAS members reviewed both documents prior to the SSC meeting.

A majority of the CPSAS remains extremely frustrated that this STAR panel review found the same unresolved problems as in prior assessments. As noted in the STAR Panel Report under Unresolved Problems and Major Uncertainties (page 9), "***The core issues for stock assessments continue to be related to the temporal and spatial scale of the surveys and insufficient sample sizes of age-length for sardine in the ATM survey.***"

The STAR Panel Report expressed concerns with all the assessment approaches offered, but reviewers were asked to recommend the "least worst" option for the Council to set management measures for the 2017 sardine fishery. Model ALT turned out to be marginally better than the biomass estimated in the summer Acoustic Trawl Method (ATM) survey proposed by the Stock Assessment Team (STAT). Following discussion, the SSC ultimately approved this approach for 2017, recognizing this as the basis for two years of update assessments before the next full assessment review.

A majority of the CPSAS ask the Council to heed fishermen who are reporting a large biomass of sardines (as well as anchovy) in waters inshore of the current ATM survey area. We agree with the concerns expressed in the CPSAS representative's statement in the STAR Panel Report. Quoting from that statement: *"ATM surveys at present do not capture fish in the upper water column, nor a large biomass of young fish (sizes 3 inches and up) that fishermen have observed in nearshore waters since late 2014; this biomass is largely inside ATM survey tracks. But the ATM survey is assigned a catchability quotient (Q) of 1 nonetheless, meaning it "sees" all the fish. The Q for Model ALT, which is based largely on ATM survey data, is estimated at 1.1, which the STAR Panel report calls into question, given for example the unquantified volume of fish in nearshore waters.*

The summer 2016 ATM survey reported a fourfold increase in age 1+ biomass, but the biomass estimate produced is substantially lower than the estimate used for management in 2016. The STAR panel found fault with the methodology used to project the 2016 biomass to 2017. So do we – but using the 2016 ATM biomass estimate without adjusting for recruitment ignores reality."

A majority of the CPSAS also express concern that stock assessments seem to be gravitating to only one independent index, ATM surveys, which measure only one point in time. In our view this is a big problem, based on the following:

- The current trawl speed (4 knots or less) likely results in under sampling larger sardines.
- The nearshore area (where young sardines are often concentrated) is not sampled.

- ATM surveys have not been able to estimate recruitment.
- Q is assumed to be 1 – and in Model ALT, Q freely estimated is 1.1, which the STAR panel questioned. Clearly, current ATM surveys do not "see" all the fish, and thus biomass estimates must be considered to be negatively biased.
- In fact, the projected biomass estimate for 2017 is lower than 2016 at a time that sardines are increasing in abundance, apparently coast-wide, but certainly in California. The STAR Panel Report attributed the reduction in biomass to a change in assessment methodology.

Nevertheless, this assessment is a recipe for disaster, and the impact is being felt coastwide. Fishermen are having a hard time finding schools of CPS with a mix of less than 40 percent sardines.

The majority of the CPSAS ask the Council to consider the following recommendations:

- Assessments should be based on more than one survey index. The 2015 and 2016 juvenile rockfish surveys were informative as evidence of recruitment and should be considered in future stock assessments.
- Please support cooperative research with industry to survey nearshore waters now missed in National Oceanic and Atmospheric Administration acoustic surveys.
- The Terms of Reference (TOR) for stock assessments should be revised to provide more flexibility, particularly in update years, to incorporate new findings and data into assessments that more accurately reflect ocean conditions. The TOR should also provide for a process to reopen a fishery based on new lines of evidence as soon as possible, rather than the current requirement to wait for the next full assessment. Without flexibility to adaptively manage dynamic CPS stocks, industry is forced to sit idle for the better part of one or two years, or even more –which may be beyond its economic tipping point.

Management Measures

The majority of the CPSAS recommends continuing the management measures approved by the Council in 2016, including:
Annual Catch Limit (ACL) 8,000 mt
Automatic in-season actions:

- An incidental per landing allowance of 40 percent Pacific sardine in non-Treaty CPS fisheries until a total of 2,000 mt of Pacific sardine are landed.
- When the 2,000 mt is achieved, the incidental per landing allowance would be reduced to 20 percent, until a total of 5,000 mt of Pacific sardine have been landed.
- When 5,000 mt have been landed, the incidental per landing allowance would be reduced to 10 percent for the remainder of the 2017-2018 fishing year.

In addition, the Council should adopt a 2 mt incidental per landing allowance in non-CPS fisheries.

Conservation representative statement:

The conservation representative of the CPSAS recommends setting incidental catch for Pacific sardine at a precautionary level that both protects the spawning stock while not unduly constraining other fisheries, including other CPS fisheries. Of an 8,000 mt ACL for the current season, approximately 1,000 mt in sardine landings have been recorded so far, suggesting that the current ACL on its own is not having a constraining effect on other fisheries. Given that the July 2017 projected biomass for Pacific sardine is lower than the estimated biomass from the past two years, and the overfishing limit and acceptable biological catch for the coming season will necessarily be reduced from the 2016-2017 specifications, the Council could consider and adopt an ACL for 2017-2018 that is commensurately reduced from last year's ACL. The conservation representative suggests that a high level of precaution is appropriate in setting incidental catch, given Pacific sardine's continued low abundance and its essential role as forage in the California Current Ecosystem. Finally, the conservation representative echoes the majority of the CPSAS's support for cooperative research to improve the capacity of acoustic surveys to survey inshore waters.

PFMC
4/10/17

Decision Summary Document
Pacific Fishery Management Council

April 7-11, 2017

Council Meeting Decision Summary Documents are highlights of significant decisions made at Council meetings. Results of agenda items that do not reach a level of highlight significance are typically not described in the Decision Summary Document. For a more detailed account of Council meeting discussions, see the Council meeting record and voting logs or the Council newsletter.

Habitat

Current Habitat Issues

The Council directed staff to communicate with the Federal Energy Regulatory Commission and California Department of Water Resources to express Council concerns about thermal regulation at Oroville Dam, to ask for clarity on specific issues related to those concerns, and to invite representatives of the two agencies to present to the Council and/or Habitat Committee (HC) in June. The Council directed staff to work with California Department of Fish and Wildlife staff to identify those specific concerns. The Council may send a follow-up letter in the future.

In addition, the Council directed staff to send the HC's letter to the U.S. Army Corps of Engineers on the Permit Renewal and Expansion on the Coast Seafoods project with edits outlined in the Supplemental California Dept. of Fish and Wildlife Report and further edited by the Council.

The Council also requested both an update from the HC and a draft letter commenting on the Environmental Protection Agency's National Pollution Discharge Elimination System general permit for the June Briefing Book.

Salmon Management

Sacramento River Winter Chinook Harvest Control Rule

The Council reviewed the progress of the ad hoc Sacramento River Winter Chinook Workgroup since their last report in September 2016. The Council provided feedback on the initial analysis and is tentatively scheduled to provide preliminary recommendations for control rules at the September 2017 Council meeting and final recommendations at the November 2017 Council meeting.

Methodology Review Preliminary Topic Review

The Council supported the list of items for review submitted by the Scientific and Statistical Committee (SSC) and the Model Evaluation Workgroup (MEW) that included: 1) Complete the documentation of the development of the new Chinook Fishery Regulation Assessment Model (FRAM) base period including algorithms, and 2) review and update the FRAM documentation and User Manual that is currently on the Council website.

The Council is scheduled to adopt the final list of topics at the September Council meeting and any final methodology changes/updates at the November Council meeting.

Final Action on 2017 Salmon Management Measures

The Council adopted management measures for 2017 ocean salmon fisheries. Detailed management measures and a press release are posted on the Council's webpage.

Groundfish Management

Final Action on Electronic Monitoring of Non-whiting Midwater and Bottom Trawl Fisheries Regulations and Update on Exempted Fishing Permit (EFP)

The Council received an update on ongoing EFPs and modified several of the preferred alternatives they had adopted in September 2014 for the non-whiting midwater trawl and bottom trawl fisheries. A complete list of final alternatives is available on the Council website. The Council also directed:

- NMFS, in consultation to the Council, to develop a process that does not require rulemaking to adjust the discard species list;
- NMFS to maintain the current practice of having Pacific States Marine Fisheries Commission (PSMFC) perform video review responsibilities, but develop protocols for transferring financial responsibility for the video review from NMFS to the industry. The Council would like NMFS to examine the feasibility of using a sole provider (PSMFC) model indefinitely;
- NMFS and Council staff work with the Groundfish Electronic Monitoring Policy Advisory Committee/Technical Advisory Committee, Groundfish Management Team (GMT), and other appropriate Council advisory bodies to develop a process for reducing the level of video review to the minimum level necessary to audit logbooks, and to develop new discard mortality rates for halibut when vessels use electronic monitoring (EM); and
- Revisions to the draft regulations to include:

    1. Changes in the final preferred alternatives adopted by the Council;

    2. A requirement for self-enforcing agreement groups to submit an annual report to the Council;

    3. Deep-sea sole, sanddabs, and starry flounder in the list of species that can be discarded. Deep-sea sole and sanddabs would be counted as individual fishing quota (IFQ) species, if mixed with IFQ species; and

4. A provision to allow state-managed species to be landed when using EM, but prohibit sale or use of those fish, and include a landing limit of 150 pounds for California halibut.

Salmon Endangered Species Act (ESA) Consultation Recommendations

The Council provided guidance to NMFS on the proposed action that will be the basis for ESA section 7 consultation on the take of listed salmonids in the Pacific Coast groundfish fishery. The recommendations include:

- A description of groundfish fisheries including the likely future distribution of fishing, range of directed catch volumes, and range of Chinook salmon bycatch rates, which can be used to estimate amount and stock composition of Chinook take.
- Chinook salmon bycatch thresholds of 11,000 for the whiting fishery, 5,500 for all other groundfish fisheries, and a 3,500 reserve to be used for additional bycatch in either of the two fisheries. The sum of these three thresholds, 20,000 Chinook, equals the sum of the bycatch thresholds specified in the current biological opinion.
- Considering additional bycatch mitigation measures as part of the 2019-2020 biennial harvest specifications and management measures process.

NMFS intends to request Council recommendations on a draft incidental take statement at the September 2017 meeting, prior to completing the biological opinion.

Trawl Catch Shares and Intersector Allocation Progress Reports and Cost Recovery Report

Catch Share Program Review: Review document will be made available as early as possible to facilitate public review.

Intersector Allocation Review: The Council identified issues requiring additional information and proposed a process involving a public review draft adopted at the June Council meeting and final action taken in the fall. The Council directed that the next draft of the intersector allocation review document:

- address the recommendations in the GMT report and the GAP report;
- include approaches for addressing the sablefish management line and related allocation issues;
- focus on set-asides in the non-trawl sectors for a select number of the species identified as trawl-dominant (i.e., darkblotched rockfish, Pacific ocean perch, petrale sole, and longspine thornyhead north of 40º 10’ N. latitude);
- evaluate species that may be constraining the non-trawl fishery while not being fully attained in the trawl fishery (e.g., lingcod south of 40º 10’ N. latitude); and,
- discontinue development of the yellowtail rockfish cap issue.

C**ost Recovery**: Council and NMFS staff will meet to discuss ways to address transparency concerns such as those raised by the GAP report.

Groundfish Non-Salmon Endangered Species Workgroup Report

The Groundfish Endangered Species Workgroup (Workgroup) reports to the Council biennially on estimated bycatch of Endangered Species Act- (ESA) listed marine mammals, sea turtles, eulachon, green sturgeon, and seabirds subject to a 2013 biological opinion on the continued operation of the Pacific Coast groundfish fishery. The Workgroup found that recent take of subject species did not warrant consideration of additional mitigation measures by the Council. The Workgroup noted that new biological opinions will be completed in 2017 for eulachon and short-tailed albatross. Based on the Workgroup Report, the Council made the following recommendations:

- Conduct a risk analysis of humpback whale takes in the groundfish fixed gear fishery and work with the fleet to reduce the risk of such takes;
- GMT work with NMFS to better estimate eulachon take in the groundfish fishery;
- Complete the new seabird biological opinion and report to the Council at the June or September 2017 meeting to allow development of additional mitigation measures, as appropriate, through the 2019-2020 groundfish biennial harvest specifications and management measures process; and,
- Facilitate greater engagement by industry representatives in future Workgroup meetings.

Final Action on Inseason Adjustments

The Council recommended increasing the open access fixed gear trip limits for sablefish north of 36° N. latitude limits to 300 pounds per day, or one landing per week of up to 1,000 pounds, not to exceed 2,000 pounds per two months because effort and landings are tracking behind recent years.

Klamath Chinook salmon, a bycatch species in the groundfish trawl fisheries, will not meet escapement goals for 2017 by a historically large margin. The Council recommended the whiting fleet voluntarily move north to avoid Chinook salmon, recognizing there could be increased interactions with Pacific ocean perch (POP), especially given the historically high whiting quotas. Therefore, the Council also recommended that NMFS reallocate 3.5 mt of POP from the incidental open access off-the-top deduction to the mothership sector and 3.5 mt to the catcher-processor sector as soon as possible.

The Council also directed the GMT to develop alternatives for potentially distributing the POP, darkblotched, and canary rockfish buffers later in the year and report back at the June Council meeting in Spokane, Washington.

Updated Coordinates for the 125 Fathom (fm) Rockfish Conservation Area Line in California

The Council adopted revised coordinates for the 125 fm line at Usal and Noyo canyons in California for public review, as shown in Table 1 of the CDFW Report. These modifications are intended to provide access to canyons that were previously open when the 150 fm line was in effect (2003-2016). The Council is scheduled to take final action on the updated coordinates at the June 2017 Council meeting. The modifications for Delgada, Point Ano Nuevo, Cordell Banks contained in the CDFW Report and any other proposed modifications will be forwarded for consideration in the 2019-2020 harvest specifications and management measures process at the September 2017 Council meeting.

Sablefish Electronic Ticket Reporting Requirements

The Council directed its Enforcement Consultants and Groundfish Advisory Subpanel to meet together at the June Council meeting, discuss non-regulatory possibilities for resolving concerns about the 24-hour reporting requirement associated with electronic fish tickets, and report to the Council.

Coastal Pelagic Species Management

Central Subpopulation of Northern Anchovy (CSNA) Overfishing Limit (OFL) Process

The SSC will further review methods for developing an OFL for the central subpopulation of northern anchovy, evaluate the results of the January 2018 acoustic-trawl survey methodology review as it could apply to anchovy biomass and F_{msy} estimates, and report to the Council in April 2018.

Methodology Review Planning

The Council approved a proposed methodology review of the SWFSC's acoustic-trawl survey, tentatively scheduled for January 2018, and directed that the review address recommendations included in the SSC report. The Council will consider a proposed Terms of Reference for the review at its September 2017 meeting.

Small-Scale Fishery Management Final Action

The Council adopted Coastal Pelagic Species (CPS) Fishery Management Plan Amendment 26 allowing for small-scale directed fishing on CPS finfish stocks that are otherwise closed to directed fishing. The amendment will allow for landings up to one metric ton per day, with a limit of one trip per day. The Coastal Pelagic Species Management Team will provide an update on the small-scale fishery at its April 2018 meeting.

Final Action on Sardine Assessment, Specifications, and Management Measures

The Council adopted the 2017 sardine stock assessment report and the following harvest specifications and management measures, as described in the Supplemental CPSMT Report:

Biomass	**86,586 mt**
OFL	**16,957 mt**
P* buffer	**0.4**
$ABC_{0.4}$	**15,479 mt**
ACL	**8,000 mt**

They adopted the following automatic inseason actions for CPS fisheries:

- An incidental per-landing allowance of 40 percent Pacific sardine in non-treaty CPS fisheries until a total of 2,000 mt of Pacific sardine are landed.
- When the 2,000 mt is achieved, the incidental per-landing allowance would be reduced to 20 percent until a total of 5,000 mt of Pacific sardine have been landed.
- When 5,000 mt have been landed, the incidental per-landing allowance would be reduced to 10 percent for the remainder of the 2017-2018 fishing year.

The Council also adopted a 2 mt incidental per-landing allowance in non-CPS fisheries, and acknowledged a letter from the Quinault Indian Nation stating their intent to harvest up to 800 mt of sardine. Tribal landings would be accounted for within the ACL.

Pacific Halibut Management

Final Incidental Landing Restrictions for the 2017-2018 Salmon Troll Fishery

The Council adopted final incidental landing restrictions May 1, 2017 through December 31, 2017 and April 1-30, 2018 as follows: license holders may land no more than one Pacific halibut per two Chinook, except one Pacific halibut may be landed without meeting the ratio requirement, and no more than 35 halibut landed per trip. Limits may be modified by inseason action.

Administrative Matters

Legislative Matters

The Council approved the requested letter to Rep. Jaime Herrera-Beutler commenting on H.R. 200, the Strengthening Fishing Communities and Increasing Flexibility in Fisheries Management Act (a Magnuson-Stevens Act reauthorization bill) with minor edits.

Membership Appointments and Council Operating Procedures

The Council adopted revisions to Council Operating Procedure (COP) 1 regarding the submission of supplemental written public comments at Council meetings and COP 20 regarding the deadline for submission of exempted fishing permits for Highly Migratory Species.

Additionally, the Council is currently soliciting nominations for a vacant California seat on the Ecosystem Advisory Subpanel. The deadline for submitting nominations is May 11, 2017. See the Council web page for further information.

PFMC
04/17/17
11:31 AM

18 Ocean pout

Susan Wigley

This assessment of the ocean pout (Zoarces americanus) stock is an operational assessment of the 2015 operational assessment (NEFSC 2015). Based on the 2015 assessment, the stock was overfished but overfishing was not occurring. This assessment updates commercial fishery catch data, research survey indices and the exploitation ratios through 2016. There are no stock projections.

State of Stock: Based on the current assessment, the ocean pout (*Zoarces americanus*) stock is overfished and overfishing is not occurring (Figures 86-87). Retrospective adjustments were not made to the model results. Biomass proxy (B) in 2016 was estimated to be 0.223 (kg/tow) which is 5% of the biomass target (B_{MSY} *proxy* = 4.94; Figure 86). The 2016 fully selected fishing mortality was estimated to be 0.221 which is 29% of the overfishing threshold proxy (F_{MSY} *proxy* = 0.76; Figure 87).

Table 52: Catch and model results table for ocean pout. Catch weights are in (mt), survey biomass is in (kg/tow), and the relative exploitation ratio is the total catch / NEFSC 3 year average spring biomass index. Model results are from the current updated index assessment. Note: A 2014 landings database correction was made.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Data										
US Commercial discards	164	118	165	125	76	94	68	74	63	49
US Commercial landings	4	7	3	0	0	0	0	0	0	0
Other landings	0	0	0	0	0	0	0	0	0	0
Catch for Assessment	167	126	168	126	77	90	68	74	63	49
Model Results										
NEFSC 3 yr average Spring Survey	0.475	0.513	0.479	0.44	0.343	0.298	0.357	0.29	0.317	0.223
Relative Exploitation Ratio	0.352	0.245	0.35	0.286	0.224	0.302	0.191	0.256	0.197	0.221

Table 53: Comparison of reference points estimated in an earlier assessment and from the current updated assessment. For ocean pout, median NEFSC 3 year average Spring survey biomass and median exploitation ratio during 1977-1985 are used as B_{MSY} and F_{MSY} proxies, respectively.

	2015	2017
F_{MSY} *proxy*	0.76	0.76
B_{MSY} *proxy* (kg/tow)	4.94	4.94
MSY (mt)	3,754	3,754
Overfishing	No	No
Overfished	Yes	Yes

Projections: The index-based assessment approach does not support catch projections; catch advice for ocean pout has been based on the target exploitation rate and the most recent centered 3-year average biomass index from the NEFSC spring survey.

Special Comments:

- What are the most important sources of uncertainty in this stock assessment? Explain, and describe qualitatively how they affect the assessment results (such as estimates of biomass, F, recruitment, and population projections).
  An important source of uncertainty is the stock has not responded to low catch as expected.

- Does this assessment model have a retrospective pattern? If so, is the pattern minor or major? (A major retrospective pattern occurs when the adjusted SSB or F_{Full} lies outside of the approximate joint confidence region for SSB and F_{Full}; see Table 8).
  The model used to estimate status of this stock does not allow estimation of a retrospective pattern.

- Based on this stock assessment, are population projections well determined or uncertain? If this stock is in a rebuilding plan, how do the projections compare to the rebuilding schedule?
  N/A

- Describe any changes that were made to the current stock assessment, beyond incorporating additional years of data and the effect these changes had in the assessment and stock status.
  A database correction was made to the 2014 ocean pout landings. This change had a negligible effect on the assessment. Recreational landings were updated and were found to be negligible (time series average of recreational landings to total catch was less than 1%) and therefore not included in this assessment.

- If the stock status has changed a lot since the previous assessment, explain why this occurred.
  Ocean pout stock status has not changed since the previous assessment.

- Provide qualitative statements describing the condition of the stock that relate to stock status.
  Discards comprise most of the catch since the no possession regulation was implemented in May 2010. The NEFSC survey indices remain at near-record low levels; there are few large fish in the population. The ocean pout stock remains in poor condition.

- Indicate what data or studies are currently lacking and which would be needed most to improve this stock assessment in the future.
  The ocean pout assessment could be improved with studies that explore why this stock is not rebuilding as expected.

- Are there other important comments?
  Biological reference points are based on catch; the estimated discards used in the catch are based on a mix of direct (1989 onward) and indirect (1988 and back) methods. The catch

used to determine MSY is based on indirect methods. Minimum estimates of scientific research removals of ocean pout ranged between 0.2 and 24.9 mt, with an average of 3 mt between 1963 and 2016. The NEFSC bottom trawl surveys, Massachusetts Division of Marine Fisheries inshore surveys, Atlantic States Marine Fisheries Commission summer shrimp surveys, and various Cooperative Research surveys (e.g., such as Industry-based surveys for cod and for yellowtail flounder) and gear studies have contributed to scientific research removals.

18.1 Reviewer Comments: Ocean pout

Assessment Recommendation:

The panel concluded that the operational assessment was acceptable as a scientific basis for management advice.

Alternative Assessment Approach:

Not applicable

Status Recommendation:

Based on the operational assessment, the panel agrees with the conclusion that the ocean pout stock is overfished and overfishing is not occurring. Discards comprise most of the catch since the no possession regulation was implemented in May 2010. The National Marine Fisheries Service survey indices remain at near-record low levels, and there are few large fish in the population. The ocean pout stock remains in poor condition.

Key Sources of Uncertainty:

An important source of uncertainty is that the stock size has not increased as a result of catch reductions. The majority of catch is comprised of discards, which are estimated using both direct and indirect methods. There are questions over whether the current perspective of the stock is due to environmental drivers influencing stock abundance.

Research Needs:

The ocean pout assessment could be improved with studies that explore why this stock is not rebuilding, in particular an exploration of whether fishing mortality, biological dynamics, or environmental drivers may be causing this issue.

References:

Northeast Fisheries Science Center. 2015. Operational Assessment of 20 Northeast Groundfish Stocks,Updated Through 2014. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 15-24; 251 p. CRD15-24

Northeast Fisheries Science Center. 2012. Assessment or Data Updates of 13 Northeast Groundfish Stocks through 2010. US Dep Commer, NOAA Fisheries, Northeast Fish Sci Cent Ref Doc. 12-06; 789 p. CRD12-06

Northeast Fisheries Science Center. 2008. Assessment of 19 Northeast Groundfish Stocks through 2007: Report of the 3^{rd} Groundfish Assessment Review Meeting (GARM III), Northeast Fisheries Science Center, Woods Hole, Massachusetts, August 4-8, 2008. US Dep Commer, NOAA Fisheries, Northeast Fish Sci Cent Ref Doc. 08-15; 884 p + xvii. CRD08-15

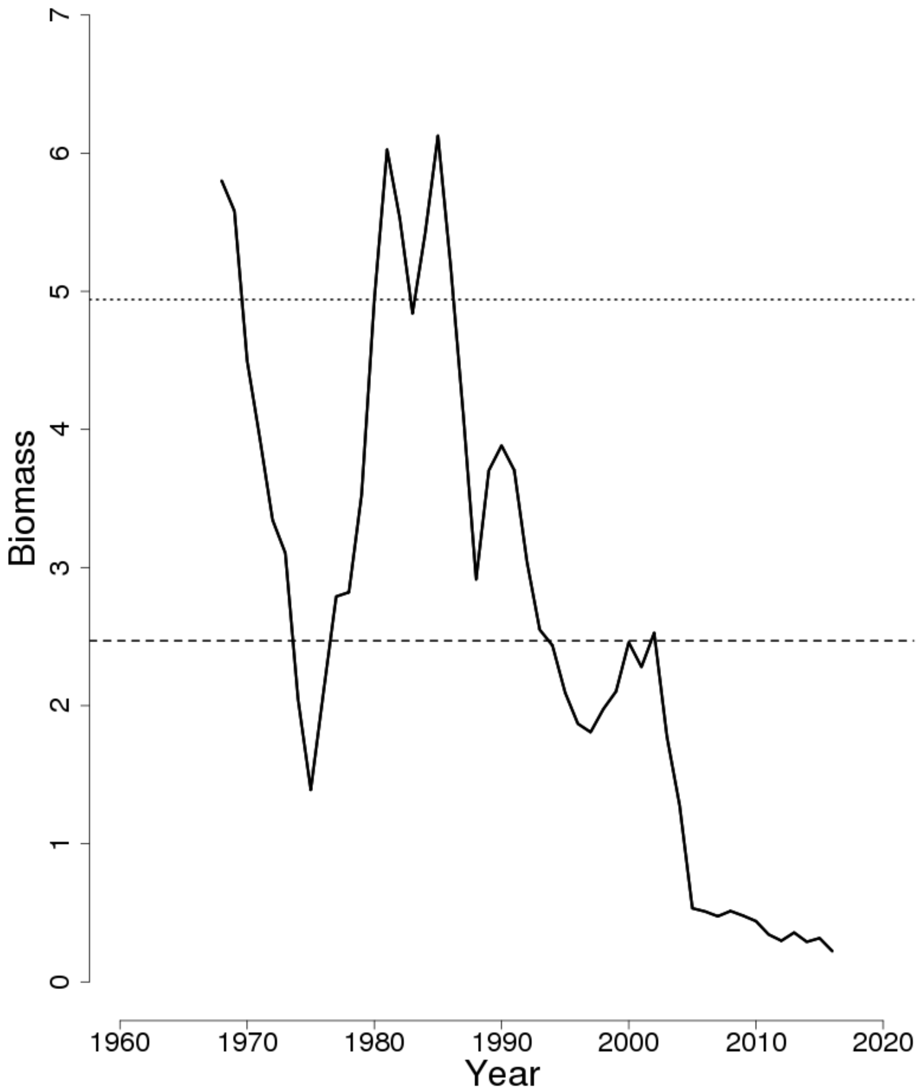

Figure 86: Trends in biomass (kg/tow) of ocean pout between 1968 and 2016 from the current (solid line) and previous (dashed line) assessment, and the corresponding $B_{Threshold}$ ($\frac{1}{2}$ B_{MSY} *proxy*; horizontal dashed line) as well as B_{Target} (B_{MSY} *proxy*; horizontal dotted line) based on the current assessment.

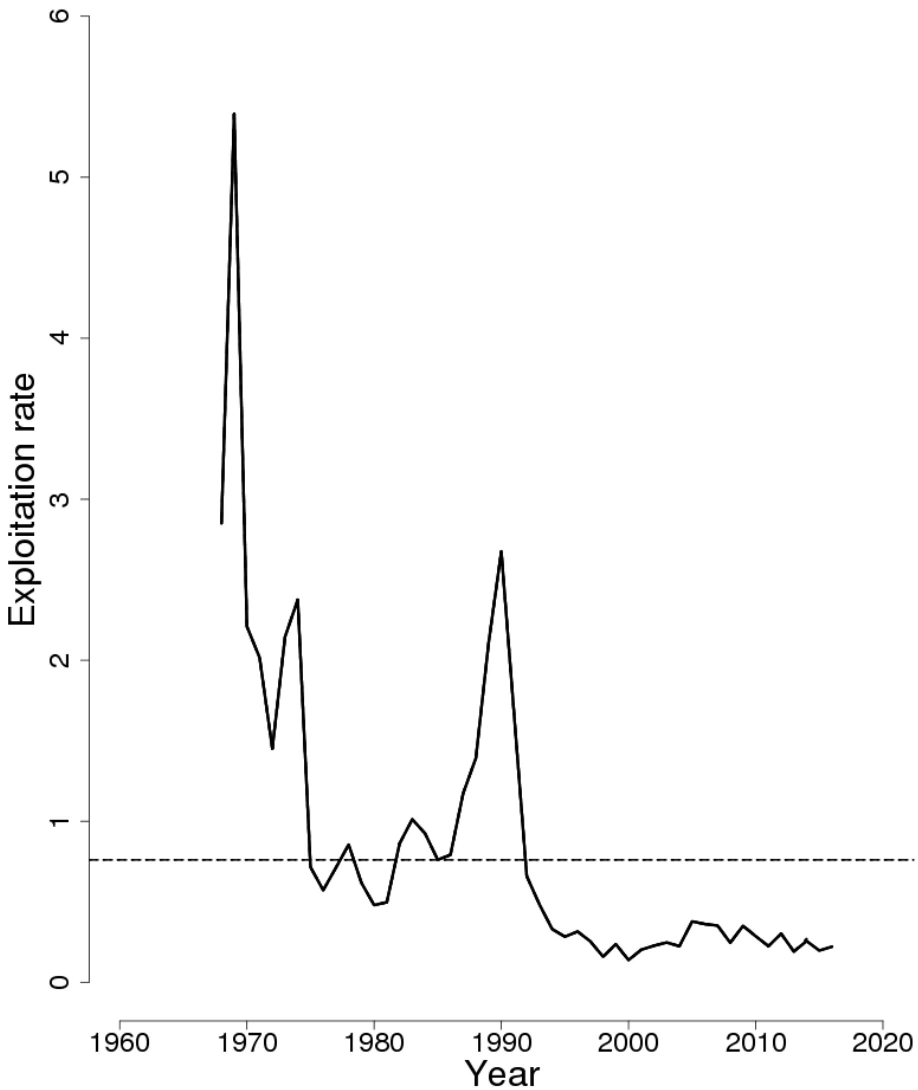

Figure 87: Trends in the exploitation rate of ocean pout between 1968 and 2016 from the current (solid line) and previous (dashed line) assessment and the corresponding $F_{Threshold}$ (F_{MSY} *proxy*=0.76; horizontal dashed line) based on the current assessment.

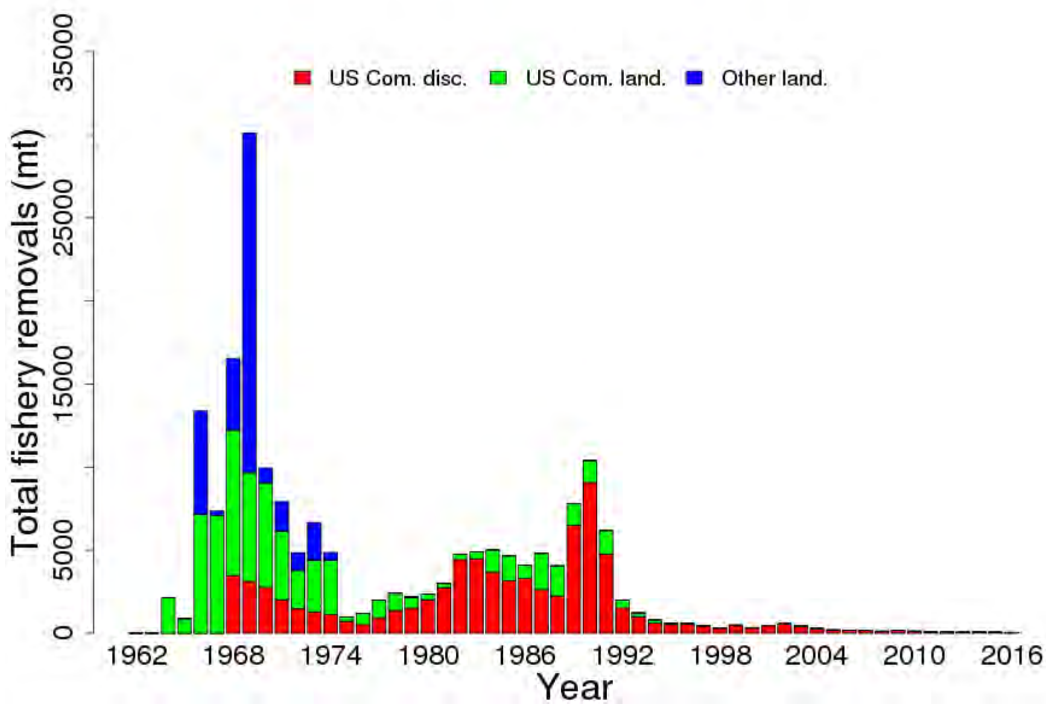

Figure 88: Total catch of ocean pout between 1968 and 2016 by fleet (US and Other) and disposition (landings and discards).

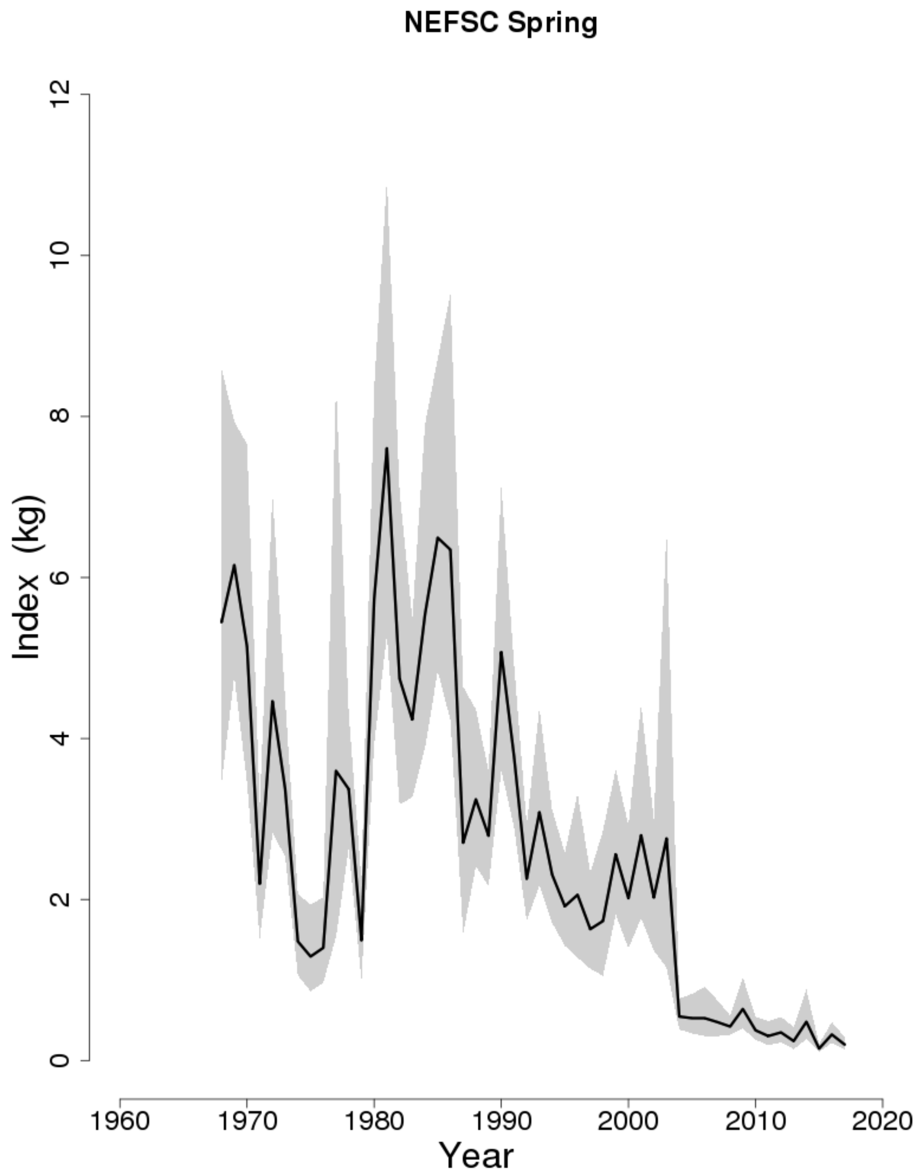

Figure 89: Indices of biomass (kg/tow) for ocean pout between 1968 and 2017 for the Northeast Fisheries Science Center (NEFSC) spring survey. The approximate 90% lognormal confidence intervals are shown.

Northeast Fisheries Science Center Reference Document 09-02a

The Northeast Data Poor Stocks Working Group Report

December 8-12, 2008 Meeting

Part A. Skate species complex, deep sea red crab, Atlantic wolffish, scup, and black sea bass

by Northeast Data Poor Stocks Working Group

NOAA's National Marine Fisheries Service, 166 Water St., Woods Hole MA 02543-1026

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

January 2009; revised July 2009

Northeast Fisheries Science Center Reference Documents

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Foreword to the NE Data Poor Stocks Report

The Northeast Regional Stock Assessment Workshop (SAW) process has three parts: preparation of stock assessments by the SAW Working Groups and/or by ASMFC Technical Committees/Assessment Committees; peer review of the assessments by a panel of outside experts who judge the adequacy of the assessment as a basis for providing scientific advice to managers; and a presentation of the results and reports to the Region's fishery management bodies. Council and Commission teams (e.g., Plan Development Teams, Monitoring and Technical Committees) formulate management advice, after an assessment has been accepted by the peer review panel.

Reports that are produced following peer review meetings typically include: an *Assessment Report* – a detailed account of the stock assessment; and the review panel report – a summary of the reviewer's opinions and recommendations. Assessment reports are available online at http://www.nefsc.noaa.gov/nefsc/publications/series/crdlist.htm. Review panel reports as well as assessment reports can be found at http://www.nefsc.noaa.gov/nefsc/saw/.

The Northeast "Data Poor Stocks" Working Group (DPWG) was formed in 2007, as part of the SAW process, to perform stock assessments of species that are difficult to assess due to lack of critical data or severe modeling problems. Monkfish was the first stock addressed by DPWG in 2007. The current report describes new work performed in 2008 by the DPWG on the NE skate species complex, deep sea red crab, Atlantic wolffish, scup, black sea bass, and weakfish. The DPWG met in October and November, 2008, and had an integrated peer review meeting during December 8-12, 2008 in Woods Hole at the Northeast Fisheries Science Center.

This Foreword contains a brief summary of the integrated peer review meeting, Terms of Reference, a list of reviewers, the December meeting agenda, and a list of meeting attendees (Tables 1-4). Maps of the Atlantic coast of the USA and Canada are also provided (Figures 1-3).

Summary of Peer Review Meeting (December 8-12, 2008):

The Working Group (DPWG) that did the analyses was comprised of NEFSC assessment scientists, and staff from NERO, NEFMC, MAFMC, and ASMFC. There was also participation by scientists from NOAA's SWFSC and SEFSC.

The Peer Review Panel examined working papers that were focused on Biological Reference Points (BRP) of Northeast skate species, deep sea red crab, Atlantic wolffish, scup, and black sea bass. The Review Panel also provided guidance for scientists to use in future weakfish assessments.

In addition to reviewing BRPs for each stock (with the exception of weakfish), the panel was asked to make a recommendation on the utility of the analyses for stock assessment. In particular the panel was asked to determine if the analyses and amount of peer review were sufficient to make a determination about stock status. If not, the panel was asked to recommend the process for further analyses and review.

The Review Panel accepted new assessment models for red crab, wolffish, scup and black sea bass. This resulted in new BRP recommendations and new estimates of those parameters. New BRPs were not recommended for the skates. However, the Panel generally advocated updating the estimates of skate biomass targets and thresholds (with the exception of Barndoor skate) to include data from recent surveys. Some changes in stock status are implied by the outcome of this peer review. The review panel report can be found at *http://www.nefsc.noaa.gov/nefsc/saw/.*

Table 1. Background and Terms of Reference for the DPWG developed by the Northeast Regional Coordinating Committee (NRCC).

Draft Terms of Reference
Data Poor Stocks Working Group
(written: 10-11-07, updated: 5-9-08**)**

Background

Data poor stocks are problematic for managers because traditional measures of status (biomass and fishing mortality) are not available. A variety of *ad hoc* metrics have been developed to address these issues but a synoptic evaluation of the problem has not been conducted in the Northeast. The term "data poor" will be used to categorize assessments limited by either data or lack of contrast in time series. Fisheries stock assessments require the integration of multiple sources of data including commercial and recreational landings, discards from multiple fleets, fishery independent survey indices, and measures of fishing effort. For some species, one or more of these data sources may not be available or have such low precision that it is not possible to use them in a conventional application within an assessment.

Objectives

1. Constitute and convene a Working Group comprising NEFSC assessment scientists, and staff from NERO, NEFMC, MAFMC, and ASMFC to:
    a. Recommend biological reference points (BRPs) and measurable BRP and maximum sustainable yield (MSY) proxies for the following data poor stocks: Black sea bass; Deep-sea red crab; Scup; Skates; Atlantic wolffish.
    b. Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop fishing level recommendations for these stocks.
    c. Consider developing BRPs for species groups for situations where the catch or landings can not be identified to species. Work on this objective will depend on, and needs to be consistent with, final guidance on implementing the Reauthorized Magnuson-Stevens Act, whenever that guidance becomes available.
    d. Comment on what can be done to improve the information, proxies or assessments for each species.
2. For weakfish, provide guidance/suggest methodologies for scientists to use in future assessments.

Participants

The Working Group (WG) will consist of representatives from the staffs of the NEFMC (2), MAFMC (2), ASMFC (2), NERO (3), and NEFSC (5).

Products

The WG product will be a document providing: (a) proposed BRPs and measurable BRP and MSY proxies for the five Northeast stocks/species groups listed in 1(a) above; (b) advice for SSCs to consider when they develop fishing level recommendations for these stocks; (c) advice on what to do about species with identification problems; (d) comments on what is needed to improve the proxies and/or assessments for each species and (e) suggested methodologies for conducting future weakfish stock assessments. Although it is expected that significant uncertainties will be associated with the proposed BRPs, MSYs, and their proxies, the intention is that the recommended values will represent the best available science.

During (or after) the WG's activities, a peer review of some type will be undertaken to ensure that the WG's recommendations and technical approaches are sound.

Table 2. Peer Reviewers of the December 8-12, 2008 "Northeast Data Poor Stocks" Working Group Meeting (See Table 4 for a list of meeting attendees).

Chairman:
Dr. Thomas Miller, Univ. of Maryland Center for Environmental Science, Chesapeake Biological Laboratory

Panelists :
Dr. Robert Muller, Florida Fish and Wildlife Commission
Mr. Robert O'Boyle, Beta Scientific Consulting Inc.
Dr. Andrew Rosenberg, Dept. Natural Resources, Univ. of New Hampshire

Table 3. Northeast Data Poor Stocks Dec. 8-12, 2008 meeting agenda.

Northeast Data Poor Stocks Working Group -- Peer Review Meeting

AGENDA *Last Update:* ***3-Dec-08***

Date /Day	*Start*	*End*	*Duration (min)*	*Topic*	*Presenter*
8-Dec	12:30	12:40	10	Welcome and Introduction	Weinberg (SAW Chair)
Mon	12:40	13:00	20	Overview of Data Poor Workshop and objectives	Rago (DPWG Chair)
Mon	13:00	13:15	15	Open Remarks, Guidance to Panel	Miller (Review Panel Chair)
Mon	13:15	14:15	60	Skate Complex	Sosebee
Mon	14:15	14:30	15	Break	
Mon	14:30	15:00	30	Skate Stock Recruitment Analyses	Brooks
Mon	15:00	15:30	30	Skate Landings and Discard Estimation	Applegate
Mon	15:30	16:15	45	Discussion--Skates	Miller
Mon	16:15	16:30	15	Break	
Mon	16:30	17:15	45	Red Crab	Chute
Mon	17:15	18:00	45	Red Crab Models: Frequency Analyses, DCAC, Two-point boundary value problem	Chute/Rago
Mon	18:00	18:45	45	Discussion--Red Crab	Miller
Mon	18:45	19:00	15	Summary/Followup	Miller
Date /Day	*Start*	*End*	*Duration (min)*	*Topic*	*Presenter*
9-Dec	*9:00*	9:15	15	Progress review and Order of the Day (Chair)	Miller (Chair)
Tues	9:15	10:00	45	Wolffish	Keith
Tues	10:00	10:45	45	Wolffish Model in SCALE	Nitschke
Tues	10:45	11:00	15	Break	
Tues	11:00	12:00	60	Wolffish--Discussion	Miller
Tues	12:00	13:00	60	Lunch	
Tues	13:00	15:00	120	Revisit on Skates, Red Crab and/or Wolffish	TBD
Tues	15:00	15:15	15	Break	
Tues	15:15	17:45	150	Conclusions: Skates, Red Crab, Wolffish	Miller/Panel
Tues	17:45	18:00	15	Summary/Followup	Miller
Date /Day	*Start*	*End*	*Duration (min)*	*Topic*	*Presenter*
10-Dec	*9:00*	9:15	15	Progress review and Order of the Day (Chair)	Miller
Wed	9:15	10:45	90	Scup	Terceiro
Wed	10:45	11:00	15	Break	
Wed	11:00	12:00	60	Discussion --Scup	Miller
Wed	12:00	13:00	60	Lunch	
Wed	13:00	13:30	30	Discussion--Scup	Miller
Wed	13:30	15:00	90	Black Sea Bass	Shepherd
Wed	15:00	15:15	15	Break	
Wed	15:15	16:45	90	Discussion--Black Sea Bass	Miller
Wed	16:45	17:00	15	Summary/Followup	Miller
Date /Day	*Start*	*End*	*Duration (min)*	*Topic*	*Presenter*
11-Dec	*9:00*	9:15	15	Progress review and Order of the Day	Rago
Thurs	9:15	10:45	90	Black Sea Bass--Conclusions	Miller
Thurs	10:45	11:00	15	Break	
Thurs	11:00	12:30	90	Scup--Conclusions	Miller
Thurs	12:30	13:30	60	Lunch	
Thurs	13:30	14:45	75	Further Discussion: Scup, Black Sea Bass Conclusions	Miller
Thurs	14:45	15:00	15	Break	
Thurs	15:00	16:30	90	Weakfish Assessment Model Summary	Brust (Weakfish Chair)
Thurs	16:30	17:30	60	Weakfish Assessment Discussion	Miller
Thurs	17:30	18:00	30	Summary/Followup (Chair)	Miller
12-Dec	*9:00*	9:15	15	Progress review and Order of the Day	Miller (Chair)
Fri	9:15	10:30	75	Synthesis of Meeting and Recommendations	TBD
Fri	10:30	10:45	15	Break	
Fri	10:45	12:00	75	Report Development and Writing	
Fri	12:00	13:00	60	Lunch	
Fri	13:00	14:30	90	Report Writing	
Fri	14:30	14:45	15	Break	
Fri	14:45	16:00	75	Report Writing	
				Adjourn	

Table 4. List of NE Stocks Data Poor Working Group meeting attendees (November – December, 2008).

Name	Affiliation	Email
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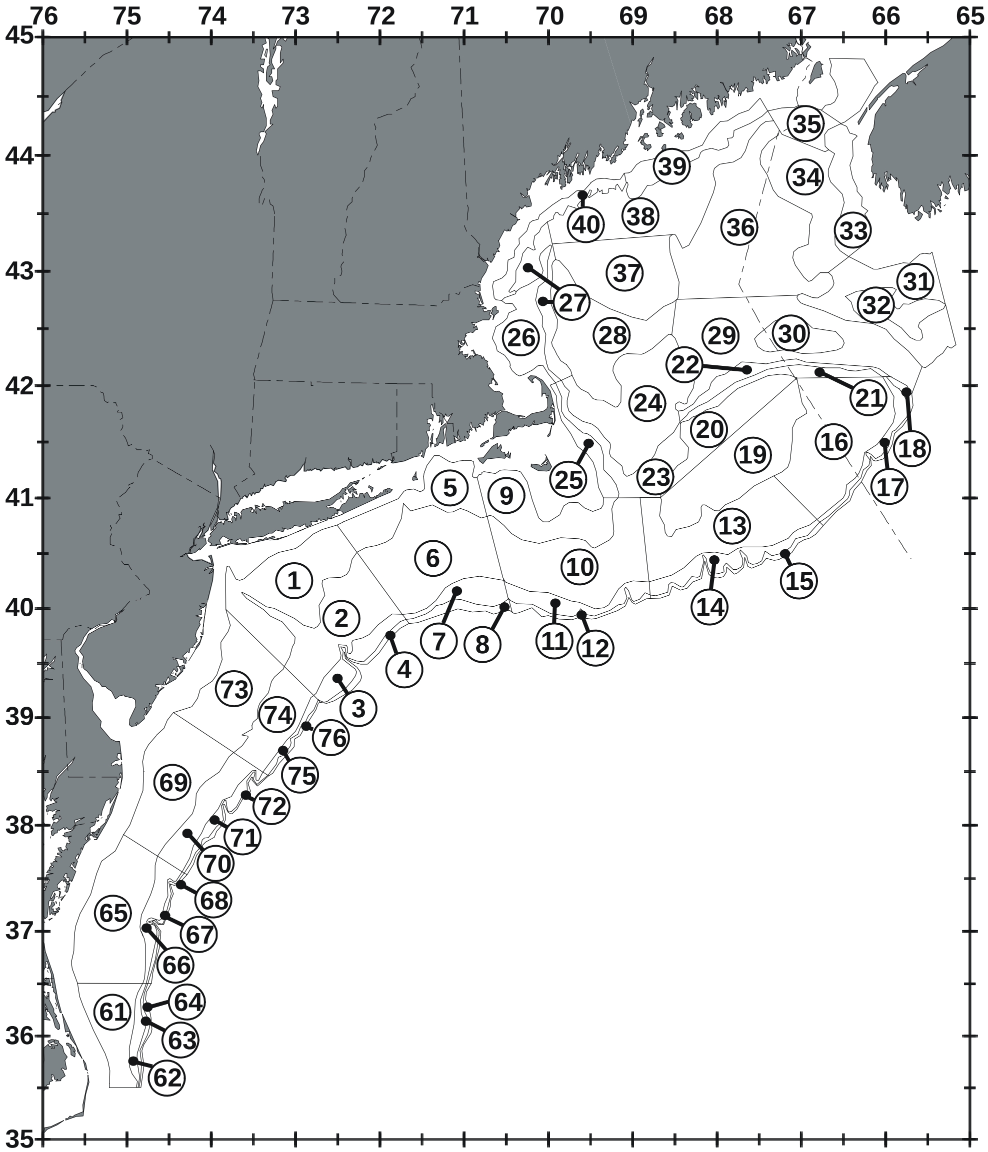

Figure 1. Offshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys.

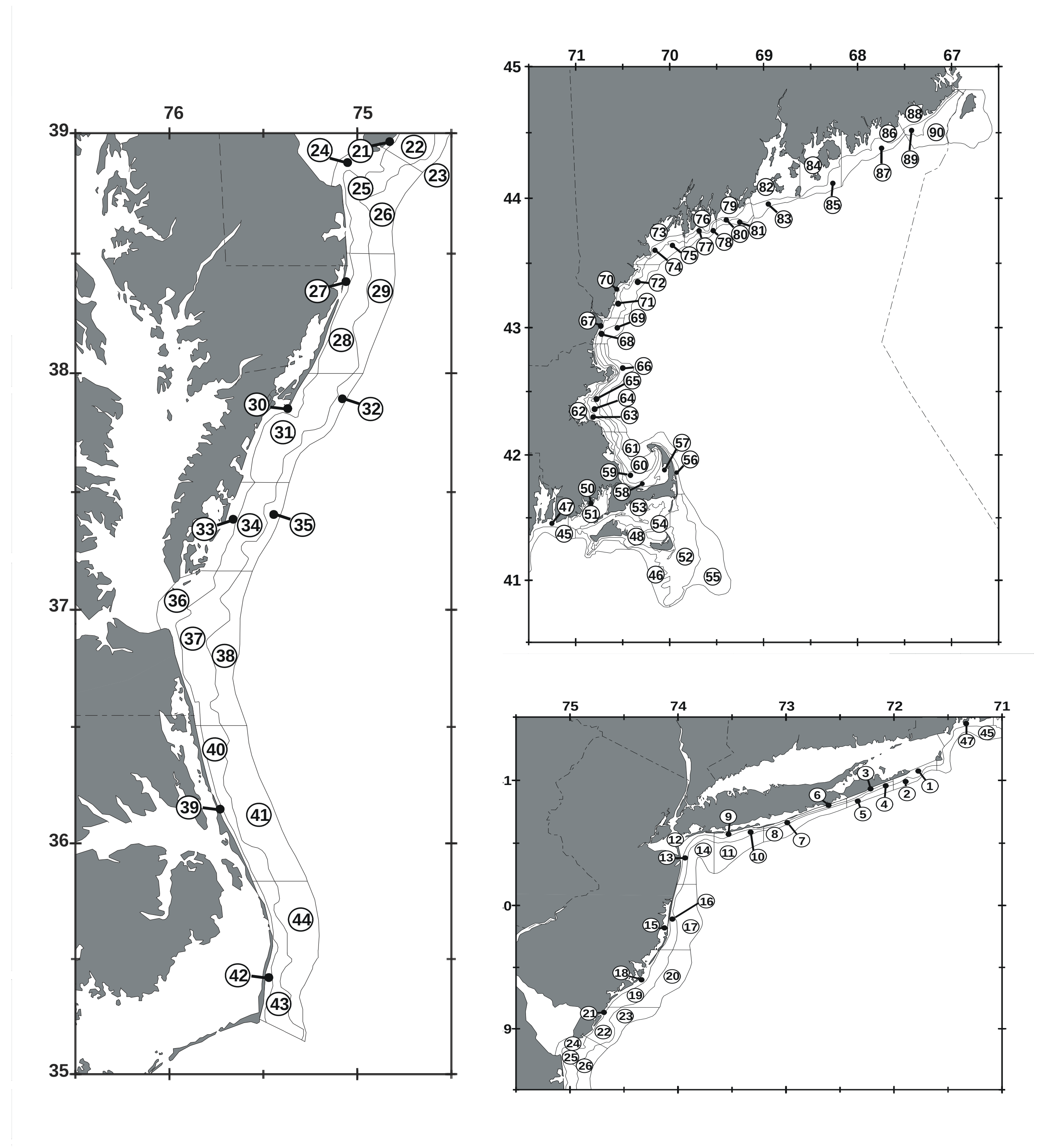

Figure 2. Inshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys.

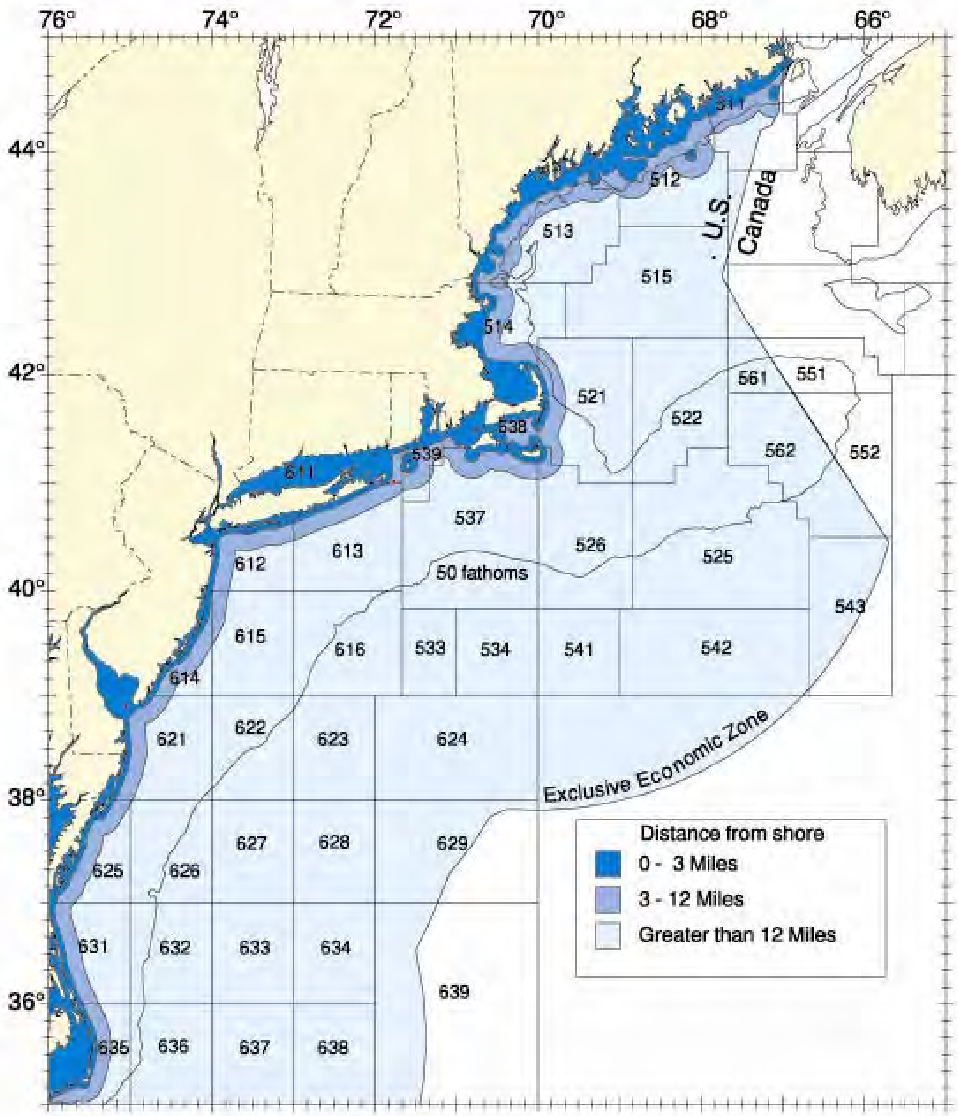

Figure 3. Statistical areas used for reporting commercial catches.

Skate Species Complex: Examination of Potential Biological Reference Points for the Northeast Region

by
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Northeast Data Poor Stocks Working Group Meeting
Woods Hole, MA
December 8-12, 2008

Executive Summary

The seven species in the Northeast Region (Maine to Virginia) skate complex are: little skate (*Leucoraja erinacea*), winter skate (*L. ocellata*), barndoor skate (*Dipturus laevis)*, thorny skate (*Amblyraja radiata*), smooth skate (*Malacoraja senta*), clearnose skate (*Raja eglanteria*), and rosette skate (*L. garmani*). Landings have generally been increasing since 2000 and the 2007 reported commercial landings of 19,000 mt were the highest on record. Discard estimates from SAW/SARC 44 in 2006 were revised in this assessment based on Standardized Bycatch Reporting Methodology. Most differences were due to inclusion of more trips from the last few years (e.g., Special Access Programs, etc.).

The landings estimates were not disaggregated to skate species in previous assessments because identification of skates is uncertain in the Domestic Observer Program (NEFSC 2007). Alternative methods to estimate landings by species were developed, each of which has strengths and weaknesses. The Review Panel concluded that progress had been made and future efforts should be encouraged, but that the Panel had insufficient time to explore the alternative methods in detail. Therefore, these approaches will be used in future modeling efforts, and will serve as an indication of the uncertainty in the catch of skates. Discards were also disaggregated to skate species using one method.

Survey indices by species were updated through 2007/2008 and aggregate indices were developed by area. These were used along with the catch data in An Index Method (AIM). Attempts to use this model were unsuccessful. Another model, SEINE (Survival Estimation in Non-Equilibrium Situations Model), was attempted to estimate fishing mortality. While the model estimated fishing mortality, it did so over a very long time period, but was not useful for producing annual estimates.

SPR-based reference points for three skate species, barndoor, winter, and thorny, were derived from life-history parameters and fitted Beverton-Holt stock recruit relationships. Future assessments might determine stock status by comparing these depletion levels either with depletion in the surveys or from a stock assessment model that incorporates information about maturity. These results were not accepted for reference points at this time.

Until new models are constructed using the new catch by species information, the existing overfishing definitions, updated through 2007/2008 will remain the best available. For barndoor skate, the current (i.e., non-updated) definition will be retained. Stock status with respect to the updated estimates is described. For skates in general, no new measurable stock status definitions were identified.

Terms of Reference

The following Terms of Reference were provided to the Data Poor Stocks Working Group for peer review in December 2008:

a. Recommend biological reference points (BRPs) and measurable BRP and maximum sustainable yield (MSY) proxies for the following data poor stocks: Black sea bass; Deep-sea red crab; Scup; Skates; Atlantic wolffish.

b. Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop fishing level recommendations for these stocks.

c. Consider developing BRPs for species groups for situations where the catch or landings can not be identified to species. Work on this objective will depend on, and needs to be consistent

with, final guidance on implementing the Reauthorized Magnuson-Stevens Act, whenever that guidance becomes available.
d. Comment on what can be done to improve the information, proxies or assessments for each species.

Introduction

The seven species in the Northeast Region (Maine to Virginia) skate complex are distributed along the coast of the northeast United States from near the tide line to depths exceeding 700 m (383 fathoms). The species are: little skate (*Leucoraja erinacea*), winter skate (*L. ocellata*), barndoor skate (*Dipturus laevis)*, thorny skate (*Amblyraja radiata*), smooth skate (*Malacoraja senta*), clearnose skate (*Raja eglanteria*), and rosette skate (*L. garmani*).

In the Northeast region, the center of distribution for the little and winter skates is Georges Bank and Southern New England. The barndoor skate is most common in the Gulf of Maine, on Georges Bank, and in Southern New England. The thorny and smooth skates are commonly found in the Gulf of Maine. The clearnose and rosette skates have a more southern distribution, and are found primarily in Southern New England and the Chesapeake Bight. Skates are not known to undertake large-scale migrations, but they do move seasonally in response to changes in water temperature, moving offshore in summer and early autumn and returning inshore during winter and spring. Members of the skate family lay eggs that are enclosed in a hard, leathery case commonly called a mermaid's purse. Incubation time is 6 to 12 months, with the young having the adult form at the time of hatching (Bigelow and Schroeder 1953).

The first stock assessment for the skate complex was conducted in 1999 at SARC/SAW 30 (NEFSC 2000). At that time there was no Fishery Management Plan (FMP) in place. The National Marine Fisheries Service had been petitioned to list barndoor skate as endangered based on a paper published by Casey and Myers (1998) and was also asked to assess the other species in the complex. SARC 30 found no cause to list barndoor as endangered but recommended that the species remain on the candidate species list as well as to put thorny skate on the candidate species list. Biomass reference points were developed for all seven species and four were listed as overfished. Fishing mortality reference points were developed for winter and little skate and overfishing was occurring for winter skate.

An FMP was developed following SARC 30 by the New England Fishery Management Council (NEFMC) when they were informed of the overfished status of thorny and barndoor (winter and smooth biomass increased in the 1999 autumn survey and were no longer considered overfished). The FMP was implemented in September of 2003 with a primary requirement for mandatory reporting of skate landings by species by both dealers and vessels. Possession prohibitions of barndoor and thorny skate as well as smooth skate in the Gulf of Maine were also provisions of the FMP. A trip limit of 10,000 lbs was implemented for winter skate with a Letter of Authorization for the bait fishery (little skate) to exceed the trip limit. The biomass reference points developed at SARC 30 were maintained, but new fishing mortality reference points were developed.

The last stock assessment for the skate complex was conducted in 2006 at SARC/SAW 44 (NEFSC 2007). Several methods were attempted to develop fishing mortality estimates and biological reference points. These included the Gedamke-Hoenig length-based mortality estimator, length-based yield-per-recruit, spawner-per-recruit, and a length-tuned model. None of these methods were accepted, although some had promise. SARC 44 did not change the biological reference points.

Commercial Fishery Landings

Skates have been reported in New England fishery landings since the late 1800s. However, commercial fishery landings, primarily from off Rhode Island, never exceeded several hundred metric tons until the advent of distant-water fleets and the industrial fishery during the 1950s and 1960s. Skate landings reached 9,500 mt in 1969, but declined quickly during the 1970s, falling to 800 mt in 1981 (Table 1, Figure 1). Landings then increased substantially; partially in response to increased demand for lobster bait, and more significantly, to the increased export market for skate wings. Landings increased to 12,900 mt in 1993 and then declined somewhat to 7,200 mt in 1995. Landings increased again and the 2007 reported commercial landings of 19,000 mt were the highest on record (Table 1, Figure 1).

United States landings of skates are reported in all months (Table 2). There is a relatively even distribution of landings across months, but the summer months do show a slightly higher percentage, probably due to the increased demand for lobster bait during those months.

Skate landings are primarily from Massachusetts and Rhode Island (mainly New Bedford and Point Judith) with 85-95% of the landings occurring in those two states (Table 3). Landings from other states did occur back through time and the table somewhat reflects better reporting as more states reported in the NMFS database. Also, the difference in total landings between Table B1.1 and B1.3 is likely the result of landings from the industrial fishery not included in the Weighout database. These landings were sampled during the 1960s and 1970s for species composition and prorated. Skates accounted for about 10% of those landings.

Otter trawls are the primary gear used to land skates in the United States, with some landings coming from sink gill nets (Table 4). In the last couple of years, landings from longline gear have increased slightly in importance. The increase in other gear reflects the new reporting system implemented in 2004.

Landings historically were taken from the Georges Bank and Southern New England during the early 1960s as the industrial fishery operated mainly out of Point Judith and the distant-water fleet fished mainly on Georges Bank (Table 5). Landings from Mid-Atlantic increased through the early 2000s while landings from Georges Bank in 2007 were the highest on record.

Landings are generally not reported by species, with over 99% of the landings reported as “unclassified skates” until the FMP was implemented in September of 2003 (Table 6). Wings are most likely taken from winter and thorny skates, the two species currently known to be used for human consumption. Bait landings are presumed to be primarily from little skate, based on areas fished and known species distribution patterns. Landings of barndoor and thorny skate are being reported by the dealers even though there is a possession prohibition for those two species. There are also wings reported for rosette, little and smooth which are known to be too small for wings. The distribution of skate landings by state and species also shows that some species are landed in areas that they do not occur (Table 7). For example, in 2004, barndoor were landed in Virginia which is too far south for barndoor skate.

Commercial Fishery Discards

Discard estimates from SAW/SARC 44 were revised in this assessment. The ratio-estimator used in this assessment is based on the methodology described in Rago et al. (2005)

and updated in Wigley et al 2007. It relies on a d/k ratio where the kept component is defined as the total landings of all species within a “fishery”. A fishery is defined as a homogeneous group of vessels with respect to gear type (longline, otter trawl, shrimp trawl, sink gill net, and scallop dredge), quarter (months 1-4, 5-6, 7-8, 9-12), and area fished (GOM, GB, SNE, MA). Mesh size was not used to split out otter trawl trips or sink gill net trips. All trips were included if they occurred within this stratification regardless of whether or not they caught skates.

The discard ratio for skates in stratum h is the sum of discard weight over all trips divided by sum of kept weights over all trips:

$$\hat{R}_h = \frac{\sum_{i=1}^{n_h} d_{ih}}{\sum_{i=1}^{n_h} k_{ih}} \qquad (1)$$

where d_{ih} is the discards for skates within trip i in stratum h and k_{ih} is the kept component of the catch for all species. R_h is the discard rate in stratum h. The stratum weighted discard to kept ratio is obtained by weighted sum of discard ratios over all strata:

$$\hat{R} = \sum_{h=1}^{H} \left(\frac{N_h}{\sum_{h=1}^{H} N_h} \right) \hat{R}_h \qquad (2)$$

The total discard within a strata is simply the product of the estimate discard ratio R and the total landings for the fishery defined as stratum h, i.e., $D_h=R_hK_h$.

Missing cells were inputed using averages of existing cells. If information existed in the same area fished, the annual average discard ratio was applied in the missing cells. If the information was missing in the area fished, but available in the region (i.e. SNE and MA or GOM and GBK), then the annual average for that region was applied. There were some cases for the longline fishery in which the entire year was averaged for all areas or for a span of 12 years (1993-2004). The details of the imputation are given in Appendix 1.

To hindcast the discard estimates back to 1964, a three-year average (the earliest three years of data) of the discards of skates/landings of all species was used. The sensitivity of this estimate was examined using a five-year average and a time-series average (Figure 2). The trends in the total estimates are similar, with the time-series average giving the lowest estimate and the three-year average the highest estimates. Using the three estimates in any future modeling efforts will give some idea of the uncertainty in the data.

Estimated discards by fishery, region and half year for 1964-2007 are summarized in Tables 8-10. The new estimated discards are different than those estimated in SARC/SAW 44 (Figure 3). There are two main reasons for these differences. First, missing cells were imputed in the new method. This should lead to higher values in general. Second, the data for any Special Access Programs for 2005 -2007 were included in the new estimates. These trips showed a higher discard ratio than those outside the closed areas. These should be placed in a separate stratum, however, there is no easy way to determine if a trip in the dealer database was fishing in an SAP. The coefficients of variation for the otter trawl are generally reasonable, while the scallop dredge estimates are highly variable (Table 11). Alternative stratification schemes were examined to determine if this had any impact on the magnitude of the discard estimates (Appendix 2). When all trips were included the estimates were all fairly similar.

The estimates from 1992-2007 were hind-cast using the first three years of the time series to compare actual estimates and hind-cast estimates (Figure 4). For years when the regulations were similar (mid-1990s), the hind-cast estimates were comparable to the actual estimates. In more recent years, management has changed and the estimates are not and probably should not be comparable.

Recreational Fishery Catch

Aggregate recreational landings of the seven species in the skate complex are relatively insignificant when compared to the commercial landings, never exceeding 300 mt during the 1981-1998 time series of Marine Recreational Fishery Statistics Survey (MRFSS) estimates. Little and clearnose skates are the most frequently landed species of the complex. For little skate, total landings varied between <1000 and 56,000 fish, equivalent to <1 to 15 mt, during 1981-1998. For clearnose skate, total landings varied between 2,000 and 145,000 fish, equivalent to 2 to 232 mt, during 1981-1998. The number of skates reported as released alive averages an order of magnitude higher than the reported landed number. Party/charter boats have historically been undersampled compared to the private/rental boat sector that accounts for most of the recreational catch, and may have a different discard rate. The recreational fishery release mortality rate of skates is unknown, but is likely comparable to that for flounders and other demersal species, which generally ranges from 10-15%. Assuming a 10-15% release mortality rate would suggest that recreational fishery discard mortality is of about the same magnitude as the recreational landings. Data from 1999 through 2005 were similar in magnitude.

Landings by Species Estimation

The landings estimates were not dis-aggregated to skate species in previous assessments because identification of skates is uncertain in the Domestic Observer Program (NEFSC 2007). Alternative methods to estimate landings by species were developed, each of which has both strengths and weaknesses. Therefore, both sets of estimates were chosen to be used in any future modeling efforts as an indication of the uncertainty in the catch of skates.

The first method used the observer lengths of the kept component of the catch directly. In order to split the data into the bait (whole) and wing components of the fishery, a length cutoff of 60 cm was used, since there is no direct way of determining the disposition of the landings until recently. This seemed justified, since the maximum size in the bait fishery was instituted to also be close to the minimum accepted length for the wing fishery. Examination of the samples by the two main gear types also showed two groups of fish with a trough at about 60 cm (Figure 5). The data were apportioned into two regions, Gulf of Maine to Georges Bank (GOMGBK – Divisions 51 and 52), and Southern New England to Mid-Atlantic (SNEMA – Divisions 53 and Subarea 6). The number of fish measured in these regions was barely sufficient (Table 12) so no further areal division was attempted. Pooling over years within a region was still required to get an adequate number of fish (Figure 6). An average skate length-weight equation was applied to the samples and used to estimate the landings numbers at length for each market category (Figure 7).

Length compositions for each species for the two regions (GOMGBK – Offshore strata 13-30, 36-40, and Inshore strata 56-66; SNEMA – Offshore strata 1-12, 61-76, and Inshore strata 1-55) were estimated. The species length-weight equations were then applied to determine weight-at-length by species. The proportions at length by species for both number and weight were applied to the commercial landings-at-length to estimate landings-at-length by species. The lengths had to be grouped into 5 cm intervals to avoid zero cells in the survey and all fish greater than 112 cm were set to be barndoor skate.

For the second method, a selectivity ogive was estimated for observed hauls in each skate fishery compared to the applicable surveys during 2004-2007. The data were fit using a three parameter logistic curve via Millar's (1992) SELECT model. Results of these logistic model fits are given in Table 13 and in Figures 8-11. In most cases where the parameters could be estimated, the L50s for winter and little skates were similar to the overall fit for all skate species (with a notable exception of little skates observed in the retained fraction of gillnet catches). Also the ogives by region were very similar to one another within each fishery and gear type. As a result, pooled selectivity ogives for each gear and skate fishery were used to determine the exploitable species composition at size in each survey stratum. In the following table, the L50s for the newly estimated ogives are compared with the PDT's assumed knife edge selectivity ogive.

Fishery	**L50 for selectivity ogive applied to survey weight per tow data**	**PDT assumed knife edge selectivity**
Trawl wing	66.9 cm	> 40 cm
Trawl whole/bait	44.4 cm and < 59 cm	< 59 cm
Gillnet	54.9 cm	> 65 cm

Average proportional weight per tow by three digit statistical area was re-estimated by determining an average stratum weight per tow and then computing an area-weighted average for the sampled strata within each three digit statistical area. While this approach does not readily allow estimation of variance (like a domain estimator), the averages computed in this way satisfy the conditions of the stratified random survey design. These average proportions of survey catch by skate species were then applied to the VTR data by gear type, fishery (product form), and trimester (corresponding to the spring, fall, and winter surveys).

Comparison of the two methods generally shows higher amounts of winter, clearnose, and rosette skate in method one (length composition) compared to the second method (selectivity ogive) and lower amounts of little, smooth, and thorny skate (Tables 14-15; Figures 12-14). Barndoor skate are generally comparable. The length composition method uses the annual length data when possible, but may be ignoring some sub-regional differences due to the low sample sizes. The selectivity ogive method, on the other hand, uses the sub-regional data while assuming that the length composition of the survey, once the skates are fully selected, reflects the length composition of the fishery. The two methods give a range of values and will both be used in any future modeling efforts.

Discards by Species Estimation

The discard estimates were not dis-aggregated to skate species in previous assessments because identification of skates is uncertain in the Domestic Observer Program (NEFSC 2007).

The observer lengths of the discarded component of the catch were used by gear type. The data were apportioned into two regions, Gulf of Maine to Georges Bank (GOMGBK – Divisions 51 and 52), and Southern New England to Mid-Atlantic (SNEMA – Divisions 53 and Subarea 6). The number of fish measured in these regions was barely sufficient (Table 16) so no further areal division was attempted. Pooling over years, sometimes over the entire time series, within a region was still required to get an adequate number of fish (Figure 15). For longline gear, all samples were used for both regions. An average skate length-weight equation was applied to the samples and used to estimate the discard numbers at length by gear category (Figure 16).

Length compositions for each species for the two regions (GOMGBK – Offshore strata 13-30, 36-40, and Inshore strata 56-66; SNEMA – Offshore strata 1-12, 61-76, and Inshore strata 1-55) were estimated. The species length-weight equations were then applied to determine weight-at-length by species. The proportions at length by species for both number and weight were applied to the commercial landings-at-length to estimate landings-at-length by species. The lengths had to be grouped into 5 cm intervals to avoid zero cells in the survey and all fish greater than 112 cm were set to be barndoor skate. The estimates by gear type and species are given in Table 17.

Research Survey Data- Total Stock Biomass

Indices of relative abundance have been developed from NEFSC bottom trawl surveys for the seven species in the skate complex, and these form the basis for most of the conclusions about the status of the complex. The NEFSC trawl survey has been conducted in the autumn from the Gulf of Maine to Southern New England since 1963 (Azarovitz 1981) and the Mid-Atlantic was added in 1967. A spring survey was started in 1968 with stations <= 27 m added in 1975. All statistically significant NEFSC gear, door, and vessel conversion factors were applied to little, winter, and smooth skate indices when applicable (Sissenwine and Bowman, 1978; NEFC 1991). Juvenile little and winter skates are not readily distinguished in the field. The numbers of juveniles were split between the two species based on the abundance of the adults in the same tow.

For the aggregate skate complex, the spring survey index of biomass was relatively constant from 1968 to 1980, then increased significantly to peak levels in the mid to late 1980s. The index of skate complex biomass then declined steadily until 1994, but increased until 2000 and has since decreased (Figure 17). If the species in the complex are divided into large (barndoor, winter, and thorny) and small sized skates (little, clearnose, rosette, and smooth), it is evident that the large increase in skate biomass in the mid to late 1980s was dominated by winter and little skate (Figure 17). The biomass of large sized skates steadily declined from the mid-1980s to the mid-1990s and has since been stable. The increase in aggregate skate biomass from the mid-1990s to 2000 was due to an increase in little skate and the subsequent decline is also due to little skate (Figure 17).

Indices were also derived for the aggregate skate complex by region. The index of skate biomass in the Gulf of Maine (Offshore strata 26-30, 36-40) was steady through the mid-1970s, started to decline and is currently among the lowest on record (Figure 18). The index for the Georges Bank region (Offshore strata 13-25) was relatively low at the start of the time series, increased to high levels in the 1980s and has since declined to low levels (Figure 18). For the Southern New England region (Offshore strata 1-12), the index either increased over time (the spring survey) or was stable (the fall survey) (Figure 19). The index for the Mid-Atlantic (Offshore strata 61-76) region has increased over time (Figure 19).

Indices of relative abundance for some of the species have also been developed from MADMF and CTDEP research surveys. Data are also available from the Maine-New Hampshire inshore survey, the ASMFC shrimp trawl survey, the monkfish survey, and the VIMS trawl survey but have not been developed into indices at this time.

The bootstrap methodology of Smith (1997) was continued from the previous SARC and also applied to the MADMF survey but the complete results are not shown. The data are shown to demonstrate what may be available for future modeling work.

Winter skate

In the NEFSC spring survey offshore strata (1968-2008), the annual total catch of winter skate has ranged from 160 fish in 1976 to 1,891 fish in 1985. In the NEFSC autumn survey offshore strata (1963-2007), the annual total catch of winter skate has ranged from 115 fish in 1975 to 1,187 fish in 1984. Calculated on a per tow basis, these spring survey catches equate to maximum stratified mean number per tow indices for the GOM-MA offshore strata of about 7.9 fish, or 16.4 kg, per tow during 1985; autumn maximum catches equate to indices of 3.7 fish, or 13.3 kg, per tow in 1984 (Tables 18-19).

The catchability of winter skate in the NEFSC winter bottom trawl survey (which substitutes a chain sweep with small cookies for the large rollers used in the spring and autumn surveys, to better target flatfish) is significantly higher than in the spring and autumn series, especially for smaller winter skates. NEFSC winter survey (1992-2007) annual catches of winter skate have ranged from 841 fish in 1993 to 4,055 fish in 1996, equating to a maximum stratified mean catch per tow of 43.5 fish, or 25.2 kg, per tow in 1996 (Table 20). The winter survey is focused in the Southern New England and Mid-Atlantic offshore regions, with a limited number of samples on Georges Bank, and no sampling in the Gulf of Maine and has been discontinued.

Indices of winter skate abundance and biomass from the NEFSC spring and autumn surveys were stable, but below the time series mean, during the late 1960s and 1970s (Figure 20). Winter skate indices increased to the time series mean by 1980, and then reached a peak during the mid 1980s. Winter skates indices began to decline in the late 1980s. Current NEFSC indices of winter skate abundance are below the time series mean, at about the same value as during the early 1970s. Current NEFSC indices of winter skate biomass are about 20% of the peak observed during the mid 1980s (Figure 20).

The NEFSC scallop dredge survey, as with the winter survey also catches winter skates mostly on Georges Bank and also does not sample in the Gulf of Maine and on the very shallowest portions of Georges Bank. However, the trends in abundance are similar to the trends in the spring and autumn surveys (Figure 21).

Indices of abundance for winter skate are available from the Massachusetts Division of Marine Fisheries (MADMF) spring and autumn research trawl surveys in the inshore waters of Massachusetts for the years 1978-2008. MADMF biomass indices of winter skate were moderate to high from 1981 through 1987. Thereafter, both spring and autumn indices declined to time series lows in 1989-1991. The spring index rebounded to moderate levels during 1992-1996 before dropping again to low values in the late 1990s and remaining low through 2008 (Figure 22). The autumn index is more erratic, but generally shows the same pattern.

Indices of abundance for winter skate are available from the Connecticut Department of Environmental Protection (CTDEP) spring and autumn finfish trawl surveys in Long Island Sound for the years 1984-2008 (1992 and later only for biomass). Annual CTDEP survey catches have ranged from 0 to 115 skates. CTDEP survey indices suggest that after increasing to a time series high from 1984 through 1989, winter skate in Long Island Sound has declined slightly (Figure 23).

Little skate

In the NEFSC spring surveys (1976-2008), the annual total catch of little skate has ranged from 2,271 fish in 2006 to 16,406 fish in 1999 (Table 21). In the NEFSC autumn surveys (1975-2007), the annual total catch of little skate has ranged from 1,124 fish in 1993 to 6,523 fish in 2003 (Table 22). Calculated on a per tow basis, these spring survey catches equate to maximum stratified mean number per tow indices for the GOM-MA inshore and offshore strata of about 28 fish, or 10 kg, per tow during 1999; autumn maximum catches equate to indices of 18 fish, or 7.7 kg, per tow in 2003 (Tables 21-22).

The catchability of little skate in the NEFSC winter bottom trawl survey (which substitutes a chain sweep with small cookies for the large rollers used in the spring and autumn surveys, to better target flatfish) is significantly higher than in the spring and autumn series. NEFSC winter survey (1992-2007) annual catches of little skate have ranged from 8,870 fish in 2003 to 18,418 fish in 1992, equating to a maximum stratified mean catch per tow of 170 fish, or 66 kg, per tow in 1992 (Table 23). The winter survey is focused in the Southern New England and Mid-Atlantic offshore regions, with a limited number of samples on Georges Bank, and no sampling in the Gulf of Maine and has been discontinued.

Indices of little skate abundance and biomass from the NEFSC spring and autumn surveys were stable, but below the time series mean, during the 1970s. Little skate spring survey indices began to increase in 1982, reached a peak in 1999, and declined thereafter (Figure 24). Autumn survey indices have been relatively stable over the duration of the time series, with a slight increase in recent years (Figure 24). The application of the NEFSC gear conversion factors to spring survey indices decreased the indices in 1981 and earlier years by 75 percent. This may account for some of the mis-match between the spring and autumn surveys.

The NEFSC scallop dredge survey, as with the winter survey also catches little skates in all areas and also does not sample in the Gulf of Maine, on the very shallowest portions of Georges Bank, and parts of Southern New England. However, the trends in abundance are similar to the spring and autumn surveys with the indices showing little trend over the time series (Figure 25).

Indices of abundance for little skate are available from the Massachusetts Division of Marine Fisheries (MADMF) spring and autumn research trawl surveys in the inshore waters of Massachusetts for the years 1978-2008 (Figure 26). MADMF biomass indices of little skate declined through the 1980's to time series lows in 1989 (autumn) and 1991 (spring). Biomass indices quickly rose to high levels in the early 1990's, and have since fluctuated without trend.

Indices of abundance for little skate are available from the Connecticut Department of Environmental Protection (CTDEP) spring and autumn finfish trawl surveys in Long Island Sound for the years 1984-2008 (1992 and later only for biomass). Little skate are the most abundant species in the skate complex in Long Island Sound, with annual CTDEP survey catches ranging from 142 to 837 skates. CTDEP survey indices suggest an increase in abundance of little skate in Long Island Sound through 1996 followed by a decline (Figure 27).

Barndoor skate

In the NEFSC spring surveys (1968-2008), the annual total catch of barndoor skate has ranged from 0 fish (several years during the 1970s and 1980s) to 325 fish in 2007 (Table 24). In the NEFSC autumn surveys (1963-2007), the annual total catch of barndoor skate has ranged from 0 fish (several years in the 1970s and 1980s) to 120 fish in 1963 (Table 25). Calculated on a per tow basis, the autumn survey catches equate to maximum stratified mean number per tow indices for the GOM-SNE offshore strata of about 0.8 fish, or 2.6 kg, per tow in 1963 while the spring maximum is 1.5 fish, or 6.8 kg, per tow in 2007 (Tables 24-25). The spring survey index was driven mainly by one large tow (277 fish; >1500 kg).

The catchability of barndoor skate in the NEFSC winter bottom trawl survey (which substitutes a chain sweep with small cookies for the large rollers used in the spring and autumn surveys, to better target flatfish) is significantly higher than in the spring and autumn series and may be particularly higher for smaller skates as in winter skates. NEFSC winter survey (1992-2007) annual catches of barndoor skate have ranged from 0 fish in 1992 to 355 in 2006, equating to a maximum stratified mean catch per tow of 3.2 fish, or 3.0 kg, per tow in 2006 (Table 26). The winter survey is focused in the Southern New England and Mid-Atlantic offshore regions, with a limited number of samples on Georges Bank, and no sampling in the Gulf of Maine and has been discontinued.

Indices of barndoor skate abundance and biomass from the NEFSC spring and autumn surveys were at their highest values during early to late 1960s, and then declined to 0 fish per tow during the early 1980s. Since 1990, both spring and autumn survey indices have steadily increased, with the spring survey at the highest value and the autumn survey nearing the peak values found in the 1960s (Figure 28).

The NEFSC scallop dredge survey, as with the winter survey also catches winter skates mostly on Georges Bank and also does not sample in the Gulf of Maine, on the very shallowest portions of Georges Bank, and parts of Southern New England. However, the trends in abundance are similar to the trends in the spring and autumn surveys showing a large increase since 1992 while the biomass is much noisier (Figure 29).

Thorny skate

In the NEFSC spring surveys (1968-2008), the annual total catch of thorny skate has ranged from 29 fish in 2006 to 574 fish in 1973 (Table 27). In the NEFSC autumn surveys (1963-2007), the annual total catch of thorny skate has ranged from 36 fish in 2005 to 874 fish in 1978 (Table 28). Calculated on a per tow basis, these spring and autumn survey catches equate to maximum stratified mean number per tow indices for the GOMSNE offshore strata of about 2 to 3 fish, or about 6.0 kg, per tow during the early 1970s (Tables 27-28).

NEFSC spring and autumn survey indices for thorny skate have declined continuously over the last 40 years. Indices of thorny skate abundance and biomass from the NEFSC spring and autumn surveys were at a peak during the early 1970s, reaching 2.9 fish per tow (5.3 kg per tow) in the spring survey and 1.8 fish per tow (5.9 kg per tow) in the autumn survey. Kulka and Mowbray (1998) indicated a similar period of high abundance for thorny skate in Canadian waters. NEFSC indices of thorny skate abundance have declined steadily since the late 1970s, reaching historically low values by 2005-2007 that are less than 10% of the peak observed in the 1970s (Figure 30).

The NEFSC scallop dredge survey also catches thorny skates primarily on the edges of Georges Bank and a sharp decline followed by no trend (Figure 31). The scallop survey also does not sample in the Gulf of Maine, on the very shallowest portions of Georges Bank and parts of Southern New England.

Indices of abundance for thorny skate are available from the Massachusetts Division of Marine Fisheries (MADMF) spring and autumn research trawl surveys in the inshore waters of Massachusetts for the years 1978-2008. MADMF indices of thorny skate biomass have been variable over the time series, but there is a decreasing trend evident in both the spring and autumn time series. The spring index has stabilized around the median of 0.2 kg/tow throughout the 2000's, while the autumn index has been below the median of 0.6 kg/tow since 1994 except for 2001 and 2002 (Figure 32).

Smooth skate

In the NEFSC spring surveys (1968-2008), the annual total catch of smooth skate has ranged from 12 fish in 1996 to 179 fish in 1973 (Table 29). In the NEFSC autumn surveys (1963-2007), the annual total catch of smooth skate has ranged from 10 fish in 1976 to 130 fish in 1978 (Table 30). Calculated on a per tow basis, these spring and autumn survey catches equate to maximum stratified mean number per tow indices for the GOM-MA offshore strata of 0.6 to 1.6 fish, or about 0.6 to 0.9 kg, per tow during the 1970s (Tables 29-30).

Indices of smooth skate abundance and biomass from the NEFSC surveys were at a peak during the early 1970s for the spring series and the late 1970s for the autumn series (Figure 33). NEFSC survey indices declined during the 1980s, before stabilizing during the early 1990s at about 25% of the autumn and 50% of the spring survey index values of the 1970s.

The NEFSC scallop dredge survey also catches smooth skates primarily on the edges of Georges Bank and the indices have slightly increased (Figure 34). The scallop survey also does not sample in the Gulf of Maine, on the very shallowest portions of Georges Bank and parts of Southern New England.

Clearnose skate

In the NEFSC spring surveys (1976-2008), the annual total catch of clearnose skate has ranged from 9 fish in 1979 to 136 fish in 1993 (Table 31). In the NEFSC autumn surveys (1975-2007), the annual total catch of clearnose skate has ranged from 19 fish in 1983 to 221 fish in 2001 (Table 32). Calculated on a per tow basis, these spring and autumn survey catches equate to maximum stratified mean number per tow indices for the Mid-Atlantic offshore and inshore strata set of 1.2-1.6 fish, or about 0.8-0.9 kg, per tow during the mid 1990s and 2000s (Tables 31-32).

The catchability of clearnose skate in the NEFSC winter bottom trawl survey (which substitutes a chain sweep with small cookies for the large rollers used in the spring and autumn surveys, to better target flatfish) is significantly higher than in the spring and autumn series. NEFSC winter survey (1992-2007) annual catches of clearnose skate have ranged from 343 fish in 1999 to 3,086 fish in 1996, equating to a maximum stratified mean catch per tow of 12 fish or 15 kg per tow in 1996 (Table 33). The winter survey is focused in the Southern New England and Mid-Atlantic offshore regions, with a limited number of samples on Georges Bank, and no sampling in the Gulf of Maine, and has been discontinued.

NEFSC spring and autumn survey indices for clearnose skate increased from the mid-1980s through 2000, declined to about average values, and increased slightly in the last few years (Figure 35).

Indices of abundance for clearnose skate are available from the Connecticut Department of Environmental Protection (CTDEP) spring and autumn finfish trawl surveys in Long Island Sound for the years 1984-2008 (1992 and later only for biomass). The CTDEP survey had caught very few clearnose skate, with annual catches ranging from 0 to 20 skates through 1998, but the indices have increased in Long Island Sound over the times series with 100 caught in 2005 (Figure 36).

Rosette skate

In the NEFSC spring surveys (1968-2008), the annual total catch of rosette skate has ranged from 0 fish, in 1970 and1984, to 70 fish in 1977 (Table 34). In the NEFSC autumn surveys (1967-2005), the annual total catch of rosette skate has ranged from 1 fish, most recently in 1982, to 46 fish in 1999 (Table 35). Calculated on a per tow basis, these spring survey catches equate to maximum stratified mean number per tow indices for the Mid-Atlantic offshore strata set of about 0.6 fish, or about 0.1 kg, per tow during 1977 (Tables 34-35).

The catchability of rosette skate in the NEFSC winter bottom trawl survey (which substitutes a chain sweep with small cookies for the large rollers used in the spring and autumn surveys, to better target flatfish) is significantly higher than in the spring and autumn series. NEFSC winter survey (1992-2007) annual catches of rosette skate have ranged from 143 fish in 1993 to 1029 fish in 2003, equating to a maximum stratified mean catch per tow of 2.8 fish or 0.7 kg per tow in 2003 (Table 36). The winter survey is focused in the Southern New England and Mid-Atlantic offshore regions, with a limited number of samples on Georges Bank, and no sampling in the Gulf of Maine and has since been discontinued.

Indices of rosette skate abundance and biomass from the NEFSC surveys were at a peak during 1975-1980, before declining through 1986. NEFSC survey indices for rosette skate increased from 1986 through 2001, declined slightly and recent indices are near the peak values of the late 1970s (Figure 37).

Research Survey Data- Spawning Stock Biomass

Maturity information was available in some form for all species to split the survey length information into mature and immature animals (Table 37). The series chosen for each species was the same as chosen for reference points at SARC30. There is a protracted spawning as females likely lay eggs year round so there is no need to pick a season based on spawning time. The autumn survey was used for all species except little as it is generally the longest. For little skate, the spring series from 1982 on was used to avoid gear conversion issues.

Winter skate SSB generally follows the pattern of the autumn total biomass index with very low values in the 1970s followed by the large expansion of the size composition in the 1980s (Table 38; Figure 38). The index of SSB declined in the mid- to late 1990s, increased slightly, and is currently at low values. Little skate SSB has been fairly stable through the time series with slightly higher values from 1999-2004 than in the 1980s and early 1990s (Table 38; Figure 38). The pattern in barndoor skate SSB indices is much the same as that of total biomass with high values in the early 1960s, followed by very low to nonexistent values in the 1970s and 1980s, and then a consistent increase in the 1990s and 2000s (Table 38; Figure 38). The decline in thorny skate SSB indices is more pronounced than for the total biomass index (Table 38; Figure 38). Smooth skate SSB indices are very variable, but exhibit a slight decline over the time series (Table 38; Figure 38). Clearnose skate SSB has increased over the time period (Table 38; Figure 38). Rosette skate SSB has been variable but has generally increased (Table 38; Figure 38).

Fishing Mortality Estimates

Gedamke and Hoenig (2006) developed a method to estimate mortality from mean length data in nonequilibrium situations, now called Survival Estimation in Non-Equilibrium Situations Model (SEINE, available at http://nft.nefsc.noaa.gov/). It is an extension of the Beverton-Holt length-based mortality estimator that assumes constant recruitment throughout the time series and mortality at fixed levels for certain periods within the time series. The approach allows for the transitory changes in mean length to be modeled as a function of mortality rate changes. After an increase in mortality, mean length will gradually decrease due to larger animals being less prevalent in the population. After a decrease in mortality, mean length will increase slowly due to growth of the fish in the population. The rates of change in both cases depend on the von Bertalanffy growth parameters and the magnitude of change in the mortality rates. Since the method requires only a series of mean length above a user defined minimum size and the von Bertalanffy growth parameters, it can be applied in many data poor situations. Gedamke and Hoenig (2006) demonstrated the utility of this approach using both simulated data and an application to data for goosefish caught in the NEFSC fall groundfish survey.

Most of the information for the six species suggests that there is one break-point in the time series. This is not useful in monitoring the species on an annual basis. Further modeling efforts are required to estimate fishing mortality.

Biological Reference Points

Current Reference Points

The existing biomass reference points were developed at SARC 30 (NEFSC 2000) and maintained at SARC 44 (NEFSC 2007) with B_{MSY} Proxy formulated as the 75th percentile of the given time series of each species, except barndoor (Table 39) and half that value for $B_{threshold}$. It was assumed that all species had at some time passed through B_{MSY} at some point in the time series. For barndoor skate, the mean of the first four years of the autumn survey were used instead, given that biomass had been extremely low during most of the time series. To reduce the variability in the survey estimates, a three-year moving average of the survey indices was proposed to evaluate stock status for all species (Table 40).

The fishing mortality reference points developed at SARC 30 were not accepted by the NEFMC and a different method for evaluating fishing mortality was developed by the Plan Development Team (PDT). The thresholds for fishing mortality are based on annual percentage declines of the three-year average of the NEFSC trawl survey time series chosen for the biomass reference points. The percentages are specified for each species individually based on historical variation within the survey. The thresholds also include what is termed a precautionary "backstop" that indicates that overfishing is occurring if the trawl survey mean weight per tow declines for three consecutive years. The main part of the definition is that overfishing is occurring when the three-year moving average of the given survey biomass index declines by more than the average CV of the time series. The resulting overfishing status determinations are shown in Table 41.

Extension of time series

One alternative biomass reference point is to use the 75th percentile of the series, but to add the nine years of survey data since the last SARC (Table 42). This gives slightly lower estimates of B_{target} for winter, thorny, and smooth, a much lower estimate for barndoor, and higher estimates for little, clearnose, and rosette.

An Index Method (AIM)

An Index Method (AIM, available at http://nft.nefsc.noaa.gov/) was attempted for all seven species using both spring and autumn surveys. For this method, the replacement ratios, defined as the biomass index in the current year divided by the average biomass indices from the previous 5 years was calculated. Autumn and spring survey biomass indices and total landings and total catch were used to compute the relative exploitation rates, defined as the catch in the current year divided by the 3 year average survey biomass index for the current year and the previous and following years. These relative exploitation rates (or relative F) may be considered a proxy for F. The relationship between replacement ratios and relative F was evaluated by a linear regression of the Log_e replacement ratio on Log_e relative F. None of the relationships were significant and some were actually positive. This method was also attempted for the aggregate skate landings/catch for the four regions. These model runs were also unsuccessful.

SPR- Based Reference Points

SPR-based reference points for three skate species, barndoor, winter, and thorny, were derived from life-history parameters and fitted Beverton-Holt stock recruit relationships (Appendix 3). Estimated overfishing reference points for these three species are $F_{25\%}$, $F_{37\%}$, and $F_{46\%}$, respectively. Future assessments could estimate comparable F's from mean length models (SEINE, e.g.), or from age-specific assessment models provided discards and landings could be disaggregated to species level. Estimates of overfished reference points are also SPR based, and are defined in terms of depletion, i.e. the proportion of spawners relative to unexploited levels. For barndoor, winter, and thorny skates, the depletion reference points are 0.20, 0.27, and 0.32, respectively. Future assessments could determine stock status by comparing these depletion levels either with depletion in the surveys or from a stock assessment model that incorporates information about maturity. There are several important caveats for the methods used in this working paper, namely, that a fixed value of M was assumed for all ages, that the errors in variables problem was ignored in fitting the stock recruit relationship (*status quo*), and that no fishing is assumed to occur prior to the age of recruitment. The sensitivity to the assumed M value is addressed by exploring alternative values. If any fishing were to occur prior to the age of recruitment, then the estimated slope at the origin (*a* in the Beverton-Holt function) would be biased low, leading to an SPR reference point having a positive bias.

Reference Point Recommendation

In general for skates, no new measurable alternative BRPs were identified or recommended. Until new models are constructed using the new catch by species information, the existing overfishing definitions, using information updated through 2007/2008 (except for barndoor skate), will remain in place (Table 43; Figure 39). For barndoor skate, the reference point estimates will not be updated through 2007/2008 because barndoor skate survey indices were extremely low during most of the time series and have been increasing recently (Table 40).

Under the current definition, a stock of skates is designated as overfished when the three year moving average of the NEFSC survey index is less than $B_{THRESHOLD}$. For each of the skate stocks, estimates of the three year moving average survey index are provided in Table 40.

Overfished status determinations can be made by comparing the survey index estimates (Table 40) to the recommended biomass-based reference points (Table 43).

The overfishing status determinations are shown in Table 41 (See additional description in the earlier section labeled "Current Reference Points".

Research Recommendations

1) Given the new information on catch by species, efforts should be made to use a more complex model such as Stock Synthesis.
2) The identification of the species composition of the skate catch should be improved.
3) Age and growth studies, for all seven species in the complex, should be continued.
4) Fecundity studies, for all seven species in the complex, are needed. Use of life history models requires these data, and may prove useful in establishing biological reference points for the skate species.
5) Estimates of commercial and recreational fishery discard mortality rates, for different fishing gears and coastal regions and/or bottom types, for all seven species in the complex, are needed.
6) Studies of the stock structure of the species in the skate complex are needed to identify unit stocks. Stock identification studies, especially for barndoor, thorny, winter, and little skate, are needed.

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Skate Complex; Tables

Table 1. Total commercial landings of skate (mt) in NAFO subareas 5 and 6 by country from 1960-2007. U.S. landings are from NAFO database from 1964-1978, weighout from 1979-2007.

	US	USSR	Others	Total
1964	4081	0	2	4083
1965	2343	0	20	2363
1966	2738	0	106	2844
1967	2715	2121	62	4898
1968	2417	3974	92	6483
1969	3045	6410	7	9462
1970	1583	2544	1	4128
1971	900	5000	5	5905
1972	866	7957	0	8823
1973	1191	6754	18	7963
1974	2026	1623	2	3651
1975	752	3216	0	3968
1976	754	412	46	1212
1977	1143	240	35	1418
1978	1130	216	7	1353
1979	1280	79	64	1423
1980	1577	0	73	1650
1981	838	0	9	847
1982	878	0	0	878
1983	3603	0	0	3603
1984	4157	0	0	4157
1985	3984	0	0	3984
1986	4159	0	94	4253
1987	5078	0	0	5078
1988	7255	0	9	7264
1989	6707	0	0	6707
1990	11403	0	0	11403
1991	11332	0	0	11332
1992	12525	0	0	12525
1993	12904	0	0	12904
1994	8783	0	0	8783
1995	7217	0	0	7217
1996	14213	0	0	14213
1997	10945	0	0	10945
1998	13832	0	0	13832
1999	11684	0	0	11684
2000	13360	0	0	13360
2001	13120	0	0	13120
2002	13004	0	0	13004
2003	15005	0	0	15005
2004	16072	0	0	16072
2005	14113	0	0	14113
2006	16158	0	0	16158
2007	19085	0	0	19085

Table 2. U.S. commerical landings (mt, live wt) of skates (all species) by month from 1964-2007.

	Month													
year	0	1	2	3	4	5	6	7	8	9	10	11	12	Total
1964	4050.3	2.0	3.9	3.6	3.1	2.0	1.6	0.9	1.3	1.6	2.0	2.1	6.4	4081.0
1965	2304.4	5.4	7.2	7.5	4.3	2.4	0.4	0.6	1.2	0.6	2.3	2.6	4.2	2343.0
1966	2707.1	6.4	7.3	6.0	1.0	0.9	0.2	0.1	0.7	1.7	1.4	2.4	2.9	2738.0
1967	2643.3	15.1	7.3	18.1	7.7	3.0	1.6	0.6	0.4	1.8	6.1	2.9	7.1	2715.0
1968	2381.3	10.3	1.9	5.3	1.3	1.5	1.3	1.5	2.6	3.0	2.8	2.5	1.7	2417.0
1969	2993.4	4.1	6.2	5.7	6.2	2.5	2.3	3.1	3.2	3.0	5.0	5.7	4.6	3045.0
1970	1513.4	6.1	8.6	13.9	7.0	4.1	3.4	5.6	5.3	8.3	4.1	2.1	1.1	1583.0
1971	836.7	4.9	6.2	8.5	7.3	7.7	2.7	3.0	2.8	3.5	8.2	3.9	4.7	900.0
1972	780.1	7.2	6.9	12.1	12.3	9.1	4.9	5.7	7.8	4.3	4.2	5.9	5.5	866.0
1973	1104.1	8.3	3.9	10.4	12.4	7.1	6.7	7.1	7.0	8.1	7.1	4.7	4.1	1191.0
1974	1945.9	5.7	4.9	5.6	12.3	8.0	4.6	4.4	12.3	6.7	5.2	2.6	7.8	2026.0
1975	637.9	7.3	10.1	16.6	16.2	13.0	7.3	6.7	7.6	9.8	5.6	6.9	6.9	752.0
1976	641.8	8.4	12.5	19.2	22.4	9.6	4.3	8.1	4.7	6.9	3.1	6.3	6.8	754.0
1977	994.7	15.4	19.7	27.9	20.0	9.0	8.9	6.8	11.0	7.0	8.8	9.3	4.5	1143.0
1978	827.4	19.3	24.7	11.7	29.8	30.5	46.4	33.9	26.2	23.2	20.9	19.3	16.7	1130.0
1979	787.4	24.8	24.8	46.5	62.6	50.4	28.1	29.4	55.5	38.8	42.1	52.9	36.5	1279.6
1980	961.1	61.5	112.6	121.1	82.8	63.9	27.3	26.4	24.4	22.8	27.4	20.5	25.4	1577.2
1981	509.9	33.9	30.8	54.4	31.1	26.7	25.3	15.1	24.5	23.1	12.3	19.2	31.9	838.4
1982	449.5	30.4	23.3	54.0	47.5	58.2	18.9	25.3	35.1	32.3	34.4	31.3	38.2	878.1
1983	2720.3	84.1	95.9	134.0	95.4	102.3	76.3	44.1	66.1	53.3	37.0	56.6	37.5	3603.0
1984	3325.7	99.4	127.3	134.9	108.6	84.0	36.7	30.9	29.0	25.9	37.0	54.2	63.0	4156.5
1985	3220.7	85.4	85.5	150.6	142.7	31.6	29.9	33.2	29.9	28.8	37.7	59.3	48.6	3984.1
1986	3173.4	98.6	89.7	149.7	147.8	91.8	36.4	33.7	49.0	28.2	72.6	86.3	102.5	4159.5
1987	3638.7	83.8	114.3	207.7	227.0	245.3	106.2	40.3	53.0	33.8	87.6	101.5	139.1	5078.4
1988	5141.7	281.6	338.2	378.7	284.0	150.3	74.5	154.5	137.9	75.0	54.1	66.2	118.8	7255.5
1989	4157.8	240.1	150.3	227.1	454.3	292.6	102.6	142.2	272.3	221.9	174.8	173.0	98.4	6707.3
1990	4252.9	136.6	182.0	424.8	834.4	948.5	1174.9	763.8	818.7	624.4	265.9	542.3	433.4	11402.5
1991	4255.9	464.0	423.8	460.9	606.0	419.8	370.4	658.1	925.7	515.5	565.5	958.9	708.0	11332.3
1992	4782.2	517.3	457.7	510.1	567.1	564.3	816.2	764.4	718.2	862.3	639.1	771.1	555.4	12525.3
1993	4860.4	335.1	265.6	471.2	741.7	875.2	823.2	1005.6	859.1	712.4	535.5	864.0	555.0	12904.0
1994	175.5	338.2	309.8	291.7	501.5	855.1	1238.5	780.9	1263.7	960.6	937.7	787.3	342.9	8783.3
1995	1.0	183.8	285.7	413.6	515.5	752.0	915.7	768.4	752.2	557.7	724.8	897.2	449.7	7217.2
1996	2.3	224.6	229.3	206.5	360.1	1012.0	1389.7	1539.8	1577.6	1720.4	2440.4	2411.8	1098.4	14212.8
1997		530.8	469.9	597.5	395.5	969.4	1127.6	1181.8	1189.6	1062.3	1084.2	1305.2	1031.1	10944.8
1998		518.9	589.8	625.4	814.9	1406.0	1702.2	1643.9	1512.7	1551.5	1224.9	1277.1	964.5	13831.8
1999		511.2	401.0	591.8	678.6	1295.5	1436.2	1039.3	1137.7	1388.8	1055.8	1250.0	898.1	11683.9
2000		667.8	615.2	1024.2	826.2	1187.7	1594.2	1188.5	1534.6	1270.1	946.4	1583.6	921.1	13359.7
2001		802.4	588.6	956.2	967.3	984.0	1058.2	1150.5	1465.1	1197.3	1115.1	1692.1	1143.6	13120.4
2002		742.3	730.7	783.2	1093.9	773.5	1372.6	998.7	1488.6	1247.8	1352.1	1264.4	1156.3	13004.0
2003		548.3	447.6	857.4	1043.7	1006.6	1183.0	1632.9	1867.9	1889.1	1993.3	1563.3	971.9	15004.9
2004		538.1	1278.0	1305.0	1391.0	1155.1	1456.9	2008.8	1557.9	1573.6	1115.7	1541.6	1150.2	16071.8
2005		871.6	1204.4	1077.6	1176.6	1071.0	1314.7	1763.2	1689.3	1336.1	828.5	974.5	805.5	14113.0
2006		939.8	1036.9	1490.8	1564.6	921.8	1250.3	1741.1	1847.2	1071.4	1498.6	1653.3	1142.1	16157.7
2007		778.6	702.9	1225.9	1481.5	1254.7	2524.2	2916.6	2498.0	1587.6	1528.2	1348.4	1238.1	19084.8

Table 3. U.S. commercial landings (mt, live wt) of skates (all species) by state from 1964-2007. Data are from weighout database.

	STATE											
year	CT	DE	ME	MD	MA	NH	NJ	NY	NC	RI	VA	Total
1964					28.2					2.4		30.7
1965					38.1					0.4		38.6
1966					30.1					0.8		30.9
1967					71.1					0.5		71.7
1968					35.7							35.7
1969					51.6							51.6
1970					69.0					0.6		69.6
1971					61.9					1.4		63.3
1972					85.2					0.7		85.9
1973			1.5		80.9					4.6		86.9
1974			8.8		67.2					4.1		80.1
1975			14.9		94.8					4.4		114.1
1976			36.2		74.9					1.1		112.2
1977			62.6		82.0					3.7		148.3
1978			86.9		161.8		2.9			50.9		302.6
1979			181.1		259.0		0.7			51.5		492.2
1980			197.5		297.5		0.4			120.7		616.1
1981			151.2		137.3	2.2	0.8			37.0		328.4
1982			175.0		210.4	3.9	0.1			39.3		428.7
1983			258.8		455.0	3.3	0.6			165.0		882.7
1984			230.8		445.4	2.6	0.7			150.8	0.5	830.8
1985			144.5		409.3	2.3	2.4			204.9		763.3
1986			107.6		363.8	1.1	10.8	55.0		447.2	0.6	986.1
1987			168.9		746.2	20.6	8.9	133.1		361.9		1439.7
1988			81.9		1376.2	51.9	10.5	172.2		420.9		2113.7
1989	12.2		99.8		2030.1	18.6	18.2	107.7		4420.0	0.7	6707.3
1990	146.9		47.1	1.7	5742.0	10.5	8.8	162.4		5282.1	1.1	11402.5
1991	113.3		16.9		5696.1	12.4	125.4	56.9		5310.7	0.6	11332.3
1992	97.0		45.1	0.6	5923.3	10.1	267.2	231.1		5950.1	0.8	12525.3
1993	237.9		167.1	4.1	6118.5	9.5	376.1	168.2		5820.3	2.3	12904.0
1994	175.5		442.9	46.6	6616.4	37.2	186.1	225.3		1047.1	6.4	8783.3
1995	309.3		349.2	45.6	2926.5	24.6	291.4	141.7		3111.5	17.3	7217.2
1996	432.0		267.4	55.8	9016.9	20.3	339.2	164.2		3908.8	8.3	14212.8
1997	357.5		221.0	97.8	3933.4	17.0	794.8	374.5	9.4	5131.4	8.1	10944.8
1998	441.9		162.2	95.6	6325.0	19.1	807.8	575.0	9.1	5372.5	23.6	13831.8
1999	518.3		218.8	63.5	4809.3	26.3	636.8	396.8	2.6	4911.9	99.6	11684.0
2000	493.8		138.0	65.6	6517.8	38.4	564.6	387.7	20.6	4825.0	308.2	13359.7
2001	618.9		138.2	55.5	6683.5	33.2	624.7	366.7	0.1	4536.2	63.4	13120.4
2002	367.6		137.2	52.0	6335.0	24.5	582.4	462.9	0.3	5029.6	12.7	13004.0
2003	433.7		76.4	26.9	8098.0	14.9	448.7	353.3	0.8	5516.6	35.7	15004.9
2004	441.7	0.0	13.3	6.2	10075.9	10.6	374.3	222.7	0.5	4881.0	45.7	16071.8
2005	353.4		10.9	8.4	8988.9	9.4	334.8	157.5	0.5	4219.1	30.3	14113.0
2006	259.6		1.5	14.6	11132.7	11.2	451.6	229.3	0.1	4051.5	5.5	16157.7
2007	256.2		29.9	18.2	13554.4	5.6	524.1	324.9	0.3	4319.4	51.8	19084.8

Table 4. U.S. Commercial landings (mt, live wt) of skates (all species) by gear type from 1964-2007. Landings are from weighout database.

	gear				
year	longline	otter trawl	other	sink gillnet	Total
1964	0.1	30.5		0.0	30.7
1965	0.3	38.2		0.0	38.6
1966		30.9			30.9
1967		71.7			71.7
1968		35.7			35.7
1969		51.5		0.0	51.6
1970	0.6	68.8	0.0	0.2	69.6
1971	1.1	62.0		0.1	63.3
1972	3.7	80.8	0.1	1.3	85.9
1973	7.0	77.9	1.9	0.2	86.9
1974	10.5	64.3	0.2	5.1	80.1
1975	11.7	101.4	0.1	0.8	114.1
1976	16.2	93.3	0.2	2.5	112.2
1977	13.4	126.8	0.9	7.2	148.3
1978	4.4	290.0	3.2	5.0	302.6
1979	18.4	456.0	5.8	12.0	492.2
1980	16.5	577.9	6.0	15.6	616.1
1981	5.1	311.7	1.2	10.4	328.4
1982	2.0	408.4	7.4	10.8	428.7
1983	3.4	846.2	22.5	10.6	882.7
1984	5.0	796.5	19.1	10.3	830.8
1985	3.7	721.5	17.8	20.3	763.3
1986	6.6	954.4	14.2	10.9	986.1
1987	22.4	1384.4	16.1	16.8	1439.7
1988	5.7	2070.7	22.2	15.2	2113.7
1989	30.6	6636.1	27.3	13.4	6707.3
1990	3.8	11339.6	47.7	11.5	11402.5
1991	24.3	11169.9	77.0	61.1	11332.3
1992	21.9	12242.5	35.1	225.8	12525.3
1993	63.4	11913.6	204.6	722.3	12904.0
1994	193.9	7174.3	374.9	1040.1	8783.3
1995	98.6	5725.5	416.2	976.8	7217.2
1996	54.3	12879.6	141.9	1137.1	14212.8
1997	47.6	9157.6	394.0	1345.5	10944.8
1998	53.9	11704.7	449.8	1623.5	13831.8
1999	38.2	10073.7	105.5	1466.6	11684.0
2000	37.7	11444.7	81.7	1795.5	13359.7
2001	13.2	10808.4	46.4	2252.5	13120.4
2002	14.2	9630.3	45.0	3314.5	13004.0
2003	30.0	10553.2	65.1	4356.5	15004.9
2004	24.7	11355.7	665.7	4025.7	16071.8
2005	175.9	9249.8	1078.6	3608.8	14113.0
2006	11.4	10523.0	838.2	4785.0	16157.7
2007	12.2	12531.0	339.1	6202.6	19084.8

Table 5. Landings of skate by region.

	gm	gb	sne	ma
1968	30	2641	3802	10
1969	50	252	8425	735
1970	62	1742	2178	146
1971	51	2681	3014	159
1972	264	5384	3087	88
1973	60	5097	2701	105
1974	63	1116	2359	113
1975	95	2965	722	186
1976	96	450	487	179
1977	126	215	823	254
1978	181	94	871	207
1979	469	215	559	179
1980	609	394	465	182
1981	344	122	272	109
1982	434	165	216	63
1983	486	240	2824	53
1984	445	234	3411	71
1985	372	183	3379	50
1986	309	103	3634	207
1987	585	333	3968	193
1988	1140	404	5394	326
1989	909	1243	4395	160
1990	1076	4905	5249	173
1991	979	4801	5306	246
1992	644	4944	6430	508
1993	982	5143	5826	953
1994	800	5964	1340	680
1995	590	2060	3826	742
1996	579	8210	4579	845
1997	549	3095	5802	1498
1998	1064	5160	5392	2216
1999	909	3997	4390	2388
2000	1050	5517	4508	2284
2001	689	5784	4294	2354
2002	799	4936	4516	2753
2003	491	6811	5575	2129
2004	259	8632	5060	2121
2005	310	6900	5571	1333
2006	337	8367	6173	1280
2007	358	11502	5664	1561

Table 6. U.S. landings (mt, live wt) of skates by species and markey category from 1964-2007. Landings are from weighout database.

	Species and Market Category																	
YEAR	Uncl.	Uncl.	Winter	Winter	Little	Little	Barndoor	Barndoor	Thorny	Thorny	Smooth	Smooth	Clearnose	Clearnose	Rose	Rose	Total	
	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings
1964	30.7																30.7	0.0
1965	38.6																38.6	0.0
1966	30.9																30.9	0.0
1967	71.7																71.7	0.0
1968	35.7																35.7	0.0
1969	51.6																51.6	0.0
1970	69.6																69.6	0.0
1971	63.3																63.3	0.0
1972	85.9																85.9	0.0
1973	86.9																86.9	0.0
1974	80.1		0.0														80.1	0.0
1975	114.1																114.1	0.0
1976	112.2																112.2	0.0
1977	148.3																148.3	0.0
1978	302.6																302.6	0.0
1979	492.2																492.2	0.0
1980	616.1																616.1	0.0
1981	328.4																328.4	0.0
1982	277.2	151.4															277.2	151.4
1983	169.6	713.0															169.6	713.0
1984	68.1	762.8															68.1	762.8
1985	68.3	695.0															68.3	695.0
1986	262.6	723.5															262.6	723.5
1987	87.5	1352.2															87.5	1352.2
1988	74.2	2039.6															74.2	2039.6
1989	4163.1	2544.2															4163.1	2544.2
1990	5002.9	6399.6															5002.9	6399.6
1991	5069.2	6262.5			0.6												5069.7	6262.5
1992	5860.5	6664.7															5860.5	6664.7
1993	5526.6	7377.5	0.0														5526.6	7377.5
1994	703.4	8079.9															703.4	8079.9
1995	3095.1	3985.5			136.6												3231.7	3985.5
1996	3981.5	10230.8	0.4		0.2												3982.0	10230.8
1997	5369.1	5575.6															5369.1	5575.6
1998	5391.8	8440.0			0.0												5391.8	8440.0
1999	5026.7	6655.3					2.1										5028.7	6655.3
2000	3633.2	8690.6	0.0		1036.0	0.1	0.0										4669.1	8690.6
2001	4399.5	8718.5	2.2		0.0	0.1						0.1					4401.7	8718.7
2002	4396.9	8606.9				0.1		0.1									4396.9	8607.1
2003	4327.8	10650.0	0.8	26.0	0.2						0.1						4328.8	10676.0
2004	998.1	8450.3	2.8	2697.5	2867.4	8.6	0.3	0.1	0.0	95.6	1.0	927.2	3.5	16.6		2.7	3873.2	12198.5
2005	417.1	6679.4	59.3	3301.4	3449.6	15.6	0.2	5.4	1.5	126.2	0.6	1.0	33.3		16.6	5.9	3978.2	10134.9
2006	1101.0	8543.5	79.3	2904.6	3138.3	6.4		2.2		137.4	0.6	31.9	189.6		8.5	14.5	4517.2	11640.5
2007	1279.3	11129.7	41.0	2796.4	3479.4	0.3		1.2	11.5	113.4	0.1	26.7	176.1		15.1	14.8	5002.5	14082.4

Table 7. U.S. landings (mt, live wt) of skates by state, species and markey category from 2004-2007.

		Species and Market Category																Total	
		Uncl.	Uncl.	Winter	Winter	Little	Little	Barndoor	Barndoor	Thorny	Thorny	Smooth	Smooth	Clearnose	Clearnose	Rosette	Rosette		
YEAR	State	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings	Whole	Wings
2004	CT	369.9	71.8															369.9	71.8
	DE	0.0																0.0	0.0
	ME	0.0	12.2		1.2													0.0	13.3
	MD	1.0	2.4		2.7	0.1												1.1	5.1
	MA	17.7	6482.2	0.2	2467.9	97.5				0.0	83.4	0.1	926.8				0.1	115.5	9960.4
	NH		5.1		5.4						0.1							0.0	10.6
	NJ	1.5	131.2	0.3	135.5	103.0	2.7				0.1							104.8	269.5
	NY	23.3	183.6	1.2	0.6	0.7	0.1				12.0	1.0	0.3					26.1	196.7
	NC		0.5															0.0	0.5
	RI	583.7	1537.3	1.2	84.2	2666.1	5.8										2.6	3251.0	1630.0
	VA	1.1	24.0					0.3	0.1					3.5	16.6			4.9	40.8
	Total	998.1	8450.3	2.8	2697.5	2867.4	8.6	0.3	0.1	0.0	95.6	1.0	927.2	3.5	16.6	0.0	2.7	3873.2	12198.5
2005	CT	275.6	77.7															275.6	77.7
	ME		10.2		0.5		0.2											0.0	10.8
	MD	2.3	6.1															2.3	6.1
	MA	60.2	5699.0	21.7	3071.7	21.1			1.3	1.5	111.6	0.0	0.7					104.5	8884.4
	NH	0.0	9.4															0.0	9.4
	NJ	0.4	120.0	24.4	110.7	45.0	1.1					0.4		32.7				102.9	231.9
	NY	12.3	96.6	0.4	1.6	12.7	0.2	0.2	4.1		12.6	0.0	0.3			16.6		42.2	115.3
	NC		0.5															0.0	0.5
	RI	65.9	630.4	12.8	116.9	3370.9	14.1				2.0	0.2	0.1				5.9	3449.7	769.4
	VA	0.3	29.3											0.7				1.0	29.3
	Total	417.1	6679.4	59.3	3301.4	3449.6	15.6	0.2	5.4	1.5	126.2	0.6	1.0	33.3	0.0	16.6	5.9	3978.2	10134.9
2006	CT	190.5	69.1															190.5	69.1
	ME		1.5															0.0	1.5
	MD	5.0	4.2		2.3	2.2	0.9											7.2	7.4
	MA	834.2	7584.2	62.7	2317.9	196.2	0.2				136.6	0.6					0.0	1093.7	10039.0
	NH		11.2								0.0							0.0	11.2
	NJ	5.3	45.8	0.7	165.9	11.8	2.9						31.8		187.4			17.8	433.9
	NY	11.2	176.0		19.3	10.1			2.2				0.1			8.5	2.1	29.7	199.6
	NC	0.1	0.0															0.1	0.0
	RI	54.7	648.1	15.9	399.2	2918.1	2.4				0.8						12.4	2988.6	1062.9
	VA		3.4											2.2				2.2	3.4
	Total	1101.0	8543.5	79.3	2904.6	3138.3	6.4	0.0	2.2	0.0	137.4	0.6	31.9	2.2	187.4	8.5	14.5	4329.8	11827.9
2007	CT	195.4	60.8															195.4	60.8
	ME		29.9															0.0	29.9
	MD	9.0	6.9		1.5	0.4	0.3											9.4	8.8
	MA	958.0	9993.9	22.7	2390.9	56.3				11.5	103.2		18.0					1048.4	12506.1
	NH		5.3		0.3													0.0	5.6
	NJ	0.1	107.2	1.8	203.4	31.8							8.3	171.6				205.2	318.9
	NY	14.3	247.8	8.3	27.8	3.9			1.2		9.4	0.1	0.3			11.9		38.5	286.4
	NC	0.3																0.3	0.0
	RI	91.7	645.4	8.2	171.5	3387.0					1.1			4.5			14.8	3491.5	832.7
	VA																	0.0	0.0
	Total	1268.7	11097.2	41.0	2795.3	3479.4	0.3	0.0	1.2	11.5	113.7	0.1	26.7	176.1	0.0	11.9	14.8	4988.7	14049.2

Table 8. Estimated discards (mt) of skates (all species) by gear type taken in the Gulf of Maine-Georges Bank region, 1964-2007.

			Half 1		Scallop				Half 2		Scallop		
year	Line Trawl	Otter Trawl	Shrimp Trawl	Sink Gill Net	Dredge	Total Half 1	Line Trawl	Otter Trawl	Shrimp Tra	Sink Gill Net	Dredge	Total Half 2	Grand Total
1964	449	37,255	0	12	5,868	43,583	403	22,824	0	7	6,541	29,775	73,358
1965	498	38,321	0	16	2,284	41,120	522	24,329	0	5	600	25,456	66,575
1966	380	39,624	0	26	742	40,771	491	22,374	0	7	1,506	24,379	65,149
1967	329	30,462	0	21	575	31,387	323	19,148	0	8	2,295	21,775	53,162
1968	259	26,067	0	36	728	27,090	299	18,036	0	10	1,651	19,995	47,085
1969	281	25,173	0	32	1,004	26,490	455	15,909	0	6	1,935	18,305	44,795
1970	308	22,927	0	22	1,228	24,485	415	15,208	0	7	1,890	17,520	42,005
1971	472	21,746	0	21	1,749	23,988	615	14,941	0	8	1,458	17,023	41,011
1972	476	19,491	0	31	1,217	21,215	659	12,401	0	13	1,724	14,796	36,011
1973	569	19,548	0	30	1,758	21,905	640	13,558	0	15	1,502	15,715	37,620
1974	614	17,687	0	57	1,043	19,400	592	11,947	0	24	1,413	13,976	33,377
1975	680	15,631	280	60	1,303	17,953	613	11,792	36	26	2,047	14,514	32,467
1976	464	15,157	66	97	1,650	17,434	353	12,139	0	37	3,115	15,645	33,078
1977	341	19,662	39	166	3,299	23,507	294	14,148	0	47	7,176	21,664	45,171
1978	561	23,070	0	186	4,012	27,828	321	14,383	0	66	7,889	22,658	50,487
1979	779	22,771	26	153	5,275	29,004	508	16,612	0	67	8,454	25,641	54,645
1980	851	28,570	21	185	7,342	36,969	155	18,066	0	96	6,972	25,288	62,258
1981	332	29,786	99	252	8,206	38,676	95	15,643	0	93	9,501	25,332	64,008
1982	302	26,789	124	89	5,632	32,937	74	19,496	7	83	7,936	27,596	60,533
1983	297	29,695	115	113	4,802	35,022	93	16,467	22	69	5,663	22,314	57,336
1984	307	27,882	152	121	3,463	31,925	19	13,640	53	94	4,359	18,165	50,090
1985	263	22,242	225	112	2,308	25,149	52	10,748	70	81	4,720	15,671	40,820
1986	322	19,142	252	166	4,010	23,892	49	8,856	83	87	6,206	15,281	39,173
1987	536	15,330	288	137	3,905	20,197	166	8,272	46	85	7,574	16,144	36,340
1988	561	17,091	183	158	6,175	24,169	199	8,410	46	90	10,002	18,746	42,915
1989	503	18,497	73	37	6,349	25,459	161	8,727	17	1,265	11,105	21,276	46,735
1990	358	23,476	208	347	7,290	31,680	156	9,910	71	940	15,222	26,299	57,979
1991	1,069	11,624	243	99	9,842	22,877	264	8,680	44	628	10,383	19,999	42,876
1992	1,269	8,056	245	162	8,843	18,575	471	2,848	0	518	10,919	14,756	33,331
1993	169	4,528	35	119	4,512	9,362	125	11,482	1	1,406	4,928	17,942	27,305
1994	82	4,912	11	130	2,294	7,429	146	10,132	1	1,382	2,103	13,764	21,193
1995	147	7,492	8	209	398	8,253	152	2,312	1	2,029	1,647	6,141	14,393
1996	123	7,507	26	284	837	8,777	121	1,181	8	1,921	3,029	6,259	15,037
1997	119	3,788	32	110	1,804	5,854	123	3,189	2	987	3,165	7,466	13,320
1998	99	5,276	8	50	2,376	7,809	142	15,784	0	1,930	4,101	21,957	29,767
1999	112	2,870	4	98	1,207	4,292	123	7,146	0	1,799	2,957	12,024	16,316
2000	62	4,490	5	121	2,086	6,764	131	7,584	0	2,100	1,387	11,201	17,965
2001	87	19,242	0	188	518	20,034	92	6,262	0	1,241	582	8,176	28,210
2002	97	11,085	1	135	1,095	12,413	44	5,761	0	1,844	2,030	9,680	22,093
2003	34	11,684	8	253	1,836	13,815	24	9,848	0	1,995	1,975	13,842	27,656
2004	3	11,505	4	269	294	12,075	17	13,832	0	1,027	1,060	15,937	28,012
2005	91	9,468	2	399	594	10,554	54	12,844	0	925	2,212	16,034	26,588
2006	193	8,042	0	173	1,085	9,494	17	9,344	1	1,599	2,408	13,369	22,863
2007	46	10,703	0	378	871	11,999	27	11,158	0	1,439	3,418	16,042	28,041

Table 9. Estimated discards (mt) of skates (all species) by gear type taken in the Southern New England-Mid-Atlantic region, 1964-2007.

			Half 1	Scallop				Half 2	Scallop		
year	Line Trawl	Otter Trawl	Sink Gill Net	Dredge	Total Half 1	Line Trawl	Otter Trawl	Sink Gill Ne	Dredge	Total Half 2	Grand Total
1964	0	16,916	0	1	16,917	0	12,929	0	494	13,422	30,339
1965	0	20,746	0	2,108	22,854	0	15,053	0	7,343	22,396	45,250
1966	0	23,680	0	5,026	28,707	0	11,657	0	4,067	15,724	44,431
1967	0	26,886	0	2,257	29,143	0	13,933	0	1,771	15,704	44,848
1968	0	30,741	0	2,926	33,667	0	13,895	0	2,516	16,411	50,077
1969	1	30,557	0	1,279	31,837	1	11,827	0	683	12,510	44,348
1970	2	21,694	0	399	22,095	0	10,272	0	462	10,734	32,829
1971	2	13,419	0	91	13,511	0	4,979	0	756	5,735	19,246
1972	2	13,272	0	724	13,999	1	6,373	0	488	6,862	20,860
1973	11	15,425	0	391	15,828	4	6,227	0	173	6,404	22,232
1974	30	19,170	0	706	19,906	11	5,279	0	987	6,277	26,183
1975	30	9,882	0	1,069	10,981	11	5,131	0	2,060	7,202	18,183
1976	17	7,688	0	2,175	9,880	9	7,804	0	3,979	11,792	21,672
1977	9	7,639	0	3,302	10,950	3	7,169	0	1,352	8,525	19,475
1978	185	12,605	0	3,946	16,736	168	8,389	0	4,215	12,772	29,509
1979	86	16,229	0	3,399	19,714	164	10,770	0	2,929	13,862	33,576
1980	170	11,730	0	2,314	14,213	131	10,958	0	2,355	13,444	27,657
1981	180	13,828	0	1,065	15,072	131	10,028	0	976	11,135	26,208
1982	115	17,088	0	1,597	18,800	77	17,764	0	2,699	20,540	39,340
1983	99	20,196	0	3,646	23,941	66	15,883	0	4,480	20,429	44,371
1984	79	21,023	0	4,933	26,035	46	17,034	0	4,046	21,126	47,161
1985	56	18,452	0	4,302	22,809	66	12,401	0	3,220	15,687	38,496
1986	94	18,225	0	3,215	21,534	74	17,119	0	4,117	21,310	42,844
1987	99	21,129	0	8,277	29,504	81	15,105	0	8,492	23,678	53,182
1988	78	18,544	0	7,704	26,326	13	13,960	0	6,365	20,339	46,664
1989	45	19,166	0	12,414	31,625	22	11,537	0	5,363	16,923	48,548
1990	35	26,989	0	10,327	37,352	29	25,810	0	4,662	30,501	67,853
1991	112	11,258	0	8,285	19,655	64	21,176	0	5,567	26,807	46,462
1992	234	5,097	107	4,661	10,100	245	16,761	51	7,177	24,234	34,333
1993	75	3,466	94	5,366	9,000	34	10,309	45	7,260	17,648	26,648
1994	36	59,775	135	4,193	64,140	16	6,039	150	3,250	9,454	73,595
1995	18	15,368	234	8,729	24,349	23	9,305	91	18,394	27,813	52,162
1996	40	8,046	135	7,738	15,960	34	23,207	66	8,544	31,851	47,811
1997	58	2,978	282	9,318	12,636	49	2,957	76	3,779	6,861	19,496
1998	47	22,088	167	4,300	26,601	36	4,876	194	4,372	9,479	36,080
1999	23	920	500	6,023	7,466	17	2,370	140	4,990	7,517	14,983
2000	19	2,341	60	3,241	5,661	23	8,924	52	3,335	12,333	17,994
2001	31	1,750	215	3,260	5,256	38	1,989	51	2,701	4,779	10,035
2002	26	1,049	255	5,190	6,520	82	3,721	2,242	5,691	11,736	18,255
2003	36	6,200	268	6,096	12,600	32	7,549	289	6,108	13,978	26,578
2004	36	2,864	180	5,178	8,258	7	7,629	248	3,099	10,982	19,240
2005	0	4,633	634	5,523	10,789	0	6,115	354	2,419	8,888	19,678
2006	2	2,526	676	4,676	7,880	0	2,846	68	2,507	5,421	13,301
2007	0	3,913	661	5,234	9,808	0	5,334	406	4,161	9,901	19,709

Table 10. Estimated discards (mt) of skates (all species) by gear type, 1964-2007.

			Half 1						Half 2				
year	Line Trawl	Otter Trawl	Shrimp Trawl	Sink Gill Net	Scallop Dredge	Total Half 1	Line Trawl	Otter Trawl	Shrimp Tra	Sink Gill Net	Scallop Dredge	Total Half 2	Grand Total
1964	449	54,171	0	12	5,869	60,500	403	35,752	0	7	7,035	43,197	103,696
1965	498	59,067	0	16	4,392	63,974	522	39,381	0	5	7,943	47,852	111,826
1966	380	63,304	0	26	5,768	69,478	491	34,031	0	7	5,573	40,103	109,580
1967	329	57,348	0	21	2,832	60,530	323	33,081	0	8	4,066	37,479	98,009
1968	259	56,808	0	36	3,653	60,756	299	31,931	0	10	4,167	36,406	97,162
1969	283	55,730	0	32	2,283	58,327	455	27,736	0	6	2,617	30,815	89,142
1970	310	44,621	0	22	1,627	46,580	415	25,480	0	7	2,352	28,253	74,833
1971	474	35,165	0	21	1,840	37,499	615	19,920	0	8	2,214	22,758	60,257
1972	478	32,764	0	31	1,941	35,213	659	18,774	0	13	2,211	21,658	56,871
1973	580	34,973	0	30	2,150	37,732	644	19,785	0	15	1,674	22,119	59,852
1974	644	36,856	0	57	1,749	39,306	603	17,226	0	24	2,400	20,253	59,560
1975	710	25,513	280	60	2,371	28,934	624	16,923	36	26	4,106	21,716	50,650
1976	481	22,845	66	97	3,825	27,314	362	19,943	0	37	7,094	27,436	54,750
1977	350	27,301	39	166	6,601	34,457	296	21,317	0	47	8,528	30,189	64,646
1978	746	35,675	0	186	7,958	44,565	489	22,772	0	66	12,104	35,430	79,995
1979	864	39,000	26	153	8,674	48,717	672	27,382	0	67	11,382	39,504	88,221
1980	1,021	40,300	21	185	9,656	51,183	285	29,024	0	96	9,327	38,732	89,915
1981	512	43,614	99	252	9,271	53,749	226	25,671	0	93	10,478	36,467	90,216
1982	417	43,877	124	89	7,228	51,737	151	37,260	7	83	10,635	48,136	99,873
1983	396	49,891	115	113	8,448	58,963	159	32,350	22	69	10,143	42,744	101,707
1984	385	48,904	152	121	8,396	57,959	65	30,674	53	94	8,406	39,292	97,251
1985	318	40,693	225	112	6,609	47,958	117	23,149	70	81	7,940	31,358	79,316
1986	415	37,367	252	166	7,225	45,425	123	25,975	83	87	10,323	36,591	82,016
1987	635	36,459	288	137	12,182	49,701	247	23,377	46	85	16,066	39,821	89,523
1988	639	35,635	183	158	13,879	50,495	212	22,370	46	90	16,366	39,085	89,579
1989	547	37,663	73	37	18,763	57,084	183	20,264	17	1,265	16,469	38,198	95,282
1990	393	50,465	208	347	17,618	69,032	185	35,720	71	940	19,884	56,800	125,832
1991	1,181	22,882	243	99	18,127	42,532	328	29,856	44	628	15,950	46,806	89,338
1992	1,503	13,153	245	269	13,504	28,674	716	19,609	0	569	18,096	38,990	67,664
1993	244	7,994	35	212	9,877	18,362	160	21,791	1	1,452	12,187	35,591	53,953
1994	118	64,688	11	265	6,487	71,569	162	16,171	1	1,532	5,352	23,218	94,788
1995	165	22,860	8	443	9,127	32,602	176	11,617	1	2,120	20,041	33,954	66,556
1996	164	15,554	26	419	8,575	24,737	155	24,388	8	1,987	11,573	38,110	62,848
1997	177	6,766	32	392	11,123	18,489	172	6,146	2	1,062	6,944	14,327	32,816
1998	146	27,363	8	217	6,676	34,410	178	20,659	0	2,124	8,474	31,436	65,846
1999	136	3,790	4	598	7,230	11,758	139	9,516	0	1,939	7,947	19,542	31,299
2000	81	6,831	5	181	5,326	12,425	153	16,508	0	2,152	4,721	23,535	35,959
2001	118	20,992	0	403	3,778	25,290	130	8,250	0	1,292	3,283	12,955	38,245
2002	123	12,134	1	390	6,285	18,933	126	9,482	0	4,087	7,721	21,416	40,348
2003	70	17,884	8	522	7,931	26,415	56	17,397	0	2,284	8,083	27,820	54,235
2004	40	14,369	4	449	5,472	20,333	24	21,461	0	1,275	4,159	26,919	47,252
2005	91	14,100	2	1,033	6,117	21,343	54	18,959	0	1,279	4,630	24,922	46,265
2006	194	10,569	0	849	5,761	17,374	18	12,190	1	1,667	4,916	18,790	36,164
2007	46	14,616	0	1,038	6,105	21,807	27	16,492	0	1,845	7,579	25,943	47,750

Table 11. Coefficients of variation for the discard estimates from the two main gear types.

	Scallop dredge	Otter trawl
1992	164.5	27.6
1993	65.8	24.9
1994	137.2	26.0
1995	84.9	22.4
1996	40.9	36.1
1997	48.2	30.3
1998	116.5	17.5
1999	120.5	19.6
2000	196.7	18.6
2001	109.1	50.8
2002	68.8	8.9
2003	384.3	11.3
2004	70.1	8.2
2005	194.0	5.3
2006	184.8	6.8
2007	94.5	6.0

Table 12. Number of landed skates measured by fishery, region and season. The bait fishery are fish <= 60 cm while the wings are those > 60 cm.

GOM-GBK

		half 1			half 2		
YEAR	bait	wings	half 1 total	bait	wings	half 1 total	Grand Total
1994	27	36	63	19	20	39	102
1995	0	118	118	0	0	0	118
1996	45	38	83	4	14	18	101
1997	0	0	0	1	15	16	16
1998	0	17	17	0	0	0	17
1999	8	160	168	0	251	251	419
2000	43	102	145	0	438	438	583
2001	0	378	378	40	1222	1262	1640
2002	1	591	592	22	2088	2110	2702
2003	4	1304	1308	166	6656	6822	8130
2004	62	1464	1526	114	5931	6045	7571
2005	147	917	1064	146	1543	1689	2753
2006	34	1063	1097	175	7087	7262	8359
2007	232	46	278	39	21	60	338

SNE-MA

		half 1			half 2		
YEAR	bait	wings	half 1 total	bait	wings	half 1 total	Grand Total
1994	0	0	0	155	191	346	346
1995	9	327	336	301	17	318	654
1996	2	408	410	152	128	280	690
1997	295	257	552	14	441	455	1007
1998	27	1462	1489	199	653	852	2341
1999	67	305	372	76	264	340	712
2000	131	335	466	526	69	595	1061
2001	886	502	1388	1359	1967	3326	4714
2002	932	873	1805	95	286	381	2186
2003	540	489	1029	939	2228	3167	4196
2004	811	2542	3353	133	945	1078	4431
2005	706	854	1560	1121	774	1895	3455
2006	1300	563	1863	584	152	736	2599
2007	749	606	1355	2288	332	2620	3975

Table 13. Selectivity parameter estimates for observed skate landings fitted to survey length frequencies using the SELECT model (Millar 1992).

	Winter skate								
	Trawl, wings			Trawl, whole			Gillnet		
	GoM	GB	MA	GoM	GB	MA	GoM	GB	MA
a =	Insufficient data	1.278	Insufficient data	Insufficient data	4.401	-3.800	3.311	2.109	1.595
b =		0.103			0.037	0.148	0.052	0.075	0.094
$\delta =$		0.00042			0.00192	0.01032	0.00147	0.00102	0.00092
L50%		**66.911**			**60.817**	**59.030**	**68.626**	**68.381**	**61.597**
SE		34530.57			901.88	4817.01	689.32	2215.72	2709.99
Range		15.32			43.07	10.66	30.19	20.90	16.81
Log-likelihood		-11.74			-26.84	-14.49	-22.41	-18.90	-15.62
AIC		29.49			59.68	34.98	50.82	43.80	37.23

	Little skate								
	Trawl, wings			Trawl, whole			Gillnet		
	GoM	GB	MA	GoM	GB	MA	GoM	GB	MA
a =	Insufficient data	Insufficient data	Insufficient data	-0.004	2.094	6.287	Insufficient data	-2.141	2.418
b =				0.111	0.125	-0.070		0.106	0.095
$\delta =$				0.01140	0.00082	0.03171		0.10842	0.00154
L50%				**43.46**	**43.04**	**35.57**		**44.23**	**46.73**
SE				774.22	4369.11	82.34		18.53	1967.88
Range				14.18	12.58	-22.80		15.39	16.62
Log-likelihood				-8.38	-5.08	-20.09		-7.42	-6.99
AIC				22.75	16.16	46.18		20.85	19.99

	All landed skates								
	Trawl, wings				Trawl, whole				Gillnet
	GoM	GB	MA	All	GoM	GB	MA	All	GoM
a =	Insufficient data	Insufficient data	Insufficient data	-0.080	2.407	1.800	1.689	5.014	1.030
b =				0.112	0.076	0.065	0.031	0.052	0.100
$\delta =$				0.002	0.003	0.010	0.068	0.001	0.001
L50%				**59.85**	**48.75**	**48.35**	**43.03**	**44.36**	**60.42**
SE				16247.71	1390.32	276.63	27.61	1789.43	231.93
Range				14.05	20.80	24.14	51.36	30.00	15.77
Log-likelihood				-5.28	-19.86	-12.20	-20.96	-11.23	-18.79
AIC				16.55	45.72	30.40	47.92	28.45	43.59

Table 14. Species composition of landings using the length composition method. The first three columns are metric tons, the last three are in pounds.

	market				market		
		bait	wings	Grand Total	bait	wings	Grand Total
1995	winter	1060.72	3392.77	4453.48	2,338,486	7,479,767	9,818,252
	little	1926.66	0.00	1926.66	4,247,565	0	4,247,565
	barndoor	2.08	81.03	83.11	4,584	178,644	183,227
	thorny	0.60	313.97	314.57	1,330	692,180	693,511
	smooth	0.77	0.00	0.77	1,706	0	1,706
	clearnose	214.47	134.01	348.48	472,827	295,431	768,258
	rosette	5.39	0.00	5.39	11,886	0	11,886
	Total	3210.70	3921.77	7132.47	7,078,384	8,646,022	15,724,406
1996	winter	1165.20	8886.34	10051.54	2,568,833	19,591,016	22,159,849
	little	2399.89	0.00	2399.89	5,290,862	0	5,290,862
	barndoor	0.02	336.37	336.39	38	741,568	741,606
	thorny	0.39	759.13	759.51	851	1,673,587	1,674,438
	smooth	0.37	0.00	0.37	822	0	822
	clearnose	377.56	162.33	539.89	832,372	357,871	1,190,243
	rosette	11.01	0.00	11.01	24,268	0	24,268
	Total	3954.44	10144.16	14098.60	8,718,046	22,364,042	31,082,087
1997	winter	1050.68	4303.02	5353.70	2,316,356	9,486,530	11,802,887
	little	3792.04	0.00	3792.04	8,360,013	0	8,360,013
	barndoor	0.01	281.03	281.04	26	619,554	619,580
	thorny	1.38	509.00	510.38	3,046	1,122,149	1,125,195
	smooth	2.64	4.35	6.99	5,815	9,584	15,399
	clearnose	451.84	296.89	748.73	996,134	654,530	1,650,664
	rosette	12.90	0.00	12.90	28,439	0	28,439
	Total	5311.49	5394.28	10705.77	11,709,829	11,892,347	23,602,176
1998	winter	1025.76	7318.49	8344.25	2,261,416	16,134,513	18,395,929
	little	4028.73	0.00	4028.73	8,881,828	0	8,881,828
	barndoor	0.62	160.49	161.12	1,378	353,828	355,205
	thorny	1.91	626.28	628.19	4,205	1,380,710	1,384,915
	smooth	7.83	0.00	7.83	17,264	0	17,264
	clearnose	266.14	181.31	447.45	586,744	399,721	986,465
	rosette	27.33	0.00	27.33	60,253	0	60,253
	Total	5358.33	8286.58	13644.90	11,813,088	18,268,771	30,081,859
1999	winter	1040.52	5826.05	6866.57	2,293,964	12,844,231	15,138,195
	little	3680.41	0.00	3680.41	8,113,912	0	8,113,912
	barndoor	5.59	446.78	452.37	12,324	984,972	997,296
	thorny	0.50	203.22	203.71	1,092	448,014	449,105
	smooth	0.95	1.15	2.09	2,089	2,527	4,617
	clearnose	234.34	90.02	324.36	516,626	198,458	715,084
	rosette	15.35	0.00	15.35	33,841	0	33,841
	Total	4977.65	6567.20	11544.86	10,973,848	14,478,203	25,452,051

Table 14 cont.

		market bait	wings	Grand Total	market bait	wings	Grand Total
2000	winter	833.19	7539.80	8372.99	1,836,873	16,622,407	18,459,279
	little	3334.57	1.45	3336.02	7,351,473	3,197	7,354,670
	barndoor	2.03	492.39	494.42	4,484	1,085,523	1,090,007
	thorny	1.18	465.21	466.39	2,602	1,025,606	1,028,208
	smooth	2.49	5.18	7.67	5,482	11,416	16,899
	clearnose	405.42	96.52	501.95	893,806	212,795	1,106,601
	rosette	19.96	0.00	19.96	44,009	0	44,009
	Total	4598.85	8600.54	13199.39	10,138,729	18,960,944	29,099,673
2001	winter	1057.56	6597.72	7655.28	2,331,521	14,545,480	16,877,001
	little	1700.99	0.00	1700.99	3,750,031	0	3,750,031
	barndoor	5.21	1531.64	1536.85	11,489	3,376,682	3,388,171
	thorny	4.55	190.88	195.42	10,026	420,810	430,836
	smooth	18.78	0.00	18.78	41,397	0	41,397
	clearnose	1558.81	301.26	1860.07	3,436,582	664,174	4,100,756
	rosette	8.61	0.00	8.61	18,992	0	18,992
	Total	4354.50	8621.50	12976.00	9,600,038	19,007,146	28,607,184
2002	winter	1230.90	5863.28	7094.18	2,713,677	12,926,318	15,639,994
	little	2371.81	0.00	2371.81	5,228,949	0	5,228,949
	barndoor	69.34	2054.33	2123.66	152,866	4,529,014	4,681,879
	thorny	2.31	399.32	401.63	5,085	880,356	885,441
	smooth	16.97	0.28	17.24	37,406	608	38,014
	clearnose	588.66	51.55	640.20	1,297,766	113,637	1,411,403
	rosette	10.72	0.00	10.72	23,629	0	23,629
	Total	4290.70	8368.75	12659.45	9,459,378	18,449,932	27,909,310
2003	winter	663.38	9322.73	9986.12	1,462,512	20,553,111	22,015,623
	little	3302.87	0.00	3302.87	7,281,580	0	7,281,580
	barndoor	89.20	765.62	854.82	196,653	1,687,903	1,884,556
	thorny	4.72	298.22	302.94	10,402	657,458	667,861
	smooth	8.11	0.43	8.55	17,890	953	18,843
	clearnose	149.05	186.56	335.61	328,603	411,288	739,891
	rosette	5.82	0.00	5.82	12,834	0	12,834
	Total	4223.16	10573.56	14796.72	9,310,475	23,310,713	32,621,188
2004	winter	1499.08	10288.74	11787.82	3,304,912	22,682,786	25,987,698
	little	1955.26	0.00	1955.26	4,310,621	0	4,310,621
	barndoor	72.65	771.86	844.52	160,176	1,701,668	1,861,844
	thorny	0.82	510.74	511.56	1,809	1,125,978	1,127,787
	smooth	5.63	0.00	5.63	12,410	0	12,410
	clearnose	277.16	67.38	344.54	611,037	148,552	759,590
	rosette	6.80	0.00	6.80	14,998	0	14,998
	Total	3817.42	11638.72	15456.14	8,415,962	25,658,985	34,074,947

Table 14 cont.

		market bait	wings	Grand Total	market bait	wings	Grand Total
2005	winter	628.98	7021.60	7650.58	1,386,658	15,479,978	16,866,636
	little	3056.36	0.00	3056.36	6,738,126	0	6,738,126
	barndoor	55.49	1920.85	1976.34	122,337	4,234,744	4,357,081
	thorny	1.69	438.17	439.86	3,733	965,997	969,730
	smooth	8.71	1.68	10.39	19,202	3,709	22,911
	clearnose	63.94	104.53	168.47	140,958	230,452	371,410
	rosette	8.97	0.00	8.97	19,773	0	19,773
	Total	3824.14	9486.83	13310.97	8,430,787	20,914,880	29,345,667
2006	winter	1624.28	7632.53	9256.81	3,580,914	16,826,851	20,407,766
	little	2392.33	0.00	2392.33	5,274,186	0	5,274,186
	barndoor	138.00	2494.83	2632.83	304,241	5,500,163	5,804,404
	thorny	2.20	640.77	642.97	4,843	1,412,653	1,417,496
	smooth	15.77	5.73	21.51	34,775	12,637	47,412
	clearnose	248.57	135.92	384.49	547,993	299,656	847,650
	rosette	8.63	0.00	8.63	19,024	0	19,024
	Total	4429.77	10909.79	15339.56	9,765,977	24,051,960	33,817,937
2007	winter	1492.23	11368.57	12860.80	3,289,800	25,063,404	28,353,204
	little	3078.31	0.00	3078.31	6,786,503	0	6,786,503
	barndoor	91.67	1919.79	2011.46	202,088	4,232,420	4,434,509
	thorny	2.23	349.68	351.91	4,914	770,915	775,828
	smooth	8.53	9.30	17.84	18,816	20,512	39,328
	clearnose	193.40	168.33	361.73	426,370	371,098	797,468
	rosette	22.41	0.00	22.41	49,398	0	49,398
	Total	4888.77	13815.67	18704.44	10,777,889	30,458,349	41,236,238

Table 15. Species composition of landings using the selectivity ogive method. The first three columns are metric tons, the last three are in pounds.

		market bait	wings/gill net	Grand Total	market bait	wings/gill net	Grand Total
1995	winter	543.41	2013.59	2557.01	1,198,024	4,439,210	5,637,234
	little	2077.88	551.82	2629.69	4,580,935	1,216,547	5,797,481
	barndoor	1.35	43.45	44.80	2,986	95,787	98,773
	thorny	6.53	1149.72	1156.25	14,389	2,534,702	2,549,091
	smooth	0.66	27.36	28.02	1,461	60,313	61,774
	clearnose	5.11	17.49	22.60	11,273	38,553	49,826
	rosette	1.04	0.08	1.11	2,287	170	2,457
	Total	2635.99	3803.50	6439.49	5,811,355	8,385,281	14,196,636
1996	winter	1059.12	7716.89	8776.01	2,334,952	17,012,833	19,347,785
	little	2751.73	842.40	3594.13	6,066,523	1,857,173	7,923,696
	barndoor	0.02	193.10	193.12	54	425,711	425,765
	thorny	6.42	1213.05	1219.47	14,152	2,674,321	2,688,474
	smooth	0.37	72.48	72.85	821	159,794	160,615
	clearnose	5.56	39.14	44.70	12,261	86,285	98,546
	rosette	0.19	0.04	0.23	408	91	499
	Total	3823.41	10077.10	13900.51	8,429,172	22,216,208	30,645,380
1997	winter	659.60	3149.35	3808.94	1,454,161	6,943,124	8,397,285
	little	4623.60	703.24	5326.84	10,193,302	1,550,375	11,743,677
	barndoor	1.13	145.26	146.39	2,496	320,243	322,739
	thorny	6.66	1016.35	1023.01	14,691	2,240,666	2,255,357
	smooth	1.52	53.07	54.59	3,349	117,002	120,352
	clearnose	42.97	114.89	157.86	94,737	253,281	348,018
	rosette	0.12	0.02	0.14	271	40	311
	Total	5335.61	5182.17	10517.78	11,763,007	11,424,732	23,187,739
1998	winter	929.83	4495.66	5425.49	2,049,928	9,911,233	11,961,161
	little	4015.43	960.18	4975.61	8,852,516	2,116,832	10,969,349
	barndoor	4.62	292.51	297.13	10,175	644,877	655,053
	thorny	1.31	2237.44	2238.76	2,899	4,932,717	4,935,616
	smooth	2.75	69.25	72.00	6,073	152,669	158,743
	clearnose	8.63	38.78	47.42	19,034	85,505	104,539
	rosette	0.33	0.19	0.51	726	409	1,135
	Total	4962.91	8094.01	13056.93	10,941,351	17,844,243	28,785,594
1999	winter	920.69	4431.13	5351.83	2,029,784	9,768,974	11,798,758
	little	3914.15	751.91	4666.06	8,629,229	1,657,669	10,286,898
	barndoor	3.67	292.22	295.90	8,096	644,245	652,341
	thorny	1.81	875.62	877.43	4,001	1,930,410	1,934,411
	smooth	3.27	73.44	76.71	7,204	161,916	169,120
	clearnose	5.12	69.83	74.95	11,279	153,955	165,234
	rosette	1.07	1.30	2.37	2,364	2,866	5,230
	Total	4849.79	6495.46	11345.25	10,691,958	14,320,035	25,011,993

Table 15 cont.

		market bait	wings/gill net	Grand Total	market bait	wings/gill net	Grand Total
2000	winter	306.95	5023.89	5330.84	676,715	11,075,785	11,752,500
	little	4046.00	954.65	5000.65	8,919,903	2,104,651	11,024,554
	barndoor	2.17	449.67	451.84	4,790	991,345	996,135
	thorny	0.79	1782.98	1783.77	1,736	3,930,806	3,932,542
	smooth	1.61	72.34	73.95	3,550	159,473	163,023
	clearnose	64.17	145.20	209.36	141,463	320,105	461,568
	rosette	6.06	0.95	7.01	13,369	2,085	15,454
	Total	4427.75	8429.67	12857.43	9,761,525	18,584,251	28,345,776
2001	winter	504.29	6011.92	6516.21	1,111,776	13,254,016	14,365,792
	little	3606.10	1105.32	4711.42	7,950,090	2,436,815	10,386,905
	barndoor	3.30	494.71	498.01	7,268	1,090,653	1,097,921
	thorny	16.61	830.96	847.57	36,608	1,831,959	1,868,568
	smooth	13.50	56.53	70.02	29,753	124,618	154,371
	clearnose	28.05	68.36	96.41	61,841	150,707	212,548
	rosette	5.46	0.36	5.82	12,044	793	12,836
	Total	4177.30	8568.16	12745.47	9,209,381	18,889,560	28,098,941
2002	winter	580.15	6003.17	6583.32	1,279,018	13,234,716	14,513,734
	little	3785.75	947.41	4733.17	8,346,161	2,088,690	10,434,851
	barndoor	19.15	325.19	344.34	42,213	716,932	759,145
	thorny	5.68	1190.99	1196.67	12,520	2,625,682	2,638,202
	smooth	15.45	58.01	73.46	34,054	127,890	161,944
	clearnose	8.59	34.30	42.89	18,933	75,627	94,559
	rosette	1.20	0.26	1.46	2,644	565	3,209
	Total	4415.97	8559.33	12975.30	9,735,542	18,870,102	28,605,643
2003	winter	446.47	7174.71	7621.18	984,297	15,817,519	16,801,816
	little	4066.26	1449.03	5515.29	8,964,572	3,194,556	12,159,128
	barndoor	17.10	687.24	704.34	37,705	1,515,097	1,552,803
	thorny	33.21	981.39	1014.60	73,219	2,163,595	2,236,813
	smooth	23.03	39.37	62.39	50,766	86,786	137,552
	clearnose	0.99	69.61	70.60	2,190	153,464	155,654
	rosette	0.89	0.05	0.94	1,953	118	2,071
	Total	4587.95	10401.39	14989.34	10,114,702	22,931,134	33,045,837
2004	winter	669.89	9395.37	10065.26	1,476,861	20,713,238	22,190,099
	little	2856.62	599.49	3456.12	6,297,778	1,321,658	7,619,436
	barndoor	17.00	876.63	893.63	37,479	1,932,636	1,970,115
	thorny	0.32	370.51	370.83	701	816,836	817,537
	smooth	7.77	49.48	57.25	17,138	109,075	126,212
	clearnose	2.72	29.64	32.36	6,002	65,334	71,337
	rosette	0.04	0.31	0.36	91	693	783
	Total	3554.37	11321.43	14875.80	7,836,049	24,959,470	32,795,519

Table 15 cont.

		market bait	wings/gill net	Grand Total	market bait	wings/gill net	Grand Total
2005	winter	528.33	6421.31	6949.64	1,164,766	14,156,572	15,321,337
	little	3041.72	1090.08	4131.79	6,705,841	2,403,206	9,109,047
	barndoor	9.30	1255.49	1264.79	20,504	2,767,871	2,788,376
	thorny	6.52	169.88	176.39	14,367	374,512	388,879
	smooth	3.78	153.39	157.17	8,338	338,169	346,507
	clearnose	3.69	25.96	29.65	8,132	57,236	65,368
	rosette	0.14	0.15	0.29	315	334	649
	Total	3593.48	9116.25	12709.73	7,922,263	20,097,900	28,020,163
2006	winter	981.76	6607.23	7589.00	2,164,413	14,566,459	16,730,872
	little	3387.88	1030.19	4418.07	7,469,003	2,271,174	9,740,177
	barndoor	26.84	2816.91	2843.75	59,181	6,210,223	6,269,404
	thorny	13.95	301.22	315.16	30,748	664,068	694,816
	smooth	29.23	287.89	317.11	64,436	634,678	699,114
	clearnose	24.31	20.20	44.51	53,599	44,532	98,131
	rosette	2.62	0.12	2.75	5,780	274	6,054
	Total	4466.60	11063.76	15530.35	9,847,161	24,391,409	34,238,569
2007	winter	752.79	10757.92	11510.70	1,659,612	23,717,145	25,376,757
	little	3824.08	1557.94	5382.02	8,430,648	3,434,679	11,865,327
	barndoor	24.69	452.76	477.45	54,429	998,173	1,052,602
	thorny	7.92	642.53	650.46	17,469	1,416,545	1,434,014
	smooth	5.49	27.79	33.28	12,103	61,265	73,368
	clearnose	32.01	52.32	84.33	70,564	115,340	185,905
	rosette	2.97	0.49	3.45	6,544	1,072	7,616
	Total	4649.94	13491.75	18141.69	10,251,369	29,744,220	39,995,590

Table 16. Number of length samples by region, year, season, and gear type of the discarded component of the skate catch from the Observer Program.

GOM-GBK

	half 1					half 2				
YEAR	longline	otter trawl	shrimp trawl	sink gill net	scallop dredge	longline	otter trawl	shrimp trawl	sink gill net	scallop dredge
1994		0	60	0	0		0		9	332
1995		726	9	55	0		90		37	
1996		626		17	0		107		7	45
1997		265	25	0	9		183		25	0
1998		0		13	1499		60		213	0
1999		0		52	0		77		18	47
2000		464		13	31		393		97	0
2001		1201		80	0		167		58	
2002		752		177	0		6089		224	762
2003	22	7508	186	552	12	0	6949		724	80
2004	41	5783	15	1710	654	56	8229		1703	634
2005	74	19162	29	702	744	13	12705		688	1169
2006	50	8075		459	346	35	8020		404	2500
2007	3	9374		392	703	52	12468		1949	2605

SNE-MDA

	half 1					half 2				
Year	longline	otter trawl	shrimp trawl	sink gill net	scallop dredge	longline	otter trawl	shrimp trawl	sink gill net	scallop dredge
1994		0	na	0	0		619	na	55	354
1995		726	na	55	0		500	na	12	
1996		626	na	17	379		247	na	0	0
1997		265	na	0	52		1323	na	46	179
1998		0	na	13	0		43	na	28	0
1999		0	na	52	0		0	na	10	0
2000		464	na	13	0		922	na	32	86
2001		1201	na	80	0		1664	na	74	
2002		752	na	177	0		1701	na	164	2125
2003	0	7508	na	552	1524	1	520	na	1312	987
2004	0	5783	na	1710	6162	0	2530	na	630	5953
2005	0	19162	na	702	1643	0	3966	na	761	1164
2006	24	8075	na	459	0	1	1743	na	192	3440
2007	0	9374	na	392	1591	0	932	na	39	1319

Table 17. Discards by species, gear type and half year from 1995-2007.

				Half 1 Gear Type					Half 2 Gear Type					Total Gear Type		
year	Species	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl
1995	winter	2575.94	211.38	118.53	0.19	11984.72	6880.52	1517.84	122.18	0.04	4162.79	9456.46	1729.22	240.71	0.23	16147.51
	little	6357.05	202.52	24.02	1.63	7319.12	12516.80	354.22	18.55	0.15	5902.89	18873.85	556.73	42.57	1.78	13222.00
	barndoor	1.30	0.28	2.70	0.00	206.84	19.40	58.80	19.09	0.00	41.05	20.70	59.08	21.79	0.00	247.89
	thorny	19.58	10.29	12.97	3.98	312.32	90.71	115.10	20.03	0.17	159.80	110.29	125.39	33.00	4.15	472.13
	smooth	8.85	9.92	2.35	1.76	286.58	105.69	43.25	2.75	0.18	103.54	114.54	53.17	5.10	1.93	390.12
	clearnose	103.50	5.55	3.11	0.00	2602.62	140.62	17.38	5.30	0.00	1127.79	244.12	22.94	8.41	0.00	3730.41
	rosette	4.49	0.08	0.00	0.00	6.74	163.92	0.30	0.01	0.00	47.64	168.41	0.38	0.01	0.00	54.38
1996	winter	2617.45	257.18	113.66	3.93	7584.85	3057.90	1438.02	163.78	1.89	6713.87	5675.35	1695.20	277.45	5.82	14298.72
	little	5843.77	139.90	29.59	9.58	6076.34	7836.97	354.78	24.93	2.83	13618.24	13680.74	494.68	54.52	12.41	19694.58
	barndoor	4.31	1.23	6.55	0.91	20.03	14.58	26.98	21.44	0.32	11.20	18.90	28.21	27.98	1.23	31.23
	thorny	13.34	4.39	5.28	7.72	87.04	163.38	105.46	12.21	1.65	81.16	176.72	109.84	17.49	9.36	168.20
	smooth	6.50	1.49	0.36	3.93	51.67	164.40	48.39	3.73	0.99	68.15	170.91	49.88	4.09	4.92	119.81
	clearnose	32.84	11.96	7.21	0.00	1635.71	54.04	10.47	7.78	0.00	3555.45	86.88	22.43	14.99	0.00	5191.16
	rosette	3.78	0.05	0.00	0.00	2.41	210.38	0.63	0.04	0.00	189.70	214.17	0.68	0.04	0.00	192.11
1997	winter	2174.14	168.54	114.86	3.09	3543.37	1920.23	778.96	93.34	0.35	2408.23	4094.37	947.50	208.21	3.43	5951.61
	little	8408.50	183.94	31.36	17.02	2598.91	4581.22	234.94	20.66	0.45	3200.03	12989.73	418.88	52.02	17.47	5798.94
	barndoor	211.92	0.69	7.70	0.00	55.31	17.04	19.70	30.77	0.00	9.37	228.96	20.39	38.47	0.00	64.68
	thorny	38.81	2.79	10.44	6.16	148.38	114.96	92.08	16.98	0.74	136.90	153.77	94.87	27.42	6.90	285.29
	smooth	28.61	0.70	0.38	5.68	31.19	189.77	29.38	3.20	0.67	201.79	218.38	30.08	3.58	6.36	232.98
	clearnose	166.51	32.53	11.22	0.00	336.86	53.65	10.84	5.96	0.00	143.34	220.16	43.37	17.17	0.00	480.20
	rosette	25.55	0.46	0.01	0.00	9.96	24.53	0.21	0.02	0.00	8.52	50.08	0.67	0.03	0.00	18.47
1998	winter	1046.54	72.21	84.83	0.15	8171.28	2343.94	1538.36	132.05	0.03	12338.24	3390.47	1610.57	216.89	0.18	20509.53
	Little	5249.09	120.08	32.44	2.93	15693.50	5702.77	490.01	21.50	0.15	6860.44	10951.86	610.10	53.94	3.09	22553.94
	barndoor	10.97	0.66	6.10	0.00	140.29	11.38	10.92	15.65	0.00	68.87	22.35	11.58	21.75	0.00	209.16
	thorny	101.80	1.32	9.48	2.41	350.86	109.09	85.99	3.58	0.17	468.93	210.89	87.31	13.06	2.57	819.79
	smooth	178.62	6.19	4.95	2.49	392.15	33.43	7.78	0.44	0.09	128.80	212.05	13.97	5.38	2.59	520.95
	clearnose	37.82	14.56	7.77	0.00	2414.69	105.83	26.68	3.51	0.00	607.17	143.65	41.24	11.28	0.00	3021.86
	rosette	9.82	0.17	0.02	0.00	32.01	115.28	1.57	0.02	0.00	59.48	125.10	1.74	0.04	0.00	91.49

Table 17 cont.

				Half 1					Half 2					Total		
				Gear Type					Gear Type					Gear Type		
year	Species	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl
1999	winter	703.27	182.27	92.72	0.23	2137.63	1991.81	1393.05	122.37	0.01	5432.98	2695.08	1575.32	215.09	0.24	7570.62
	Little	6369.41	353.58	31.99	0.25	1402.49	5586.79	413.62	20.95	0.04	3082.78	11956.20	767.20	52.94	0.29	4485.26
	barndoor	5.12	0.77	3.99	0.01	18.29	43.56	22.86	26.24	0.00	100.43	48.67	23.63	30.23	0.01	118.72
	thorny	17.03	1.03	1.43	0.87	44.98	116.34	57.38	2.67	0.03	198.34	133.37	58.41	4.10	0.90	243.32
	smooth	33.32	1.55	0.84	2.37	40.50	41.52	16.14	1.25	0.01	153.32	74.84	17.70	2.10	2.38	193.82
	clearnose	49.32	55.01	3.79	0.00	120.89	45.46	23.29	5.64	0.00	472.19	94.77	78.29	9.43	0.00	593.08
	rosette	8.18	0.46	0.00	0.00	1.60	72.41	0.79	0.02	0.00	17.62	80.59	1.25	0.02	0.00	19.23
2000	winter	731.54	82.47	50.29	0.37	3362.87	1203.23	1552.52	87.04	0.01	6321.91	1934.77	1634.99	137.33	0.38	9684.78
	Little	4394.88	83.65	20.58	2.88	2849.42	3297.27	439.12	19.60	0.02	7164.16	7692.16	522.76	40.17	2.90	10013.58
	barndoor	39.56	2.92	5.15	0.00	149.55	4.07	25.12	31.63	0.00	1134.40	43.63	28.04	36.78	0.00	1283.95
	thorny	60.54	1.78	1.58	1.66	116.53	37.45	76.84	9.28	0.04	275.87	97.99	78.62	10.86	1.69	392.40
	smooth	24.56	2.57	0.48	0.40	69.87	45.93	36.43	2.33	0.03	159.76	70.48	39.00	2.80	0.43	229.63
	clearnose	40.04	6.11	2.75	0.00	238.26	28.44	8.28	2.58	0.00	1254.93	68.47	14.38	5.33	0.00	1493.20
	rosette	2.55	0.03	0.00	0.00	2.36	75.76	0.38	0.01	0.00	95.30	78.31	0.42	0.01	0.00	97.66
2001	winter	610.66	178.6	68.39292		10483.5	518.056	1005.6	76.0568		4021.27	1128.72	1184.29	144.45	0.00	14504.81
	little	3062	170	34.11211		8579.03	2516.46	276.27	16.29889		1769.56	5578.50	446.31	50.41	0.00	10348.59
	barndoor	10.19	11.91	4.83		683.64	8.70	125.84	27.58		1034.13	18.89	137.76	32.41	0.00	1717.77
	thorny	12.90	10.27	3.55		779.67	10.38	20.48	0.96		85.23	23.29	30.75	4.51	0.00	864.91
	smooth	12.14	4.35	1.60		324.85	40.60	58.60	3.01		239.16	52.74	62.95	4.61	0.00	564.01
	clearnose	31.40	25.04	4.45		10.37	38.67	42.08	4.73		1045.62	70.07	67.12	9.18	0.00	1055.99
	rosette	5.17	0.25	0.00		1.72	129.82	4.04	0.05		4.37	134.99	4.29	0.06	0.00	6.09
2002	winter	413.56	209.52	62.18	0.09	6012.98	1502.58	3372.67	84.28		5864.64	1916.14	3582.19	146.47	0.09	11877.62
	little	5705.43	63.13	34.63	0.31	3473.59	5737.55	272.85	17.61		1960.72	11442.97	335.98	52.23	0.31	5434.31
	barndoor	38.02	55.00	14.04	0.00	1527.48	79.27	300.10	15.12		369.34	117.28	355.11	29.16	0.00	1896.82
	thorny	18.10	12.38	4.76	0.18	696.08	22.90	21.29	0.35		75.81	41.01	33.67	5.11	0.18	771.88
	smooth	38.86	6.23	3.47	0.21	323.61	55.59	40.72	0.64		112.39	94.44	46.95	4.11	0.21	435.99
	clearnose	26.14	41.39	2.83	0.00	33.79	207.14	53.66	7.16		1038.69	233.28	95.06	9.99	0.00	1072.49
	rosette	6.10	0.00	0.00	0.00	0.10	68.42	0.09	0.06		2.21	74.51	0.10	0.07	0.00	2.31

Table 17 cont.

				Half 1 Gear Type					Half 2 Gear Type					Total Gear Type		
year	Species	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl
2003	winter	1049.56	324.86	39.94	1.04	8936.49	877.36	1545.44	33.89		7232.20	1926.92	1870.30	73.83	1.04	16168.69
	little	6664.13	79.66	17.94	0.60	6948.71	6824.40	309.58	8.50		7902.79	13488.53	389.24	26.44	0.60	14851.49
	barndoor	38.86	79.76	5.25	0.06	702.72	48.35	226.61	8.85		373.64	87.21	306.37	14.10	0.06	1076.36
	thorny	31.42	15.12	1.43	1.64	478.64	94.16	85.95	0.74		469.39	125.58	101.07	2.17	1.64	948.03
	smooth	72.24	9.11	1.05	4.60	460.31	152.53	48.54	0.50		458.02	224.77	57.64	1.54	4.60	918.33
	clearnose	14.15	10.02	3.59	0.00	236.78	26.89	53.38	3.25		847.79	41.05	63.40	6.84	0.00	1084.57
	rosette	12.02	0.05	0.01	0.00	10.15	9.25	0.11	0.00		6.53	21.26	0.16	0.01	0.00	16.68
2004	winter	1521.17	214.72	23.11	0.66	8200.57	1654.52	863.08	14.34	0.02	11645.92	3175.68	1077.80	37.45	0.68	19846.48
	little	3620.75	97.27	9.49	1.99	4591.50	1974.36	233.16	2.45	0.01	6962.03	5595.11	330.43	11.94	2.00	11553.53
	barndoor	58.49	105.04	2.81	0.00	519.91	22.89	77.54	5.39	0.00	657.79	81.38	182.58	8.20	0.00	1177.70
	thorny	5.18	7.67	0.12	0.46	275.00	27.47	35.21	0.37	0.03	369.88	32.65	42.88	0.49	0.49	644.88
	smooth	13.60	15.62	0.14	1.07	571.56	88.88	41.11	0.54	0.11	857.39	102.48	56.72	0.68	1.19	1428.95
	clearnose	211.88	5.65	3.70	0.00	119.12	356.73	16.83	0.62	0.00	806.37	568.61	22.48	4.31	0.00	925.49
	rosette	7.01	0.00	0.00	0.00	2.66	8.61	0.28	0.00	0.00	29.17	15.62	0.29	0.00	0.00	31.83
2005	winter	1964.26	556.59	39.74	0.26	5967.05	1600.00	696.13	26.53	0.01	8071.63	3564.25	1252.72	66.28	0.27	14038.68
	little	3294.29	154.67	17.95	0.28	4855.81	2425.36	290.48	5.60	0.03	8054.99	5719.66	445.15	23.55	0.31	12910.80
	barndoor	379.78	219.52	20.64	0.27	1263.90	277.40	489.30	19.57	0.00	1576.52	657.17	708.83	40.21	0.27	2840.41
	thorny	20.39	21.30	4.98	0.44	478.08	35.54	14.98	0.59	0.01	185.03	55.93	36.28	5.57	0.45	663.11
	smooth	96.95	44.69	7.28	1.15	1136.78	73.48	23.97	0.96	0.05	453.69	170.44	68.65	8.24	1.20	1590.47
	clearnose	293.51	29.28	0.00	0.00	298.89	165.44	58.71	0.00	0.00	478.90	458.95	87.98	0.00	0.00	777.79
	rosette	29.94	0.32	0.00	0.00	12.93	24.68	0.75	0.01	0.00	21.69	54.62	1.07	0.01	0.00	34.61
2006	winter	1870.57	466.42	105.59	0.04	5449.79	1784.91	717.39	89.87	0.09	5404.90	3655.48	1183.81	195.46	0.13	10854.69
	little	3551.05	30.82	37.69	0.05	2755.35	2532.95	206.95	23.42	0.22	4347.21	6084.00	237.77	61.11	0.27	7102.56
	barndoor	166.18	320.57	38.67	0.01	1375.82	227.09	613.16	84.51	0.00	1428.08	393.27	933.73	123.18	0.01	2803.90
	thorny	16.29	2.83	3.31	0.02	125.64	69.86	69.90	7.51	0.13	299.26	86.15	72.72	10.81	0.15	424.89
	smooth	59.35	10.17	7.80	0.04	506.45	89.19	39.94	5.17	0.11	407.48	148.54	50.11	12.97	0.14	913.94
	clearnose	58.37	13.38	0.18	0.00	290.17	165.23	8.55	0.13	0.00	202.28	223.60	21.93	0.32	0.00	492.45
	rosette	3.84	0.01	0.00	0.00	0.42	16.25	0.40	0.00	0.00	25.32	20.09	0.41	0.00	0.00	25.74

Table 17 cont.

year	Species	Half 1 Gear Type					Half 2 Gear Type					Total Gear Type				
		dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl	dredge	gillnet	longline	shrimp	trawl
2007	winter	724.50	704.35	22.80	0.04	5826.92	2964.42	1330.14	12.55	0.00	9437.23	3688.92	2034.49	35.35	0.04	15264.15
	Little	5069.34	194.05	10.09	0.10	5200.60	4128.47	238.32	2.57	0.00	4170.34	9197.81	432.37	12.66	0.10	9370.95
	barndoor	135.26	75.39	11.45	0.00	2465.17	167.73	156.75	10.79	0.00	1042.24	303.00	232.13	22.25	0.00	3507.40
	thorny	12.33	5.58	0.69	0.03	172.78	55.58	16.98	0.48	0.02	179.56	67.91	22.56	1.18	0.05	352.35
	smooth	27.01	14.24	1.10	0.08	395.69	101.80	22.13	0.33	0.01	303.58	128.80	36.37	1.42	0.09	699.27
	clearnose	96.347	38.47	0	0	464.41	90.1909	66.433	0	0	1246.24	186.54	104.91	0.00	0.00	1710.65
	rosette	3.0999	0.027	0	0	0.92939	23.916	3.1576	0	0	11.5952	27.02	3.18	0.00	0.00	12.52

Table 18. Abundance and biomass from NEFSC spring surveys for winter skate for the Gulf of Maine to Mid-Atlantic region (offshore strata 1-30,33-40,61-76). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1968-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1968	2.171	1.640	2.978	0.854	0.530	1.178	2.542	32	42	56	58.6	79	112	36	232
1969	5.913	4.283	7.543	2.790	1.907	3.672	2.119	15	25	53	53.5	79	111	68	640
1970	2.645	1.627	3.663	0.971	0.626	1.317	2.723	37	43	59	61.0	83	103	44	275
1971	3.387	2.066	4.708	1.894	0.873	2.915	1.788	15	30	48	51.8	76	103	41	513
1972	4.620	3.033	6.207	2.602	1.253	3.951	1.776	15	24	48	49.5	74	97	63	634
1973	2.905	2.024	3.786	1.257	0.824	1.689	2.311	21	32	55	55.5	79	100	49	347
1974	2.091	1.352	2.830	0.943	0.505	1.381	2.218	29	34	53	55.6	76	101	46	222
1975	2.395	1.521	3.269	0.893	0.556	1.230	2.682	17	38	59	59.4	79	99	46	227
1976	2.153	1.075	3.231	0.628	0.279	0.978	3.428	22	38	64	63.1	86	97	29	160
1977	3.111	1.815	4.408	0.838	0.513	1.163	3.712	20	29	69	64.7	93	106	35	204
1978	8.275	-0.327	16.877	1.355	0.121	2.589	6.108	43	62	79	78.5	89	96	41	395
1979	1.852	1.095	2.608	0.333	0.206	0.459	5.568	23	35	78	73.5	93	105	50	204
1980	2.990	1.751	4.229	0.538	0.331	0.745	5.559	22	45	78	74.8	97	104	49	187
1981	4.140	2.905	5.376	2.083	1.199	2.966	1.988	15	22	39	47.6	91	104	56	586
1982	5.773	3.876	7.670	2.137	1.195	3.080	2.701	15	26	46	54.9	95	109	64	707
1983	14.329	8.182	20.476	3.264	1.772	4.756	4.391	15	28	67	64.4	96	108	65	817
1984	10.480	6.816	14.144	2.948	1.694	4.201	3.555	15	22	60	59.0	94	106	59	753
1985	16.373	11.119	21.627	7.861	4.653	11.069	2.083	15	22	46	54.3	94	116	65	1891
1986	10.019	6.973	13.064	3.538	2.181	4.894	2.832	15	27	58	62.2	97	108	67	969
1987	13.126	8.428	17.824	4.821	2.926	6.716	2.723	15	29	56	60.8	97	108	69	1221
1988	14.543	10.508	18.577	7.409	4.736	10.082	1.963	15	25	43	53.4	95	107	73	1827
1989	10.141	7.736	12.546	4.252	3.095	5.409	2.385	15	25	59	61.4	94	109	74	1429
1990	7.183	5.184	9.183	5.087	2.657	7.517	1.412	15	27	41	49.9	91	105	67	1678
1991	6.965	4.012	9.918	3.239	1.979	4.499	2.150	17	29	54	58.6	93	107	57	1027
1992	5.988	3.369	8.607	5.208	0.635	9.780	1.150	15	23	42	46.2	82	106	51	1303
1993	4.761	3.392	6.131	4.305	2.561	6.049	1.106	15	25	42	46.5	82	103	62	1118
1994	1.421	0.990	1.852	1.673	1.150	2.196	0.849	20	32	43	46.5	69	99	49	519
1995	2.151	1.340	2.961	1.998	1.231	2.766	1.076	15	34	44	48.4	71	103	49	476
1996	4.547	2.499	6.594	4.470	2.384	6.556	1.017	15	34	46	49.0	68	96	56	1004
1997	3.065	1.325	4.806	1.834	0.987	2.680	1.672	15	23	51	53.5	78	93	39	458
1998	1.504	0.913	2.096	1.045	0.561	1.529	1.439	15	32	51	53.4	79	94	52	341
1999	2.968	1.303	4.632	1.876	0.870	2.883	1.582	16	27	54	54.9	79	100	52	482
2000	4.358	2.273	6.443	1.998	1.041	2.954	2.181	15	34	62	62.2	82	99	57	457
2001	3.496	1.889	5.103	2.350	0.912	3.787	1.488	20	27	44	52.1	82	100	48	556
2002	3.132	1.650	4.614	1.688	0.949	2.426	1.856	15	29	59	58.6	82	93	48	407
2003	2.799	1.471	4.127	2.047	1.164	2.931	1.367	15	29	49	53.4	82	100	61	606
2004	2.446	1.512	3.379	1.547	1.015	2.080	1.581	18	29	50	54.6	85	97	56	356
2005	1.757	0.869	2.645	1.672	0.470	2.874	1.051	15	30	45	48.6	75	97	52	375
2006	3.041	1.020	5.062	3.067	0.465	5.668	0.992	15	24	43	47.2	75	99	55	779
2007	4.732	3.428	6.035	1.798	1.326	2.269	2.632	17	36	63	64.4	93	101	66	547
2008	2.996	1.224	4.767	1.843	0.726	2.959	1.625	16	36	56	57.2	81	95	55	750

Table 19. Abundance and biomass from NEFSC autumn surveys for winter skate for the Gulf of Maine to Mid-Atlantic region (offshore strata 1-30,33-40,61-76). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1967-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1967	2.159	1.248	3.070	0.825	0.544	1.106	2.617	15	32	56	57.0	83	107	35	213
1968	1.865	1.264	2.466	0.928	0.573	1.284	2.009	15	25	51	51.8	80	100	56	227
1969	1.315	0.856	1.774	0.540	0.351	0.730	2.435	16	37	58	58.3	78	90	36	161
1970	2.996	1.663	4.328	1.357	0.576	2.138	2.208	21	33	54	56.0	77	97	53	331
1971	1.078	0.542	1.615	0.588	0.238	0.938	1.833	18	27	50	50.5	77	93	35	163
1972	2.958	2.113	3.804	2.071	1.413	2.728	1.429	15	24	42	46.9	74	96	64	592
1973	4.686	3.348	6.024	2.238	1.510	2.967	2.093	21	32	54	55.1	78	101	48	662
1974	2.097	1.418	2.777	1.024	0.672	1.376	2.048	17	30	52	53.6	77	103	39	262
1975	1.315	0.682	1.948	0.420	0.260	0.580	3.130	16	24	62	60.9	84	103	31	115
1976	2.655	0.918	4.392	0.766	0.257	1.274	3.468	19	22	70	59.9	83	98	21	190
1977	4.095	2.814	5.376	1.617	1.049	2.185	2.533	15	25	47	54.8	87	100	51	662
1978	4.989	3.778	6.199	1.042	0.777	1.307	4.787	15	36	77	73.6	94	105	94	762
1979	5.121	3.768	6.475	1.290	0.976	1.603	3.971	20	31	75	66.0	93	113	89	975
1980	6.233	3.806	8.660	1.558	1.015	2.100	4.002	15	37	66	66.4	95	108	60	602
1981	5.668	3.726	7.610	1.505	0.916	2.094	3.766	15	25	61	62.3	99	110	54	516
1982	8.306	4.780	11.831	3.889	0.502	7.275	2.136	15	22	35	46.7	92	112	45	950
1983	12.852	5.693	20.012	2.590	1.447	3.733	4.962	16	28	78	70.5	95	108	42	843
1984	13.323	8.465	18.181	3.653	2.450	4.857	3.647	15	21	55	59.0	95	110	52	1187
1985	9.182	6.552	11.811	2.665	1.842	3.488	3.446	15	32	79	69.7	97	107	37	827
1986	15.800	7.184	24.415	4.196	2.496	5.895	3.766	15	34	75	71.5	97	110	46	1089
1987	11.063	8.200	13.925	4.291	2.783	5.800	2.578	15	25	58	60.1	97	109	49	1165
1988	7.564	4.961	10.167	3.126	2.223	4.028	2.420	15	23	49	57.4	97	110	45	888
1989	5.081	3.288	6.874	2.084	1.422	2.745	2.439	15	27	59	61.0	96	106	48	720
1990	7.145	4.658	9.632	2.451	1.397	3.505	2.915	22	33	68	66.5	97	107	44	895
1991	4.724	3.627	5.821	2.631	1.866	3.396	1.796	17	31	48	56.3	94	106	58	941
1992	3.582	2.140	5.024	1.862	1.116	2.608	1.923	22	33	51	57.4	91	103	39	509
1993	1.905	1.280	2.530	1.458	0.965	1.951	1.307	16	33	48	52.8	88	104	50	452
1994	2.120	1.432	2.808	1.925	1.217	2.633	1.101	15	26	44	47.6	84	106	52	503
1995	1.985	1.214	2.757	1.769	1.047	2.491	1.122	17	31	46	49.4	77	102	43	424
1996	2.276	1.615	2.937	1.426	0.985	1.867	1.596	17	35	51	54.9	83	104	44	370
1997	2.455	1.150	3.760	1.611	0.738	2.484	1.524	19	34	54	55.5	79	101	55	415
1998	3.753	2.488	5.018	2.140	1.438	2.843	1.753	19	27	55	56.8	83	101	50	609
1999	5.089	2.080	8.098	2.642	1.320	3.963	1.927	15	31	58	58.0	80	111	53	966
2000	4.378	2.390	6.366	2.535	1.351	3.718	1.727	18	25	56	55.5	82	99	45	756
2001	3.887	2.442	5.333	2.165	1.415	2.914	1.796	15	32	58	57.8	83	98	53	601
2002	5.600	3.417	7.782	2.323	1.535	3.111	2.411	16	33	66	63.9	87	101	55	743
2003	3.386	2.111	4.662	1.498	0.928	2.068	2.260	16	33	62	63.0	87	104	43	435
2004	4.031	2.632	5.430	1.942	1.343	2.542	2.075	15	33	62	60.4	87	102	50	611
2005	2.615	1.791	3.439	1.671	1.005	2.337	1.565	18	31	52	55.1	81	98	54	475
2006	2.484	1.416	3.553	1.759	1.124	2.395	1.412	18	31	50	52.2	78	99	52	619
2007	3.705	2.169	5.241	2.324	1.208	3.440	1.594	15	33	53	55.0	80	94	56	747

Table 20. Abundance and biomass from NEFSC winter surveys for winter skate for the Georges Bank to Mid-Atlantic region (offshore strata 1-3,5-7,9-11,13-14,16,61-63,65-67,69-71,73-75). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1992-2007. Stratum 16 not sampled in 1993, 2000, 2002-2007. Strata 13 and 14 not sampled in 2003 and 2007. Stratum 63 not sampled in 1993. Stratum 14 not sampled in 2005 and 2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1992	31.571	21.666	41.476	39.759	23.811	55.707	0.794	15	24	38	42.4	74	105	62	4042
1993	10.261	6.052	14.469	10.676	2.331	19.021	0.961	15	23	41	44.1	81	106	47	841
1994	14.439	10.586	18.293	14.216	8.465	19.966	1.016	15	29	40	45.4	81	102	33	1079
1995	23.268	14.507	32.029	35.528	18.060	52.996	0.655	15	27	40	42.2	59	104	53	3773
1996	25.239	7.110	43.369	43.515	7.434	79.596	0.580	15	25	40	41.2	56	99	59	4055
1997	11.643	7.287	15.999	12.565	7.109	18.022	0.927	15	27	45	46.9	71	98	46	1414
1998	22.464	15.878	29.050	19.950	13.556	26.344	1.126	15	26	48	49.4	74	105	60	2092
1999	21.089	13.628	28.549	18.380	10.899	25.860	1.147	15	24	49	49.0	74	101	52	1932
2000	11.315	4.814	17.815	5.697	2.799	8.596	1.986	18	27	56	57.6	88	101	33	486
2001	28.634	19.682	37.585	15.555	9.234	21.875	1.841	16	30	58	57.5	84	100	76	2025
2002	28.733	17.246	40.220	15.982	6.565	25.400	1.798	15	24	49	55.1	88	107	53	1849
2003	17.425	7.871	26.979	29.540	-6.318	64.399	0.590	15	15	28	34.8	75	99	34	1662
2004	26.618	13.793	39.444	13.833	9.244	18.422	1.924	15	31	55	58.0	86	102	58	1342
2005	19.424	8.976	29.872	16.081	6.327	25.836	1.208	16	26	48	50.3	76	95	46	972
2006	32.411	12.125	52.697	18.233	9.593	26.874	1.778	15	30	56	57.4	86	102	60	1776
2007	14.689	5.443	23.936	13.020	3.847	22.193	1.128	15	27	48	50.2	73	93	38	1087

Table 21. Abundance and biomass from NEFSC spring surveys for little skate for the Gulf of Maine to Mid-Atlantic region (offshore strata 1-30,33-40,61-76, and inshore strata 1-66). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1976-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1976	1.308	0.861	1.755	3.218	2.136	4.301	0.406	8	12	40	36.9	48	58	172	4202
1977	1.347	0.882	1.811	3.336	2.177	4.494	0.404	6	19	41	38.7	48	57	160	4218
1978	1.391	0.962	1.821	3.286	2.363	4.209	0.423	8	11	42	37.5	48	62	160	3945
1979	0.650	0.501	0.799	2.182	1.429	2.934	0.298	4	12	31	32.7	48	56	204	5684
1980	2.206	1.705	2.707	5.898	4.384	7.413	0.374	8	12	37	36.0	48	57	224	9031
1981	1.501	1.200	1.803	3.426	2.714	4.137	0.438	6	15	41	38.3	49	55	175	4113
1982	3.627	2.644	4.611	7.214	5.351	9.076	0.503	9	18	43	40.7	49	55	153	3564
1983	5.718	4.017	7.420	13.024	9.215	16.832	0.439	6	16	42	37.9	48	57	167	6365
1984	4.094	2.615	5.574	10.023	6.787	13.258	0.409	7	11	40	35.8	48	55	139	4573
1985	6.265	4.628	7.901	15.175	10.575	19.775	0.413	8	11	40	36.8	48	57	148	6535
1986	2.753	1.712	3.795	8.554	3.399	13.709	0.322	6	14	33	34.5	48	57	153	3512
1987	4.625	3.149	6.102	16.031	10.222	21.839	0.289	8	12	32	33.1	47	55	145	9584
1988	5.083	3.444	6.721	14.593	9.688	19.498	0.348	8	11	36	34.5	48	55	130	4195
1989	6.634	3.434	9.834	21.643	9.844	33.441	0.307	8	13	34	33.4	46	55	144	10760
1990	4.993	2.397	7.589	14.979	5.250	24.708	0.333	8	11	37	34.7	47	56	132	7085
1991	5.990	4.672	7.308	18.731	14.059	23.403	0.320	8	13	34	34.2	47	58	178	11986
1992	5.297	2.477	8.118	16.793	5.234	28.352	0.315	8	16	33	34.1	46	57	136	6392
1993	7.524	5.187	9.862	22.361	15.110	29.611	0.336	9	12	36	35.0	47	54	160	9574
1994	3.622	2.425	4.819	9.365	6.297	12.434	0.387	9	19	39	37.3	46	54	154	8548
1995	2.872	2.024	3.720	7.574	5.215	9.933	0.379	8	10	39	36.1	47	59	148	3801
1996	7.574	5.522	9.626	18.185	12.647	23.722	0.417	7	17	41	38.3	48	58	168	9086
1997	2.708	2.231	3.184	6.671	5.504	7.837	0.406	9	13	40	37.8	48	54	151	4840
1998	7.471	6.156	8.787	20.938	16.232	25.644	0.357	7	17	37	35.8	47	56	195	15710
1999	9.978	7.688	12.267	28.377	20.345	36.409	0.352	8	12	38	35.4	47	56	157	16406
2000	8.596	6.647	10.545	19.677	15.270	24.083	0.437	9	21	41	38.9	47	57	179	15367
2001	6.835	4.297	9.372	15.347	9.900	20.794	0.445	8	18	42	39.5	48	58	154	6978
2002	6.444	4.546	8.341	16.280	11.306	21.254	0.396	8	11	42	37.7	48	57	154	11983
2003	6.486	4.505	8.486	15.116	10.195	20.036	0.429	9	22	42	40.1	48	55	169	6919
2004	7.219	5.374	9.064	17.039	11.917	22.162	0.424	7	25	42	39.9	47	57	147	9866
2005	3.241	2.305	4.177	7.328	5.515	9.141	0.442	8	13	43	38.9	48	53	138	3108
2006	3.323	1.892	4.753	7.878	4.544	11.211	0.422	7	11	42	38.4	48	55	138	2771
2007	4.459	3.031	5.887	9.081	6.385	11.778	0.491	9	16	44	41.1	48	58	159	5538
2008	7.339	4.537	10.142	16.659	9.678	23.641	0.441	9	17	42	39.1	47	58	149	11863

Table 22. Abundance and biomass from NEFSC autumn surveys for little skate for the Gulf of Maine to Mid-Atlantic region (offshore strata 1-30,33-40,61-76, and inshore strata 1-66). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1975-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1975	2.379	1.508	3.249	4.858	3.063	6.654	0.490	10	18	43	40.3	49	56	118	1386
1976	2.185	1.582	2.788	4.576	3.278	5.875	0.477	8	22	43	40.6	48	58	74	1421
1977	3.172	2.271	4.072	6.589	4.683	8.495	0.481	9	22	43	40.7	49	56	122	2438
1978	2.938	2.140	3.736	5.613	3.947	7.279	0.523	10	22	44	42.0	49	62	144	3171
1979	2.902	2.343	3.461	5.944	4.790	7.098	0.488	8	21	44	41.0	49	58	177	4597
1980	2.312	1.768	2.855	5.055	4.102	6.008	0.457	9	13	43	37.9	49	55	142	2451
1981	2.779	2.175	3.382	5.847	4.479	7.215	0.475	9	19	43	39.9	49	58	111	1728
1982	5.799	2.673	8.925	15.391	6.979	23.803	0.377	9	18	36	36.4	48	56	123	3848
1983	1.990	1.340	2.639	5.244	3.268	7.219	0.379	8	17	38	36.6	49	55	100	1313
1984	2.483	1.688	3.279	5.487	3.789	7.185	0.453	10	13	43	38.3	49	56	95	1350
1985	2.423	1.629	3.217	6.103	4.006	8.199	0.397	9	17	40	37.5	49	58	119	2761
1986	1.502	1.125	1.879	4.203	2.759	5.648	0.357	10	16	36	35.7	49	55	96	1240
1987	2.311	1.532	3.090	8.104	4.084	12.124	0.285	10	14	31	32.4	48	55	96	2093
1988	1.177	0.663	1.692	3.524	2.144	4.903	0.334	9	13	34	33.8	48	56	80	1128
1989	2.321	1.091	3.552	6.698	3.574	9.823	0.347	5	13	38	35.2	48	56	100	2288
1990	1.242	0.802	1.681	3.204	1.913	4.495	0.388	9	17	40	37.3	48	54	98	1183
1991	3.552	1.494	5.610	8.854	3.301	14.408	0.401	11	24	40	39.3	47	55	102	2866
1992	1.542	1.126	1.958	4.294	2.993	5.595	0.359	6	14	38	36.0	49	63	107	1460
1993	1.180	0.805	1.555	3.136	2.174	4.099	0.376	10	14	41	36.3	49	55	115	1124
1994	1.906	1.349	2.463	4.329	3.102	5.556	0.440	9	18	42	39.4	49	59	131	1729
1995	2.682	1.795	3.569	5.527	3.739	7.316	0.485	9	21	43	41.2	48	56	118	2058
1996	2.239	1.504	2.973	5.146	3.582	6.711	0.435	9	13	42	38.1	49	60	112	1878
1997	2.148	1.533	2.763	4.825	3.407	6.243	0.445	10	21	43	40.0	49	60	109	1757
1998	2.704	1.968	3.441	5.914	4.237	7.591	0.457	10	20	43	40.2	49	57	129	1713
1999	3.210	2.344	4.076	7.698	5.042	10.355	0.417	6	21	41	38.4	48	58	143	2289
2000	2.550	1.607	3.493	5.711	3.761	7.661	0.447	10	22	43	40.1	49	63	116	1759
2001	2.845	2.032	3.658	6.044	4.265	7.823	0.471	10	22	43	41.4	49	57	130	1985
2002	3.375	2.371	4.379	7.358	5.170	9.545	0.459	9	23	43	40.8	49	54	135	2515
2003	7.740	5.218	10.261	18.199	11.697	24.702	0.425	10	18	41	39.3	48	55	141	6523
2004	2.265	1.388	3.141	4.556	2.714	6.399	0.497	8	26	43	42.3	49	57	122	2270
2005	3.766	2.281	5.252	7.606	4.698	10.515	0.495	9	21	44	41.8	49	55	122	2437
2006	3.551	2.492	4.611	7.339	5.154	9.524	0.484	9	20	43	41.4	49	57	130	3349
2007	2.030	1.199	2.861	5.111	2.997	7.225	0.397	10	13	42	36.6	49	55	118	1439

Table 23. Abundance and biomass from NEFSC winter surveys for little skate for the Georges Bank to Mid-Atlantic region (offshore strata 1-3,5-7,9-11,13-14,16,61-63,65-67,69-71,73-75). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1992-2007. Stratum 16 not sampled in 1993, 2000, 2002-2007. Strata 13 and 14 not sampled in 2003 and 2007. Stratum 63 not sampled in 1993. Stratum 14 not sampled in 2005 and 2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1992	66.321	50.335	82.306	170.155	127.459	212.852	0.390	9	21	39	38.0	47	62	89	18418
1993	56.377	43.992	68.761	166.927	120.808	213.045	0.338	9	19	36	35.8	46	53	94	16026
1994	49.812	37.387	62.236	131.570	95.199	167.940	0.379	10	20	39	37.5	47	60	67	10113
1995	57.368	39.311	75.424	138.769	87.458	190.081	0.413	8	24	40	39.1	47	53	95	14530
1996	64.056	47.616	80.495	150.579	108.945	192.213	0.425	9	15	41	38.7	47	62	102	15701
1997	51.901	39.986	63.816	117.751	92.288	143.214	0.441	9	23	42	40.2	47	58	92	12084
1998	57.512	49.249	65.775	138.503	111.869	165.136	0.415	9	20	41	38.7	47	57	105	14492
1999	58.566	46.296	70.837	138.876	104.459	173.292	0.422	6	22	41	39.3	48	55	99	14740
2000	50.725	37.806	63.643	115.572	87.597	143.547	0.439	8	20	42	39.5	47	53	92	10722
2001	47.429	38.584	56.274	105.749	85.050	126.447	0.449	8	11	42	39.7	48	63	120	12956
2002	63.321	49.704	76.937	149.228	116.464	181.993	0.424	8	23	42	40.2	48	56	110	17329
2003	63.943	44.340	83.546	151.185	105.428	196.943	0.423	9	24	41	40.0	48	54	62	8870
2004	71.803	50.398	87.208	162.456	128.807	196.106	0.442	10	25	41	40.5	47	54	94	13822
2005	64.149	45.820	82.478	140.444	93.239	187.648	0.457	9	25	42	40.9	47	54	68	9544
2006	59.254	48.374	70.134	116.433	96.399	136.467	0.509	9	23	43	42.1	49	55	87	12687
2007	48.498	33.785	63.210	106.848	70.103	143.593	0.454	9	22	43	40.8	48	58	86	9258

Table 24. Abundance and biomass from NEFSC spring surveys for barndoor skate for the Gulf of Maine to Southern New England region (offshore strata 1-30, 33-40). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1968-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1968	0.374	0.075	0.673	0.138	0.026	0.249	2.716	41	46	61	71.7	115	118	10	21
1969	0.658	-0.364	1.681	0.145	-0.011	0.301	4.539	33	42	70	83.1	119	120	8	22
1970	0.111	0.033	0.188	0.047	0.017	0.078	2.350	45	44	62	68.2	104	105	9	10
1971	0.116	0.018	0.214	0.102	0.021	0.183	1.134	26	31	59	57.1	69	80	8	20
1972	0.222	0.028	0.416	0.023	0.005	0.041	9.617	63	62	119	104.7	123	124	6	6
1973	0.010	-0.001	0.022	0.017	0.000	0.034	0.621	51	51	51	54.1	59	60	3	3
1974	0.020	-0.005	0.045	0.017	-0.002	0.037	1.146	43	43	58	53.3	59	60	3	3
1975	0.001	-0.001	0.003	0.001	-0.001	0.003	0.900	60	60	60	60.0	60	60	1	1
1976	0.010	-0.010	0.030	0.006	-0.005	0.017	1.800	61	61	61	61.0	61	61	1	1
1977	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1978	0.015	-0.009	0.040	0.016	-0.006	0.039	0.933	51	50	55	56.3	61	62	2	3
1979	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1980	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1981	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1982	0.002	-0.001	0.005	0.002	-0.002	0.005	1.000	54	54	54	54.0	54	54	1	1
1983	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1984	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1985	0.001	0.000	0.002	0.007	-0.004	0.017	0.076	20	20	20	24.6	37	38	2	2
1986	0.003	-0.001	0.007	0.011	-0.004	0.026	0.250	33	33	41	37.5	41	42	2	2
1987	0.002	-0.002	0.006	0.007	-0.006	0.020	0.300	37	37	37	37.0	37	37	1	1
1988	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1989	0.007	-0.007	0.021	0.006	-0.006	0.019	1.100	60	60	60	60.0	60	60	1	1
1990	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1991	0.002	-0.002	0.006	0.007	-0.006	0.020	0.300	38	38	38	38.0	38	38	1	1
1992	0.136	-0.117	0.389	0.013	-0.006	0.032	10.397	41	41	117	98.2	124	125	2	4
1993	0.032	0.024	0.039	0.028	0.005	0.051	1.147	31	31	37	45.3	89	90	5	5
1994	0.084	-0.023	0.191	0.029	-0.001	0.059	2.926	46	46	65	70.1	120	121	4	6
1995	0.015	-0.007	0.037	0.012	-0.005	0.029	1.254	55	55	63	59.6	63	64	2	2
1996	0.062	-0.039	0.162	0.025	-0.003	0.054	2.465	23	23	66	63.2	111	112	4	6
1997	0.077	0.006	0.148	0.035	0.007	0.063	2.216	39	39	67	68.7	89	90	6	7
1998	0.169	-0.024	0.363	0.061	0.015	0.106	2.799	26	26	60	64.4	122	123	8	15
1999	0.279	-0.102	0.660	0.052	0.011	0.094	5.343	28	28	74	80.9	125	126	8	11
2000	0.473	0.246	0.699	0.138	0.076	0.200	3.419	19	20	68	71.4	125	127	14	29
2001	0.170	0.032	0.307	0.141	0.048	0.234	1.200	20	20	52	54.8	77	115	13	30
2002	0.477	0.233	0.721	0.129	0.047	0.212	3.690	35	35	66	77.3	127	133	13	26
2003	0.885	0.341	1.429	0.302	0.172	0.432	2.928	19	19	54	64.0	126	132	23	64
2004	0.103	0.039	0.167	0.111	0.032	0.189	0.928	19	19	55	50.6	81	89	12	24
2005	0.670	0.120	1.221	0.319	0.073	0.565	2.101	26	33	68	68.1	109	122	15	59
2006	1.706	-0.995	4.407	0.586	-0.087	1.260	2.910	19	19	69	69.9	123	134	22	196
2007	6.711	6.606	6.816	1.451	1.331	1.572	4.624	20	35	73	83.4	128	133	23	325
2008	1.370	-0.678	3.419	0.519	-0.059	1.096	2.641	28	33	67	70.9	113	133	17	140

Table 25. Abundance and biomass from NEFSC autumn surveys for barndoor skate for the Gulf of Maine to Southern New England region (offshore strata 1-30, 33-40). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1963-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1963	2.633	1.604	3.663	0.762	0.468	1.056	3.458	28	44	69	74.6	121	136	47	120
1964	1.212	0.489	1.934	0.400	0.229	0.570	3.030	40	41	69	72.7	112	122	32	63
1965	1.822	1.115	2.528	0.695	0.441	0.949	2.622	27	42	67	69.9	111	134	36	95
1966	0.811	0.394	1.229	0.459	0.243	0.675	1.767	23	38	60	63.0	88	115	26	62
1967	0.438	-0.025	0.901	0.064	0.017	0.111	6.844	45	52	65	81.0	119	120	10	14
1968	0.285	0.123	0.447	0.132	0.067	0.198	2.150	42	42	67	69.1	96	132	18	29
1969	0.054	-0.003	0.111	0.035	-0.006	0.076	1.551	51	51	62	62.0	73	74	5	8
1970	0.066	-0.046	0.178	0.011	-0.005	0.027	5.868	66	66	65	89.1	128	129	2	2
1971	0.170	-0.051	0.392	0.117	-0.077	0.311	1.455	35	35	53	54.6	63	120	6	19
1972	0.096	-0.073	0.265	0.012	-0.001	0.026	7.751	59	59	70	90.3	132	133	3	3
1973	0.004	-0.001	0.009	0.008	-0.003	0.019	0.474	41	41	47	48.7	52	53	2	3
1974	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1975	0.017	-0.016	0.049	0.010	-0.010	0.031	1.600	70	70	70	70.0	70	70	1	2
1976	0.047	0.002	0.091	0.058	-0.003	0.119	0.810	50	50	51	54.6	61	62	7	10
1977	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1978	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1979	0.009	-0.008	0.026	0.003	-0.003	0.009	3.000	78	78	78	78.0	78	78	1	1
1980	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1981	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1982	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1983	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1984	0.010	-0.004	0.024	0.003	0.000	0.007	2.900	61	61	84	73.0	84	85	2	2
1985	0.004	-0.004	0.012	0.002	-0.002	0.005	2.300	70	70	70	70.0	70	70	1	1
1986	0.029	-0.018	0.077	0.015	-0.002	0.032	2.008	22	22	52	51.0	90	91	3	3
1987	0.014	-0.005	0.032	0.012	-0.004	0.027	1.200	53	53	63	58.5	63	64	2	2
1988	0.007	-0.005	0.020	0.009	-0.005	0.022	0.850	34	34	33	44.8	76	77	2	2
1989	0.005	-0.005	0.014	0.002	-0.002	0.007	2.100	71	71	71	71.0	71	71	1	1
1990	0.028	-0.022	0.078	0.010	-0.005	0.024	2.964	60	60	66	76.3	95	96	2	3
1991	0.031	0.000	0.062	0.020	0.000	0.040	1.579	54	54	61	61.3	73	74	4	5
1992	0.002	-0.002	0.007	0.004	-0.004	0.013	0.550	46	46	51	49.0	51	52	1	2
1993	0.141	-0.040	0.321	0.023	0.004	0.042	6.180	45	45	74	86.6	127	128	5	6
1994	0.035	0.001	0.069	0.044	0.006	0.082	0.790	33	33	47	49.4	75	76	6	9
1995	0.111	-0.009	0.231	0.040	-0.006	0.085	2.810	48	48	62	70.9	113	114	4	10
1996	0.042	-0.020	0.104	0.023	0.000	0.046	1.841	25	25	61	59.8	92	93	4	5
1997	0.105	-0.024	0.234	0.026	0.004	0.047	4.065	36	36	79	73.3	124	125	5	5
1998	0.089	-0.036	0.214	0.026	0.002	0.050	3.453	48	48	71	73.9	120	121	4	5
1999	0.300	0.051	0.549	0.085	0.041	0.130	3.511	23	23	54	68.0	120	121	13	15
2000	0.288	0.054	0.521	0.054	0.023	0.085	5.360	29	29	89	85.5	121	122	12	15
2001	0.543	0.050	1.036	0.149	0.052	0.247	3.635	24	40	75	75.5	121	126	16	34
2002	0.778	0.351	1.205	0.269	0.130	0.407	2.893	26	27	59	68.0	119	129	24	59
2003	0.553	0.255	0.852	0.251	0.157	0.345	2.203	22	22	48	57.1	115	120	29	55
2004	1.295	0.677	1.913	0.229	0.122	0.336	5.662	42	47	80	90.1	124	128	23	58
2005	1.036	0.482	1.590	0.360	0.207	0.513	2.877	18	25	64	68.1	118	132	29	73
2006	1.168	0.392	1.945	0.435	0.169	0.701	2.687	19	29	58	65.5	118	127	35	102
2007	0.798	0.387	1.208	0.305	0.125	0.485	2.617	26	33	59	67.0	126	140	24	71

Table 26. Abundance and biomass from NEFSC winter surveys for barndoor skate for the Georges Bank to Mid-Atlantic region (offshore strata1-3,5-7,9-11,13-14,16,61-63,65-67,69-71,73-75). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1992-2007. Stratum 16 not sampled in 1993, 2000, 2002-2007. Strata 13 and 14 not sampled in 2003 and 2007. Stratum 63 not sampled in 1993. Stratum 14 not sampled in 2005 and 2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1992	0.000	0.000	0.000	0.000	0.000	0.000	-	-			-		-	0	0
1993	0.123	-0.066	0.311	0.052	0.004	0.100	2.358	20	20	65	57.3	119	120	4	6
1994	0.185	-0.027	0.397	0.080	0.011	0.148	2.328	21	21	60	63.5	102	103	5	7
1995	0.362	0.121	0.603	0.198	0.056	0.340	1.828	33	33	62	63.6	88	109	11	24
1996	0.291	0.079	0.503	0.203	0.054	0.352	1.434	19	20	61	56.4	85	92	12	23
1997	0.618	0.208	1.028	0.275	0.032	0.519	2.247	35	38	65	67.7	112	117	10	28
1998	0.455	0.146	0.765	0.464	0.092	0.837	0.980	20	26	41	46.8	83	123	12	57
1999	1.053	0.347	1.760	0.709	0.318	1.099	1.486	23	27	46	53.2	113	124	22	81
2000	2.718	0.153	5.284	1.081	0.518	1.643	2.515	19	19	56	62.8	122	126	12	69
2001	1.373	0.375	2.370	0.929	0.168	1.691	1.477	19	30	60	58.7	95	127	21	107
2002	2.126	0.506	3.746	0.950	0.441	1.459	2.238	18	29	58	63.9	119	126	24	123
2003	0.872	0.429	1.316	0.776	0.227	1.324	1.125	26	31	46	52.0	90	131	11	47
2004	3.397	1.214	5.581	1.786	0.972	2.601	1.902	18	30	53	60.9	116	130	23	247
2005	1.061	0.542	1.581	1.23101	0.703	1.759	0.862	18	19	44	47.8	84	102	21	103
2006	3.015	1.519	4.511	3.171	1.622	4.719	0.951	20	29	51	52.9	78	111	37	355
2007	1.847	0.815	2.878	2.318	0.199	4.438	0.797	20	30	44	48.5	80	118	25	220

Table 27. Abundance and biomass from NEFSC spring surveys for thorny skate for the Gulf of Maine to Southern New England region (offshore strata 1-30,33-40). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1968-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1968	3.181	2.137	4.225	1.600	1.067	2.134	1.987	12	16	44	47.8	91	105	60	252
1969	4.526	3.186	5.865	1.680	1.161	2.199	2.694	12	13	47	51.1	98	109	64	294
1970	4.202	3.229	5.174	1.990	1.478	2.502	2.112	12	16	41	48.2	95	110	84	363
1971	3.683	2.475	4.891	1.974	1.473	2.475	1.866	12	15	44	47.8	95	116	81	424
1972	4.984	3.757	6.212	2.219	1.773	2.665	2.246	12	16	47	50.7	94	110	91	443
1973	6.622	4.867	8.377	3.562	2.640	4.483	1.859	12	15	44	47.9	91	108	75	574
1974	3.774	2.939	4.608	2.450	1.938	2.962	1.540	9	14	43	45.8	87	106	81	376
1975	3.189	2.222	4.157	1.360	0.990	1.731	2.344	10	15	46	50.5	95	102	62	192
1976	2.895	2.041	3.750	1.671	1.281	2.060	1.733	13	15	43	47.2	90	106	79	339
1977	1.623	1.175	2.070	0.942	0.675	1.209	1.722	12	15	42	48.1	89	111	74	213
1978	1.250	0.806	1.695	0.800	0.579	1.020	1.564	10	15	49	46.8	83	97	71	191
1979	1.079	0.729	1.429	0.582	0.410	0.754	1.853	12	17	51	50.5	84	102	68	163
1980	2.105	1.308	2.901	1.319	0.880	1.757	1.596	11	13	37	43.6	92	100	60	250
1981	2.700	2.065	3.335	1.535	1.139	1.930	1.760	9	13	47	48.1	87	100	60	255
1982	2.345	1.685	3.004	1.144	0.878	1.411	2.049	10	17	53	52.4	85	97	62	218
1983	2.142	1.398	2.886	0.968	0.728	1.209	2.212	12	15	52	52.3	91	103	55	156
1984	1.453	0.818	2.087	0.608	0.462	0.755	2.389	12	16	51	53.0	96	100	40	97
1985	3.074	2.124	4.024	1.413	1.060	1.766	2.175	11	14	44	48.4	95	102	59	209
1986	2.619	1.974	3.263	1.718	1.377	2.058	1.525	10	15	38	44.0	83	98	69	276
1987	1.469	0.805	2.133	0.852	0.646	1.058	1.724	14	16	42	46.6	87	109	53	141
1988	1.173	0.735	1.612	1.106	0.766	1.446	1.061	11	14	32	38.5	82	98	59	176
1989	1.481	0.793	2.169	1.221	0.801	1.640	1.213	11	15	34	40.0	84	101	57	175
1990	1.565	0.833	2.296	1.097	0.688	1.506	1.427	14	16	39	44.5	82	99	49	167
1991	1.542	0.945	2.139	0.858	0.569	1.147	1.797	11	13	47	48.5	89	99	47	132
1992	1.092	0.621	1.564	0.612	0.384	0.840	1.784	14	15	47	48.4	89	102	31	86
1993	0.700	0.366	1.034	0.486	0.327	0.646	1.440	13	13	36	42.0	91	105	37	79
1994	0.435	0.242	0.629	0.439	0.270	0.609	0.991	12	12	37	39.3	67	92	39	80
1995	0.564	0.307	0.821	0.384	0.236	0.533	1.467	9	12	42	45.8	84	92	31	66
1996	0.371	0.178	0.563	0.321	0.106	0.535	1.156	12	12	36	40.8	80	93	24	63
1997	0.422	0.117	0.727	0.270	0.153	0.387	1.560	15	20	47	47.9	82	87	25	47
1998	0.480	0.209	0.752	0.334	0.236	0.431	1.440	12	14	35	40.8	89	98	42	85
1999	0.369	0.093	0.646	0.255	0.163	0.347	1.448	11	17	40	46.2	83	89	26	44
2000	0.423	0.166	0.680	0.470	0.013	0.927	0.900	12	12	24	34.0	82	89	28	103
2001	0.493	0.217	0.769	0.221	0.080	0.362	2.234	14	33	56	57.7	80	92	16	35
2002	0.333	0.138	0.529	0.248	0.127	0.369	1.340	13	15	38	42.0	88	93	24	53
2003	0.594	0.268	0.920	0.332	0.203	0.461	1.790	19	19	50	50.9	86	102	30	57
2004	0.368	0.178	0.557	0.212	0.128	0.296	1.731	15	15	47	49.3	91	95	22	48
2005	0.435	0.154	0.716	0.371	0.167	0.576	1.171	16	17	44	44.4	76	89	19	62
2006	0.201	0.035	0.366	0.186	0.020	0.352	1.079	12	14	41	41.9	83	87	15	29
2007	0.390	0.144	0.635	0.430	0.228	0.632	0.907	9	11	24	32.3	88	98	26	99
2008	0.255	0.088	0.422	0.184	0.086	0.281	1.387	10	12	37	41.5	90	94	20	39

Table 28. Abundance and biomass from NEFSC autumn surveys for thorny skate for the Gulf of Maine to Southern New England region (offshore strata 1-30, 33-40). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1963-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1963	5.371	3.788	6.954	1.672	1.305	2.039	3.213	10	15	60	60.4	99	107	65	297
1964	4.403	3.273	5.534	1.651	1.110	2.192	2.667	10	14	49	52.7	96	110	66	278
1965	4.474	3.268	5.681	1.825	1.243	2.408	2.451	10	14	45	49.6	95	107	55	352
1966	7.971	6.163	9.780	2.371	1.855	2.886	3.362	9	13	61	59.4	95	112	72	364
1967	2.712	1.422	4.001	0.982	0.383	1.580	2.763	12	14	49	52.5	95	100	54	165
1968	4.421	3.321	5.521	1.440	1.040	1.840	3.071	12	16	55	57.5	97	107	59	217
1969	5.715	4.320	7.110	1.833	1.359	2.307	3.117	12	14	55	56.7	97	106	72	289
1970	7.347	5.630	9.065	2.216	1.474	2.958	3.316	8	19	57	60.4	98	109	77	403
1971	5.357	4.149	6.565	1.434	1.095	1.774	3.735	12	18	63	64.1	99	111	69	284
1972	4.119	2.974	5.263	1.717	1.302	2.132	2.399	12	16	51	53.1	94	105	75	306
1973	4.564	3.227	5.902	1.536	1.134	1.939	2.971	12	17	59	61.2	95	111	72	274
1974	3.038	2.166	3.910	1.392	1.025	1.759	2.182	10	14	50	51.1	89	111	79	293
1975	2.474	1.483	3.464	1.027	0.716	1.338	2.409	10	12	47	50.0	94	106	70	232
1976	1.720	1.003	2.437	0.798	0.543	1.052	2.157	12	15	44	49.1	91	103	57	143
1977	3.221	2.513	3.928	1.548	1.223	1.874	2.080	10	13	49	50.7	89	107	108	446
1978	4.291	3.473	5.109	2.145	1.643	2.648	2.000	10	16	49	51.1	88	107	155	874
1979	3.612	2.750	4.474	1.283	0.864	1.702	2.815	11	21	59	59.5	89	101	134	486
1980	4.601	3.344	5.859	1.882	1.484	2.280	2.445	11	14	54	54.4	90	100	84	416
1981	3.339	2.551	4.127	1.305	0.957	1.653	2.559	12	15	55	57.1	90	103	71	223
1982	0.646	0.312	0.981	0.393	0.194	0.592	1.644	11	13	33	43.0	85	96	31	83
1983	2.409	1.553	3.266	0.833	0.589	1.077	2.892	15	20	56	58.8	93	108	49	121
1984	2.887	1.978	3.795	1.270	0.975	1.565	2.272	10	13	48	49.8	94	107	70	211
1985	2.877	1.765	3.988	1.438	1.094	1.783	2.000	12	16	49	49.6	87	103	66	260
1986	1.629	1.068	2.189	1.019	0.771	1.268	1.598	11	15	35	44.2	83	101	61	183
1987	0.944	0.590	1.297	0.841	0.600	1.082	1.123	12	14	36	40.2	78	92	49	143
1988	1.488	0.998	1.978	1.099	0.702	1.497	1.354	13	15	31	41.5	84	101	56	208
1989	1.883	0.980	2.786	1.129	0.787	1.471	1.668	12	14	40	46.2	85	101	63	198
1990	1.704	1.090	2.318	1.040	0.744	1.335	1.639	12	17	42	47.2	85	95	53	202
1991	1.632	0.519	2.745	0.921	0.591	1.251	1.772	13	15	47	49.5	86	108	54	153
1992	0.962	0.551	1.373	0.775	0.461	1.088	1.242	12	13	36	41.2	83	99	48	144
1993	1.658	0.639	2.676	0.901	0.440	1.361	1.840	12	13	47	47.8	91	101	50	157
1994	1.509	0.343	2.675	0.981	0.311	1.652	1.538	13	17	45	46.9	84	97	41	170
1995	0.783	0.331	1.235	0.639	0.183	1.095	1.226	13	14	39	42.2	72	99	37	107
1996	0.814	0.360	1.269	0.602	0.362	0.842	1.352	14	14	39	43.3	85	99	37	102
1997	0.849	0.405	1.293	0.404	0.241	0.567	2.101	12	20	50	52.3	83	99	33	79
1998	0.648	0.297	0.999	0.307	0.145	0.468	2.113	13	14	51	52.4	87	93	30	60
1999	0.479	0.249	0.710	0.326	0.195	0.457	1.469	13	14	41	46.3	87	94	38	72
2000	0.832	0.391	1.274	0.374	0.239	0.510	2.224	13	17	49	52.7	92	102	27	70
2001	0.332	0.087	0.577	0.294	0.157	0.430	1.129	16	17	44	44.1	74	82	23	60
2002	0.436	0.188	0.684	0.260	0.126	0.393	1.679	14	15	35	44.2	85	95	25	52
2003	0.742	0.450	1.035	0.930	0.168	1.691	0.798	12	14	23	34.2	74	89	34	175
2004	0.710	0.272	1.148	0.358	0.167	0.550	1.980	14	18	45	50.1	87	90	23	65
2005	0.224	0.092	0.357	0.205	-0.034	0.443	1.096	13	18	39	42.6	76	90	17	36
2006	0.726	0.385	1.066	0.254	0.154	0.354	2.857	13	15	51	54.6	93	94	27	52
2007	0.316	0.083	0.549	0.296	0.072	0.520	1.068	10	13	19	34.6	84	92	22	45

Table 29. Abundance and biomass from NEFSC spring surveys for smooth skate for the Gulf of Maine to Southern New England region (offshore strata 1-30,33-40). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1968-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1968	0.211	0.080	0.342	0.484	0.129	0.838	0.436	12	24	41	42.1	58	64	17	41
1969	0.377	0.193	0.562	0.834	0.521	1.147	0.452	11	19	48	43.3	58	63	28	82
1970	0.346	0.134	0.557	0.702	0.376	1.028	0.492	9	14	47	40.9	57	61	25	68
1971	0.800	0.395	1.205	1.185	0.650	1.719	0.675	9	20	51	48.2	61	63	40	114
1972	0.621	0.355	0.886	1.016	0.582	1.450	0.611	14	20	47	44.3	59	64	34	122
1973	1.000	0.745	1.255	1.907	1.401	2.414	0.524	9	24	45	44.2	59	65	51	179
1974	1.092	0.594	1.590	2.003	1.109	2.896	0.545	9	9	47	42.7	59	63	47	172
1975	0.240	0.133	0.346	0.383	0.224	0.543	0.626	19	25	49	46.8	59	61	22	37
1976	0.534	0.413	0.655	1.150	0.870	1.429	0.464	12	16	43	39.8	57	60	49	134
1977	0.122	0.066	0.178	0.302	0.158	0.445	0.405	15	18	40	41.4	57	60	28	45
1978	0.251	0.144	0.358	0.413	0.258	0.567	0.609	24	26	50	46.7	58	61	33	56
1979	0.218	0.097	0.340	0.410	0.163	0.657	0.533	15	19	39	40.2	54	61	27	54
1980	0.484	0.316	0.651	0.948	0.625	1.271	0.510	16	20	42	41.9	56	60	42	84
1981	0.358	0.227	0.489	0.782	0.513	1.050	0.458	8	13	38	37.2	57	65	38	70
1982	0.152	0.057	0.247	0.225	0.092	0.357	0.677	11	10	52	45.6	57	64	14	23
1983	0.363	0.219	0.507	0.531	0.335	0.727	0.683	11	21	50	47.9	57	69	25	50
1984	0.065	0.010	0.120	0.124	0.026	0.221	0.523	19	20	48	39.8	59	60	9	13
1985	0.211	0.136	0.286	0.450	0.298	0.602	0.469	18	20	41	40.4	57	63	31	59
1986	0.250	0.137	0.362	0.466	0.256	0.677	0.536	20	24	48	46.7	59	65	30	93
1987	0.069	0.029	0.108	0.105	0.044	0.166	0.655	43	42	48	50.2	59	62	12	15
1988	0.115	0.044	0.186	0.328	0.175	0.480	0.350	11	13	36	36.3	57	60	24	49
1989	0.225	0.107	0.343	0.620	0.402	0.838	0.363	13	15	37	38.8	60	63	30	88
1990	0.152	0.010	0.294	0.294	0.080	0.509	0.515	11	16	46	44.0	57	62	18	40
1991	0.137	0.073	0.200	0.237	0.136	0.337	0.576	11	17	49	47.1	59	62	22	34
1992	0.063	0.025	0.101	0.104	0.035	0.172	0.608	22	40	49	48.5	56	57	12	16
1993	0.086	0.021	0.151	0.214	0.020	0.408	0.403	21	23	42	41.2	56	58	14	35
1994	0.098	0.043	0.153	0.176	0.082	0.269	0.558	29	29	47	47.1	56	58	15	30
1995	0.101	0.050	0.152	0.234	0.119	0.349	0.432	9	20	42	41.9	55	59	18	33
1996	0.036	0.014	0.058	0.084	0.038	0.129	0.429	20	19	48	43.8	53	59	10	12
1997	0.037	0.015	0.059	0.122	0.035	0.208	0.307	17	20	36	38.9	55	58	11	22
1998	0.200	0.089	0.311	0.410	0.206	0.613	0.489	9	19	46	44.6	56	60	28	77
1999	0.243	0.068	0.418	0.925	-0.074	1.924	0.262	18	20	32	35.6	51	65	23	111
2000	0.060	0.025	0.095	0.220	-0.021	0.460	0.272	10	10	27	30.9	59	62	13	30
2001	0.058	0.020	0.096	0.125	0.058	0.192	0.466	19	28	46	44.6	57	60	16	25
2002	0.184	0.096	0.271	0.482	0.297	0.667	0.381	10	13	45	40.4	55	61	26	78
2003	0.224	0.161	0.287	0.642	0.429	0.348	0.348	14	19	40	40.4	55	59	36	95
2004	0.262	0.141	0.383	0.650	0.278	1.022	0.403	12	19	43	42.3	56	60	32	125
2005	0.457	0.125	0.788	1.207	0.288	2.126	0.378	10	27	42	42.4	53	60	22	178
2006	0.203	0.005	0.401	0.531	-0.009	1.072	0.382	19	21	41	41.3	56	62	22	71
2007	0.125	0.035	0.214	0.294	0.095	0.494	0.423	16	21	46	41.9	57	60	18	64
2008	0.340	0.075	0.604	1.050	0.156	1.945	0.323	9	14	38	36.8	55	59	20	168

Table 30. Abundance and biomass from NEFSC autumn surveys for smooth skate for the Gulf of Maine to Southern New England region (offshore strata 1-30,33-40). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1963-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1963	0.498	0.306	0.689	0.543	0.282	0.804	0.917	9	20	48	43.9	58	62	26	53
1964	0.326	0.152	0.501	0.360	0.209	0.512	0.906	9	20	42	41.7	59	64	19	35
1965	0.475	0.140	0.811	1.221	0.440	2.001	0.389	11	16	35	38.1	56	64	27	94
1966	0.323	0.175	0.471	0.867	0.519	1.216	0.372	13	17	37	38.6	58	59	28	60
1967	0.152	0.036	0.268	0.293	0.118	0.469	0.518	22	24	48	46.5	62	69	16	27
1968	0.385	0.211	0.559	0.665	0.375	0.955	0.579	17	20	48	45.9	58	62	24	56
1969	0.290	0.131	0.449	0.604	0.282	0.925	0.481	12	16	41	39.6	58	64	21	50
1970	0.232	0.121	0.343	0.530	0.289	0.771	0.437	9	13	45	38.3	59	62	25	50
1971	0.157	0.077	0.238	0.250	0.120	0.379	0.631	17	36	53	51.0	57	59	18	27
1972	0.332	0.185	0.478	0.499	0.285	0.713	0.664	16	24	49	49.8	62	64	30	52
1973	0.311	0.199	0.423	0.506	0.344	0.667	0.614	17	22	48	46.9	58	60	32	56
1974	0.123	0.055	0.192	0.180	0.088	0.273	0.684	11	11	50	48.5	60	63	13	21
1975	0.076	0.029	0.123	0.104	0.043	0.165	0.727	21	30	49	46.7	56	57	12	15
1976	0.039	0.004	0.074	0.077	0.020	0.135	0.501	17	36	41	43.9	52	60	9	10
1977	0.376	0.274	0.478	0.600	0.443	0.757	0.627	19	24	48	44.9	56	61	50	84
1978	0.450	0.240	0.661	0.635	0.359	0.912	0.709	8	25	50	48.0	59	66	49	130
1979	0.182	0.075	0.288	0.239	0.116	0.362	0.761	9	29	50	48.7	60	62	31	60
1980	0.343	0.167	0.519	0.522	0.254	0.789	0.658	15	23	52	46.4	58	62	37	60
1981	0.119	0.039	0.199	0.167	0.069	0.264	0.715	23	26	49	48.1	60	61	13	18
1982	0.039	0.007	0.071	0.074	0.025	0.123	0.521	9	9	49	41.9	63	64	11	11
1983	0.146	0.056	0.236	0.255	0.085	0.426	0.573	14	14	46	40.9	57	59	12	24
1984	0.199	0.106	0.292	0.389	0.171	0.607	0.512	14	22	37	39.2	58	71	23	39
1985	0.210	0.088	0.332	0.340	0.180	0.500	0.617	12	15	51	45.2	59	63	28	64
1986	0.209	0.118	0.300	0.392	0.216	0.567	0.534	13	21	47	45.0	63	66	24	63
1987	0.095	0.045	0.145	0.164	0.081	0.247	0.581	15	15	48	44.8	60	61	19	28
1988	0.284	0.103	0.465	0.446	0.223	0.670	0.637	20	20	51	48.3	59	65	27	90
1989	0.128	0.072	0.185	0.336	0.194	0.478	0.382	13	16	33	36.8	59	62	27	52
1990	0.194	0.120	0.268	0.332	0.202	0.462	0.584	16	23	48	46.4	58	62	27	45
1991	0.167	0.070	0.265	0.335	0.188	0.482	0.500	18	20	46	43.9	57	62	25	59
1992	0.126	0.024	0.228	0.316	0.120	0.511	0.400	12	18	43	40.0	58	60	16	56
1993	0.227	0.107	0.346	0.818	0.273	1.362	0.277	13	13	26	32.6	56	62	29	123
1994	0.099	0.030	0.169	0.269	0.105	0.433	0.370	11	11	36	38.0	57	59	17	36
1995	0.189	0.115	0.263	0.764	0.315	1.214	0.247	10	13	30	32.6	56	59	29	119
1996	0.176	0.093	0.260	0.421	0.249	0.594	0.418	15	18	46	41.6	56	59	26	55
1997	0.232	0.117	0.347	0.449	0.232	0.665	0.517	16	21	47	45.2	60	64	20	59
1998	0.028	0.005	0.051	0.108	0.021	0.194	0.263	18	17	29	35.2	51	53	11	18
1999	0.070	0.032	0.109	0.110	0.050	0.171	0.638	22	22	50	48.7	60	62	16	22
2000	0.154	0.083	0.226	0.318	0.190	0.447	0.485	10	11	45	42.3	59	73	27	55
2001	0.287	0.169	0.405	0.565	0.349	0.781	0.507	17	23	49	46.5	58	62	29	84
2002	0.111	0.067	0.155	0.209	0.140	0.278	0.533	15	24	50	46.2	60	62	25	32
2003	0.190	0.076	0.304	0.646	0.248	1.045	0.294	10	14	39	36.3	52	62	30	84
2004	0.214	0.126	0.303	0.467	0.283	0.652	0.458	18	24	47	45.3	55	59	29	58
2005	0.131	0.039	0.224	0.291	0.143	0.439	0.451	15	17	47	43.1	59	62	18	44
2006	0.211	0.106	0.316	0.387	0.230	0.544	0.545	10	14	50	45.6	59	62	27	56
2007	0.089	0.048	0.131	0.198	0.107	0.289	0.451	16	24	47	43.6	58	71	19	31

Table 31. Abundance and biomass from NEFSC spring surveys for clearnose skate for the Mid-Atlantic region (offshore strata 61-76, inshore strata 15-44). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1976-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1976	0.100	0.020	0.179	0.129	0.040	0.218	0.770	26	26	43	48.5	66	67	8	12
1977	0.509	0.297	0.722	0.500	0.260	0.741	1.017	23	23	56	52.5	63	64	17	41
1978	0.211	-0.094	0.516	0.237	-0.057	0.530	0.893	20	20	57	52.2	68	69	8	21
1979	0.109	0.010	0.209	0.125	0.004	0.247	0.875	25	25	42	50.3	77	78	6	9
1980	0.319	0.100	0.538	0.456	0.136	0.775	0.700	25	25	41	45.1	64	69	14	44
1981	0.891	-0.141	1.923	0.606	0.106	1.107	1.469	24	26	60	55.9	67	72	10	44
1982	0.328	0.165	0.491	0.368	0.126	0.610	0.892	30	32	52	53.6	66	71	14	40
1983	0.138	0.005	0.270	0.127	0.003	0.252	1.081	13	13	58	51.3	65	66	7	11
1984	0.380	0.103	0.658	0.288	0.018	0.557	1.321	48	48	62	60.7	70	74	11	25
1985	0.493	-0.166	1.151	0.436	-0.203	1.076	1.129	48	48	58	59.3	69	72	10	37
1986	0.155	0.035	0.274	0.232	0.038	0.427	0.666	27	27	44	44.8	68	69	11	15
1987	0.306	0.150	0.463	0.202	0.109	0.204	1.519	49	51	63	61.9	69	72	16	20
1988	0.340	0.171	0.508	0.300	0.097	0.502	1.134	44	44	58	57.1	67	71	11	19
1989	0.424	0.258	0.590	0.415	0.275	0.554	1.023	25	25	58	52.3	68	72	14	40
1990	0.501	0.283	0.719	0.420	0.243	0.597	1.192	30	30	59	56.2	67	72	15	52
1991	0.690	0.463	0.918	0.543	0.354	0.731	1.272	27	27	62	58.8	68	71	23	59
1992	0.748	0.324	1.172	0.489	0.218	0.760	1.529	46	46	63	63.0	68	80	23	47
1993	0.856	0.479	1.233	0.656	0.216	1.096	1.305	21	33	63	58.6	70	74	12	136
1994	0.319	0.052	0.585	0.188	0.043	0.333	1.699	51	57	65	66.0	73	74	8	24
1995	0.669	0.361	0.977	0.464	0.261	0.666	1.443	46	46	67	62.4	68	74	18	32
1996	1.224	0.194	2.254	0.948	0.255	1.641	1.291	13	27	62	59.8	70	75	30	95
1997	1.290	0.885	1.695	0.972	0.542	1.403	1.326	33	39	63	61.3	71	78	22	80
1998	0.903	0.674	1.133	0.667	0.369	0.964	1.355	26	38	62	60.2	70	74	29	81
1999	0.943	0.647	1.238	0.862	0.470	1.255	1.093	26	28	59	57.3	67	72	19	54
2000	1.391	1.046	1.736	1.140	0.789	1.491	1.221	24	40	59	59.4	70	76	31	126
2001	1.380	0.674	2.087	1.097	0.456	1.738	1.258	42	49	62	60.8	68	72	19	74
2002	0.836	0.281	1.392	0.617	0.241	0.993	1.355	29	42	62	60.5	69	74	23	59
2003	0.622	0.366	0.879	0.448	0.265	0.631	1.389	49	49	62	62.7	75	76	16	35
2004	0.433	0.050	0.815	0.376	0.049	0.703	1.151	35	35	59	56.2	70	72	9	23
2005	0.569	0.030	1.109	0.414	0.008	0.820	1.374	42	42	61	61.2	70	73	11	27
2006	0.567	0.189	0.946	0.420	0.179	0.661	1.350	36	41	63	60.7	68	72	18	39
2007	0.857	0.406	1.308	0.745	0.273	1.217	1.150	28	30	60	58.4	69	73	19	48
2008	1.188	0.603	1.773	0.846	0.370	1.322	1.404	27	43	62	62.4	72	79	30	103

Table 32. Abundance and biomass from NEFSC autumn surveys for clearnose skate for the Mid-Atlantic region (offshore strata 61-76, inshore strata 15-44). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th,and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1975-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1975	0.237	0.086	0.388	0.246	0.133	0.360	0.961	21	21	53	50.3	63	66	31	49
1976	0.302	0.189	0.415	0.348	0.236	0.459	0.869	18	34	52	52.1	64	69	26	54
1977	0.768	0.288	1.248	0.742	0.281	1.203	1.035	15	37	57	55.4	65	68	32	106
1978	0.156	0.073	0.240	0.224	0.086	0.363	0.697	10	10	44	40.8	64	66	14	23
1979	0.419	0.116	0.721	0.346	0.146	0.545	1.211	22	24	56	55.4	67	71	27	46
1980	0.685	0.408	0.961	0.549	0.322	0.775	1.248	33	37	59	58.1	69	72	32	80
1981	0.171	0.081	0.260	0.179	0.087	0.271	0.954	27	27	55	51.5	65	68	19	28
1982	0.213	0.099	0.326	0.183	0.095	0.271	1.163	32	43	59	58.3	67	72	26	37
1983	0.141	0.027	0.254	0.127	0.043	0.210	1.110	16	16	57	52.2	64	70	15	19
1984	0.178	0.064	0.293	0.189	0.063	0.315	0.945	34	37	53	54.0	67	83	20	32
1985	0.306	0.173	0.439	0.315	0.182	0.447	0.974	32	41	56	54.9	66	71	23	42
1986	0.545	-0.038	1.027	0.591	0.091	1.092	0.921	23	23	59	52.6	64	71	31	62
1987	0.320	0.176	0.465	0.289	0.167	0.412	1.107	15	41	56	55.5	69	70	23	42
1988	0.335	0.157	0.513	0.329	0.163	0.495	1.019	33	37	57	56.0	66	71	19	60
1989	0.273	0.075	0.471	0.324	0.064	0.584	0.843	37	37	52	52.7	63	70	20	39
1990	0.402	0.157	0.646	0.306	0.114	0.499	1.311	16	41	60	57.9	69	72	17	50
1991	0.922	0.279	1.566	0.816	0.339	1.294	1.130	35	39	58	57.1	69	71	35	119
1992	0.345	0.185	0.505	0.312	0.185	0.440	1.104	16	42	59	56.7	67	69	22	48
1993	0.495	0.145	0.844	0.474	0.188	0.759	1.044	35	40	57	56.8	66	73	27	104
1994	0.938	0.479	1.398	0.842	0.494	1.190	1.115	35	40	57	57.1	66	73	35	129
1995	0.331	0.189	0.473	0.426	0.233	0.618	0.777	14	14	51	45.5	66	72	25	63
1996	0.430	0.194	0.666	0.369	0.163	0.576	1.165	29	45	59	58.8	68	72	20	42
1997	0.614	0.296	0.932	0.484	0.281	0.688	1.269	43	43	61	60.2	69	77	27	60
1998	1.121	0.115	2.128	1.096	0.124	2.068	1.023	34	43	57	57.5	68	73	32	98
1999	1.053	0.536	1.570	0.928	0.525	1.332	1.134	15	32	61	57.8	69	71	41	84
2000	1.032	0.422	1.642	0.795	0.353	1.238	1.298	14	47	60	60.5	69	74	29	61
2001	1.614	1.092	2.136	1.494	0.984	2.004	1.081	13	15	59	55.2	68	73	41	221
2002	0.891	0.372	1.411	0.863	0.317	1.409	1.033	14	38	55	56.0	68	73	27	63
2003	0.661	0.417	0.906	0.640	0.456	0.823	1.034	15	30	54	54.5	71	78	38	81
2004	0.709	0.201	1.217	0.590	0.172	1.008	1.201	37	43	62	60.1	69	75	18	55
2005	0.524	0.192	0.855	0.452	0.207	0.697	1.159	26	37	62	59.6	71	74	30	71
2006	0.533	0.257	0.809	0.654	0.347	0.961	0.816	13	37	53	52.6	64	71	35	77
2007	0.853	0.430	1.276	0.788	0.386	1.191	1.082	13	34	60	57.9	67	74	25	74

Table 33. Abundance and biomass from NEFSC winter surveys for clearnose skate for the Georges Bank to Mid-Atlantic region (offshore strata1-3,5-7,9-11,13-14,16,61-63,65-67,69-71,73-75). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1992-2007. Stratum 16 not sampled in 1993, 2000, 2002-2007. Strata 13 and 14 not sampled in 2003 and 2007. Stratum 63 not sampled in 1993. Stratum 14 not sampled in 2005 and 2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1992	5.622	3.247	7.997	5.247	2.974	7.519	1.072	23	26	59	54.7	67	93	22	551
1993	6.013	3.818	8.208	5.973	3.852	8.093	1.007	22	33	57	54.3	67	81	23	716
1994	8.854	4.037	13.672	7.692	2.152	13.233	1.151	27	33	60	57.5	69	77	16	639
1995	7.924	2.521	13.327	6.247	1.301	11.194	1.268	24	45	61	60.2	69	76	23	737
1996	14.725	8.266	21.183	11.555	6.347	16.762	1.274	22	40	61	60.0	69	77	32	3086
1997	5.522	3.154	7.890	5.069	2.158	7.980	1.089	22	35	59	56.2	70	76	32	682
1998	6.031	4.470	7.592	4.878	3.195	6.560	1.236	22	36	60	58.3	71	88	32	1091
1999	3.826	2.335	5.317	3.022	1.586	4.459	1.266	23	37	61	59.6	70	76	30	343
2000	10.102	5.693	14.510	8.864	4.579	13.150	1.140	25	42	59	58.2	69	93	43	1449
2001	8.316	5.624	11.008	6.599	4.240	8.957	1.260	25	43	61	60.6	69	86	41	1300
2002	12.223	8.343	16.102	8.864	5.886	11.843	1.379	23	39	63	61.6	70	74	51	1704
2003	19.637	13.819	25.455	15.769	10.902	20.635	1.245	23	39	62	59.1	70	81	36	2260
2004	11.566	7.743	15.389	10.162	6.344	13.979	1.138	20	35	60	58.1	70	80	38	1880
2005	6.036	3.837	8.235	5.078	2.425	7.731	1.189	24	44	60	59.1	70	82	26	1047
2006	11.723	4.862	18.585	11.085	4.693	17.477	1.058	23	35	57	56.7	70	77	41	1916
2007	15.151	10.623	19.679	11.760	8.466	15.054	1.288	25	44	62	60.5	70	82	51	1731

Table 34. Abundance and biomass from NEFSC spring surveys for rosette skate for the Mid-Atlantic region (offshore strata 61-76). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1968-2008.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1968	0.005	-0.002	0.012	0.014	0.000	0.029	0.356	33	33	33	34.4	35	36	3	3
1969	0.001	-0.001	0.002	0.003	-0.003	0.010	0.200	37	37	37	37.0	37	37	1	1
1970	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1971	0.005	-0.005	0.014	0.010	-0.009	0.028	0.500	57	57	57	57.0	57	57	1	1
1972	0.000	0.000	0.001	0.003	-0.003	0.010	0.100	35	35	35	35.0	35	35	1	1
1973	0.006	-0.001	0.012	0.023	-0.006	0.052	0.240	38	38	38	38.6	41	42	4	5
1974	0.005	-0.005	0.015	0.025	-0.024	0.074	0.200	41	41	41	41.0	41	41	1	1
1975	0.001	-0.001	0.003	0.005	-0.005	0.014	0.200	38	38	38	38.5	39	39	1	2
1976	0.007	0.000	0.015	0.035	-0.003	0.073	0.208	31	31	36	36.9	44	45	4	6
1977	0.102	0.019	0.186	0.552	0.107	0.998	0.185	20	26	32	33.6	37	42	11	70
1978	0.010	0.001	0.019	0.041	0.008	0.074	0.232	12	25	35	35.3	40	41	7	10
1979	0.007	0.005	0.009	0.040	0.031	0.048	0.171	13	13	34	31.6	40	41	4	10
1980	0.072	0.030	0.115	0.373	0.167	0.580	0.194	26	27	34	35.3	41	42	15	47
1981	0.013	0.001	0.025	0.057	0.006	0.109	0.231	19	28	37	36.3	41	42	6	17
1982	0.025	0.010	0.040	0.108	0.043	0.174	0.234	22	25	37	37.4	43	44	11	20
1983	0.002	-0.001	0.004	0.012	-0.006	0.029	0.147	29	29	34	34.2	35	36	2	5
1984	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	-	-	-	0	0
1985	0.005	-0.001	0.011	0.059	0.040	0.079	0.080	17	17	18	21.0	29	42	3	9
1986	0.002	-0.002	0.006	0.012	-0.008	0.031	0.182	32	32	35	35.3	35	36	2	2
1987	0.003	-0.002	0.009	0.017	-0.012	0.046	0.200	35	35	36	36.7	36	37	2	2
1988	0.020	-0.001	0.041	0.111	-0.002	0.223	0.180	26	26	35	32.8	35	36	4	6
1989	0.010	-0.004	0.025	0.051	-0.036	0.137	0.200	28	28	34	34.6	40	41	2	15
1990	0.010	-0.004	0.024	0.049	-0.022	0.121	0.200	36	36	35	36.0	35	36	3	3
1991	0.036	0.014	0.058	0.143	0.057	0.228	0.253	19	33	37	37.2	40	42	7	19
1992	0.014	-0.001	0.029	0.063	0.012	0.113	0.223	24	24	37	36.0	40	41	5	5
1993	0.009	0.007	0.011	0.037	0.030	0.043	0.255	38	38	37	38.6	39	40	2	5
1994	0.005	0.001	0.009	0.021	0.006	0.035	0.243	36	36	38	38.7	40	41	4	4
1995	0.010	0.000	0.020	0.056	0.003	0.110	0.173	19	19	35	32.9	36	37	3	5
1996	0.014	-0.011	0.039	0.095	-0.013	0.203	0.149	9	9	35	29.3	42	43	5	19
1997	0.028	0.022	0.033	0.138	0.091	0.186	0.200	30	30	34	35.6	41	42	4	25
1998	0.038	0.007	0.068	0.132	0.041	0.223	0.287	32	33	38	38.0	41	42	11	15
1999	0.043	0.003	0.083	0.206	0.012	0.399	0.211	15	29	37	36.7	42	43	9	16
2000	0.026	0.009	0.043	0.106	0.040	0.171	0.247	30	32	37	38.0	41	42	7	15
2001	0.010	-0.005	0.025	0.041	-0.012	0.095	0.244	21	21	40	38.2	40	41	4	4
2002	0.019	-0.007	0.045	0.076	-0.029	0.180	0.252	12	12	38	34.1	39	40	3	5
2003	0.028	-0.002	0.057	0.115	0.003	0.226	0.241	9	24	38	37.0	39	41	5	17
2004	0.023	-0.009	0.055	0.084	-0.025	0.193	0.276	30	32	39	39.2	40	41	3	7
2005	0.050	-0.029	0.128	0.216	-0.131	0.564	0.229	13	31	37	36.7	40	41	5	21
2006	0.012	0.007	0.016	0.051	0.020	0.081	0.230	25	25	39	35.5	40	41	5	8
2007	0.006	0.001	0.010	0.033	0.008	0.058	0.167	18	18	31	32.3	39	40	8	11
2008	0.024	-0.008	0.057	0.172	-0.044	0.388	0.142	7	7	27	29.9	38	41	4	24

Table 35. Abundance and biomass from NEFSC autumn surveys for rosette skate for the Mid-Atlantic region (offshore strata 61-76). The mean index, 95% confidence intervals, individual fish weight, minimum, mean, and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1967-2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1967	0.019	0.002	0.037	0.117	0.010	0.224	0.166	10	18	34	34.3	39	42	7	17
1968	0.003	-0.001	0.008	0.023	-0.019	0.065	0.135	28	28	28	28.9	37	38	2	2
1969	0.002	-0.002	0.006	0.010	-0.009	0.028	0.200	38	38	38	38.0	38	38	1	1
1970	0.009	-0.006	0.024	0.033	-0.025	0.090	0.276	39	39	39	39.5	39	40	2	3
1971	0.001	-0.001	0.004	0.006	-0.005	0.016	0.250	40	40	40	40.5	40	41	1	2
1972	0.016	0.001	0.032	0.058	0.021	0.094	0.285	12	12	34	34.2	40	41	7	8
1973	0.012	-0.008	0.032	0.053	-0.016	0.122	0.224	16	16	28	29.0	40	41	3	5
1974	0.012	-0.002	0.026	0.079	-0.014	0.171	0.156	23	23	34	33.8	40	41	4	11
1975	0.004	-0.001	0.009	0.034	-0.001	0.070	0.122	25	25	34	33.6	38	39	4	8
1976	0.024	0.003	0.045	0.149	0.016	0.281	0.163	28	28	33	33.7	37	40	7	21
1977	0.020	-0.002	0.043	0.087	-0.011	0.185	0.231	31	31	33	35.2	40	41	5	8
1978	0.007	-0.007	0.022	0.015	-0.014	0.043	0.500	39	39	39	39.0	39	39	1	1
1979	0.010	-0.004	0.025	0.043	-0.016	0.101	0.242	22	22	35	36.1	39	40	3	6
1980	0.090	0.042	0.138	0.312	0.120	0.505	0.287	14	25	38	36.6	41	42	10	24
1981	0.079	0.011	0.148	0.296	0.052	0.539	0.268	27	28	37	37.5	41	43	10	45
1982	0.006	-0.006	0.018	0.020	-0.019	0.059	0.300	39	39	39	39.0	39	39	1	1
1983	0.001	-0.001	0.003	0.010	-0.010	0.030	0.100	12	12	12	20.7	36	37	1	3
1984	0.029	0.005	0.053	0.128	0.033	0.223	0.229	13	26	36	35.6	39	40	7	16
1985	0.005	0.004	0.007	0.036	0.019	0.054	0.146	14	14	25	28.0	35	36	5	6
1986	0.003	0.001	0.004	0.009	0.005	0.013	0.300	37	37	37	38.2	39	40	3	3
1987	0.028	0.006	0.050	0.112	0.040	0.183	0.253	11	15	38	32.7	41	42	7	10
1988	0.021	0.000	0.043	0.093	-0.002	0.188	0.228	30	30	32	35.0	41	42	5	8
1989	0.018	-0.005	0.041	0.046	-0.012	0.105	0.378	33	33	33	33.5	36	37	3	4
1990	0.023	-0.004	0.049	0.099	0.001	0.198	0.228	32	32	37	37.7	41	42	5	10
1991	0.005	-0.004	0.014	0.021	-0.009	0.051	0.237	15	15	34	31.4	34	35	3	3
1992	0.035	0.006	0.064	0.170	0.033	0.308	0.203	25	25	35	35.3	41	42	9	11
1993	0.021	0.005	0.037	0.102	0.033	0.170	0.211	25	25	37	35.1	40	41	4	8
1994	0.073	0.000	0.146	0.301	0.006	0.597	0.242	27	27	37	36.8	42	43	6	21
1995	0.039	-0.005	0.084	0.174	-0.009	0.358	0.227	19	24	35	35.1	38	39	7	13
1996	0.043	-0.014	0.100	0.273	-0.127	0.674	0.158	7	19	32	31.6	38	42	7	21
1997	0.013	0.000	0.026	0.074	-0.014	0.162	0.176	31	31	33	34.0	42	43	4	6
1998	0.050	-0.008	0.108	0.208	-0.042	0.458	0.241	33	33	37	38.1	40	41	7	22
1999	0.067	0.038	0.096	0.380	0.182	0.578	0.177	12	18	34	32.6	41	42	8	46
2000	0.033	-0.006	0.073	0.134	-0.015	0.283	0.248	26	30	35	36.5	39	40	7	10
2001	0.121	-0.007	0.249	0.472	-0.016	0.961	0.257	11	34	39	38.6	43	44	10	28
2002	0.052	0.009	0.095	0.347	0.045	0.648	0.150	8	8	30	28.0	40	42	11	29
2003	0.033	0.016	0.051	0.136	0.071	0.200	0.247	33	33	36	37.4	39	41	7	18
2004	0.048	0.003	0.092	0.231	0.030	0.432	0.206	19	29	35	35.5	37	40	8	29
2005	0.065	0.001	0.129	0.286	-0.004	0.575	0.227	30	30	35	36.4	39	40	7	24
2006	0.058	0.015	0.101	0.211	0.062	0.361	0.275	35	35	38	39.6	42	43	10	23
2007	0.070	0.002	0.137	0.268	0.037	0.499	0.260	24	24	38	37.4	40	41	7	17

Table 36. Abundance and biomass from NEFSC winter surveys for rosette skate for the Georges Bank to Mid-Atlantic region (offshore strata 1-3,5-7,9-11,13-14,16,61-63,65-67,69-71,73-75). The mean index, 95% confidence intervals, individual fish weight, minimum, mean and maximum length, 5th, 50th, and 95th percentiles of length, number of nonzero tows, and number of fish caught are presented for 1992-2007. Stratum 16 not sampled in 1993, 2000, 2002-2007. Strata 13 and 14 not sampled in 2003 and 2007. Stratum 63 not sampled in 1993. Stratum 14 not sampled in 2005 and 2007.

	weight/tow			number/tow				length						nonzero	
	mean	lower	upper	mean	lower	upper	ind wt	min	5%	50%	mean	95%	max	tows	no fish
1992	0.264	0.138	0.390	1.125	0.619	1.632	0.235	16	27	36	36.4	41	45	15	230
1993	0.149	0.048	0.251	0.663	0.197	1.130	0.225	26	29	36	36.7	39	41	9	143
1994	0.199	0.148	0.249	0.761	0.608	0.914	0.261	16	28	37	36.8	40	44	15	162
1995	0.195	0.066	0.323	0.774	0.273	1.275	0.252	19	32	37	37.9	41	42	23	197
1996	0.324	0.121	0.526	1.410	0.443	2.376	0.230	19	28	36	36.3	40	46	23	899
1997	0.258	-0.051	0.567	1.079	-0.194	2.353	0.239	13	30	36	36.9	40	44	21	238
1998	0.160	0.102	0.219	0.664	0.421	0.907	0.241	15	30	36	36.5	40	45	21	350
1999	0.271	0.043	0.500	1.151	0.082	2.220	0.236	24	27	37	36.6	41	44	25	228
2000	0.344	0.198	0.491	1.357	0.725	1.989	0.254	8	28	37	37.5	43	47	34	740
2001	0.437	0.185	0.690	1.718	0.797	2.640	0.254	9	24	38	37.6	41	46	36	790
2002	0.723	0.140	1.307	2.655	0.603	4.708	0.272	8	29	38	38.3	42	47	34	913
2003	0.670	0.195	1.144	2.774	0.802	4.745	0.242	8	26	37	36.9	41	47	28	1029
2004	0.300	0.171	0.429	1.192	0.653	1.730	0.252	16	31	37	37.8	41	46	29	784
2005	0.189	0.090	0.289	0.716	0.357	1.076	0.264	12	30	38	38.2	43	45	19	281
2006	0.437	0.209	0.665	1.738	0.821	2.654	0.251	8	31	37	37.7	42	45	28	513
2007	0.634	0.262	1.006	2.446	1.110	3.781	0.259	9	33	38	38.2	41	44	28	750

Table 37. Estimates of size at 50% maturity, length-weight parameters (Wigley et al 2003) and Von Bertalanffy Parameter estimates used to estimate SSB and to calculate Hoenig (1987) mortality estimates. Smooth skate data in parentheses are female values. Clearnose data in parentheses are in disk width.

Species (Study)	L50	ln(a)	b	Linf	K	t0 (L0)
Winter (Frisk 2004)	76	-13.1531	3.3199	122.1	0.07	-2.06
Little (Frisk 2004)	44	-12.4462	3.128	56.1	0.19	-1.17
Barndoor (Gedamke 2005)	116	-13.3224	3.2919	166.3	0.14	-1.2912
Thorny (Sulikowski 2005, 2006)	88	-12.088	3.1197	124.0	0.12	-0.35
Smooth (Sosebee 2005; Natanson et al 2007)	50	-13.0139	3.1812	75.4 (69.6)	0.12	11 cm (10cm)
Clearnose(Gelsleichter 1998; Sosebee 2005)	66	-13.8683	3.4235	94.3(61.8)	0.17	-0.88
Rosette (Sosebee 2005)	34	-12.5504	3.0718			

Table 38. Estimates of spawning stock biomass indices from NEFSC surveys using sizes at 50% maturity as knife-edge cutpoints.

	Winter	Little	Barndoor	Thorny	Smooth	Clearnose	Rosette
1963			0.796	3.934	0.202		
1964			0.227	2.799	0.091		
1965			0.135	2.848	0.297		
1966			0.000	4.673	0.218		
1967	0.553		0.063	1.411	0.126		0.022
1968	0.338		0.073	2.857	0.229		0.001
1969	0.183		0.000	3.668	0.190		0.002
1970	0.534		0.060	5.155	0.152		0.009
1971	0.151		0.047	3.921	0.134		0.002
1972	0.464		0.077	2.593	0.244		0.010
1973	0.892		0.000	2.987	0.189		0.001
1974	0.377		0.000	1.368	0.080		0.013
1975	0.327		0.000	1.344	0.039	0.003	0.005
1976	1.117		0.000	0.943	0.015	0.019	0.020
1977	1.863		0.000	1.450	0.201	0.076	0.015
1978	3.008		0.000	1.514	0.288	0.007	0.004
1979	3.400		0.000	1.569	0.112	0.073	0.009
1980	3.663		0.000	1.972	0.217	0.166	0.070
1981	3.513		0.000	1.312	0.079	0.016	0.070
1982	4.203	2.744	0.000	0.261	0.035	0.038	0.005
1983	7.598	4.058	0.000	1.065	0.073	0.006	0.001
1984	7.253	2.655	0.000	1.480	0.095	0.041	0.024
1985	8.514	4.184	0.000	1.077	0.169	0.069	0.003
1986	12.279	1.599	0.000	0.653	0.152	0.030	0.002
1987	7.768	2.168	0.000	0.209	0.062	0.085	0.021
1988	5.594	2.936	0.000	0.521	0.207	0.072	0.011
1989	3.753	2.832	0.000	0.709	0.073	0.028	0.002
1990	6.129	2.983	0.000	0.790	0.122	0.072	0.023
1991	3.499	2.854	0.000	0.734	0.116	0.341	0.003
1992	2.083	2.384	0.000	0.292	0.079	0.080	0.033
1993	1.012	3.875	0.134	0.700	0.146	0.110	0.018
1994	0.841	1.742	0.000	0.434	0.072	0.184	0.063
1995	0.536	1.706	0.000	0.189	0.081	0.097	0.033
1996	0.793	4.551	0.000	0.318	0.128	0.083	0.029
1997	0.664	1.601	0.052	0.333	0.167	0.269	0.009
1998	1.576	3.634	0.062	0.319	0.016	0.234	0.051
1999	1.331	5.078	0.118	0.145	0.062	0.442	0.055
2000	1.753	4.424	0.048	0.420	0.102	0.371	0.028
2001	1.397	4.783	0.250	0.066	0.226	0.376	0.129
2002	3.154	4.858	0.366	0.196	0.094	0.261	0.034
2003	1.912	4.401	0.161	0.233	0.106	0.353	0.032
2004	2.222	4.340	0.773	0.365	0.146	0.259	0.043
2005	1.005	2.455	0.285	0.047	0.082	0.253	0.057
2006	0.638	2.472	0.477	0.482	0.180	0.042	0.060
2007	1.033	3.555	0.353	0.207	0.071	0.228	0.065
2008		5.048					

Table 39. Current (i.e., not updated) estimates of biomass-based reference points for skates. The estimates for barndoor are an average of 1963-1966 biomass estimates.

	B_{MSY}	$B_{THRESHOLD}$
Winter	6.46	3.43
Little	6.54	3.27
Barndoor	1.62	0.81
Thorny	4.41	2.2
Smooth	0.31	0.16
Clearnose	0.56	0.28
Rosette	0.029	0.015

Table 40. Three-year moving average of the chosen time series from 1965-2008.

	Winter	Little	Barndoor	Thorny	Smooth	Clearnose	Rosette
1965			1.89	4.75	0.43		
1966			1.28	5.62	0.37		
1967			1.02	5.05	0.32		
1968			0.51	5.03	0.29		
1969	1.78		0.26	4.28	0.28		0.008
1970	2.06		0.13	5.83	0.30		0.005
1971	1.80		0.10	6.14	0.23		0.004
1972	2.34		0.11	5.61	0.24		0.009
1973	2.91		0.09	4.68	0.27		0.010
1974	3.25		0.03	3.91	0.26		0.014
1975	2.70		0.01	3.36	0.17		0.009
1976	2.02		0.02	2.41	0.08		0.014
1977	2.69		0.02	2.47	0.16	0.44	0.016
1978	3.91		0.02	3.08	0.29	0.41	0.017
1979	4.74		0.00	3.71	0.34	0.45	0.013
1980	5.45		0.00	4.17	0.33	0.42	0.036
1981	5.67		0.00	3.85	0.21	0.43	0.060
1982	6.74		0.00	2.86	0.17	0.36	0.058
1983	8.94		0.00	2.13	0.10	0.18	0.029
1984	11.49	4.48	0.00	1.98	0.13	0.18	0.012
1985	11.79	5.36	0.00	2.72	0.19	0.21	0.012
1986	12.77	4.37	0.01	2.46	0.21	0.34	0.012
1987	12.02	4.55	0.02	1.82	0.17	0.39	0.012
1988	11.48	4.15	0.02	1.35	0.20	0.40	0.017
1989	7.90	5.45	0.01	1.44	0.17	0.31	0.022
1990	6.60	5.57	0.01	1.69	0.20	0.34	0.020
1991	5.65	5.87	0.02	1.74	0.16	0.53	0.015
1992	5.15	5.43	0.02	1.43	0.16	0.56	0.021
1993	3.40	6.27	0.06	1.42	0.17	0.59	0.020
1994	2.54	5.48	0.06	1.38	0.15	0.59	0.043
1995	2.00	4.67	0.10	1.32	0.17	0.59	0.045
1996	2.13	4.69	0.06	1.04	0.15	0.57	0.052
1997	2.24	4.38	0.09	0.82	0.20	0.46	0.032
1998	2.83	5.92	0.08	0.77	0.15	0.72	0.035
1999	3.77	6.72	0.16	0.66	0.11	0.93	0.043
2000	4.41	8.68	0.23	0.65	0.08	1.07	0.050
2001	4.45	8.47	0.38	0.55	0.17	1.23	0.074
2002	4.62	7.29	0.54	0.53	0.18	1.18	0.069
2003	4.29	6.59	0.62	0.50	0.20	1.06	0.069
2004	4.34	6.72	0.88	0.63	0.17	0.75	0.044
2005	3.34	5.65	0.96	0.56	0.18	0.63	0.049
2006	3.04	4.59	1.17	0.55	0.19	0.59	0.057
2007	2.93	3.67	1.00	0.42	0.14	0.64	0.064
2008		5.04					

Table 41. Fishing mortality overfishing definition for skates based on the average coefficient of variation in the survey. The percentages are percent change from one three-year moving average to the next. The shaded cells indicate overfishing is ocurring.

	Winter	Little	Barndoor	Thorny	Smooth	Clearnose	Rosette
	-20%	-20%	-30%	-20%	-30%	-30%	-60%
1992	-8.8	-7.6	-3.8	-17.6	-0.4	4.5	37.7
1993	-33.9	15.6	180.7	-1.1	6.7	5.6	-2.0
1994	-25.5	-12.6	2.0	-2.9	-13.0	0.9	110.9
1995	-21.0	-14.8	61.3	-4.3	13.8	-0.8	3.8
1996	6.2	0.4	-34.3	-21.4	-9.8	-3.6	16.4
1997	5.3	-6.5	37.3	-21.2	28.6	-19.1	-38.4
1998	26.3	35.0	-8.6	-5.5	-26.9	57.5	11.1
1999	33.2	13.5	109.2	-14.5	-24.2	28.8	22.5
2000	17.0	29.2	37.1	-0.9	-23.6	15.0	15.3
2001	1.0	-2.4	66.0	-16.1	102.3	15.4	47.1
2002	3.8	-13.9	42.5	-2.6	8.1	-4.4	-6.9
2003	-7.2	-9.6	16.5	-5.6	6.5	-10.5	0.2
2004	1.1	1.9	40.7	25.0	-12.4	-28.6	-35.4
2005	-22.9	-15.9	9.8	-11.2	3.7	-16.2	9.7
2006	-9.0	-18.7	21.3	-1.0	3.9	-6.8	16.8
2007	-3.6	-20.0	-14.2	-23.7	-22.4	8.1	12.7
2008		37.2					

Table 42. Estimates of biomass-based reference points for skates updated through 2007/2008.

	B_{MSY}	$B_{THRESHOLD}$
Winter	5.60	2.80
Little	7.03	3.51
Barndoor	0.44	0.22
Thorny	4.12	2.06
Smooth	0.29	0.14
Clearnose	0.77	0.38
Rosette	0.048	0.024

Table 43. Recommendation for new biomass-based reference points for skates updated through 2007/2008. The estimates for barndoor are an average of 1963-1966 biomass estimates.

	B_{MSY}	$B_{THRESHOLD}$
Winter	5.60	2.80
Little	7.03	3.51
Barndoor	1.62	0.81
Thorny	4.12	2.06
Smooth	0.29	0.14
Clearnose	0.77	0.38
Rosette	0.048	0.024

Skate Complex; Figures

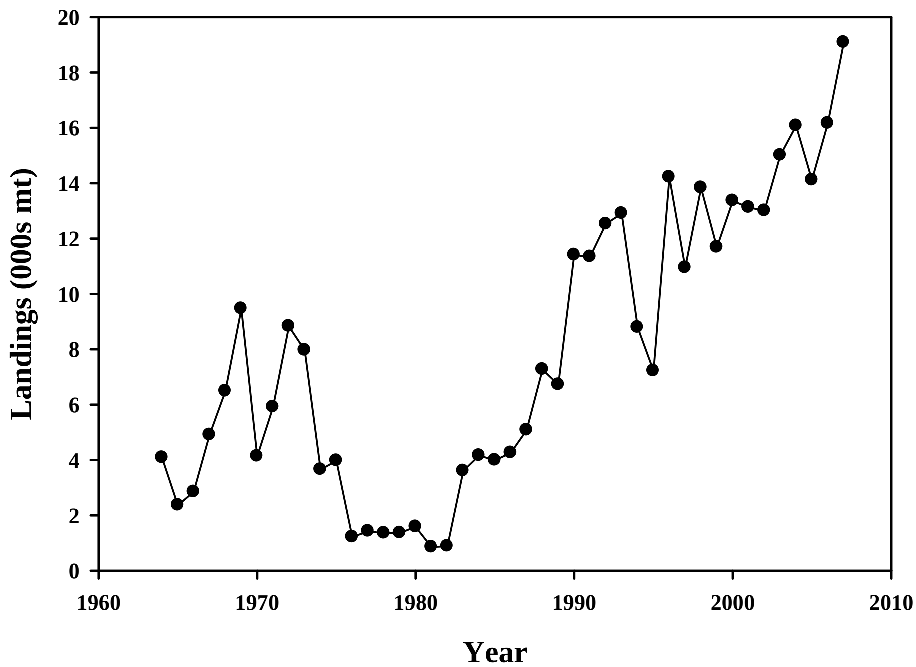

Figure 1. Total reported landings of skates in NAFO subareas 5 and 6.

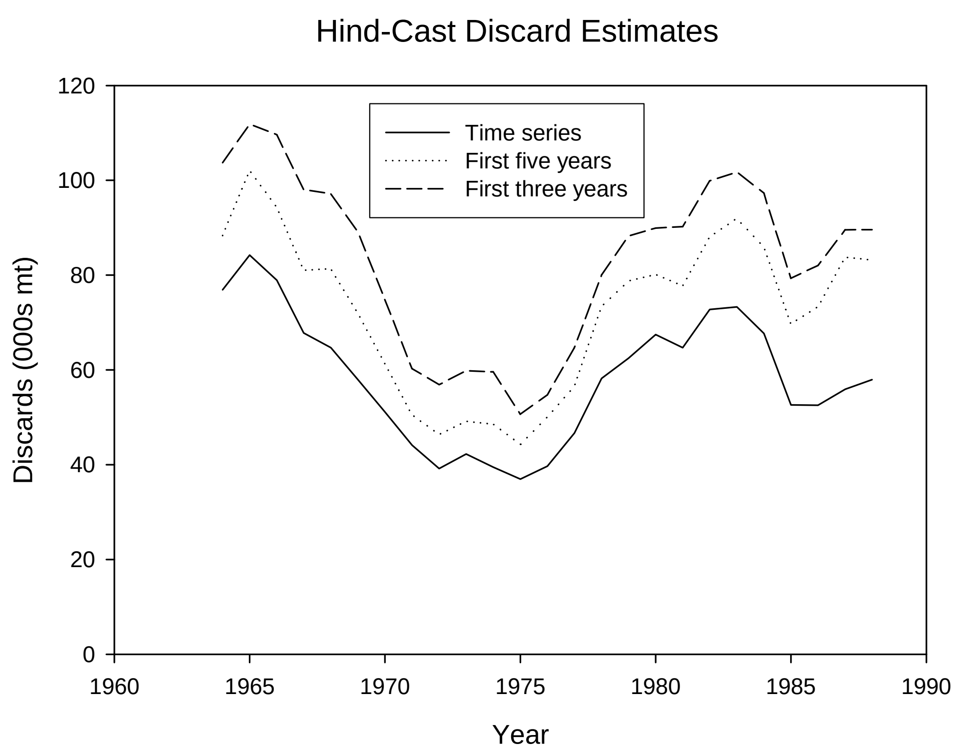

Figure 2. Estimates of discards hind-cast using three different methods.

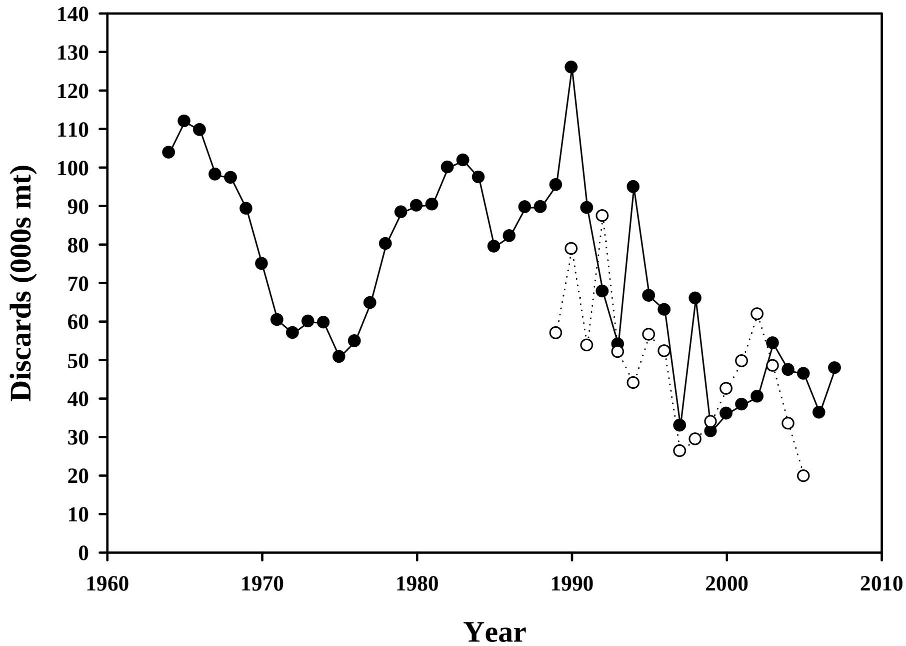

Figure 3. Total discards of skates in NAFO subareas 5 and 6. The closed circles represent the new estimates which include all sources. The circles from 1964-1988 are hind-cast using the first three years. The open circles are the SARC44 estimates which did not impute missing information and/or

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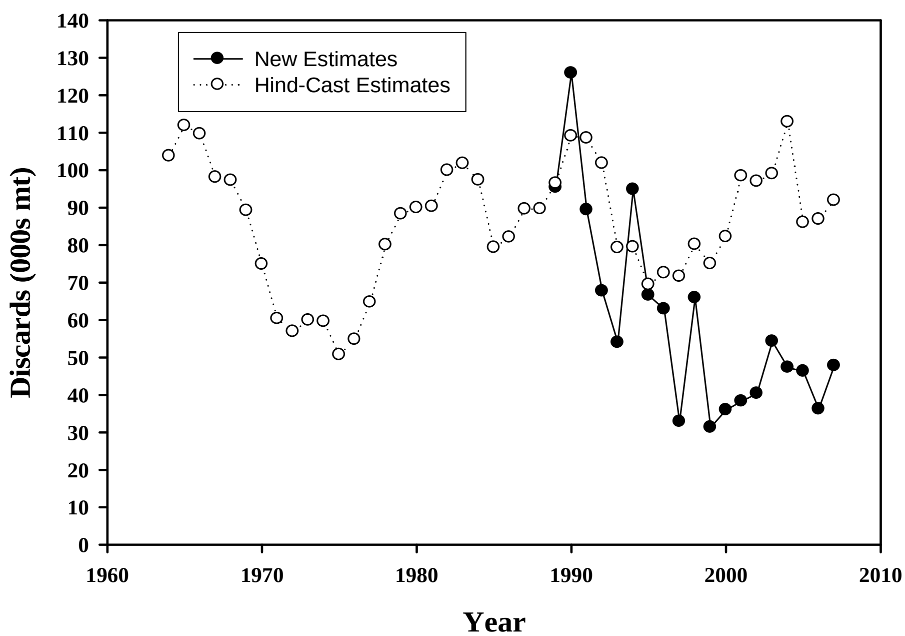


Figure 4 Estimates of discards comparing hind-cast estimates (first three years) for the entire time series.

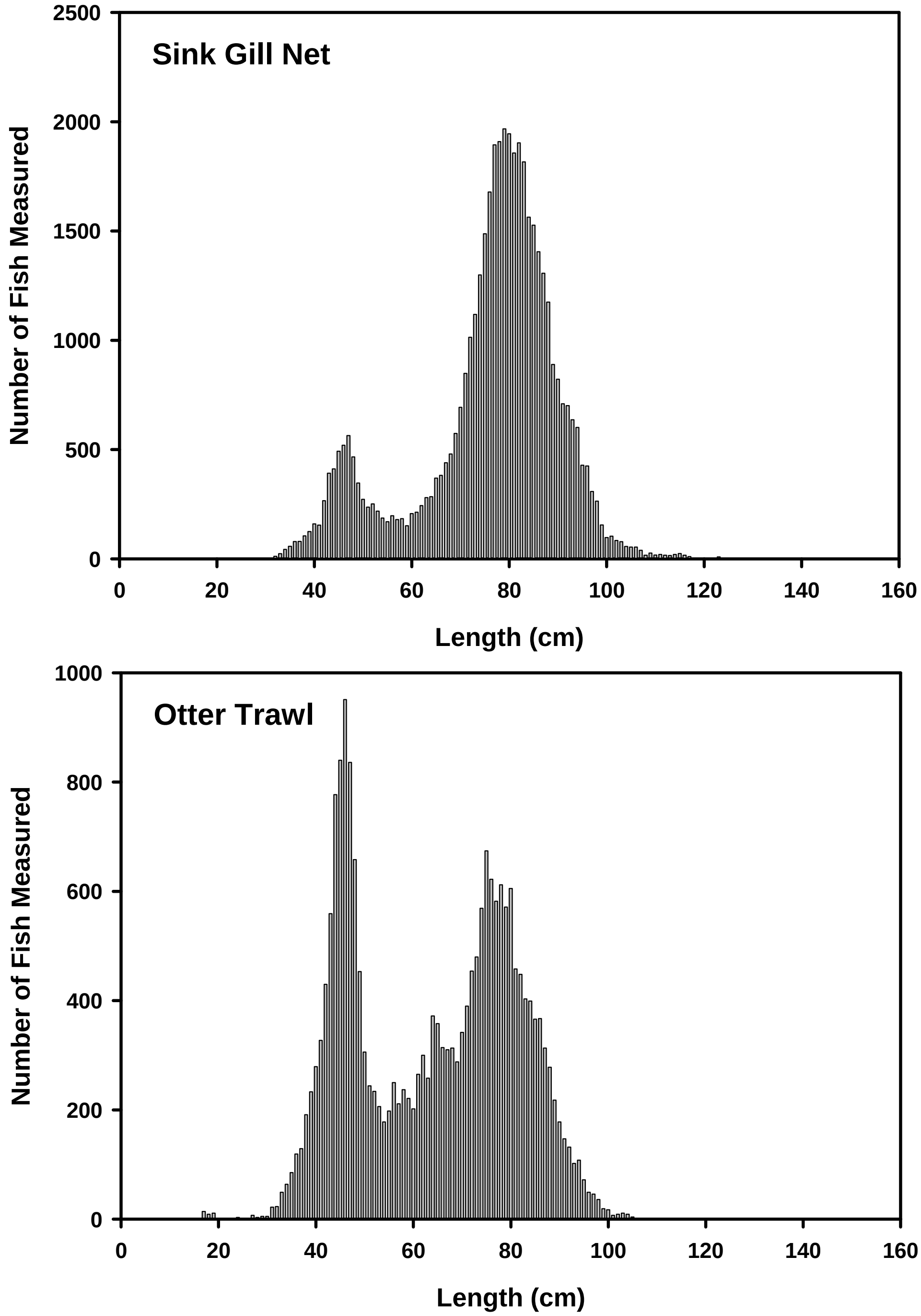


Figure 5. Length composition of the kept skate measured by the Observer Program by gear type.

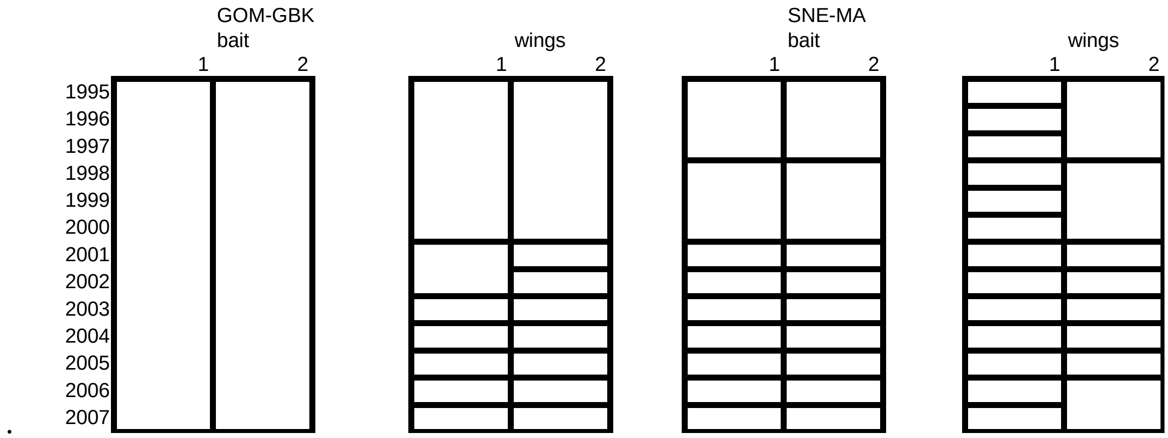


Figure 6. Pooling scheme used to derive length compositions for the landed component of the skate catch

All Skates
Landings Length Frequencies

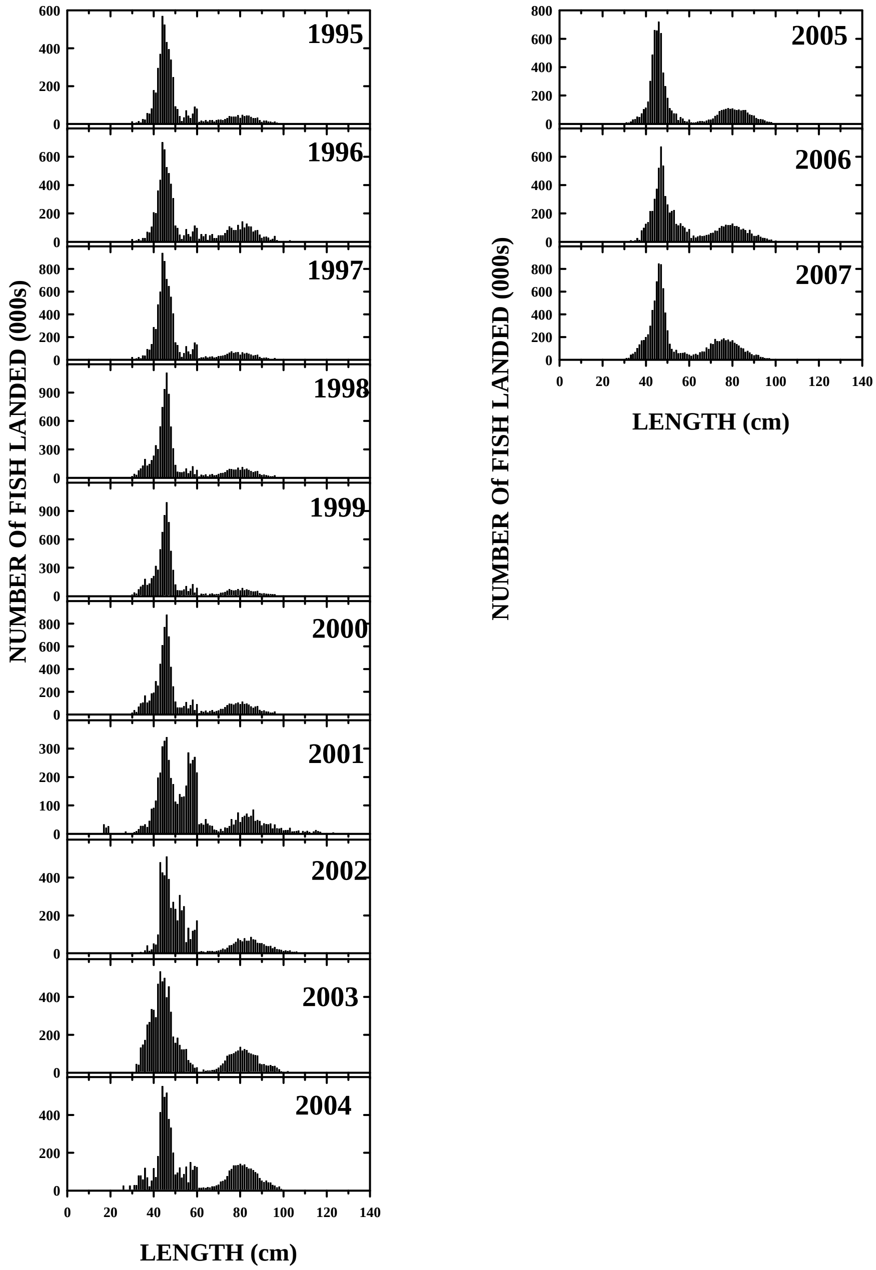


Figure 7. Skate length composition from commercial landings data, 1995-2007.

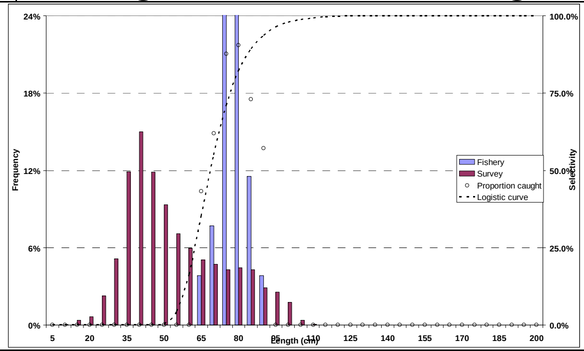
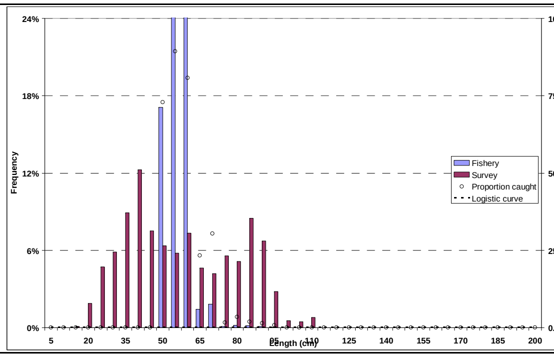
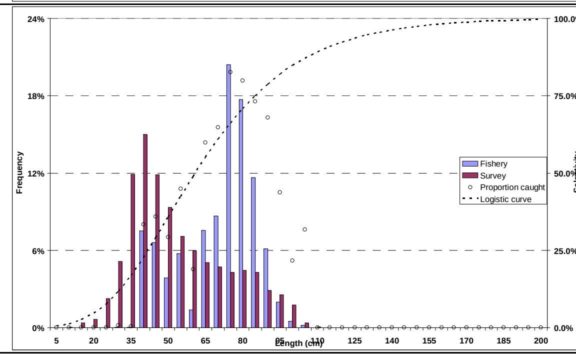
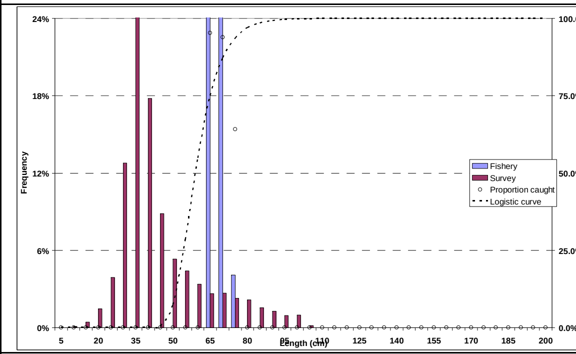
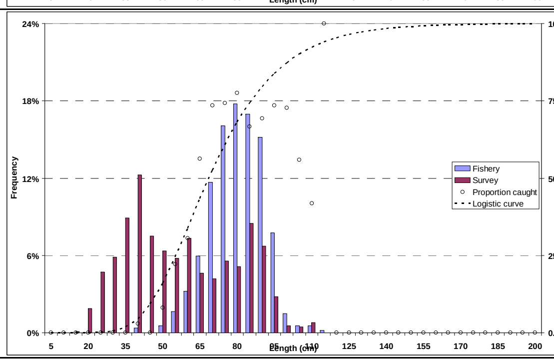
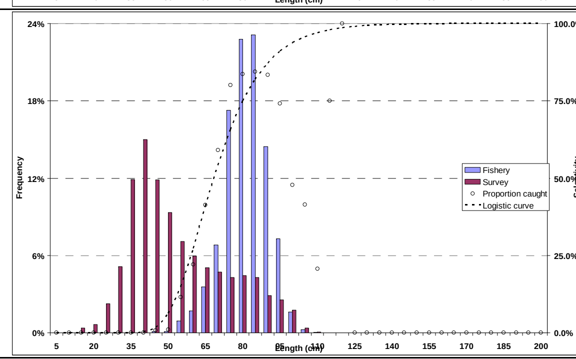
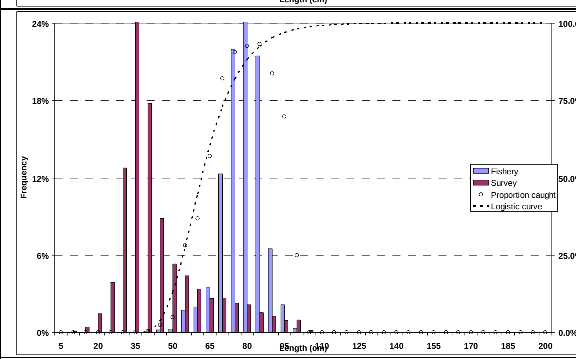
	Gulf of Maine	Georges Bank/Southern New England	Mid-Atlantic
Winter Trawl Wings	**Insufficient data**		**Insufficient data**
Winter Trawl Whole			
Winter Gillnet			

Figure 8. Selectivity of observed winter skate landings by region, gear, and product type, 2004-2007, estimated with the SELECT model (Millar 1992).

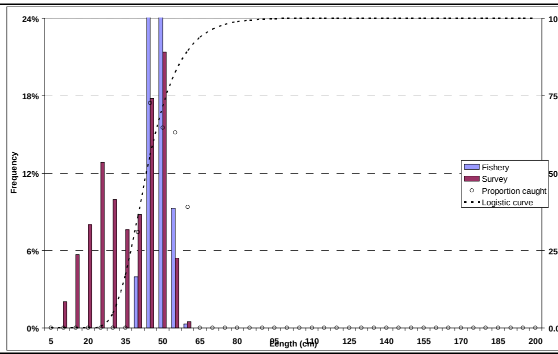
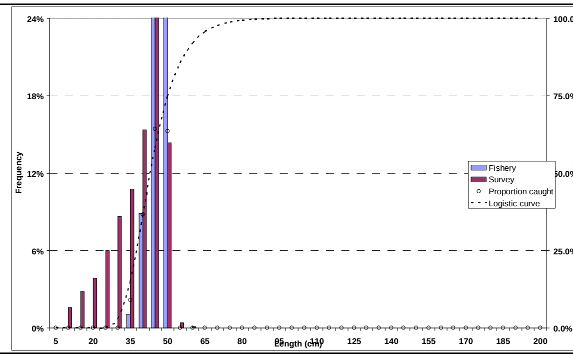
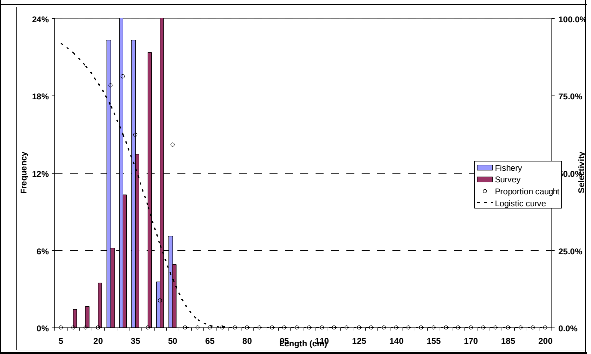
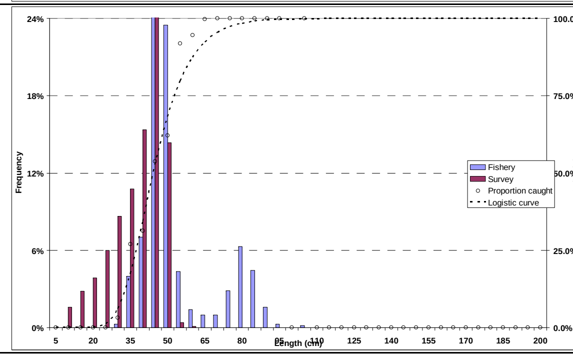
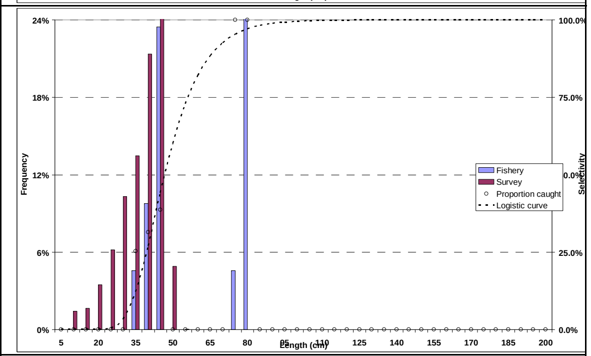
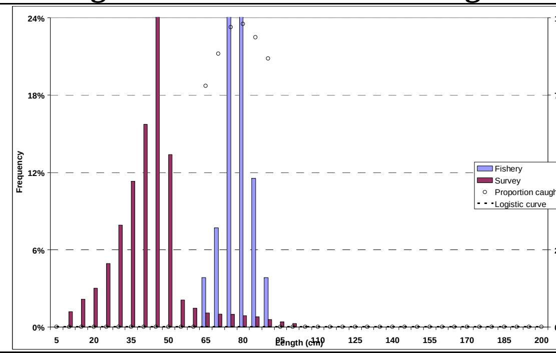
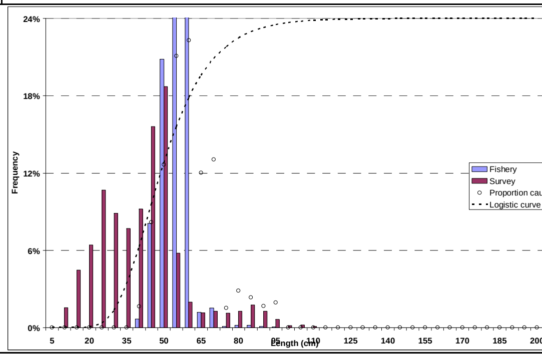
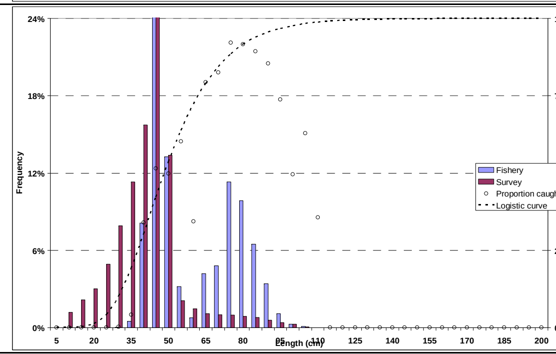
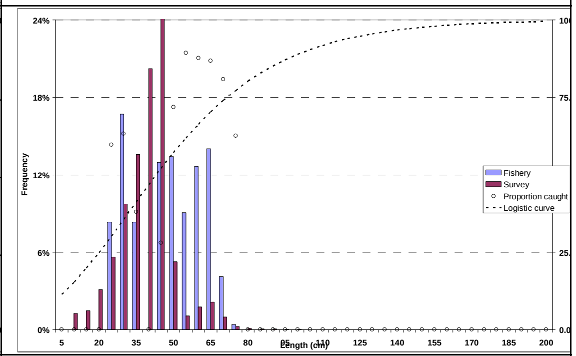
	Gulf of Maine	Georges Bank/Southern New England	Mid-Atlantic
Little Trawl Wings	**Insufficient data**	**Insufficient data**	**Insufficient data**
Little Trawl Whole			
Little Gillnet	**Insufficient data**		

Figure 9. Selectivity of observed little skate landings by region, gear, and product type, 2004-2007, estimated with the SELECT model (Millar 1992).

<table>
<tr><th></th><th>Gulf of Maine</th><th>Georges Bank/Southern New England</th><th>Mid-Atlantic</th></tr>
<tr><td>Clearnose, Little, Rosette, & Winter Trawl Wings</td><td>Insufficient data</td><td>
</td><td>Insufficient data</td></tr>
<tr><td>Clearnose, Little, Rosette, & Winter Trawl Whole</td><td>
</td><td>
</td><td>
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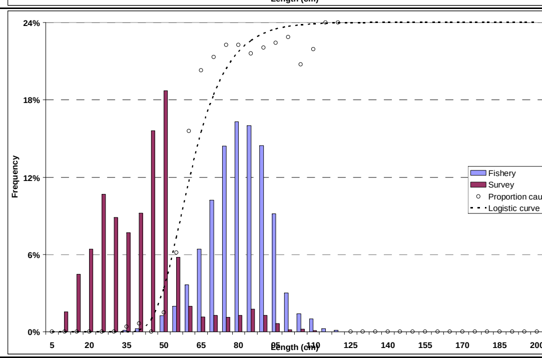
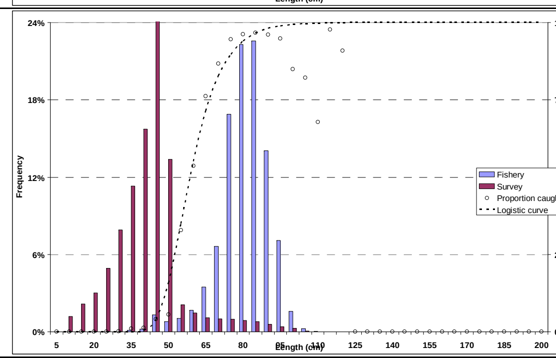
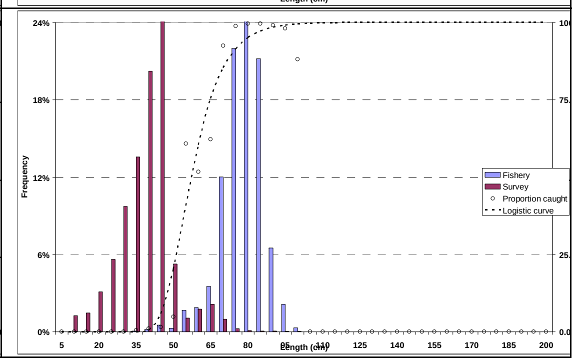
<tr><td>Clearnose, Little, Rosette, & Winter Gillnet</td><td>
</td><td>
</td><td>
</td></tr>
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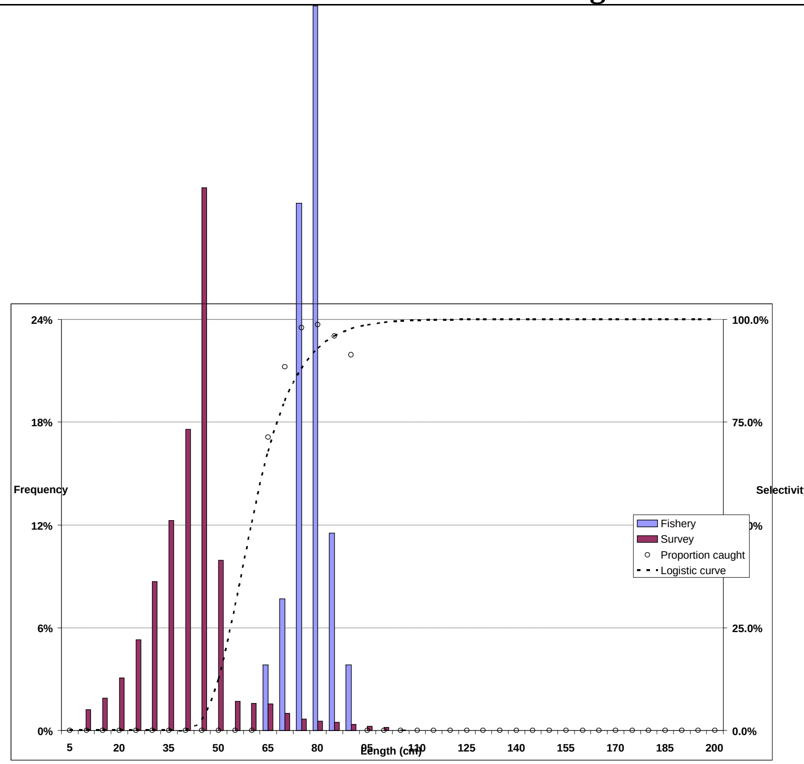
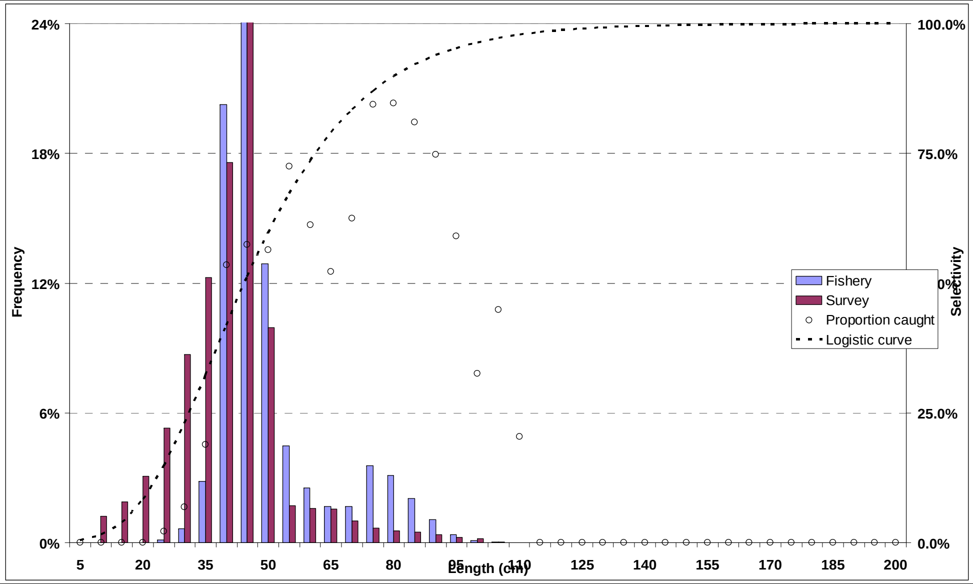
Figure 10. Selectivity of observed aggregate skate landings by region, gear, and product type, 2004-2007, estimated with the SELECT model (Millar 1992). Survey size frequency is for clearnose, little, rosette, and winter skates.

	All regions
Clearnose, Little, Rosette, & Winter Trawl Wings	

Clearnose, Little, Rosette, & Winter Trawl Whole



Clearnose, Little, Rosette, & Winter Gillnet

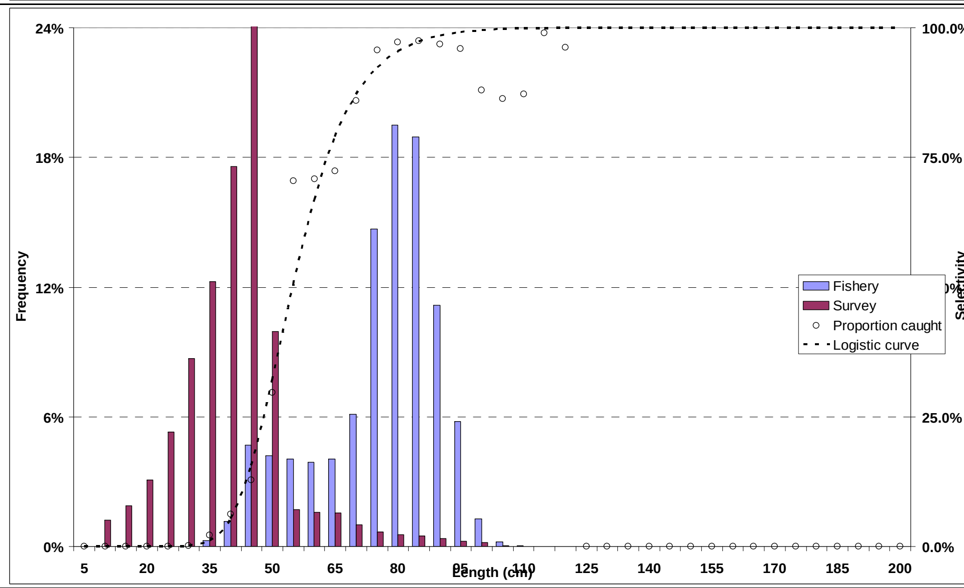


Figure 11. Selectivity of observed aggregate skate landings by gear and product type, 2004-2007, estimated with the SELECT model (Millar 1992). Survey size frequency is for clearnose, little, rosette, and winter skates

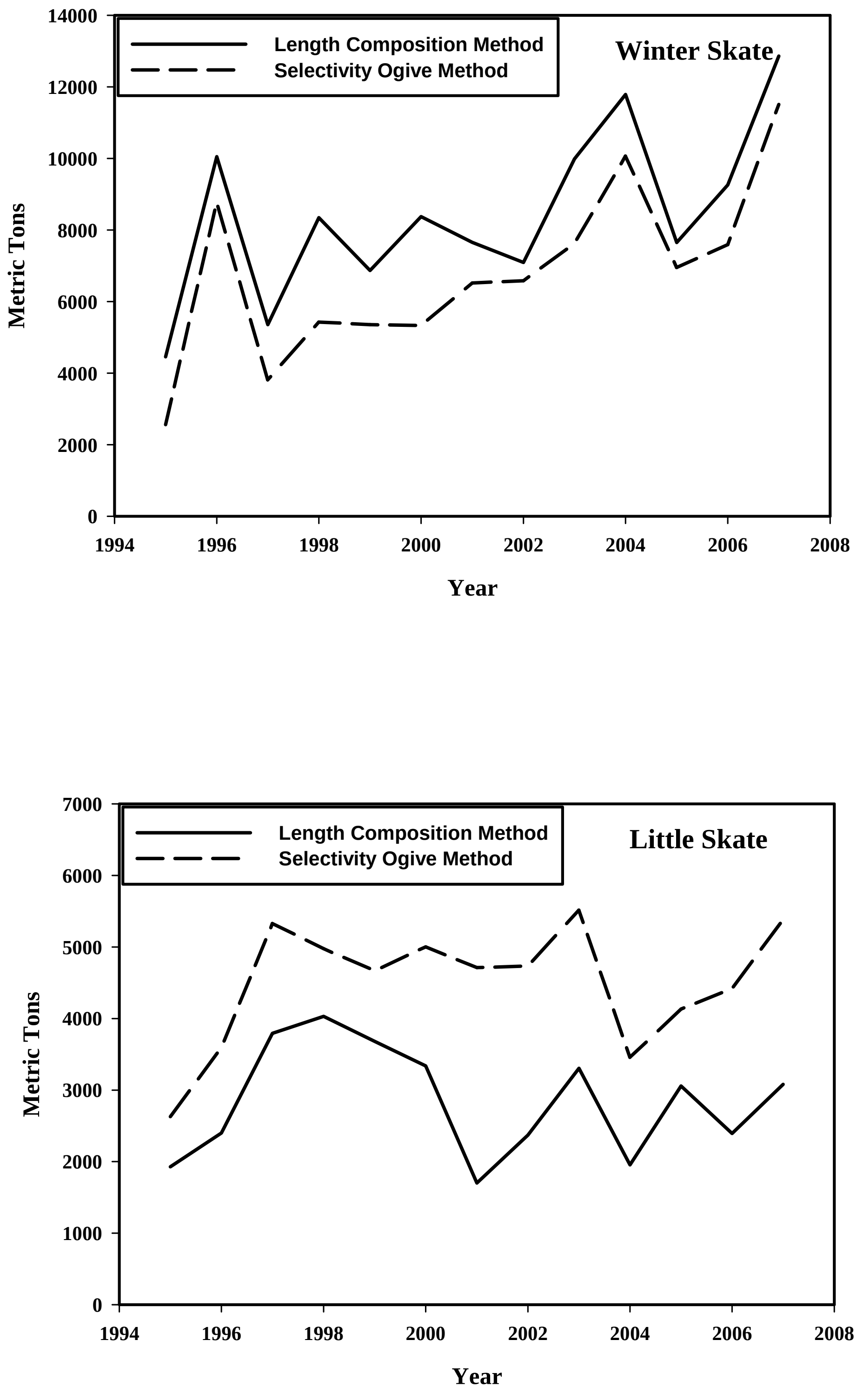


Figure 12. Comparison of landings for winter and little skate using two different methods.

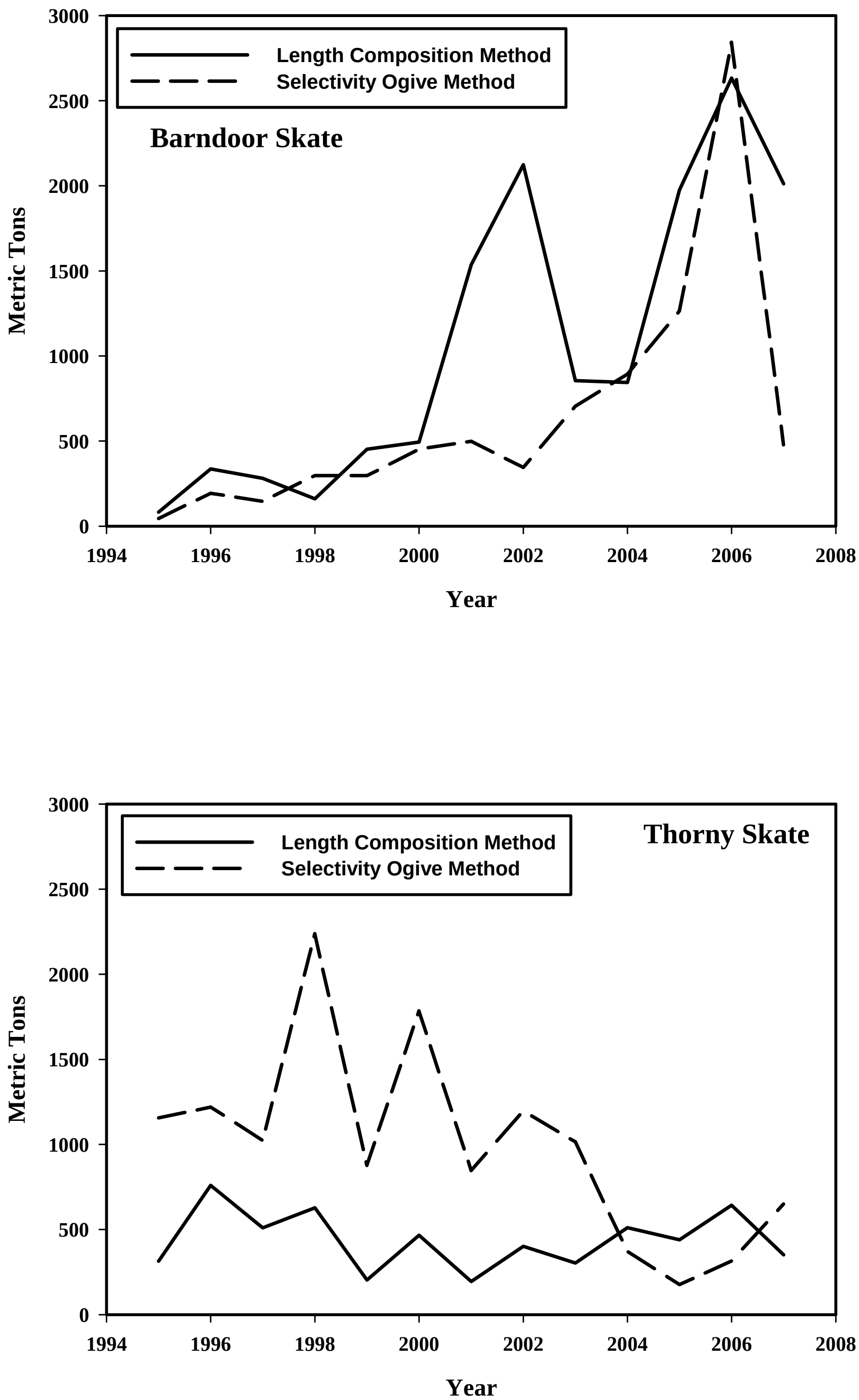


Figure 13. Comparison of landings for barndoor and thorny skate using two different methods.

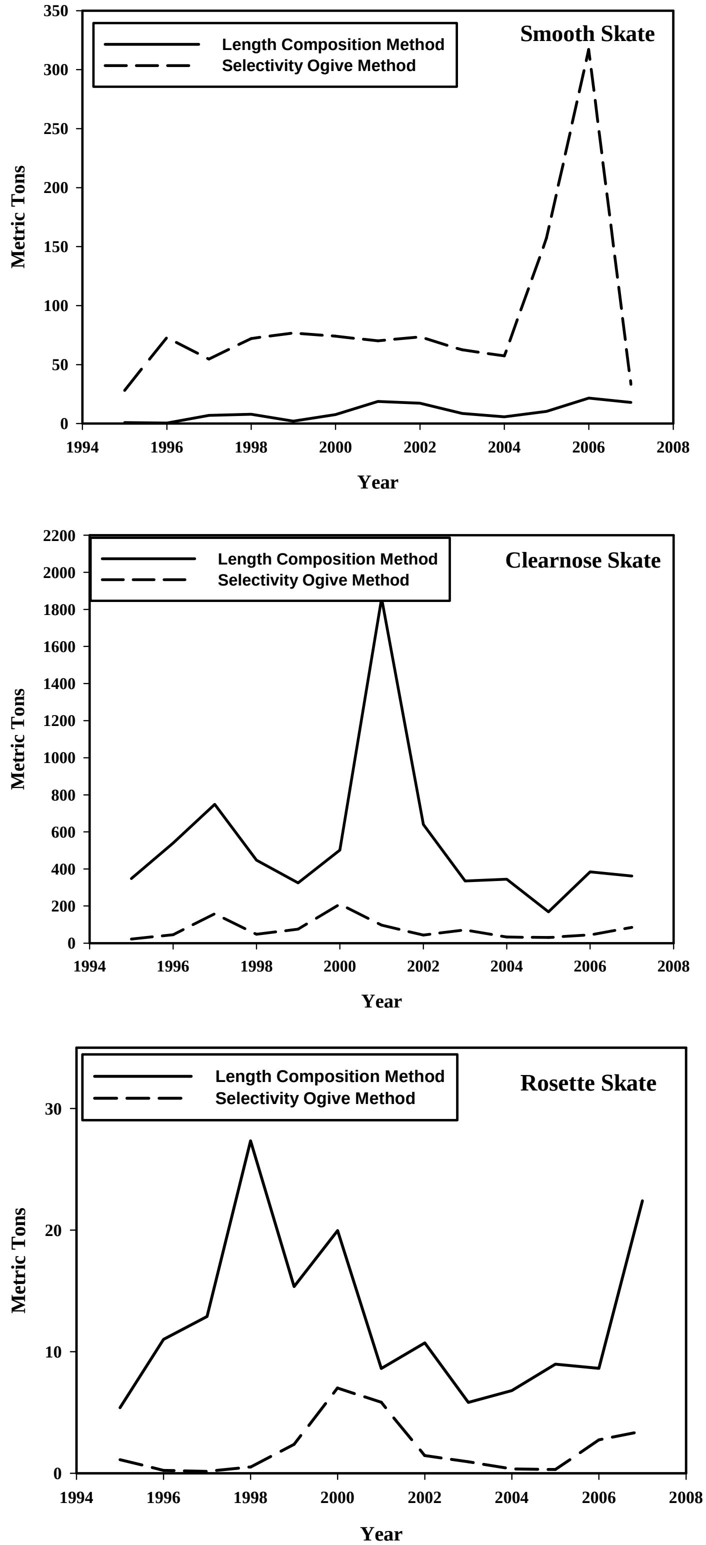


Figure 14. Comparison of landings for smooth, clearnose, and rosette skate using two different methods.

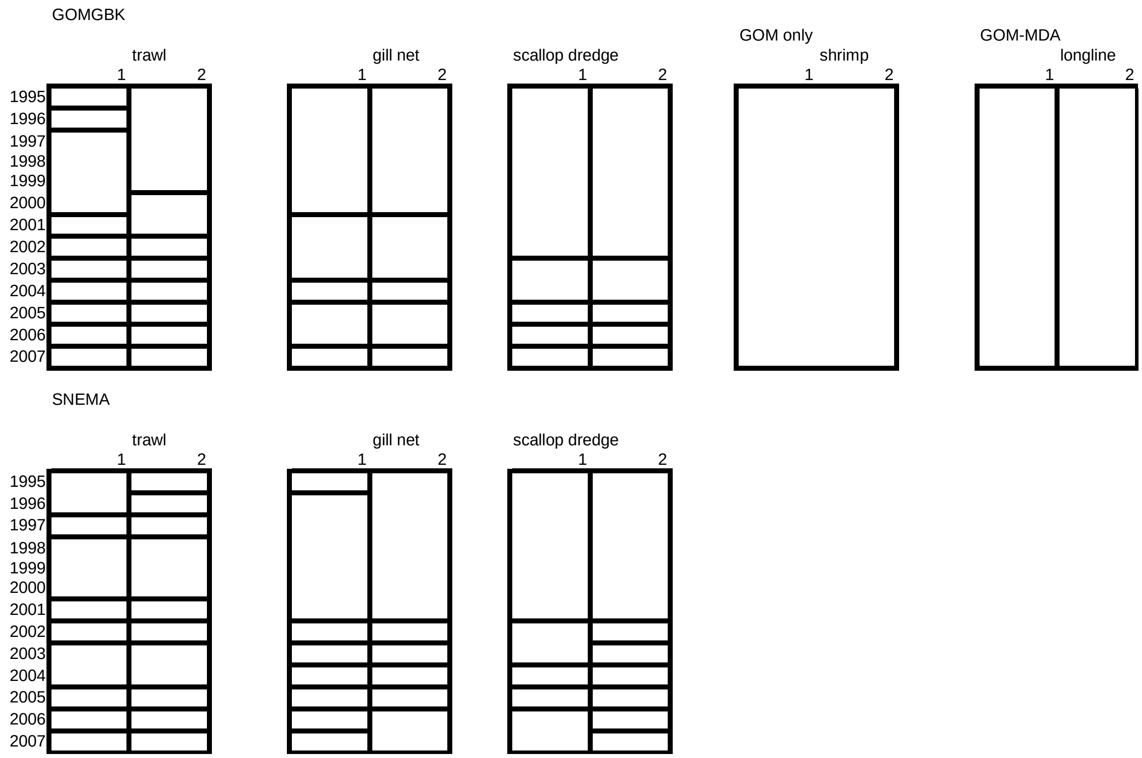


Figure 15. Pooling scheme used to derive the length composition of the discarded component of the skate catch.

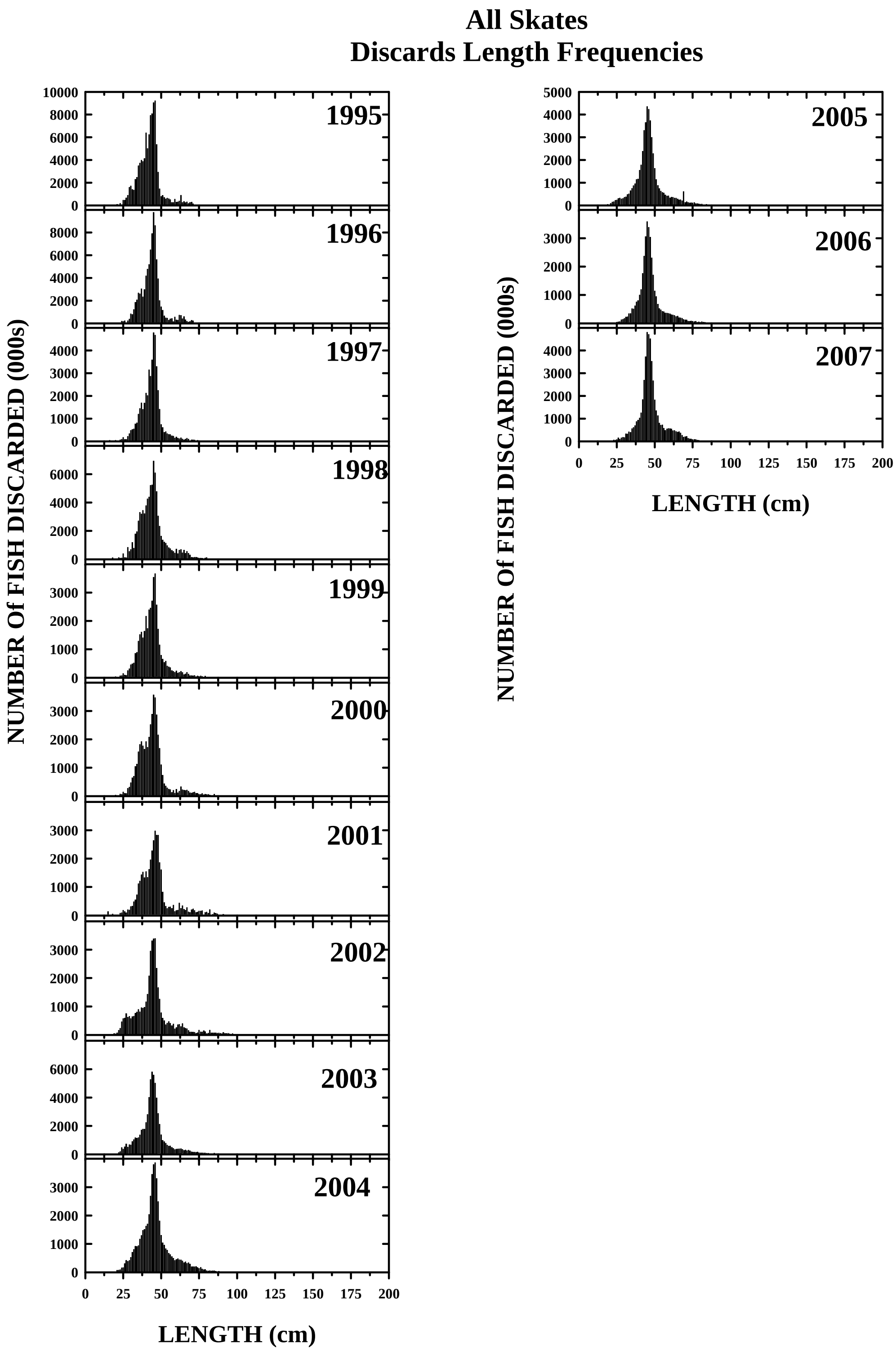


Figure 16. Skate length composition from commercial discard data, 1995-2007.

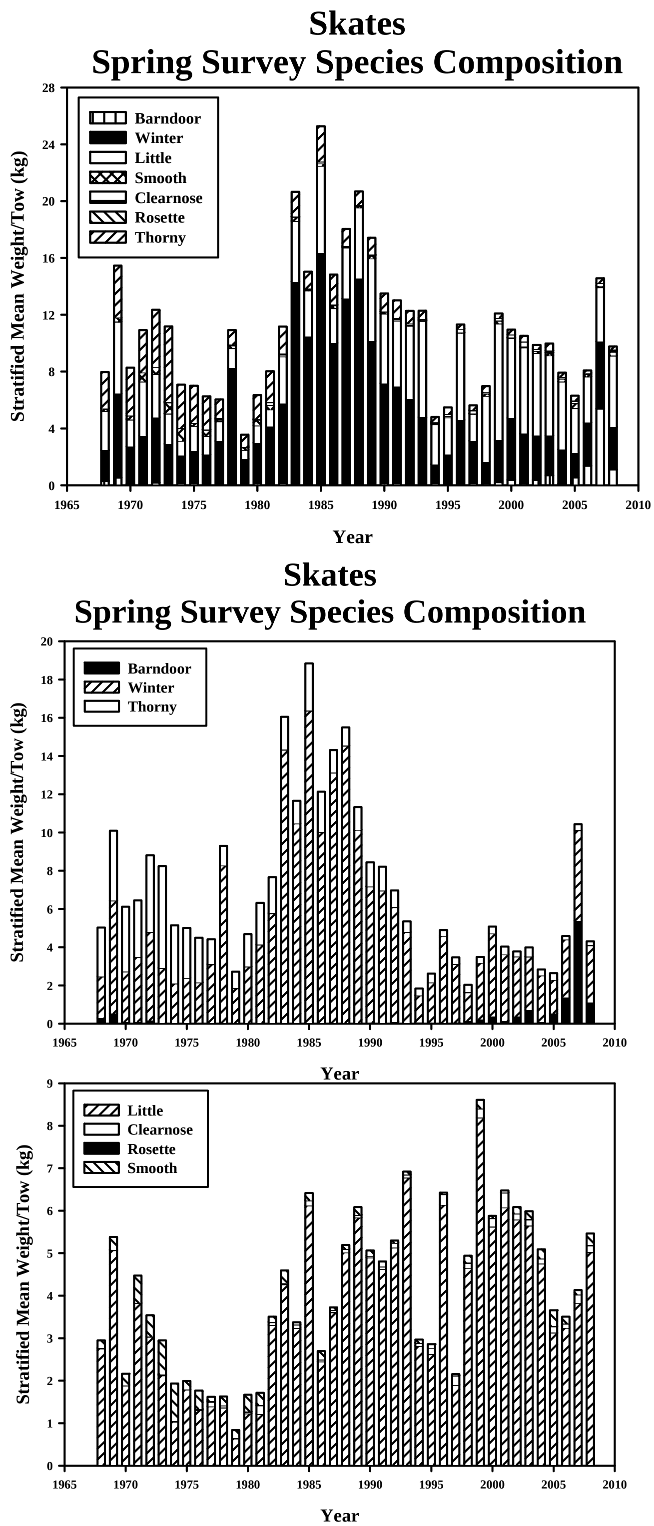


Figure 17. Species composition of skates from the spring survey. The top panel is all skates, the middle panel shows the composition of large species (>100 cm maximum length) while the bottom panel shows the composition of the small species (maximum length < 100cm).

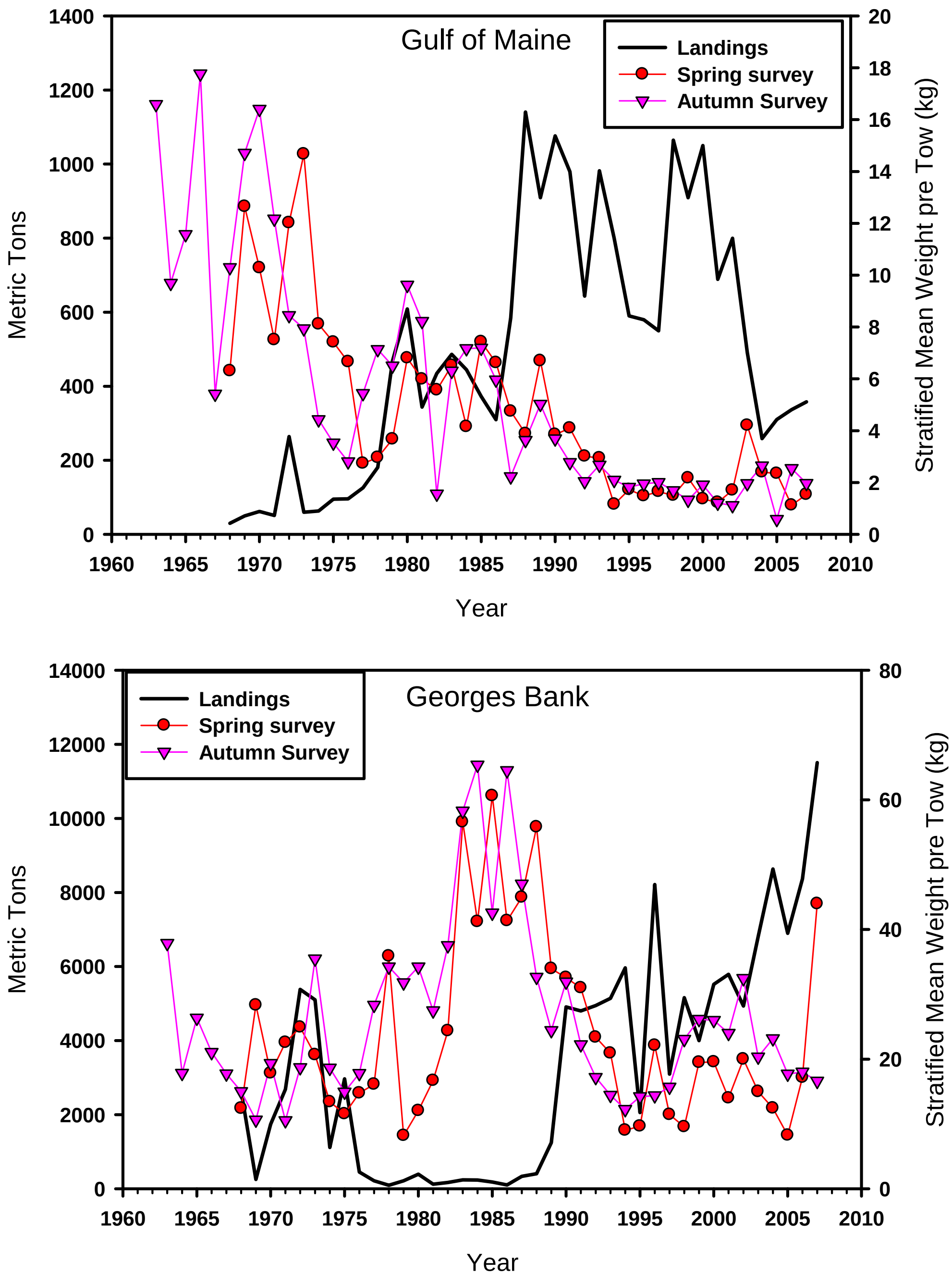


Figure 18. Landings and survey indices of skates from the Gulf of Maine (top panel) and Georges Bank (bottom panel).

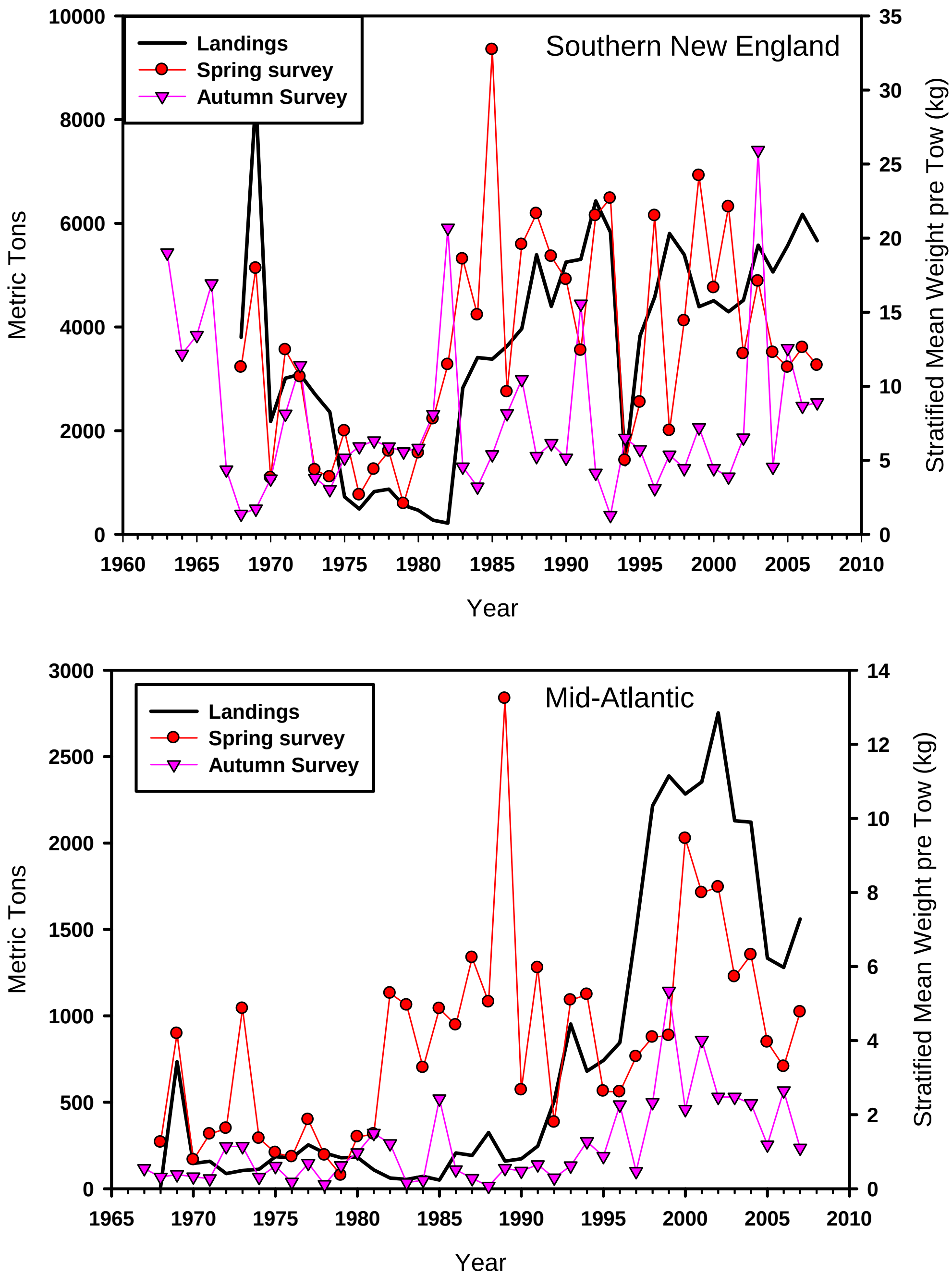


Figure 19. Landings and survey indices of skates from Southern New England (top panel) and the Mid-Atlantic (bottom panel).

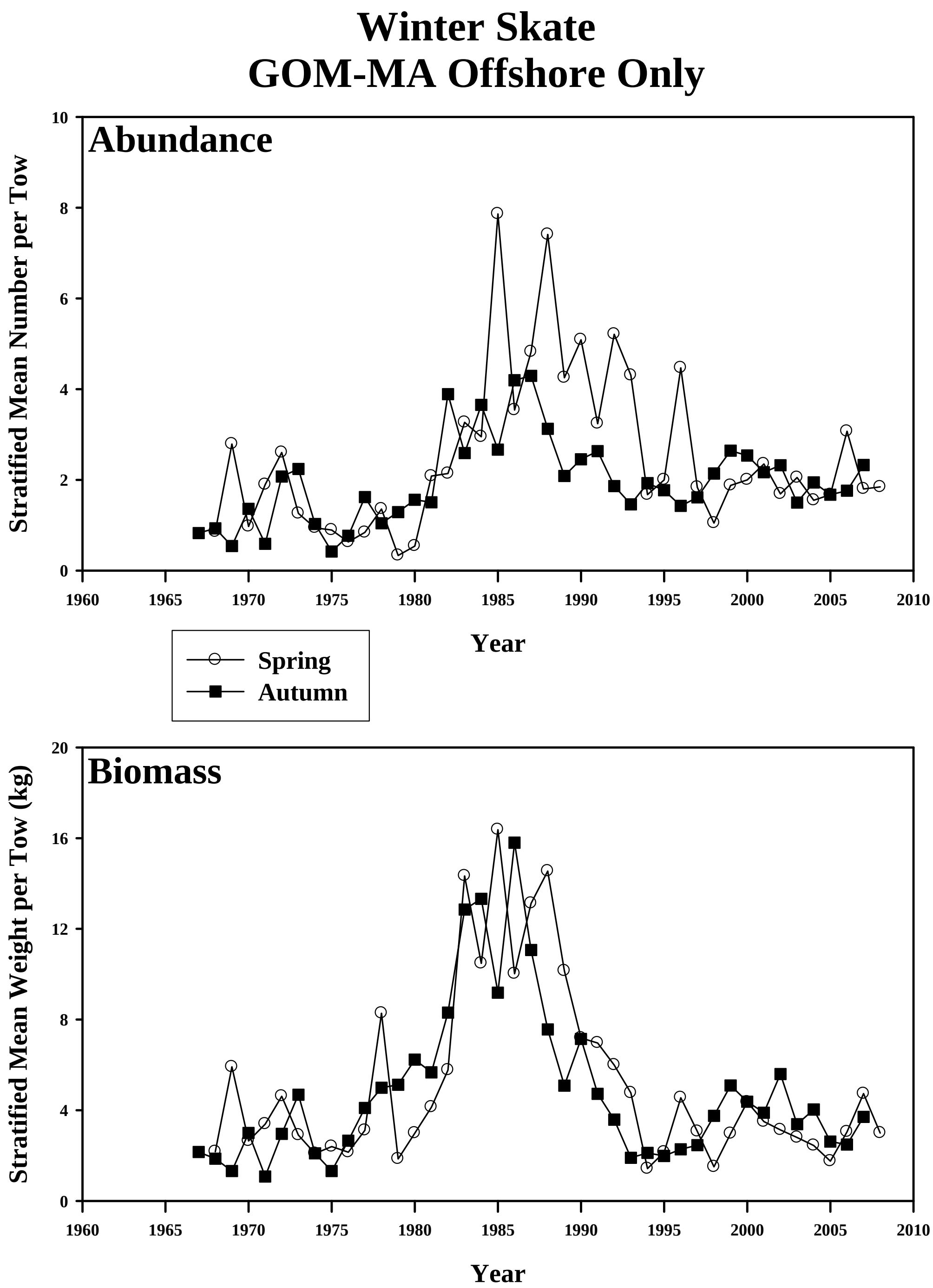


Figure 20. Abundance and biomass of winter skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1967-2008 in the Gulf of Maine to Mid-Atlantic offshore region.

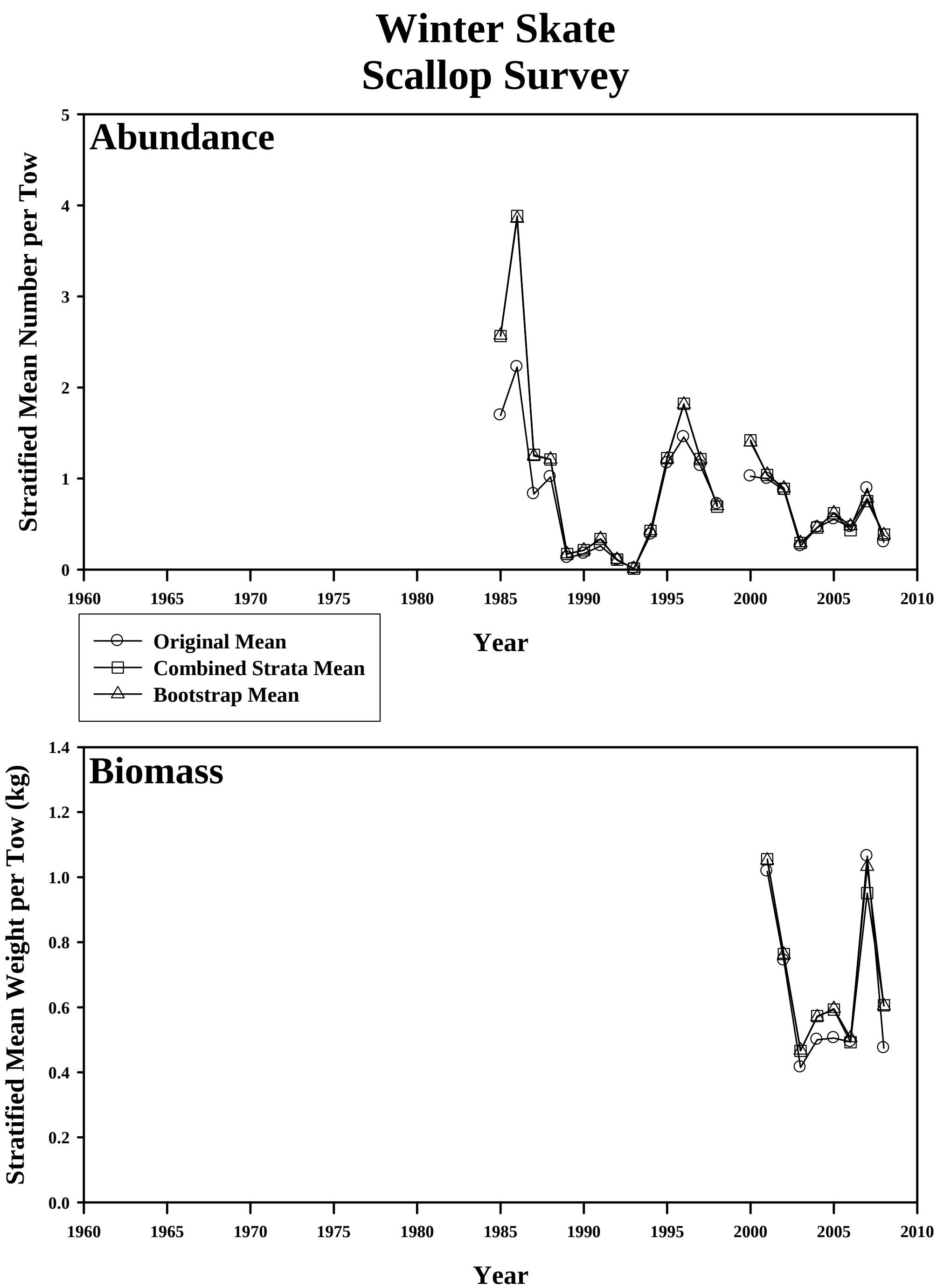


Figure 21. Abundance and biomass of winter skate from the NESFC scallop dredge surveys from 1985-2008. The circles represent the original stratified mean, the squares represent the mean combining strata for bootstrapping, and the triangles represent the bootstrapped mean.

Winter Skate - Massachusetts Trawl Survey

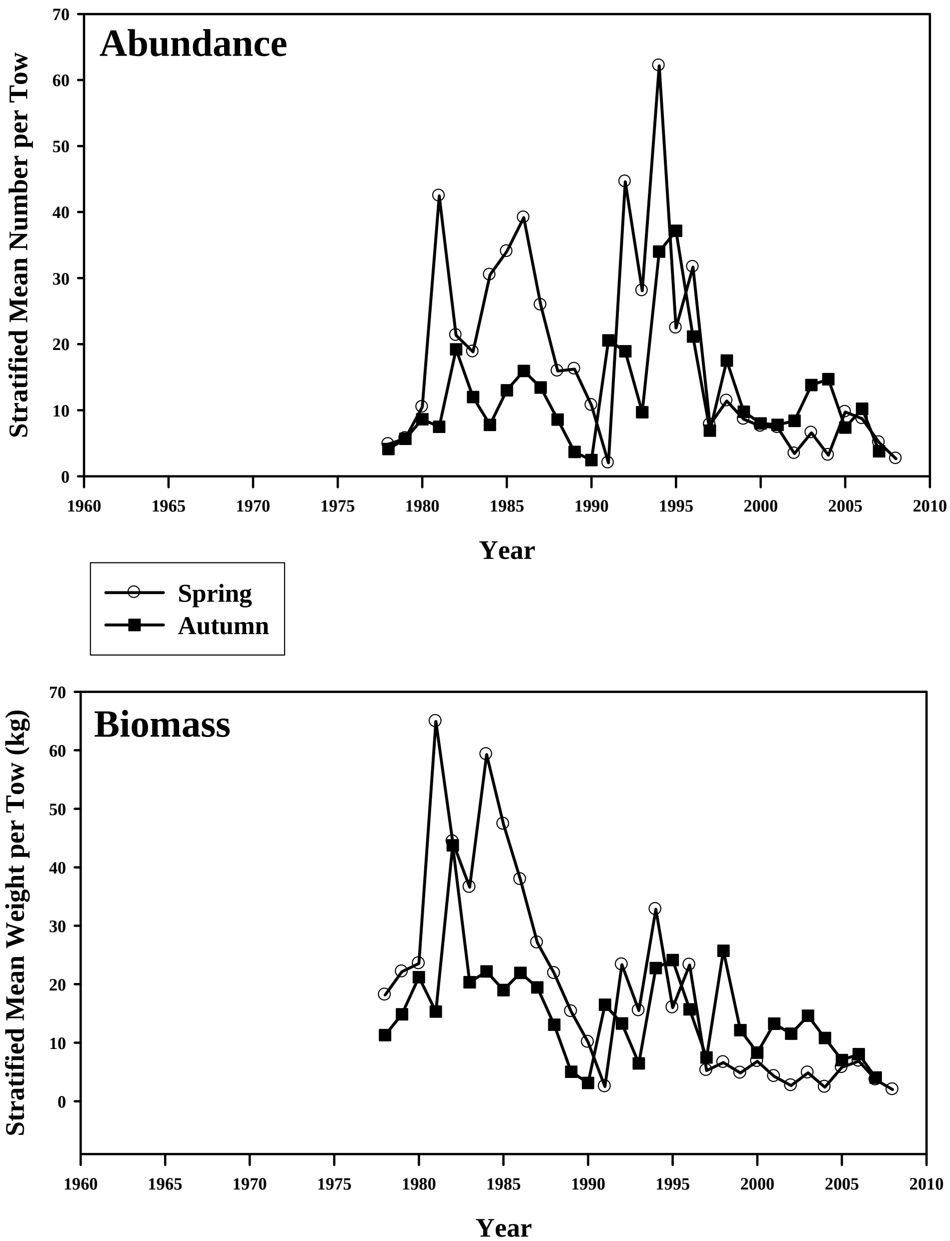


Figure 22. Abundance and biomass of winter skate from the Massachusetts spring and autumn finfish bottom trawl survey in state waters (strata 11-36).

Winter Skate - CTDEP Finfish Survey

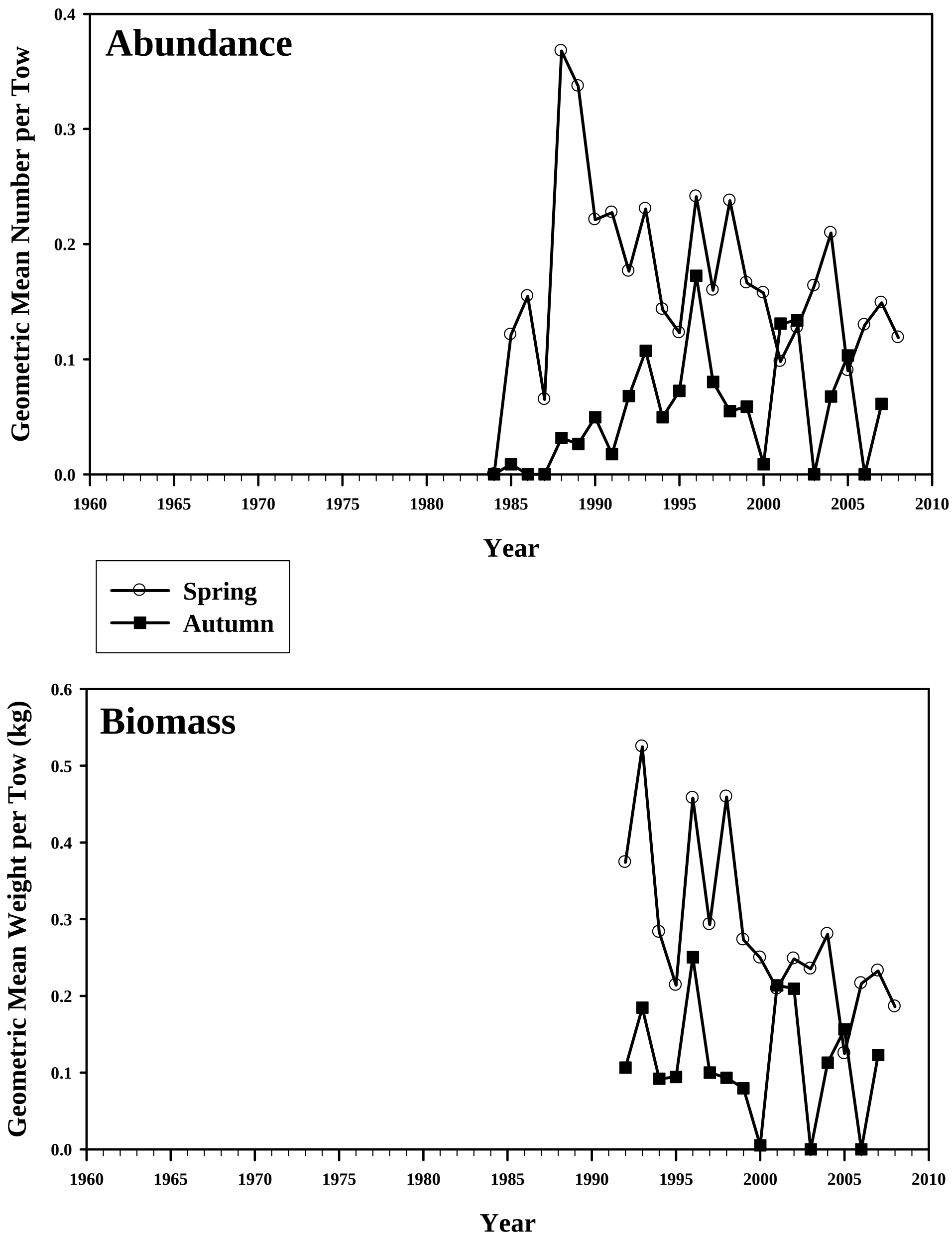


Figure 23. Abundance and biomass of winter skate from the CTDEP spring and autumn finfish bottom trawl survey in Connecticut state waters, 1984-2008.

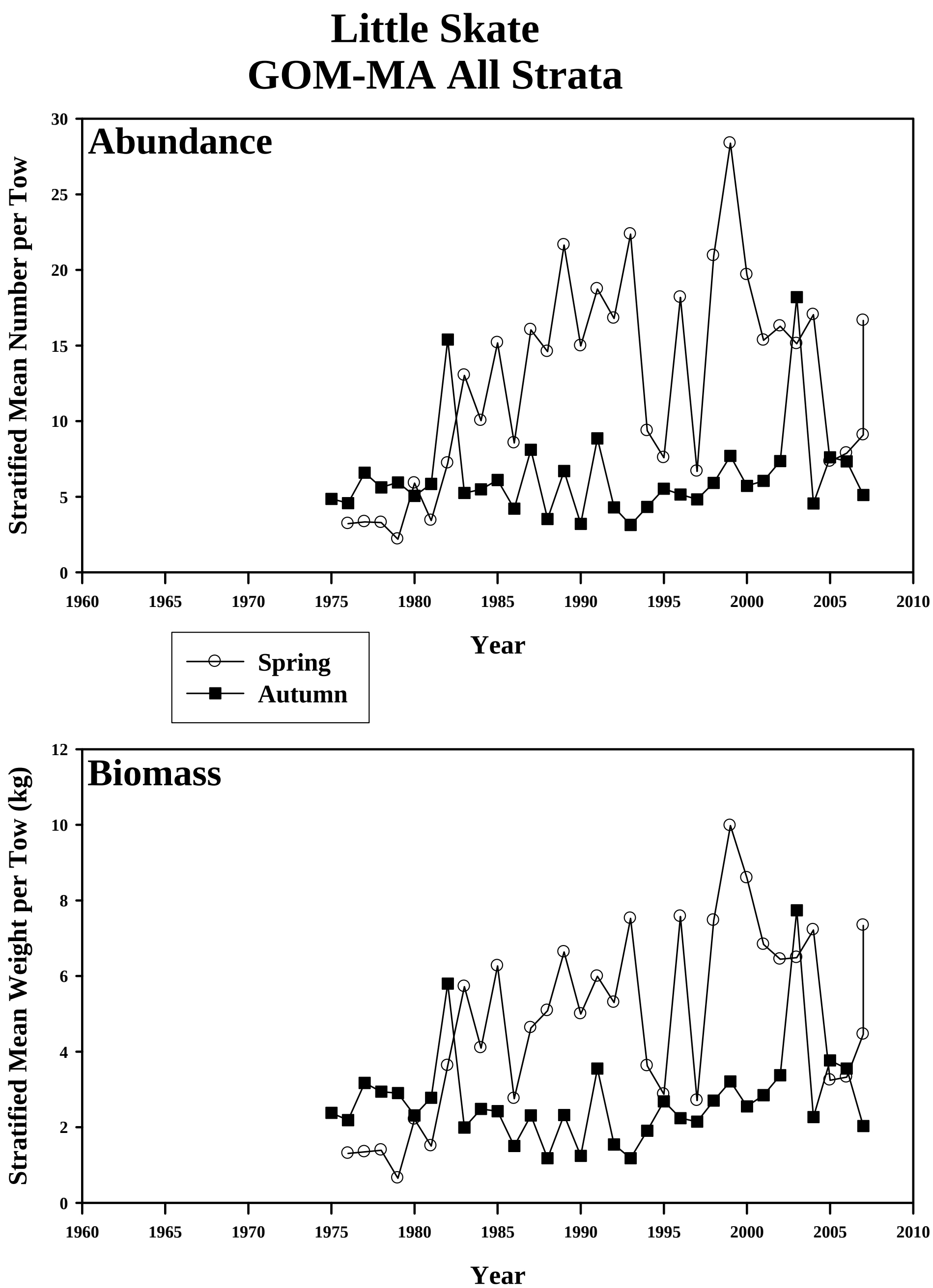


Figure 24. Abundance and biomass of little skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1975-2008 in the Gulf of Maine to Mid-Atlantic offshore and inshore regions.

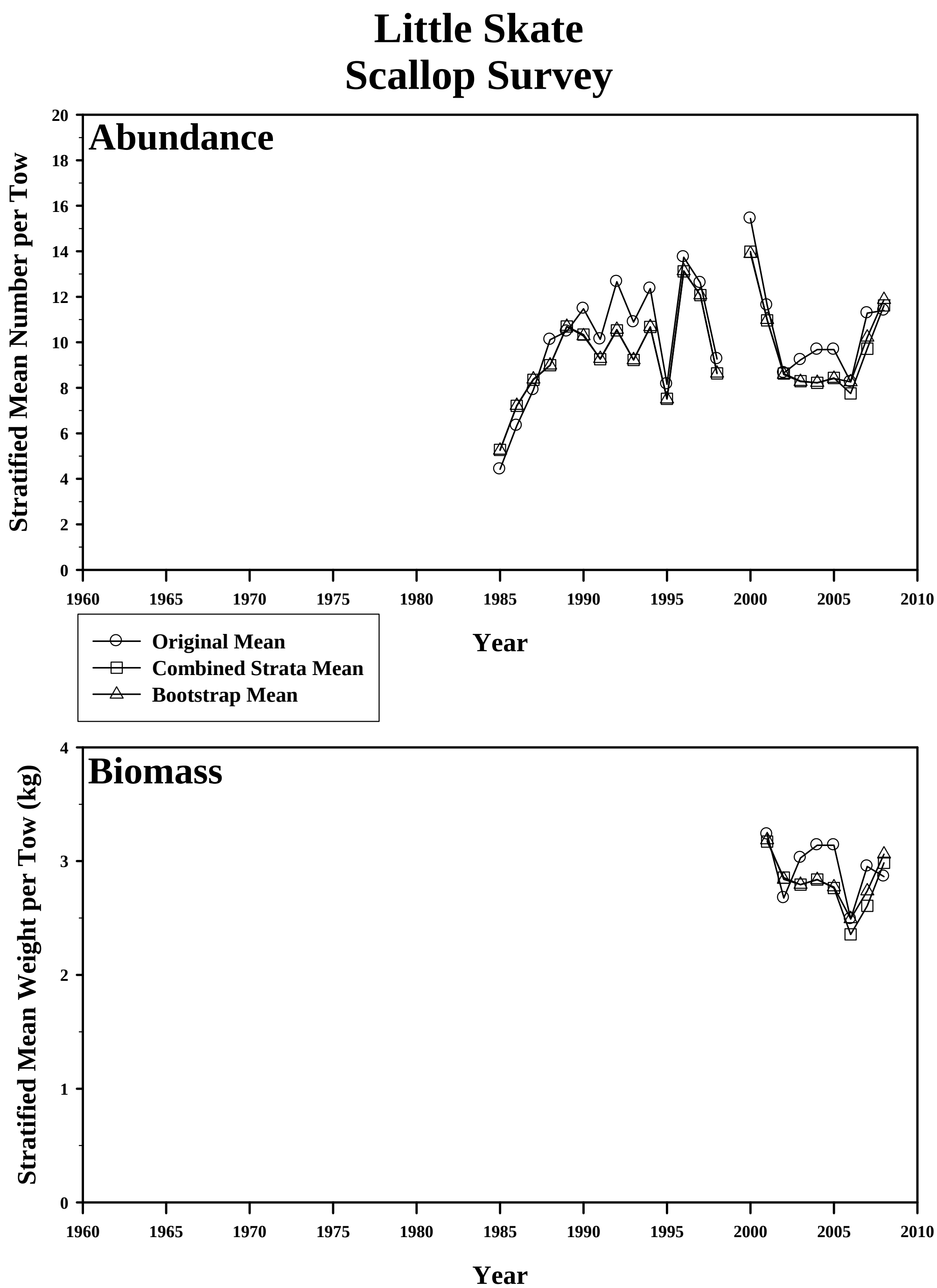


Figure 25. Abundance and biomass of little skate from the NESFC scallop dredge surveys from 1985-2008. The circles represent the original stratified mean, the squares represent the mean combining strata for bootstrapping, and the triangles represent the bootstrapped mean.

Little Skate - Massachusetts Trawl Survey

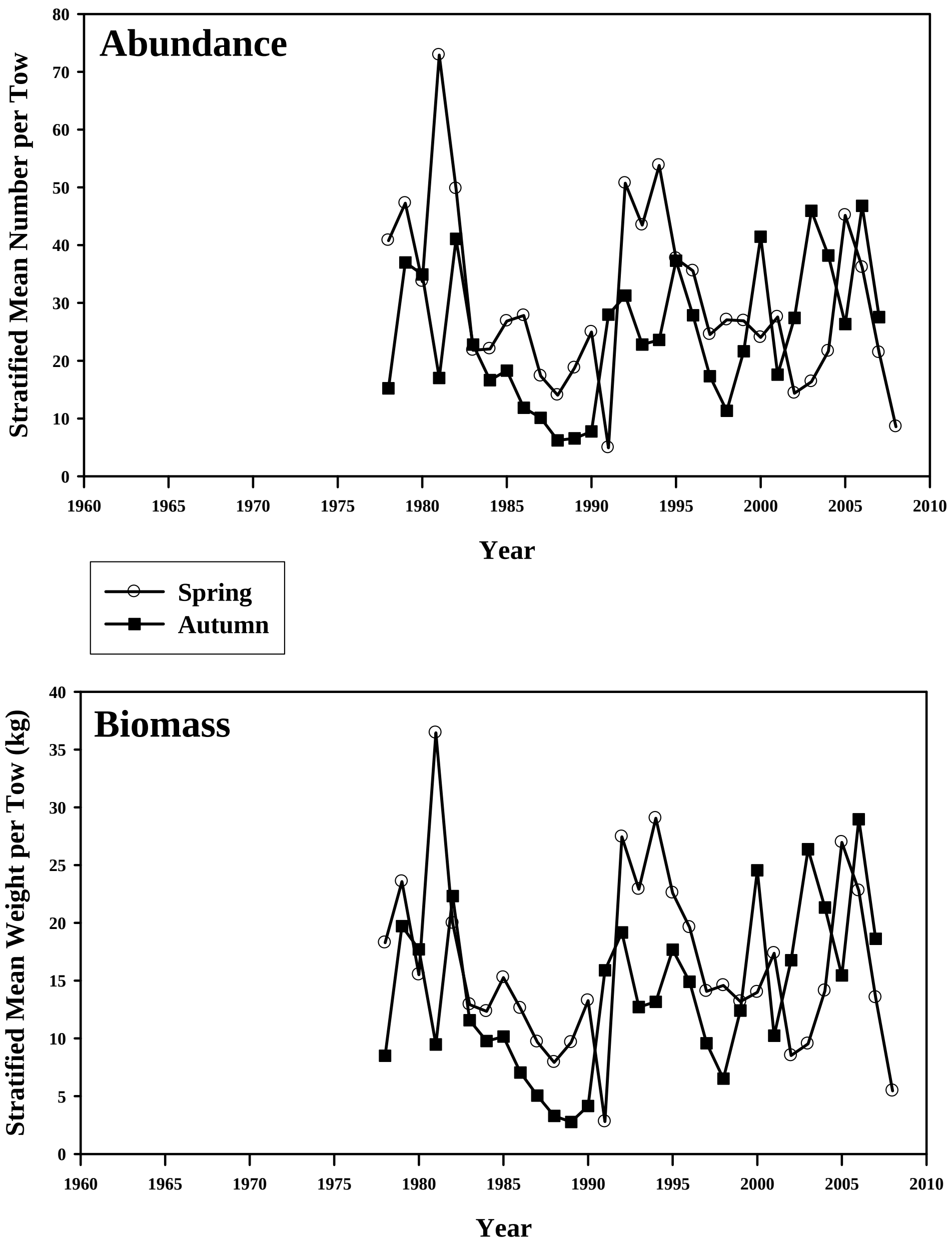


Figure 26. Abundance and biomass of little skate from the Massachusetts spring and autumn finfish bottom trawl survey in state waters (Strata 11-36).

Little Skate - CTDEP Finfish Survey

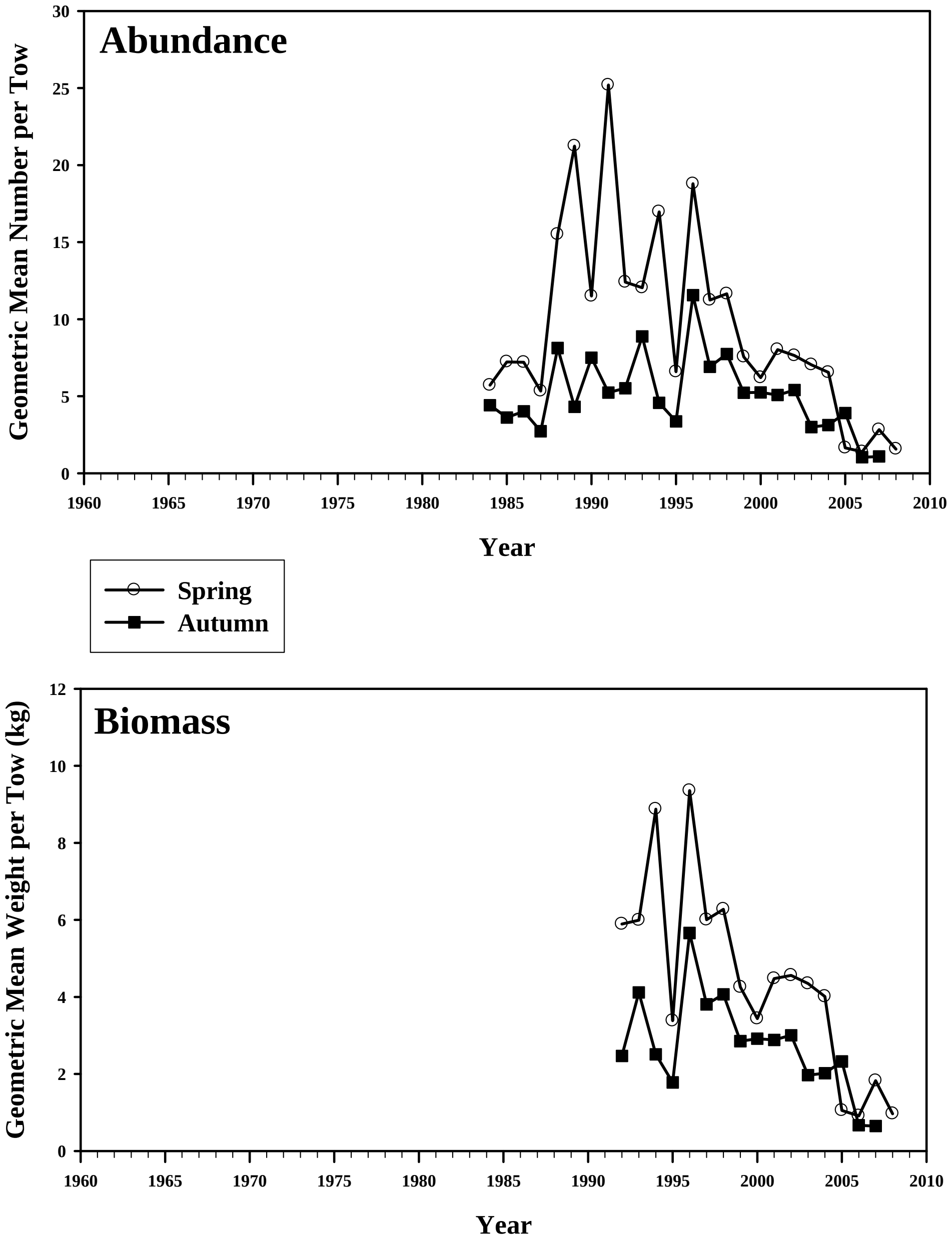


Figure 27. Abundance and biomass of little skate from the CTDEP spring and autumn finfish bottom trawl survey in Connecticut state waters, 1984-2008.

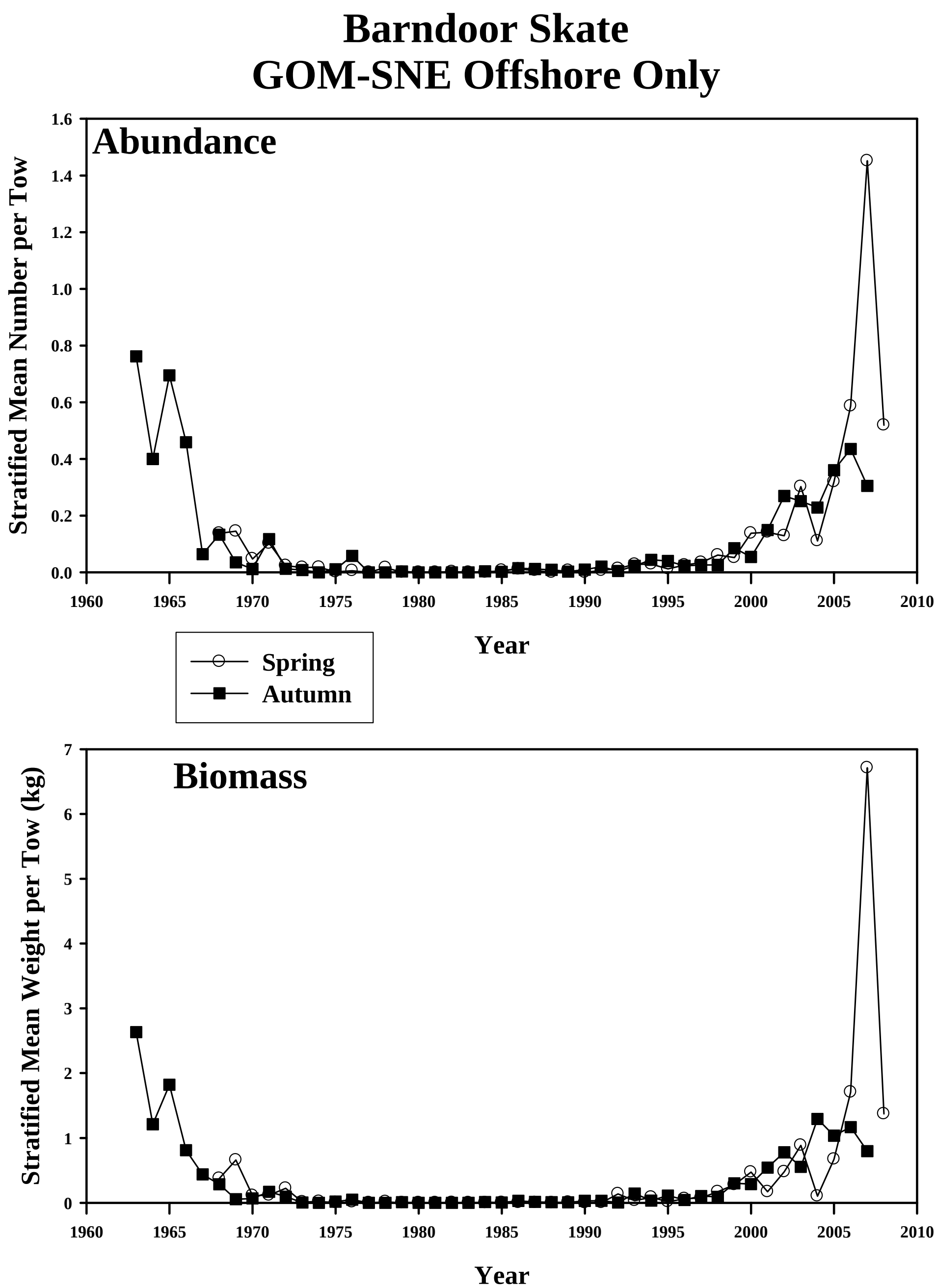


Figure 28. Abundance and biomass of barndoor skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1963-2008 in the Gulf of Maine-Southern New England offshore region.

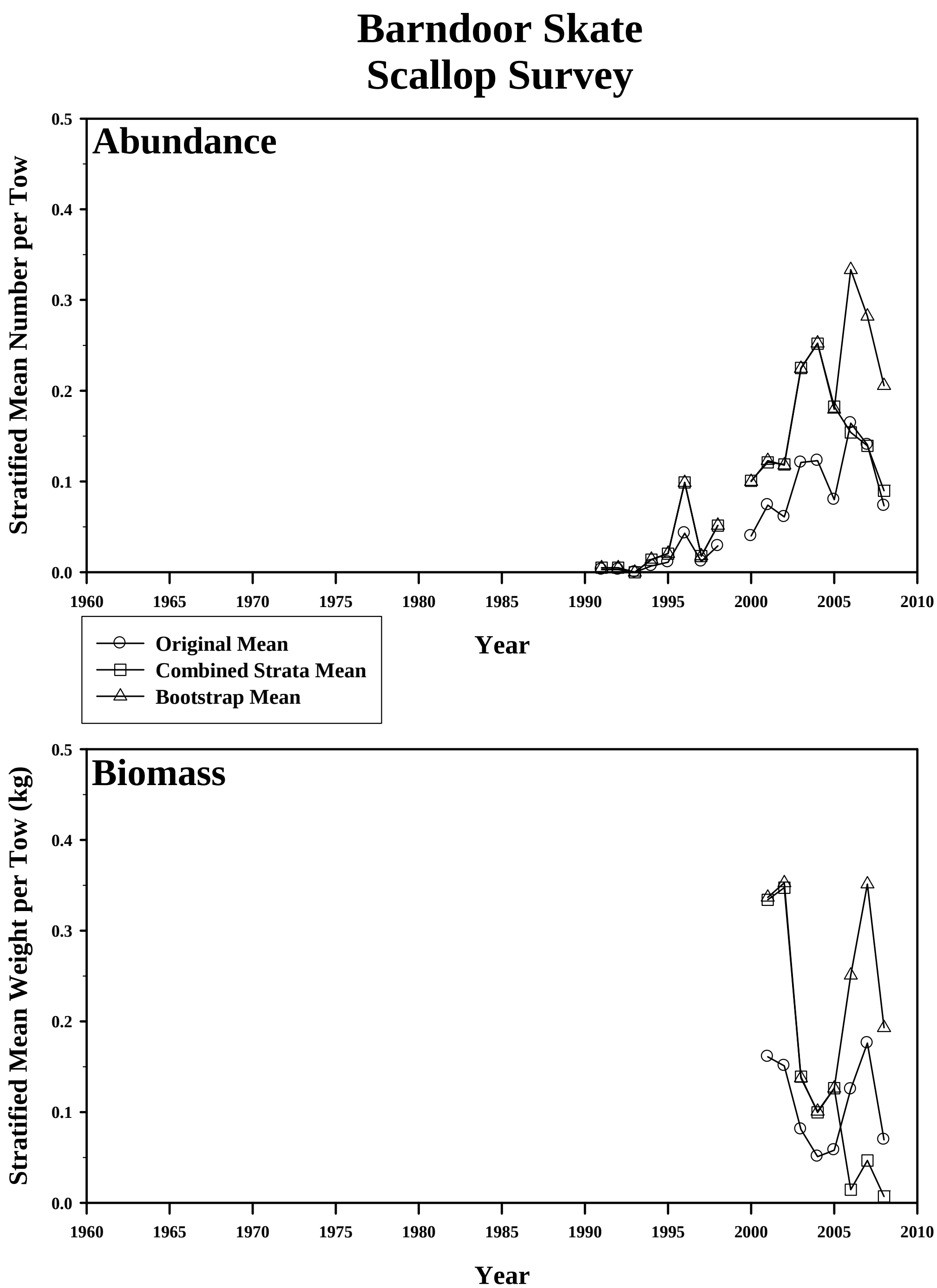


Figure 29. Abundance and biomass of barndoor skate from the NESFC scallop dredge surveys from 1992-2008. The circles represent the original stratified mean, the squares represent the mean combining strata for bootstrapping, and the triangles represent the bootstrapped mean.

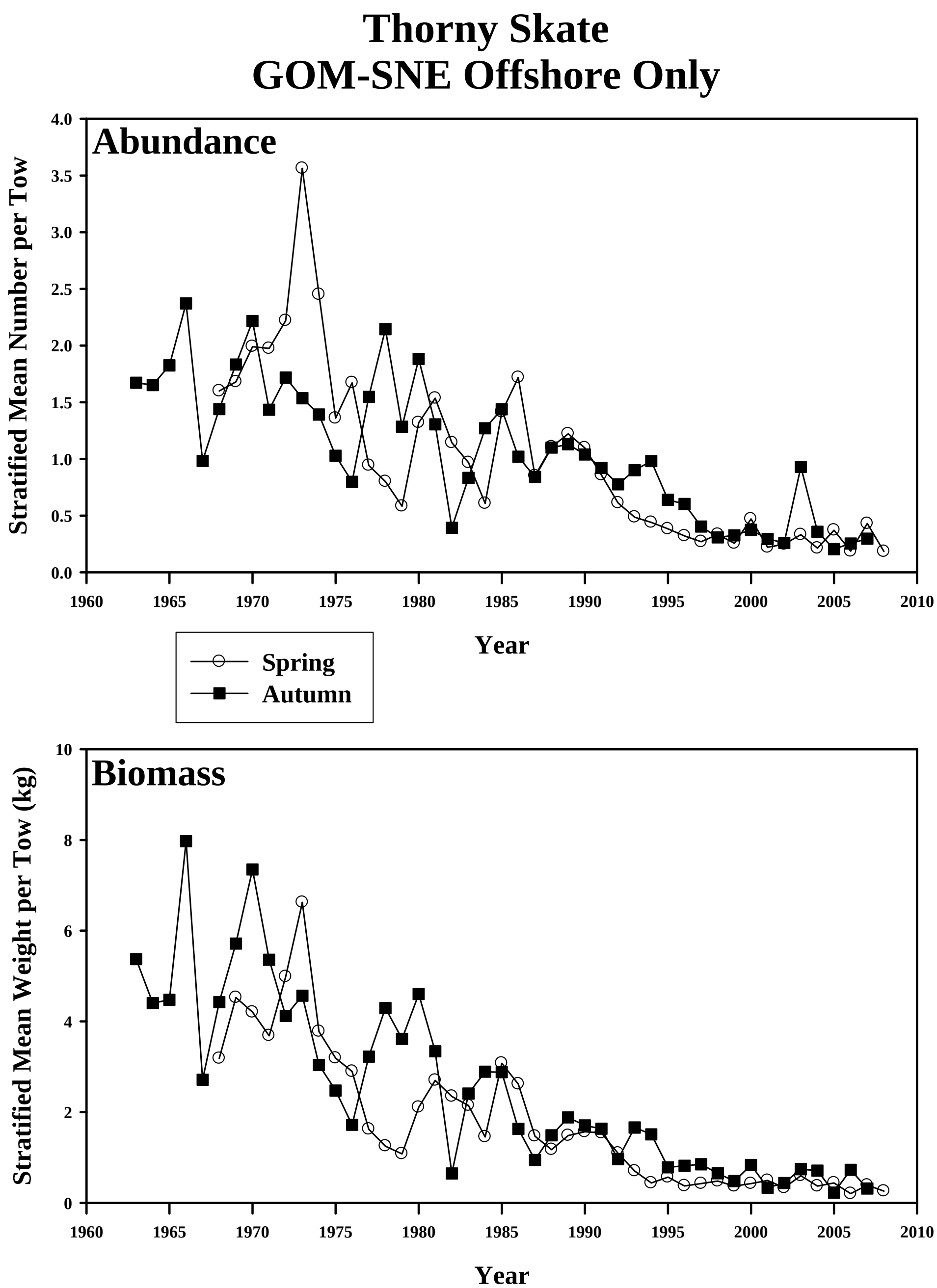


Figure 30. Abundance and biomass of thorny skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1963-2008 in the Gulf of Maine to Southern New England offshore region.

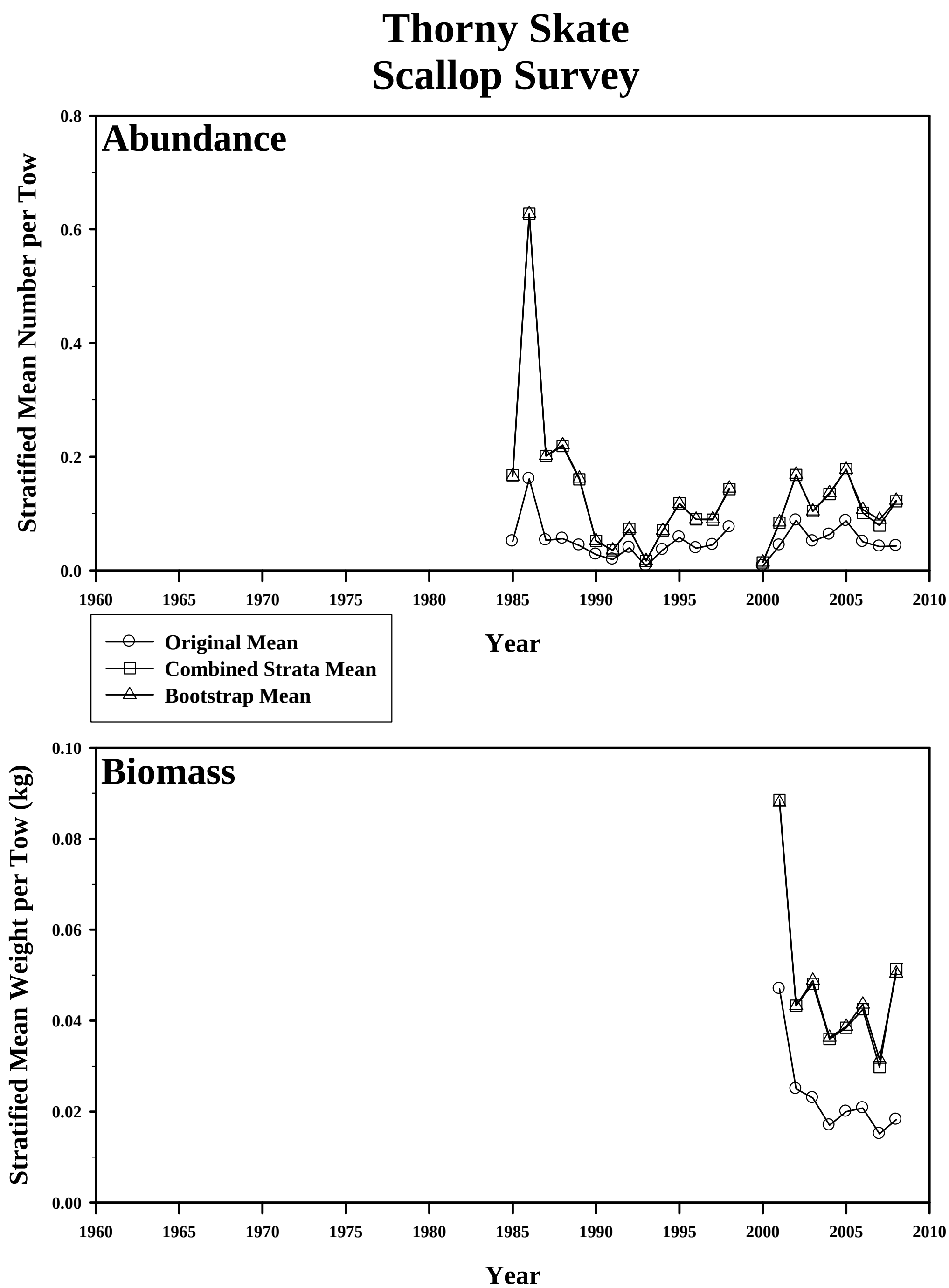


Figure 31. Abundance and biomass of thorny skate from the NESFC scallop dredge surveys from 1985-2008. The circles represent the original stratified mean, the squares represent the mean combining strata for bootstrapping, and the triangles represent the bootstrapped mean.

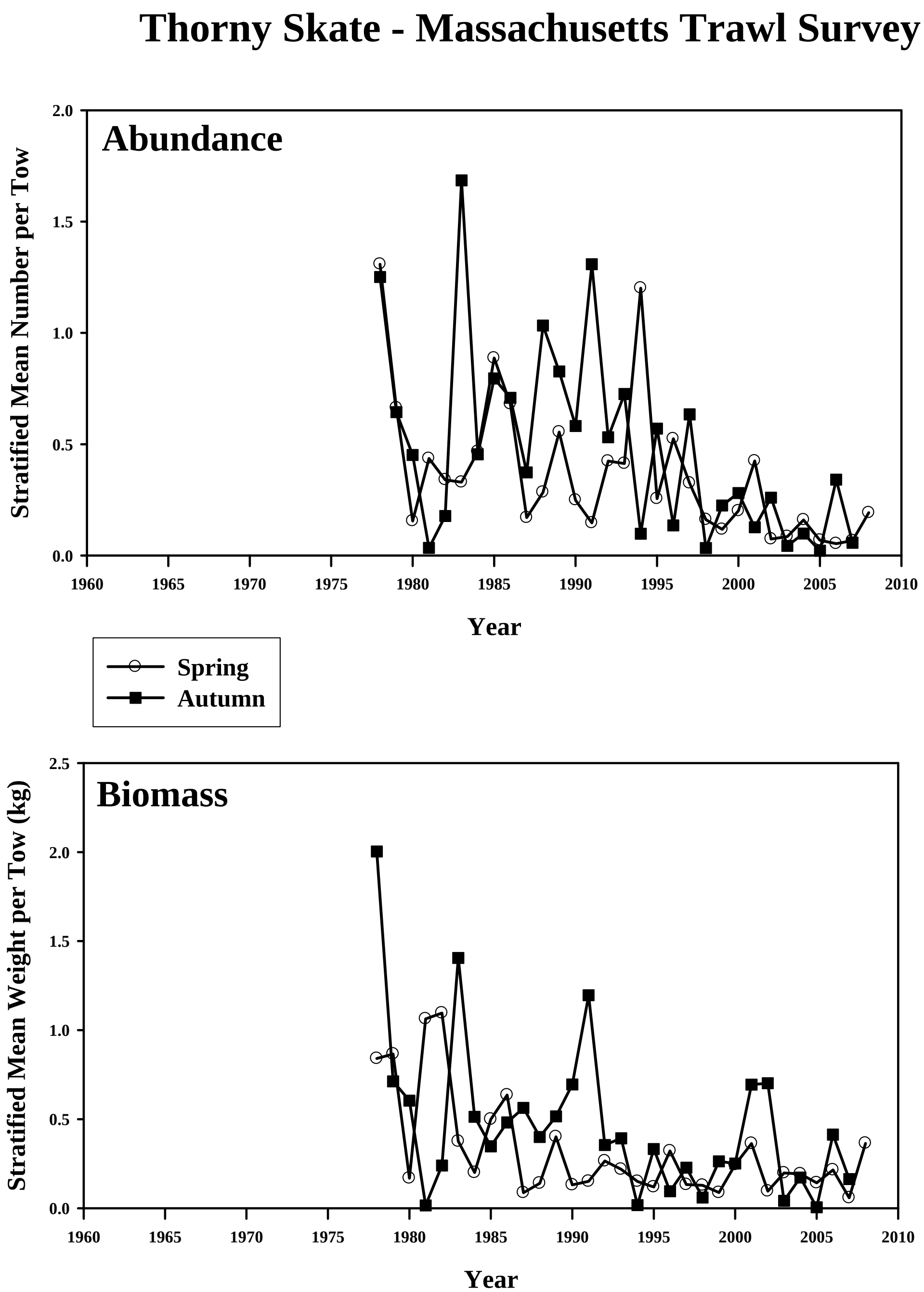


Figure 32. Abundance and biomass of thorny skate from the Massachusetts spring and autumn finfish bottom trawl survey in state waters (Strata 25-36).

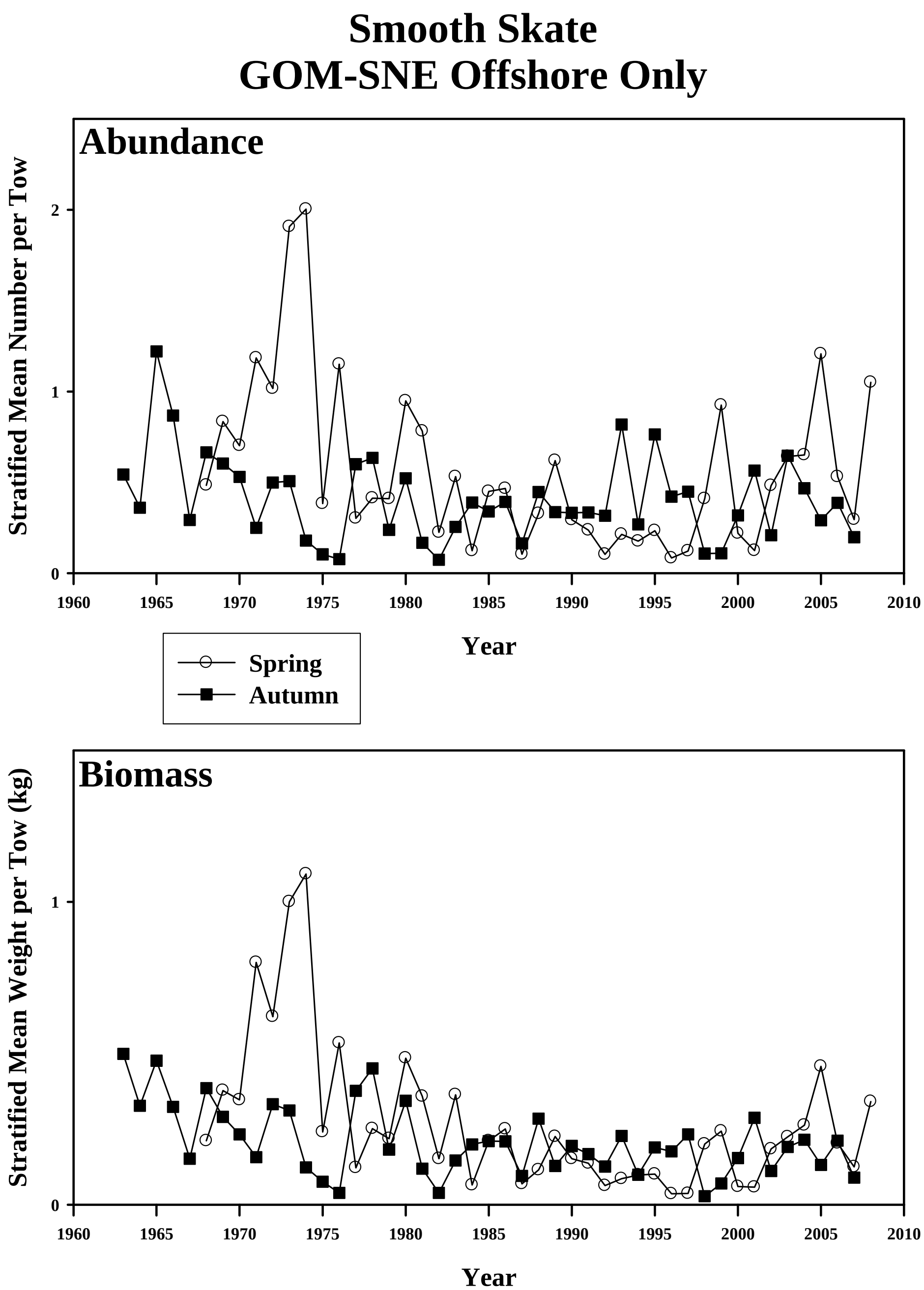


Figure 33. Abundance and biomass of smooth skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1963-2008 in the Gulf of Maine to Southern New England offshore region.

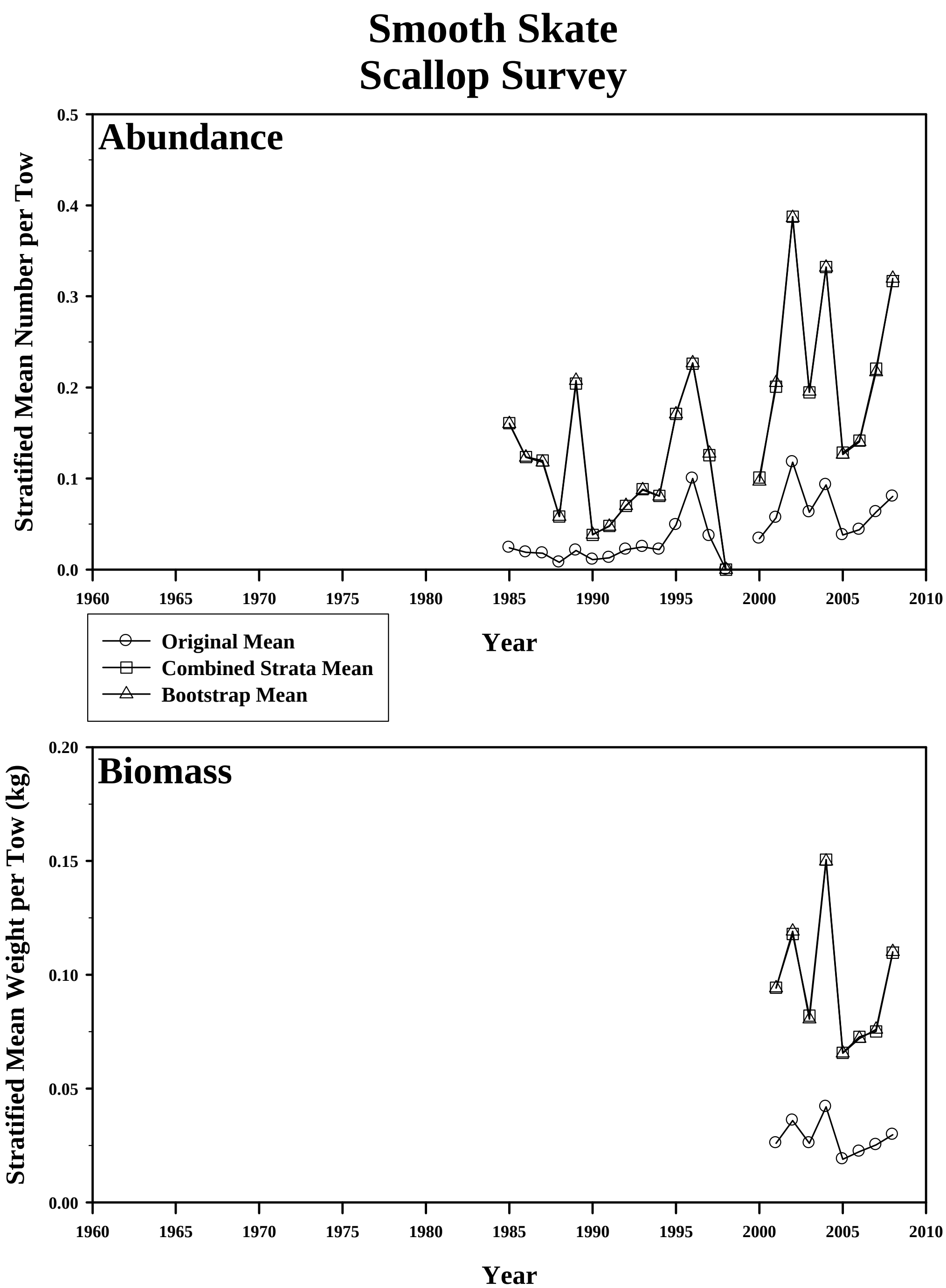


Figure 34. Abundance and biomass of smooth skate from the NESFC scallop dredge surveys from 1985-2008. The circles represent the original stratified mean, the squares represent the mean combining strata for bootstrapping, and the triangles represent the bootstrapped mean.

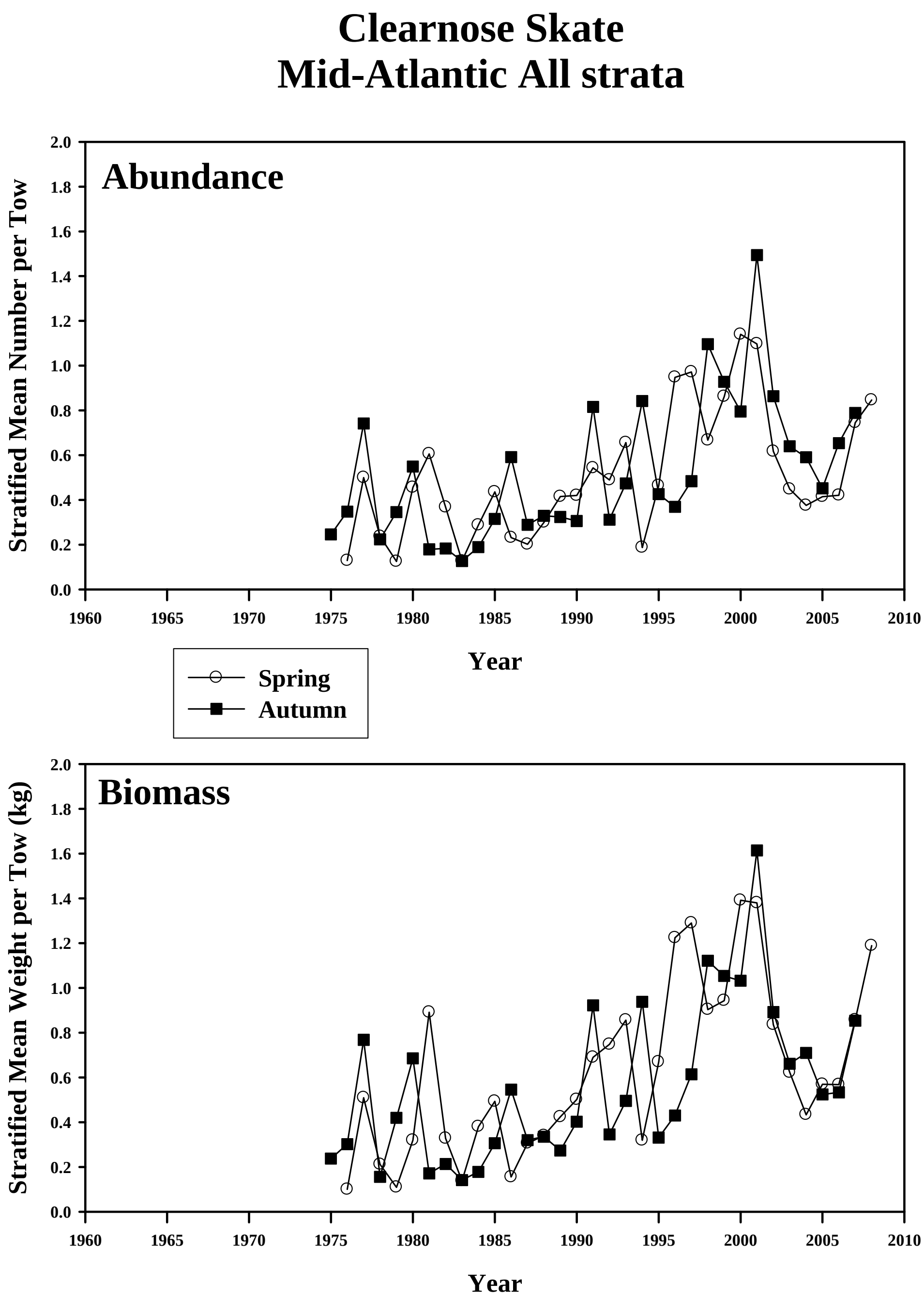


Figure 35. Abundance and biomass of clearnose skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1975-2008 in the Mid-Atlantic offshore and inshore regions.

Clearnose Skate - CTDEP Finfish Survey

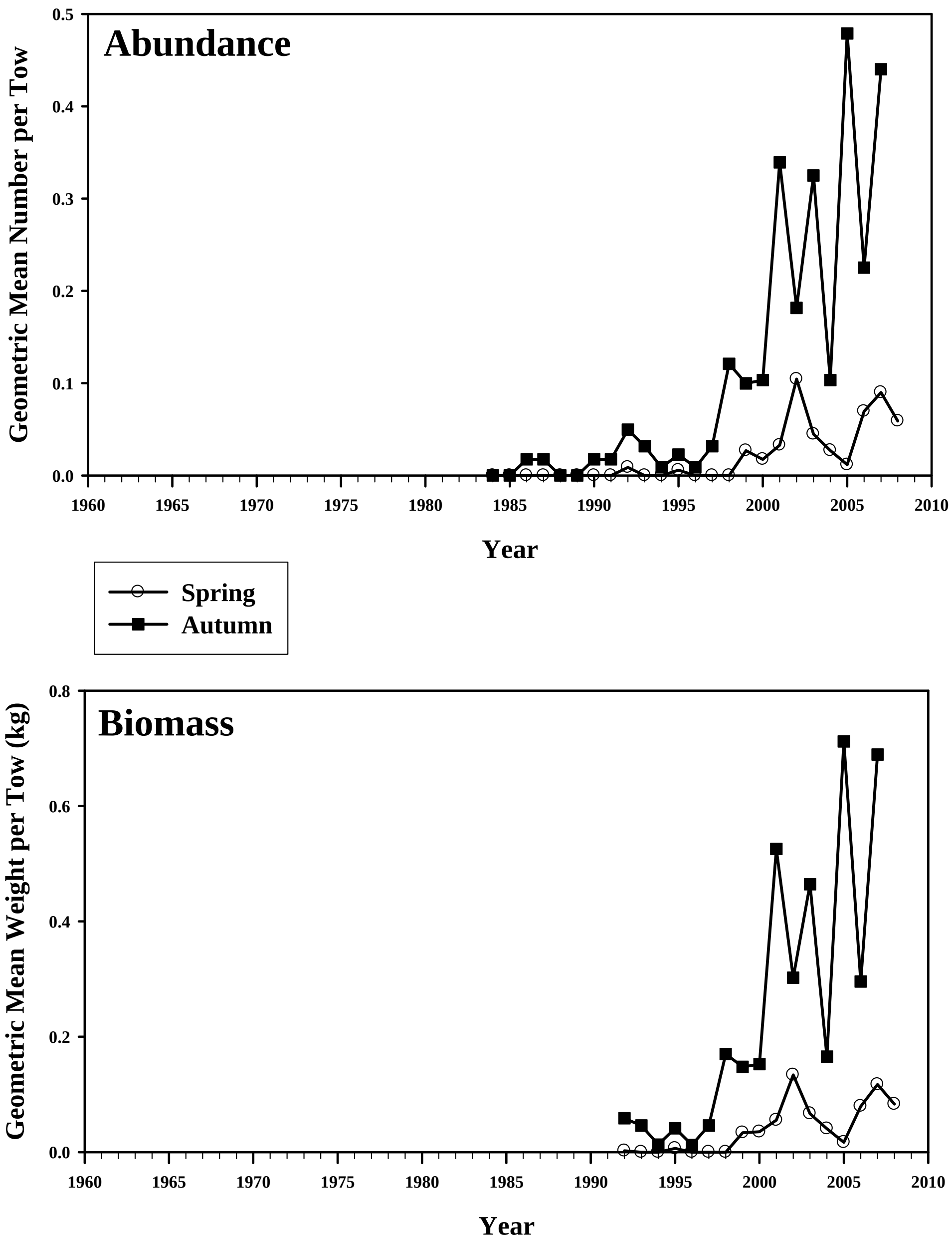


Figure 36. Abundance and biomass of clearnose skate from the CTDEP spring and autumn finfish bottom trawl survey in Connecticut state waters 1984-2008.

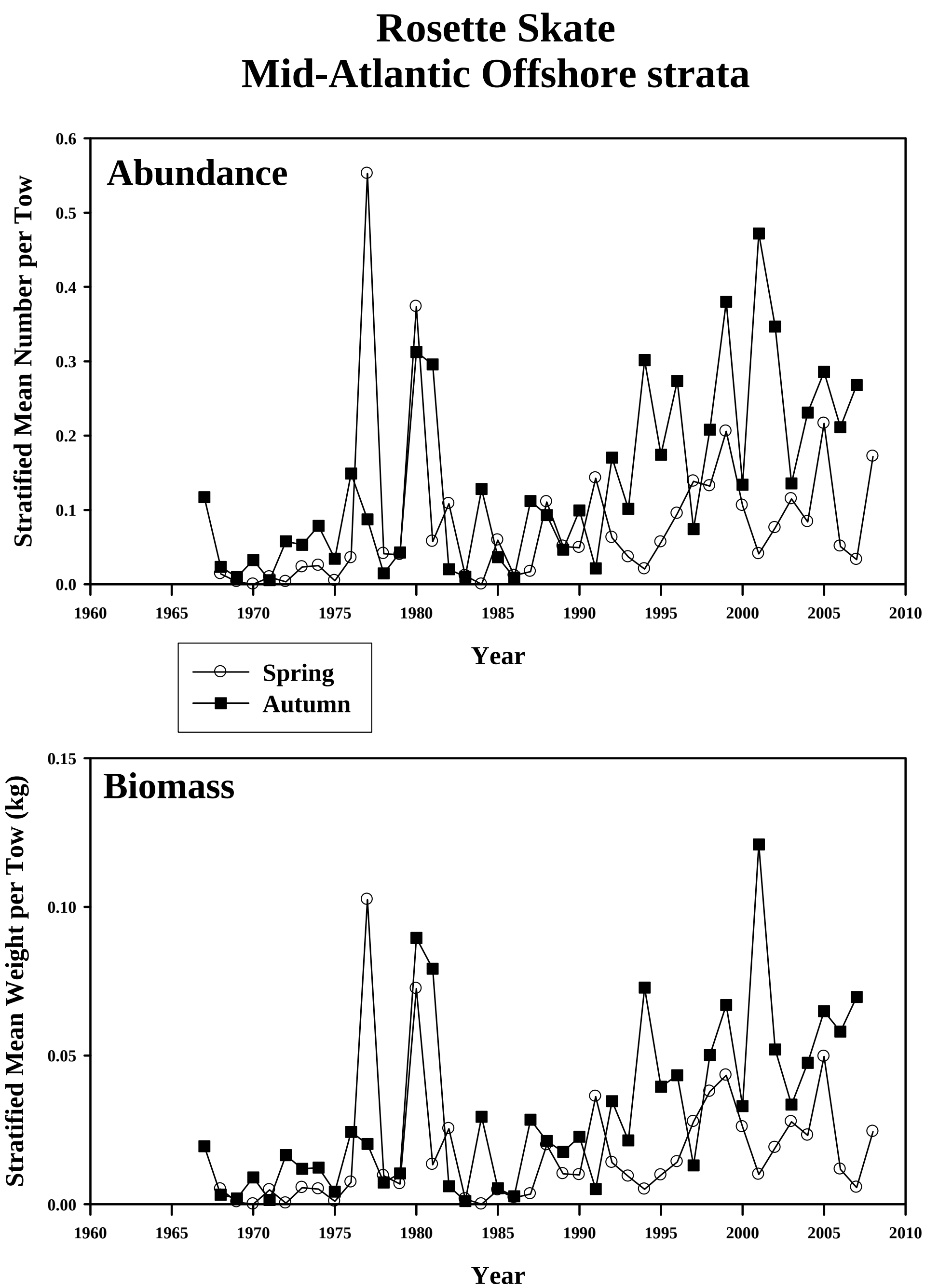


Figure 37. Abundance and biomass of rosette skate from the NESFC spring (circles) and autumn (squares) bottom trawl surveys from 1967-2008 in the Mid-Atlantic offshore region.

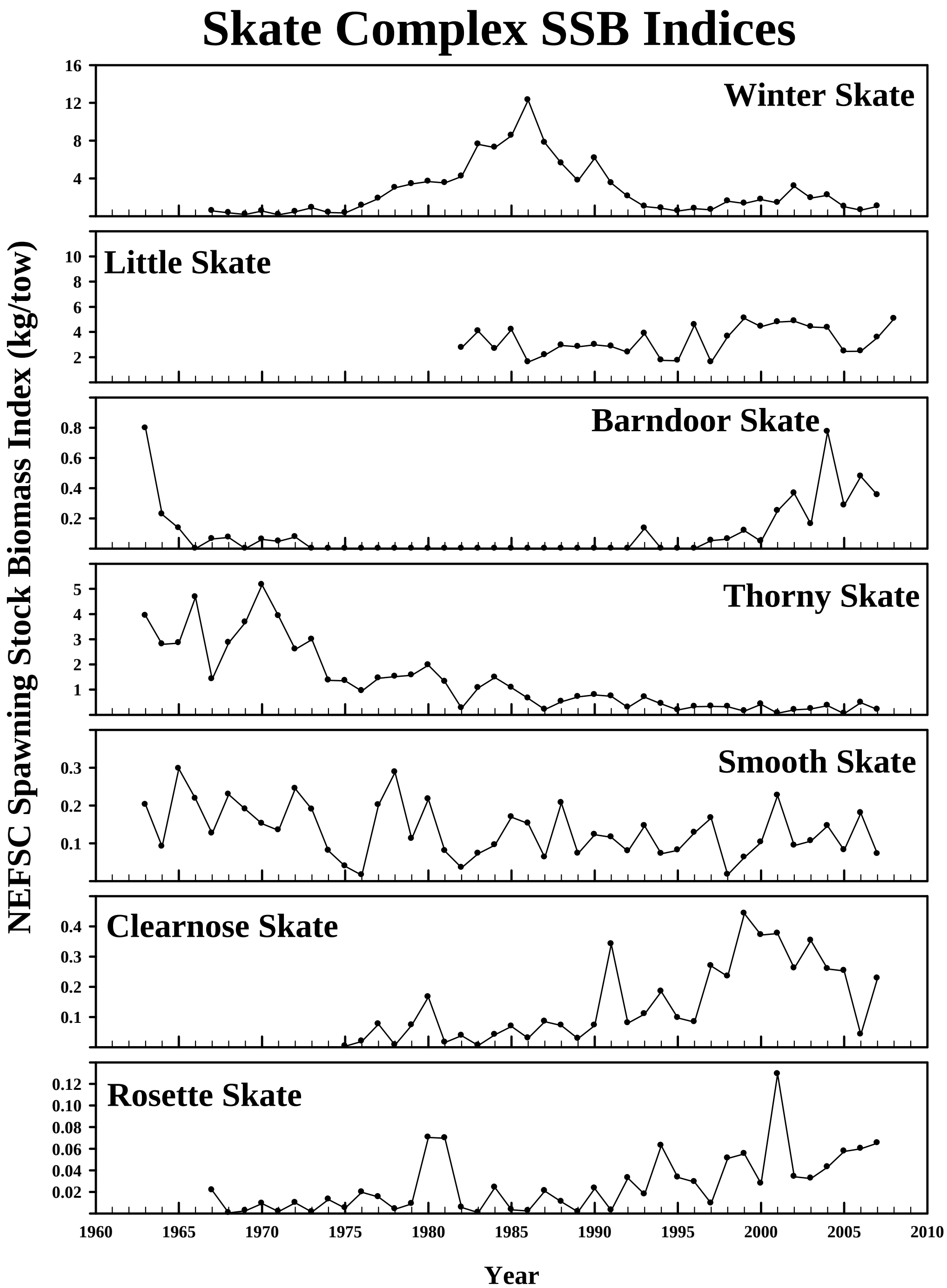


Figure 38. NEFSC survey spawning stock biomass indices (kg/tow).

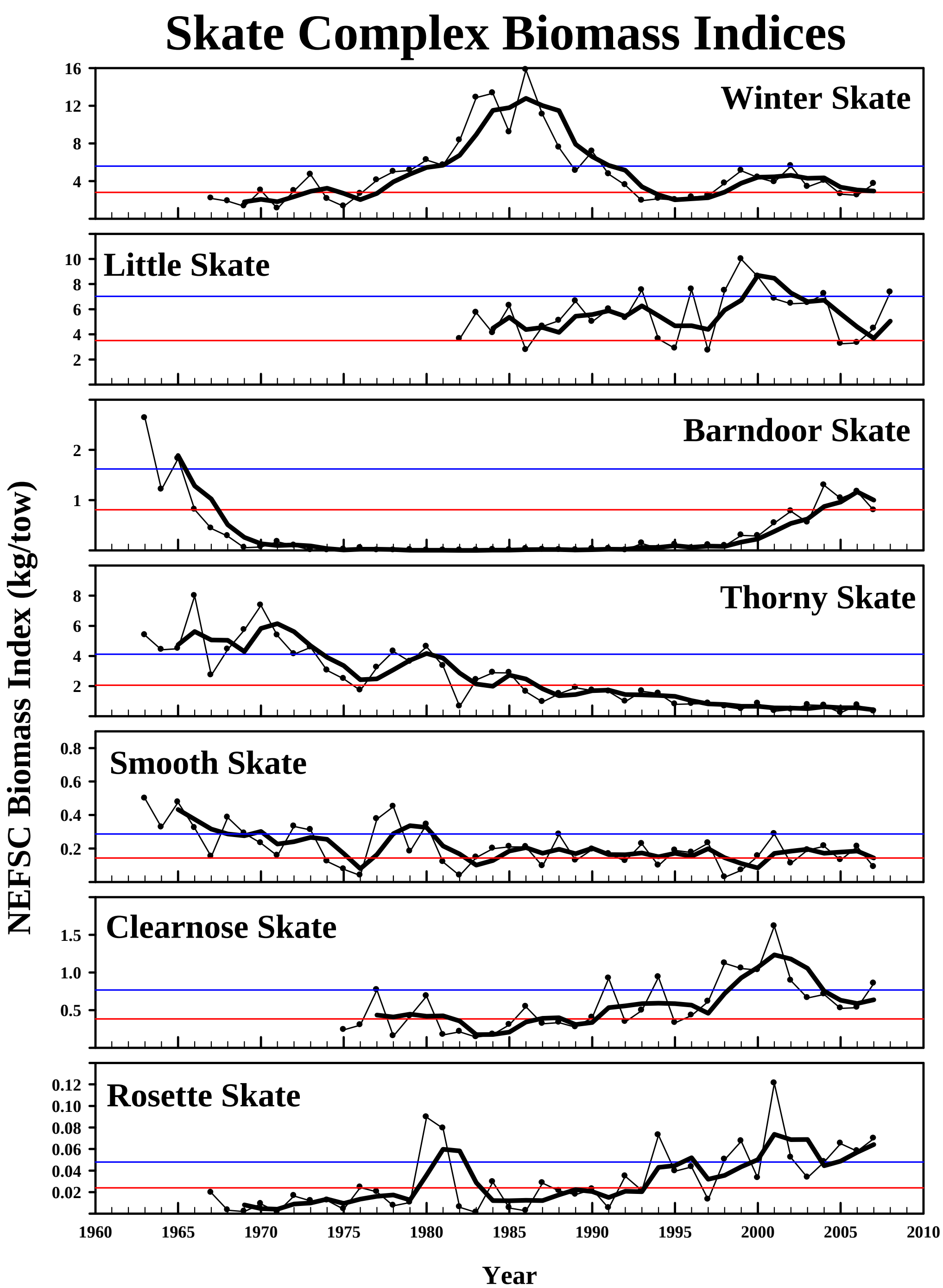


Figure 39. NEFSC survey biomass indices (kg/tow). Thin lines with symbols are annual indices, thick lines are 3-year moving averages, and the thin horizontal line are the biomass target and threshold.

January 13, 2009

Skate Complex
Skate Appendix 1

by
Data Poor Stocks Working Group
National Marine Fisheries Service
Northeast Fisheries Science Center

Data Poor Working Group Meeting
Woods Hole, MA

December 8-12, 2008

Table 1. Discard estimates by stratum for the longline fishery.

Legend: yellow = mean within areaf; green = mean within combined region (ie sne-ma); cyan = average across year; red = average - 1993-2004

YEAR	QTR	areaf	kept	discards	dkratio	mt kept	total discards
1991	1	GBK	15961.0	12350.0	0.7738	970.0	750.53
1991	2	GBK	18109.7	5863.3	0.3296	485.1	159.90
1991	3	GBK	18109.7	5863.3	0.3296	442.3	145.79
1991	4	GBK	27562.0	4796.0	0.1740	393.9	68.55
1991	1	GOM	18109.7	5863.3	0.3296	359.8	118.61
1991	2	GOM	18109.7	5863.3	0.3296	122.1	40.24
1991	3	GOM	18109.7	5863.3	0.3296	131.6	43.38
1991	4	GOM	10806.0	444.0	0.0411	141.7	5.82
1991	1	MA	18109.7	5863.3	0.3296	164.1	54.08
1991	2	MA	18109.7	5863.3	0.3296	58.6	19.32
1991	3	MA	18109.7	5863.3	0.3296	26.5	8.72
1991	4	MA	18109.7	5863.3	0.3296	124.5	41.02
1991	1	SNE	18109.7	5863.3	0.3296	84.9	27.99
1991	2	SNE	18109.7	5863.3	0.3296	32.2	10.60
1991	3	SNE	18109.7	5863.3	0.3296	15.5	5.10
1991	4	SNE	18109.7	5863.3	0.3296	28.1	9.25
1992	1	GBK	30379.5	27527.0	0.9061	1116.6	1011.79
1992	2	GBK	1922.0	426.0	0.2216	632.5	140.19
1992	3	GBK	16579.3	7918.8	0.3095	460.6	142.54
1992	4	GBK	16579.3	7918.8	0.3095	499.4	154.55
1992	1	GOM	33786.8	3722.0	0.1102	800.8	88.22
1992	2	GOM	16579.3	7918.8	0.3095	93.9	29.05
1992	3	GOM	16579.3	7918.8	0.3095	176.6	54.66
1992	4	GOM	16579.3	7918.8	0.3095	386.0	119.45
1992	1	MA	16579.3	7918.8	0.3095	226.1	69.98
1992	2	MA	229.0	0.0	0.0000	64.9	0.00
1992	3	MA	16579.3	7918.8	0.3095	111.6	34.55
1992	4	MA	16579.3	7918.8	0.3095	124.0	38.38
1992	1	SNE	16579.3	7918.8	0.3095	330.0	102.11
1992	2	SNE	16579.3	7918.8	0.3095	200.3	62.00
1992	3	SNE	16579.3	7918.8	0.3095	151.1	46.76
1992	4	SNE	16579.3	7918.8	0.3095	403.4	124.83
1993	1	GBK	32995.7	394.5	0.0679	1220.1	82.89
1993	2	GBK	32995.7	394.5	0.0679	579.3	39.36
1993	3	GBK	32995.7	394.5	0.0679	587.7	39.93
1993	4	GBK	32995.7	394.5	0.0679	606.0	41.17
1993	1	GOM	296.0	26.0	0.0878	380.0	33.38
1993	2	GOM	32995.7	394.5	0.0679	193.9	13.17
1993	3	GOM	32995.7	394.5	0.0679	247.8	16.84
1993	4	GOM	32995.7	394.5	0.0679	404.4	27.47
1993	1	MA	4205.0	0.0	0.0000	138.0	0.00
1993	2	MA	32995.7	394.5	0.0679	96.8	6.57
1993	3	MA	578.0	0.0	0.0000	45.3	0.00
1993	4	MA	32995.7	394.5	0.0679	116.7	7.93
1993	1	SNE	32995.7	394.5	0.0679	569.6	38.70

Table 1. cont.

1993	2	SNE	32995.7	394.5	0.0679	434.8	29.54
1993	3	SNE	32995.7	394.5	0.0679	146.9	9.98
1993	4	SNE	32995.7	394.5	0.0679	239.3	16.26
1994	1	GBK	481.0	0.0	0.0000	989.6	0.00
1994	2	GBK	32995.7	394.5	0.0679	568.2	38.60
1994	3	GBK	32995.7	394.5	0.0679	512.1	34.79
1994	4	GBK	32995.7	394.5	0.0679	676.0	45.92
1994	1	GOM	32995.7	394.5	0.0679	268.2	18.22
1994	2	GOM	32995.7	394.5	0.0679	365.9	24.86
1994	3	GOM	32995.7	394.5	0.0679	649.2	44.10
1994	4	GOM	32995.7	394.5	0.0679	314.0	21.33
1994	1	MA	64.4	0.0	0.0000	101.9	0.00
1994	2	MA	32995.7	394.5	0.0679	50.3	3.42
1994	3	MA	32995.7	394.5	0.0679	3.0	0.20
1994	4	MA	32995.7	394.5	0.0679	1.5	0.11
1994	1	SNE	32995.7	394.5	0.0679	382.1	25.96
1994	2	SNE	32995.7	394.5	0.0679	104.5	7.10
1994	3	SNE	32995.7	394.5	0.0679	69.4	4.71
1994	4	SNE	32995.7	394.5	0.0679	160.6	10.91
1995	1	GBK	32995.7	394.5	0.0679	948.1	64.41
1995	2	GBK	32995.7	394.5	0.0679	691.6	46.98
1995	3	GBK	32995.7	394.5	0.0679	436.9	29.68
1995	4	GBK	32995.7	394.5	0.0679	811.2	55.11
1995	1	GOM	32995.7	394.5	0.0679	221.9	15.08
1995	2	GOM	32995.7	394.5	0.0679	297.2	20.19
1995	3	GOM	32995.7	394.5	0.0679	463.0	31.45
1995	4	GOM	32995.7	394.5	0.0679	529.8	35.99
1995	1	MA	0.0	0.0		135.2	0.00
1995	2	MA	32995.7	394.5	0.0679	64.3	4.37
1995	3	MA	32995.7	394.5	0.0679	43.5	2.96
1995	4	MA	32995.7	394.5	0.0679	46.3	3.14
1995	1	SNE	32995.7	394.5	0.0679	186.3	12.66
1995	2	SNE	32995.7	394.5	0.0679	15.5	1.05
1995	3	SNE	32995.7	394.5	0.0679	30.3	2.06
1995	4	SNE	32995.7	394.5	0.0679	223.0	15.15
1996	1	GBK	32995.7	394.5	0.0679	649.6	44.13
1996	2	GBK	32995.7	394.5	0.0679	576.0	39.13
1996	3	GBK	32995.7	394.5	0.0679	380.5	25.85
1996	4	GBK	32995.7	394.5	0.0679	841.8	57.19
1996	1	GOM	32995.7	394.5	0.0679	325.5	22.11
1996	2	GOM	32995.7	394.5	0.0679	263.6	17.91
1996	3	GOM	32995.7	394.5	0.0679	171.4	11.64
1996	4	GOM	32995.7	394.5	0.0679	394.5	26.80
1996	1	MA	32995.7	394.5	0.0679	120.9	8.21
1996	2	MA	32995.7	394.5	0.0679	79.5	5.40
1996	3	MA	32995.7	394.5	0.0679	76.5	5.20
1996	4	MA	32995.7	394.5	0.0679	109.2	7.42
1996	1	SNE	32995.7	394.5	0.0679	319.5	21.70
1996	2	SNE	32995.7	394.5	0.0679	74.9	5.09

Table 1 cont.

1996	3	SNE	32995.7	394.5	0.0679	86.0	5.84
1996	4	SNE	32995.7	394.5	0.0679	221.9	15.08
1997	1	GBK	32995.7	394.5	0.0679	416.1	28.27
1997	2	GBK	32995.7	394.5	0.0679	662.5	45.01
1997	3	GBK	32995.7	394.5	0.0679	306.6	20.83
1997	4	GBK	32995.7	394.5	0.0679	645.3	43.84
1997	1	GOM	32995.7	394.5	0.0679	342.2	23.25
1997	2	GOM	32995.7	394.5	0.0679	336.1	22.83
1997	3	GOM	32995.7	394.5	0.0679	292.0	19.84
1997	4	GOM	32995.7	394.5	0.0679	563.6	38.29
1997	1	MA	32995.7	394.5	0.0679	86.7	5.89
1997	2	MA	32995.7	394.5	0.0679	113.0	7.68
1997	3	MA	32995.7	394.5	0.0679	98.4	6.68
1997	4	MA	32995.7	394.5	0.0679	134.7	9.15
1997	1	SNE	32995.7	394.5	0.0679	463.8	31.51
1997	2	SNE	32995.7	394.5	0.0679	185.6	12.61
1997	3	SNE	32995.7	394.5	0.0679	119.8	8.14
1997	4	SNE	32995.7	394.5	0.0679	370.9	25.20
1998	1	GBK	32995.7	394.5	0.0679	661.8	44.96
1998	2	GBK	32995.7	394.5	0.0679	276.2	18.77
1998	3	GBK	32995.7	394.5	0.0679	358.4	24.35
1998	4	GBK	32995.7	394.5	0.0679	1137.5	77.27
1998	1	GOM	32995.7	394.5	0.0679	254.2	17.27
1998	2	GOM	32995.7	394.5	0.0679	271.8	18.46
1998	3	GOM	32995.7	394.5	0.0679	205.0	13.93
1998	4	GOM	32995.7	394.5	0.0679	384.4	26.12
1998	1	MA	32995.7	394.5	0.0679	173.2	11.77
1998	2	MA	32995.7	394.5	0.0679	62.7	4.26
1998	3	MA	115.0	10.0	0.0870	43.3	3.77
1998	4	MA	32995.7	394.5	0.0679	255.6	17.36
1998	1	SNE	32995.7	394.5	0.0679	322.8	21.93
1998	2	SNE	32995.7	394.5	0.0679	133.3	9.06
1998	3	SNE	32995.7	394.5	0.0679	94.1	6.39
1998	4	SNE	32995.7	394.5	0.0679	127.8	8.69
1999	1	GBK	32995.7	394.5	0.0679	805.6	54.73
1999	2	GBK	32995.7	394.5	0.0679	589.2	40.02
1999	3	GBK	32995.7	394.5	0.0679	482.1	32.75
1999	4	GBK	32995.7	394.5	0.0679	1145.9	77.85
1999	1	GOM	32995.7	394.5	0.0679	84.0	5.71
1999	2	GOM	32995.7	394.5	0.0679	177.1	12.03
1999	3	GOM	32995.7	394.5	0.0679	64.3	4.37
1999	4	GOM	32995.7	394.5	0.0679	112.8	7.66
1999	1	MA	32995.7	394.5	0.0679	103.8	7.05
1999	2	MA	32995.7	394.5	0.0679	57.4	3.90
1999	3	MA	32995.7	394.5	0.0679	37.4	2.54
1999	4	MA	32995.7	394.5	0.0679	112.4	7.64
1999	1	SNE	32995.7	394.5	0.0679	109.1	7.41
1999	2	SNE	32995.7	394.5	0.0679	70.4	4.78
1999	3	SNE	32995.7	394.5	0.0679	42.0	2.86

Table 1 cont.

1999	4	SNE	32995.7	394.5	0.0679	54.1	3.67
2000	1	GBK	32995.7	394.5	0.0679	474.0	32.20
2000	2	GBK	32995.7	394.5	0.0679	309.0	20.99
2000	3	GBK	32995.7	394.5	0.0679	1545.6	105.00
2000	4	GBK	32995.7	394.5	0.0679	200.5	13.62
2000	1	GOM	32995.7	394.5	0.0679	64.0	4.35
2000	2	GOM	32995.7	394.5	0.0679	65.6	4.46
2000	3	GOM	32995.7	394.5	0.0679	98.6	6.70
2000	4	GOM	32995.7	394.5	0.0679	80.5	5.47
2000	1	MA	32995.7	394.5	0.0679	108.4	7.36
2000	2	MA	32995.7	394.5	0.0679	36.7	2.49
2000	3	MA	32995.7	394.5	0.0679	43.3	2.94
2000	4	MA	32995.7	394.5	0.0679	168.6	11.45
2000	1	SNE	32995.7	394.5	0.0679	79.3	5.38
2000	2	SNE	32995.7	394.5	0.0679	60.6	4.12
2000	3	SNE	32995.7	394.5	0.0679	65.6	4.46
2000	4	SNE	32995.7	394.5	0.0679	54.5	3.71
2001	1	GBK	32995.7	394.5	0.0679	446.2	30.31
2001	2	GBK	32995.7	394.5	0.0679	739.7	50.25
2001	3	GBK	32995.7	394.5	0.0679	438.0	29.76
2001	4	GBK	32995.7	394.5	0.0679	805.7	54.73
2001	1	GOM	32995.7	394.5	0.0679	34.8	2.36
2001	2	GOM	32995.7	394.5	0.0679	53.5	3.64
2001	3	GOM	32995.7	394.5	0.0679	21.9	1.48
2001	4	GOM	32995.7	394.5	0.0679	87.4	5.94
2001	1	MA	32995.7	394.5	0.0679	177.3	12.04
2001	2	MA	32995.7	394.5	0.0679	124.3	8.45
2001	3	MA	32995.7	394.5	0.0679	109.9	7.47
2001	4	MA	32995.7	394.5	0.0679	304.8	20.71
2001	1	SNE	32995.7	394.5	0.0679	123.9	8.42
2001	2	SNE	32995.7	394.5	0.0679	32.6	2.22
2001	3	SNE	32995.7	394.5	0.0679	47.2	3.21
2001	4	SNE	32995.7	394.5	0.0679	91.9	6.24
2002	1	GBK	32995.7	394.5	0.0679	619.8	42.10
2002	2	GBK	32995.7	394.5	0.0679	451.4	30.67
2002	3	GBK	683.0	145.0	0.2123	113.1	24.00
2002	4	GBK	6362.0	208.0	0.0327	527.0	17.23
2002	1	GOM	32995.7	394.5	0.0679	105.1	7.14
2002	2	GOM	32995.7	394.5	0.0679	246.4	16.74
2002	3	GOM	32995.7	394.5	0.0679	36.7	2.49
2002	4	GOM	1.5	0.0	0.0000	63.6	0.00
2002	1	MA	32995.7	394.5	0.0679	204.3	13.88
2002	2	MA	32995.7	394.5	0.0679	78.7	5.34
2002	3	MA	32995.7	394.5	0.0679	70.4	4.78
2002	4	MA	32995.7	394.5	0.0679	163.9	11.13
2002	1	SNE	32995.7	394.5	0.0679	53.2	3.62
2002	2	SNE	32995.7	394.5	0.0679	45.7	3.11
2002	3	SNE	32995.7	394.5	0.0679	69.3	4.71
2002	4	SNE	937.0	427.0	0.4557	135.3	61.64

Table 1 cont.

2003	1	GBK	4138.0	643.0	0.1554	140.9	21.89
2003	2	GBK	32995.7	394.5	0.0679	16.6	1.13
2003	3	GBK	32995.7	394.5	0.0679	195.3	13.26
2003	4	GBK	6300.0	0.0	0.0000	747.4	0.00
2003	1	GOM	9886.9	567.0	0.0573	170.8	9.79
2003	2	GOM	32995.7	394.5	0.0679	17.7	1.20
2003	3	GOM	32995.7	394.5	0.0679	47.8	3.24
2003	4	GOM	32995.7	394.5	0.0679	110.9	7.53
2003	1	MA	32995.7	394.5	0.0679	205.0	13.93
2003	2	MA	32995.7	394.5	0.0679	141.6	9.62
2003	3	MA	32995.7	394.5	0.0679	145.2	9.86
2003	4	MA	32995.7	394.5	0.0679	215.0	14.60
2003	1	SNE	32995.7	394.5	0.0679	137.4	9.34
2003	2	SNE	32995.7	394.5	0.0679	41.2	2.80
2003	3	SNE	32995.7	394.5	0.0679	26.5	1.80
2003	4	SNE	32995.7	394.5	0.0679	85.6	5.81
2004	1	GBK	684.0	9.0	0.0132	105.8	1.39
2004	2	GBK	32995.7	394.5	0.0679	4.5	0.31
2004	3	GBK	18336.1	638.0	0.0348	87.0	3.03
2004	4	GBK	533137.1	4358.3	0.0082	669.8	5.48
2004	1	GOM	6638.8	70.0	0.0105	142.1	1.50
2004	2	GOM	32995.7	394.5	0.0679	4.1	0.28
2004	3	GOM	32995.7	394.5	0.0679	66.1	4.49
2004	4	GOM	32995.7	394.5	0.0679	62.0	4.21
2004	1	MA	32995.7	394.5	0.0679	148.2	10.07
2004	2	MA	32995.7	394.5	0.0679	43.2	2.94
2004	3	MA	32995.7	394.5	0.0679	61.7	4.19
2004	4	MA	1144.0	0.0	0.0000	218.6	0.00
2004	1	SNE	32995.7	394.5	0.0679	316.8	21.52
2004	2	SNE	32995.7	394.5	0.0679	23.6	1.61
2004	3	SNE	32995.7	394.5	0.0679	38.0	2.58
2004	4	SNE	14802.0	0.0	0.0000	161.3	0.00
2005	1	GBK	25875.8	2416.0	0.0934	276.1	25.78
2005	2	GBK	103532.8	29924.0	0.2890	130.7	37.79
2005	3	GBK	52318.8	5492.0	0.1050	216.7	22.75
2005	4	GBK	625960.6	21498.1	0.0343	850.2	29.20
2005	1	GOM	36869.1	1932.0	0.0524	465.7	24.40
2005	2	GOM	4250.0	101.0	0.0238	132.7	3.15
2005	3	GOM	5209.4	62.0	0.0119	128.5	1.53
2005	4	GOM	12918.0	11.5	0.0009	154.8	0.14
2005	1	MA	24285.0	0.0	0.0000	930.0	0.00
2005	2	MA	24285.0	0.0	0.0000	315.1	0.00
2005	3	MA	24285.0	0.0	0.0000	381.1	0.00
2005	4	MA	11009.0	0.0	0.0000	325.1	0.00
2005	1	SNE	37561.0	0.0	0.0000	733.2	0.00
2005	2	SNE	24285.0	0.0	0.0000	62.4	0.00
2005	3	SNE	24285.0	0.0	0.0000	124.5	0.00
2005	4	SNE	13904.0	0.0	0.0000	251.3	0.00
2006	1	GBK	5382.3	2678.0	0.4976	329.8	164.08

Table 1 cont.

2006	2	GBK	15863.0	3717.0	0.2343	77.5	18.16
2006	3	GBK	725.0	0.0	0.0000	20.6	0.00
2006	4	GBK	122382.7	6628.4	0.0542	282.3	15.29
2006	1	GOM	29380.8	1181.6	0.0402	251.9	10.13
2006	2	GOM	11947.3	469.9	0.0264	11.4	0.30
2006	3	GOM	591.0	0.0	0.0000	9.3	0.00
2006	4	GOM	5870.0	228.0	0.0388	49.7	1.93
2006	1	MA	26623.8	1.5	0.0001	190.4	0.01
2006	2	MA	25933.5	3.0	0.0001	120.0	0.01
2006	3	MA	25392.0	48.0	0.0015	161.2	0.24
2006	4	MA	27314.0	0.0	0.0000	354.7	0.00
2006	1	SNE	36898.8	281.0	0.0076	206.0	1.57
2006	2	SNE	23469.9	96.0	0.0030	63.5	0.19
2006	3	SNE	28359.0	0.0	0.0000	74.9	0.00
2006	4	SNE	5152.0	7.0	0.0014	171.9	0.23
2007	1	GBK	19980.8	7508.0	0.3758	40.3	15.15
2007	2	GBK	13550.6	618.0	0.0456	85.2	3.89
2007	3	GBK	704.0	57.0	0.0810	94.2	7.62
2007	4	GBK	162247.8	8277.1	0.0510	302.4	15.43
2007	1	GOM	15599.3	1455.8	0.0933	292.0	27.25
2007	2	GOM	1315.8	45.0	0.0342	3.7	0.13
2007	3	GOM	679.2	61.8	0.0910	37.8	3.44
2007	4	GOM	15414.0	78.1	0.0051	88.5	0.45
2007	1	MA	13696.6	0.0	0.0000	148.8	0.00
2007	2	MA	13696.6	0.0	0.0000	111.8	0.00
2007	3	MA	21468.9	0.0	0.0000	192.4	0.00
2007	4	MA	2793.0	0.0	0.0000	480.6	0.00
2007	1	SNE	13696.6	0.0	0.0000	188.6	0.00
2007	2	SNE	13696.6	0.0	0.0000	77.3	0.00
2007	3	SNE	13696.6	0.0	0.0000	38.3	0.00
2007	4	SNE	16828.0	0.0	0.0000	85.9	0.00

Table 2. Discard estimates by stratum for the otter trawl fishery.

average within areaf

YEAR	QTR	areaf	ksums	dsums	dkratio	cf_totalmt	disc
1989	1	GBK	117519.0	94262.0	0.8021	15772.5	12651.1
1989	2	GBK	210790.2	57319.0	0.2719	10299.5	2800.7
1989	3	GBK	454241.8	129818.0	0.2858	8532.2	2438.4
1989	4	GBK	252775.0	97525.0	0.3858	11330.0	4371.3
1989	1	GOM	48544.0	16810.0	0.3463	6779.9	2347.8
1989	2	GOM	27026.8	4486.0	0.1660	4201.0	697.3
1989	3	GOM	50683.0	6507.0	0.1284	3824.7	491.0
1989	4	GOM	42992.8	8354.0	0.1943	7340.8	1426.4
1989	1	MA	203087.8	43259.0	0.2130	19939.2	4247.2
1989	2	MA	52984.0	1248.0	0.0236	4127.6	97.2
1989	3	MA	11208.1	5721.0	0.5104	6179.5	3154.2
1989	4	MA	109527.0	15869.0	0.1449	12396.1	1796.0
1989	1	SNE	80602.4	136040.0	1.6878	7660.9	12930.0
1989	2	SNE	64276.6	19099.0	0.2971	6365.3	1891.4
1989	3	SNE	20408.4	23176.0	1.1356	2033.9	2309.8
1989	4	SNE	157064.6	89395.0	0.5692	7514.9	4277.2
1990	1	GBK	169125.7	175388.0	1.0370	16371.4	16977.6
1990	2	GBK	200458.5	67116.0	0.3348	12978.9	4345.5
1990	3	GBK	140104.7	17486.0	0.1248	11239.0	1402.7
1990	4	GBK	198538.0	55702.0	0.2806	16617.9	4662.3
1990	1	GOM	1822.0	448.0	0.2459	5568.7	1369.3
1990	2	GOM	23842.0	3089.0	0.1296	6045.3	783.2
1990	3	GOM	27414.7	765.0	0.0279	7291.1	203.5
1990	4	GOM	75133.5	21051.0	0.2802	12997.3	3641.6
1990	1	MA	262107.9	37787.0	0.1442	16534.5	2383.7
1990	2	MA	18160.1	1863.0	0.1026	4986.0	511.5
1990	3	MA	11400.1	4375.0	0.3838	7225.0	2772.7
1990	4	MA	107716.6	45878.0	0.4259	15494.3	6599.2
1990	1	SNE	95622.5	246951.0	2.5826	9198.6	23755.8
1990	2	SNE	234679.7	18902.0	0.0805	4201.0	338.4
1990	3	SNE	24171.4	3174.0	0.1313	2545.7	334.3
1990	4	SNE	77514.8	141495.0	1.8254	8822.3	16104.1
1991	1	GBK	286394.1	98774.0	0.3449	16731.6	5770.5
1991	2	GBK	81042.4	32320.0	0.3988	12068.2	4812.8
1991	3	GBK	265911.0	19991.0	0.0752	9653.7	725.8
1991	4	GBK	321971.0	166273.0	0.5164	12115.9	6256.9
1991	1	GOM	29317.0	3598.0	0.1227	6247.8	766.8
1991	2	GOM	44616.2	1855.0	0.0416	6581.6	273.6
1991	3	GOM	31819.0	2640.0	0.0830	7495.0	621.9
1991	4	GOM	300163.0	25951.0	0.0865	12435.0	1075.1
1991	1	MA	638472.8	6016.0	0.0094	26490.5	249.6
1991	2	MA	19918.0	8849.0	0.4443	5490.1	2439.1
1991	3	MA	7639.0	12186.0	1.5952	8983.1	14330.0
1991	4	MA	1221565.0	255263.0	0.2090	15782.6	3298.0
1991	1	SNE	144929.0	102308.0	0.7059	9132.3	6446.7
1991	2	SNE	104618.7	47207.0	0.4512	4703.6	2122.4

Table 2 cont.

1991	3	SNE	76042.7	27575.0	0.3626	3685.5	1336.4
1991	4	SNE	269344.8	69244.0	0.2571	8602.9	2211.7
1992	1	GBK	211715.5	100398.0	0.4742	12897.5	6116.1
1992	2	GBK	127642.0	12823.0	0.1005	11609.2	1166.3
1992	3	GBK	109207.0	3158.0	0.0289	9223.0	266.7
1992	4	GBK	224868.0	38302.0	0.1703	11227.9	1912.5
1992	1	GOM	219231.0	22429.0	0.1023	6679.5	683.4
1992	2	GOM	51966.3	728.0	0.0140	6444.1	90.3
1992	3	GOM	42787.0	1023.0	0.0239	7549.5	180.5
1992	4	GOM	107219.0	5166.0	0.0482	10138.2	488.5
1992	1	MA	432338.9	47195.0	0.1092	27963.5	3052.6
1992	2	MA	3688.0	75.0	0.0203	7562.2	153.8
1992	3	MA	4008.1	850.0	0.2121	10730.1	2275.5
1992	4	MA	264680.4	161108.0	0.6087	16932.3	10306.5
1992	1	SNE	260659.6	6965.0	0.0267	9872.3	263.8
1992	2	SNE	25181.0	9938.0	0.3947	4122.2	1626.9
1992	3	SNE	157759.0	36466.0	0.2312	2338.8	540.6
1992	4	SNE	114864.2	67854.0	0.5907	6158.5	3638.0
1993	1	GBK	134660.8	15600.0	0.1158	9861.9	1142.5
1993	2	GBK	127030.0	32601.0	0.2566	9047.7	2322.0
1993	3	GBK	160014.0	3233.0	0.0202	9184.4	185.6
1993	4	GBK	79910.0	59777.0	0.7481	13966.0	10447.3
1993	1	GOM	36155.0	5288.0	0.1463	5540.6	810.4
1993	2	GOM	53969.0	2862.0	0.0530	4782.4	253.6
1993	3	GOM	18086.0	446.0	0.0247	5934.0	146.3
1993	4	GOM	69066.0	5482.0	0.0794	8854.3	702.8
1993	1	MA	292580.3	7047.0	0.0241	24397.6	587.6
1993	2	MA	871.0	39.0	0.0448	5242.9	234.8
1993	3	MA	4335.0	205.0	0.0473	12974.8	613.6
1993	4	MA	65343.2	29027.0	0.4442	13454.6	5976.8
1993	1	SNE	128829.0	7757.0	0.0602	6354.0	382.6
1993	2	SNE	22059.2	14224.0	0.6448	3506.2	2260.8
1993	3	SNE	43748.0	37881.0	0.8659	1693.1	1466.0
1993	4	SNE	280056.4	72207.0	0.2578	8737.8	2252.9
1994	1	GBK	436769.0	88920.0	0.2036	8945.5	1821.2
1994	2	GBK	72759.5	33874.0	0.4656	5641.3	2626.4
1994	3	GBK	46292.5	11055.0	0.2388	6584.7	1572.5
1994	4	GBK	35845.9	31958.0	0.8915	8935.1	7966.0
1994	1	GOM	24887.0	738.0	0.0297	5544.9	164.4
1994	2	GOM	3141.0	220.0	0.0700	4287.4	300.3
1994	3	GOM	14080.0	1000.0	0.0710	5197.5	369.1
1994	4	GOM	21317.4	554.0	0.0260	8638.0	224.5
1994	1	MA	381053.6	37798.0	0.0992	20620.1	2045.4
1994	2	MA	6763.5	36765.0	5.4358	9182.5	49914.0
1994	3	MA	23752.0	1130.0	0.0476	11546.8	549.3
1994	4	MA	138197.2	18468.6	0.1336	15207.5	2032.3
1994	1	SNE	294069.2	1267.0	0.0043	8344.8	36.0
1994	2	SNE	1871.0	4222.0	2.2565	3447.9	7780.2
1994	3	SNE	2871.0	204.0	0.0711	3812.2	270.9

Table 2 cont.

1994	4	SNE	47233.3	15154.0	0.3208	9931.6	3186.4
1995	1	GBK	398782.6	165691.7	0.4155	7122.9	2959.5
1995	2	GBK	100454.1	76175.0	0.7583	5439.9	4125.1
1995	3	GBK	42319.5	5071.0	0.1198	4323.4	518.1
1995	4	GBK	106802.9	25099.0	0.2350	6558.7	1541.3
1995	1	GOM	177529.2	8604.4	0.0485	5299.9	256.9
1995	2	GOM	37469.2	1324.0	0.0353	4249.4	150.2
1995	3	GOM	73591.3	818.2	0.0111	4344.0	48.3
1995	4	GOM	127430.2	3981.0	0.0312	6542.1	204.4
1995	1	MA	265025.8	167568.1	0.6323	17081.4	10800.0
1995	2	MA	38774.2	11692.0	0.3015	6733.4	2030.4
1995	3	MA	155938.2	16521.1	0.1059	9038.7	957.6
1995	4	MA	175000.0	96826.8	0.5533	12480.0	6905.1
1995	1	SNE	38708.1	3904.0	0.1009	8666.6	874.1
1995	2	SNE	4411.8	2159.0	0.4894	3399.2	1663.5
1995	3	SNE	9451.3	1015.0	0.1074	4432.9	476.1
1995	4	SNE	88329.5	12063.0	0.1366	7074.4	966.1
1996	1	GBK	184663.6	113637.0	0.6154	7858.4	4835.9
1996	2	GBK	117595.1	37819.0	0.3216	7171.7	2306.4
1996	3	GBK	0.0	0.0		6840.9	0.0
1996	4	GBK	209964.4	16941.0	0.0807	11369.5	917.3
1996	1	GOM	61714.6	2034.0	0.0330	4742.3	156.3
1996	2	GOM	69868.1	3330.0	0.0477	4379.7	208.7
1996	3	GOM	63234.1	6.2	0.0001	4269.6	0.4
1996	4	GOM	141362.8	4941.7	0.0350	7532.8	263.3
1996	1	MA	479520.5	107702.1	0.2246	24713.8	5550.8
1996	2	MA	264761.7	9485.0	0.0358	6571.0	235.4
1996	3	MA	965224.6	3855.3	0.0040	7059.7	28.2
1996	4	MA	944748.5	69812.6	0.0739	11609.4	857.9
1996	1	SNE	10668.2	1410.0	0.1322	7603.4	1004.9
1996	2	SNE	48753.8	14780.0	0.3032	4140.8	1255.3
1996	3	SNE	5599.4	11266.0	2.0120	3906.9	7860.7
1996	4	SNE	77863.0	112269.0	1.4419	10028.6	14460.1
1997	1	GBK	227488.1	54825.9	0.2410	7139.8	1720.7
1997	2	GBK	170456.4	34555.0	0.2186	6615.0	1446.1
1997	3	GBK	222203.6	32189.0	0.1449	4697.8	680.5
1997	4	GBK	61677.5	16650.0	0.2700	8173.5	2206.4
1997	1	GOM	95497.2	12207.0	0.1278	4563.5	583.3
1997	2	GOM	542.0	6.0	0.0111	3408.8	37.7
1997	3	GOM	16785.2	71.0	0.0042	2774.3	11.7
1997	4	GOM	37608.1	4094.7	0.0477	6084.7	290.3
1997	1	MA	565473.0	44438.5	0.0786	19625.7	1542.3
1997	2	MA	1007214.8	17920.1	0.0326	3915.8	127.6
1997	3	MA	2280771.0	6448.3	0.0028	11231.8	31.8
1997	4	MA	175400.4	2873.5	0.0164	16504.1	270.4
1997	1	SNE	107043.1	13335.0	0.1246	8470.6	1055.2
1997	2	SNE	19773.8	1151.0	0.0582	4338.8	252.6
1997	3	SNE	148705.0	78903.0	0.5306	4355.4	2311.0
1997	4	SNE	74102.4	3041.0	0.0410	8380.8	343.9

Table 2 cont.

1998	1	GBK	114649.0	19374.5	0.1690	9249.6	1563.1
1998	2	GBK	54096.1	17653.8	0.4888	6539.3	3196.5
1998	3	GBK	21141.4	3131.0	0.1481	6382.8	945.3
1998	4	GBK	26497.8	30456.0	1.1494	10561.3	12138.9
1998	1	GOM	20993.4	1933.0	0.0921	4942.6	455.1
1998	2	GOM	3021.6	71.0	0.0235	2594.6	61.0
1998	3	GOM	19.0	11.0	0.5789	2411.0	1395.9
1998	4	GOM	8011.3	671.7	0.2315	5630.4	1303.5
1998	1	MA	395451.2	20314.5	0.0514	23801.8	1222.7
1998	2	MA	733.3	1455.0	1.9842	9736.8	19319.3
1998	3	MA	348354.9	39500.0	0.1134	14521.9	1646.6
1998	4	MA	111097.6	12894.0	0.1161	10795.8	1253.0
1998	1	SNE	74163.6	5339.0	0.0720	10848.1	780.9
1998	2	SNE	507.4	93.0	0.1833	4171.6	764.6
1998	3	SNE	28215.2	1813.0	0.0643	4222.3	271.3
1998	4	SNE	11191.0	2065.0	0.1845	9238.2	1704.7
1999	1	GBK	89278.8	383.0	0.0043	11941.5	51.2
1999	2	GBK	70345.7	26052.0	0.3703	7255.9	2687.2
1999	3	GBK	41587.0	16863.0	0.4055	7114.1	2884.7
1999	4	GBK	126953.2	53410.0	0.4207	9847.4	4142.8
1999	1	GOM	27103.3	275.2	0.0229	3908.0	89.5
1999	2	GOM	454.9	9.0	0.0198	2124.4	42.0
1999	3	GOM	7163.2	300.5	0.0420	1932.4	81.1
1999	4	GOM	73691.8	516.1	0.0070	5311.1	37.2
1999	1	MA	1013097.0	10230.0	0.0101	17301.2	174.7
1999	2	MA	35400.0	4903.0	0.1385	4809.8	666.2
1999	3	MA	178663.2	1582.0	0.0089	7405.0	65.6
1999	4	MA	249211.4	27940.0	0.1121	13499.0	1513.4
1999	1	SNE	152117.7	918.0	0.0060	8584.7	51.8
1999	2	SNE	37805.6	297.0	0.0079	3448.9	27.1
1999	3	SNE	73651.9	1449.0	0.0383	3281.6	125.6
1999	4	SNE	31032.6	3132.0	0.1009	6597.4	665.8
2000	1	GBK	501596.7	61654.5	0.1229	13462.5	1654.8
2000	2	GBK	83110.4	24463.0	0.2943	6144.5	1808.6
2000	3	GBK	151326.8	29832.0	0.1971	5143.5	1014.0
2000	4	GBK	389648.5	211490.0	0.5428	11464.9	6222.8
2000	1	GOM	61838.6	9326.0	0.1508	4204.0	634.0
2000	2	GOM	75118.8	8142.0	0.1084	3622.9	392.7
2000	3	GOM	121344.3	1973.0	0.0163	3294.2	53.6
2000	4	GOM	88946.2	4701.0	0.0529	5555.4	293.6
2000	1	MA	1383068.8	54066.0	0.0391	15666.5	612.4
2000	2	MA	224847.0	27600.0	0.1228	4468.3	548.5
2000	3	MA	867161.0	9318.0	0.0107	8165.7	87.7
2000	4	MA	129964.5	57963.0	0.4460	11506.8	5131.9
2000	1	SNE	26945.5	2520.0	0.0935	6498.4	607.7
2000	2	SNE	27953.0	4273.0	0.1529	3743.4	572.2
2000	3	SNE	289.9	54.0	0.1863	4355.6	811.5
2000	4	SNE	50400.0	23473.0	0.4657	6211.3	2892.8
2001	1	GBK	502325.9	567152.5	1.1291	15645.4	17664.5

Table 2 cont.

2001	2	GBK	163268.7	23552.0	0.1443	7396.8	1067.0
2001	3	GBK	179922.9	29426.0	0.1635	6675.5	1091.8
2001	4	GBK	429590.9	132451.0	0.3083	15368.5	4738.4
2001	1	GOM	39995.0	2465.0	0.0616	4963.4	305.9
2001	2	GOM	87230.2	4889.0	0.0560	3651.8	204.7
2001	3	GOM	50757.2	3269.0	0.0644	2783.3	179.3
2001	4	GOM	271527.6	9978.0	0.0367	6863.4	252.2
2001	1	MA	3117272.2	13786.0	0.0044	12403.5	54.9
2001	2	MA	53707.4	3795.0	0.0707	3036.1	214.5
2001	3	MA	586146.4	7925.5	0.0135	4713.0	63.7
2001	4	MA	236560.3	14662.5	0.0620	9509.3	589.4
2001	1	SNE	118525.2	4803.0	0.0405	9405.5	381.1
2001	2	SNE	4475.0	1444.0	0.3227	3407.2	1099.5
2001	3	SNE	3995.0	456.0	0.1141	3987.4	455.1
2001	4	SNE	33110.6	7189.0	0.2171	4054.6	880.3
2002	1	GBK	285255.2	130977.0	0.4592	16750.6	7691.2
2002	2	GBK	321494.8	135567.5	0.4217	7098.2	2993.1
2002	3	GBK	853066.8	263641.2	0.3091	5735.8	1772.6
2002	4	GBK	1850673.9	534334.8	0.2887	11038.8	3187.2
2002	1	GOM	211295.9	6556.0	0.0310	6421.0	199.2
2002	2	GOM	16769.4	1546.0	0.0922	2186.5	201.6
2002	3	GOM	230292.9	16668.9	0.0724	3351.7	242.6
2002	4	GOM	292352.7	27891.6	0.0954	5858.3	558.9
2002	1	MA	636320.1	41276.0	0.0649	10552.9	684.5
2002	2	MA	14028.4	1118.5	0.0797	2976.1	237.3
2002	3	MA	217428.1	12693.0	0.0584	5233.4	305.5
2002	4	MA	88761.5	19159.0	0.2158	9490.7	2048.5
2002	1	SNE	36892.0	3.0	0.0001	6232.9	0.5
2002	2	SNE	30767.5	1388.0	0.0451	2814.1	126.9
2002	3	SNE	2765.5	224.0	0.0810	2226.0	180.3
2002	4	SNE	36505.7	12143.0	0.3326	3566.9	1186.5
2003	1	GBK	2025154.8	1165520.9	0.5755	14506.5	8348.8
2003	2	GBK	913155.6	287681.7	0.3150	8159.6	2570.6
2003	3	GBK	764077.2	360934.0	0.4724	6512.7	3076.5
2003	4	GBK	1488066.9	671086.7	0.4510	13722.5	6188.6
2003	1	GOM	816958.4	62916.9	0.0770	7344.1	565.6
2003	2	GOM	296503.7	23768.3	0.0802	2477.7	198.6
2003	3	GOM	206323.8	17607.8	0.0853	2939.0	250.8
2003	4	GOM	491413.8	27891.4	0.0568	5860.4	332.6
2003	1	MA	264353.0	49131.7	0.1859	12727.0	2365.4
2003	2	MA	44843.7	7188.0	0.1603	2450.4	392.8
2003	3	MA	2116191.0	10965.9	0.0052	3789.2	19.6
2003	4	MA	805656.0	84646.5	0.1051	8999.7	945.6
2003	1	SNE	66694.2	47740.5	0.7158	4730.9	3386.5
2003	2	SNE	24570.5	864.0	0.0352	1580.9	55.6
2003	3	SNE	2574.3	5833.5	2.2660	1960.4	4442.3
2003	4	SNE	71582.1	24892.0	0.3477	6158.4	2141.5
2004	1	GBK	1906366.7	850612.0	0.4462	13896.7	6200.6
2004	2	GBK	1196759.3	679946.0	0.5682	7900.6	4488.8

Table 2 cont.

2004	3	GBK	1310535.8	812051.2	0.6196	9243.2	5727.4
2004	4	GBK	2329145.1	1308189.5	0.5617	11898.2	6682.7
2004	1	GOM	663041.1	32656.5	0.0493	5842.7	287.8
2004	2	GOM	111970.8	13358.7	0.1193	4420.4	527.4
2004	3	GOM	140897.7	5950.6	0.0422	8207.7	346.6
2004	4	GOM	789168.0	93840.7	0.1189	9043.0	1075.3
2004	1	MA	1315546.7	84251.6	0.0640	13442.2	860.9
2004	2	MA	309818.9	24332.0	0.0785	10123.4	795.1
2004	3	MA	1688970.5	38723.0	0.0229	16252.8	372.6
2004	4	MA	2167080.6	96405.2	0.0445	14202.6	631.8
2004	1	SNE	163708.3	18157.0	0.1109	6955.0	771.4
2004	2	SNE	103306.4	17879.5	0.1731	2524.4	436.9
2004	3	SNE	39012.3	28424.5	0.7286	2811.4	2048.4
2004	4	SNE	111008.8	96013.5	0.8649	5290.5	4575.9
2005	1	GBK	7807344.5	4202547.8	0.5383	9767.2	5257.5
2005	2	GBK	4814352.4	2749110.2	0.5710	6521.3	3723.8
2005	3	GBK	2242281.5	1610769.3	0.7184	5950.3	4274.5
2005	4	GBK	5070013.8	3456805.2	0.6818	10262.1	6996.8
2005	1	GOM	1460432.0	86059.9	0.0589	5309.4	312.9
2005	2	GOM	366527.9	22120.3	0.0604	2874.2	173.5
2005	3	GOM	363672.6	24488.2	0.0673	4164.6	280.4
2005	4	GOM	905399.7	157153.5	0.1736	7443.5	1292.0
2005	1	MA	1406306.4	63760.8	0.0453	16560.4	750.8
2005	2	MA	150171.1	49163.0	0.3274	4843.3	1585.6
2005	3	MA	293991.1	45674.3	0.1554	7761.4	1205.8
2005	4	MA	1050916.6	115930.0	0.1103	10842.3	1196.0
2005	1	SNE	575564.0	96978.0	0.1685	5434.7	915.7
2005	2	SNE	59569.3	56647.1	0.9509	1451.7	1380.5
2005	3	SNE	167366.8	105007.1	0.6274	1783.4	1118.9
2005	4	SNE	279194.2	181264.2	0.6492	3996.5	2594.7
2006	1	GBK	3424697.6	2457176.4	0.7175	7699.6	5524.4
2006	2	GBK	1622453.8	731960.0	0.4511	4057.1	1830.3
2006	3	GBK	1933865.4	1412239.9	0.7303	4459.1	3256.3
2006	4	GBK	1578415.8	1128798.5	0.7151	7837.4	5604.9
2006	1	GOM	711124.0	75375.0	0.1060	4452.7	472.0
2006	2	GOM	19006.0	3383.0	0.1780	1211.8	215.7
2006	3	GOM	92619.0	7354.8	0.0794	2978.2	236.5
2006	4	GOM	198574.3	15191.4	0.0765	3213.8	245.9
2006	1	MA	1871943.9	62970.2	0.0336	32892.0	1106.5
2006	2	MA	1647404.2	59383.5	0.0360	4259.7	153.5
2006	3	MA	1991620.9	40898.7	0.0205	9085.0	186.6
2006	4	MA	1096588.4	87026.7	0.0794	13777.2	1093.4
2006	1	SNE	860190.4	149848.5	0.1742	6488.1	1130.2
2006	2	SNE	87581.6	6228.5	0.0711	1913.9	136.1
2006	3	SNE	85786.2	23498.0	0.2739	2553.5	699.4
2006	4	SNE	227163.2	52487.5	0.2311	3750.6	866.6
2007	1	GBK	2716869.7	1847037.5	0.6798	10413.1	7079.3
2007	2	GBK	2002073.1	1113493.0	0.5562	5199.6	2891.8
2007	3	GBK	1385278.3	1471099.1	1.0620	4478.8	4756.3

Table 2 cont.

2007	4	GBK	3181301.6	2050467.9	0.6445	9427.9	6076.6
2007	1	GOM	732365.3	112054.9	0.1530	4161.4	636.7
2007	2	GOM	290266.9	17910.3	0.0617	1546.3	95.4
2007	3	GOM	358148.5	10986.0	0.0307	2091.2	64.1
2007	4	GOM	611896.9	49552.7	0.0810	3220.8	260.8
2007	1	MA	962031.0	104525.7	0.1087	11354.0	1233.6
2007	2	MA	93576.9	51220.5	0.5474	1957.8	1071.6
2007	3	MA	1939160.2	97902.8	0.0505	4913.8	248.1
2007	4	MA	1735005.5	369938.7	0.2132	10653.6	2271.6
2007	1	SNE	564348.9	100567.6	0.1782	5368.0	956.6
2007	2	SNE	102264.1	42452.0	0.4151	1569.1	651.3
2007	3	SNE	260652.2	124886.5	0.4791	2211.9	1059.8
2007	4	SNE	251575.7	96107.7	0.3820	4593.7	1754.9

Table 3. Discard estimates by stratum for the shrimp trawl fishery.

(yellow) average within areaf across mesh — (green) average across comb region (ie sne-ma) — (red) Average 1995-2007

YEAR	QTR	areaf	kept	discards	dkratio	mt kept	Total discards
1989	1	GBK	761.0	0.0	0.0000		0.0000
1989	1	GOM	37722.0	763.0	0.0202	3213.4194	64.9976
1989	2	GOM	8980.0	380.0	0.0423	198.7805	8.4117
1989	4	GOM	12558.0	227.0	0.0181	931.1231	16.8311
1990	1	GBK	17384.3	917.7	0.0582	16.6527	0.9694
1990	2	GBK	17384.3	917.7	0.0582	37.1733	2.1640
1990	1	GOM	37744.0	1877.0	0.0497	4014.9878	199.6644
1990	2	GOM	7437.0	82.0	0.0110	478.8901	5.2802
1990	4	GOM	6972.0	794.0	0.1139	619.7042	70.5745
1991	1	GBK	691.0	200.0	0.2894	51.3303	14.8568
1991	1	GOM	54049.0	3704.0	0.0685	3144.6289	215.5025
1991	2	GOM	8673.0	330.0	0.0380	339.8328	12.9303
1991	4	GOM	6233.0	807.0	0.1295	340.0274	44.0241
1992	1	GBK	27845.0	2040.7	0.0263	49.5051	1.3012
1992	1	GOM	78834.0	6117.0	0.0776	3137.5987	243.4570
1992	2	GOM	725.0	0.0	0.0000	98.3130	0.0000
1992	4	GOM	3976.0	5.0	0.0013	161.2525	0.2028
1993	1	GBK	2300.0	0.0	0.0000		0.0000
1993	1	GOM	62135.0	1145.0	0.0184	1885.0247	34.7365
1993	2	GOM	33122.5	579.5	0.0109	5.0068	0.0547
1993	4	GOM	4110.0	14.0	0.0034	316.2319	1.0772
1994	1	GBK	41229.5	168.5	0.0027	23.0974	0.0618
1994	4	GBK	41229.5	168.5	0.0027	0.0454	0.0001
1994	1	GOM	72823.0	329.0	0.0045	2419.8023	10.9322
1994	3	GOM	41229.5	168.5	0.0027	9.1372	0.0244
1994	4	GOM	9636.0	8.0	0.0008	897.0524	0.7448
1995	1	GBK	48706.0	67.9	0.0010	22.2133	0.0233
1995	4	GBK	48706.0	67.9	0.0010	5.4626	0.0057
1995	1	GOM	74054.0	126.8	0.0017	4426.6070	7.5795
1995	2	GOM	48706.0	67.9	0.0010	5.4390	0.0057
1995	3	GOM	48706.0	67.9	0.0010	12.4094	0.0130
1995	4	GOM	23358.0	9.0	0.0004	1359.4640	0.5238
1996	1	GBK	15813.3	53.7	0.0032	42.2716	0.1340
1996	1	GOM	32304.0	128.7	0.0040	6560.2339	26.1361
1996	2	GOM	9342.0	0.7	0.0001	979.4293	0.0734
1996	4	GOM	5794.0	31.6	0.0055	1416.1748	7.7237
1997	1	GBK	1590.0	1.0	0.0006	24.8224	0.0156
1997	4	GBK	10800.0	63.5	0.0035	3.0699	0.0106
1997	1	GOM	20010.0	125.9	0.0063	4761.5655	29.9591
1997	2	GOM	10800.0	63.5	0.0035	629.2601	2.1775
1997	3	GOM	10800.0	63.5	0.0035	15.0107	0.0519
1997	4	GOM	10800.0	63.5	0.0035	630.9021	2.1832
1998	1	GOM	26486.6	53.8	0.0026	2875.1596	7.4407
1998	2	GOM	26486.6	53.8	0.0026	219.7514	0.5687
1998	3	GOM	26486.6	53.8	0.0026	9.0877	0.0235

Table 3 cont.

1998	4	GOM	26486.6	53.8	0.0026	159.0295	0.4116
1999	1	GBK	26486.6	53.8	0.0026	12.9020	0.0334
1999	1	GOM	26486.6	53.8	0.0026	1177.4074	3.0470
1999	2	GOM	26486.6	53.8	0.0026	229.1803	0.5931
1999	3	GOM	26486.6	53.8	0.0026	32.2999	0.0836
1999	4	GOM	26486.6	53.8	0.0026	0.9453	0.0024
2000	1	GOM	26486.6	53.8	0.0026	2067.9439	5.3517
2000	3	GOM	26486.6	53.8	0.0026	22.0582	0.0571
2000	4	GOM	26486.6	53.8	0.0026	12.6198	0.0327
2001	1	GBK	26486.6	53.8	0.0026	0.2155	0.0006
2001	1	GOM	4950.0	0.0	0.0000	812.8656	0.0000
2001	2	GOM	26486.6	53.8	0.0026	0.0408	0.0001
2002	1	GOM	26486.6	53.8	0.0026	307.5170	0.7958
2003	1	GOM	14519.3	135.6	0.0093	855.2058	7.9870
2003	2	GOM	26486.6	53.8	0.0026	0.2572	0.0007
2004	1	GBK	21444.0	84.7	0.0039	0.2132	0.0008
2004	1	GOM	21444.0	84.7	0.0039	1065.2263	4.2075
2004	2	GOM	21444.0	84.7	0.0039	3.5045	0.0138
2004	3	GOM	21444.0	84.7	0.0039	1.8715	0.0074
2004	4	GOM	21444.0	84.7	0.0039	42.6259	0.1684
2005	1	GOM	27219.2	78.8	0.0029	835.6192	2.4191
2005	4	GOM	27219.2	78.8	0.0029	39.6508	0.1148
2006	4	GBK	43012.6	12.1	0.0007	1.6806	0.0012
2006	1	GOM	77625.1	14.1	0.0002	846.9831	0.1538
2006	3	GOM	43012.6	12.1	0.0007	1.4678	0.0010
2006	4	GOM	8400.0	10.1	0.0012	445.9153	0.5362
2007	2	GBK	50203.0	6.6	0.0001	26.7878	0.0035
2007	3	GBK	50203.0	6.6	0.0001	17.6080	0.0023
2007	4	GBK	50203.0	6.6	0.0001	1.8538	0.0002
2007	1	GOM	50203.0	6.6	0.0001	1828.3506	0.2404
2007	2	GOM	50203.0	6.6	0.0001	40.7557	0.0054
2007	3	GOM	50203.0	6.6	0.0001	57.4321	0.0076
2007	4	GOM	50203.0	6.6	0.0001	281.7607	0.0370

Table 4. Discard estimates by stratum for the sink gill net fishery.

(yellow) average within areaf (green) average across comb region (ie sne-ma)

YEAR	QTR	areaf	ksums	dsums	dkratio	cf_totalmt	disc
1989	1	GBK	22453.7	245.0	0.0084	586.7	5.0
1989	2	GBK	3410.0	11.0	0.0032	1039.2	3.4
1989	3	GBK	30690.0	140.0	0.0046	2108.0	9.6
1989	4	GBK	33261.1	584.0	0.0176	1194.9	21.0
1989	1	GOM	98651.0	716.5	0.0055	2085.5	11.5
1989	2	GOM	98651.0	716.5	0.0055	3209.8	17.7
1989	3	GOM	13516.0	47.0	0.0035	4023.2	14.0
1989	4	GOM	183786.0	1386.0	0.0075	6232.1	47.0
1989	1	MA	106.3	0.0	0.0000	1079.2	0.0
1989	2	MA	106.3	0.0	0.0000	769.4	0.0
1989	3	MA	106.3	0.0	0.0000	820.8	0.0
1989	4	MA	106.3	0.0	0.0000	1222.8	0.0
1989	1	SNE	106.3	0.0	0.0000	324.1	0.0
1989	2	SNE	106.3	0.0	0.0000	38.1	0.0
1989	3	SNE	106.3	0.0	0.0000	83.9	0.0
1989	4	SNE	106.3	0.0	0.0000	264.0	0.0
1990	1	GBK	4037.0	58.0	0.0144	306.3	4.4
1990	2	GBK	8856.0	119.0	0.0134	1017.9	13.7
1990	3	GBK	104237.1	29.0	0.0003	1598.3	0.4
1990	4	GBK	59828.1	122.0	0.0020	869.0	1.8
1990	1	GOM	31339.0	3354.0	0.1070	1775.3	190.0
1990	2	GOM	23717.0	1114.0	0.0470	2967.6	139.4
1990	3	GOM	94015.6	323.0	0.0034	6385.8	21.9
1990	4	GOM	72931.2	655.0	0.0090	5447.0	48.9
1990	1	MA	2261.4	0.0	0.0000	1180.8	0.0
1990	2	MA	255.7	0.0	0.0000	541.7	0.0
1990	3	MA	2261.4	0.0	0.0000	670.5	0.0
1990	4	MA	4267.1	0.0	0.0000	1384.0	0.0
1990	1	SNE	1138.4	0.0	0.0000	363.8	0.0
1990	2	SNE	1138.4	0.0	0.0000	1060.2	0.0
1990	3	SNE	1138.4	0.0	0.0000	238.4	0.0
1990	4	SNE	1138.4	0.0	0.0000	1155.4	0.0
1991	1	GBK	6139.0	32.0	0.0052	166.8	0.9
1991	2	GBK	100725.3	730.0	0.0072	833.0	6.0
1991	3	GBK	221500.1	4243.0	0.0192	1248.6	23.9
1991	4	GBK	78760.0	3517.0	0.0447	539.7	24.1
1991	1	GOM	21516.0	882.0	0.0410	1258.5	51.6
1991	2	GOM	338493.2	4779.0	0.0141	2867.9	40.5
1991	3	GOM	1032744.5	8763.0	0.0085	4929.0	41.8
1991	4	GOM	576265.9	3962.0	0.0069	3354.7	23.1
1991	1	MA	1947.7	0.0	0.0000	1441.7	0.0
1991	2	MA	3226.6	0.0	0.0000	1042.6	0.0
1991	3	MA	2587.1	0.0	0.0000	894.0	0.0
1991	4	MA	2587.1	0.0	0.0000	2591.0	0.0
1991	1	SNE	657.0	0.0	0.0000	1954.6	0.0
1991	2	SNE	657.0	0.0	0.0000	1629.6	0.0
1991	3	SNE	1057.0	0.0	0.0000	110.3	0.0

Table 4 cont.

1991	4	SNE	257.0	0.0	0.0000	2105.3	0.0
1992	1	GBK	8797.0	466.0	0.0530	119.9	6.4
1992	2	GBK	64292.0	805.0	0.0125	582.4	7.3
1992	3	GBK	257302.9	558.0	0.0022	1262.9	2.7
1992	4	GBK	26579.0	1041.0	0.0392	480.8	18.8
1992	1	GOM	83433.0	8691.0	0.1042	1018.6	106.1
1992	2	GOM	327513.2	5495.0	0.0168	2507.2	42.1
1992	3	GOM	619171.0	2005.0	0.0032	5062.0	16.4
1992	4	GOM	422764.0	1933.0	0.0046	3928.4	18.0
1992	1	MA	159421.1	0.0	0.0000	1552.6	0.0
1992	2	MA	159421.1	0.0	0.0000	1284.1	0.0
1992	3	MA	159421.1	0.0	0.0000	855.9	0.0
1992	4	MA	159421.1	0.0	0.0000	2243.4	0.0
1992	1	SNE	24339.0	381.0	0.0157	994.4	15.6
1992	2	SNE	158927.0	8499.0	0.0535	1717.9	91.9
1992	3	SNE	12277.0	824.0	0.0671	63.8	4.3
1992	4	SNE	116631.4	2077.0	0.0178	2636.8	47.0
1993	1	GBK	10907.0	190.0	0.0174	134.9	2.4
1993	2	GBK	35533.1	177.0	0.0050	604.0	3.0
1993	3	GBK	184496.5	419.0	0.0023	994.0	2.3
1993	4	GBK	79788.8	1556.0	0.0195	1368.6	26.7
1993	1	GOM	65333.1	3277.0	0.0502	1164.5	58.4
1993	2	GOM	195803.4	3330.0	0.0170	3220.8	54.8
1993	3	GOM	220513.3	474.0	0.0021	6614.9	14.2
1993	4	GOM	322639.1	1296.0	0.0040	5316.5	21.4
1993	1	MA	88819.2	0.0	0.0000	2446.1	0.0
1993	2	MA	39302.1	19.0	0.0007	1684.6	1.2
1993	3	MA	1798.0	0.0	0.0000	1248.5	0.0
1993	4	MA	27289.0	57.0	0.0021	3380.6	7.1
1993	1	SNE	17184.0	759.0	0.0442	491.1	21.7
1993	2	SNE	66155.0	2719.0	0.0411	1719.1	70.7
1993	3	SNE	7014.0	1190.0	0.1697	135.3	23.0
1993	4	SNE	116496.0	1243.0	0.0107	1419.2	15.1
1994	1	GBK	11743.0	78.0	0.0066	117.4	0.8
1994	2	GBK	50530.1	0.0	0.0000	803.0	0.0
1994	3	GBK	102328.1	7.0	0.0001	1897.1	0.1
1994	4	GBK	32304.7	501.0	0.0155	1330.6	20.6
1994	1	GOM	12656.0	1302.0	0.1029	1172.1	120.6
1994	2	GOM	9843.3	30.0	0.0030	2806.3	8.6
1994	3	GOM	47074.7	24.0	0.0005	6382.9	3.3
1994	4	GOM	64128.1	814.0	0.0127	3814.1	48.4
1994	1	MA	424842.9	2959.0	0.0070	2214.1	15.4
1994	2	MA	62247.1	206.0	0.0033	1410.4	4.7
1994	3	MA	46100.8	31.0	0.0007	1614.0	1.1
1994	4	MA	290493.6	3790.5	0.0130	3221.9	42.0
1994	1	SNE	15407.0	216.0	0.0140	653.6	9.2
1994	2	SNE	1780.0	122.0	0.0685	1542.2	105.7
1994	3	SNE	39030.0	2901.7	0.0554	282.8	15.7
1994	4	SNE	99903.1	8367.0	0.0838	1085.2	90.9

Table 4 cont.

1995	1	GBK	5379.6	165.0	0.0307	239.6	7.3
1995	2	GBK	107372.2	350.0	0.0033	1658.3	5.4
1995	3	GBK	154650.9	432.0	0.0028	1825.6	5.1
1995	4	GBK	44697.3	597.0	0.0134	1793.9	24.0
1995	1	GOM	16330.9	1583.1	0.0969	1365.0	132.3
1995	2	GOM	29104.0	532.5	0.0183	3486.5	63.8
1995	3	GOM	80281.6	216.0	0.0027	6267.8	16.9
1995	4	GOM	39633.4	1990.0	0.0502	4241.2	213.0
1995	1	MA	755815.3	10447.5	0.0138	2503.3	34.6
1995	2	MA	125150.4	1229.0	0.0098	1809.5	17.8
1995	3	MA	52056.3	216.0	0.0041	847.1	3.5
1995	4	MA	262332.0	3379.3	0.0129	3991.1	51.4
1995	1	SNE	8833.0	678.0	0.0768	595.0	45.7
1995	2	SNE	31651.4	1999.0	0.0632	2150.8	135.8
1995	3	SNE	3936.0	447.0	0.1136	172.4	19.6
1995	4	SNE	33918.5	468.0	0.0138	1204.2	16.6
1996	1	GBK	10373.0	365.0	0.0352	200.0	7.0
1996	2	GBK	25715.0	64.0	0.0025	1371.7	3.4
1996	3	GBK	112924.3	861.0	0.0076	1572.6	12.0
1996	4	GBK	33751.5	361.1	0.0107	1875.5	20.1
1996	1	GOM	22662.2	4893.8	0.2159	1081.5	233.6
1996	2	GOM	15555.1	266.0	0.0171	2323.0	39.7
1996	3	GOM	32440.7	140.0	0.0043	6154.5	26.6
1996	4	GOM	75904.3	111.9	0.0015	4372.9	6.4
1996	1	MA	800368.3	12530.5	0.0157	5261.4	82.4
1996	2	MA	148496.3	1423.4	0.0096	3097.0	29.7
1996	3	MA	42831.4	280.0	0.0065	1745.6	11.4
1996	4	MA	214088.6	1649.0	0.0077	5262.4	40.5
1996	1	SNE	18515.5	75.0	0.0041	386.4	1.6
1996	2	SNE	9094.5	116.0	0.0128	1681.4	21.4
1996	3	SNE	1277.3	0.0	0.0000	216.0	0.0
1996	4	SNE	1110.9	15.0	0.0135	1044.4	14.1
1997	1	GBK	20931.9	102.0	0.0049	428.3	2.1
1997	2	GBK	5213.2	44.0	0.0084	1641.7	13.9
1997	3	GBK	5882.0	3.0	0.0005	1166.1	0.6
1997	4	GBK	7335.2	59.0	0.0080	978.7	7.9
1997	1	GOM	4971.0	236.7	0.0476	1335.0	63.6
1997	2	GOM	25021.5	311.7	0.0125	2471.6	30.8
1997	3	GOM	29352.1	3.0	0.0001	4699.3	0.5
1997	4	GOM	44359.9	78.6	0.0018	3821.1	6.8
1997	1	MA	711796.5	13753.7	0.0193	7893.1	152.5
1997	2	MA	138710.4	6381.0	0.0460	2791.0	128.4
1997	3	MA	54975.6	11.0	0.0002	1862.2	0.4
1997	4	MA	176529.4	1573.0	0.0089	5587.1	49.8
1997	1	SNE	22081.1	47.5	0.0022	398.9	0.9
1997	2	SNE	7321.8	0.0	0.0000	1130.0	0.0
1997	3	SNE	3082.4	94.0	0.0305	160.5	4.9
1997	4	SNE	22597.5	470.0	0.0208	989.9	20.6
1998	1	GBK	13254.0	289.0	0.0218	428.2	9.3

Table 4 cont.

1998	2	GBK	13539.2	21.0	0.0016	1012.1	1.6
1998	3	GBK	103634.0	2259.0	0.0218	783.5	17.1
1998	4	GBK	81759.1	317.4	0.0039	1880.9	7.3
1998	1	GOM	8246.3	173.1	0.0210	1544.7	32.4
1998	2	GOM	65996.6	216.0	0.0033	2135.8	7.0
1998	3	GOM	49801.2	34.0	0.0007	5544.6	3.8
1998	4	GOM	193863.8	1266.7	0.0065	4330.9	28.3
1998	1	MA	748403.1	6338.5	0.0085	7460.2	63.2
1998	2	MA	76002.7	1863.0	0.0245	3902.1	95.6
1998	3	MA	2258.0	64.0	0.0283	1692.5	48.0
1998	4	MA	77028.3	1279.1	0.0166	7274.9	120.8
1998	1	SNE	1614.1	3.0	0.0019	408.4	0.8
1998	2	SNE	20995.3	120.0	0.0057	1211.2	6.9
1998	3	SNE	19049.8	229.0	0.0080	162.2	1.3
1998	4	SNE	34540.0	563.9	0.0163	1486.6	24.3
1999	1	GBK	17467.9	1572.2	0.0900	605.4	54.5
1999	2	GBK	41630.0	126.0	0.0030	1612.3	4.9
1999	3	GBK	58207.3	189.0	0.0032	1217.7	4.0
1999	4	GBK	28471.6	114.0	0.0040	1695.2	6.8
1999	1	GOM	22623.7	188.7	0.0083	1176.5	9.8
1999	2	GOM	33414.6	507.9	0.0152	1910.8	29.0
1999	3	GOM	94138.0	271.1	0.0029	2414.2	7.0
1999	4	GOM	176380.0	6468.1	0.0367	2529.0	92.7
1999	1	MA	63037.4	1342.0	0.0213	8640.0	183.9
1999	2	MA	18830.8	1496.5	0.0795	3584.5	284.9
1999	3	MA	5370.5	0.0	0.0000	1480.7	0.0
1999	4	MA	25202.0	383.5	0.0152	4889.5	74.4
1999	1	SNE	8739.8	122.0	0.0140	885.0	12.4
1999	2	SNE	8818.0	119.0	0.0135	1406.2	19.0
1999	3	SNE	7389.7	169.0	0.0284	338.3	9.6
1999	4	SNE	4611.2	266.0	0.0577	973.9	56.2
2000	1	GBK	21170.1	331.8	0.0157	709.6	11.1
2000	2	GBK	17915.7	683.3	0.0381	976.1	37.2
2000	3	GBK	19154.2	9308.0	0.4860	1119.1	543.8
2000	4	GBK	51549.7	4942.1	0.0959	1504.5	144.2
2000	1	GOM	23536.8	341.9	0.0145	1103.9	16.0
2000	2	GOM	30212.8	957.8	0.0317	1776.8	56.3
2000	3	GOM	34168.9	242.6	0.0071	2376.4	16.9
2000	4	GOM	38219.2	446.7	0.0117	2964.0	34.6
2000	1	MA	49061.9	16.0	0.0003	6565.2	2.1
2000	2	MA	15007.2	79.0	0.0053	2654.3	14.0
2000	3	MA	12557.5	0.0	0.0000	1958.7	0.0
2000	4	MA	62224.3	533.0	0.0086	4986.7	42.7
2000	1	SNE	9597.0	222.0	0.0231	918.0	21.2
2000	2	SNE	22779.3	738.0	0.0324	697.5	22.6
2000	3	SNE	13675.7	355.3	0.0226	100.6	2.3
2000	4	SNE	8650.7	106.0	0.0123	579.9	7.1
2001	1	GBK	23497.4	1354.3	0.0576	875.6	50.5
2001	2	GBK	20554.2	380.0	0.0185	953.7	17.6

Table 4 cont.

2001	3	GBK	8626.2	81.0	0.0094	1118.3	10.5
2001	4	GBK	21143.6	1650.0	0.0780	1180.4	92.1
2001	1	GOM	4458.5	88.0	0.0197	913.8	18.0
2001	2	GOM	24667.5	1391.0	0.0564	1802.7	101.7
2001	3	GOM	27845.6	314.0	0.0113	2129.1	24.0
2001	4	GOM	15130.2	145.5	0.0096	2701.6	26.0
2001	1	MA	73646.7	287.0	0.0039	4166.3	16.2
2001	2	MA	26561.1	168.9	0.0064	2656.1	16.9
2001	3	MA	4520.2	0.0	0.0000	1374.3	0.0
2001	4	MA	27136.9	143.0	0.0053	5366.6	28.3
2001	1	SNE	3451.0	0.0	0.0000	296.6	0.0
2001	2	SNE	4886.0	896.0	0.1834	992.5	182.0
2001	3	SNE	55.0	0.0	0.0000	162.7	0.0
2001	4	SNE	5146.0	82.0	0.0159	1455.3	23.2
2002	1	GBK	9228.4	308.0	0.0334	960.7	32.1
2002	2	GBK	32100.7	3809.0	0.1187	691.9	82.1
2002	3	GBK	10484.5	235.0	0.0224	986.8	22.1
2002	4	GBK	23319.1	701.4	0.0301	1696.6	51.0
2002	1	GOM	34205.3	55.0	0.0016	1337.1	2.2
2002	2	GOM	27988.8	441.1	0.0158	1198.4	18.9
2002	3	GOM	21374.4	1106.5	0.0518	1789.4	92.6
2002	4	GOM	45843.6	611.0	0.0133	2488.4	33.2
2002	1	MA	37080.4	1069.0	0.0288	4219.3	121.6
2002	2	MA	5868.0	90.0	0.0153	2569.0	39.4
2002	3	MA	2315.9	0.0	0.0000	1376.1	0.0
2002	4	MA	29532.6	95.0	0.0032	4375.4	14.1
2002	1	SNE	10840.5	381.0	0.0351	1141.9	40.1
2002	2	SNE	9468.0	428.0	0.0452	1186.8	53.6
2002	3	SNE	963.0	20.0	0.0208	169.1	3.5
2002	4	SNE	6070.0	10329.0	1.7016	1307.3	2224.5
2003	1	GBK	4577.5	1311.1	0.2864	652.0	186.8
2003	2	GBK	43470.1	818.8	0.0188	356.4	6.7
2003	3	GBK	88411.1	3181.0	0.0360	1988.6	71.5
2003	4	GBK	177024.0	3756.3	0.0212	1881.1	39.9
2003	1	GOM	16371.3	481.0	0.0294	1262.1	37.1
2003	2	GOM	88920.5	1586.0	0.0178	1282.3	22.9
2003	3	GOM	140135.5	1562.9	0.0112	1866.6	20.8
2003	4	GOM	169528.6	1429.1	0.0084	2504.9	21.1
2003	1	MA	19277.5	483.0	0.0251	3761.1	94.2
2003	2	MA	22960.6	85.5	0.0037	3871.1	14.4
2003	3	MA	15101.8	0.0	0.0000	1356.5	0.0
2003	4	MA	27781.5	671.0	0.0242	4402.7	106.3
2003	1	SNE	21451.2	1487.0	0.0693	1023.0	70.9
2003	2	SNE	95480.1	4352.0	0.0456	1948.2	88.8
2003	3	SNE	28536.0	1581.1	0.0554	317.6	17.6
2003	4	SNE	135270.5	13896.6	0.1027	1608.6	165.3
2004	1	GBK	81315.1	5199.0	0.0639	3067.2	196.1
2004	2	GBK	129247.6	2860.5	0.0221	822.7	18.2
2004	3	GBK	374557.7	17328.5	0.0463	1744.6	80.7

Table 4 cont.

2004	4	GBK	270667.2	18566.0	0.0686	868.8	59.6
2004	1	GOM	85320.3	2177.7	0.0255	1491.0	38.1
2004	2	GOM	50461.3	907.2	0.0180	927.6	16.7
2004	3	GOM	383048.0	3395.8	0.0089	1855.8	16.5
2004	4	GOM	702958.2	14946.0	0.0213	2891.6	61.5
2004	1	MA	3046.2	0.0	0.0000	4538.0	0.0
2004	2	MA	3174.0	0.0	0.0000	1957.1	0.0
2004	3	MA	24512.5	1109.5	0.0165	1198.8	19.8
2004	4	MA	67317.3	3328.4	0.0494	3915.3	193.6
2004	1	SNE	207015.0	7432.5	0.0359	3361.1	120.7
2004	2	SNE	145289.2	6361.6	0.0438	1347.6	59.0
2004	3	SNE	3084.4	77.5	0.0251	131.5	3.3
2004	4	SNE	76143.0	4066.9	0.0534	579.3	30.9
2005	1	GBK	23149.2	17751.8	0.7668	395.2	303.0
2005	2	GBK	8228.8	56.0	0.0068	326.5	2.2
2005	3	GBK	387916.7	17402.0	0.0449	1476.1	66.2
2005	4	GBK	260812.3	30642.3	0.1175	816.7	96.0
2005	1	GOM	78700.7	3997.6	0.0508	1268.2	64.4
2005	2	GOM	39841.1	1358.5	0.0341	857.1	29.2
2005	3	GOM	473344.6	4407.0	0.0093	2259.6	21.0
2005	4	GOM	721567.1	5408.5	0.0075	2766.7	20.7
2005	1	MA	22404.2	555.0	0.0248	5461.8	135.3
2005	2	MA	163104.8	17011.0	0.1043	2885.5	300.9
2005	3	MA	9684.2	366.0	0.0378	1627.0	61.5
2005	4	MA	58178.3	3033.5	0.0521	4218.2	219.9
2005	1	SNE	28835.0	1689.0	0.0586	779.4	45.7
2005	2	SNE	85795.2	7663.3	0.0893	1700.7	151.9
2005	3	SNE	74307.2	7851.0	0.1057	357.9	37.8
2005	4	SNE	104448.1	6386.0	0.0611	569.0	34.8
2006	1	GBK	44571.9	1004.2	0.0225	505.5	11.4
2006	2	GBK	3979.8	911.0	0.2289	427.2	97.8
2006	3	GBK	96432.4	5581.0	0.0579	2044.7	118.3
2006	4	GBK	90164.1	8982.2	0.0996	1449.4	144.4
2006	1	GOM	82164.8	4076.8	0.0496	928.5	46.1
2006	2	GOM	11490.3	348.8	0.0304	598.9	18.2
2006	3	GOM	35246.8	271.1	0.0077	1835.5	14.1
2006	4	GOM	177169.4	992.2	0.0056	3050.9	17.1
2006	1	MA	41258.2	1454.5	0.0353	3138.0	110.6
2006	2	MA	18235.7	1563.0	0.0857	1662.8	142.5
2006	3	MA	20961.0	55.0	0.0026	666.8	1.7
2006	4	MA	34747.8	776.0	0.0223	2173.8	48.5
2006	1	SNE	59437.3	3969.0	0.0668	1173.6	78.4
2006	2	SNE	9257.0	3059.0	0.3305	1042.1	344.4
2006	3	SNE	3466.3	438.0	0.1264	130.5	16.5
2006	4	SNE	4979.8	7.5	0.0015	539.4	0.8
2007	1	GBK	13029.1	8109.6	0.6224	497.4	309.6
2007	2	GBK	27562.6	902.0	0.0327	1017.4	33.3
2007	3	GBK	471464.1	32418.6	0.0688	2927.8	201.3
2007	4	GBK	327498.6	27336.1	0.0835	1174.2	98.0

Table 4 cont.

2007	1	GOM	95553.5	1742.9	0.0182	976.4	17.8
2007	2	GOM	19165.0	358.5	0.0187	918.0	17.2
2007	3	GOM	54180.0	699.2	0.0129	1723.1	22.2
2007	4	GOM	226349.7	2411.7	0.0107	3896.9	41.5
2007	1	MA	24863.2	629.3	0.0253	5147.9	130.3
2007	2	MA	30796.9	3589.5	0.1166	3028.1	352.9
2007	3	MA	11744.1	154.5	0.0132	1726.3	22.7
2007	4	MA	35426.4	668.2	0.0189	4732.4	89.3
2007	1	SNE	101559.1	12113.1	0.1193	845.4	100.8
2007	2	SNE	25749.0	1942.5	0.0754	1014.5	76.5
2007	3	SNE	3710.3	149.0	0.0402	222.5	8.9
2007	4	SNE	32680.2	13702.3	0.4193	679.9	285.1

Table 5. Discard estimates by stratum for the scallop dredge fishery.

(yellow) average within areaf (green) average across comb region (ie sne-ma)

YEAR	QTR	areaf	trp	kept	discards	dkratio	mt kept	total discards
1992	1	GBK	GEN	50291.2	14561.0	0.2508	31.6	7.9
1992	2	GBK	GEN	50291.2	14561.0	0.2508	5.9	1.5
1992	3	GBK	GEN	50291.2	14561.0	0.2508	7.6	1.9
1992	4	GBK	GEN	50291.2	14561.0	0.2508	45.2	11.3
1992	1	GBK	LIM	37455.6	6519.0	0.1740	21901.7	3811.9
1992	2	GBK	LIM	86300.4	23051.0	0.2671	16714.3	4464.4
1992	3	GBK	LIM	6944.1	1275.0	0.1836	18107.8	3324.8
1992	4	GBK	LIM	111608.7	39436.0	0.3533	18596.8	6571.0
1992	1	GOM	GEN	50291.2	14561.0	0.2508	47.7	12.0
1992	2	GOM	GEN	50291.2	14561.0	0.2508	24.7	6.2
1992	3	GOM	GEN	50291.2	14561.0	0.2508	24.1	6.0
1992	4	GOM	GEN	50291.2	14561.0	0.2508	43.4	10.9
1992	1	GOM	LIM	50291.2	14561.0	0.2508	2086.3	523.3
1992	2	GOM	LIM	50291.2	14561.0	0.2508	62.5	15.7
1992	3	GOM	LIM	50291.2	14561.0	0.2508	187.2	46.9
1992	4	GOM	LIM	9147.1	2524.0	0.2759	3429.0	946.2
1992	1	MA	GEN	26547.6	9060.2	0.4585	29.3	13.4
1992	2	MA	GEN	26547.6	9060.2	0.4585	26.8	12.3
1992	3	MA	GEN	26547.6	9060.2	0.4585	18.0	8.3
1992	4	MA	GEN	26547.6	9060.2	0.4585	43.6	20.0
1992	1	MA	LIM	19225.3	5127.0	0.2667	13260.1	3536.2
1992	2	MA	LIM	38383.6	4037.0	0.1052	8296.8	872.6
1992	3	MA	LIM	41502.6	4989.0	0.1202	8151.2	979.9
1992	4	MA	LIM	42997.7	23748.0	0.5523	9604.1	5304.4
1992	1	SNE	GEN	26547.6	9060.2	0.4585	14.7	6.7
1992	4	SNE	GEN	26547.6	9060.2	0.4585	2.4	1.1
1992	1	SNE	LIM	3488.0	2360.0	0.6766	245.0	165.8
1992	2	SNE	LIM	26547.6	9060.2	0.4585	117.7	54.0
1992	3	SNE	LIM	26547.6	9060.2	0.4585	108.5	49.7
1992	4	SNE	LIM	13688.2	14100.0	1.0301	790.1	813.9
1993	1	GBK	GEN	69938.1	14547.0	0.2001	20.4	4.1
1993	2	GBK	GEN	69938.1	14547.0	0.2001	18.8	3.8
1993	3	GBK	GEN	69938.1	14547.0	0.2001	1.4	0.3
1993	4	GBK	GEN	69938.1	14547.0	0.2001	2.7	0.5
1993	1	GBK	LIM	66175.0	15317.0	0.2315	12972.9	3002.7
1993	2	GBK	LIM	80588.9	7761.0	0.0963	8057.1	775.9
1993	3	GBK	LIM	43354.5	6788.0	0.1566	8084.3	1265.8
1993	4	GBK	LIM	89633.9	28322.0	0.3160	9741.0	3077.9
1993	1	GOM	GEN	69938.1	14547.0	0.2001	68.5	13.7
1993	2	GOM	GEN	69938.1	14547.0	0.2001	1.9	0.4
1993	3	GOM	GEN	69938.1	14547.0	0.2001	3.9	0.8
1993	4	GOM	GEN	69938.1	14547.0	0.2001	50.8	10.2
1993	1	GOM	LIM	69938.1	14547.0	0.2001	3048.1	609.9
1993	2	GOM	LIM	69938.1	14547.0	0.2001	505.6	101.2
1993	3	GOM	LIM	69938.1	14547.0	0.2001	134.0	26.8
1993	4	GOM	LIM	69938.1	14547.0	0.2001	2725.3	545.3

Table 5 cont.

1993	1	MA	GEN	38607.5	18893.3	0.7720	17.5	13.5
1993	2	MA	GEN	38607.5	18893.3	0.7720	3.5	2.7
1993	3	MA	GEN	38607.5	18893.3	0.7720	20.7	16.0
1993	4	MA	GEN	38607.5	18893.3	0.7720	53.8	41.5
1993	1	MA	LIM	96891.4	51649.0	0.5331	7909.9	4216.4
1993	2	MA	LIM	71762.1	14807.0	0.2063	4591.2	947.3
1993	3	MA	LIM	23586.3	12465.0	0.5285	4652.4	2458.7
1993	4	MA	LIM	31743.4	24792.0	0.7810	5251.9	4101.8
1993	1	SNE	GEN	38607.5	18893.3	0.7720	9.0	6.9
1993	2	SNE	GEN	38607.5	18893.3	0.7720	22.8	17.6
1993	3	SNE	GEN	38607.5	18893.3	0.7720	5.7	4.4
1993	4	SNE	GEN	38607.5	18893.3	0.7720	2.8	2.1
1993	1	SNE	LIM	3955.1	1147.0	0.2900	346.9	100.6
1993	2	SNE	LIM	38607.5	18893.3	0.7720	78.7	60.7
1993	3	SNE	LIM	38607.5	18893.3	0.7720	68.4	52.8
1993	4	SNE	LIM	3707.0	8500.0	2.2929	254.0	582.4
1994	1	GBK	GEN	37743.1	7367.8	0.2589	4.8	1.3
1994	2	GBK	GEN	37743.1	7367.8	0.2589	1.0	0.3
1994	4	GBK	GEN	37743.1	7367.8	0.2589	1.0	0.3
1994	1	GBK	LIM	6226.1	1147.0	0.1842	3979.7	733.2
1994	2	GBK	LIM	43256.7	7210.0	0.1667	2855.3	475.9
1994	3	GBK	LIM	33287.5	12404.0	0.3726	3220.2	1199.9
1994	4	GBK	LIM	132915.5	20306.0	0.1528	2961.9	452.5
1994	1	GOM	GEN	37743.1	7367.8	0.2589	46.7	12.1
1994	2	GOM	GEN	37743.1	7367.8	0.2589	17.1	4.4
1994	3	GOM	GEN	37743.1	7367.8	0.2589	7.5	2.0
1994	4	GOM	GEN	37743.1	7367.8	0.2589	1117.0	289.2
1994	1	GOM	LIM	4347.1	2530.0	0.5820	1754.9	1021.4
1994	2	GOM	LIM	37743.1	7367.8	0.2589	176.0	45.6
1994	3	GOM	LIM	37743.1	7367.8	0.2589	86.7	22.4
1994	4	GOM	LIM	6426.1	610.0	0.0949	1437.5	136.5
1994	1	MA	GEN	109751.8	19117.9	0.5178	220.0	113.9
1994	2	MA	GEN	109751.8	19117.9	0.5178	586.9	303.9
1994	3	MA	GEN	109751.8	19117.9	0.5178	295.0	152.8
1994	4	MA	GEN	109751.8	19117.9	0.5178	343.9	178.1
1994	1	MA	LIM	291785.5	52137.0	0.1787	13240.8	2365.9
1994	2	MA	LIM	40392.6	5693.0	0.1409	8982.1	1266.0
1994	3	MA	LIM	86889.7	883.1	0.0102	8358.9	85.0
1994	4	MA	LIM	122573.3	22078.5	0.1801	12326.9	2220.4
1994	1	SNE	GEN	109751.8	19117.9	0.5178	7.2	3.7
1994	2	SNE	GEN	109751.8	19117.9	0.5178	50.9	26.3
1994	1	SNE	LIM	109751.8	19117.9	0.5178	195.2	101.1
1994	2	SNE	LIM	109751.8	19117.9	0.5178	24.4	12.6
1994	4	SNE	LIM	7118.0	14798.0	2.0790	295.1	613.5
1995	1	GBK	GEN	35218.7	4671.0	0.1330	1.1	0.1
1995	1	GBK	LIM	6959.1	1098.0	0.1578	868.0	136.9
1995	2	GBK	LIM	35218.7	4671.0	0.1330	425.7	56.6
1995	3	GBK	LIM	44731.1	11497.0	0.2570	4489.5	1153.9
1995	4	GBK	LIM	62540.7	5166.0	0.0826	3713.5	306.7

Table 5 cont.

1995	1	GOM	GEN	35218.7	4671.0	0.1330	737.5	98.1
1995	2	GOM	GEN	35218.7	4671.0	0.1330	18.1	2.4
1995	3	GOM	GEN	35218.7	4671.0	0.1330	5.5	0.7
1995	4	GOM	GEN	35218.7	4671.0	0.1330	553.6	73.6
1995	1	GOM	LIM	35218.7	4671.0	0.1330	367.4	48.9
1995	2	GOM	LIM	35218.7	4671.0	0.1330	411.4	54.7
1995	3	GOM	LIM	35218.7	4671.0	0.1330	547.1	72.8
1995	4	GOM	LIM	26643.9	923.0	0.0346	1140.0	39.5
1995	1	MA	GEN	162275.3	54457.4	0.7607	356.6	271.3
1995	2	MA	GEN	162275.3	54457.4	0.7607	232.9	177.1
1995	3	MA	GEN	162275.3	54457.4	0.7607	118.8	90.4
1995	4	MA	GEN	162275.3	54457.4	0.7607	101.6	77.3
1995	1	MA	LIM	424321.9	83199.8	0.1961	17547.8	3440.7
1995	2	MA	LIM	107649.9	32633.8	0.3031	15124.0	4584.8
1995	3	MA	LIM	78172.3	5807.0	0.0743	6990.4	519.3
1995	4	MA	LIM	38957.1	96189.0	2.4691	7096.1	17521.0
1995	2	SNE	GEN	162275.3	54457.4	0.7607	0.1	0.1
1995	3	SNE	GEN	162275.3	54457.4	0.7607	66.4	50.5
1995	4	SNE	GEN	162275.3	54457.4	0.7607	0.4	0.3
1995	1	SNE	LIM	162275.3	54457.4	0.7607	232.4	176.8
1995	2	SNE	LIM	162275.3	54457.4	0.7607	102.9	78.3
1995	3	SNE	LIM	162275.3	54457.4	0.7607	74.6	56.8
1995	4	SNE	LIM	162275.3	54457.4	0.7607	102.9	78.3
1996	1	GBK	GEN				78.4	0.0
1996	2	GBK	GEN	91775.8	11306.1	0.1461	11.8	1.7
1996	3	GBK	GEN	91775.8	11306.1	0.1461	14.5	2.1
1996	4	GBK	GEN	91775.8	11306.1	0.1461	79.8	11.7
1996	1	GBK	LIM	193963.0	18448.6	0.0951	2333.8	222.0
1996	2	GBK	LIM	73941.0	9214.4	0.1246	2869.5	357.6
1996	3	GBK	LIM	140909.2	13983.1	0.0992	5825.1	578.1
1996	4	GBK	LIM	82763.7	19698.7	0.2380	8059.0	1918.1
1996	1	GOM	GEN	91775.8	11306.1	0.1461	350.1	51.2
1996	2	GOM	GEN	91775.8	11306.1	0.1461	45.3	6.6
1996	3	GOM	GEN	91775.8	11306.1	0.1461	217.7	31.8
1996	4	GOM	GEN	91775.8	11306.1	0.1461	323.5	47.3
1996	1	GOM	LIM	58226.0	6312.0	0.1084	794.6	86.1
1996	2	GOM	LIM	91775.8	11306.1	0.1461	763.3	111.5
1996	3	GOM	LIM	91775.8	11306.1	0.1461	531.9	77.7
1996	4	GOM	LIM	851.7	180.0	0.2113	1711.8	361.8
1996	1	MA	GEN	103404.7	40576.2	0.7423	143.5	106.5
1996	2	MA	GEN	103404.7	40576.2	0.7423	242.2	179.8
1996	3	MA	GEN	103404.7	40576.2	0.7423	85.0	63.1
1996	4	MA	GEN	103404.7	40576.2	0.7423	135.7	100.7
1996	1	MA	LIM	254269.2	51641.0	0.2031	12247.5	2487.4
1996	2	MA	LIM	139290.9	52641.5	0.3779	12782.6	4830.8
1996	3	MA	LIM	133185.7	32433.2	0.2435	8449.0	2057.5
1996	4	MA	LIM	83422.2	93504.9	1.1209	4974.9	5576.1
1996	1	SNE	GEN	103404.7	40576.2	0.7423	24.1	17.9
1996	2	SNE	GEN	103404.7	40576.2	0.7423	9.3	6.9

Table 5 cont.

1996	4	SNE	GEN	103404.7	40576.2	0.7423	5.3	3.9
1996	1	SNE	LIM	103404.7	40576.2	0.7423	111.8	83.0
1996	2	SNE	LIM	103404.7	40576.2	0.7423	34.6	25.7
1996	3	SNE	LIM	1867.1	2236.0	1.1976	184.5	221.0
1996	4	SNE	LIM	8393.0	11000.8	1.3107	398.3	522.0
1997	1	GBK	GEN	71654.1	13615.5	0.1640	62.5	10.2
1997	2	GBK	GEN	71654.1	13615.5	0.1640	2.2	0.4
1997	3	GBK	GEN	71654.1	13615.5	0.1640	2.8	0.5
1997	4	GBK	GEN	71654.1	13615.5	0.1640	33.7	5.5
1997	1	GBK	LIM	118384.4	12318.9	0.1041	6089.8	633.7
1997	2	GBK	LIM	97509.7	13445.1	0.1379	5545.3	764.6
1997	3	GBK	LIM	79412.4	32942.9	0.4148	4835.8	2006.0
1997	4	GBK	LIM	97398.0	18331.6	0.1882	5211.2	980.8
1997	1	GOM	GEN	71654.1	13615.5	0.1640	516.5	84.7
1997	2	GOM	GEN	71654.1	13615.5	0.1640	64.8	10.6
1997	3	GOM	GEN	71654.1	13615.5	0.1640	63.4	10.4
1997	4	GOM	GEN	71654.1	13615.5	0.1640	246.8	40.5
1997	1	GOM	LIM	34113.0	4646.7	0.1362	1698.9	231.4
1997	2	GOM	LIM	71654.1	13615.5	0.1640	417.6	68.5
1997	3	GOM	LIM	71654.1	13615.5	0.1640	709.9	116.4
1997	4	GOM	LIM	3107.0	8.0	0.0026	2049.2	5.3
1997	1	MA	GEN	1017.1	795.0	0.7816	75.3	58.8
1997	2	MA	GEN	280.0	550.0	1.9643	182.7	358.9
1997	3	MA	GEN	63184.8	28637.5	1.1428	135.4	154.8
1997	4	MA	GEN	63184.8	28637.5	1.1428	149.1	170.4
1997	1	MA	LIM	185187.6	96703.0	0.5222	7755.5	4049.9
1997	2	MA	LIM	97013.5	58382.0	0.6018	6919.4	4164.1
1997	3	MA	LIM	59890.5	14226.0	0.2375	4788.9	1137.5
1997	4	MA	LIM	98861.3	29649.3	0.2999	5276.8	1582.5
1997	1	SNE	GEN	63184.8	28637.5	1.1428	11.7	13.3
1997	3	SNE	GEN	63184.8	28637.5	1.1428	36.1	41.3
1997	4	SNE	GEN	63184.8	28637.5	1.1428	33.7	38.5
1997	1	SNE	LIM	63184.8	28637.5	1.1428	118.1	134.9
1997	2	SNE	LIM	43.7	157.0	3.5926	149.9	538.5
1997	3	SNE	LIM	63184.8	28637.5	1.1428	194.9	222.7
1997	4	SNE	LIM	63184.8	28637.5	1.1428	377.2	431.1
1998	1	GBK	GEN	54814.9	16487.8	0.2686	13.6	3.6
1998	2	GBK	GEN	54814.9	16487.8	0.2686	13.8	3.7
1998	3	GBK	GEN	54814.9	16487.8	0.2686	1.2	0.3
1998	4	GBK	GEN	54814.9	16487.8	0.2686	10.6	2.9
1998	1	GBK	LIM	54814.9	16487.8	0.2686	4903.1	1316.9
1998	2	GBK	LIM	46777.6	6201.0	0.1326	4105.2	544.2
1998	3	GBK	LIM	20064.1	7128.0	0.3553	4911.3	1744.8
1998	4	GBK	LIM	124771.5	46771.0	0.3749	5428.4	2034.9
1998	1	GOM	GEN	54814.9	16487.8	0.2686	350.0	94.0
1998	2	GOM	GEN	54814.9	16487.8	0.2686	55.9	15.0
1998	3	GOM	GEN	54814.9	16487.8	0.2686	50.0	13.4
1998	4	GOM	GEN	54814.9	16487.8	0.2686	149.2	40.1
1998	1	GOM	LIM	54814.9	16487.8	0.2686	1255.2	337.1

Table 5 cont.

1998	2	GOM	LIM	54814.9	16487.8	0.2686	228.0	61.2
1998	3	GOM	LIM	54814.9	16487.8	0.2686	57.5	15.5
1998	4	GOM	LIM	27646.3	5851.0	0.2116	1179.8	249.7
1998	1	MA	GEN	27193.7	10898.2	0.4998	149.5	74.7
1998	2	MA	GEN	209.1	240.0	1.1477	127.9	146.8
1998	3	MA	GEN	27193.7	10898.2	0.4998	192.8	96.4
1998	4	MA	GEN	16905.3	13181.0	0.7797	139.6	108.8
1998	1	MA	LIM	24099.0	5711.0	0.2370	7089.8	1680.2
1998	2	MA	LIM	112632.5	41451.5	0.3680	5633.0	2073.1
1998	3	MA	LIM	17567.8	6319.0	0.3597	3980.5	1431.8
1998	4	MA	LIM	18657.1	9355.0	0.5014	5213.8	2614.3
1998	1	SNE	GEN	27193.7	10898.2	0.4998	121.8	60.9
1998	2	SNE	GEN	27193.7	10898.2	0.4998	18.0	9.0
1998	3	SNE	GEN	27193.7	10898.2	0.4998	56.3	28.2
1998	4	SNE	GEN	27193.7	10898.2	0.4998	3.5	1.7
1998	1	SNE	LIM	27193.7	10898.2	0.4998	235.3	117.6
1998	2	SNE	LIM	27193.7	10898.2	0.4998	275.5	137.7
1998	3	SNE	LIM	27193.7	10898.2	0.4998	144.5	72.2
1998	4	SNE	LIM	285.0	30.0	0.1053	181.3	19.1
1999	1	GBK	GEN	369905.3	32992.6	0.0851	86.5	7.4
1999	2	GBK	GEN	369905.3	32992.6	0.0851	216.7	18.4
1999	3	GBK	GEN	369905.3	32992.6	0.0851	208.2	17.7
1999	4	GBK	GEN	369905.3	32992.6	0.0851	27.4	2.3
1999	1	GBK	LIM	369905.3	32992.6	0.0851	5313.5	452.2
1999	2	GBK	LIM	195274.1	13165.0	0.0674	9508.8	641.1
1999	3	GBK	LIM	614597.1	57555.3	0.0936	13175.9	1233.9
1999	4	GBK	LIM	299844.6	28257.5	0.0942	16243.1	1530.8
1999	1	GOM	GEN	369905.3	32992.6	0.0851	244.8	20.8
1999	2	GOM	GEN	369905.3	32992.6	0.0851	37.7	3.2
1999	3	GOM	GEN	369905.3	32992.6	0.0851	689.6	58.7
1999	4	GOM	GEN	369905.3	32992.6	0.0851	470.3	40.0
1999	1	GOM	LIM	369905.3	32992.6	0.0851	723.5	61.6
1999	2	GOM	LIM	369905.3	32992.6	0.0851	32.7	2.8
1999	3	GOM	LIM	369905.3	32992.6	0.0851	13.3	1.1
1999	4	GOM	LIM	369905.3	32992.6	0.0851	848.4	72.2
1999	1	MA	GEN	40167.7	12772.8	0.3235	63.2	20.4
1999	2	MA	GEN	40167.7	12772.8	0.3235	100.5	32.5
1999	3	MA	GEN	7301.1	3450.0	0.4725	65.0	30.7
1999	4	MA	GEN	6453.1	268.0	0.0415	195.3	8.1
1999	1	MA	LIM	40167.7	12772.8	0.3235	11180.6	3617.1
1999	2	MA	LIM	128464.8	27604.0	0.2149	10468.4	2249.4
1999	3	MA	LIM	40581.7	21755.0	0.5361	4921.5	2638.3
1999	4	MA	LIM	36516.6	21910.0	0.6000	3704.5	2222.7
1999	1	SNE	GEN	40167.7	12772.8	0.3235	0.7	0.2
1999	3	SNE	GEN	40167.7	12772.8	0.3235	7.4	2.4
1999	4	SNE	GEN	40167.7	12772.8	0.3235	0.4	0.1
1999	1	SNE	LIM	40167.7	12772.8	0.3235	287.0	92.9
1999	2	SNE	LIM	21688.8	1650.0	0.0761	133.6	10.2
1999	3	SNE	LIM	40167.7	12772.8	0.3235	204.2	66.1

Table 5 cont.

1999	4	SNE	LIM	40167.7	12772.8	0.3235	66.8	21.6
2000	1	GBK	GEN	3457047.2	186667.1	0.0746	92.6	6.9
2000	2	GBK	GEN	3457047.2	186667.1	0.0746	175.4	13.1
2000	3	GBK	GEN	3457047.2	186667.1	0.0746	200.9	15.0
2000	4	GBK	GEN	21015.3	152.0	0.0072	370.3	2.7
2000	1	GBK	LIM	3457047.2	186667.1	0.0746	4192.9	312.7
2000	2	GBK	LIM	1177880.0	218514.9	0.1855	9072.3	1683.0
2000	3	GBK	LIM	4167318.0	354352.8	0.0850	12036.1	1023.4
2000	4	GBK	LIM	8461975.4	173648.5	0.0205	15449.1	317.0
2000	1	GOM	GEN	3457047.2	186667.1	0.0746	126.1	9.4
2000	2	GOM	GEN	3457047.2	186667.1	0.0746	156.0	11.6
2000	3	GOM	GEN	3457047.2	186667.1	0.0746	133.1	9.9
2000	4	GOM	GEN	3457047.2	186667.1	0.0746	37.1	2.8
2000	1	GOM	LIM	3457047.2	186667.1	0.0746	559.5	41.7
2000	2	GOM	LIM	3457047.2	186667.1	0.0746	95.5	7.1
2000	3	GOM	LIM	3457047.2	186667.1	0.0746	17.1	1.3
2000	4	GOM	LIM	3457047.2	186667.1	0.0746	192.9	14.4
2000	1	MA	GEN	6530.1	625.0	0.0957	320.2	30.6
2000	2	MA	GEN	11461.2	3415.0	0.2980	516.4	153.9
2000	3	MA	GEN	117173.4	16514.3	0.1416	282.2	39.9
2000	4	MA	GEN	29437.1	6616.0	0.2248	430.0	96.6
2000	1	MA	LIM	413530.5	65296.3	0.1579	19122.7	3019.5
2000	2	MA	LIM	648.1	0.0	0.0000	19744.1	0.0
2000	3	MA	LIM	170769.5	6511.8	0.0381	12072.2	460.3
2000	4	MA	LIM	187837.4	33136.0	0.1764	15440.1	2723.8
2000	1	SNE	GEN	2001.7	88.7	0.0554	98.7	5.5
2000	4	SNE	GEN	2001.7	88.7	0.0554	0.4	0.0
2000	1	SNE	LIM	2001.7	88.7	0.0554	567.1	31.4
2000	2	SNE	LIM	1381.8	115.0	0.0832		0.0
2000	3	SNE	LIM	1762.5	138.0	0.0783	175.7	13.8
2000	4	SNE	LIM	2860.9	13.0	0.0045	61.6	0.3
2001	1	GBK	GEN	730341.6	17320.0	0.0249	443.5	11.0
2001	2	GBK	GEN	730341.6	17320.0	0.0249	494.3	12.3
2001	3	GBK	GEN	730341.6	17320.0	0.0249	280.5	7.0
2001	4	GBK	GEN	730341.6	17320.0	0.0249	95.3	2.4
2001	1	GBK	LIM	1368169.2	32211.0	0.0235	10806.5	254.4
2001	2	GBK	LIM	92514.0	2429.0	0.0263	7261.0	190.6
2001	3	GBK	LIM	730341.6	17320.0	0.0249	12396.2	308.7
2001	4	GBK	LIM	730341.6	17320.0	0.0249	9160.7	228.1
2001	1	GOM	GEN	730341.6	17320.0	0.0249	216.6	5.4
2001	2	GOM	GEN	730341.6	17320.0	0.0249	1535.0	38.2
2001	3	GOM	GEN	730341.6	17320.0	0.0249	538.2	13.4
2001	4	GOM	GEN	730341.6	17320.0	0.0249	408.6	10.2
2001	1	GOM	LIM	730341.6	17320.0	0.0249	74.0	1.8
2001	2	GOM	LIM	730341.6	17320.0	0.0249	146.9	3.7
2001	3	GOM	LIM	730341.6	17320.0	0.0249	81.9	2.0
2001	4	GOM	LIM	730341.6	17320.0	0.0249	412.4	10.3
2001	1	MA	GEN	1680313.3	67121.0	0.0477	450.6	21.5
2001	2	MA	GEN	1680313.3	67121.0	0.0477	430.1	20.5

Table 5 cont.

2001	3	MA	GEN	1680313.3	67121.0	0.0477	518.2	24.7
2001	4	MA	GEN	1680313.3	67121.0	0.0477	265.9	12.7
2001	1	MA	LIM	207896.6	17123.0	0.0824	27830.9	2292.2
2001	2	MA	LIM	3522211.6	107337.1	0.0305	30088.7	916.9
2001	3	MA	LIM	2152093.3	81877.5	0.0380	21323.6	811.3
2001	4	MA	LIM	2516352.0	129157.5	0.0513	36061.8	1851.0
2001	1	SNE	GEN	1680313.3	67121.0	0.0477	0.2	0.0
2001	2	SNE	GEN	1680313.3	67121.0	0.0477	2.6	0.1
2001	3	SNE	GEN	1680313.3	67121.0	0.0477	0.0	0.0
2001	4	SNE	GEN	1680313.3	67121.0	0.0477	8.3	0.4
2001	1	SNE	LIM	3013.0	110.0	0.0365	131.4	4.8
2001	2	SNE	LIM	1680313.3	67121.0	0.0477	84.2	4.0
2001	3	SNE	LIM	1680313.3	67121.0	0.0477	10.5	0.5
2001	4	SNE	LIM	1680313.3	67121.0	0.0477	7.3	0.3
2002	1	GBK	GEN	318272.9	16620.7	0.0620	129.0	8.0
2002	2	GBK	GEN	318272.9	16620.7	0.0620	155.5	9.6
2002	3	GBK	GEN	318272.9	16620.7	0.0620	223.7	13.9
2002	4	GBK	GEN	318272.9	16620.7	0.0620	112.0	6.9
2002	1	GBK	LIM	318272.9	16620.7	0.0620	5761.6	356.9
2002	2	GBK	LIM	318272.9	16620.7	0.0620	9314.7	577.1
2002	3	GBK	LIM	368114.9	28007.5	0.0761	18366.3	1397.4
2002	4	GBK	LIM	581835.7	21500.1	0.0370	15534.0	574.0
2002	1	GOM	GEN	318272.9	16620.7	0.0620	756.8	46.9
2002	2	GOM	GEN	318272.9	16620.7	0.0620	406.6	25.2
2002	3	GOM	GEN	318272.9	16620.7	0.0620	251.4	15.6
2002	4	GOM	GEN	4868.1	354.5	0.0728	147.3	10.7
2002	1	GOM	LIM	318272.9	16620.7	0.0620	1144.7	70.9
2002	2	GOM	LIM	318272.9	16620.7	0.0620	11.7	0.7
2002	3	GOM	LIM	318272.9	16620.7	0.0620	108.6	6.7
2002	4	GOM	LIM	318272.9	16620.7	0.0620	82.3	5.1
2002	1	MA	GEN	1479173.1	122872.0	0.1024	420.7	43.1
2002	2	MA	GEN	1479173.1	122872.0	0.1024	818.0	83.7
2002	3	MA	GEN	1479173.1	122872.0	0.1024	762.8	78.1
2002	4	MA	GEN	9769.2	1792.0	0.1834	1715.0	314.6
2002	1	MA	LIM	1622662.7	122137.0	0.0753	39750.2	2992.0
2002	2	MA	LIM	1654031.2	100861.0	0.0610	33889.7	2066.6
2002	3	MA	LIM	1691190.7	174917.1	0.1034	23042.3	2383.2
2002	4	MA	LIM	2418211.5	214653.0	0.0888	32696.2	2902.3
2002	1	SNE	GEN	1479173.1	122872.0	0.1024	1.0	0.1
2002	2	SNE	GEN	1479173.1	122872.0	0.1024	4.1	0.4
2002	3	SNE	GEN	1479173.1	122872.0	0.1024	2.2	0.2
2002	4	SNE	GEN	1479173.1	122872.0	0.1024	1.7	0.2
2002	1	SNE	LIM	1479173.1	122872.0	0.1024	35.7	3.7
2002	3	SNE	LIM	1479173.1	122872.0	0.1024	106.1	10.9
2002	4	SNE	LIM	1479173.1	122872.0	0.1024	11.5	1.2
2003	1	GBK	GEN	183288.2	13948.4	0.0888	188.7	16.8
2003	2	GBK	GEN	183288.2	13948.4	0.0888	392.9	34.9
2003	3	GBK	GEN	183288.2	13948.4	0.0888	663.4	58.9
2003	4	GBK	GEN	19728.3	2844.0	0.1442	431.6	62.2

Table 5 cont.

2003	1	GBK	LIM	249438.1	4599.0	0.0184	8836.7	162.9
2003	2	GBK	LIM	159227.5	24910.0	0.1564	9834.4	1538.5
2003	3	GBK	LIM	98491.0	9761.3	0.0991	13445.5	1332.6
2003	4	GBK	LIM	572128.5	41546.2	0.0726	6749.3	490.1
2003	1	GOM	GEN	716.0	30.0	0.0419	665.4	27.9
2003	2	GOM	GEN	183288.2	13948.4	0.0888	309.2	27.4
2003	3	GOM	GEN	183288.2	13948.4	0.0888	164.8	14.6
2003	4	GOM	GEN	183288.2	13948.4	0.0888	131.2	11.6
2003	1	GOM	LIM	183288.2	13948.4	0.0888	100.7	8.9
2003	2	GOM	LIM	183288.2	13948.4	0.0888	206.3	18.3
2003	3	GOM	LIM	183288.2	13948.4	0.0888	8.7	0.8
2003	4	GOM	LIM	183288.2	13948.4	0.0888	43.3	3.8
2003	1	MA	GEN	13839.7	681.0	0.0492	2210.3	108.8
2003	2	MA	GEN	2864.0	475.0	0.1658	1038.3	172.2
2003	3	MA	GEN	16803.3	6195.0	0.3687	1609.2	593.3
2003	4	MA	GEN	28628.5	315.0	0.0110	2055.3	22.6
2003	1	MA	LIM	1738457.1	169608.8	0.0976	33207.8	3239.8
2003	2	MA	LIM	1809350.1	112134.5	0.0620	41415.9	2566.8
2003	3	MA	LIM	1912523.4	125992.5	0.0659	29962.6	1973.9
2003	4	MA	LIM	3431011.6	254800.5	0.0743	46569.2	3458.4
2003	1	SNE	GEN	914442.6	67316.9	0.1299	8.1	1.1
2003	2	SNE	GEN	914442.6	67316.9	0.1299	1.5	0.2
2003	3	SNE	GEN	914442.6	67316.9	0.1299	3.6	0.5
2003	4	SNE	GEN	914442.6	67316.9	0.1299	21.5	2.8
2003	1	SNE	LIM	187199.1	1481.0	0.0079	265.3	2.1
2003	2	SNE	LIM	914442.6	67316.9	0.1299	35.8	4.6
2003	4	SNE	LIM	3749.0	1486.0	0.3964	142.7	56.6
2004	1	GBK	GEN	903834.1	41687.0	0.0599	347.4	20.8
2004	2	GBK	GEN	903834.1	41687.0	0.0599	478.6	28.7
2004	3	GBK	GEN	903834.1	41687.0	0.0599	219.3	13.1
2004	4	GBK	GEN	34306.1	2300.2	0.0670	574.1	38.5
2004	1	GBK	LIM	145522.9	6479.0	0.0445	4375.4	194.8
2004	2	GBK	LIM	903834.1	41687.0	0.0599	736.0	44.1
2004	3	GBK	LIM	903834.1	41687.0	0.0599	2782.7	166.7
2004	4	GBK	LIM	4320027.3	197057.4	0.0456	18164.4	828.6
2004	1	GOM	GEN	696.0	2.0	0.0029	126.6	0.4
2004	2	GOM	GEN	903834.1	41687.0	0.0599	69.2	4.1
2004	3	GOM	GEN	903834.1	41687.0	0.0599	44.8	2.7
2004	4	GOM	GEN	18618.0	2596.5	0.1395	62.4	8.7
2004	1	GOM	LIM	903834.1	41687.0	0.0599	13.6	0.8
2004	2	GOM	LIM	903834.1	41687.0	0.0599	4.8	0.3
2004	3	GOM	LIM	903834.1	41687.0	0.0599	7.6	0.5
2004	4	GOM	LIM	903834.1	41687.0	0.0599	17.9	1.1
2004	1	MA	GEN	1850198.5	88558.9	0.1417	2108.4	298.7
2004	2	MA	GEN	11665.2	1152.0	0.0988	1469.8	145.1
2004	3	MA	GEN	51917.9	6628.5	0.1277	1746.8	223.0
2004	4	MA	GEN	75295.0	7013.5	0.0931	2082.7	194.0
2004	1	MA	LIM	3512382.0	218198.2	0.0621	52059.4	3234.1
2004	2	MA	LIM	4242871.1	152827.9	0.0360	40819.4	1470.3

Table 5 cont

2004	3	MA	LIM	3747024.5	140658.8	0.0375	28934.5	1086.2
2004	4	MA	LIM	5005748.4	270046.3	0.0539	27941.7	1507.4
2004	1	SNE	GEN	1850198.5	88558.9	0.1417	121.9	17.3
2004	2	SNE	GEN	1850198.5	88558.9	0.1417	18.2	2.6
2004	3	SNE	GEN	1850198.5	88558.9	0.1417	179.7	25.5
2004	4	SNE	GEN	4403.1	155.0	0.0352	162.2	5.7
2004	1	SNE	LIM	1850198.5	88558.9	0.1417	59.7	8.5
2004	2	SNE	LIM	1850198.5	88558.9	0.1417	8.7	1.2
2004	3	SNE	LIM	1850198.5	88558.9	0.1417	235.7	33.4
2004	4	SNE	LIM	479.0	350.0	0.7307	33.0	24.1
2005	1	GBK	GEN	41555.5	907.1	0.0218	156.3	3.4
2005	2	GBK	GEN	21770.8	260.5	0.0120	761.2	9.1
2005	3	GBK	GEN	33530.6	1006.0	0.0300	1251.3	37.5
2005	4	GBK	GEN	6791.4	148.0	0.0218	1262.2	27.5
2005	1	GBK	LIM	1555423.6	45189.8	0.0291	11253.2	326.9
2005	2	GBK	LIM	506638.5	28918.0	0.0571	4017.4	229.3
2005	3	GBK	LIM	3279688.8	158732.0	0.0484	25084.8	1214.1
2005	4	GBK	LIM	4234053.2	177304.3	0.0419	21842.3	914.7
2005	1	GOM	GEN	11563.2	586.9	0.0508	261.5	13.3
2005	2	GOM	GEN	11563.2	586.9	0.0508	128.6	6.5
2005	3	GOM	GEN	11563.2	586.9	0.0508	162.7	8.3
2005	4	GOM	GEN	11563.2	586.9	0.0508	165.1	8.4
2005	1	GOM	LIM	11563.2	586.9	0.0508	86.0	4.4
2005	2	GOM	LIM	11563.2	586.9	0.0508	16.2	0.8
2005	3	GOM	LIM	11563.2	586.9	0.0508	8.7	0.4
2005	4	GOM	LIM	11563.2	586.9	0.0508	18.7	1.0
2005	1	MA	GEN	61095.5	13888.0	0.2273	2243.3	509.9
2005	2	MA	GEN	49746.3	3487.0	0.0701	1595.9	111.9
2005	3	MA	GEN	105742.2	7938.0	0.0751	2087.8	156.7
2005	4	MA	GEN	198930.7	30837.0	0.1550	2610.5	404.7
2005	1	MA	LIM	2664400.4	179014.5	0.0672	32820.5	2205.1
2005	2	MA	LIM	1606428.9	97359.5	0.0606	37930.8	2298.8
2005	3	MA	LIM	1041484.0	92504.5	0.0888	10527.7	935.1
2005	4	MA	LIM	911974.9	58671.5	0.0643	10021.0	644.7
2005	1	SNE	GEN	5845.1	1536.0	0.2628	225.5	59.3
2005	2	SNE	GEN	3141.7	920.7	0.3310	321.8	106.5
2005	3	SNE	GEN	3141.7	920.7	0.3310	292.9	97.0
2005	4	SNE	GEN	3076.1	1026.0	0.3335	251.7	84.0
2005	1	SNE	LIM	3141.7	920.7	0.3310	200.2	66.3
2005	2	SNE	LIM	3141.7	920.7	0.3310	499.1	165.2
2005	3	SNE	LIM	504.0	200.0	0.3968	73.0	29.0
2005	4	SNE	LIM	3141.7	920.7	0.3310	204.2	67.6
2006	1	GBK	GEN	1512131.0	50721.1	0.0430	830.6	35.8
2006	2	GBK	GEN	26456.1	274.4	0.0104	1566.4	16.2
2006	3	GBK	GEN	26567.8	2245.6	0.0845	1082.4	91.5
2006	4	GBK	GEN	45981.8	2645.6	0.0575	1305.6	75.1
2006	1	GBK	LIM	1052972.5	43136.0	0.0410	11703.4	479.4
2006	2	GBK	LIM	1776873.6	29162.4	0.0164	31707.2	520.4
2006	3	GBK	LIM	4908723.7	59263.8	0.0121	44152.5	533.1

Table 5 cont.

2006	4	GBK	LIM	2747341.3	218319.9	0.0795	21441.8	1703.9
2006	1	GOM	GEN	1512131.0	50721.1	0.0430	228.7	9.8
2006	2	GOM	GEN	1512131.0	50721.1	0.0430	314.2	13.5
2006	3	GOM	GEN	1512131.0	50721.1	0.0430	64.3	2.8
2006	4	GOM	GEN	1512131.0	50721.1	0.0430	36.7	1.6
2006	1	GOM	LIM	1512131.0	50721.1	0.0430	107.0	4.6
2006	2	GOM	LIM	1512131.0	50721.1	0.0430	128.6	5.5
2006	3	GOM	LIM	1512131.0	50721.1	0.0430	1.7	0.1
2006	4	GOM	LIM	1512131.0	50721.1	0.0430	11.4	0.5
2006	1	MA	GEN	19798.3	1046.5	0.0529	3376.0	178.5
2006	2	MA	GEN	262927.9	39213.7	0.1556	2295.4	357.3
2006	3	MA	GEN	11021.8	2654.0	0.2408	1999.7	481.5
2006	4	MA	GEN	167288.2	61724.6	0.3690	2107.8	777.7
2006	1	MA	LIM	201969.6	19943.0	0.0987	24214.1	2391.0
2006	2	MA	LIM	262927.9	39213.7	0.1556	9894.9	1540.1
2006	3	MA	LIM	66415.1	2655.0	0.0400	1594.3	63.7
2006	4	MA	LIM	1111074.6	147259.0	0.1325	7411.1	982.2
2006	1	SNE	GEN	4205.3	620.7	0.1641	321.2	52.7
2006	2	SNE	GEN	4205.3	620.7	0.1641	613.7	100.7
2006	3	SNE	GEN	5919.8	897.0	0.1515	697.4	105.7
2006	4	SNE	GEN	2826.0	959.0	0.3393	81.8	27.8
2006	1	SNE	LIM	4205.3	620.7	0.1641	200.0	32.8
2006	2	SNE	LIM	4205.3	620.7	0.1641	138.3	22.7
2006	3	SNE	LIM	4205.3	620.7	0.1641	285.5	46.9
2006	4	SNE	LIM	4205.3	620.7	0.1641	132.6	21.8
2007	1	GBK	GEN	3870.1	6.0	0.0016	532.5	0.8
2007	2	GBK	GEN	358236.7	4589.8	0.0128	1451.1	18.6
2007	3	GBK	GEN	288991.1	7412.7	0.0257	1733.7	44.5
2007	4	GBK	GEN	1247.0	384.0	0.3079	757.2	233.2
2007	1	GBK	LIM	593878.9	41340.9	0.0696	6329.5	440.6
2007	2	GBK	LIM	2849421.4	46885.3	0.0165	23308.7	383.5
2007	3	GBK	LIM	3884526.0	140290.9	0.0361	27790.1	1003.6
2007	4	GBK	LIM	2561393.5	380441.5	0.1485	14195.1	2108.4
2007	1	GOM	GEN	2047.0	161.8	0.0764	233.1	17.8
2007	2	GOM	GEN	1866.0	87.0	0.0466	118.9	5.5
2007	3	GOM	GEN	2047.0	161.8	0.0764	67.9	5.2
2007	4	GOM	GEN	2228.0	236.5	0.1061	97.4	10.3
2007	1	GOM	LIM	2047.0	161.8	0.0764	49.1	3.7
2007	2	GOM	LIM	2047.0	161.8	0.0764	8.3	0.6
2007	3	GOM	LIM	2047.0	161.8	0.0764	110.6	8.4
2007	4	GOM	LIM	2047.0	161.8	0.0764	56.2	4.3
2007	1	MA	GEN	70251.7	10615.7	0.1511	4568.1	690.3
2007	2	MA	GEN	29147.2	1961.5	0.0673	3812.6	256.6
2007	3	MA	GEN	78997.6	5916.0	0.0749	3056.1	228.9
2007	4	MA	GEN	85023.5	9005.0	0.1059	3266.0	345.9
2007	1	MA	LIM	2004191.4	123968.2	0.0619	42576.1	2633.5
2007	2	MA	LIM	2129420.5	79156.8	0.0372	31869.6	1184.7
2007	3	MA	LIM	1126763.4	68026.4	0.0604	13663.4	824.9
2007	4	MA	LIM	2908179.8	194294.7	0.0668	24775.2	1655.2

Table 5 cont.

2007	1	SNE	GEN	2468.6	518.0	0.8185	68.3	55.9
2007	2	SNE	GEN	1926.0	240.0	0.1246	299.0	37.3
2007	3	SNE	GEN	2468.6	518.0	0.8185	361.5	295.9
2007	4	SNE	GEN	7787.3	1657.0	0.2128	395.9	84.2
2007	1	SNE	LIM	126.0	100.0	0.7936	19.2	15.3
2007	2	SNE	LIM	2468.6	518.0	0.8185	440.7	360.7
2007	3	SNE	LIM	2468.6	518.0	0.8185	225.0	184.1
2007	4	SNE	LIM	35.0	75.0	2.1428	252.8	541.7

Skates:
Discard Estimations
Appendix 2

By
Andrew Applegate
New England Fishery Management Council
Newburyport, MA

Data Poor Stocks Working Group Meeting
Woods Hole, MA
December 8-12, 2008

This Working Paper was distributed for pre-dissemination peer review at the NE Data Poor Stocks Peer Review Meeting, December 8-12, 2008. It does not represent any final NOAA agency determination or policy. Some comments in the Peer Review Panel's Report of the Data Poor Stock Working Group are in response to this WP.

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John Pappalardo, *Chairman* | Paul J. Howard, *Executive Director*

MEMORANDUM

DATE: **December 11, 2008**

TO: Data Poor Assessment Workshop

FROM: Andrew Applegate

SUBJECT: **Discard estimation**

During the Data Poor Assessment Workshop (DPWS), new skate discard estimates were presented which differed substantially (see Figure 1) from those estimated during SAW44 and updated by the Skate PDT during the development of Amendment 3. Most of the differences were thought to be associated with filling unmatched trips with average DK (live weight ratio of observed discarded skates to the observed kept of all species). Like the SAW44 estimate, a three level stratification was applied to observed trips and dealer landings (obtained from the area allocation "AA" tables). The stratification included gear (longline, limited access scallop dredge, general category scallop dredge, shrimp trawl, sink gillnet, and fish trawl), region (Gulf of Maine, Georges Bank, Southern New England, Mid-Atlantic) and quarter (1-4).

The new estimates had the same trend as the previous ones through 2002, but differed substantially from 2003 to 2006 (Figure 1). Most filled DK rations, however, were concentrated in earlier years (Figures 4-7), the largest difference arising from longline gear in 1991 and 1992 and trawl gear in 1998. The cause of the differences for 2003-2006 were not apparent. These more recent discard estimates are critically important because the Council uses the last three years of the discard time series (2004-2006) to reduce the allowable catch limits and set landings targets. Based on the earlier estimates, it was believed that discards had declined substantially due to regulatory effects. The new estimated discards do not show this decline.

To explore the source of these important differences the sea sampling and dealer data were analyzed independently using a different stratification schema to potentially reduce the effects of oversampling of the US/CA area, access area, and special access program trips which are distributed in special areas. Also mesh categories were also introduced to account for DK differences that might be caused by small (< 5.5 inches), large (5.5 to 8 inches), and very large mesh (> 8 inches) for trawl and sink gillnets. A seasonal stratification was also applied (fall 07-10, spring 03-06, and winter 11-02) to comport with the three annual finfish NMFS trawl surveys so that the aggregate discard estimates could be allocated by species. A four level stratification was applied to both data sets: gear (longline, scallop dredge, scallop trawl, sink gillnet, fish trawl, shrimp trawl, and other), sub-region (Delmarva, E. Georges Bank, E. Gulf of Maine, NY Bight, Offshore, S. Channel, Southern New England, and Other), season (see above), and mesh (see above). Dealer data that matched observed DK ratios from observed trips accounted for about 65-75% of total landings. Where DK matches did not exist, the DK ratio for a two level stratification (gear and sub-region) was applied. Together, the combined matches accounted for 95-99% of total landings. The remaining unmatched trips were for combinations that generally seemed to be associated with low skate discards and the DK ratios were assumed to be zero. No general linear modeling was applied (see analysis below for further discussion) at the time of these discard estimates.

Similar to the NEFSC estimates, the ratio of sums (DK) were applied to total live weight landings of all species on the dealer reports. A simplified method was also applied which discards are the multiplicative product of the observed skate discards per trip times the number of trips landed by dealers. For both, discard 95% confidence levels were computed by bootstrapping the trips (10% of trips in 100 iterations) to obtain a standard deviation for the DK mean by gear. The discard estimates in each 'cell' were then calculated over 1000 iterations with a log normal distribution on DK with a mean μ and a standard deviation σ.

The alternative discard estimates (Figure 2) tend to agree reasonably well with the NEFSC estimates since 1999, and particularly well for estimates since 2003. Before 1998, the discard estimates diverge due to low sample size, but generally all estimates show a declining trend from 1996-1999.

These discard estimates did not however reveal the source of the error in the SAW44 discard estimates. Further exploration of the discard rates was conducted to try to understand why skate discards do not appear to be declining despite more restrictive groundfish regulations during the recent period. For vessels using trawls, skate discards per haul, trip, and kept landings increased from 2000 to 2008 (Figure 9). A similar pattern was observed for vessels using sink gillnets (Figure 10). Observed skate discard rates declined for vessels using scallop dredges (Figure 11). In all three cases, the trends could be caused by oversampling trips in special access programs that could have skate discard rates that differ from regular trips.

Skate discards for vessels landing more than 1000 lbs. of skates (live weight) also increased since 2001 (Figure 12), but appear to level off since 2005 and possible decline in 2008 (a partial year). Skate discard rates for vessels fishing in the Gulf of Maine (Figure 14) and the Mid-Atlantic (Figure 16) appeared to vary without trend (Figure 13) at very low levels particularly since 1999, either per trip or per lb. kept. There appears to be a moderate upward trend in discards in Southern New England (Figure 15) since 2000. Skate discard rates on Georges Bank appear to have trended upward since 2001 (Figure 14), mimicking the overall trend.

When broken out by management program, skate discard rates for regular trawl trips in the Georges Bank region varied without trend from 1989 to 2000, then increased in 2001 and varied at a higher level since that time. In the more recent period, discards averaged 0.3 to 0.6 lbs. of skates per pound kept. In contrast, skate discards on oversampled US/CA area trips were much higher, averaging 0.6 to 0.8 lbs. of skate discards per pound kept.

During the comparison of the discard estimates during the DPWS, it was determined that the SAW44 estimates did not include the US/CA area, scallop access area, and groundfish special access program observed trips. It seems plausible that this omission may have contributed to the estimated declining trend in skate discards that was previously estimated. On the other hand, the high skate discard rates in the US/CA trips may also in some cases be inappropriately applied to non-US/CA area trips, but there is no field in the dealer data to determine trip type. Some post-stratification of DK rates and dealer landings by sub-region and time could reduce this undue influence on the discard estimation.

Also during the DPWS, it was suggested that a General Linear Model (GLM) analysis should be conducted to determine which type of stratification of observed trips would be better a better model to follow. All three stratifications were analyzed via GLM, plus the NEFSC stratification with only regular management program trips (excluding US/CA area, scallop access area, Multispecies Category B DAS, and special access program trips). All models were significant and one stratification wasn't clearly superior to the other, except that simpler models (i.e. less independent variables) explained a significant amount of the DK variance, but all models had relatively low predictive capability (low R).

More detailed information about the GLM analyses are shown in Tables 2-5. For model 1 (Table 2), the MSE for all independent variables except quarter were significant. Holding the effects of the other independent variables constant, the least squares means increased from 2001 to 2007. Trawl DK rates were substantially higher than other gears and higher in the Southern New England region than the others. Similar trends were observed for a GLM applied to only regular management program observed trips (Table 3).

For model 3 (Table 4), which was applied to unmatched trips in this analysis, all independent variables (year, gear, sub-region) were significant and explained a significant fraction of the DK variation. DK trends for year and gear were similar to those for models 1 and 2. DK rates were high for the E. Georges Bank, NY Bight, and Southern New England sub-regions. All independent variables in model 4 (which was used in this analysis to estimate discards on matched trips) were significant (Table 5), except for season which was retained to comport with the survey data to be used to allocate aggregate discards to species. Holding the effects of the other independent variables constant, the least squares means showed a similar trend for year, but the discard rate for trawls was lower than the other model formulations which did not use mesh as an independent variable. Somewhat counter intuitively, the DK rate was highest for large mesh trawls and gillnets, and lowest for small mesh trawls and gillnets. This may be related to the lower amount of kept for other species compared to the discard of skates for vessels using large mesh. It also suggests that vessels using mesh larger than 8 inches may have a lower skate discard rate – or simply catch more of the target species relative to the amount of skates discarded.

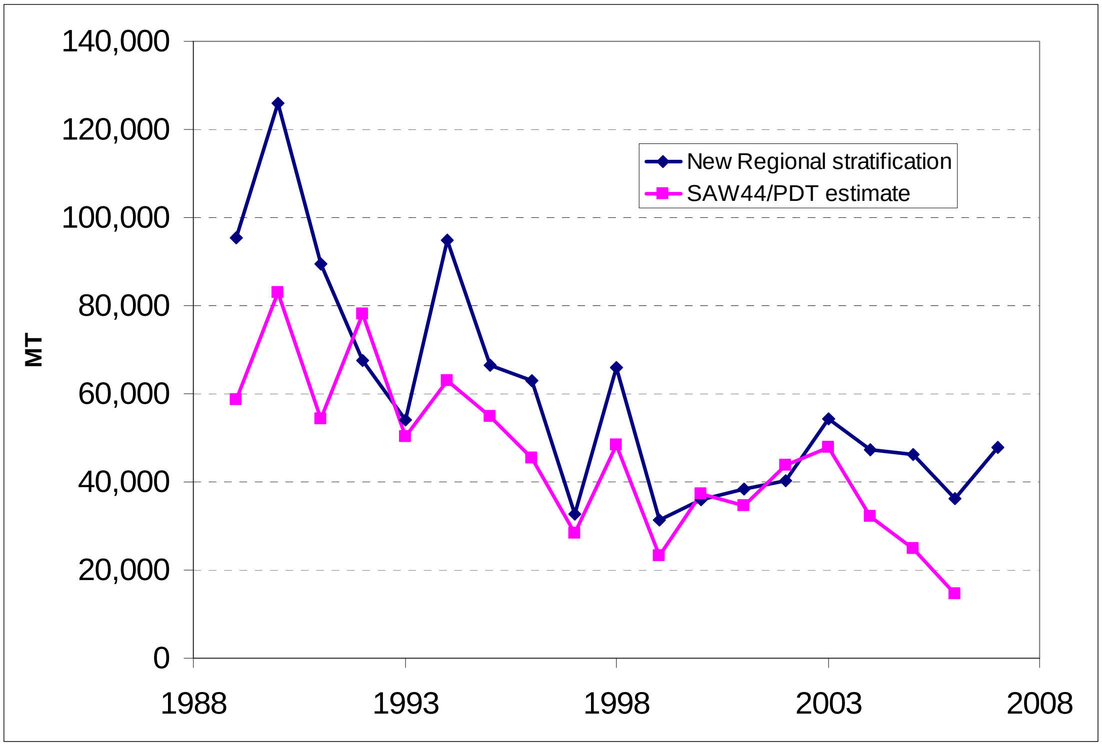


Figure 1. Comparison of new NEFSC discard estimates with SAW44/PDT discard estimates.

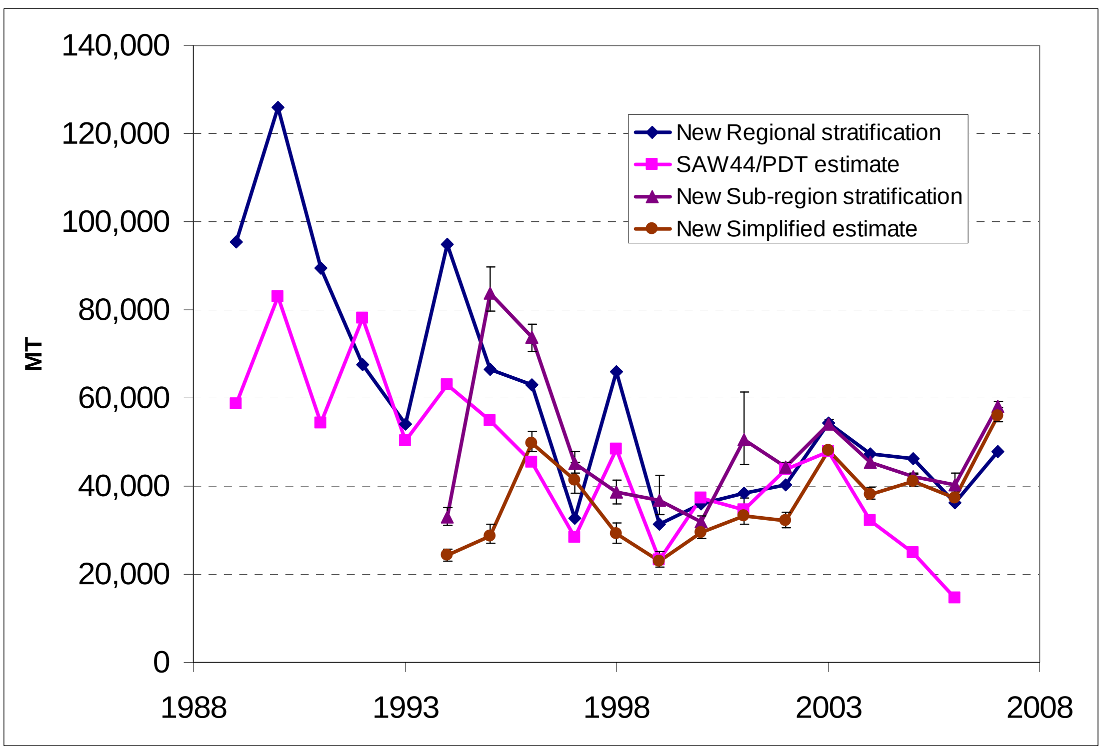


Figure 2. Comparison of discard estimates, including one using a simplified method and a re-stratification at the subregion level (gear, sub-region, season, mesh)

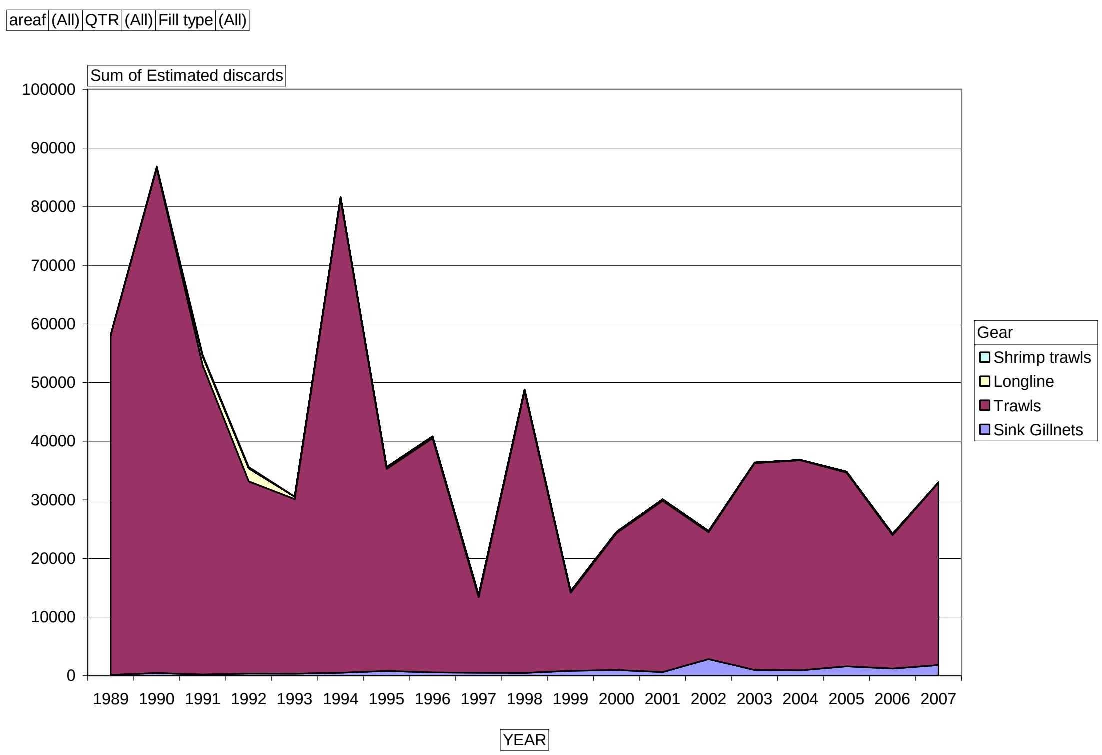


Figure 3. Match trips and all fill types: Estimated discards by gear type via the new NEFSC skate discard estimation.

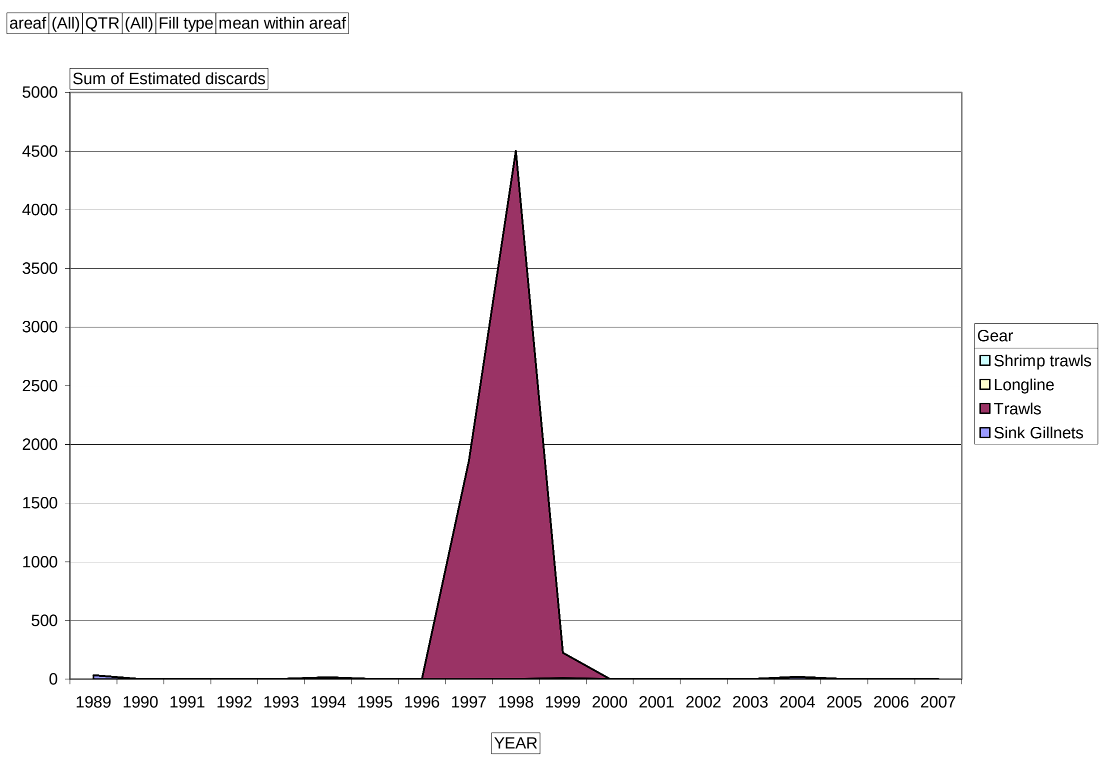


Figure 4. Mean within area fill: Estimated discards by gear type via the new NEFSC skate discard estimation.

areaf	(All)	QTR	(All)	Fill type	mean combined region (ie sne-ma)

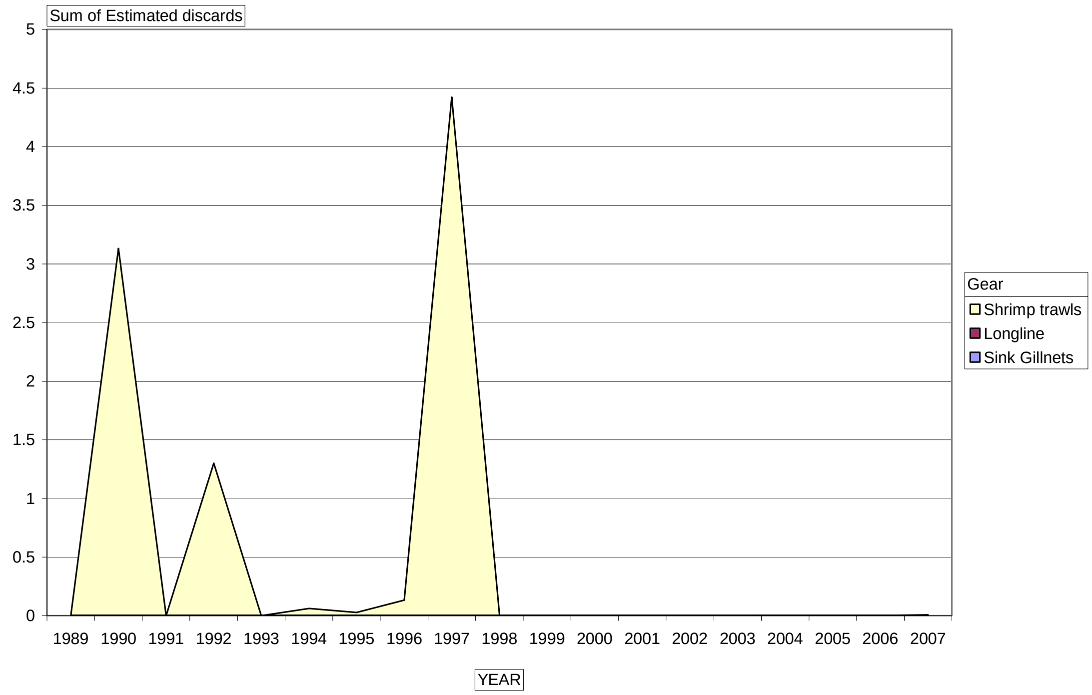


Figure 5. Mean within region fill: Estimated discards by gear type via the new NEFSC skate discard estimation.

areaf	(All)	QTR	(All)	Fill type	average across year

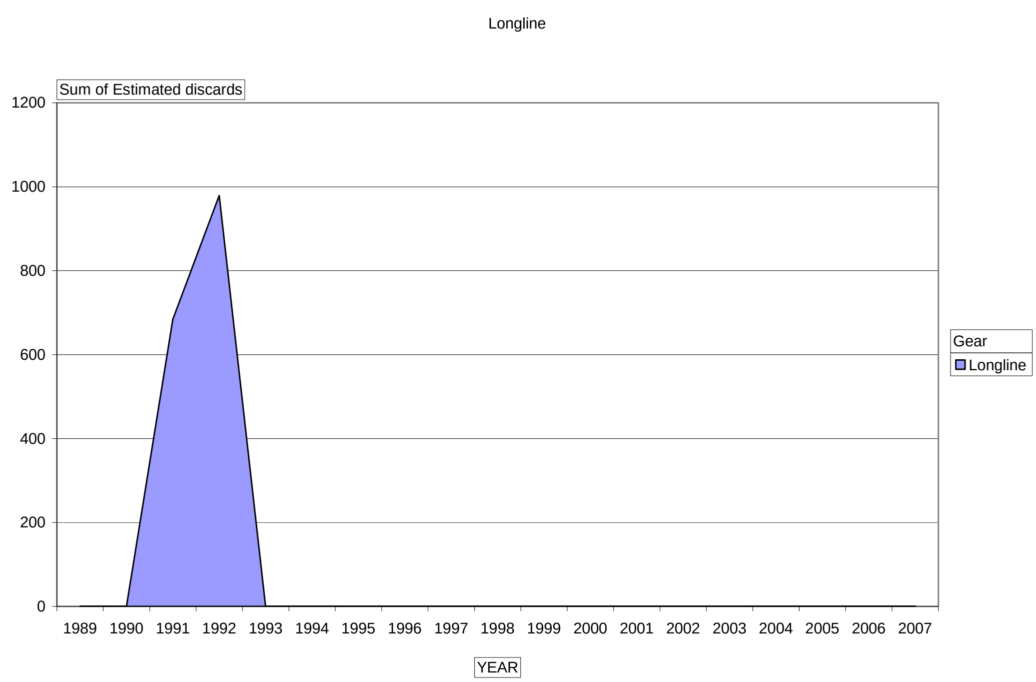


Figure 6. Mean within year fill: Estimated discards by gear type via the new NEFSC skate discard estimation.

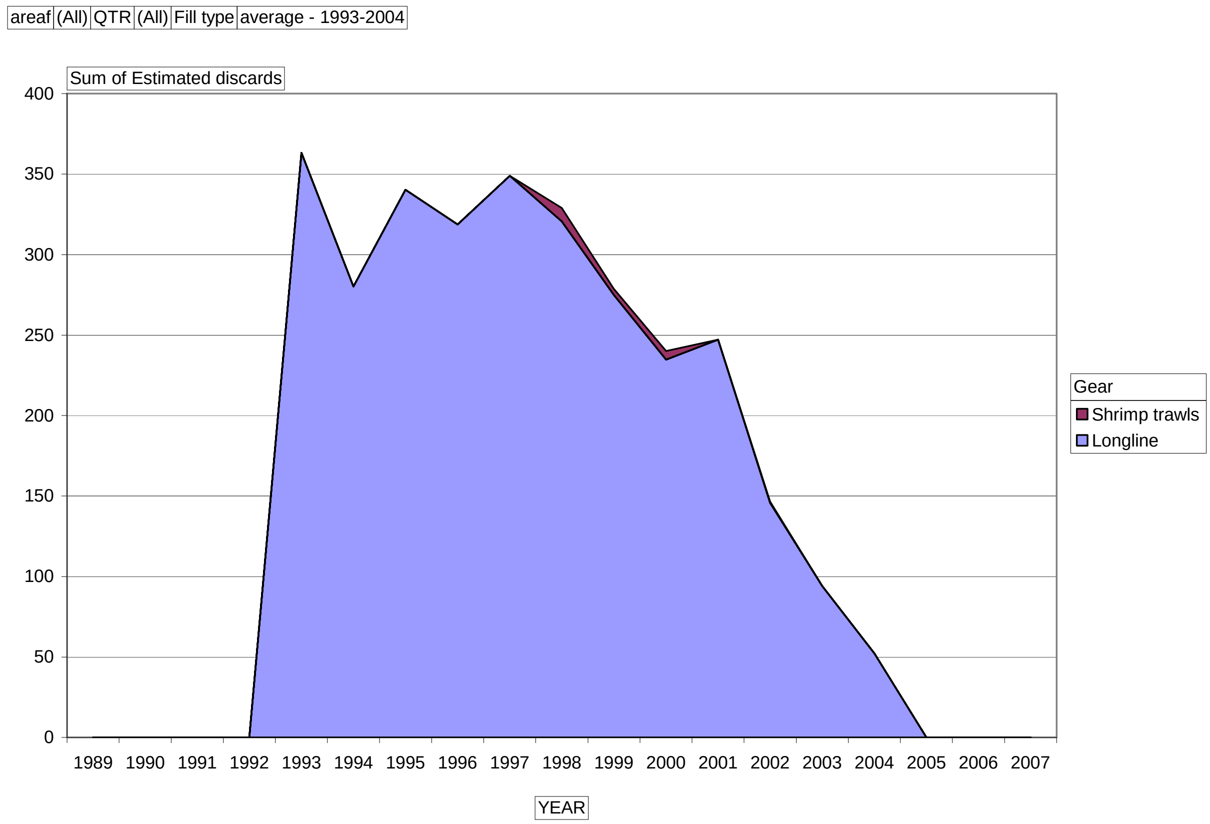


Figure 7. Mean for gear fill: Estimated discards by gear type via the new NEFSC skate discard estimation.

Fill type	None

Average of dkratio		Gear	areaf																	
		Longline				Scallop dredges				Shrimp trawls		Sink Gillnets				Trawls				Grand Total
YEAR	QTR	GBK	GOM	MA	SNE	GBK	GOM	MA	SNE	GBK	GOM	GBK	GOM	MA	SNE	GBK	GOM	MA	SNE	
1989	1									0.000	0.020				0.000	0.802	0.346	0.213	1.688	0.438
	2										0.042	0.003			0.000	0.272	0.166	0.024	0.297	0.115
	3											0.005	0.003		0.000	0.286	0.128	0.510	1.136	0.295
	4										0.018	0.018	0.008		0.000	0.386	0.194	0.145	0.569	0.167
1990	1										0.050	0.014	0.107			1.037	0.246	0.144	2.583	0.597
	2										0.011	0.013	0.047	0.000		0.335	0.130	0.103	0.081	0.090
	3											0.000	0.003			0.125	0.028	0.384	0.131	0.112
	4										0.114	0.002	0.009	0.000	0.000	0.281	0.280	0.426	1.825	0.326
1991	1	0.774								0.289	0.069	0.005	0.041	0.000		0.345	0.123	0.009	0.706	0.236
	2										0.038	0.007	0.014	0.000		0.399	0.042	0.444	0.451	0.174
	3											0.019	0.008		0.000	0.075	0.083	1.595	0.363	0.306
	4	0.174	0.041								0.129	0.045	0.007		0.000	0.516	0.086	0.209	0.257	0.147
1992	1	0.906	0.110								0.078	0.053	0.104	0.000	0.016	0.474	0.102	0.109	0.027	0.180
	2	0.222		0.000							0.000	0.013	0.017		0.053	0.100	0.014	0.020	0.395	0.083
	3											0.002	0.003		0.067	0.029	0.024	0.212	0.231	0.081
	4										0.001	0.039	0.005		0.018	0.170	0.048	0.609	0.591	0.185
1993	1		0.088	0.000						0.000	0.018	0.017	0.050	0.000	0.044	0.116	0.146	0.024	0.060	0.047
	2			0.068								0.005	0.017		0.041	0.257	0.053	0.045	0.645	0.141
	3			0.000								0.002	0.002	0.000	0.170	0.020	0.025	0.047	0.866	0.126
	4										0.003	0.020	0.004	0.002	0.011	0.748	0.079	0.444	0.258	0.174
1994	1	0.000		0.000							0.005	0.007	0.103	0.007	0.014	0.204	0.030	0.099	0.004	0.043
	2											0.000	0.003	0.003	0.069	0.466	0.070	5.436	2.257	1.038
	3											0.000	0.001	0.001		0.239	0.071	0.048	0.071	0.061
	4										0.001	0.016	0.013	0.013	0.084	0.892	0.026	0.134	0.321	0.166
1995	1										0.002	0.031	0.097	0.014	0.077	0.415	0.048	0.632	0.101	0.157
	2											0.003	0.018	0.010	0.063	0.758	0.035	0.302	0.489	0.210
	3											0.003	0.003	0.004	0.114	0.120	0.011	0.106	0.107	0.058
	4										0.000	0.013	0.050	0.013	0.014	0.235	0.031	0.553	0.137	0.116
1996	1										0.004	0.035	0.216	0.016	0.004	0.615	0.033	0.225	0.132	0.142
	2										0.000	0.002	0.017	0.010	0.013	0.322	0.048	0.036	0.303	0.083
	3											0.008	0.004	0.007	0.000		0.000	0.004	2.012	0.291
	4										0.005	0.011	0.001	0.008	0.014	0.081	0.035	0.074	1.442	0.186
1997	1									0.001	0.006	0.005	0.048	0.019	0.002	0.241	0.128	0.079	0.125	0.065
	2											0.008	0.012	0.046	0.000		0.011		0.058	0.023
	3											0.001	0.000	0.000	0.030	0.145	0.004	0.003	0.531	0.089
	4											0.008	0.002	0.009	0.021	0.270		0.016	0.041	0.052
1998	1											0.022	0.021	0.008	0.002	0.169	0.092	0.051	0.072	0.055
	2											0.002	0.003	0.025	0.006		0.023	1.984	0.183	0.318
	3			0.087								0.022	0.001	0.028		0.148	0.579	0.113	0.064	0.130
	4											0.004	0.007	0.017	0.016	1.149		0.116	0.185	0.213
1999	1											0.090	0.008	0.021	0.014	0.004		0.010	0.006	0.022
	2											0.003	0.015	0.079	0.013	0.370	0.020	0.139	0.008	0.081
	3											0.003	0.003	0.000		0.405	0.042	0.009		0.077
	4											0.004	0.037	0.015	0.058	0.421	0.007	0.112	0.101	0.094
2000	1											0.016	0.015	0.000	0.023	0.123	0.151	0.039	0.094	0.057
	2											0.038	0.032	0.005	0.032	0.294	0.108	0.123	0.153	0.098
	3											0.486	0.007	0.000		0.197	0.016	0.011	0.186	0.129
	4											0.096	0.012	0.009	0.012	0.543	0.053	0.446	0.466	0.204
2001	1										0.000	0.058	0.020	0.004	0.000	1.129	0.062	0.004	0.041	0.146
	2											0.018	0.056	0.006	0.183	0.144	0.056	0.071	0.323	0.107
	3											0.009	0.011	0.000	0.000	0.164	0.064	0.014	0.114	0.047
	4											0.078	0.010	0.005	0.016	0.308	0.037	0.062	0.217	0.092
2002	1											0.033	0.002	0.029	0.035	0.459	0.031	0.065	0.000	0.082
	2											0.119	0.016	0.015	0.045	0.422	0.092	0.080	0.045	0.104
	3	0.212										0.022	0.052	0.000	0.021	0.309	0.072	0.058	0.081	0.092
	4	0.033	0.000		0.456							0.030	0.013	0.003	1.702	0.289	0.095	0.216	0.333	0.288
2003	1	0.155	0.057			0.018	0.042	0.073	0.008		0.009	0.286	0.029	0.025	0.069	0.576	0.077	0.186	0.716	0.150
	2					0.156		0.114				0.019	0.018	0.004	0.046	0.315	0.080	0.160	0.035	0.096
	3					0.099		0.217				0.036	0.011	0.000	0.055	0.472	0.085	0.005	2.266	0.315
	4	0.000				0.108		0.043	0.396			0.021	0.008	0.024	0.103	0.451	0.057	0.105	0.348	0.130
2004	1	0.013	0.011			0.045	0.003	0.062			0.004	0.064	0.026	0.000	0.036	0.446	0.049	0.064	0.111	0.067
	2							0.067				0.022	0.018	0.000	0.044	0.568	0.119	0.079	0.173	0.116
	3	0.035						0.083				0.046	0.009		0.025	0.620	0.042	0.023	0.729	0.169
	4	0.008		0.000	0.000	0.056	0.139	0.074	0.383			0.069	0.021	0.049	0.053	0.562	0.119	0.044	0.865	0.164
2005	1	0.093	0.052		0.000	0.025	0.051	0.147	0.263		0.003	0.767	0.051	0.025	0.059	0.538	0.059	0.045	0.168	0.140
	2	0.289	0.024			0.035		0.065				0.007	0.034	0.104	0.089	0.571	0.060	0.327	0.951	0.190
	3	0.105	0.012			0.039		0.082	0.397			0.045	0.009	0.038	0.106	0.718	0.067	0.155	0.627	0.168
	4	0.034	0.001	0.000	0.000	0.032		0.110	0.334			0.117	0.007	0.052	0.061	0.682	0.174	0.110	0.649	0.147
2006	1	0.498	0.040		0.008	0.041		0.076			0.000	0.023	0.050	0.035	0.067	0.717	0.106	0.034	0.174	0.130
	2	0.234		0.000		0.013						0.229	0.030	0.086	0.330	0.451	0.178	0.036	0.071	0.139
	3	0.000	0.000		0.000	0.048		0.140	0.152			0.058	0.008	0.003	0.126	0.730	0.079	0.021	0.274	0.114
	4	0.054	0.039	0.000	0.001	0.069		0.251	0.339		0.001	0.100	0.006	0.022	0.002	0.715	0.077	0.079	0.231	0.128
2007	1	0.376	0.093			0.036		0.106	0.794		0.000	0.622	0.018	0.025	0.119	0.680	0.153	0.109	0.178	0.216
	2	0.046	0.034			0.015	0.047	0.052	0.125			0.033	0.019	0.117	0.075	0.556	0.062	0.547	0.415	0.138
	3	0.081	0.091	0.000		0.031		0.068				0.069	0.013	0.013	0.040	1.062	0.031	0.050	0.479	0.142
	4	0.051	0.005	0.000	0.000	0.228	0.106	0.086	1.178			0.083	0.011	0.019	0.419	0.645	0.081	0.213	0.382	0.263
Grand Total		0.183	0.041	0.013	0.058	0.059	0.065	0.102	0.456	0.073	0.022	0.057	0.024	0.017	0.075	0.423	0.086	0.261	0.451	0.160

Figure 8. Observed D/K ratios by stratum, NEFSC estimation.

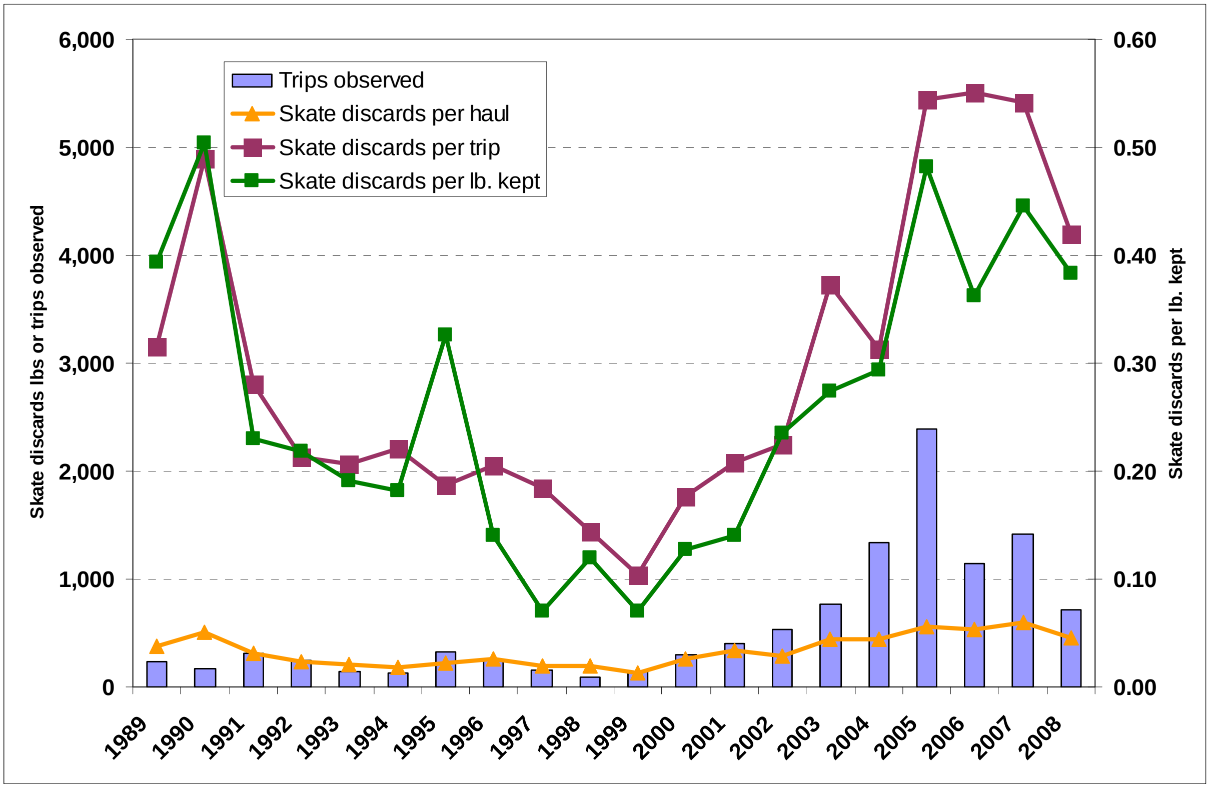


Figure 9. Observed skate discard rate for vessels using trawls.

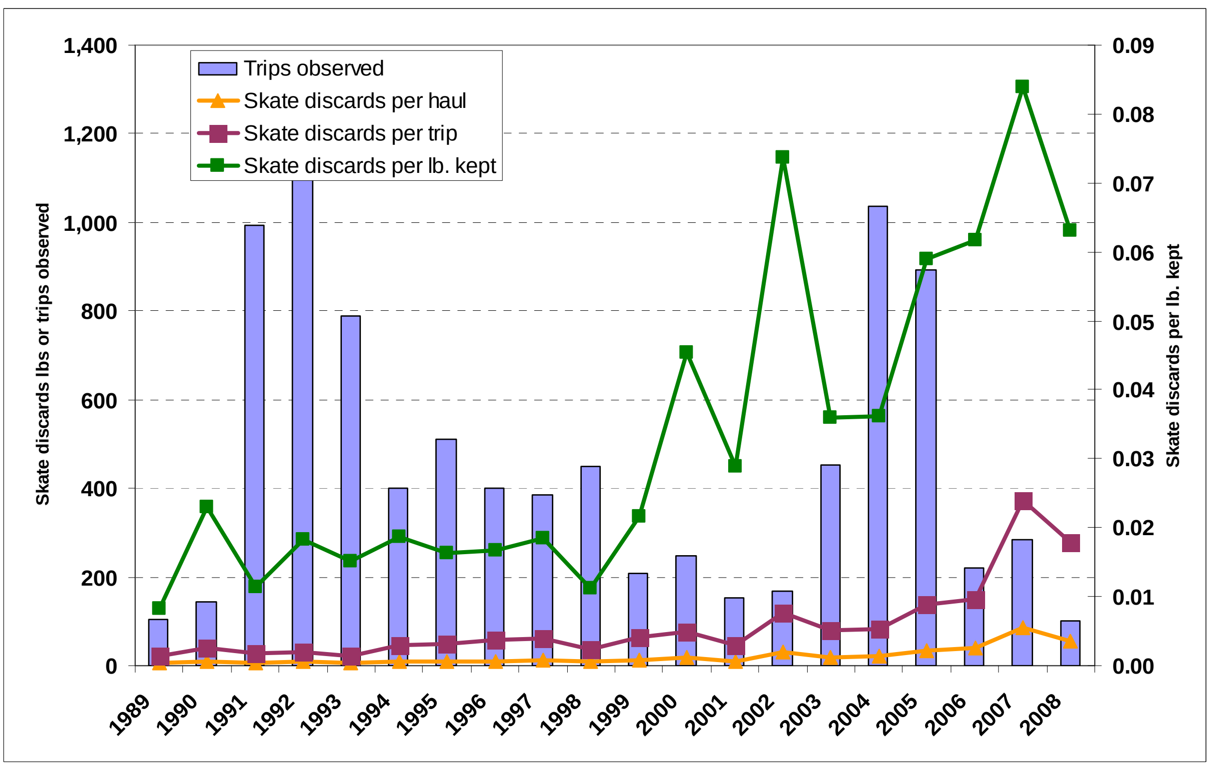


Figure 10. Observed skate discard rate for vessels using sink gillnets.

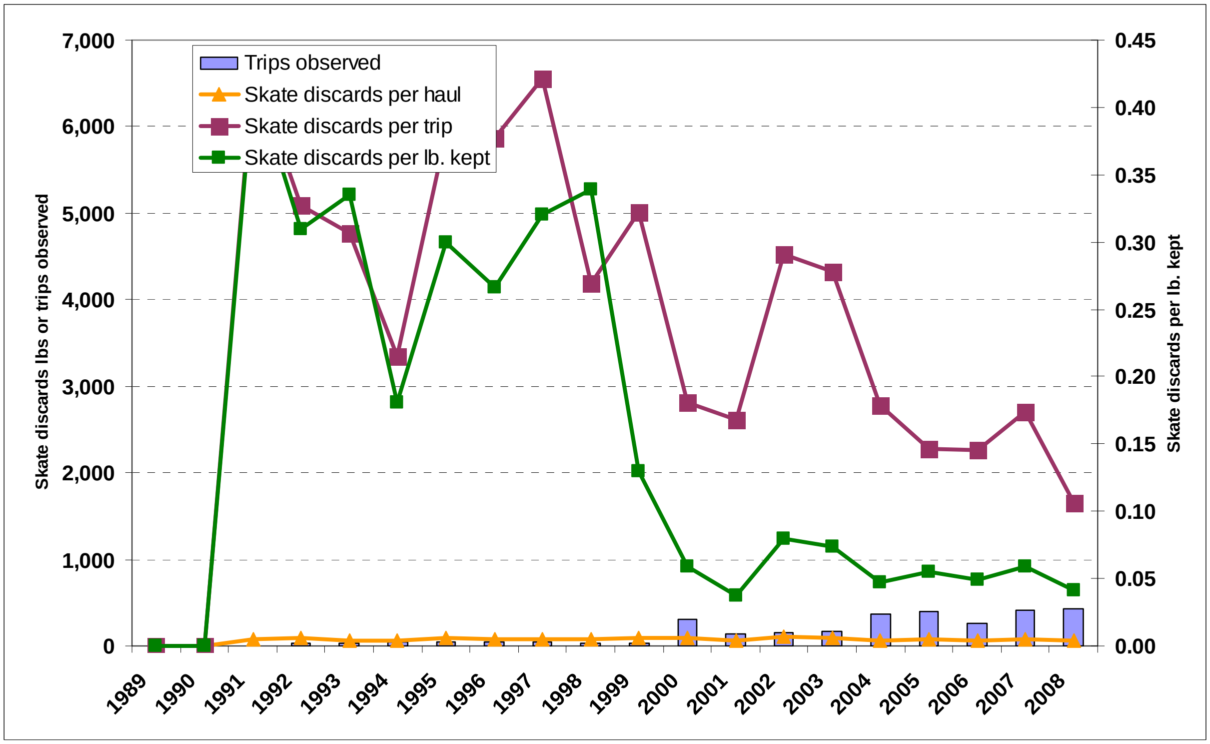


Figure 11. Observed skate discard rate for vessels using scallop dredges.

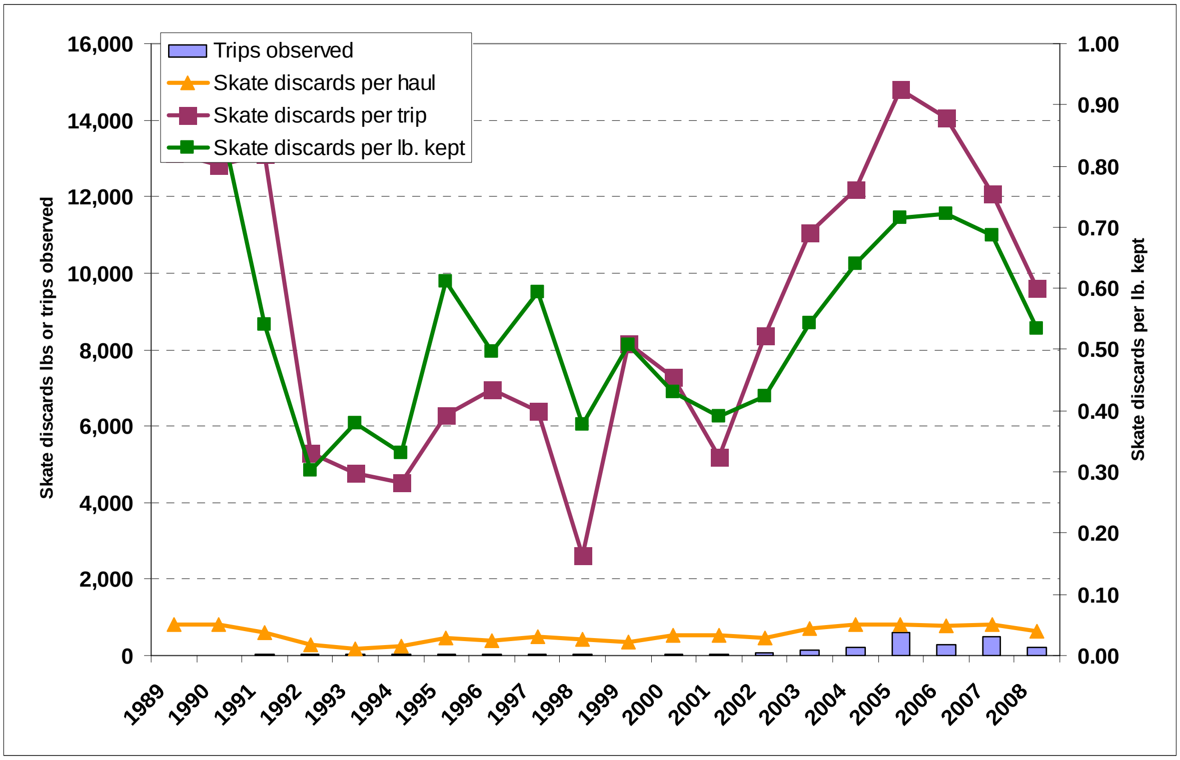


Figure 12. Observed skate discard rate for vessels landing > 1000 lbs. of skate, live weight.

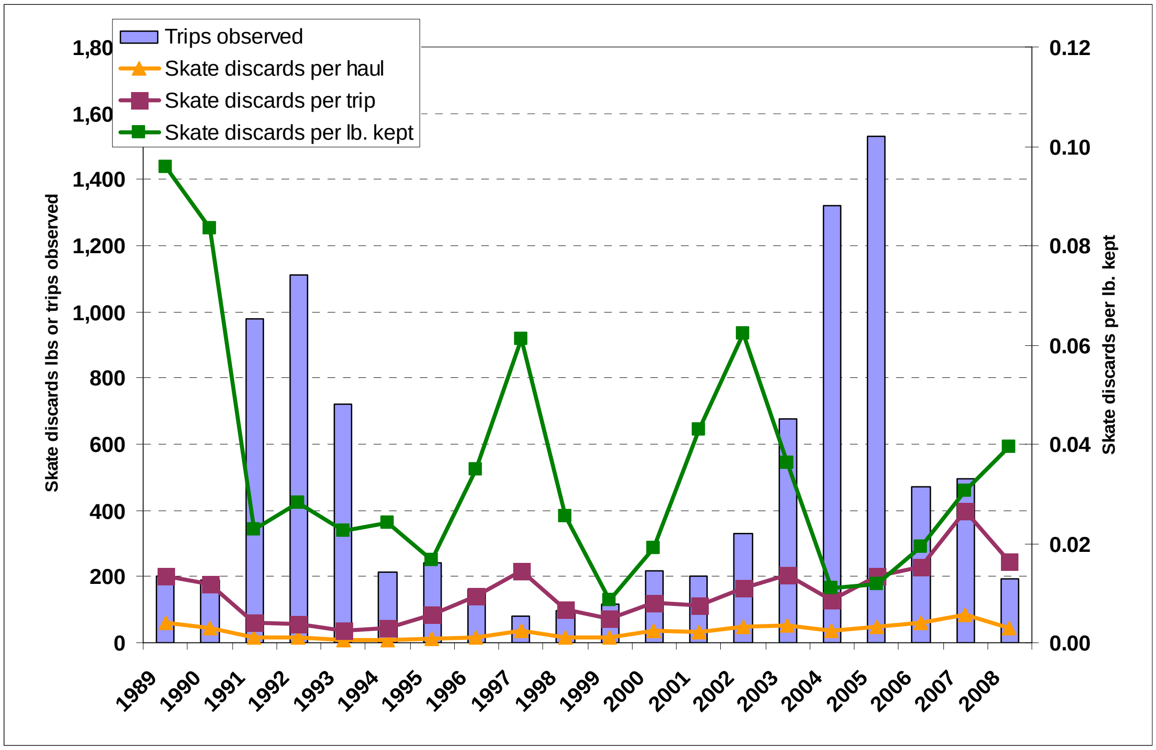


Figure 13. Observed skate discard rate for vessels fishing in the Gulf of Maine.

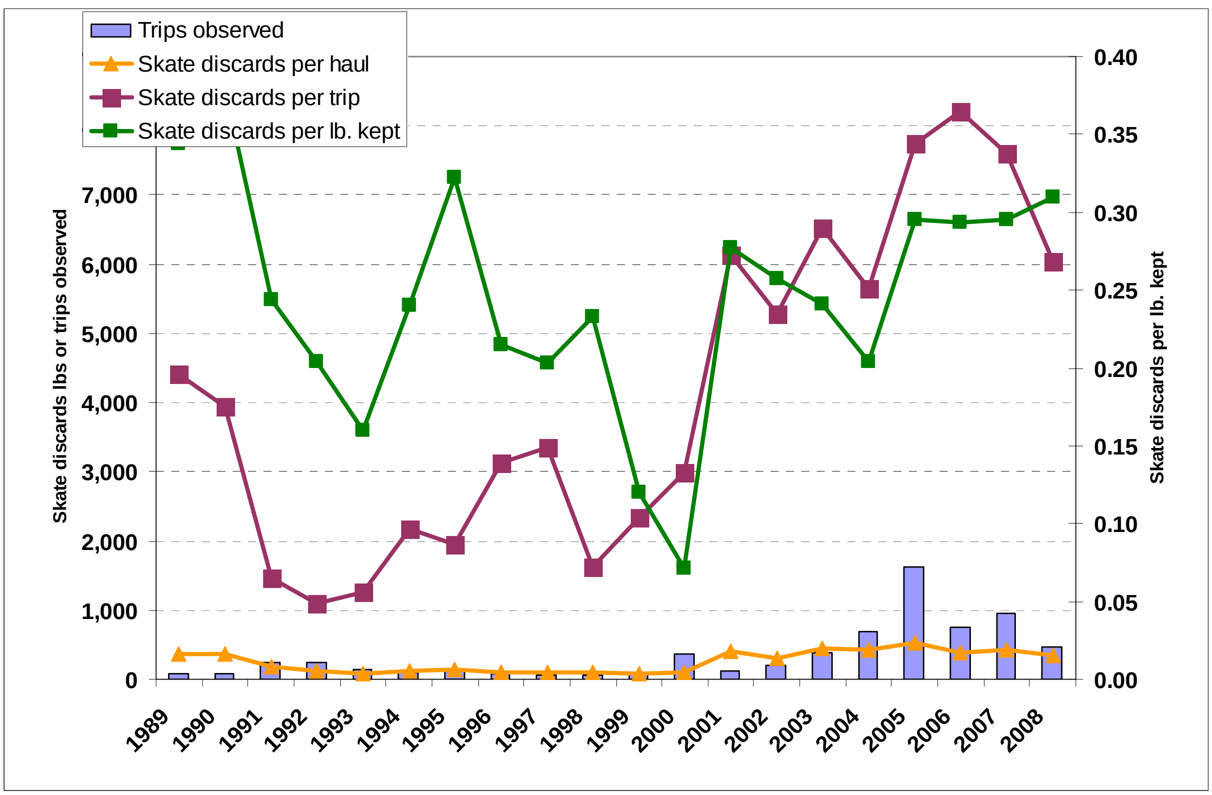


Figure 14. Observed skate discard rate for vessels fishing on Georges Bank.

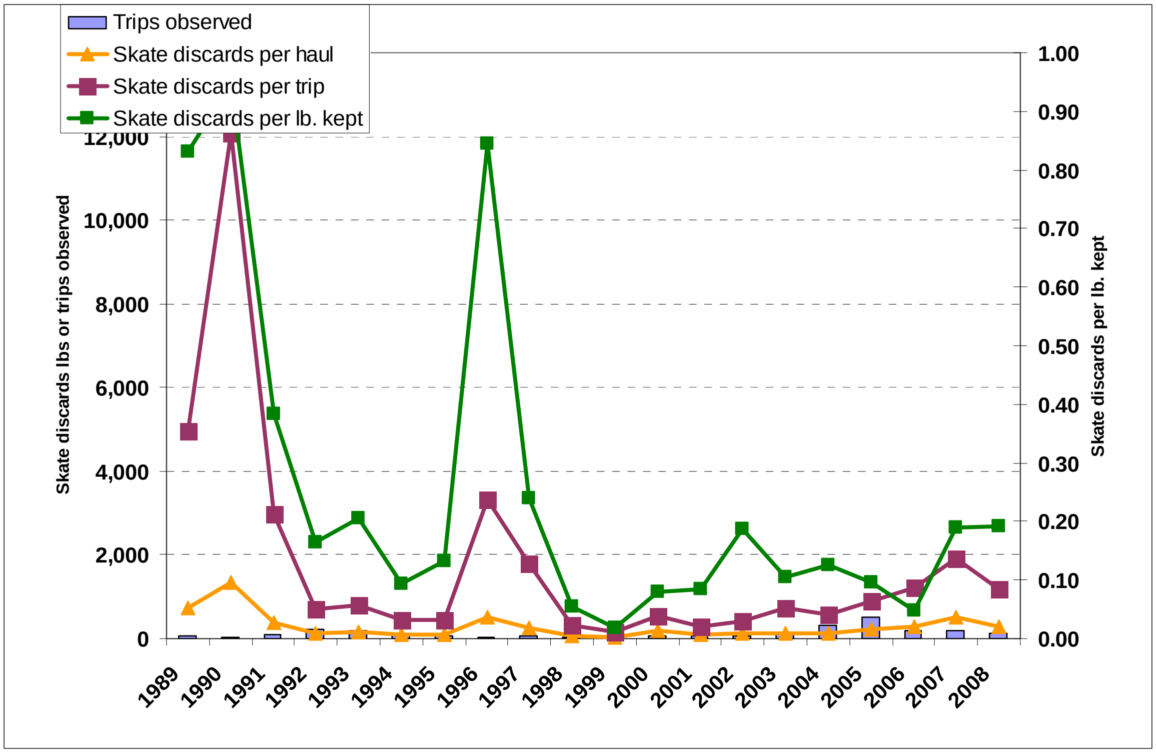


Figure 15. Observed skate discard rate for vessels fishing in Southern New England.

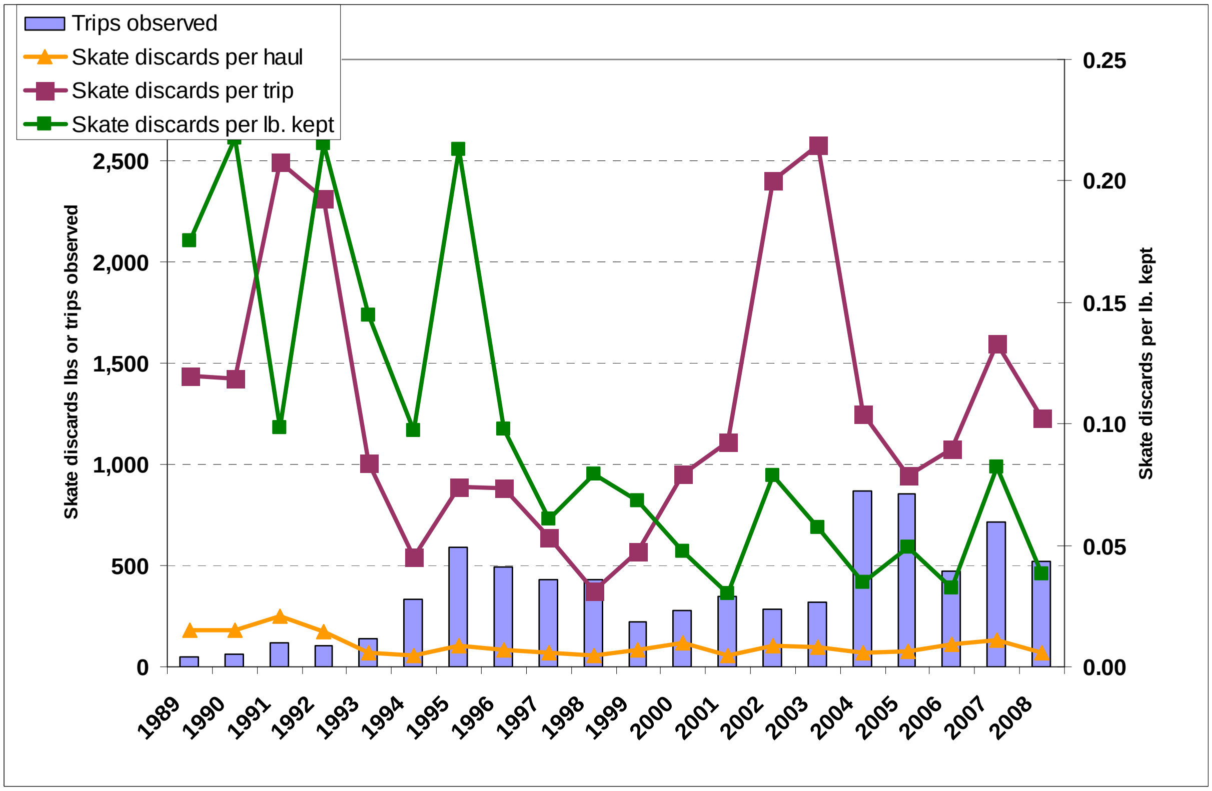


Figure 16. Observed skate discard rate for vessels fishing in the Mid-Atlantic.

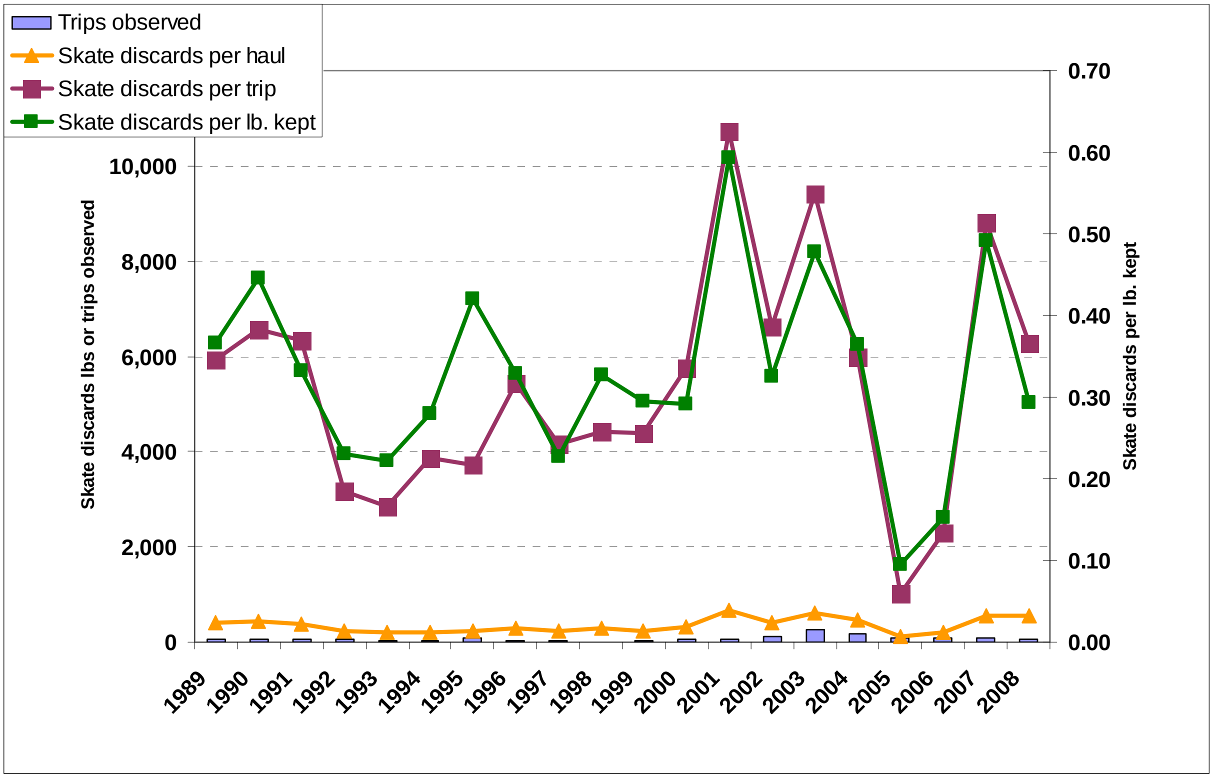


Figure 17. Observed skate discards for vessels using trawls on regular Georges Bank region trips.

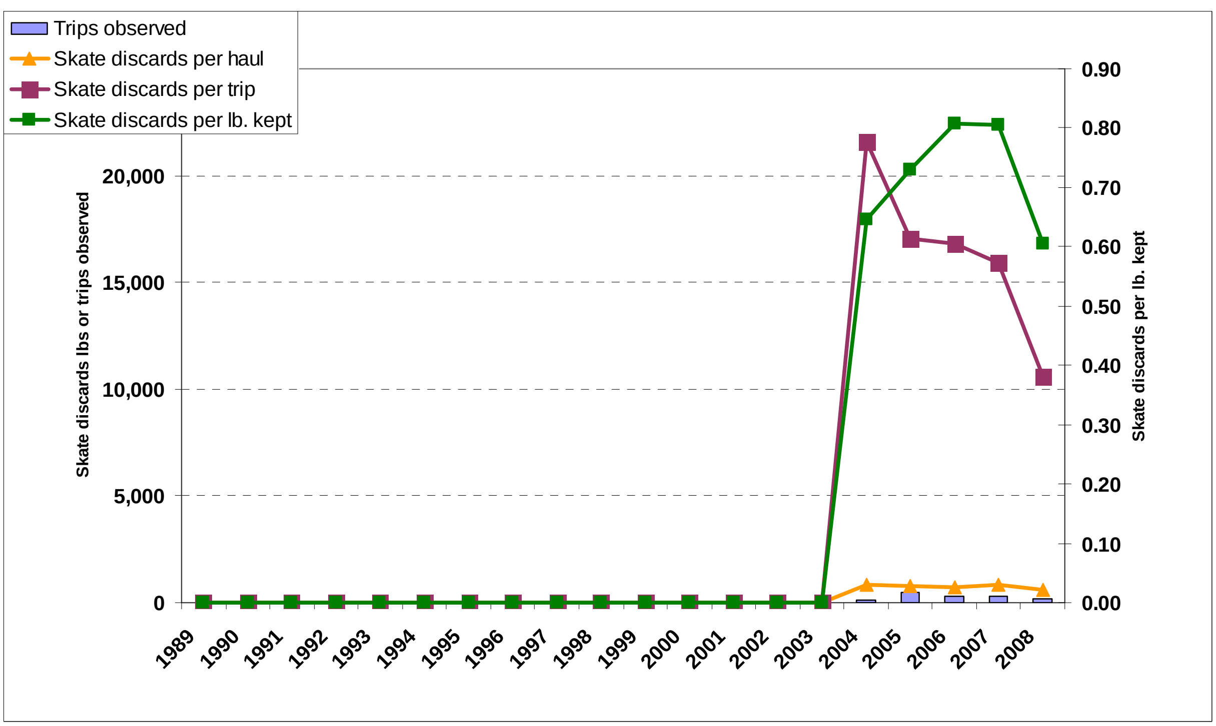


Figure 18. Observed skate discards for vessels using trawls on US/CA trips in the E. Georges Bank sub-region.

Table 1. GLM statistics for various independent variables predictors of average observed DK ratios.

Stratification model	Statistic					
	Multiple R	F-ratio (df)	p-value	Kolmogorov -Smirnov	Durbin-Watson D	AIC
1. NEFSC	0.127	13.45 (24)	0	0.361	1.927	90,347
2. NEFSC regular trips	0.112	7.573 (24)	0	0.378	1.945	69,420
3. Gear/ Sub-region	0.136	14.012 (27)	0	0.358	1.930	92,665
4. Gear/ sub-region/ season/mesh	0.136	9.902 (28)	0	0.368	1.941	71,517

Table 2. GLM statistics and results for Model 1, gear/region/quarter.

Analysis of Variance

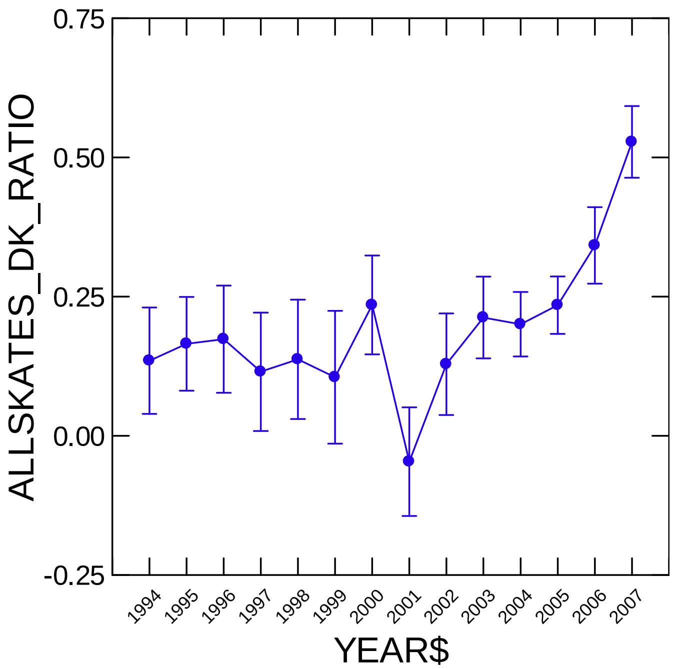
Source	Type III SS	df	Mean Squares	F-ratio	p-value
YEAR$	307.2600	13	23.6354	4.0798	0.0000
GEAR$	1035.3742	5	207.0748	35.7442	0.0000
REGION$	140.1059	3	46.7020	8.0615	0.0000
QTR$	23.3255	3	7.7752	1.3421	0.2587
Error	113738.7331	19633	5.7932		

Estimates of Effects B = $(X'X)^{-1}X'Y$

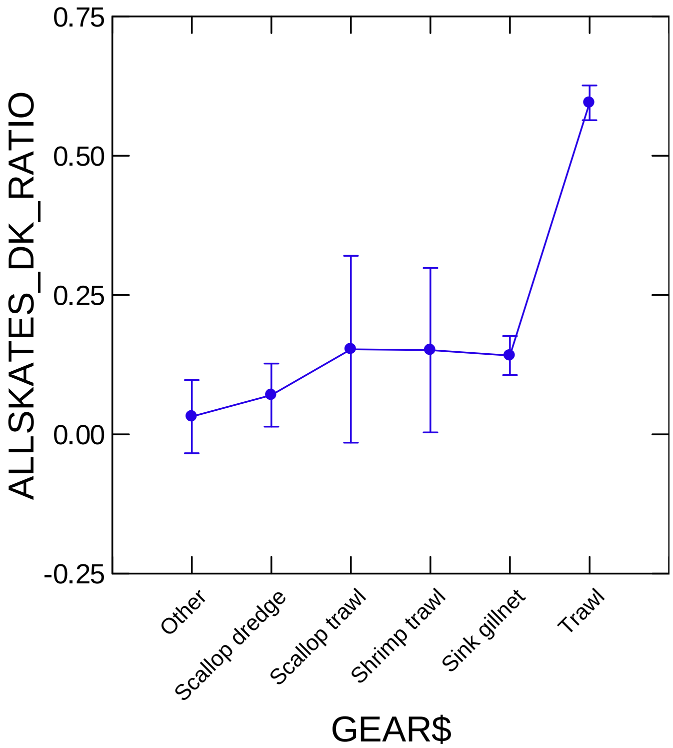
Factor	Level	ALLSKATES_DK_RA-TIO
CONSTANT		0.1932
YEAR$	1994	-0.0532
YEAR$	1995	-0.0242
YEAR$	1996	-0.0193
YEAR$	1997	-0.0731
YEAR$	1998	-0.0556
YEAR$	1999	-0.0910
YEAR$	2000	0.0417
YEAR$	2001	-0.2394
YEAR$	2002	-0.0589
YEAR$	2003	0.0209
YEAR$	2004	0.0098
YEAR$	2005	0.0469
YEAR$	2006	0.1568
GEAR$	Other	-0.1614
GEAR$	Scallop dredge	-0.1201
GEAR$	Scallop trawl	-0.0262
GEAR$	Shrimp trawl	-0.0413
GEAR$	Sink gillnet	-0.0526

Estimates of Effects B = $(X'X)^{-1}X'Y$		
Factor	**Level**	**ALLSKATES_DK_RATIO**
REGION$	GB	-0.0575
REGION$	GOM	-0.1278
REGION$	MA	0.0080
QTR$	1.000000	-0.0405
QTR$	2.000000	0.0334
QTR$	3.000000	-0.0295

Least Squares Means



Least Squares Means



Least Squares Means

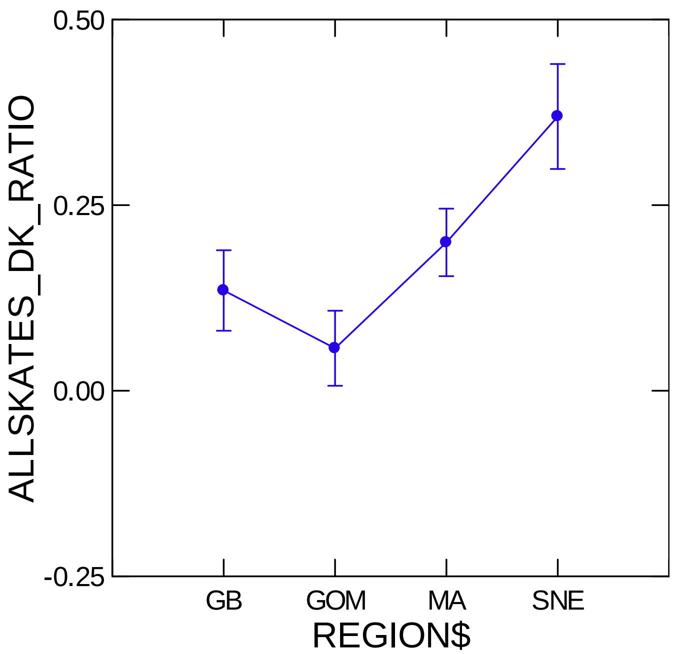


Table 3. GLM statistics and results for Model 2, gear/region/quarter, using only regular management program observed trips.

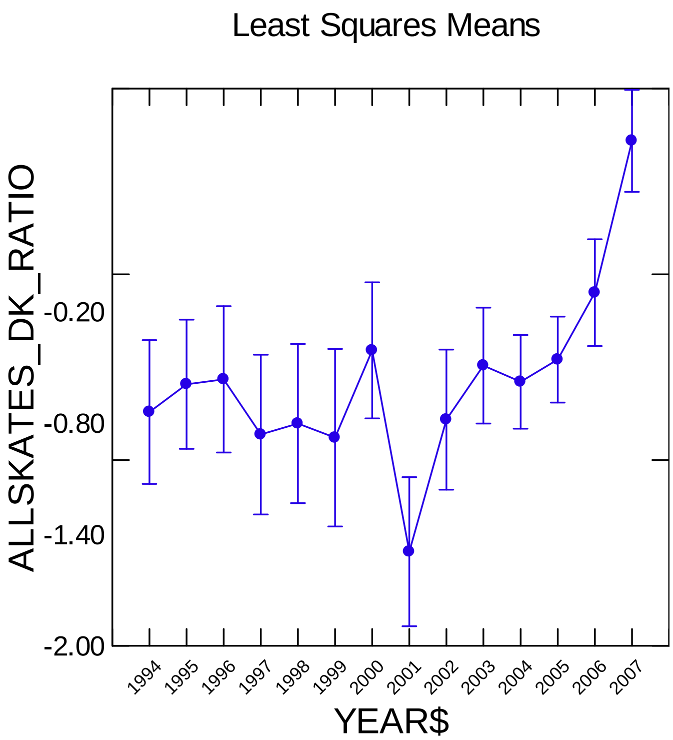
Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
YEAR$	371.1617	13	28.5509	3.8103	0.0000
GEAR$	601.7510	5	120.3502	16.0615	0.0000
REGION$	67.3027	3	22.4342	2.9940	0.0296
QTR$	33.3625	3	11.1208	1.4841	0.2166
Error	106679.1384	14237	7.4931		

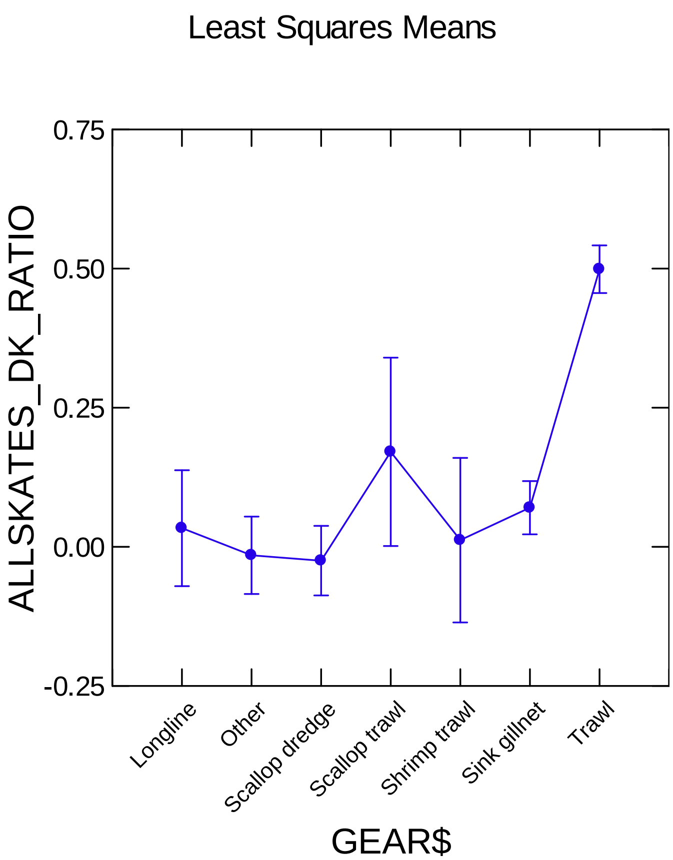
Estimates of Effects B = (X'X)$^{-1}$X'Y		
Factor	**Level**	**ALLSKATES_DK_RA-TIO**
CONSTANT		0.2075
YEAR$	1994	-0.0629
YEAR$	1995	-0.0254
YEAR$	1996	0.0037
YEAR$	1997	-0.0752
YEAR$	1998	-0.0660
YEAR$	1999	-0.1071
YEAR$	2000	0.0294
YEAR$	2001	-0.2749
YEAR$	2002	-0.0525
YEAR$	2003	0.0028
YEAR$	2004	-0.0375
YEAR$	2005	0.0097
YEAR$	2006	0.1379
GEAR$	Other	-0.1651
GEAR$	Scallop dredge	-0.0354
GEAR$	Scallop trawl	0.0017
GEAR$	Shrimp trawl	-0.1078
GEAR$	Sink gillnet	-0.0570
REGION$	GB	-0.0754
REGION$	GOM	-0.0773
REGION$	MA	-0.0015
QTR$	1.000000	-0.0389
QTR$	2.000000	0.0372
QTR$	3.000000	-0.0556

Table 4. GLM statistics and results for Model 3, DK rates post stratified by gear and sub-region.

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
YEAR$	277.7085	13	21.3622	3.8130	0.0000
GEAR$	966.1356	6	161.0226	28.7414	0.0000
SUB_REGION$	378.6510	8	47.3314	8.4483	0.0000
Error	113629.0190	20282	5.6025		

Factor	Level	ALLSKATES_DK_RATIO
CONSTANT		0.1064
YEAR$	1994	-0.0418
YEAR$	1995	-0.0045
YEAR$	1996	0.0022
YEAR$	1997	-0.0721
YEAR$	1998	-0.0573
YEAR$	1999	-0.0764
YEAR$	2000	0.0412
YEAR$	2001	-0.2299
YEAR$	2002	-0.0521
YEAR$	2003	0.0208
YEAR$	2004	-0.0011
YEAR$	2005	0.0288
YEAR$	2006	0.1189
GEAR$	Longline	-0.0729
GEAR$	Other	-0.1217
GEAR$	Scallop dredge	-0.1314
GEAR$	Scallop trawl	0.0643
GEAR$	Shrimp trawl	-0.0946
GEAR$	Sink gillnet	-0.0362
SUB_REGION$	Delmarva	-0.0171
SUB_REGION$	E. GB	0.1545
SUB_REGION$	E. GM	-0.3530
SUB_REGION$	NY Bight	0.2262
SUB_REGION$	Offshore	-0.2487
SUB_REGION$	Other	0.0182
SUB_REGION$	S. Channel	-0.0531
SUB_REGION$	SNE	0.2751


Least Squares Means
ALLSKATES_DK_RATIO
-0.20
-0.80
-1.40
-2.00
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
YEAR$


Least Squares Means
ALLSKATES_DK_RATIO
0.75
0.50
0.25
0.00
-0.25
Longline
Other
Scallop dredge
Scallop trawl
Shrimp trawl
Sink gillnet
Trawl
GEAR$

Least Squares Means

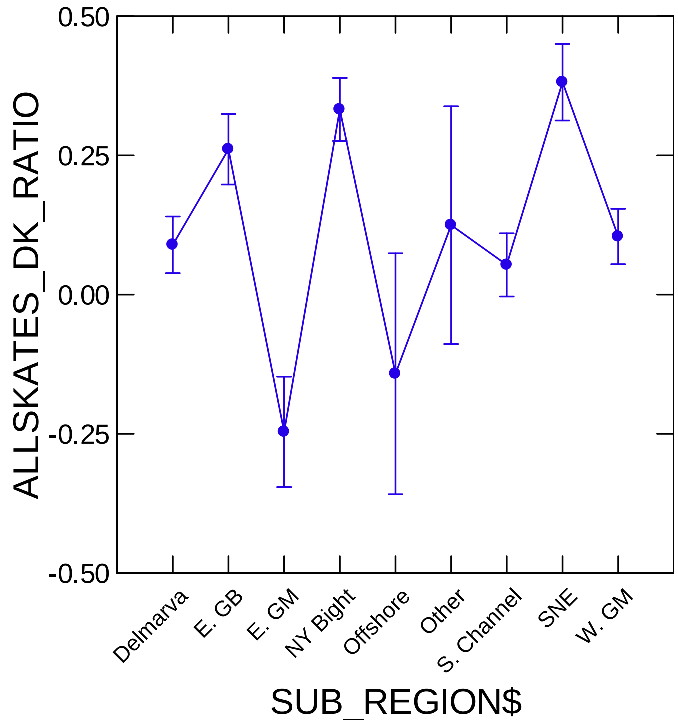


Table 5. GLM statistics and results for Model 4, DK rates post stratified by gear, sub-region, season, and mesh.

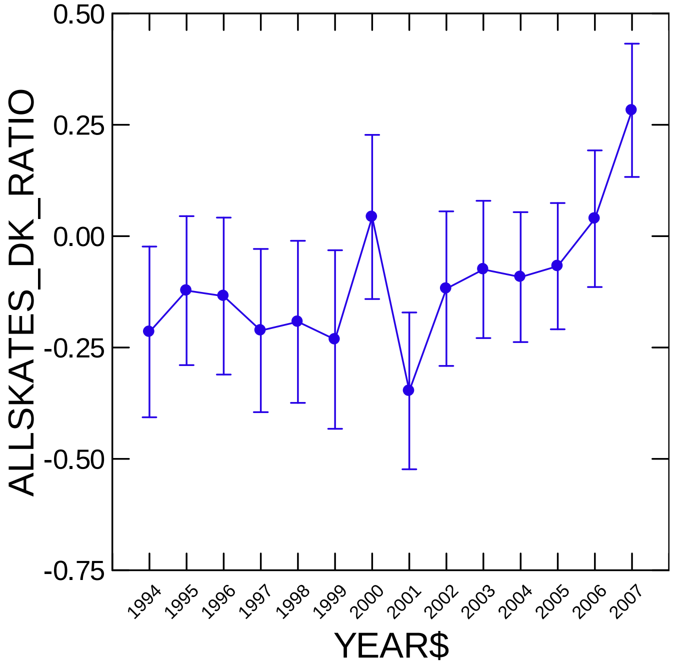
Analysis of Variance

Source	Type III SS	df	Mean Squares	F-ratio	p-value
YEAR$	282.2944	13	21.7150	3.0537	0.0002
GEAR$	332.8477	4	83.2119	11.7016	0.0000
SUB_REGION$	518.3715	8	64.7964	9.1120	0.0000
SEASON$	26.4886	2	13.2443	1.8625	0.1553
MESH$	244.0847	2	122.0423	17.1621	0.0000
Error	105372.8981	14818	7.1111		

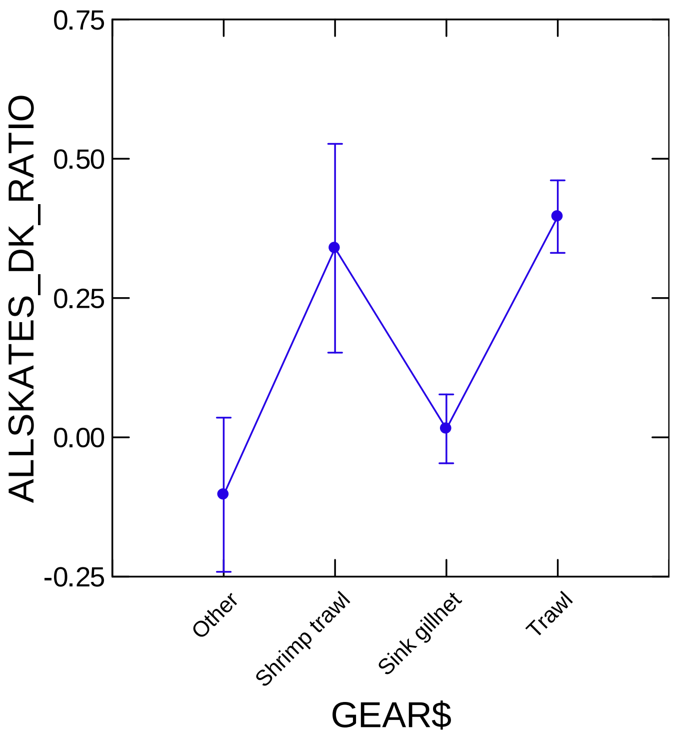
Estimates of Effects B = $(X'X)^{-1}X'Y$

Factor	Level	ALLSKATES_DK_RATIO
CONSTANT		0.5507
YEAR$	1994	-0.4975
YEAR$	1995	-0.4047
YEAR$	1996	-0.4169
YEAR$	1997	-0.4944
YEAR$	1998	-0.4748
YEAR$	1999	-0.5144
YEAR$	2000	-0.2394
YEAR$	2001	-0.6300
YEAR$	2002	-0.4004
YEAR$	2003	-0.3571
YEAR$	2004	-0.3743
YEAR$	2005	-0.3498
YEAR$	2006	-0.2432
GEAR$	Other	-0.4991
GEAR$	Shrimp trawl	-0.0567
GEAR$	Sink gillnet	-0.3809
SUB_REGION$	Delmarva	0.1714
SUB_REGION$	E. GB	0.2404
SUB_REGION$	E. GM	-0.3755
SUB_REGION$	NY Bight	0.4924
SUB_REGION$	Offshore	-0.0499
SUB_REGION$	Other	0.2337
SUB_REGION$	S. Channel	0.0072
SUB_REGION$	SNE	0.4252
MESH$	Large	0.2542
MESH$	Small	-0.0982
SEASON$	FALL	0.1023
SEASON$	SPRING	0.0493

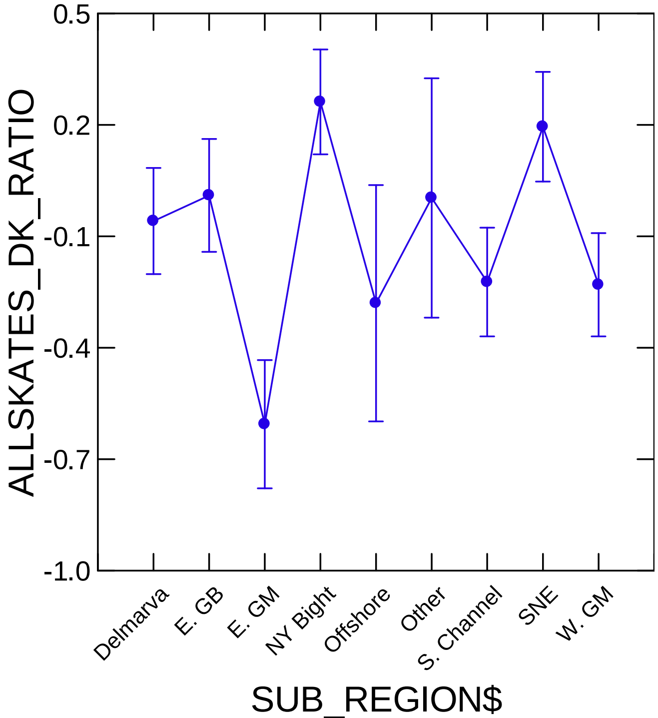
Least Squares Means



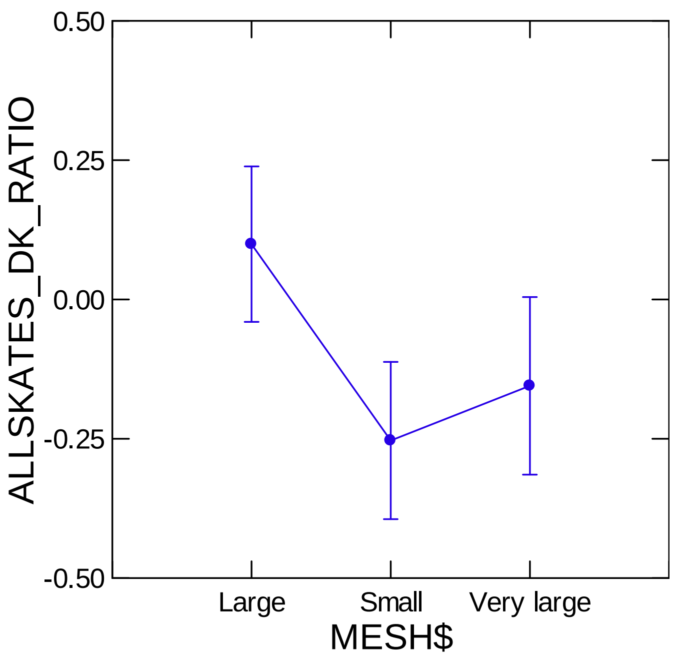
Least Squares Means

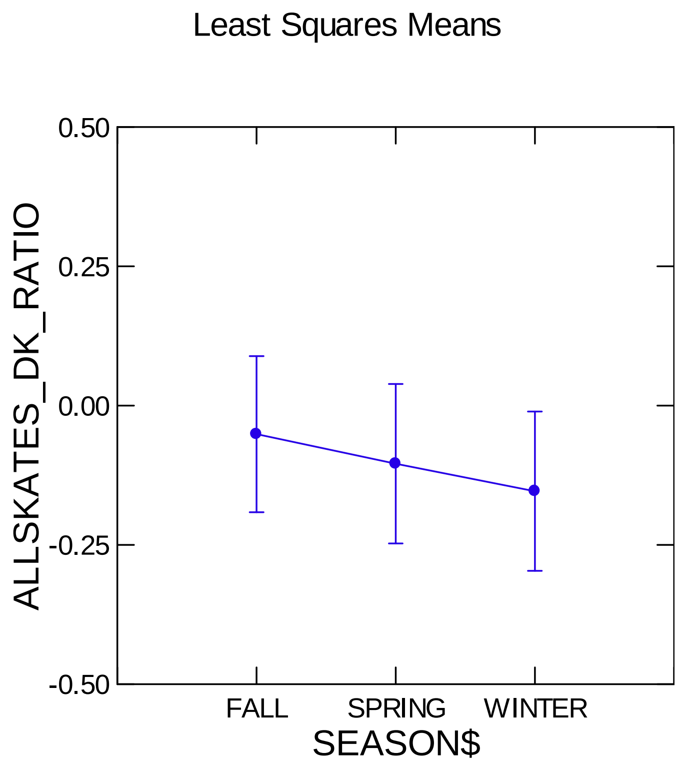


Least Squares Means



Least Squares Means





Draft Working Paper for pre-dissemination peer review only.

Skate Complex
Methodology to determine overfished and overfishing reference points
Appendix 3

By
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Data Poor Stocks Working Group Meeting
Woods Hole, MA
December 8-12, 2008

This Working Paper was distributed for pre-dissemination peer review at the NE Data Poor Stocks Peer Review Meeting, December 8-12, 2008. It does not represent any final NOAA agency determination or policy. Some comments in the Peer Review Panel's Report of the Data Poor Stock Working Group are in response to this WP.

Executive Summary

SPR-based reference points for three skate species, Barndoor, Winter, and Thorny, were derived from life-history parameters and fitted Beverton-Holt stock recruit relationships. Estimated overfishing reference points for these three species are $F_{25\%}$, $F_{37\%}$, and $F_{46\%}$, respectively. Future assessments could estimate comparable F's from mean length models (SEINE, e.g.), or from age-specific assessment models provided discards and landings could be disaggregated to species level. Estimates of overfished reference points are also SPR based, and are defined in terms of depletion, i.e. the proportion of spawners relative to unexploited levels. For Barndoor, Winter, and Thorny skates, the depletion reference points are 0.20, 0.27, and 0.32, respectively. Future assessments could determine stock status by comparing these depletion levels either with depletion in the surveys (provided information is available to estimate depletion for the first year in the survey) or from a stock assessment model that incorporates information about maturity. The same approach to derive reference points was attempted for Clearnose skate, however the parameter estimates from stock recruit curve were unrealistic.

There are several important caveats for the methods used in this working paper, namely, that a fixed value of M was assumed for all ages, that the errors in variables problem was ignored in fitting the stock recruit relationship (*status quo*), and that no fishing is assumed to occur prior to the age of recruitment. The sensitivity to the assumed M value is addressed by exploring alternative values. If any fishing were to occur prior to the age of recruitment, then the estimated slope at the origin (*a* in the Beverton-Holt function) would be biased low, leading to an SPR reference point having a positive bias.

Introduction

Determination of stock status requires a set of reference points that are measured in the same units as estimates of current stock levels. The *de facto* target reference points are associated with Maximum Sustainable Yield (MSY), with limit reference points being some fraction of the target, typically one-half of the target. When MSY estimates can't be obtained, reference points based on spawning potential ratio (SPR) are a common proxy. There is abundant literature exploring the use of SPR (Goodyear 1977; Gabriel et al. 1989; Goodyear 1993; Mace 1993) and recommending appropriate levels of SPR (Clark 1991; Mace and Sissenwine 1993). Brooks et al. (*in prep.*) suggest that the appropriate level depends on species-specific characteristics, and that the level can be derived analytically from life-history parameters. The ability to express the reference point explicitly in terms of survival, maturity, and fecundity allows the proxy SPR level to be tailored to the species of interest. The appropriateness of the SPR level can be evaluated by inspection of the individual components to determine whether they are biologically realistic, and sensitivity to assumed rates can be calculated directly.

As is discussed in this WP, skate landings are not disaggregated to the species level, and there is uncertainty in the species identification of observed skate discards. The lack of species specific catch poses a major problem to conducting stock assessment analyses. The methods proposed in this working paper for deriving biological reference points use only data from the research surveys conducted by the Northeast Fisheries Science Center, thereby avoiding the potential problems associated with disaggregating the commercial catches.

Methods

Overfishing and overfished reference points are derived in terms of the SPR level that achieves maximum excess recruitment (MER, Goodyear 1980). MER differs from MSY in that it solves for the maximum yield in numbers rather than in weight. By comparison, $SPR_{MER}<SPR_{MSY}$ because the F that achieves MER is greater. This is due to the fact that MSY is achieved by allowing more fish to survive to older, hence heavier, ages. MER reference points are expressed in terms of maximum lifetime reproduction, $\hat{\alpha}$ (Myers et al., 1997, 1999), where

$$(1) \qquad \hat{\alpha} = a \sum_{age=r}^{A\max} p_{age} E_{age} \prod_{j=1}^{age-1} e^{-M_j} \ .$$

In (1), r is the age of recruitment, p_{age} is the proportion mature at age, E_{age} is the number of eggs produced at age, M is natural mortality, and a is the slope at the origin in the Beverton-Holt equation

$$(2) \qquad R = \frac{aS}{1 + S/K} .$$

The level of SPR corresponding to MER is given by

$$(3) \qquad SPR_{MER} = \frac{1}{\sqrt{\hat{\alpha}}} .$$

After calculating $\hat{\alpha}$, the resulting SPR_{MER} could be used to determine the overfishing target by calculating $F_{\%SPR}$. An overfished target could similarly be calculated from $\hat{\alpha}$ as

$$(4) \qquad \frac{SSB_{MER}}{SSB_0} = \frac{\sqrt{\hat{\alpha}} - 1}{\hat{\alpha} - 1} .$$

The calculated value in (4) gives a target depletion level, against which current estimates of spawner depletion could be compared.

In order to calculate the reference points, the components of $\hat{\alpha}$ are needed. First, the slope at the origin, a, was obtained by fitting Beverton-Holt curves to NEFSC fall bottom trawl survey data following Gedamke et al. (2009). Annual estimates of mean number of spawners per tow were derived by assuming knife-edged maturity at L_{50}. To obtain a time series of recruitment, the length corresponding to age of full vulnerability to the gear (L_{Crit}) was determined, and this was converted to a mean age from von Bertalanffy growth curves (Table 1).

The stratified mean number of fish per tow above L_{50} (spawners) and for the year class corresponding to L_c (recruits) was then estimated for all years. The vector of mean number of spawners per year was then paired with the vector of mean number of recruits given the appropriate lag (Table 2). For instance, if recruitment was determined to occur at age 4, then a lag of 5 years was taken to account for the additional year spent as an egg. Years with missing data in these lagged pairs were dropped from the analysis. We emphasize that we used spawning number rather than spawning biomass. This is a more realistic approach for elasmobranchs, because they typically produce a few large eggs sacks (or pups, in the case of live bearers).

Counting the number of spawners reflects the fact that there is a finite capacity for egg production and internal storage, whereas using spawning biomass as a proxy implies that fecundity increases by a power function with age. The fall survey was used because it is a longer time series and was more likely to reflect a wider range of observed stock sizes (NEFSC 2000).
Beverton-Holt curves were fit in ADMB (Otter Research, Ltd. 2004) assuming log-normal error in recruitment. We note that while the observations of spawners are not measured without error, the errors in variable problem is ignored (*status quo*).

The estimate of *a* obtained from the Beverton-Holt fits is a compound term that expresses survival from the egg stage (S_{egg}) to the age of recruitment (S_{r-1}) as well as the number of eggs produced per spawner (*E*), which is assumed to be a constant for all ages:

(5) $$a = ES_{egg}S_0S_1 \cdots S_{r-1}.$$

Given the definition of $\hat{\alpha}$ in (1), the remaining term depends only on the natural mortality rate (*M*) assumed:

(6) $$\hat{\alpha} = a\sum_{age=r}^{A\max} p_{age} \prod_{j=1}^{age-r} e^{-M_j} = ae^{-(Amat-r)*M} \sum_{age=Amat}^{A\max} e^{-(age-Amat)*M} = a\frac{e^{-(Amat-r)*M}}{1-e^{-M}}.$$

The final term above is the closed form solution for the sum of a geometric series, which results for very large *Amax*, the maximum age. If Amax is 30 years or greater, then the difference between the finite sum and the infinite sum is small (Appendix 1). Estimates of an age-constant natural mortality (M) were calculated using four different methods based on life-history parameters: Pauly (1980), Hoenig (1983), and the Jensen (1996) age at maturity and k methods. Estimates ranged from 0.09 to 0.17 yr^{-1}, 0.15 to 0.18 yr^{-1}, and 0.17 to 0.25 yr^{-1} for winter, thorny and barndoor skates, respectively. The base case values used for these three species were 0.15, 0.18, and 0.18, respectively. For the clearnose skate, an M of 0.15 was used based on similarity with the other skates. Note that an estimate of water temperature is required for the Pauly (1980) estimator and we used 8.5 C as reported by Myers et al. (1997).

The reasonableness of the estimate of *a* can be evaluated by dividing *a* by *E*, the total number of eggs produced by a female in a year. The term remaining from this division is the cumulative survival from egg stage to the age of recruitment, $S_{egg}S_0S_1 \ldots S_{r-1}$. Assuming that survival is constant at each of these pre-recruit stages, then the annual survival can be calculated as $(S_{egg}S_0S_1 \ldots S_{r-1})^{1/r}$.

The sensitivity of $\hat{\alpha}$ and SPR based reference points was explored for a reasonable range of alternative M values that bracketed the estimates discussed above (0.10-0.25). The resulting SPR_{MER} and the level of F that would produce SPR_{MER} were calculated for each of the possible M values. Uncertainty in the reference points arising from uncertainty in *a* was evaluated with MCMC in AD Model Builder (Otter Research, Ltd, 2004). Two independent chains of length 1E+06 were simulated, with a thinning rate of 1/50. The first 35% of each chain was dropped (burn-in), and the remaining values were retained for analysis.

Results

The results of fitting Beverton-Holt relationships to the observed spawner and recruit data were evaluated by examination of diagnostic plots (Figures 1-4). For Barndoor, Thorny, and Winter skate, the diagnostics are acceptable, and the estimated parameters are reasonable (Table 3). However, for Clearnose skate, the residuals show unacceptable time trends (Figure 4) and the estimates are not reasonable (Tables 3 and 4; steepness of about 0.96).

The estimated precision for the reference points only reflects the precision of the estimated stock-recruit parameters (*a* and *K*). Sensitivity of the estimated reference points and the associated fishing mortality rate for alternative values of M are given in Tables 5-7. For higher M, SPR_{MER} and depletion at MER are also higher, which equates to a lower F. This may initially seem counterintuitive, for one often finds that assuming a higher M leads to a higher estimate of F_{MSY} in a typical stock assessment. However, in this case, the result of a higher M producing a lower $F_{\%SPR}$ is due to the direct impact of M on the unexploited calculation of spawners per recruit (Table 8). It is this parameter that scales *a* to yield $\hat{\alpha}$, from which the reference points are estimated.

Barndoor skate

There were 14 observations of (S_y, R_y) for Barndoor skate from the fall NEFSC bottom trawl survey (Table 2). The estimated slope at the origin was 5.78, which gives a maximum lifetime reproduction of 15.61 ($\hat{\alpha}$, Table 3). From equations (3) and (4) above, SPR_{MER}=0.25 and the depletion of spawners at MER (S_{MER}/S_0) is 0.20. The estimated fishing mortality that achieves an SPR of 0.25 is $F_{25\%}$= 0.18. The implied annual survival during the pre-recruit stage is 0.27/year for three years (egg stage to age 2, Table 3). The long right tail in the posterior distribution of the slope at the origin (*a*) reflects the poorer precision of that parameter (CV=50%). By comparison, the reference points were twice as precise.

Winter skate

There were 36 observations of (S_y, R_y) for Winter skate from the fall NEFSC bottom trawl survey (Table 2). The estimated slope at the origin was 2.94, which gives a maximum lifetime reproduction of 7.39 ($\hat{\alpha}$, Table 3). From equations (3) and (4) above, SPR_{MER}=0.37 and the depletion of spawners at MER (S_{MER}/S_0) is 0.27. The estimated fishing mortality that achieves an SPR of 0.37 is $F_{37\%}$=0.08. The implied annual survival during the pre-recruit stage is 0.43/year for five years (egg stage to age 4, Table 3). As was the case with barndoor skate, the estimated CV for the slope at the origin (*a*) was twice that of the reference points (0.39 for *a* versus 0.19 and 0.14 for SPR_{MER} and depletion at MER).

Thorny skate

There were 40 observations of (S_y, R_y) for Thorny skate from the fall NEFSC bottom trawl survey (Table 2). The estimated slope at the origin was 2.71, which gives a maximum lifetime reproduction of 4.67 ($\hat{\alpha}$, Table 3). From equations (3) and (4) above, SPR_{MER}=0.46 and the depletion of spawners at MER (S_{MER}/S_0) is 0.32. The estimated fishing mortality that achieves an SPR of 0.46 is $F_{46\%}$=0.07. The implied annual survival during the pre-recruit stage is 0.44/year for five years (egg stage to age 4, Table 3). As was the case with barndoor skate, the estimated CV for the slope at the origin (*a*) was twice that of the reference points (0.31 for *a* versus 0.16 and 0.11 for SPR_{MER} and depletion at MER).

Clearnose skate

There were 28 observations of (S_y, R_y) for Clearnose skate from the fall NEFSC bottom trawl survey (Table 2). The estimated slope at the origin was 101.10, which gives a maximum lifetime reproduction of 15.61 ($\hat{\alpha}$, Table 3). The diagnostics were not acceptable, and the parameter estimates were unrealistic (steepness=0.96, Table 4); therefore, the estimated reference points are considered inappropriate for management advice. No MCMC simulations were conducted for this species based on the poor initial model fit.

Conclusions

Assessment of skate species has proven to be difficult, due to the aggregated nature of commercial landings and the lack of data on discards for much of the time series. The difficulty applies equally to the estimation of reference points for skates. The methodology of Gedamke et al. (2008) provided a method to estimate the slope at the origin for Beverton-Holt stock recruit relationships. Management reference points are strongly dependent on the stock recruitment curve, and the slope parameter is a key component in determining appropriate reference points. Combining the slope with other biological parameters, the analytic solutions for SPR_{MER} were derived from results in Brooks et al. (2008, *in preparation*).

Data were sufficient to attempt fitting stock recruit curves to four skate species: Barndoor (14 data points), Thorny (40 data points), Winter (36 data points), and Clearnose skate (28 data points). The diagnostics were acceptable for all but Clearnose skate, and the parameter estimates for the remaining three species appear reasonable. The resulting reference point estimates are on a scale that would be compatible with existing assessment methodology. For example, models such as SEINE (2008; NMFS Toolbox module based on Gedamke and Hoenig, 2006) , or other mean length based models, could provide estimates of fishing mortality, provided the lengths examined included only those above the full vulnerability to the gear. These assessment-based estimates of F could then be compared to the $F_{\%SPR}$ estimated in this working paper to determine the overfishing status. The overfished status could be determined by examining the implied depletion of spawners, for example by examining the final point in the scaled index of mean spawners/tow ($S_y/S_{y=1}$). The scaled index of spawners would be depletion from an unexploited state if it was appropriate to assume that the stock was unexploited in year $y=1$. If that is not the case, then the index could be multiplied by a scalar, *d*, which reflects a measure (or expert opinion) of the level of depletion in year $y=1$. Alternatively, if algorithms to dissociate the landings and to hindcast discards are developed and agreed upon, then traditional stock assessment methods could be applied to estimate current levels of fishing mortality and stock size.

These SPR reference points were bounded by considering sensitivity across a reasonable range of natural mortality (M) levels.

Beverton-Holt curves were fit, but no Ricker curves were attempted because there is no obvious mechanism that would lead to overcompensation, nor is there data available that would suggest it.

As is common in most stock-recruit curve fitting exercises, the error in observed spawners per tow is ignored. Walters and Ludwig (1981) suggest that the estimation performance from ignoring error in the 'independent' variable is worse if the observations all come from a period where the stock was already heavily exploited. As the time series used in fitting Beverton-Holt curves extends back to the 1960s, it may be that a fairly broad range of spawning stock sizes is reflected in the observations.

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Appendix 1. Evaluation of the bias generated by calculating unexploited spawners per recruit, spr(F=0), as either an infinite sum or by calculating the series only up to the maximum age (Amax). For this exercise, the ratio between terms in the series is $r=e^{-M}$. The infinite sum is $1/(1-r)$ while the sum to Amax is given by $(1-r^{Amax+1})/(1-r)$. The combinations of Alag and M in this illustration correspond to the observed pairs for skate species examined in this document.

Amax	Alag	M	spr(F=0) Sum to Amax	spr(F=0) Infinite sum	% bias (Infinite sum - Sum to Amax)/ Sum to Amax
15	4.5	0.18	2.36	2.70	14%
20	4.5	0.18	2.56	2.70	5%
25	4.5	0.18	2.64	2.70	2%
30	4.5	0.18	2.68	2.70	1%
35	4.5	0.18	2.69	2.70	0%
40	4.5	0.18	2.70	2.70	0%
15	7	0.15	1.86	2.51	35%
20	7	0.15	2.20	2.51	14%
25	7	0.15	2.37	2.51	6%
30	7	0.15	2.44	2.51	3%
35	7	0.15	2.48	2.51	1%
40	7	0.15	2.50	2.51	1%
15	7	0.18	1.38	1.72	25%
20	7	0.18	1.58	1.72	9%
25	7	0.18	1.67	1.72	3%
30	7	0.18	1.70	1.72	1%
35	7	0.18	1.71	1.72	1%
40	7	0.18	1.72	1.72	0%

Table 1. Criteria used to define the age at recruitment (full vulnerability to the survey gear), the age at maturity (assumed to be knife-edged), and the NEFSC bottom trawl survey used to generate paired observations of spawners and recruits.

Parameter	**Barndoor**	**Thorny**	**Winter**	**Clearnose**
Length range at full vulnerability	55-69 cm	46-54 cm	40-44 cm	42-50 cm
Age at full vulnerability (recruitment)	2	4	4	4
Length at full maturity	116	88	76	66
Age at full maturity	6.5	11	11	6
NEFSC survey used (SPRING/FALL)	FALL	FALL	FALL	FALL

Table 2. Pairs of observed number of spawners/tow and number of recruits/tow for Barndoor, Thorny, Winter, and Clearnose skate. The year indicates the year that eggs were spawned. Note that the year differs between the skate species.

Barndoor			Thorny			Winter			Clearnose		
Year	**Spawners**	**Recruits**	**Year**	**Spawners**	**Recruits**	**Year**	**Spawners**	**Recruits**	**Year**	**Spawners**	**Recruits**
1963	0.0592	0.1703	1963	0.5141	0.1175	1967	0.1024	0.3502	1975	0.0022	0.0692
1964	0.0194	0.0181	1964	0.3766	0.1723	1968	0.0657	0.2330	1976	0.0106	0.0489
1965	0.0092	0.0572	1965	0.3774	0.2832	1969	0.0448	0.1035	1977	0.0459	0.0350
1967	0.0055	0.0072	1966	0.6772	0.1568	1970	0.1228	0.0197	1978	0.0044	0.0026
1968	0.0047	0.0495	1967	0.1945	0.1997	1971	0.0358	0.0256	1979	0.0414	0.0306
1993	0.0100	0.0039	1968	0.3602	0.2635	1972	0.1025	0.1320	1980	0.0902	0.0516
1997	0.0040	0.0073	1969	0.4592	0.1408	1973	0.2083	0.0442	1981	0.0094	0.0621
1998	0.0053	0.0286	1970	0.6659	0.0716	1974	0.0895	0.1283	1982	0.0216	0.0689
1999	0.0106	0.0747	1971	0.5239	0.0853	1975	0.0688	0.1684	1983	0.0031	0.0627
2000	0.0039	0.0388	1972	0.3609	0.1978	1976	0.2673	0.1504	1984	0.0214	0.0573
2001	0.0219	0.0295	1973	0.4130	0.4055	1977	0.3921	0.2500	1985	0.0395	0.0957
2002	0.0297	0.0890	1974	0.1989	0.1295	1978	0.5990	0.1135	1986	0.0162	0.2069
2003	0.0151	0.0691	1975	0.1850	0.1982	1979	0.6634	0.3065	1987	0.0456	0.0528
2004	0.0642	0.1059	1976	0.1344	0.2253	1980	0.6649	0.2047	1988	0.0413	0.0969
			1977	0.2131	0.0258	1981	0.5778	0.1448	1989	0.0161	0.1828
			1978	0.2172	0.1476	1982	0.7272	0.4153	1990	0.0374	0.0408
			1979	0.2480	0.1543	1983	1.4457	0.3024	1991	0.1917	0.0732
			1980	0.2864	0.1213	1984	1.2900	0.1518	1992	0.0455	0.0653
			1981	0.1973	0.0380	1985	1.4719	0.2345	1993	0.0642	0.3494
			1982	0.0384	0.1114	1986	2.1119	0.3594	1994	0.1021	0.1941
			1983	0.1424	0.0934	1987	1.3070	0.2254	1995	0.0555	0.1712
			1984	0.1925	0.1368	1988	0.9280	0.2203	1996	0.0452	0.2421
			1985	0.1490	0.1241	1989	0.6537	0.3772	1997	0.1473	0.2520
			1986	0.1069	0.1899	1990	1.0601	0.3256	1998	0.1215	0.1001
			1987	0.0321	0.0723	1991	0.6036	0.2136	1999	0.2430	0.0612
			1988	0.0812	0.1316	1992	0.3846	0.1167	2000	0.2059	0.0582
			1989	0.0997	0.2209	1993	0.1721	0.1284	2001	0.2110	0.1417
			1990	0.1313	0.1271	1994	0.1436	0.2063	2002	0.1428	0.1216
			1991	0.1087	0.0782	1995	0.1048	0.2237			
			1992	0.0449	0.0605	1996	0.1557	0.2399			
			1993	0.0963	0.0370	1997	0.1460	0.1339			
			1994	0.0655	0.0481	1998	0.3493	0.0740			
			1995	0.0270	0.0605	1999	0.2881	0.2109			
			1996	0.0450	0.0568	2000	0.4001	0.2149			
			1997	0.0528	0.0214	2001	0.3131	0.2157			
			1998	0.0516	0.1567	2002	0.6870	0.2470			
			1999	0.0197	0.0482						
			2000	0.0605	0.0175						
			2001	0.0127	0.0311						
			2002	0.0303	0.0234						

Table 3. Estimates of Beverton-Holt parameters, and implied annual survival $(S_{egg}S_0 \ldots S_{r-1})^{1/r}$ for the product of total number of eggs per female per year and cumulative survival to recruitment, $S_{egg}S_0 \ldots S_{r-1}$.

Parameter	Barndoor	Thorny	Winter	Clearnose
a (slope at origin)	5.78 (0.50)	2.71 (0.31)	2.94 (0.39)	*19.01 (0.65)*
K	0.01 (1.65)	0.08 (0.48)	0.10 (0.52)	*0.01 (0.80)*
E (Total Number of eggs/female)	80	41	48	40
$S_{egg}S_0 \ldots S_{r-1}$	0.07	0.03	0.04	*0.24*
$(S_{egg}S_0 \ldots S_{r-1})^{1/r}$	0.27	0.51	0.50	0.83

Table 4. Species specific reference points (and CV) for the assumed natural mortality rate (M), the estimated maximum lifetime reproduction ($\hat{\alpha}$), and the implied steepness (steepness is related to $\hat{\alpha}$ as $\hat{\alpha}/(\hat{\alpha}+4)$). No reference points are given for Clearnose skate as diagnostics and estimates were unsatisfactory.

Parameter	Barndoor	Thorny	Winter	Clearnose
M (natural mortality)	0.18	0.18	0.15	*0.15*
$\hat{\alpha}$	15.61 (0.50)	4.67 (0.31)	7.39 (0.39)	101.10 (0.33)
steepness	0.80	0.54	0.65	0.96
SPR_{MER}	0.25 (0.25)	0.46 (0.16)	0.37 (0.19)	N/A
S_{MER}/S_0	0.20 (0.20)	0.32 (0.11)	0.27 (0.14)	N/A

Table 5. Sensitivity of SPR_{MER} reference points to the assumed level of natural mortality (M). For each species, the value in bold is the base case value assumed for M.

M value	Barndoor	Thorny	Winter
0.10	0.16	0.27	0.26
0.15	0.22	0.38	**0.37**
0.18	**0.25**	**0.46**	0.44
0.20	0.28	0.52	0.50
0.25	0.34	0.68	0.66

Table 6. Sensitivity of depletion reference points (S_{MER}/S_0)to the assumed level of natural mortality (M). For each species, the value in bold is the base case value assumed for M.

M value	Barndoor	Thorny	Winter
0.10	0.14	0.21	0.20
0.15	0.18	0.28	**0.27**
0.18	**0.20**	**0.32**	0.31
0.20	0.22	0.34	0.33
0.25	0.26	0.41	0.40

Table 7. Estimated fishing mortality rate (F) that achieves SPR_{MER} given the base value assumed for M. For each species, the value in bold is the base case value assumed for M.

M value	Barndoor	Thorny	Winter
0.10	0.19	0.10	0.10
0.15	0.18	0.08	**0.08**
0.18	**0.18**	**0.07**	0.07
0.20	0.17	0.06	0.06
0.25	0.15	0.04	0.04

Table 8. Effect of Alag (difference in years between maturity and recruitment ages) and M on the unexploited spawners per recruit, spr(F=0).

Alag	M	spr(F=0)
4.5	0.10	6.70
4.5	0.12	5.15
4.5	0.15	3.66
4.5	0.18	2.70
4.5	0.20	2.24
4.5	0.22	1.88
7	0.10	5.22
7	0.12	3.82
7	0.15	2.51
7	0.18	1.72
7	0.20	1.36
7	0.22	1.09

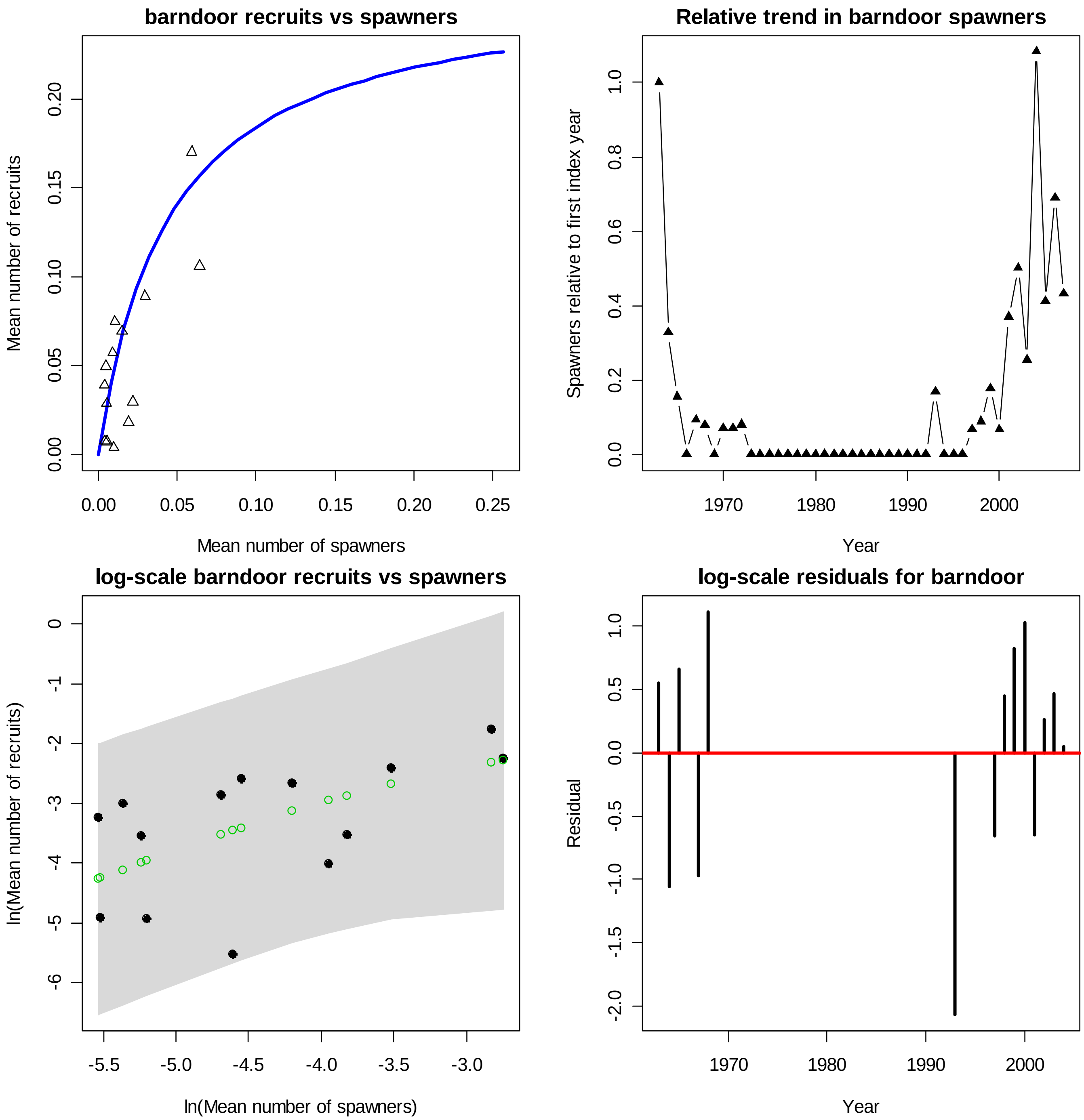

Figure 1. Diagnostic plots for **barndoor** skate: observed (open triangles) versus predicted mean number of recruits (top left), observed time series of spawners scaled by the first observation ($S_y/S_{y=1}$) (top right), log-scale fit of observed (solid circles) to predicted (open circles) number of recruits/tow with shaded 95% confidence interval (bottom left), and standardized log-scale residuals (bottom right).

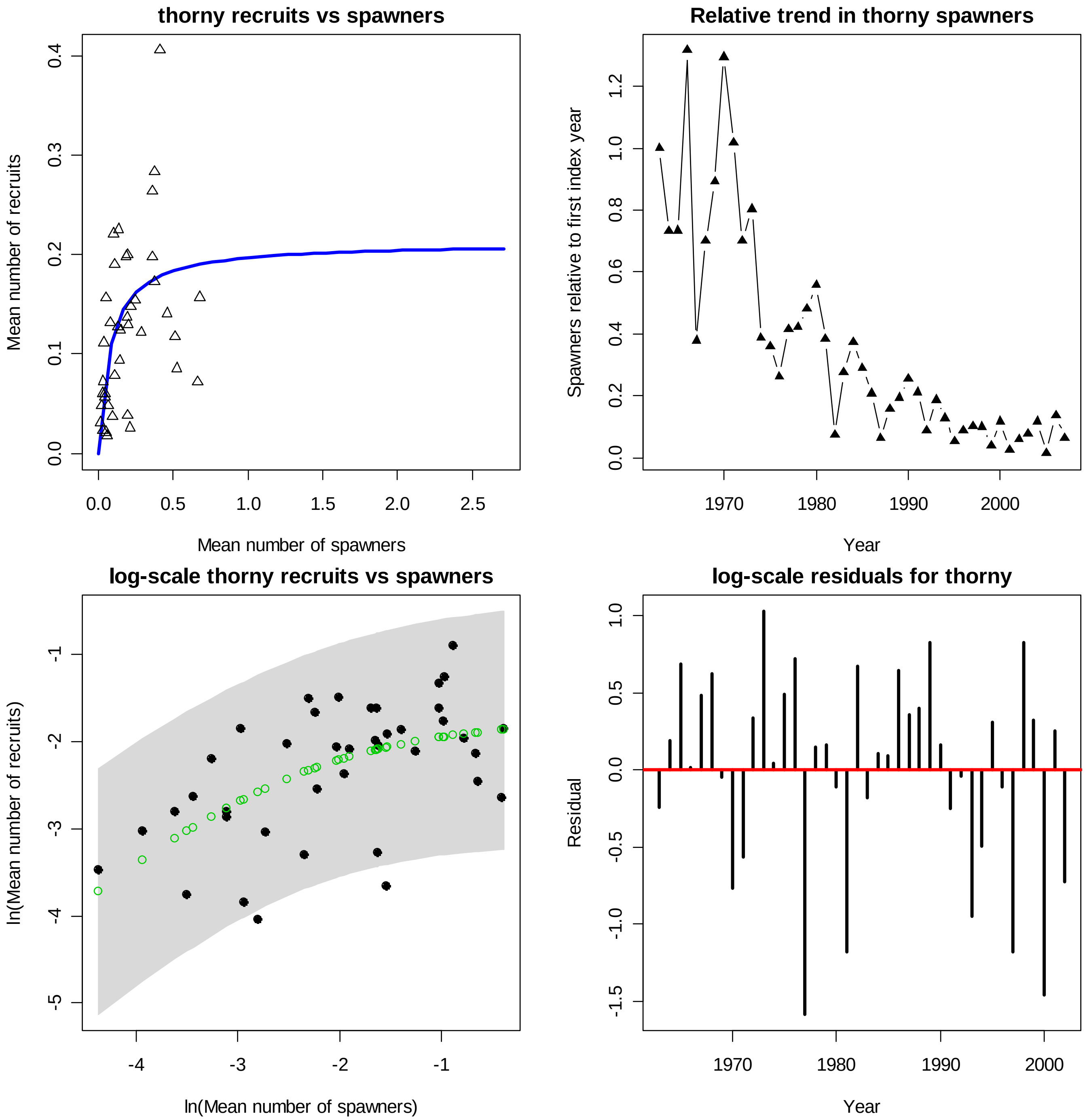

Figure 2. Diagnostic plots for **thorny** skate: observed (open triangles) versus predicted mean number of recruits (top left), observed time series of spawners scaled by the first observation ($S_y/S_{y=1}$) (top right), log-scale fit of observed (solid circles) to predicted (open circles) number of recruits/tow with shaded 95% confidence interval (bottom left), and standardized log-scale residuals (bottom right).

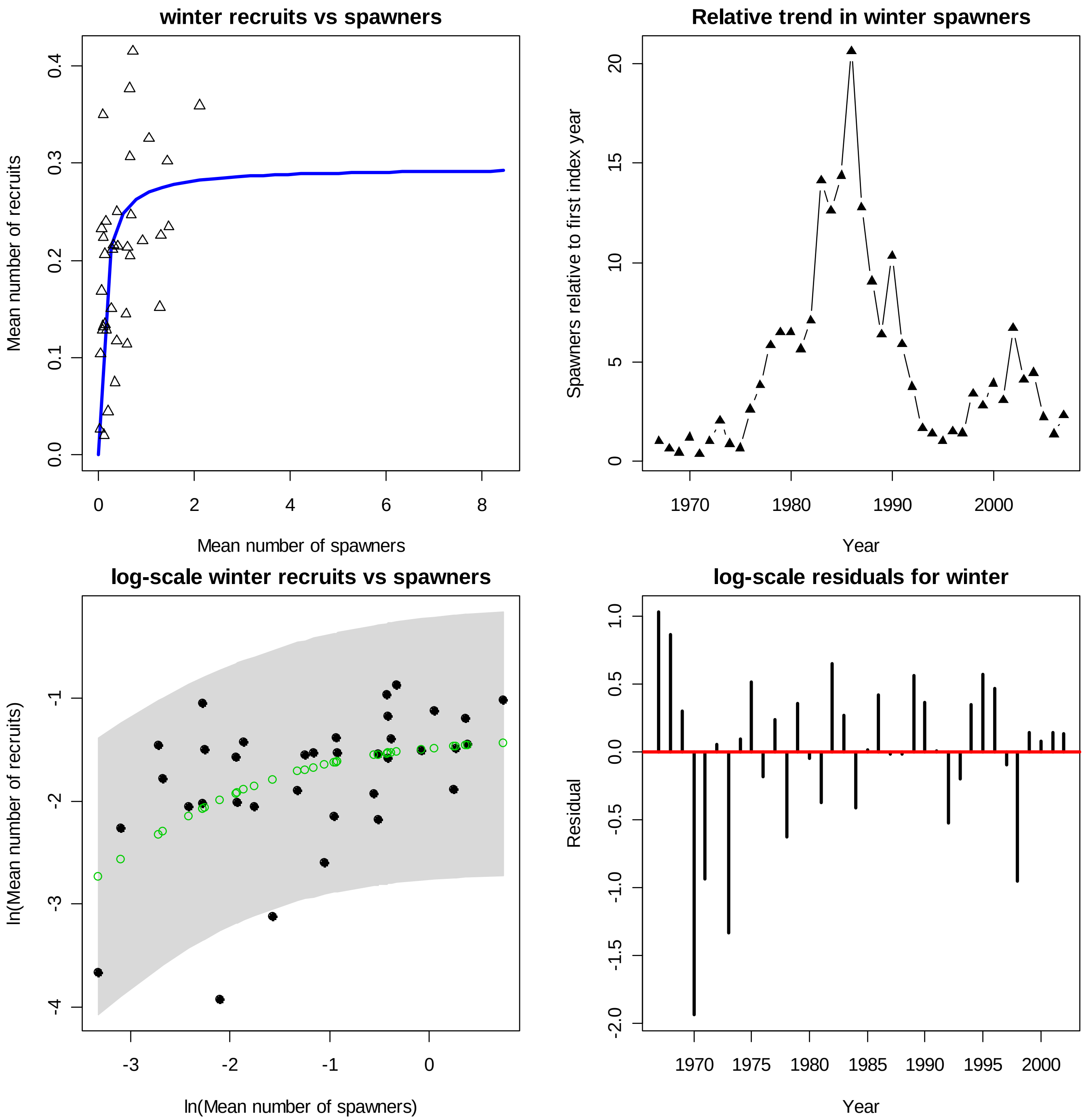

Figure 3. Diagnostic plots for **winter** skate: observed (open triangles) versus predicted mean number of recruits (top left), observed time series of spawners scaled by the first observation ($S_y/S_{y=1}$) (top right), log-scale fit of observed (solid circles) to predicted (open circles) number of recruits/tow with shaded 95% confidence interval (bottom left), and standardized log-scale residuals (bottom right).

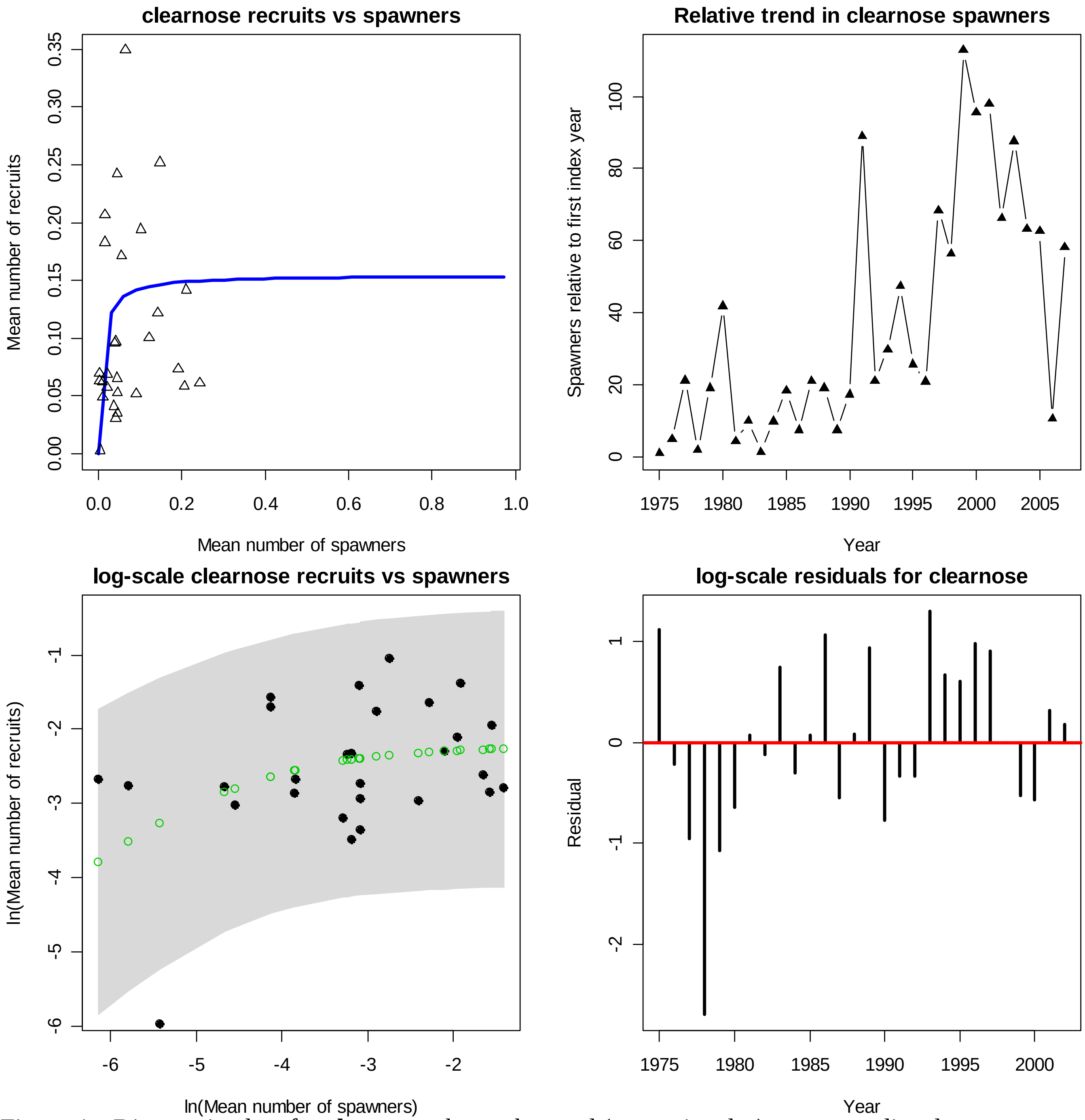

Figure 4. Diagnostic plots for **clearnose** skate: observed (open triangles) versus predicted mean number of recruits (top left), observed time series of spawners scaled by the first observation ($S_y/S_{y=1}$) (top right), log-scale fit of observed (solid circles) to predicted (open circles) number of recruits/tow with shaded 95% confidence interval (bottom left), and standardized log-scale residuals (bottom right).

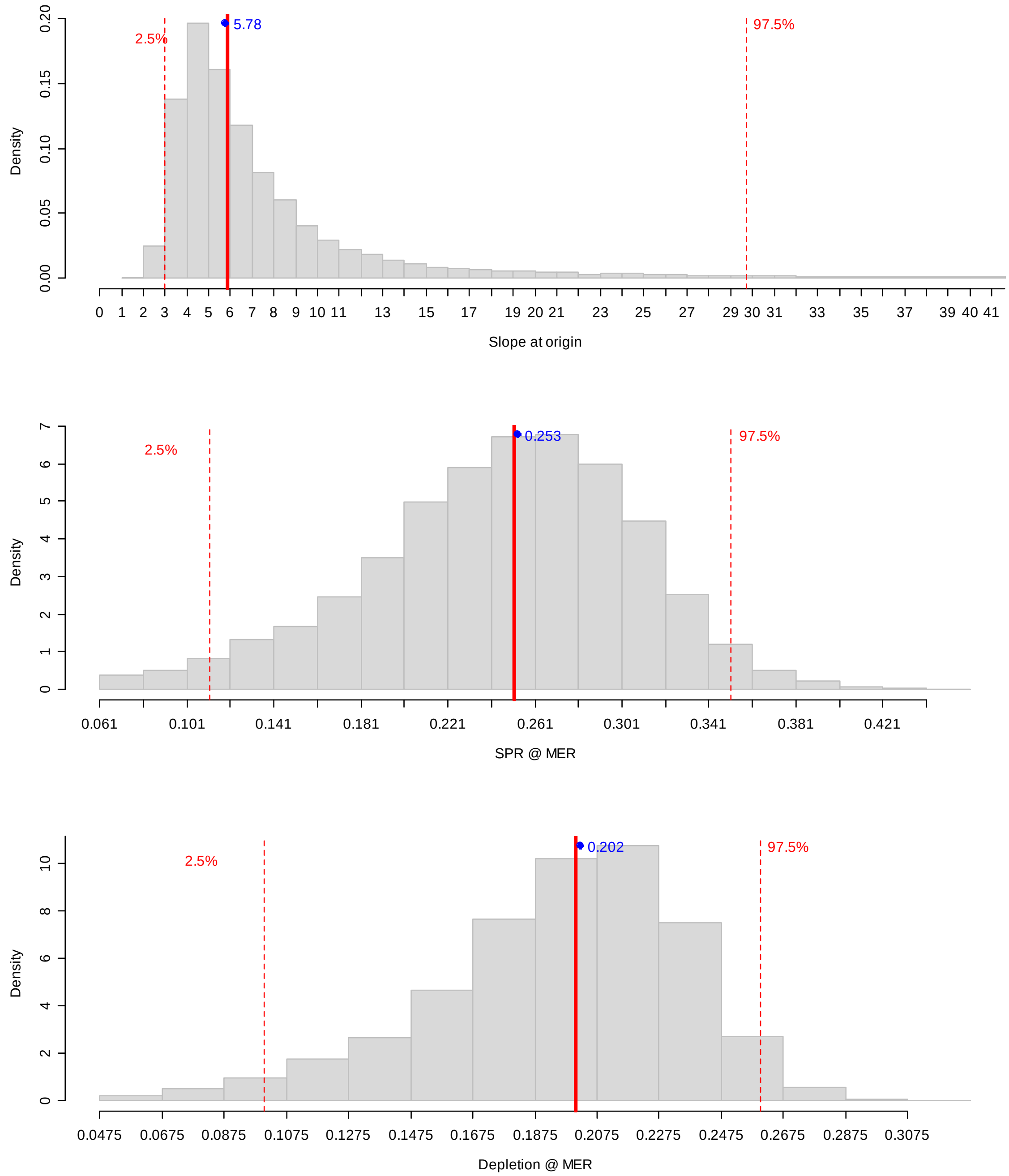

Figure 5. Posterior distributions from MCMC for the slope at the origin (top), SPR_{MER} (middle), and depletion at MER(bottom) for **barndoor** skate. In each plot, the point estimate is indicated by a solid circle and that value is beside the point. The median of the posterior is indicated by a solid vertical red line, while the 2.5th and 97.5th percentiles are indicated by dashed vertical red lines.

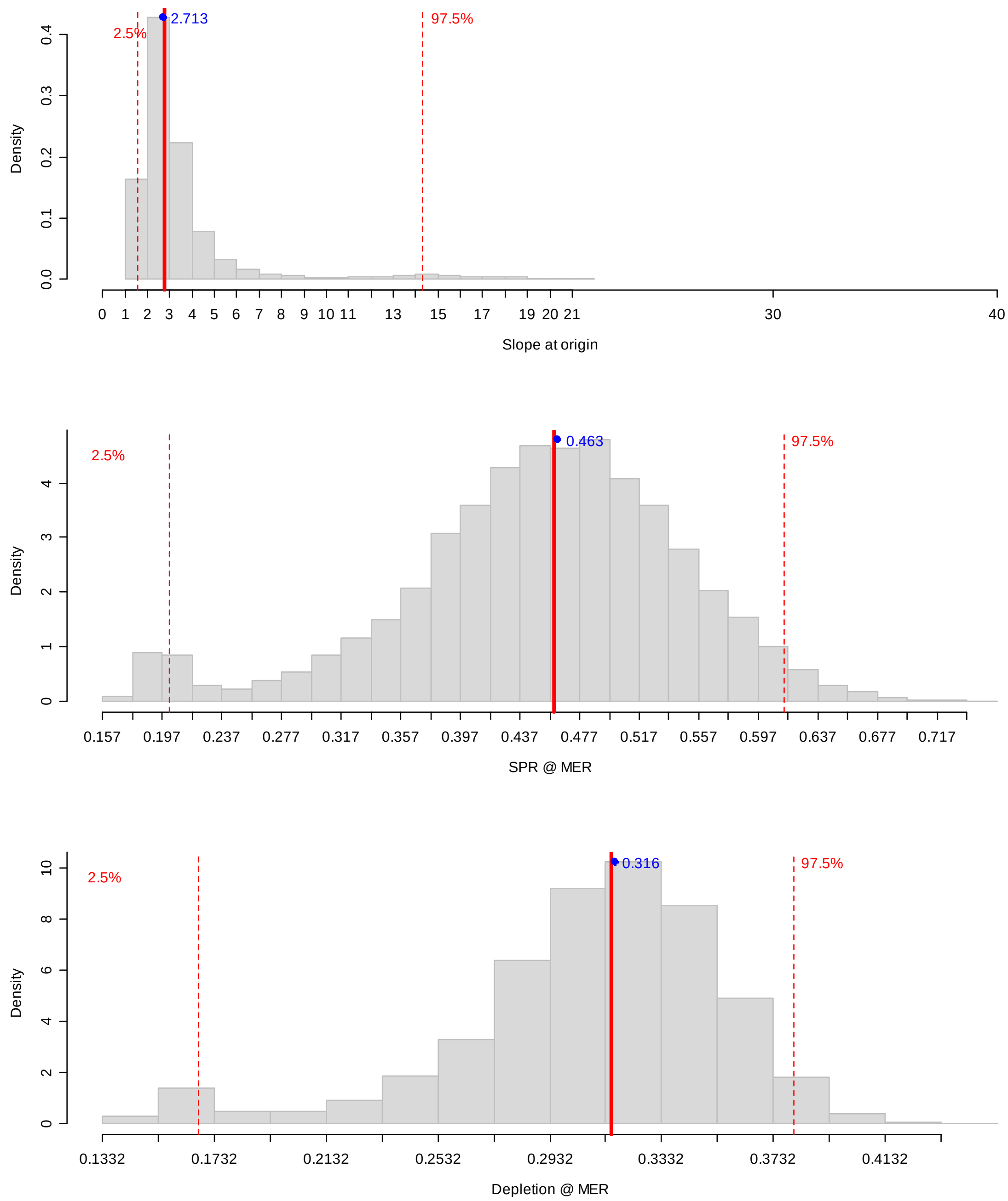

Figure 6. Posterior distributions from MCMC for the slope at the origin (top), SPR_{MER} (middle), and depletion at MER(bottom) for **thorny** skate. In each plot, the point estimate is indicated by a solid circle and that value is beside the point. The median of the posterior is indicated by a solid vertical red line, while the 2.5th and 97.5th percentiles are indicated by dashed vertical red lines.

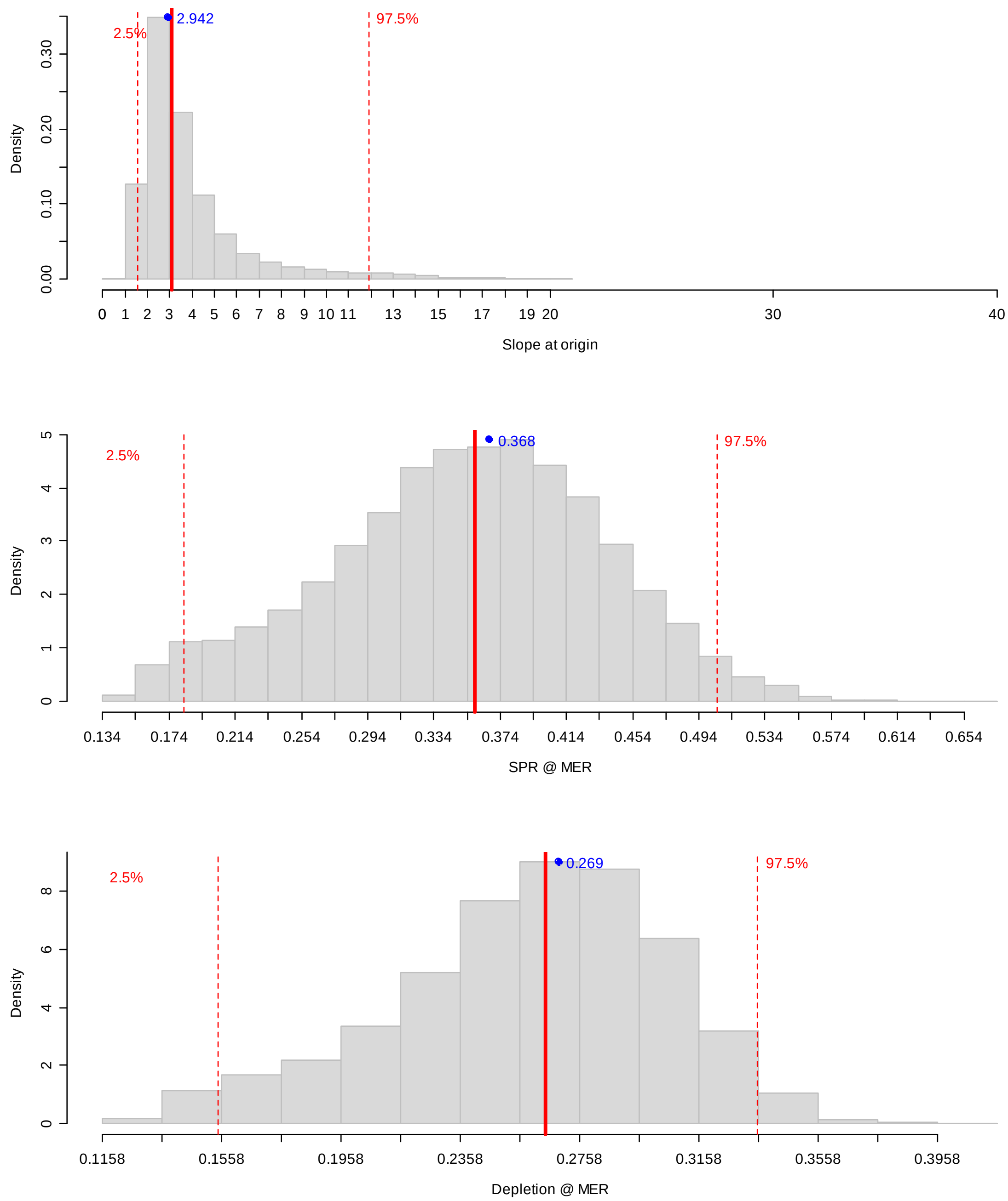

Figure 7. Posterior distributions from MCMC for the slope at the origin (top), SPR_{MER} (middle), and depletion at MER(bottom) for **winter** skate. In each plot, the point estimate is indicated by a solid circle and that value is beside the point. The median of the posterior is indicated by a solid vertical red line, while the 2.5^{th} and 97.5^{th} percentiles are indicated by dashed vertical red lines.

Deep sea red crab

Deep Sea red crab

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Northeast Data Poor Stocks Working Group Meeting
Woods Hole, MA
December 8-12, 2008

***Editor's Note: The authors of this red crab report added italicized text to this chapter, summarizing the Peer Review Panel Report (that full report is available at http://www.nefsc.noaa.gov/nefsc/saw/).**

Executive summary

Deep sea red crabs in the northwest Atlantic represent a data-poor stock because they inhabit deep water, are rarely caught in NMFS bottom trawl surveys, require targeted surveys to collect data on abundance, and little is known about their life history. Data from related species has been considered to make assumptions about the life history. Targeted surveys were conducted in 1974 (Wigley et al. 1975) and during 2003-2005 (Wahle et al. 2008). Two stock assessments have been completed for red crabs (Serchuk 1977; NEFSC 2006a).

This male-only fishery began in the late 1970's. Quality of commercial landings data is variable. The most recent targeted survey (2003-2005) found that there had been a significant reduction in abundance of large male crabs since 1974. In 1974 the minimum acceptable marketable size was 114 mm carapace width (CW). In 2008 the minimum market size of landed crabs was less than 90 mm. The size distribution of the females did not change, indicating that the change in male size frequency was due to harvesting. The male red crab carries the female during mating, and the male must be larger than the female for successful mating. The reduction in large males in the population could reduce mating success. Females might not find males of the right size and sperm shortage might occur.

The deep sea red crab fishery management plan (FMP) was implemented in 2002. The FMP set an MSY (2830 mt) based on the biomass of male red crabs over 102 mm in carapace width. Overfishing is considered to be occurring if catch>MSY, or a proxy thereof. The B_{MSY} calculated for the FMP is 18,867 mt of males, and if biomass goes below ½ B_{MSY} then the stock is considered overfished.

Three options for updating B_{MSY} were considered. The first was status quo (i.e., the value in the FMP), the second was to use an updated MSY (provided there was one) to calculate a B_{MSY} proxy, and the third option was to use the biomass of fishable males from the more recent survey as a B_{MSY} proxy. The review panel did not recommend a new B_{MSY} or B_{MSY} proxy, but they were concerned with the change in size of harvested crabs over time. B_{MSY} for red crabs will remain at the default level of 18,867 mt of males.

Several options for updating MSY for red crab were considered. Two models were used, the depletion corrected average catch model (DCAC) (A. MacCall, pers. comm.) and a 2-point boundary model. Runs made over a range of assumed M values (0.05 to 0.15) estimated sustainable catches from 1785-2004 mt. The long-term average catch (1775 mt) was also suggested as a possible MSY proxy. It was also suggested that MSY could be calculated with an updated version of Gulland's (1970) equation with an F_{MSY} to M ratio of 0.8 and the same range of M values, which gave estimates of 549-1740 mt. MSY values from the new options were smaller than the status quo value of 2830 mt.

The panel rejected the current estimate of MSY (2830 mt) as too high, based on observed changes in population size structure since the beginning of the fishery. Based on congruence between average landings and results from the DCAC model, the panel concluded that MSY ranges from 1700-1900 mt of males.

The review panel did not change the overfishing definition for red crab (i.e. overfishing occurs if catch of males >MSY).

Terms of reference (TOR)

a) Recommend biological reference points (BRPs) and measurable BRP and maximum sustainable yield (MSY) proxies.

b) Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop fishing level recommendations for these stocks.
c) Consider developing BRPs for species groups for situations where the catch or landings can not be identified to species. Work on this objective will depends on, and needs to be consistent with, final guidance on implementing the Reauthorized Magnuson-Stevens Act, whenever that guidance becomes available. (This TOR not applicable to red crab)
d) Comment on what can be done to improve the information, proxies or assessments for each species.

Biological characteristics[1]

Information in this section is summarized primarily from Steimle et al. (2001) and Wahle et al. (2008). Deep-sea red crabs (*Chaceon quinquedens*) are a brachyuran crab (family Geryonidae) inhabiting the edge of the continental shelf and slope from Emerald Bank, Nova Scotia, the Gulf of Maine, and south through the mid-Atlantic Bight and into the Gulf of Mexico. According to Weinberg et al. (2003), genetic differences between deep-sea red crabs from southern New England and the Gulf of Mexico indicate that crabs in the two areas belong to different biological populations (figure 1). Red crabs in Southern New England and the Mid-Atlantic Bight (south of Georges Bank) and the Gulf of Maine (north of Georges Bank) are assumed to be the same stock although fishing occurs primarily off Southern New England. Red crabs in the Gulf of Maine are smaller and the bottom is rough so little fishing for red crab occurs there.

Deep-sea red crabs live at depths of 200–1800 m, where temperatures are between 5 and 8 ^{o}C. Adult crabs are segregated incompletely by sex. Adult females generally inhabit shallower water than adult males, and juveniles tend to be deeper than adults, suggesting a deep-to-shallow migration as the crabs mature.

Information on the growth, longevity and mortality of red crabs is scarce. Natural mortality rates were assumed to be 0.2 y^{-1} in Serchuk (1977) and 0.15 y^{-1} in the current Fishery Management Plan (FMP) for Deep-Sea Red Crab. An assumed longevity of 30 or more years corresponds approximately to $M = 0.1\ y^{-1}$ (see below).

On the basis of limited laboratory data, red crabs are believed to require 5–6 years to attain a size of 114 mm carapace width (CW). Male red crabs are estimated to mature at about 75 mm CW and to reach a maximum size of about 180 mm CW. Females begin to mature at somewhat smaller sizes and reach a smaller maximum size of about 136 mm CW.

As in other brachyuran crabs, the mating male is larger than the female and forms a protective “cage” around the female while she molts and becomes receptive to copulation. The protective copulatory period may last as long as 2–3 weeks in red crabs. The minimum size of males relative to females required for successful mating is unknown. Information about sperm storage is not available for female red crabs.

Fishery and management

Red crabs in the US waters outside the Gulf of Mexico are managed as a single stock located primarily in the Mid-Atlantic Bight to Gulf of Maine region, although red crabs in the Gulf of Maine are not considered in calculation of reference points, biomass estimates or other management analyses.

[1] Based on Steimle et al. (2001) and Wahle et al. (2008).

A small experimental fishery for red crabs was established in the early 1970s. Before the initial targeted survey for red crabs (Wigley et al. 1975), fishery catches were small and sporadic. In the 1980s and 1990s, fishing effort was inconsistent due to market demand. A directed fishery for male red crabs and consistent markets developed in the mid-1990s.

The current US fishery for male red crabs has limited entry and as of 2006 consisted of four or fewer vessels 30+ m long. The fishery uses specially designed traps almost exclusively, although small catches are taken also in lobster traps. Fishing occurs year round and catches are made mainly along the continental shelf from the Canadian border (Hague Line), at the eastern end of Georges Bank, to Cape Hatteras, NC, USA, in depths ranging from 400 to 800 m.

Annual US commercial landings of red crabs during the period 1982–2005 ranged from 466 mt (1996) to 4000 mt (2001); there was no fishery in 1994. Since 2002, when the FMP was implemented, landings have been stable at about 2000 t per year. The current fishery is authorized to operate with a target TAC of 2688 mt, and an effort allocation of 780 days at sea. There is no recreational fishery for the species.

Minimum market sizes and fishery size selectivity have decreased since the early 1970s. The minimum market size for male deep sea red crabs in 1974 was 114+ mm CW. The minimum market size for male deep sea red crabs in recent years is about 85 mm CW. Fishery size selectivity has been estimated for the current fishery during 2004-2005 (L_{50}=92 mm CW) but no selectivity estimates are available for earlier years.

Based on limited log book, sea- and port sample information, discards of female and undersize male red crabs appear to average about 30% of total catch but can range from about 10% to 69% of total red crab catch. Discard mortality from being brought to the surface and handled on deck averages about 5%. (Tallack 2007). Bycatch of red crab in fisheries directed at other species is minor.

The major fishery related uncertainties for red crab are discards, discard mortality, as well as historical and recent fishery size composition. In addition, the expected response of the stock to fishing in terms of growth and recruitment is uncertain.

The infrequency of stock assessments is another key uncertainty. Only two stock assessments have been completed for deep-sea red crab off Southern New England (Serchuk 1977; NEFSC 2006a). Both were based on camera/trawl surveys completed just prior to the assessment.

Data availability

The principle fishery data for red crab are landings data from dealer reports starting in 1973, logbooks that start in 1994, size composition data for marketable males from routine port samples, and sea sample data for females and all males from a pilot program involving one vessel during 2004-2005. Landings data from dealer reports for years prior to 1982 are less reliable than data for later years. Landings per unit effort data are available from logbooks and dealer reports but are difficult to interpret. The fishery occurs off south of Georges Bank and virtually no fishery data are available for the Gulf of Maine. As described above, discard estimates based on limited sea-, port and logbook data are available and size selectivity estimates for the recent commercial fishery are available from comparison of sea- and port sample data.

The principle fishery independent data for red crab are from camera sled/bottom trawl surveys conducted during 1974 and 2003-2005 on red crab habitat between Maryland and the eastern tip of Georges Bank (excluding the Gulf of Maine). Camera data provide information about red crab density and bottom tow data provide information and sex- and size composition. The survey data for 2003-2005 are generally combined and treated as one survey. Data from a variety of research bottom trawl surveys are of limited use for red crab because catches are very low. The NMFS Cooperative Monkfish Survey may provide some useful information about red crab in the Gulf of Maine.

Camera and trawl tows in the 1974 and recent surveys were generally from the same or similar sites and sample locations. The two sets of surveys used bottom trawls of the same design and the same trawling protocols, although different vessels were used. Efforts were made to make camera data from the two surveys as comparable as possible but there is uncertainty about the effective area sampled (and therefore red crab density) by images collected during the 1974 survey. Density estimates from the recent survey are believed to be biased low because crab densities were significantly lower in the foreground (close to the camera sled) than in the background of the sampled area suggesting crabs were avoiding the camera, but the extent of the potential bias is unknown. The most reliable survey data are bottom trawl size compositions from both sets of surveys and density estimates from the most recent surveys.

Current stock status

Information in this section is summarized from NEFSC (2006a). The most recent assessment concluded that overfishing was not occurring because red crab landings during 2005 (2013 mt) were less than an MSY proxy (2830 mt, see below). Recent fishing mortality estimates were available but not used to determine overfishing because no F based reference point or proxy for F_{MSY} was available.

Based on the most recent assessment, average fishing mortality rate (landings / fishable biomass) on male red crabs was estimated to be F=0.055 (SE 0.008) y^{-1} during 2003-2005. This estimate is probably an underestimate because it does not consider potential mortality due to discarding of undersized male crabs and completely omits mortality due to discarding of females. Fishing mortality estimates are calculated using biomass estimates from surveys during 2003-2005, which are relatively certain but possibly biased low due to avoidance of the camera sled. Red crab biomass is appreciable but catches are currently near zero in the Gulf of Maine.

Alternate fishing mortality estimates including discards and based on best available discard estimates for sea- and port samples are given below (Table 1) for males only, females only and males plus females. Results indicate that total fishing mortality (including discards) during 2003-2005 were $F \leq 0.08$ y^{-1} for both sexes and for the sexes combined. The alternative estimates are “worse-case” scenarios because they assume that 50% of discarded red crabs die, whereas the current best estimate of discard mortality indicate that about 5% of discarded red crabs die from being brought to the surface and handled on deck (Tallack 2007). Discard rates (discard/total catch) were from sea- and port samples during 2003-2004 (Table D4.5 in NEFSC 2006a). In this exercise, fishing mortality for red crab was approximated as catch (landings + discards) divided by total biomass and catch divided by 90+ CW biomass (the approximation for F are relatively precise because mortality rates are low). Calculations using total biomass may understate fishing mortality because total biomass includes small size groups probably not taken in traps although potential bias may be small because small crabs have low weight. Calculations using 90+ CW biomass may overstate fishing mortality because red crabs of sizes smaller than 90+ CW make up the bulk of the discard.

Based on the most recent assessment (Table 2), fishable red crab biomass during 2003-2005 was about 36,000 mt. Overfished status was not determined for lack of an adequate B_{MSY} estimate or proxy (see below).

Comparisons of biomass estimates from the two surveys are uncertain due to uncertainty about the effective area sampled by cameras during 1974. However, biomass estimates from the two sets of surveys (table 2) indicate that male fishable biomass (based on current fishery selectivity) increased by about 20% during 1974 to 2003-2005. Female biomass (total, 90+ and 114+ CW) increased substantially by 150%-250%. In contrast, total male biomass increased by only 75% and biomass of large (114+ CW) males decreased by about 43%. Size composition data from the surveys indicates that both male and female red crabs have benefitted from recruitment in recent years (figure 2). The loss of large (114+ CW) male biomass and relatively modest increase biomass of males 90+ mm CW can probably be attributed to size-selective fishing (Weinberg and Keith 2003).

Red crab overfishing definitions

The Magnuson-Stevens act includes the requirement that all FMPs "specify objective and measurable criteria for identifying when the fishery to which the plan applies is overfished." The National Standard Guidelines (NSGs) require the specification of "status determination criteria" (63 FR 24212). These criteria are to be "expressed in a way that enables the Council and Secretary to monitor the stock or stock complex and determine annually whether overfishing is occurring and whether the stock or stock complex is overfished."

The National Standard Guidelines define overfished stock conditions and overfishing. According to the NSGs, an overfished stock is one "whose size is sufficiently small that a change in management practices is required in order to achieve an appropriate level and rate of rebuilding." A stock is considered overfished when its size falls below the minimum stock size threshold (MSST). The Magnuson-Stevens Act requires a rebuilding plan for stocks that are overfished. According to the NSGs, overfishing "occurs whenever a stock or stock complex is subjected to a rate or level of fishing mortality that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis." Overfishing is considered to occur if the maximum fishing mortality threshold (MFMT) is exceeded for one year or more.

Reference point approaches for red crab do not establish a fixed metric or approach to measuring stock biomass or exploitation. Based on the current FMP, overfished stock status and overfishing for red crab should be defined in terms of the best available measures of stock biomass and exploitation or fishing mortality relative to the value of the measures under MSY conditions. Choice of the particular measure or proxy depends on best available data and circumstances but a list of potential proxies and conditions is described in the FMP. In particular, based on the FMP, the red crab stock will be considered to be in an overfished condition if one of the following three conditions is met:

Condition 1 -- The current biomass of red crab is below ½ B_{MSY} in the New England Council's management area (excluding the Gulf of Maine).

Condition 2 -- The annual fleet average CPUE, measured as marketable crabs landed per trap haul, continues to decline below a baseline level for three or more consecutive years.

Condition 3 -- The annual fleet average CPUE, measured as marketable crabs landed per trap haul, falls below a minimum threshold level in any single year.

Similarly two potential approaches or proxies for identifying overfishing are described:

Proxy #1: F / F_{MSY} -- It is common for data sparse stocks to estimate trends in fishing mortality as an exploitation ratio, i.e., landings or catch divided by an index of abundance, usually from a survey. As a proxy for F_{MSY}, Councils in the past have selected an exploitation level that existed during a time with no trend in biomass at an intermediate biomass level.

Proxy #2: Landings / MSY – In the absence of other information, overfishing can be defined as catches in excess of an estimate of MSY. Although crude, provides an indication of current fishing effort relative to MSY conditions.\

The FMP describes a default control rule (figure 3) that could be used by managers, although this has proved impractical due to lack of biomass, exploitation, natural mortality and reference point estimates.

Current reference points

Information in this section is summarized from NEFSC (2006b). The reference point used as a fishing mortality threshold is MSY = 2,830 mt (6.24 million pounds).
The reference point used as a biomass target is B_{MSY} = 18,867 mt (41.6 million pounds) of male red crabs 102+ mm CW (4" CW). The reference point used as a biomass threshold reference point ½ B_{MSY} = 9,434 mt. A suggested CPUE baseline (presumably for use as a target) is 26-29 market-size crabs per trap, before adjustment for an equivalent number of 102 mm (4") CW market-size crabs.

Logic and justifications

In view of survey data limitations and infrequency of stock assessments for red crab, a landings-based BRP (e.g. estimate of MSY) for overall exploitation is appropriate for use as a threshold for exploitation rates in deep-sea red crab.

Serchuk's (1977) original MSY estimate (1,247 mt or 2.75 million lbs) assumed an underlying Schafer surplus production model, and used estimated biomass for male red crabs 114+ mm CW from the 1974 camera/trawl survey as an estimate of virgin biomass B_0 (114 mm CW was the minimum marketable size at that time). Based on the Schaefer surplus production model, MSY= $\frac{1}{2}MB_0$ and it was assumed that $F_{MSY} \cong M$. For the original red crab estimate, M=0.2 y^{-1} and B_0=24,948 mt of male red crabs 114+ mm CW.

The MSY estimate (2,903 mt) currently used by managers was made using the same formula and revised values for M and B_0. The revised value for natural mortality M=0.15 y^{-1} was thought to be a better estimate than M=0.2 y^{-1} for red crab. The original B_0 value was adjusted downward to account for part of the survey being in Canadian waters, adjusted upward to include male crabs 102 mm (4") CW and larger, as compared to the 1974 marketable size of 114 mm (4.5") CW, and adjusted upward again to account for the fact that the area fished is larger than the area surveyed. The adjustments took away biomass which now belongs to Canada, and added biomass to account for the area of the fishery south of the survey boundary to Cape Hatteras.

Reference point weaknesses

In the most recent stock assessments (NEFSC 2006) the current MSY and B_{MSY} estimates for red crabs were criticized and judged unreliable due to uncertainty about biological parameters and the model used to calculate MSY. New estimates were not developed due to lack of information about growth, longevity and trends in abundance.

Relatively little new information has become available since the last assessment. However, limited data for related species (*Geryon maritae*; Mellville-Smith 1989) suggest that M may be as low as 0.1 y^{-1}, which is lower than the previous estimates (0.15 and 0.2 y^{-1}).

The assumption that $F_{MSY}=M$ has been criticized recently. Walters and Martell (2004) suggest that F_{MSY} is lower and approximately 0.8M for many species.
The assumption that B_{MSY} = ½B_0 (Schaefer surplus production curve) is reasonable if the underlying spawner-recruit relationship is a Ricker curve. However, $B_{MSY}<$ ½B_0 if the underlying spawner-recruit relationship is a Beverton-Holt curve. Beverton-Holt recruitment dynamics are more likely for red crab because there is no known biological mechanism that might result in maximum recruitment at intermediate spawning biomass levels.

The current B_{MSY} estimate of 18,867 mt in the FMP is for male red crabs 102+ mm CW (4") which is not representative of current fishery conditions. The current fishery lands male red crabs 80+ mm and the L50 for current fishery selectivity is 92 mm CW.

The survey biomass for 1974 may be a poor estimate of B_0 because of statistical variance in the estimate (variances are not available for the estimate), uncertainty about effective area sampled by the camera sled, or because some fishing had already taken place prior to 1974. The total biomass for male red crabs during 2003-2005 (56,443 mt) exceeds the estimate for 1974 (32,190 mt) despite consistent fishing indicating that the estimate for 1974 is a poor estimate of B_0.

The fishery appears to have substantially reduced the abundance of the largest male red crabs. Smaller male crabs may not be able to mate with large females. There is concern that reduced abundance of large male crabs may lead to sperm limitation and reduced levels of egg production if there are no males left in the population to mate with the larger females.
Landings per unit of fishing effort data (LPUE) are mentioned in the FMP as a baseline stock biomass indicator for red crab but LPUE data have proven difficult to interpret, particularly as long time series (NEFSC 2006a).

Options and recommendations

This section outlines a range of options for exploitation and biomass based biological reference points to be used managing deep-sea red crab in the management area outside the Gulf of Maine.
The exploitation BRPs described here are thresholds specified in terms of landed weight (yield). Yield based approaches are the only practical approach for red crab because the only fishery dependent or fishery independent data routinely available for red crabs are landings. The options for yield based BRPs are intended as proxies for landings at F_{MSY}.

Options outlined below emphasize the most reliable information sources for red crab, which are landings since 1982 and biomass, abundance and size composition data the most recent camera/trawl survey conducted during 2003-2005, and size composition data from the original camera/trawl survey conducted during 1974. Biomass estimates from 1974 are less reliable and more uncertain because of questions about the effective area sampled by cameras in that survey. Uncertainty about biomass estimates makes trend analysis uncertain. Size composition data from 1974 are more reliable and are comparable to size composition data from 2003-2005 because bottom trawls and towing protocols used in 1974 were well documented and because trawls and protocols used in later years were the same.

Fishing for females

All options outlined in this report assume a male only fishery for deep-sea red crab. None are applicable to fishery involving female red crabs. If a female red crab fishery is ever established, then all yield- and biomass based BRPs should be revaluated.

Marketable sizes and fishery selectivity

In laying out options for BRPs, we assume that fishery selectivity in the future will be the same as during 2003-2005. As described above, fishery selectivity for red crab has changed over time. Marketable size males were 114+ mm CW during the late 1970s. Based on the last stock assessment, the selectivity pattern in the current fishery follows a steeply increasing logistic pattern with selectivity near 0% at 80 mm CW, 50% selectivity at 92 mm CW and nearly 100% at 120 mm CW. If fishery selectivity changes, then all yield- and biomass based BRPs should be reevaluated.

OPTIONS for a Gulf of Maine stock

The management area for red crab excludes the Gulf of Maine and this situation complicates the development of biomass based BRPs. Red crabs in the Gulf of Maine (where little or no fishing occurs) and red crabs in the Southern New England and the Mid-Atlantic regions where (fishing occurs) are considered to be a single US stock. It is possible that depletion of red crabs south of Georges Bank might be "hidden" by including some level of unfished biomass in the Gulf of Maine as part of the stock as a whole, to the detriment of the entire stock and the fishery. Thus, the separation of red crabs into one management area and an area with no active management complicates specification and probably reduces the potential benefits of BRPs.

Under these conditions, it may be advisable to manage the areas north (Gulf of Maine) and south (Southern New England and Mid-Atlantic areas) as separate stocks. Red crab are a demersal species that migrate ontogenetically and seasonally from shallow to deep but there is no evidence of strong migratory movement of juveniles and adults along the coast. Thus, localized depletion may occur in red crabs due to continuous fishing in areas south of Georges Bank. The shallow waters and geography of Georges Bank effectively separate the Gulf of Maine from other habitat areas along the US coast. Red crabs in the Gulf of Maine appear to be smaller than red crabs in southern areas where the fishery is occurring, suggesting differences in growth rates and other biological characteristics. However, it is unlikely that red crabs in different areas off the northeast coast of the US differ genetically. It is also likely that recruitment is linked to some extent along the entire US coast due to transport of larvae in currents.

Two options are proposed.

Option 1: Continue to manage a single US stock of red crabs. The main advantages of this option are minimization and simplicity of regulations. The main disadvantages are loss or potential benefits from BRPs.

Option 2: Manage red crab in the Gulf of Maine and areas south of Georges Bank (Southern New England and Mid-Atlantic regions) as separate stocks.

Under this option, the exploitation BRP used to define overfishing for the Gulf of Maine stock would be F_{MSY} or the best available proxy. BRPs used to define the biomass target and biomass threshold for the Gulf of Maine would be B_{MSY} and $\frac{1}{2}B_{MSY}$ or the best available proxies. F_{MSY} and B_{MSY} for the Gulf of Maine are currently unknown and would have to be determined if interest in a Gulf of Maine red crab fishery develops. One or more special surveys designed to target red crabs would likely be required.

The main disadvantages of this option are increased regulations and complexity although any increases would be modest. The main advantage would be increased benefits of BRPs for red crab in the area were fishing occurs.

The second option (separate stocks) is recommended because the hypothesis of two stocks is scientifically credible, in view of restricted adult movement around Georges Bank and smaller red crabs in the Gulf of Maine, and because the potential utility of BRPs for the fished and unfished stock areas is increased. Under current legislation, BRPs used to define overfishing and overfished stock conditions must apply to entire stocks. Overfishing definitions for parts of stocks, such as the current management area for red crab, are apparently not allowed. Therefore, meaningful BRPs that address only red crab in the current management area appear impractical. *The review panel did not discuss management of deep sea red crabs in the Gulf of Maine.*

OPTIONS to regulate minimum legal size for male red crabs

Minimum size regulations may be desirable and should be evaluated for use in the red crab fishery. Minimum size regulations are used with some success in many crab and lobster fisheries. It is much easier to recommend biomass based reference points once the fishable stock (including minimum size) is clearly established and BRPs for a specified fishable stock are likely to be more meaningful and useful. Moreover, none of the options for exploitation and biomass based BRPs in this report deal effectively with concerns that sperm limitation may result from removal of large males by fishing. Exploitation and biomass based BRPs are indirect approaches to dealing with these potential issues.

Because marketable sizes, fishery selectivity and potential sperm limitation are important, three options for regulating minimum marketable sizes are presented for consideration by managers. Detailed analysis of this topic is an important area for research which should be carried out as soon as possible under any option because the full range of cost and benefits to the stock and fishery have not bet identified.

Option 1: No action. The main advantage is minimal impact on the fishery and minimal management costs. There is no evidence of serious problems in the fishery so no actions to regulate minimum legal size may be necessary. Minimum legal size regulations could be implemented in the future if required. The main disadvantage is the potential for changes in marketable sizes that tend to make BRPs for deep-sea red crabs moot. It is also possible that shifts in marketable sizes could exacerbate loss of large males which may be important for successful reproduction.

Option 2: Implement a minimum legal size for red crab that would leave some larger males in the population yet allow for a significant portion of crabs currently landed to remain marketable. This option would prohibit landings of male red crabs less than a specified CW. This minimum legal size should be close to the current minimum marketable size, such as 85-90 mm CW, to minimize fishery impacts yet large enough to leave males suitable for mating with newly mature females. With this option in place further losses of large males and the potential for sperm limitation in the population might be minimized. BRPs for red crabs would be more meaningful and useful if the fishable stock is defined.

Option 3: Defer minimum legal size regulations until more analysis is carried out to determine the optimum minimum legal size from the fishery and biological perspectives. This option is basically a combination of options 1 and 2.

Option 2 is recommended to increase potential benefits of BRPs and to help avoid potential problems with loss of large males. Impacts on the current fishery would be minimal.

The review panel did not discuss minimum legal size for male red crabs.

Biomass based biological reference points

As described above, biomass based reference points can be outlined for red crabs but data limitations and infrequent assessments will probably undermine their utility. Exploitation (yield-based) reference points are likely to be more important in a practical sense for deep-sea red crabs.

Some MSY analyses and estimates described in this report for red crab assume virgin or near virgin biomass conditions during 1974. Many are basically trend analyses which assume that biomass estimates for 1974 and 2003-2005 are directly comparable. The results of these analyses are uncertain to the extent that biomass estimates for 1974 are uncertain because of questions about the area of the sea floor the camera sled was able to illuminate and photograph clearly during the 1974 survey. Biomass estimates from more recent 2003-2005 surveys are better understood, better documented and the area covered by the cameras is well defined. Recent estimates were affected by some avoidance behavior that resulted in negative bias and some underestimation of stock biomass. Avoidance behavior may affect 1974 estimates as well but uncertainty about the effective area of the camera is most important. Biomass estimates for 1974 are also uncertain because biomass estimates for all but large male crabs were substantially higher for 2003-2005 than for 1974, despite substantial fishery removals during 1974-2003.

OPTIONS for biomass based BRPs

Terms of Reference and NSGs require biomass based BRPs that describe target and threshold biomass levels. It is possible to define biomass based BRPs for red crabs but they are likely to be of little use because of lack of stock assessments, lack of useful survey data and difficulties in interpreting fishery catch rates (LPUE). None of the proposed options for biomass BRPs involve commercial catch rates (LPUE) because they have proven difficult to interpret for red crab (NEFSC 2006).

Three proposed options for B_{MSY} estimates that could be used as target BRPs for red crabs are described below. In each case, the threshold BRP would be ½ of the B_{MSY} estimate or proxy.

Option	B_{MSY} (males only)
1	18,867 mt 102+ mm CW
2	16,904 mt fishable sizes
3	36,253 mt fishable sizes

Option 1: Status quo or no action (Listed in red crab FMP, 2002, Section 3.6.4). This gives a biomass based target B_{MSY} =18,867 mt of male red crabs 102+ mm CW, developed from the approximation $MSY = ½MB_0$ where B_0 was the estimated biomass of male red crabs during 1974 with adjustments for male

biomass at size and for areas not sampled in the survey. The biomass threshold that defines an overfished stock biomass is ½B_{MSY} = 9,434 mt. Weaknesses with Option 1 are described in earlier section of this report "Reference Point Weaknesses". Weaknesses are related to underlying assumptions about the spawner recruit curve, what B_0 represents in terms of virgin biomass, and M.

Option 2: Use the updated estimate of MSY (to be selected, see below) and current fishable biomass from the most recent assessment to estimate B_{MSY}. The biomass threshold that defines overfished stock biomass conditions is ½ B_{MSY}.

The main advantage of Option 2 is ensuring that biomass BRPs are consistent with exploitation based BRPs. If virgin biomass is very uncertain, then it may be better to base biomass reference points on the MSY proxy or estimate of sustainable catch. The main disadvantage is that it necessitates additional information about stock productivity. In addition, it may provide a poor estimate of B_{MSY} if the F_{MSY} proxy is inaccurate or the estimate of sustainable yield is substantially different from MSY.

In particular, assume $F_{MSY} = cM$ where c=0.7 (see below) and the natural mortality rate M= 0.15 y^{-1} (see below), then MSY= F_{MSY} B_{MSY} = 0.7(0.15) B_{MSY} = 0.105 B_{MSY} and B_{MSY} = MSY / 0.105 = 9.52 MSY. For example, if MSY= 1775 mt (the long term average catch and within the range of sustainable yield and MSY proxy options given below), then the biomass target B_{MSY} = 9.52 x 1775 = 16,904 mt fishable biomass and the biomass threshold B_{MSY} /2 = 8,452 mt fishable biomass.

Option 3: Use the most recent estimate of fishable biomass from the last assessment (36,247 mt) as B_{MSY}. The biomass threshold that defines overfished stock biomass conditions is ½ B_{MSY}.

The main advantage of Option 3 is that it is based on the relatively reliable 2003-2005 biomass estimate. As described above, uncertainties about the 1974 biomass estimate for red crab may preclude its use in estimating virgin biomass. The stock shows signs of fishing down (reduction in abundance of large males) expected under fishing at MSY levels. Current fishing mortality rates appear to be relatively low (F=0.055 y^{-1} in the managed stock area ignoring discards and no more than 0.1 y^{-1} including discards). These fishery induced mortality estimates are comparable to the range of F_{MSY} levels (F_{MSY} =0.6 M to 0.8 M, with M=0.1-0.2 y-1) that might be considered for red crabs and potentially sustainable. The main disadvantage is the possibility that current biomass is substantially larger or smaller than B_{MSY}.

Option 2 (use the updated estimate of MSY to specify B_{MSY}) is recommended by the Working Group because virgin biomass is uncertain. Option 1 is not recommended because it involves poor approximations to F_{MSY} and B_{MSY}. Option 3 is not recommended because it implies MSY= F_{MSY} B_{MSY} levels of about 0.7 (0.1) * 36,253 = 2,538 mt per year. This estimate is substantially larger than the long term average catch which has a pronounced effect on the relative abundance of large males.

The Peer Review Panel recommended Option 1 for B_{MSY}. The Panel did not recommend changing B_{MSY} or the B_{MSY} proxy for red crab, due to concerns about the shifting size of *marketable crabs and fishery-induced size frequency changes in the population. A simple biomass-based B_{MSY} proxy would not be reliable under the present circumstances of the fishery.*

Options for exploitation based BRPs

All of the options for exploitation based BRPs in this report are specified in terms of landings (yield) because landings are the only data consistently available for the fishery. Landings based BRPs are also desirable for red crabs because they are simple and easy for managers to use outside the formal stock assessment process and without extensive review.

Ideally, all exploitation BRPs for red crabs based on landings would be MSY estimates or proxies to be used as thresholds that define overfishing. In principal, these BRPs are not used as targets. In particular, current NSGs indicate that managers may specify any annual catch limit (ACL) as long as exploitation is below the exploitation threshold BRP. In other words, managers are expected to consider uncertainties and risks in setting ACLs in addition to not exceeding the threshold reference point. In this report, we focus primarily on uncertainties about the reference points themselves and ignore many of the uncertainties managers face in setting ACLs.

A number of the methods used to calculate potential exploitation based BRPs are estimators for “sustainable” catch levels, rather than estimates or proxies for MSY. There is no guarantee that sustainable catch levels calculated for red crab are near MSY. Sustainable yield estimates are often estimates of average catch with or without adjustments for unsustainable “windfall” catches that may occur as virgin stock is fished down towards B_{MSY}. MSY is the maximum sustainable catch level at biomass levels usually less than ½ virgin biomass.

A number of the methods used in this report to calculate potential exploitation based BRPs are equilibrium estimators that assume constant recruitment, growth and mortality over the period of years in the model. Equilibrium estimators are often used in data poor circumstances but they tend to perform poorly in non-equilibrium situations. Size composition data from surveys during 1974 and 2003-2005 indicate changes in recruitment because small male and female red crabs were abundant during the latter survey. Changes in growth and recruitment would, in fact, be expected as the near virgin stock in 1974 was fished down over several decades. Results of the equilibrium estimators are uncertain to the extent that equilibrium assumptions may have been violated.

We used 4 methods to estimate MSY or proxies thereof:

1) Long-term average catch. We can make the argument that if CPUE in pounds per day at sea has been relatively stable and the biomass of currently marketable red crabs hasn’t changed much from 1974 to 2005, then the level of fishing on the population since the 1970s must be sustainable. If summed recorded landings from 1973-2007 (35 years) equal 62,132mt, then the mean annual take of red crab has been 1,775mt, which is slightly less than mean landings since 2002.

2) Updated yield equation. The equation used to calculate MSY for the FMP was Y = (0.5)(M)(B_0) = (0.5)(0.15)(B_0 of males >114mm). However, $B_{MSY} < ½B_0$ if the underlying spawner-recruit relationship is a Beverton-Holt curve. Beverton-Holt recruitment dynamics are more likely for red crab because there is no known biological mechanism that might result in maximum recruitment at intermediate spawning biomass levels. Secondly, the ratio of F_{MSY} to M at maximum sustainable yield has been found to be less than one for most fisheries (Walters and Martell 2004). A coefficient c should be applied to M that is often 0.8 but for stocks more

vulnerable to overfishing can be as low as 0.5. To update the equation to match the conditions of the current red crab fishery, the B_0 must be for males smaller than the >114mm CW it was originally calculated for. So that leaves the equation Y = (0.4)(*c*)(*M*)(B_0 fishable males). We used a range of *M* values and calculated MSYs based on both the 1974 and 2003-2005 survey biomass of fishable males.

3) Depletion-corrected average catch (DCAC) model. The addition of a second survey allowed us to run two models which use length frequency or abundance data from two points in time to look at potential sustainable yields. The DCAC model input consists of summed annual landings, an estimate of *M*, an estimate of the F_{MSY} to *M* ratio, the amount of depletion between the two surveys and the number of years between them. It calculates a sustainable yield of a population after accounting for the "windfall" which occurs at the beginning of a fishery. We ran the model using several different estimates of *M*. For model details see appendix 2.

4) Two-point boundary model. This approach also uses abundance data from 2 points in time, and was run using various values of *M*. Estimates of median recruitment of males and females of various sizes, average *F*, and catch at equilibrium were derived for male and female red crabs from the 1974 and 2003-2005 surveys, and landings from 1974 to 2003. For model details see appendix 3.

Most of the yield based reference points presented in this report (Table 3) are lower than the current estimate of MSY (2830 mt) and target TAC (2688 mt). Most are lower than the observed catches during some years. Most of the estimates are reasonably consistent, possibly because they are based on average landings or because they assume fishable stock biomass levels were similar during 1974 and 2003-2005. The similarity of many of the new MSY estimates (figure 4) to the long-term average catch (from 1973 to 2007, 1775 mt) supports the idea that this level of landings is sustainable. Recent catches from 2002 to 2007 (mean 1853 mt) have been in this range, yet declining over the last few years. We recommend a catch limit that mimics both recent and long term mean annual landings, and suggest the current MSY of 2830 mt is not sustainable.

The review panel agreed that the MSY calculated for the FMP (2,830 mt) is not reliable. If the assumption that the changes in red crab population structure were caused by fishing is true, then previous higher catches have not been at sustainable MSY levels. The review panel concluded that, using the best available scientific information, estimates of MSY for male crabs only was in the range of 1700-1900 mt. The depletion corrected average catch model (DCAC), which estimated MSY to be very similar to the long-term mean catch, was deemed an acceptable model for this rarely-surveyed resource. The panel found no reason to change the overfishing definition of catch>MSY.

The panel noted that the change in the size distribution of landed male crabs over time may introduce uncertainty in the DCAC model. Even though the data were standardized to the same size structure, it is unclear how the removal of smaller and smaller male crabs over time may affect the model estimates of BRPs.

The review panel suggested that BRPs based on size and sex ratio may be useful in the future due to the importance of preventing sperm limitation in the red crab population. Unfortunately, that would require regular surveying, since fishery-dependent data does not give an accurate picture of the whole population as large males are targeted and the crabs are generally segregated by sex.

Since there is evidence the red crab fishery may be moving southward into previously lightly-fished areas as large males are depleted in the traditional fishing areas, the review panel noted the estimated BRPs are for the current area being fished and/or the extent of the surveys.

Scientific risks and uncertainties

Risks and uncertainties regarding BRPs for deep-sea red crabs are described below which are important in the context of choosing among BRP options, and in setting ACLs once BRPs are chosen. Risks to the stock due to overharvest and to the fishery due to foregone harvest are described in general terms but have not been quantified (no formal risk analyses were carried out).

Biomass based BRPs are difficult to evaluate for red crabs at this time due to lack of routinely available information about biomass levels and trends, and infrequent stock assessments. Therefore, risks and uncertainties regarding exploitation based BRPs are particularly important.

The following key uncertainties are listed in approximate order of importance.

a) There is a great deal of uncertainty about fundamental life history parameters in red crab, including longevity and natural mortality, growth and maturity, and reproductive biology. There is also uncertainty about whether red crabs have a terminal molt and the extent to which females can store sperm.
b) There is no available information about the spawner-recruit pattern and recruitment variability in red crab. There is uncertainty about the potential productivity of red crab due to uncertainty about fundamental life history parameters and recruitment.
c) Minimum marketable sizes and fishery size selectivity have changes since the early 1970s and processors now accept smaller male red crabs. There are no management measures regulating minimum size. Thus future fishery selectivity patterns are uncertain.
d) Based on the last stock assessment (NEFSC 2006a; 2006b), there is no evidence of serious problems in the red crab population (fishery induced mortality rates are $< 0.1\ y^{-1}$) and recruitment was apparently occurring during 2003-2005. However, survey size composition data from 1974 and 2003-2005 show reduced abundance of large males (114+ CW) probably due to fishing. There is little uncertainty about reductions in occurrence of large males. There are questions about the potential importance of large males in spawning. In particular, loss of large males may affect reproductive capacity of the red crab stock. These questions have a sound logical basis but have not been fully investigated.
e) Discards of undersize males and females are thought to be about 30% of total catch but the estimates are uncertain. Mortality of discarded crabs was relatively low in a recent study (~5%) but the estimate is uncertain and may be higher during routine fishing.
f) Some of the methods used to calculate biological reference points in this report rely heavily on landings data collected during a period when exploitation levels were relatively low. Historical catches may understate MSY to the extent that fishing mortality has been less than F_{MSY} during recent years. Thus, there is appreciable risk that reference points in this report will result in unnecessarily foregone catches.
g) Some of the methods used to calculate biological reference points in this report involved equilibrium assumptions that may not be justified for red crab. The potential effects of the equilibrium assumptions are uncertain.

h) As noted above, biomass estimates from the camera/trawl survey during 1974 are uncertain because of questions about the effective area searched by camera. Uncertainty in the 1974 biomass estimate increases uncertainty in BRP calculations that evaluate long term biomass trends or use the 1974 survey to characterize virgin or near-virgin stock levels.
i) Recent red crab biomass estimates from surveys during 2003-2005 have a negative bias due to a statistically significant level of red crab avoidance behavior. The magnitudes of red crab avoidance behavior and bias have not been evaluated.
j) There is uncertainty about whether new NEFSC bottom trawl surveys will provide useful information about red crabs. Available data from comparative fishing experiments provide little evidence one way or the other in this regard.
k) Changes in fishing locations have occurred during recent years, presumably due to localized depletion.

The review panel, in their report under "advice about scientific uncertainties" emphasized what they thought were the most significant sources of uncertainty. Under "observation uncertainty", they listed aspects of the biology, the survey and the fishery for red crab. Regarding red crab biology, the most significant sources of uncertainty were the lack of basic knowledge of life history, especially maximum age, growth per molt, intermolt period, and the occurrence of a terminal molt. Seasonal changes in distribution were also noted as a source of possible uncertainty.

Uncertainties involving the surveys exist because only two have been conducted (30 years apart). Also, there are concerns about comparability of the two surveys because of uncertainty about how crab counts from the illuminated area in the first survey were expanded and extrapolated to estimate the number of crabs in the entire region.

There is also uncertainty surrounding the fishery and the distribution of effort both spatially and temporally, and whether the distribution of the crabs was affecting the behavior of the fishery. The panel noted that an assumption of all the red crab analyses was that the pattern of harvest was from a stationary population.

In terms of "process uncertainty", the panel emphasized several possible sources. The first was that there is no knowledge of the influence of male to female ratios, in both number and size, on reproductive potential. The removal of a significant portion of the large males over time may have significant consequences on the population as males must be larger than females to mate. Other process uncertainties are the fact that the fishery may be changing its distribution and thus changing availability patterns, and the unreliability of the VTR discard data.

Research recommendations

a) Establish a regular schedule for surveys that provide useful information about deep-sea red crab. This is the most important research recommendation for red crabs.
b) Develop practical survey approaches for red crab in deep water. Recent cooperative work indicates that towed body video surveys are accurate and useful for sea scallops. It is likely that the same equipment and approaches would be useful for deep-sea red crab.
c) Evaluate the importance of large male red crabs in reproduction considering the size distribution and molting cycle of females, sperm storage, length of the mating season, duration of copulation and other key parameters.
d) Studies to refine estimates of growth parameters, longevity, natural mortality and reproductive parameters are needed.

e) Place scientific observers on board fishing vessels during routine fishing trips to collect data about discards.

The review panel recommended several additional research needs and general suggestions which would reduce the uncertainties in the BRPs:

a) Consider additional fishery-independent surveys, with continued industry support and involvement. These cooperative surveys might include standardized trap-based sampling or HABCAM (cameara) surveys. The panel noted that the industry is already supporting a sizeable tagging program.

b) Additional information on relative sizes of mating pairs and its consequences on reproductive potential (sperm limitation) would allow for the inclusion of additional size-based BRPs

i) Consider simulation modeling to explore the response of the population sex ratio to different exploitation patterns to determine whether sex ratios may serve as a tool to inform management on current catch rates. The review team noted that such an approach would only work if knowledge of the population wide sex ratio was indexed.

c) Studies of brood production, incubation period, and pattern of sperm storage would be helpful.

d) Studies to refine growth (intermolt period and growth per molt) and longevity estimates would improve understanding of stock dynamics.

e) Assessment of whether females, in particular, exhibit a terminal molt would help development of growth models.

f) Information on movement and behavior of crabs within their range would be of utility.

g) Abundance-habitat relationships.

h) Role of economic factors in crab and other fisheries may alter distribution and interpretation of fishing effort.

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Deep sea red crab; Tables

Table 1. Total annual mortality due to fishing (landings and mortal discard) during 2003-2005, by sex.

	Males	Females	Total
Average 2003-2005 landings (mt)	1,992	0	1,992
Discard/(total male + female catch)	0.11	0.18	0.29
Catch (mt, includes all discards)	2,238	2,429	4,667
Discard (mt)	246	2,429	2,675
Discard mortality rate (5 x best estimate)		0.5	
Mortal discard (mt)	123	1,215	1,338
Landings + mortal discard (mt)	2,115	1,215	3,330
Total biomass (mt)	56,443	74,689	131,132
90+ CW biomass (mt)	38,220	55,279	93,499
F relative to total biomass	0.04	0.02	0.03
F relative to 90+ biomass	0.06	0.02	0.04

Table 2: Biomass estimates, standard errors and CVs from deep-sea red crab camera/bottom trawl surveys. The standard errors for 1974 estimates are approximations based on the assumption that CVs for variability among samples was the same during 1974 as during 2003 to 2005. The differences in CVs between the two periods are due do differences in assumed effective sample size.

		Males			Females			Total		
Year	Size groups (mm CW)	Biomass (mt)	SE (mt)	CV	Biomass (mt)	SE (mt)	CV	Biomass (mt)	SE (mt)	CV
1974	90+ mm	29,991	6,298	0.21	15,654	3,719	0.24	45,645	7,314	0.16
	114+ mm	23,794	4,303	0.18	2,106	433	0.21	25,900	4,325	0.17
	Fishable	30,302	6,363	0.21	NA	NA	NA	NA	NA	NA
	All	32,190	5,001	0.16	20,674	5,221	0.25	52,864	7,230	0.14
2003 to 2005	90+ mm	38,220	4,298	0.11	55,279	7,033	0.13	93,499	8,242	0.09
	114+ mm	13,770	1,334	0.10	5,224	576	0.11	18,994	1,453	0.08
	Fishable	36,247	4,612	0.13	NA	NA	NA	NA	NA	NA
	All	56,443	4,646	0.08	74,689	10,102	0.14	131,132	11,119	0.08

Table 3. Summary of exploitation based BRPs as MSY or MSY proxy options.

Method	Method or model	Result	Estimate or range of estimates	Uses 1974 survey Information?	Equilibrium estimator?
1	Status quo MSY	MSY	2830 mt	Yes	No
2	Long term sustainable catch	Sustainable yield	1775 mt	No	Yes
3	Updated yield equation applied to 1974 biomass	MSY	549 - 1646 mt	No	No
4	Updated yield equation applied to 2003-2005 biomass	MSY	580 - 1740 mt	No	No
5	DCAC model	Sustainable yield	1785 - 1862 mt	Yes	Yes
6	2-point boundary model	Equilibrium catch	1987 - 2044 mt	Yes	Yes

Deep sea red crab; Figures

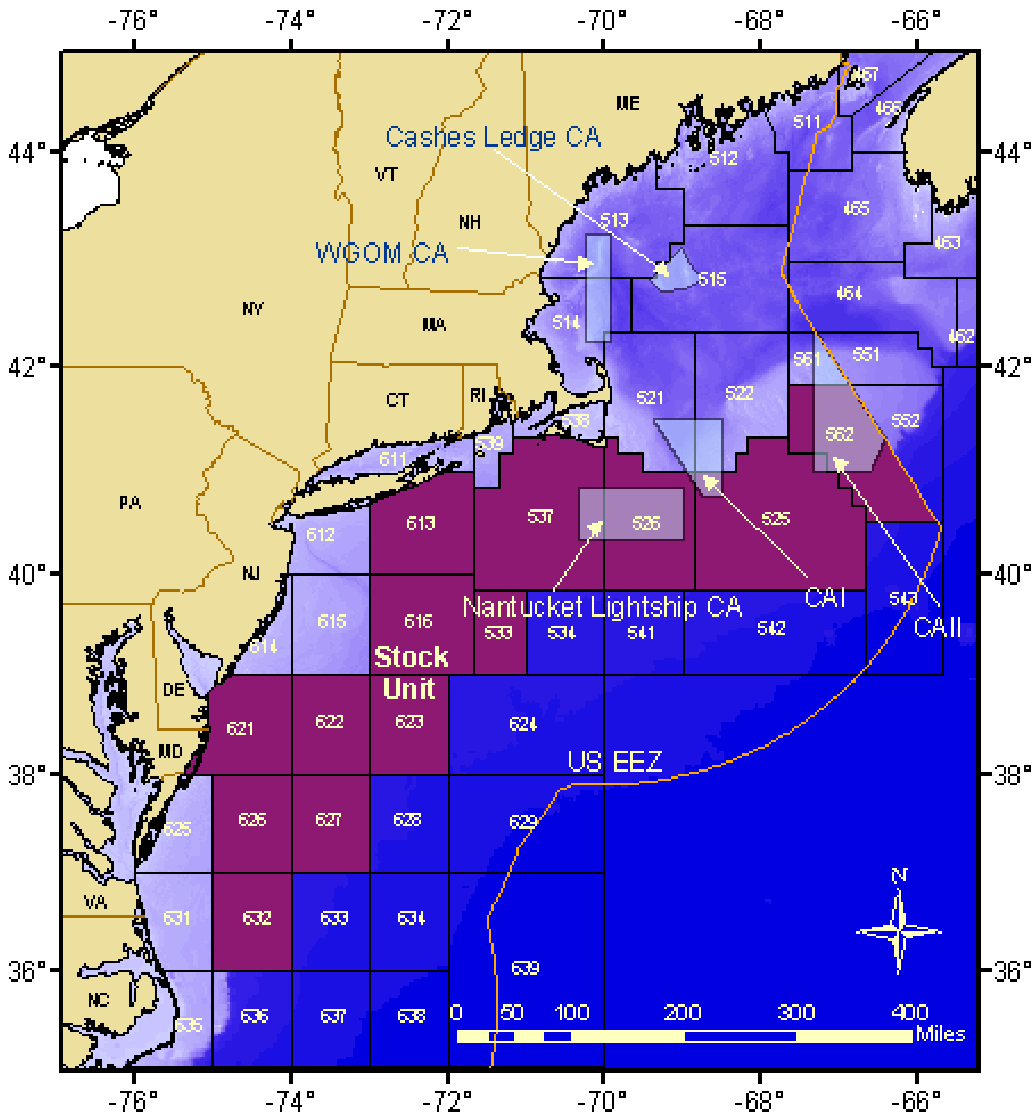
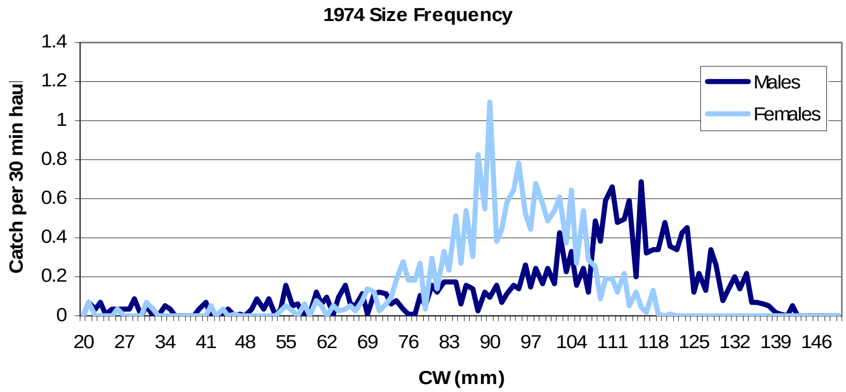


Figure 37.1. Statistical areas used to define the deep sea red crab stock.

Figure 1. The management area used by the New England Fishery Management Council for deep-sea red crab. The portion of the stock in the Gulf of Maine is excluded.



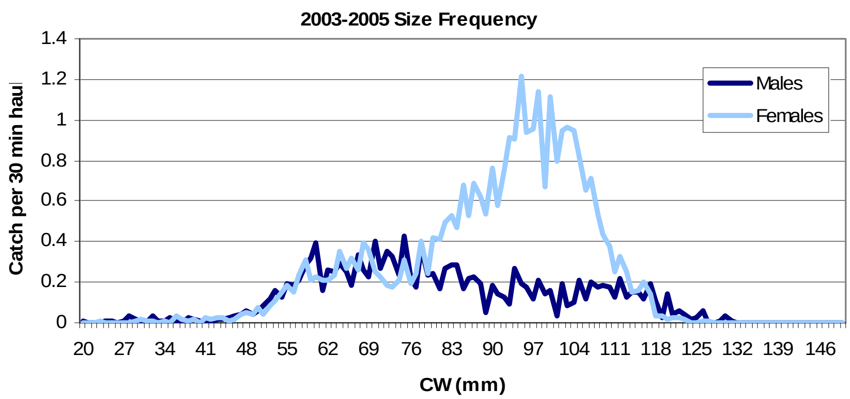


Figure 2. Catch per 30-minute trawl by size in the 1974 survey (top) and 2003-2005 surveys.

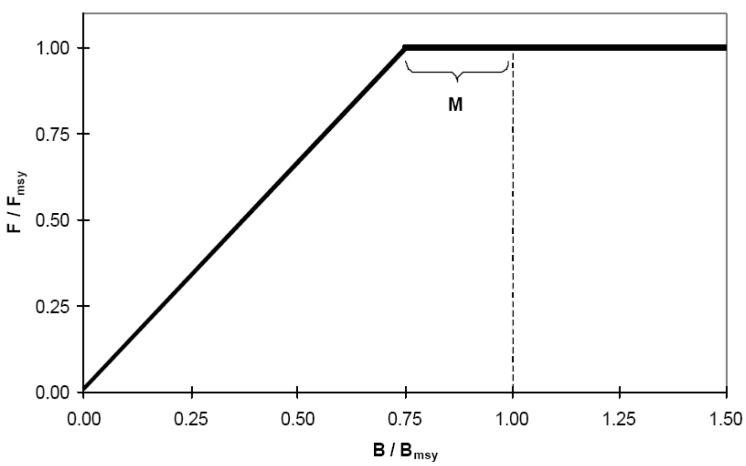


Figure 3. Default MSY control rule in the FMP for deep-sea red crab.

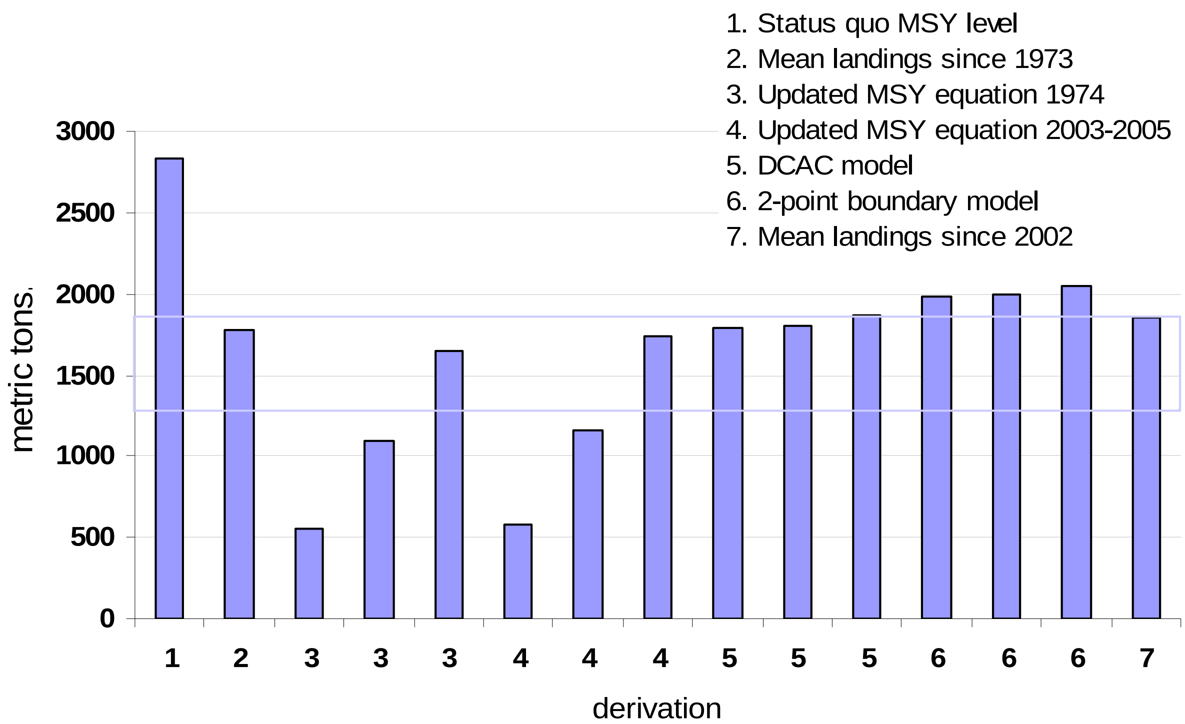


Figure 4. Summary of estimates of sustainable yield for red crab estimated using various methods. The upper boundary of the shaded area is the mean annual landings of red crab since 2002 and the lower boundary represents landings during 2007.

Deep sea red crab; Appendix 1

Red crab size composition analysis

Based on the ratio of minimum mature size, and ratio of mean size in 1974, we assume that males must be at least 25% larger than females to mate successfully (alternative assumptions could be explored). This analysis examines the impact of the fishery on the size structure of the population, specifically with regard to the ratio of number of males to the number of females small enough for the males to fertilize.

Direct analysis of survey results has the benefit of being able to explore the sex ratio in terms of observed densities of crabs, but lacks the ability to interpret those results in terms of a reference point of no fishing. It may be possible to interpret the 1974 survey as representing size distributions under light fishing, so that 1974 could serve directly as a reference distribution.

Direct analysis of survey densities

Table 1a shows summary statistics of mature red crabs from the 1974 and 2003-2005 surveys. Females are assumed to mature at 70mm, and males at 90mm. The densities of mature male crabs per 30-minute tow declined slightly, but the density of female crabs increased substantially in the later survey. This poses some difficulty for interpretation, with the main hypotheses being that it is due to imprecision (including differences in survey locations—all this needs to be explored), or alternatively that it is due to exploitation effects on a population that otherwise would have been more abundant in the later period. If the 1974 ratio of males to females is applied to the density of females in 2003-2005, the expected male density would have been approximately 30, in which case the relatively low observed value of 15 is presumably due to exploitation effects. Mean size of females is similar in the two surveys, but mean size of males declined as would be expected from exploitation effects including a shift of minimum marketable size from 114mm to 90mm. By tabulating the sum of densities of females smaller than the minimum sized female each male size class is capable of mating with, table 1a below shows the mean number of females available to the males, weighted by the size frequency of males. In order to maintain a similar level of fertilization, the average male in 2003-2005 must mate with 2.33 times the number of females that it did in 1974. If the1974 size composition already showed exploitation effects, the population impact is greater than is shown in table 1a.

Table 1a. Summary of size composition analysis.

Survey date	1974		2003-2005	
	males	females	males	females
Size at maturity (mm)	90	70	90	70
total density (n per 30-min tow)	17.2	17.8	15.0	31.3
mean size of mature crabs (mm)	113.8	94.1	105.7	95.1
mean ratio of size-dependent available females to males	25.3		58.9	

Deep sea red crab; Appendix 2

Depletion-Adjusted Average Catch Model

Alec MacCall, NMFS/SWFSC/FED (draft 9/6/07)

Unlike the classic fishery problem of estimating MSY, data-poor fishery analysis must be content simply to estimate a yield that is likely to be sustainable. While absurdly low yield estimates would have this property, they are of little practical use. Here, the problem is to identify a moderately high yield that is sustainable, while having a low chance that the estimated yield level greatly exceeds MSY and therefore is a dangerous overestimate that could inadvertently cause overfishing and potentially lead to resource depletion before the error can be detected in the course of fishery monitoring and management.

Perhaps the most direct evidence for a sustainable yield would be a prolonged period over which that yield has been taken without indication of a reduction in resource abundance.

The estimate of sustainable yield would be nothing more than the long-term average annual catch over that period. However, it is rare that a resource is exploited without some change in underlying abundance. If the resource declines in abundance (which is necessarily the case for newly-developed fisheries), a portion of the associated catch stream is derived from that one-time decline, and does not represent potential future yield supported by sustainable production. If that non-sustainable portion is mistakenly included in the averaging procedure, the average will tend to overestimate the sustainable yield. This error has been frequently made in fishery management. Based on these concepts, we present a simple method for estimating sustainable catch levels when the data available are little more than a time series of catches. The method needs extensive testing, both on simulated data and on cases where reliable assessments exist for comparison. So far, test cases indicate that it may be a robust calculation.

The Windfall/Sustainable Yield Ratio

The old potential yield formula Ypot = 0.5*M* $B_{UNFISHED}$ (Alverson and Pereyra, 1969; Gulland, 1970) is based on combining two approximations: 1) that B_{MSY} occurs at 0.5*$B_{UNFISHED}$, and 2) that F_{MSY} = M. In this and the following calculations fishing mortality rate (F) and exploitation rate are treated as roughly equivalent.

However, it is possible to take the potential yield rationale one step farther, and calculate the ratio of the one-time “windfall” harvest (W) due to reducing the abundance from $B_{UNFISHED}$ to the assumed B_{MSY} level. After that reduction in biomass has occurred, a tentatively sustainable annual yield Y is given by the potential yield formula. So we have the following simple relationships:

$Y = 0.5*M* B_{UNFISHED}$, and

$W = 0.5* B_{UNFISHED}$.

Under the potential yield assumptions, the ratio of one-time windfall yield to sustainable yield is the windfall/sustainable yield ratio (or simply the “windfall ratio”) W/Y = 1/M. For example, if M = 0.1, the windfall is equal to 10 units of annual sustainable yield.

An Update

The assumptions underlying the potential yield formula are out-of-date, and merit reconsideration. Most stock-recruitment relationships indicate that MSY of fishes occurs somewhat below the level of 0.5*

$B_{UNFISHED}$. We replace the value of 0.5 with a value of 0.4 as a better approximation of common stock-recruitment relationships.

The F_{MSY} = M assumption also requires revision, as fishery experience has shown it tends to be too high, and should be replaced by a F_{MSY} = c*M assumption (Deriso, 1982; Walters and Martell, 2004). Walters and Martell suggest that coefficient c is commonly around 0.8, but may be 0.6 or less for vulnerable stocks. Figure 1 shows the distribution of c values for West Coast groundfish stocks assessed in 2005. The average of c for those West Coast species is 0.62, but there is a substantial density of lower values. Because the risk is asymmetrical (ACLs are specifically intended to prevent overfishing), use of the average value is risk-prone. Consequently, we have used a value of c=0.5 in the following calculations.

The yield that is potentially sustainable under these revised assumptions is

$Y = 0.4^* B_{UNFISHED} {}^*c^*M$,

or for c = 0.5,

$Y = 0.2^* B_{UNFISHED} {}^*M$.

The windfall is based on the reduction in abundance from the beginning of the catch time series to the end of the series,

$W = Bbegin - Bend = DELTA^* B_{UNFISHED}$,

where DELTA is the fractional reduction in biomass from the beginning to the end of the time series, relative to unfished biomass. The analogous case to the potential yield formula is Bbegin = $B_{UNFISHED}$, and Bend = 0.4* $B_{UNFISHED}$, in which case DELTA = 0.6. In practice, Bbegin is rarely $B_{UNFISHED}$, and DELTA is unlikely to be known explicitly. Although data may be insufficient for use of conventional stock assessment methods, an estimate (or range) of DELTA based on expert opinion is sufficient for this calculation. The windfall ratio is now

$W/Y = DELTA/(0.4^*c^*M)$,

or in the case of c=0.5,

$W/Y = DELTA/(0.2^*M)$.

For example, in the case of fishing down from $B_{UNFISHED}$ to near B_{MSY} where DELTA=0.6, if c = 0.5, W/Y = 3/M. Thus the revised calculation gives a much larger estimate of the windfall ratio. For the previous example of M = 0.1, the windfall ratio is now estimated at 30 units of sustainable annual yield.

A Sustainable Yield Calculation

Assume that in addition to the windfall associated with reduction in stock size, each year produces one unit of annual sustainable yield. The cumulative number of annual sustainable yield units harvested from the beginning to the end of the time series is n + W/Y, where n is the length of the series. In this calculation it should not matter when the reduction in abundance actually occurs in the time series because assumed production is not a function of biomass. Of course, in view of the probable domed shape of the true production curve, the temporal pattern of exploitation may influence the approximation.

The estimate of annual sustainable yield (Ysust) is

Ysust = sum(C)/(n + W/Y).
In the special case of no change in biomass, DELTA = 0, W/Y = 0, and Ysust is the historical average catch. If abundance increases, DELTA is negative, W/Y is negative, and Ysust will be larger than the historical average catch.

Examples

The widow rockfish fishery began harvesting a nearly unexploited stock in 1981 and for the first three years, fishing was nearly unrestricted (Table 1). Reliable estimates of sustainable yield based on conventional stock assessments were not available for many years afterward. By the mid-1990s, stock assessments were producing estimates of sustainable yield ca. 5000 mtons, with indications that abundance had fallen to 20-33% of $B_{UNFISHED}$.

Application of depletion-corrected catch averaging indicates good performance of the method within a few years of the beginning of the fishery. Two alternative calculations are given in Table 1. The first calculation assumes M = 0.15, c = 0.5, and that biomass was near B_{MSY} at the end of the time period, so that DELTA = 0.6. The second calculation is closer to the most recent stock assessment (He et al., 2007) and assumes M = 0.125, c = 0.5, DELTA = 0.75 (ending biomass in year 2000 is about 25% of $B_{UNFISHED}$).

Other examples would be worth exploring, especially were they can be compared with "ground truth" from a corresponding formal stock assessment.

Low biomasses

The yields given by these calculations can only be sustained if the biomass is at or above B_{MSY}. If the resource has fallen below B_{MSY}, the currently sustainable yield (Ycurrent) is necessarily smaller. A possible approximation would be based on the ratio of Bcurrent to B_{MSY},

Ycurrent = Ysust*(Bcurrent/ B_{MSY}) if Bcurrent< B_{MSY}

Implementation

This method is most useful for species with low natural mortality rates; stocks with low mortality rates tend to pose the most serious difficulties in rebuilding from an overfished condition. As natural mortality rate increases (M > 0.2), the windfall ratio becomes relatively small, and the depletion correction has little effect on the calculation.

The relationship between F_{MSY} and M may vary among taxonomic groups of fishes, and among geographic regions, and would be a good candidate for meta-analysis. Uncertainty in parameter values can be represented by probability distributions. A Monte Carlo sampling system such as WinBUGS can easily estimate the output probability distribution resulting from specified distributions of the inputs.
With minor modifications, this method could also be applied to marine mammal populations. Although estimation of sustainable yields is not a central issue for marine mammals nowadays, the method would be especially well suited to analysis of historical whaling data, for example.

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Deep sea red crab; Appendix 3

2-point boundary model

Estimation of Average Recruitment, Biomass Weighted F, and Equilibrium Catch

Two quantitative surveys of red crab abundance and long-term record of landings provide an opportunity to estimate the average recruitment necessary to support the observed time series of catch. This is accomplished by using a simple mass balance equation with boundary conditions defined as the initial and final survey values.

Process Equation

Let B_t represent the biomass at time t and specify the boundary conditions B_0 and B_T. The biomass at time t+1 can be expressed as

$$B_{t+1} = (B_t - C_t + R_t)S \qquad (1)$$

Where C_t is the total catch and R_t is total recruitment of biomass to the population. The parameter S can be thought of as either the survival rate = e^{-M} or the difference between the instantaneous rate of growth G and M or $S=e^{-(G-M)}$. For this application it was assumed that increments to population biomass via growth are included in the Rt term; therefore $S=e^{-M}$ No information is available to estimate the annual recruitment to the population but Eq. 1 can be simplified by let R_t equal a constant, say R.

$$B_{t+2} = (B_{t+1} - C_{t+1} + R)S \qquad (2)$$

Substituting Eq. 1 into 2 recursively leads to

$$B_{t+2} = ((B_t - C_t + R)S - C_{t+1} + R)S$$

$$B_{t+3} = (B_{t+2} - C_{t+2} + R)S$$

$$B_{t+3} = (((B_t - C_t + R)S - C_{t+1} + R)S - C_{t+2} + R)S$$

….

$$B_{t+T} = B_t S^{T-1} + \sum_{j=1}^{T-1} S^j R - \sum_{j=1}^{T-1} C_j S^{T-j} \qquad (3)$$

If we let B_t=B(0), B_{t+T}=B(T) and assume S then it is possible to estimate R as the average recruitment necessary to satisfy Eq. 3.

$$R = \frac{B(T) - B(0)S^{T-1} + \sum_{j=1}^{T-1} C_j S^{T-j}}{\sum_{j=1}^{T-1} S^j} \qquad (4)$$

Given the average recruitment R, the year-specific F_t can be estimated as

$$\hat{F}_t \approx \frac{C_t}{B_t + R} \qquad (5)$$

The estimates of year specific F_t are unreliable since they depend on the average recruitment estimate R. However, the average F over the period can be estimated as

$$\overline{F} = \sum_{j=1}^{T-1} \frac{\hat{F}_j}{T-1} \qquad (6)$$

The average catch sufficient to maintain the population at its current size can be estimated by setting $B_{T+1}=B_T$ in Eq. 1 and solving for C as

$$\begin{aligned} B_T &= \left(B_T - \overline{C}_{EQ} + R\right)S \\ \overline{C}_{EQ} &= R - \frac{B_T(1-S)}{S} \end{aligned} \qquad (7)$$

Eq. 4, 6 and 7 can now be used to estimate the average recruitment necessary to support the total removals between time t and t+T, the average biomass weighted F experienced by the population, and the average catch necessary to maintain the population at its current value of B_T.

Incorporating the Uncertainty in Population Size

The uncertainty in initial and final population sizes has important implications for the uncertainty in the average R, Fbar and C_{EQ}. This uncertainty can be approximated by convolving the distribution of initial population size with the final population size. Assume that the survey mean estimates are normally distributed. Let $B_t \sim N(\mu_t\ \sigma_t^2)$, $B_{t+T} \sim N(\mu_{t+T}\ \sigma_{t+T}^2)$ and $\Phi(.)$ define the cdf of the normal distribution. The inverse of the normal cdf, say $\Phi^{-1}(.)$, can be used to define population estimates for equal probability intervals

$$\begin{aligned} B_{t,\alpha} &= \Phi^{-1}\left(\mu_t, \sigma_t^2, \alpha\right), \quad \alpha = \alpha_{\min}, \ldots \alpha_{\max} \\ B_{T,\beta} &= \Phi^{-1}\left(\mu_T, \sigma_T^2, \beta\right), \quad \beta = \beta_{\min}, \ldots \beta_{\max} \end{aligned} \qquad (8)$$

Define $R_{\alpha,\beta}$ as the average recruitment obtained by substituting $B_{t,\alpha}$ and $B_{T,\beta}$ in Eq. 4 for B(0) and B(T) respectively. The sampling distribution of R and by extension, Fbar and Cbar, can now be obtained by simply matching all possible values of α with all possible values of β. More economically, one can define a small step size, say δ and evaluate $R_{\alpha,\beta}$ for equal increments between the minimum and maximum values of the cdf. The sampling distribution of R, Fbar, and Ceq is just the collection of discrete estimates since all estimates $R_{\alpha,\beta}$ have equal probabilities of occurrence = δ^2 and the sum of all δ^2 's is one.

Application to Red Crab

Estimates of R, Fbar, and C_{EQ} were derived for male and female red crab from the 1974 and 2004 fishery independent surveys (Table A3-1) and landings from 1974 to 2003 (Table A3-2). The distributions of R, Fbar and CEQ were based on convolution of 51 equal probability cut points representing a 95% confidence interval for the initial and final year biomass estimates. The convolution distribution was based on 2601 (i.e. 51 x 51) evaluations of Eq. 4. Annual survival for the base runs was assumed to be 0.86 (i.e., M=0.15)

Model results suggest that the median male recruitment is about 8500 mt per year. Historical average F between 1974 and 2004 was about 0.04 (Table A3-3). Given the population size in 2004, catches of 2,060 mt would keep the population at its current size of about 36,000 mt. This is about 16% higher than the average catch between 1973 and 2007 but 10% less than landings since 2000.

Between 1974 and 2004 the female population (>90 mm CW) increased nearly four-fold from 15 kt to 55 kt. Under the assumption that fishing mortality on the females was essentially zero, the estimated median recruitment was 9837 mt. The confidence intervals for median recruitment levels for males and females overlap which suggest comparable rates of biomass recruitment. The parameters for average recruitment and survival are confounded and the small differences in average recruitment estimates between male and female recruitment could be due to slightly different mortality rates or growth rates between sexes. For example, assuming an M=0.13 for females results in a median R of 7,810 mt that is about the same as the median R for males when M=0.15.

The sensitivity of the R, Fbar and C_{EQ} to changes in M are illustrated in Tables A3-4 to A3-6. Estimated average recruitment increases about three-fold as M increases (or S declines) from 0.05 to 0.20. The estimated equilibrium catch is relatively unchanged remaining at about 2,000 mt. Figures A3-1 and A3-2 demonstrate that as S approaches 1 the long-term catch equals the estimated average recruitment.

Table A3-1. Estimated survey biomass of male and female red crab, 1974 and 2004.

Category	Initial Biomass (SE)	Final Biomass (SE)
Fishable Biomass of Males	30,302 (6,363)	36,247 (4,612)
Female Biomass (>90 mm CW)	15,654 (3,719)	55,279 (7,033)

Table A3-2. Summary of annual landings (mt) of red crab in US.

Year	Landings (mt)
73	112.5
74	503.1
75	307.3
76	637.9
77	1244.6
78	1247.6
79	1210.8
80	2481.2
81	3031.8
82	2445.6
83	3252.4
84	3875.0
85	2236.7
86	1248.7
87	2110.3
88	3592.7
89	2393.2
90	1526.7
91	1791.0
92	1061.2
93	1439.9
94	0.3
95	572.0
96	465.6
97	1725.2
98	1501.1
99	1869.2
00	3129.4
01	4002.7
02	2142.5
03	1920.0
04	2040.3
05	2013.2
06	1716.0
07	1284.0

Table A3-3. Estimated median recruitment, average F, and equilibrium catch based on 2-point boundary value method. Values in parentheses represent 90% confidence interval. Natural mortality is assumed to be 0.15 (S=0.861).

Category	Recruitment	Fishing Mortality	Equilibrium Catch
Fishable Biomass of Males	7,928 (6.856, 9,068)	0.042 (0.036, 0.049)	2,044 (2,023, 2,064)
Female Biomass (>90 mm CW)	9,044 (7,408, 10,785)	0	72 (52, 93)

Table A3-4. Estimated median recruitment, average F, and equilibrium catch based on 2-point boundary value method. Values in parentheses represent 90% confidence interval. Natural mortality is assumed to be 0.05 (S=0.95).

Category	Recruitment	Fishing Mortality	Equilibrium Catch
Fishable Biomass of Males	3,850 (3,402, 4,324)	0.047 (0.041, 0.054)	1,987 (1,819, 2,152)
Female Biomass (>90 mm CW)	3,427 (2,766, 4,127)	0	584 (419, 757)

Table A3-5. Estimated median recruitment, average F, and equilibrium catch based on 2-point boundary value method. Values in parentheses represent 90% confidence interval. Natural mortality is assumed to be 0.1 (S=0.905).

Category	Recruitment	Fishing Mortality	Equilibrium Catch
Fishable Biomass of Males	5,819 (5,095, 6587)	0.044 (0.038, 0.051)	1,996 (1,932, 2,058)
Female Biomass (>90 mm CW)	6,049 (4,945, 7,224)	0	219 (157, 283)

Table A3-6. Estimated median recruitment, average F, and equilibrium catch based on 2-point boundary value method. Values in parentheses represent 90% confidence interval. Natural mortality is assumed to be 0.2 (S=0.819).

Category	Recruitment	Fishing Mortality	Equilibrium Catch
Fishable Biomass of Males	10,159 (8,704, 11,707)	0.039 (0.034, 0.046)	2,110 (2,104, 2,116)
Female Biomass (>90 mm CW)	12,297 (10,077, 14,658)	0	22 (16, 28)

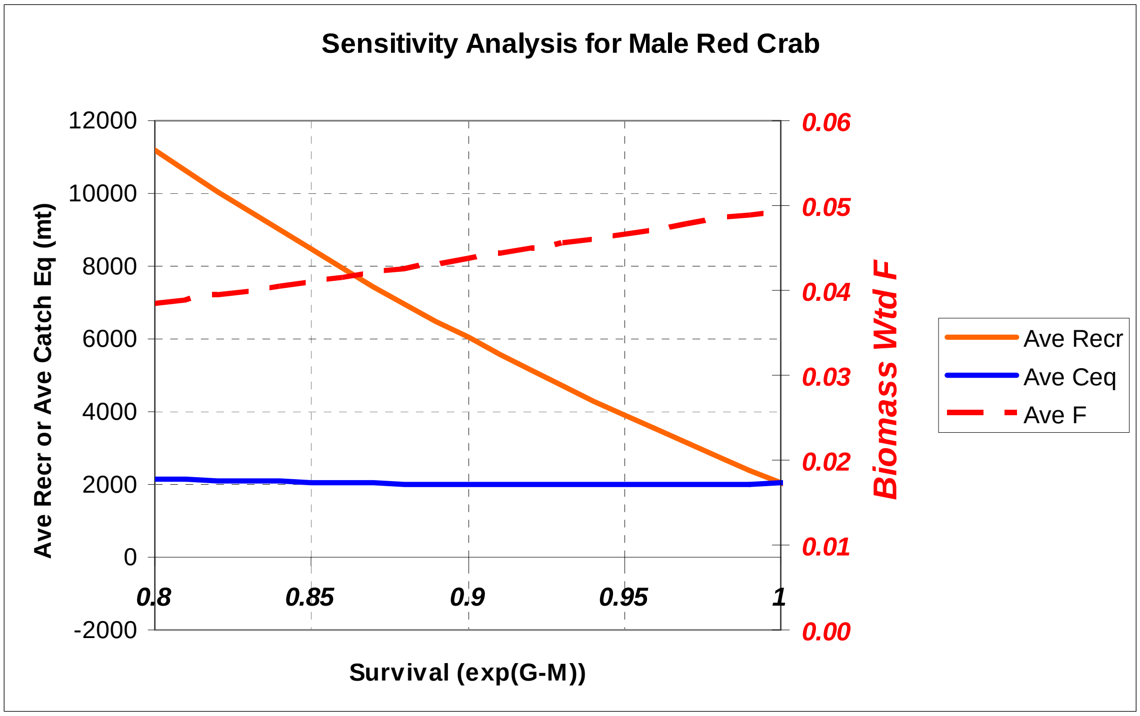

Fig A3-1. Sensitivity analysis of recruitment, average F and equilibrium catch for male red crab to varying levels of survival rate.

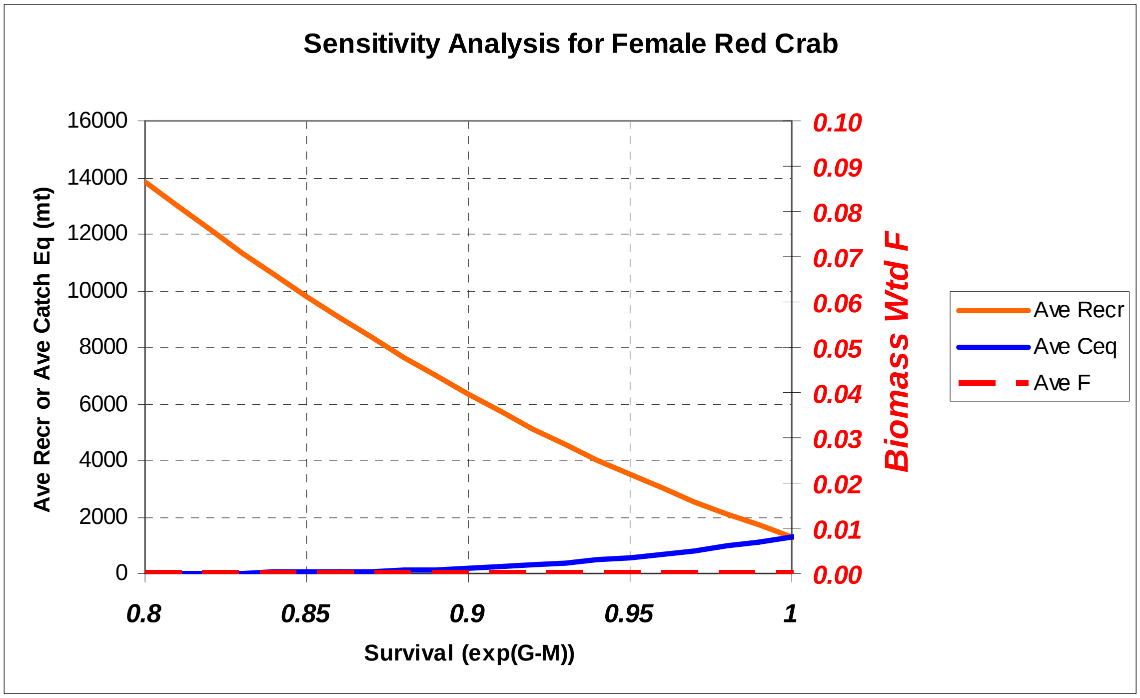

Fig. A3-2. Sensitivity analysis of recruitment, average F and equilibrium catch for female red crab to varying levels of survival rate.

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Atlantic wolffish

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Northeast Data Poor Stocks Working Group Meeting
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Atlantic Wolffish: Explanation of Corrections/Revisions in this Report

During the course of assessing Atlantic wolffish for the Northeast Data Poor Stocks Working Group Meeting, December 8-12, 2008, an incorrect conversion factor was applied to the NEFSC commercial fisheries database resulting in lower than expected commercial landings. Specifically, Atlantic wolffish landings data were extracted from the database as pounds and converted into kilograms. The landings data were then imported into a spreadsheet where it was mistakenly multiplied by 0.45359237, the conversion factor for pounds to kilograms, reducing the overall magnitude of the landings data by approximately 45%. Table 1A shows the original and corrected datasets. An example using 1964 shows corrected landings as 114.32 mt and the originally reported landings as 51.86 mt, which is 45% of the corrected amount.

Recreational catch and commercial discard data were not affected by this miscalculation. NEFSC survey indices were also unchanged. However, total catch, which is composed primarily of commercial landings and is a key component in many analyses presented in this report, was affected. Analyses that needed to be updated included the Statistical Catch at Length model (SCALE), exploitation ratios, Depletion Corrected Average Catch model (DCAC), and An Index Method model (AIM).

The SCALE model was accepted by the Peer Review Panel in December 2008 as the basis for determining biological reference points and stock status for Atlantic wolffish. The changes to commercial landings and total catch of Atlantic wolffish had mixed effects on SCALE model results. Newly estimated values of Initial Recruitment, MSY, SSB_{MSY}, and SSB_{2007}, have approximately doubled from original values, while F_{MSY}, YPR, and SSB/recruit remained mostly unchanged. The status determinations that were reported in the original version of this report still hold, and were not altered by making corrections to the commercial landings. Atlantic wolffish remains overfished (assuming a $B_{THRESHOLD}$ of ½ B_{MSY}) and overfishing status continues to be uncertain. For comparison, the original and updated (i.e., with corrected input data) estimates of Initial Recruitment, MSY, SSB_{MSY}, $SSB_{2007,}$ F_{MSY}, YPR, SSB/recruit and status determination are listed in Table 2A. In the updated section of Table 2A, inputs to SCALE model Runs 2 and 3 are the same, but Runs 2 and 3 give results corresponding to two different F_{MSY} proxies ($F_{40\%}$ and $F_{50\%}$).

Corrections were also made to catch per unit of effort indices based on observer data. Fishing effort (days fished) was double counted in the original analysis when both kept and discarded wolffish were reported by an observer. As a result of decreasing the observed effort, the magnitude of the estimated CPUE increased while the overall declining trend in CPUE remained the same. A table comparing revised and original values can be seen in Table 3A.

Corrections were made to the document with the intent to make them as seamless as possible and much of the text, figures, and tables remain unchanged. However some figures and tables were eliminated and values modified as a result of the updated analyses. A comprehensive list of changes is presented in Table 4A.

Table 1A. Differences between the originally reported NEFSC commercial fisheries database landings for Atlantic wolffish and corrected landings. Values are metric tons unless otherwise noted. The MRFSS and Discard data were not changed.

				Original		Corrected		
YEAR	MRFSS*	Discard** OT LL GN US Only	CFDBS Landings US only	Total Catch US only	Total Catch (1000 mt)	CFDBS Landings US only	Total Catch US only	Total Catch (1000 mt)
1963	--	--	--	--	--	--	--	--
1964	--	--	51.86	51.86	0.05	114.32	114.32	0.11
1965	--	--	75.53	75.53	0.08	166.51	166.51	0.17
1966	--	--	79.12	79.12	0.08	174.42	174.42	0.17
1967	--	--	67.85	67.85	0.07	149.58	149.58	0.15
1968	--	--	52.72	52.72	0.05	116.22	116.22	0.12
1969	--	--	74.06	74.06	0.07	163.28	163.28	0.16
1970	--	--	70.23	70.23	0.07	154.83	154.83	0.15
1971	--	--	78.38	78.38	0.08	172.80	172.80	0.17
1972	--	--	110.65	110.65	0.11	243.94	243.94	0.24
1973	--	--	110.06	110.06	0.11	242.63	242.63	0.24
1974	--	--	160.02	160.02	0.16	352.79	352.79	0.35
1975	--	--	142.03	142.03	0.14	313.12	313.12	0.31
1976	--	--	182.31	182.31	0.18	401.93	401.93	0.40
1977	--	--	178.61	178.61	0.18	393.76	393.76	0.39
1978	--	--	274.53	274.53	0.27	605.24	605.24	0.61
1979	--	--	297.78	297.78	0.30	656.49	656.49	0.66
1980	--	--	374.88	374.88	0.37	826.46	826.46	0.83
1981	0.81	--	304.64	305.44	0.31	671.61	672.42	0.67
1982	23.12	--	344.91	368.03	0.37	760.40	783.52	0.78
1983	11.90	--	498.92	510.82	0.51	1099.92	1111.83	1.11
1984	13.18	--	424.25	437.44	0.44	935.31	948.50	0.95
1985	15.95	--	399.14	415.10	0.42	879.96	895.91	0.90
1986	7.24	--	358.24	365.49	0.37	789.79	797.03	0.80
1987	37.71	--	301.70	339.40	0.34	665.13	702.83	0.70
1988	9.03	--	229.33	238.36	0.24	505.59	514.62	0.51
1989	20.49	26.98	211.76	259.23	0.26	466.84	514.31	0.51
1990	29.17	2.63	171.53	203.32	0.20	378.16	409.95	0.41
1991	16.86	1.95	202.56	221.37	0.22	446.56	465.37	0.47
1992	10.73	19.18	195.46	225.37	0.23	430.92	460.83	0.46
1993	20.11	13.38	211.93	245.41	0.25	467.22	500.71	0.50
1994	18.54	0.11	206.56	225.21	0.23	455.39	474.04	0.47
1995	20.45	5.77	204.03	230.25	0.23	449.81	476.02	0.48
1996	12.33	4.53	157.84	174.70	0.17	347.98	364.84	0.36
1997	20.21	7.82	136.88	164.91	0.16	301.77	329.79	0.33
1998	16.84	2.25	130.11	149.19	0.15	286.84	305.92	0.31
1999	8.54	0.35	110.11	119.00	0.12	242.75	251.64	0.25
2000	12.40	0.54	86.79	99.74	0.10	191.34	204.29	0.20
2001	16.67	6.47	107.05	130.19	0.13	236.00	259.14	0.26
2002	9.82	13.10	66.03	88.96	0.09	145.58	168.50	0.17
2003	24.23	3.82	55.82	83.87	0.08	123.05	151.11	0.15
2004	12.45	1.58	53.05	67.08	0.07	116.95	130.98	0.13
2005	10.73	1.31	51.73	63.76	0.06	114.04	126.08	0.13
2006	17.86	1.45	36.31	55.62	0.06	80.05	99.36	0.10
2007	12.87	0.84	28.72	42.43	0.04	63.32	77.03	0.08
2008	--	--	--	--	--			0.00

* MRFSS data unchanged

** Discard estimates unchanged

Table 2A. A comparison of the corrected ("updated") and initially reported ("original") biological reference points and status determination results for Atlantic wolffish.

	SCALE run	1			2			3		
	Selectivity	L_{50} = 90			slope = 0.15			slope = 0.15		
	Length of maturity	40cm (L_{50} = 90)	65cm (L_{50} = 90)	75cm (L_{50} = 90)	40cm (slope = 0.15)	65cm (slope = 0.15)	75cm (slope = 0.15)	40cm (slope = 0.15)	65cm (slope = 0.15)	75cm (slope = 0.15)
Updated	F_{MSY} proxy	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{50\%}$	$F_{50\%}$	$F_{50\%}$
	F_{MSY}	0.686	0.486	0.374	0.319	0.233	0.185	0.197	0.156	0.129
	YPR	0.872	0.839	0.799	0.861	0.817	0.771	0.784	0.728	0.679
	SSB per Recruit	6.098	5.432	4.846	6.098	5.430	4.838	7.627	6.796	6.050
	Initial Recruits (000s)	355	355	355	361	361	361	361	361	361
	MSY (mt)	310	298	284	311	295	278	283	264	245
	SSB_{MSY} (mt)	2,167	1,931	1,722	2,202	1,961	1,747	2,754	2,448	2,184
	SSB_{07} (mt)	890	656	475	998	753	562	998	753	562
	F_{07}	0.413	0.413	0.413	0.158	0.158	0.158	0.158	0.158	0.158
	SSB_{07}/SSB_{MSY}	41%	34%	28%	45%	38%	32%	36%	31%	26%
	F_{07}/F_{MSY}	60%	85%	111%	50%	68%	86%	80%	102%	123%
Original	F_{MSY} proxy	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{50\%}$	$F_{50\%}$	$F_{50\%}$
	F_{MSY}	0.70	0.51	0.39	0.35	0.25	0.20	0.195	0.154	0.128
	F_{max}	> 0.8	> 0.8	> 0.8	0.60	0.60	0.60	0.60	0.60	0.60
	YPR	0.871	0.841	0.809	0.854	0.829	0.788	0.783	0.728	0.678
	SSB per Recruit	5.987	5.247	4.686	5.792	5.166	4.548	7.629	6.796	6.050
	Initial Recruits (000s)	171	171	171	175	175	175	172	172	172
	MSY (mt)	149	144	138	149	145	138	135	125	117
	SSB_{MSY} (mt)	1,024	898	802	1,011	902	794	1,314	1,171	1,042
	SSB_{07} (mt)	405	293	209	457	339	249	447	330	242
	F_{07}	0.516	0.516	0.516	0.195	0.195	0.195	0.202	0.202	0.202
	SSB_{07}/SSB_{MSY}	40%	33%	26%	45%	38%	31%	34%	28%	23%
	F_{07}/F_{MSY}	74%	101%	132%	56%	78%	98%	104%	131%	158%

Table 3A. A comparison of original and revised catch per unit of effort tables from observer data.

	Gear Type					
YEAR	**original LLB**	**original OTF**	**original GNF**	**revised LLB**	**revised OTF**	**revised GNF**
1989		2.56	0.58		19.51	5.79
1990		0.71	2.90		9.47	28.84
1991	8.80	1.40	1.57	52.25	19.64	14.72
1992	8.52	2.90	1.76	54.43	39.68	17.56
1993	45.65	3.05	2.15	262.50	43.05	21.25
1994		3.89	2.61		54.08	25.77
1995		1.29	6.03		19.57	62.17
1996		1.22	3.81		18.94	50.92
1997		1.82	1.84		30.09	17.75
1998		1.26	2.08		21.58	19.86
1999		1.30	1.49		20.47	14.52
2000		1.32	1.90		19.12	19.37
2001		1.59	2.04		24.45	18.70
2002	11.79	1.05	1.79	86.70	10.69	18.90
2003	5.14	0.86	3.03	29.60	12.91	32.67
2004	1.19	0.61	1.72	9.36	9.69	17.48
2005	2.48	0.36	1.88	18.98	5.45	19.87
2006	1.56	0.37	1.70	9.91	5.83	16.16
2007	1.28	0.39	0.95	8.20	5.72	8.03

Table 4A. A list of tables and figures where changes were made between the original ("OLD") document and the present corrected version.

Table/Figure Edited	Changes Made
Section 5 table	Recalculated all values for SCALE runs 1 & 2 (F40%) and run 3 (F50%)
Table 1	Updated CFDBS values, total catch, and exploitation indices
Table 2	Recalculated percent commercial landings by fishery statistical area and year
Table 10	Recalculated observer catch per unit of effort (CPUE)–removed double counted effort
Table 11	Changed Charter/Party boat effort units to million angler days fished
Table 13	Updated Q parameters from SCALE model
Table 14	Updated Q parameters for Runs 1 & 2 and dropped Run 3 as it is identical to Run 2
Table 15	Recalculated all values for SCALE runs 1 & 2 (F40%) and run 3 (F50%)
Table 16	Updated DCAC output using corrected commercial catch values
Figure 3	Corrected commercial landings of Atlantic wolffish
Figure 4	Updated percent commercial landings by gear type – added Danish seine
Figure 5	Updated percent commercial landings by US fishery statistical areas
Figure 6	Changed recreational landings graph from bar chart to a line graph –values unchanged
Figure 7	Updated total catch using corrected commercial landings
Figure 13	Recalculated observer based CPUE–removed double counted effort
Figure 14	Changed Charter/Party boat effort units to million angler days fished
Figure 34	Updated sensitivity analysis of fitting the recruitment index & the estimated F with different penalty weights on recruitment variation (VREC = 0.01, 2, 10)
Figure 35	Updated sensitivity analysis of estimated recruitment index & fishing mortality with different penalty weights on recruitment variation (VREC = 0.01, 2, 10)
Figure 36	Updated sensitivity analysis of fitting the recruitment index and the estimated F with different penalty weights on the recruitment index (Spr Age 1 = 0.01, 2, 10)
Figure 37	Updated sensitivity analysis of estimated recruitment index & fishing mortality with different penalty weights on recruitment index (Spr Age 1 = 0.01, 2, 10)
Figure 41	Updated run 1 SCALE model estimates for F, total catch, age 1 recruitment, and total biomass
Figure 42	Updated run 2 SCALE model estimates for F, total catch, age 1 recruitment, and total biomass
Figure 43	Updated retrospective patterns on F, total biomass and age-1 recruitment
Figure 44	Updated sensitivity analysis of recruitment & fishing mortality using three different assumed L-infinity values (100, 110, 120) on growth
Figure 45	Updated yield per recruit and spawning stock biomass per recruit curves for F50% proxy (SCALE model Run 3)
Old Figures 46-48	These figures were removed as there is no difference in SCALE model run 2 & 3 except for the F proxy used to determine biological reference points
Old Figure 49 – new 46	Recalculated exploitation indices using corrected commercial catch
Old Figure 50 – new 47	Updated sensitivity analysis of the DCAC model using corrected commercial catch
Old Figure 51 – new 48	Spring biomass and updated commercial catch used in the AIM model
Old Figure 52 – new 49	Updated AIM model results using the corrected commercial catch
Appendix 1 and Reference Section	Appendix 1 :Updated percent commercial catch by major gear and year – added Danish seine. Reference Section: citation corrected

Executive Summary

Atlantic wolffish in the Gulf of Maine and Georges Bank regions inhabit the southern edge of the species distribution. Analyses herein were limited to the stock component completely within United States waters, which excluded some historically important transboundary portions of Georges Bank. There is currently no fishery management plan for the Atlantic wolffish in U.S. waters. Wolffish are associated with rough topography. Catchability of wolffish is low in NEFSC trawl surveys due to this habitat preference. Atlantic wolffish are long-lived (22 years), late maturing, and of low fecundity. Males guard the eggs in nests in the fall. Larger wolffish are caught in the spring survey compared to the fall, perhaps due to nest guarding behavior. All fishery independent survey indices show a declining trend in abundance over the time series. The commercial catch has also declined steadily since 1983. However there is no size truncation in the catch over the time series. A wolffish growth study from the 1980s in the Gulf of Maine and Georges Bank region was done by Nelson and Ross (1992). The DCAC model, AIM model, and simple exploitation ratios were examined for this assessment and presented to the Data Poor Stocks Peer Review Panel. A forward projection model, Statistical Catch At Length (SCALE), which tunes to size and age data from trawl survey recruitment and adult indices, total catch, and catch size distributions along with overall growth information, was developed for this assessment. This model was accepted by the Peer Review Panel as a basis for determining the biological reference points (BRPs) for Atlantic wolffish. The SCALE model had difficulty estimating selectivity due to the sparse data. Two different selectivity regimes were chosen to determine BRPs and their influence on stock status, using $F_{40\%}$ as a proxy for F_{MSY}. The maturation schedule of wolffish in U.S. waters is uncertain and this influences BRPs derived from the SCALE model. The sensitivity of these non-parametric BRPs was tested with a range of knife edge maturity cutoffs. Early Data-Poor Stocks Working Group meetings indicated that, given the wolffish life history, $F_{50\%}$ may be an appropriate proxy for F_{MSY} and this was presented as a third option to the Panel. Based on all SCALE model runs, the stock in 2007 is at a low biomass level (26% to 45% of B_{MSY}) and is overfished (*assuming a $B_{THRESHOLD}$ of ½ B_{MSY}). The Peer Review Panel concluded that $F_{40\%}$ is a reasonable F_{MSY} proxy and that its value is probably <0.35. The overfishing status is uncertain, and the ratio of F_{2007} to F_{MSY} falls in the range of 50% to 123%. MSY is likely in the range of 278-311 mt and SSB_{MSY} is likely in the range of 1,747-2,202 mt.

*(*Editor's note: This assumption about the definition of $B_{THRESHOLD}$ was confirmed with the Chairman of the Peer Review Panel after the December meeting.)*

Section 1. Provide the current exact, legal definitions for overfished and overfishing given in the FMP (if the definition was revised with an official FMP amendment, then give that def.). (NEFSC staff should consult with appropriate RO and Council staff that is on the DPWG to get this info).

NONE

Section 2. List the current Biological Reference Points (parameters and values). (e.g., the proxy for B_{MSY} is the 3-yr average of survey catch per tow from years 19xx to 19yy. The estimate is zzz kg/tow). Include the targets and thresholds for both overfishing and overfished, if those definitions exist.

NONE

Section 3. Explain the logic/justification for why the current definitions were adopted.
NA

Section 4. Explain weaknesses with the current definitions (e.g., not easily measured, not logical, outdated, etc.). If they are OK, say so.
NA

Section 5. (If a change to the BRPs is being recommended by the WG:) Recommend biological reference points (BRPs) and measurable BRP and MSY proxies. Provide justification for the recommendation. Be as specific as possible. If something might be proposed that is not yet measurable, then make that clear and explain what is needed to make it measurable.

A range of biological reference points were available to the Data Poor Stocks Review Panel via the forward projecting SCALE model under various model scenarios. Non-parametric biological reference points (BRP) were developed for both the selectivity L_{50} = 90 run (Run 1) and the slope = 0.15 run (Run 2) within the SCALE model using $F_{40\%}$ as a proxy for F_{MSY}. A range of knife edge maturity values were used in estimating the BRPs. Maturity as 40+ cm, a 65+ cm and 75+ cm cutoffs were used as bounds taken from NEFSC survey results and literature. The Data Poor Working Group suggested $F_{50\%}$, may be an appropriate proxy for a species which is long lived, late maturing and has low fecundity. $F_{50\%}$ BRPs were then developed for the slope =0.15 scenario. SCALE Run 2 was accepted by the Data Poor Stocks Peer Review Panel as an appropriate range of values for Atlantic wolffish biological reference points.

SCALE run	1			2			3		
Selectivity	L50 = 90			slope = 0.15			slope = 0.15		
Length of maturity	40cm	65cm	75cm	40cm	65cm	75cm	40cm	65cm	75cm
F_{MSY} proxy	F40%	F40%	F40%	F40%	F40%	F40%	F50%	F50%	F50%
F_{MSY}	0.686	0.486	0.374	0.319	0.233	0.185	0.197	0.156	0.129
YPR	0.872	0.839	0.799	0.861	0.817	0.771	0.784	0.728	0.679
SSB per Recruit	6.098	5.432	4.846	6.098	5.430	4.838	7.627	6.796	6.050
Initial Recruits (000s)	355	355	355	361	361	361	361	361	361
MSY (mt)	310	298	284	311	295	278	283	264	245
SSB_{MSY} (mt)	2,167	1,931	1,722	2,202	1,961	1,747	2,754	2,448	2,184
SSB_{07} (mt)	890	656	475	998	753	562	998	753	562
F_{07}	0.413	0.413	0.413	0.158	0.158	0.158	0.158	0.158	0.158
SSB_{07}/SSB_{MSY}	41%	34%	28%	45%	38%	32%	36%	31%	26%
F_{07}/F_{MSY}	60%	85%	111%	50%	68%	86%	80%	102%	123%

Section 6. Provide supporting information for Section 5.

Basic Biology and Ecology

Geographic Range

Atlantic wolffish (*Anarhichas lupus*) can be found in northern latitudes of the eastern and western North Atlantic Ocean (Figure 1). In the north and eastern Atlantic they range from eastern Greenland to Iceland, along northern Europe and the Scandinavian coast extending north and west to the Barents and White Sea's. In the northwest Atlantic they are found from Davis

Straits off of western Greenland, along Newfoundland and Labrador and continue southward through the Canadian Maritime Provinces to Cape Cod, USA. They are found infrequently in southern New England to New Jersey (Rountree, R.A. 2002). Northeast Fishery Science Centers Bottom Trawl surveys have only encountered 1 fish southwest of Martha's Vineyard, Massachusetts since 1963.

Habitats

Atlantic wolffish are demersal and prefer complex habitats with large stones and rocks which provide shelter and nesting sites (Pavlov and Novikov 1993). They are occasionally seen in soft sediments such as sand or mud substrate and likely forage for food sources in these habitats (Rountree, R.A. 2002; Falk-Petersen and Hansen 1991). They are believed to be relatively sedentary and populations localized. Tagging studies from Newfoundland, Greenland and Iceland indicate that most individuals were recaptured within short distances, ~8km, of the original tagging sites (Templeman 1984; Riget and Messtorff 1988; Jonsson 1982). Three significantly longer migrations were reported in Newfoundland ranging from 338 – 853 km (Templeman 1984).

Atlantic wolffish occupy varying depth ranges across its geographic range. In the Gulf of Maine they inhabit depths of 40 – 240 m, in Greenland and Newfoundland 0 – 600 m, in Iceland 8 – 450 m and in Norway and the Barents Sea from 10 – 215 m (Riget and Messtorff 1988; Albikovskaya 1982; Templeman 1984; Jonsson 1982; Falk-Petersen and Hansen 1991). In U.S. waters, abundance appears to be highest in the southwestern portion of the Gulf of Maine, from Jefferies Ledge to the Great South Channel, corresponding to the 100 m depth contour (Nelson and Ross 1992). Similarly, abundance is highest in the Browns Bank, Scotian shelf and northeast peak of Georges Bank areas in the Canadian portion of the Gulf of Maine (Nelson and Ross 1992). Atlantic wolffish in Newfoundland and Icelandic waters were identified as most abundant in depths 101 – 350 m and 40 - 180 m, respectively (Albikovskaya 1982; Jonsson 1982).

Temperature ranges where Atlantic wolffish occurs also deviate slightly with geographic region. Historically in the Gulf of Maine they have been associated with temperatures ranging from 0 – 11.1°C (Bigelow and Schroeder 1953). Bottom temperatures collected from NEFSC bottom trawl surveys where wolffish were encountered range from 0 – 10°C in spring and 0 – 14.3°C in fall. In Newfoundland wolffish thermal habitat ranged from -1.9 – 11.0 °C, Norway from -1.3 - 11 °C and in Iceland and Northern Europe -1.3 – 10.2 °C (Rountree, R.A. 2002; Falk-Petersen and Hansen 1991; Jonsson 1982). Laboratory studies indicate wolffish can survive a wide span of temperatures -1.7 – 17.0°C and that feeding is negatively correlated with the higher temperature extremes (Hagen and Mann 1992; King et al. 1989).

Reproduction

In general Atlantic wolffish are solitary in habit, except during mating season when bonded pairs form in spring/summer depending on geographic location (Rountree, R.A. 2002; Keats et al 1985; Pavlov and Novikov 1993). Spawning is believed to occur in September through October in the Gulf of Maine but is likely to depend on temperature and possibly photoperiod (Rountree, R.A. 2002; Pavlov and Moksness 1994). Spawning is reported to occur from August – September in Nova Scotia, during autumn in Newfoundland, September – October in Iceland, July – October in Norway, and late summer – early autumn in the White Sea (Keats et al. 1985; Templeman 1986; Jonsson 1982; Falk-Petersen, Hansen 1991; Pavlov, Novikov 1993). In the Gulf of Maine there is weak indication of a seasonal migration as wolffish may travel from shallow to deep in autumn and then deep to shallow in spring (Nelson and Ross 1992). Similar migrations occur in Iceland and the White Sea where wolffish migrate to colder temperatures before the spawning season (Pavlov and Novikov 1993; Jonsson 1982). Atlantic wolffish have the lowest fecundity compared to their relatives, the spotted wolffish (*Anarhichas minor*) and the northern wolffish (*Anarhichas denticulus*). Fecundity is related to fish size and body mass in this species and increases exponentially with length. Newfoundland mean fecundity estimates, combined from several NAFO statistical areas, range from 2,440 eggs at 40 cm to 35,320 eggs at 120 cm (Templeman 1986). In Norway a female at 60 cm produces approximately 5,000 eggs while a female 80-90 cm will lay 12,000 eggs (Falk-Petersen and Hansen 1991). Potential fecundity of wolffish in Iceland was measured between 400 and 16,000 eggs for fish at lengths of 25 and 83 cm respectively (Gunnarsson et al. 2006). Mature eggs are large measuring 5.5 – 6.8 mm in diameter (Rountree, R.A. 2002). Male Atlantic wolffish have small testes and produce small amounts of sperm peaking during late summer and autumn. These data along with morphological development of a papilla on the urogenital pore during spawning suggest internal fertilization (Pavlov and Novikov 1993; Pavlov and Moksness 1994, Johannessen et al 1993). Males have been observed guarding egg clusters for several months but it is not certain if they continue until hatching (Keats et al. 1985; Rountree, R.A. 2002). Hatching may take 3 to 9 months depending on temperature (Rountree, R.A. 2002).

Food Habits

The diet of Gulf of Maine and Georges Bank wolffish consist primarily of bivalves, gastropods, decapods and echinoderms (Nelson. Ross 1992). Wolffish possess specialized teeth, including protruding canine tusks (hence its name) and large rounded molars, which allow for removal of organisms from the sea floor and crushing of hard shelled prey (Rountree, R.A. 2002). Due to diet teeth are replaced annually (Albikovskaya 1983; Rountree, R.A. 2002). Fish have also been reported as an important food source in other regions along with amphipods and euphausiid shrimp for smaller individuals, 1 – 10 cm (Rountree, R.A. 2002; Albikovskaya 1983; Bowman et al. 2000). Travel between shelters and feeding grounds occurs during feeding periods as evidenced by crushed shells and debris observed in the vicinity of occupied shelters (Rountree, R.A. 2002; Pavlov and Novikov 1993). Fasting does occur for several months while replacing teeth, spawning and nest guarding occurs (Rountree, R.A. 2002).

Size

In the Gulf of Maine and Georges Bank regions individuals may attain lengths of 150 cm and weights of 18 kg (Goode 1884; Idoine 1998). Northeast Fishery Science Center bottom trawl surveys have captured animals ranging in size from 3 – 137 cm in spring and 4 – 120 cm in fall and with a maximum weight of 11.77 kg.

Age and Growth

Mean length at age for Atlantic wolffish in the Gulf of Maine was determined to be 22 years at 98 cm and 0 years at 4 cm (Nelson, Ross 1992). Fish over 100 cm were not sampled extensively in this study, 10 fish from 100-118 cm. Ages in the Gulf of Maine are comparable to wolffish ages in other regions, such as 21 years in east Iceland and 23 years in Norway (Gunnarsson et al. 2006; Falk-Petersen and Hansen 1991). Age 0 fish grow quickly in Icelandic waters and may reach 10.5 cm in the first year (Jonsson 1982). Gulf of Maine wolffish growth rates are faster than wolffish in Iceland, but grow fastest in the North Sea region (Nelson and Ross 1992; Liao and Lucas 2000). Growth in the Gulf of Maine for both male and female wolffish was best estimated using a Gompertz growth function, $L\infty = 98.9$ cm, $K = 0.22$ and $t_0 = 4.74$ (Nelson and Ross 1992). Female growth from Iceland has been modeled using a logistic growth function and coefficients estimated using non-linear optimization (Gauss-Newton method), results from the east and west regions were: $L\infty$ = 90.919, K = 0.230 and t_0 = 8.837 and $L\infty$ = 70.046, K = 0.378 and t_0 = 4.691, respectively (Gunnarsson et al. 2006). Von Bertalanffy growth parameters for the North Sea population of wolffish were $L\infty$ = 111.2, K = 0.12 and t_0 = -0.43 and $L\infty$ = 115.1, K = 0.11 and t_0 = -0.39, for males and females respectively (Liao and Lucas 2000).

Maturity

In the Gulf of Maine individuals are believed to reach maturity by age 5-6 when they reach approximately 47 cm total length (Nelson, Ross 1992; Templeman 1986). Size at fifty percent maturity (L_{50}) of females varies latitudinally which is likely due to the effects of temperature. Templeman (1986) showed that northern fish mature at smaller sizes than faster growing southern fish in Newfoundland. L_{50} was reported as 51.4 cm in the northern area, 61.0 cm in the intermediate region and 68.2 cm in the south. In a study somewhat contradictory to Templeman 1986, Atlantic wolffish in east Iceland, where water temperatures are colder, had larger L_{50} values than fish in the relatively warmer waters of east Iceland (Gunnarsson et al. 2006). Authors indicate that maturity may be difficult to determine using visual methods in females because of large eggs size in this species. Second generation eggs are visible in young, immature fish when the reach the cortical alveolus stage but they may not be able to spawn for several more years (Gunnarsson et al. 2006; Templeman 1986).

The US Fishery

Landings and Total Catch

NMFS Commercial Fishery Databases contain historical and current catch and effort information of Atlantic wolffish, 1963 - 2007. Data presented here are only from fishery statistical reporting areas that are completely or almost entirely within US territorial waters throughout the time series (Figure 2). The International Court of Justice in 1984 established the maritime boundary in the Gulf of Maine, known as the Hague Line, which divided US and Canadian Exclusive Economic Zones (ICJ 1984). In 1985 fishery statistical areas 523 and 524, which overlapped the US/Canada boundary in the Georges Bank region, were separated into distinct areas 551, 552, 561 and 562 (Figure 2). Disaggregating United States and Canadian landings data in areas 523 and 524 prior to 1985 was not possible so they are not reported here. Also not reported are landings in the newly created areas in US waters because they do not span the entire time frame.

US landings increased until it peaking in 1983 at 1,100 metric tons (mt) and then decline steadily until 2007, the latest complete year available, where landings were 63.32 mt (Figure 3 and Table 1). In the US, Atlantic wolffish are taken primarily as bycatch in the otter trawl fishery. Over all years, percent commercial landings of wolffish were dominated by otter trawl gear (90.83%), followed by fixed gillnets (4.33%) and bottom tending longlines (3.3%) (Figure 4). However, otter trawls have decreased in importance over time as evidenced by increased reported landings of gillnets and longlines (Appendix 1). Otter trawl gear accounted for a minimum of 73.2% to a maximum of 97.8% of the wolffish landings from 1964 to 2007 (Appendix 1). Fixed gill nets and bottom tending longline fisheries account for the majority of remaining landings. Trends in commercial landings are likely to be highly influenced by fisheries management for other groundfish species.

Reported US commercial wolffish landings come primarily from fishery statistical areas 513, 514, 515, 521 and 522 (Figure 5 and Table 2). Landings have fluctuated between statistical areas over time and spatial differences may be difficult to interpret due to management actions, such as permanent closures and rolling time closures, in the Gulf of Maine.

Commercial fishery discards from the Northeast Fisheries Observer Program database were estimated for the period 1989-2007 from US only statistical areas based on the Standardized Bycatch Reporting Methodology combined ratio estimation (Wigley et al 2007). Discards appear to be a small component of the overall catch of Atlantic wolffish (Figure 7 and Table 1). The maximum estimated discards in any one year are 26.98 mt, 1989 (Table 3). Otter trawls account for 98.3% of the total discarded wolffish from all years. Discards appear to be increasing in the gillnet sector, which reported approximately 17% of the total wolffish discarded for 2007 (Table 3).

Recreational catch data was retrieved from the MRFSS database (Figure 6 and Table 4). Landings are reported in total number of fish and total weight per year. Landings include both A and B1 fish, these are fish permanently removed from the population. B2 fish are discarded live and are assumed to have survived. Adjusted landings were developed because average weight of an individual wolffish was highly variable. Average weight (kg) was calculated based on the reported numbers of landed fish (A + B1) divided by the reported landed weight (kg). A grand mean was calculated from average weights and used in the new adjusted landings values. Adjusted landing are less variable than the original reported values and are likely to describe the recreational portion of total catch. Recreational catches have become more significant in recent years as commercial landings have steadily declined (Figure 7 and Table 1). Recreational catch makes up approximately 16% of the total catch and is 1/5 as large as the commercial landings for 2007 (Table 1).

Total Catch is comprised of reported landings, estimates of commercial discards from the primary fishery sectors and recreational catch from US waters as previously described (Figure 7 and Table 1). Recreational catches begin in 1981 and discard estimates begin in 1989. Total US catch peaked in 1983 with 1,111.83 mt and has decreased steadily reaching a low of 77.03 mt in 2007.

Commercial Lengths Data and CPUE

Fishery observers collect length samples at sea opportunistically providing information on the size structure of the population. Observer lengths have been collected since 1989. Sample sizes from early in the time series are low but have exceeded 100 samples per year during 2003-2007 (Table 5). Median length has been variable over time but increased slightly during the 2003-2007 period indicating that larger fish are being harvested (Figure 8). Differences in length composition by commercial gear types were also plotted (Figure 9). Sample sizes are small in all gears except for otter trawl and gillnet, where size distributions and median values are similar (Table 6).

Commercial lengths from port samples have been taken irregularly during the span of the commercial fishery. A significant amount of samples were collected during 1982 – 1985 and have also been taken consistently since 2001. Commercial port sample length distributions were plotted by year (Figure 10). An increase in median length can be seen during the 2001 – 2007 time period. The median has increased from 75 cm in 2001 to 84 cm in 2007 (Table 7). This data suggests that size in the commercial fishery may be increasing as the 95% confidence intervals from the 2001-2003 period do not overlap with the 2004-2007 period. Differences were then examined to see if the increase could be explained by major gear type since longlines, and gill nets have become a larger component of the fishery (Figure11). Slight differences were observed in the size compositions of the various gears but this may be an artifact of low sample size of commercial gears other than otter trawls (Table 8). Commercial length samples were also plotted by statistical area to determine if any geographic trend in size could be seen (Figure 12). The primary fishery areas, 512-522, show similar length distributions. Areas 526 and 537 had anomalous length distributions but also had low sample sizes (Table 9).

Indices of catch per unit of effort (CPUE) were calculated from fishery observer trips and self reported Vessel Trip Reports (VTRs) in party and charter boat sectors for Atlantic wolffish. Observer CPUE was estimated for 1989-2007 in the longline, gillnet and otter trawl fisheries for US statistical areas 512-515, 521-522, 525-526 and 537 (Table 10). CPUE was calculated based on the ratio: sum of kept wolffish per year / sum of days fished per year. Observer CPUE has declined in the 3 fishing sectors reviewed (Figure 13). Atlantic wolffish CPUE for the longline fishery is plotted on the second y-axis as it is significantly higher than the otter trawl and gillnet sectors.

Party and Charter boat CPUE have also declined (Figure 14; Table 11). These indices were calculated from the number wolffish reported landed on VTRs and angler days fished. Angler days fished was estimated by number anglers * hours fished / 24 per year for all party and charter trips in areas 514 and 515.

Research Vessel Survey Data

Survey Length, Weight and Maturity

Atlantic wolffish catches were grouped by decade to reduce data gaps in length frequency plots. Distributions were plotted using proportion at length and number at length (Figures 15 and 16). The numbers at length graphs show an overall reduction in numbers by decade across the length range of Atlantic wolffish. The proportion at length graphs indicate that different size fish are available to the bottom trawl gear in spring and fall. In general, spring survey encounters larger individuals (>= 50 cm) and the fall survey captures smaller individuals ranging from 10-30 cm. The spring survey also captures a unique distribution of small individuals, less than or equal to 7 cm, and may be used as a juvenile index.

Length weight relationships were developed for Atlantic wolffish from NEFSC bottom trawl survey data. Spring and fall survey data were combined to create one relationship for both male and female fish as no differences were found between seasons or sexes (Figure 17). Linear regression of log transformed data provided a good fit, $R^2 = 0.996$.

A logistic maturity ogive was developed for female Atlantic wolffish based on spring and fall survey vessel data (Figure 18). L_{50} was estimated at approximately 35 cm from these data. This L_{50} for female wolffish is lower than estimates reported in Newfoundland and Iceland where females containing second generation eggs were considered immature (Templeman 1986; Gunnarsson et al. 2006). NEFSC maturity data is based on visual inspection of the reproductive organs. Fish are classified into 1 of 7 stages of maturity (Burnett et al 1989). Fish classifications for females include immature, developing, ripe, eyed (unique for redfish), ripe and running, spent and resting. This analysis considered fish that were in the developing through resting stages as a mature and immature were those fish that contained no visible eggs. Size at maturity may be difficult to interpret for wolffish from these data as they may have an additional developing stage, or a set of second generation eggs which may last for several years, where fish are reproductively immature (Gunnarsson et al. 2006). These immature fish would likely be classified as developing in NEFSC surveys and were considered mature in the ogive thereby reducing the size at 50% mature.

Biomass and Abundance

Atlantic wolffish are encountered infrequently on NEFSC bottom trawl surveys. Strata used in wolffish analyses were limited to offshore areas completely or almost completely within US waters (Figure 19). Some historically important strata were excluded from this analysis, specifically on the Canadian portion of Georges Bank, but due to the sedentary nature of this fish it is believed to have not affected the estimation of the indices or overall trends in US waters (Figures 20 &21). Sampling effort per survey stratum in the Gulf of Maine has remained relatively consistent over most of the time series (Figure 22). The timing of the surveys in the Gulf of Maine has also been consistent during the spring and fall. Inshore sampling did not commence until the mid 1970's and was therefore not used. Higher sampling intensity did occur in portions of the 1970's and 1980's in select survey stratum but elevated abundance and biomass are not likely due to increased sampling effort (Figure 23).

In general the NEFSC spring and fall bottom trawl survey indices show abundance and biomass of Atlantic wolffish has declined over the last two to three decades (Figure 24.). The spring survey typically encounters higher abundance and biomass than the fall survey and was considered by the Data Poor Working Group to be optimal for assessing resource trends (Table 1). Survey differences may be attributed to wolffish being less available to the sampling gear while nest guarding in the fall (Rountree, R.A. 2002). Inter-annual variability among both surveys is high.

The spring biomass index averaged 0.786 kg/tow and ranged between 0.38 and 1.44 kg/tow from 1968 to 1988. Since the mid to late 1980's the resource has steadily declined. The average spring biomass index for 1989-2007 was 0.143 kg/tow, only 18% of the 1968-1988 average, and ranged from 0.0 kg/tow to 0.42 kg/tow. The fall biomass index shows little trend over time and is relatively low over most of the time series (Figure 24). A large anomalous peak in biomass appears in 1981 but is not seen again in subsequent years. Since the mid 1990's wolffish biomass has fluctuated with a slightly declining trend.

Abundance indices in both surveys show a decline in stratified mean number per tow since the mid 1990's. 3 year centered moving average plots of abundance and biomass removes the inter-annual variability within the indices and depicts an overall declining trend in the resource (Figure 25).

Spring and fall percent positive Atlantic wolffish catch was plotted by year (Figure 26). This type of index for species rarely captured can be a good indicator of how frequently rare events occur over time. These indices indicate that the number of survey tows catching at least one wolffish has decreased with time in both the spring and fall. The spring index shows an almost continuous declining trend since the late 1970's/early 1980's, averaging around 12% and dropping to approximately 2%. The fall index appears relatively stable from the mid 1960's through the early 1990's, fluctuating around 6 %. It then declines quickly from 1993 to 1996 and becomes relatively stable again near 2 % until 2007 where it reaches zero.

The spatial distribution of Atlantic wolffish has contracted according to the spring and fall bottom trawl surveys. Data were grouped by decade and survey catch in numbers were displayed using GIS (Figures 27 and 28). The spring survey shows high catch along Jefferies Ledge, Stellwagen Bank National Marine Sanctuary and off outer Cape Cod through the Great South Channel during the 1970's and 1980's. Catches in the 1990's extend across a similar area but appear with less abundance and frequency. Highest catches during the 2000's are limited to Stellwagen Bank region. A similar pattern emerges from fall survey catches and the resource appears to be more concentrated within the Jefferies Ledge and Stellwagen Bank regions. During the 1990's and 2000's catches are smaller and appear less frequently in the fall.

Modeling Results

SCALE Model

Incomplete or lack of age-specific catch and survey indices often limits the application of a full age-structured assessment (e.g. Virtual Population Analysis and many forward projecting age-structured models). Stock assessments will often rely on the simpler size/age aggregated models (e.g. surplus production models) when age-specific information is lacking. However the simpler size/age aggregated models may not utilize all of the available information for a stock assessment. Knowledge of a species growth and lifespan, along with total catch data, size composition of the removals, recruitment indices and indices on numbers and size composition of the large fish in a survey can provide insights on population status using a simple model framework.

The Statistical Catch At Length (SCALE) model, is a forward projecting age-structured model tuned with total catch (mt), catch at length or proportional catch at length, recruitment at a specified age (usually estimated from first length mode in the survey), survey indices of abundance of the larger/older fish (usually adult fish) and the survey length frequency distributions (NOAA Fisheries Toolbox 2008a). The SCALE model was developed in the AD model builder framework. The model parameter estimates are fishing mortality and recruitment in each year, fishing mortality to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years and Qs for each survey index.

The SCALE model was developed as an age-structured model that does NOT rely on age-specific information on a yearly basis. The model is designed to fit length information, abundance indices, and recruitment at age which can be estimated by using survey length slicing. However the model does require an accurate representation of the average overall growth of the population which is input to the model as mean lengths at age. Growth can be modeled as sex-specific growth and natural mortality or growth and natural mortality can be model with the sexes combined. The SCALE model will allow for missing data.

Model Configuration

The SCALE model assumes growth follows the mean input length at age with predetermined input error in length at age. Therefore a growth model or estimates of mean length at age are essential for reliable results. The model assumes static growth and therefore population mean length/weight at age are assumed constant over time. A depiction of model assumed population growth at age using the input mean lengths at age and variation can be seen in table 12 and figure 29.

The SCALE model estimates logistic parameters for a flattop selectivity curve at length in each time block specified by the user for the calculation of population and catch age-length matrices or the user can input fixed logistic selectivity parameters. Presently the SCALE model can not account for the dome shaped selectivity pattern.

The SCALE model computes an initial age-length population matrix in year one of the model as follows. First the estimated populations numbers at age starting with age-1 recruitment get normally distributed at one cm length intervals using the mean length at age with the assumed standard deviation. Next the initial population numbers at age are calculated from the previous age at length abundance using the survival equation. An estimated fishing mortality (Fstart) is also used to produce the initial population. This F can be thought of as the average fishing mortality that occurred before the first year in the model. Now the process repeats itself with the total of the estimated abundance at age getting redistributed according to the mean length at age and standard deviation in the next age (age+1).

This two step process is used to incorporate the effects of length specific selectivities and fishing mortality. The initial population length and age distribution is constructed by assuming population equilibrium with an initial value of F, called F_{start}. Length specific mortality is estimated as a two step process in which the population is first decremented for the length specific effects of mortality as follows:

$$N^*_{a,len,y_1} = N_{a-1,len,y_1} e^{-\left(PR_{len}F_{start}+M\right)}$$

In the second step, the total population of survivors is then redistributed over the lengths at age *a* by assuming that the proportions of numbers at length at age *a* follow a normal distribution with a mean length derived from the input growth curve (mean lengths at age).

$$N_{a,len,y_1} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^*_{a,len,y_1}$$

where

$$\pi_{len,a} = \Phi\left(len+1 \mid \mu_a, \sigma_a^2\right) - \Phi\left(len \mid \mu_a, \sigma_a^2\right)$$

where

$$\mu_a = L_\infty \left(1 - e^{-K(a-t_0)}\right)$$

Mean lengths at age can be calculated from a von Bertalanffy model from a prior study as shown in the equation above or mean lengths at age can be calculated directly from an age-length key. Variation in length at age a = σ_s^2 can often be approximated empirically from the growth study used for the estimation of mean lengths at age. If large differences in growth exist between the sexes then growth can be input as sex-specific growth with sex-specific natural mortality. However catch and survey data are still fitted with sexes combined.

This SCALE model formulation does not explicitly track the dynamics of length groups across age because the consequences of differential survival at length at age a do not alter the mean length of fish at age a+1. However, it does more realistically account for the variations in age-specific partial recruitment patterns by incorporating the expected distribution of lengths at age.

In the next step the population numbers at age and length for years after the calculation of the initial population use the previous age and year for the estimate of abundance. Here the calculations are done on a cohort basis. Like in the previous initial population survival equation the partial recruitment is estimated on a length vector.

$$N^*_{a,len,y} = N_{a-1,len,y-1} e^{-\left(PR_{len}F_{y-1}+M\right)}$$

second stage

$$N_{a,len,y} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^*_{a,len,y}$$

Constant M is assumed along with an estimated length-weight relationship to convert estimated catch in numbers to catch in weight. The standard Baranov's catch equation is used to remove the catch from the population in estimating fishing mortality.

$$C_{y,a,len} = \frac{N_{y,a,len}\, F_y\, PR_{len}\left(1 - e^{-\left(F_y PR_{len} + M\right)}\right)}{(F_y \;\; PR_{len}) + M}$$

Catch is converted to yield by assuming a time invariant average weight at length.

$$Y_{y,a,len} = C_{y,a,len} W_{len}$$

The SCALE model results in the calculation of population and catch age-length matrices for the starting population and then for each year thereafter. The model is programmed to estimate recruitment in year 1 and estimate variation in recruitment relative to recruitment in year 1 for each year thereafter. Estimated recruitment in year one can be thought of as the estimated average long term recruitment in the population since it produces the initial population. The residual sum of squares of the variation in recruitment $\sum(\text{Vrec})^2$ is than used as a component of the total objective function. The weight on the recruitment variation component of the objective function (Vrec) can be used to penalize the model for estimating large changes in recruitment relative to estimated recruitment in year one.

The model requires an age-1 recruitment index for tuning or the user can assume relatively constant recruitment over time by using a high weight on Vrec. Usually there is little overlap in ages at length for fish that are one and/or two years of age in a survey of abundance. The first mode in a survey can generally index age-1 recruitment using length slicing. In addition numbers and the length frequency of the larger fish (adult fish) in a survey where overlap in ages at a particular length occurs can be used for tuning population abundance. The model tunes to the catch and survey length frequency data using a multinomial distribution. The user specifies the minimum size (cm) for the model to fit. Different minimum sizes can be fit for the catch and survey data length frequencies.

The number of parameters estimated is equal to the number of years in estimating F and recruitment plus one for the F to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years, and for each survey Q. The total likelihood function to be minimized is made up of likelihood components comprised of fits to the catch, catch length frequencies, the recruitment variation penalty, each recruitment index, each adult index, and adult survey length frequencies:

$$\text{L}_{\text{catch}} = \sum_{years}\left(l\,\text{n}(Y_{\text{obs,y}} + 1) - \ln\left(\sum_a \sum_{len} \text{Y}_{\text{pred,len,a,y}} + 1 \right)\right)^2$$

$$L_{catch\_lf} = -N_{eff} \sum_{y} \left(\sum_{inlen}^{L_\infty} \left((C_{y,len}+1) \ln\left(1 + \sum_{a} C_{pred,y,a,len} \right) - \ln(C_{y,len}+1) \right) \right)$$

$$\text{L}_{\text{vrec}} = \sum_{y=2}^{Nyears} (Vrec_y)^2 = \sum_{y=2}^{Nyears} (R_1 - R_y)^2$$

$$\sum L_{rec} = \sum_{i=1}^{Nrec} \left[\sum_{y}^{Nyears} \left(\ln(I_{rec_i,inage_i,y}) - \ln\left(\sum_{len}^{L_\infty} N_{y,inage_i,len} * q_{rec\,i} \right) \right)^2 \right]$$

$$\sum L_{adult} = \sum_{i=1}^{Nadult} \left[\sum_{y}^{Nyears} \left(\ln(I_{adult_i,inlen+_i,y}) - \left(\sum_{a} \sum_{inlen_i}^{L_\infty} \ln(N_{pred,y,a,len} * q_{adult\,i}) \right) \right)^2 \right]$$

$$\sum L_{lf} = \sum_{i=1}^{Nlf} \left[-N_{eff} \sum_{y} \left(\sum_{inlen_i}^{L_\infty} \left((I_{lf_i,y,len}+1) \ln\left(1 + \sum_{a} N_{pred,y,a,len} \right) - \ln(I_{lf_i,y,len}+1) \right) \right) \right]$$

In equation L_{catch_lf} calculations of the sum of length are made from the user input specified catch length to the maximum length for fitting the catch. Input user specified fits are indicated with the prefix "in" in the equations. LF indicates fits to length frequencies. In equation L_{rec} the input specified recruitment age and in L_{adult} and L_{lf} the input survey specified lengths up to the maximum length are used in the calculation.

$$Obj\ \ fcn = \sum_{i=1}^{N} \lambda_i L_i$$

Lambdas represent the weights to be set by the user for each likelihood component in the total objective function.

Wolffish SCALE Model Configuration and results

Mean lengths at age and variation in mean length at age were based on fish collected during the 1980s from Nelson and Ross (1992). A Gompertz relationship had the best fit using all ages. We have re-estimated a von Bertalanffy relationship using data limited to fish older than 4 with L-infinity fixed at 110 cm (Figure 30). The mean lengths from Nelson and Ross's Gompertz relationship for fish younger than age 5 were also used in the SCALE model. The mean lengths from the younger fish do not have a large effect on the SCALE model results. In the final growth model we fixed L-infinity (110) at a slightly higher value than what was estimated by the Gompertz (98.9) model because few larger and older fish exist in Nelson and

Ross's study and the SCALE model had difficultly predicting larger fish that are in seen in the catch length frequency distributions. A North Sea wolffish growth study estimated L-infinity at 111 for males and 115 for females (Liao and Lucas, 2000). Figure 31 shows the predicted catch length distribution under low Fs (F=0.001) assuming different L-infinities. A standard deviation of 6 was used for fish older then age-7. The assumed variation around the mean lengths at age can be seen in Table 12 and Figure 29. Nelson and Ross's oldest fish was 22 years. The age matrix was dimensioned from ages 1 to 30 with an assumed natural mortality of 0.15.

Only one recruitment index exists in the SCALE model (Figure 32). The spring NEFSC survey shows a distinct mode between 1 and 7 cm. This index was tuned to age-1. The recruitment index suffers from zero catches in many years and at times in blocks of several years. A 40+ cm index was developed from the NEFSC spring, NEFSC fall and the MDMF spring survey (Figure 33). All three surveys show declining trends in abundance with the indices also suffering from zero catches at the end of the time series. The survey length frequency distributions are limited due to the low numbers of wolffish caught in the surveys. There is concern that biomass may have fallen below detection in the surveys. Preliminary evidence suggests the Bigelow survey may also suffer from the same low catchablility issue. Survey indices were scaled using the approximate area of survey coverage divided by the average coverage of a survey tow (Table 13). The area swept estimates can provide some insight from estimated survey efficiencies using the estimated Qs in the SCALE model.

Zero catches were set to missing in the SCALE model. Setting zeros to the smallest value in the time series appears to have a large unsubstantiated influence on the model results. The age-1 recruitment series was given a relatively low weight (Table 14). Setting the weight to high on the recruitment index will force SCALE to fit the recruitment index very closely but the model is less constrained in estimating recruitment for years where recruitment information is missing which can produce unrealistic results. The age-1 index was used more as a guide with setting the penalty on recruitment variation. The penalty on recruitment variation was set high enough to produce recruitment variation within the bounds of what was observed in the recruitment index. The model has to estimate a declining trend in recruitment to fit the decline in the 40+ cm indices and the declining trend in the catch since 1983. The recruitment index was used as guidance on whether recruitment failure has occurred for the wolffish stock. Sensitivity of the model to the weighting on the recruitment index and the penalty on variation in recruitment can be seen in Figures 34 through 37.

The catch length frequency distributions are an important component of the SCALE model. Observer trawl kept length sampling and port samples where combined to characterize the catch size distributions. Catch length frequency information exists from 1982 to 1985 and from 2001 to 2007. A single selectivity block over the time series was used due to the lack of a distinct shift in the size distribution and due to the lack of size information in many years. There is no indication of size truncation in the catch length frequency distributions over time.

The lack of data prevents the SCALE model from estimating a reliable logistic selectivity curve. The SCALE model estimates a very flat selectivity curve that produces a L-50 at very large sizes. There is a tradeoff in the SCALE model between the estimated selectivity and fishing mortality rates. Two different selectivity regimes were chosen to determine its influence of stock status determination (Figure 38). Run one had a relativity flat selectivity curve which was allowed to hit the L-50 bound of 90 cm. Run two was setup to hit the slope parameter bound of 0.15 which produces a steeper selectivity function with a lower L-50 estimate. Results of the two selectivity runs are summarized in Figures 39-42 and Table 14.

The SCALE model time series starts in 1968 with the beginning of the NEFSC spring index. The SCALE model estimates virgin conditions at the beginning of the time series with a low Fstart estimate (0.001) in 1968 when the catch was low. A strong retrospective pattern did not exist with the Slope = 0.15 run (Figure 43). The sensitivity of the assumed L-infinity for growth on the model estimated Fs and recruitment can be seen in Figure 44.

Non-parametric biological reference points (BRP) were developed for both the selectivity L-50 = 90 run (Run 1) and the slope = 0.15 run (Run 2) within the SCALE model using $F_{40\%}$ as a Proxy for F_{MSY} (Table 15). A range of knife edge maturities values were used in estimating the BRPs. Maturity as 40+ cm fish was used to correspond to NEFSC survey maturity results, a 65+ cm and 75+ cm cutoffs were used as bounds taken from the Gunnarsson et al (2006) and Templeman (1986). Templeman found maturation occurring at larger sizes in lower latitudes. However Gunnarsson et al (2006) found maturation occurring at larger sizes in the colder waters on the eastern side of Iceland compared to the western side. The Data Poor Stocks Working Group suggested that $F_{50\%}$ may be a better proxy of F_{MSY} for a species that is long lived, late maturing, and has low fecundity. $F_{50\%}$ BRPs were developed for the Slope = 0.15 run (Table 15 and Figure 45). Based on all SCALE model runs, the wolffish stock in 2007 is at a low biomass (26% to 45% of B_{MSY}) and is overfished (*assuming a $B_{THRESHOLD}$ of ½ B_{MSY}). The overfishing status determination was more uncertain with F_{2007} to F_{MSY} ratios ranging from 50% to 123%. The Peer Review Panel concluded that $F_{40\%}$ is reasonable and justifiable and that the F_{MSY} proxy < 0.35 is most probable. Therefore, MSY is likely in the range of 278-311 mt and SSB_{MSY} are likely between 1,750-2,200 mt.

*(*This assumption was confirmed by the Chairman of the Peer Review Panel after the December meeting.)*

Exploitation Ratios

Exploitation indices were created from reported wolffish catch and spring and fall biomass estimates (Figures 46; Table 1). Exploitation appears to have increased and could indicate this species is being over harvested even at low level commercial catches. Due to low survey catches some values cannot be shown on the chart. The spring exploitation index peaks at a value of 4,169.42 in 2004 and fall exploitation index contains 2 high points at approximately 42.64 in 1998 and 62.94 in 2006. Exploitation ratios were informative to the Review Panel but were considered to be highly variable.

DCAC Model

The DCAC model input consists of summed annual catch, an estimate of M, an estimate of the F_{MSY} to M ratio, the ratio of catch depletion over time and the number of years being analyzed (NOAA Fisheries Toolbox 2008b). It calculates a sustainable yield of a population after accounting for the “windfall” which occurs at the beginning of a fishery. When natural mortality is high, the DCAC model is the same as calculating the average landings. We conducted a sensitivity analysis of the delta depletion parameter over several time blocks to look at potential sustainable yields (Figure 47; Table 16). All of the time blocks cover the majority of the fishery and include high, moderate and low catch levels. The depletion-corrected average catch was significantly lower than the uncorrected average catch in each time block. Time block did not affect the DCAC but the delta depletion ratio has strong influence. DCAC results ranged from 297.4 mt to 378.0 mt and the Data Poor Stocks Review Panel believed were comparable to and supportive of the MSY values derived from the SCALE model.

AIM – An Index Method

The relationship between total catch of Atlantic wolffish and the spring biomass was explored using the An Index Method (AIM) model (NEFSC 2002 and NOAA Fisheries Toolbox 2008c). Both catch and the survey index have been declining over time with little response of the spring index to declining catches (Figure 48). The linear regression between the log_e replacement ratio and log_e relative F was not significant in a randomization test, critical value -0.387 and a significance level of 0.128 (Figure 49). Therefore this model was considered insufficient for providing results on Atlantic wolffish by the Review Panel.

Section 7. Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop fishing level recommendations for these stocks.

Major sources of uncertainty include:

1. Life history – size at maturity, age composition, $L\infty$ within the Gulf of Maine
2. Catchability in NEFSC bottom trawl surveys
3. Commercial length compositions and impacts to SCALE Model
4. Interpretation of 0 catches in recent years – modeling implications
5. Discard information from commercial fisheries
6. Habitat association is poorly known

The Data Poor Stocks Review Panel expanded upon this list of uncertainties. They included natural mortality, maximum age, fecundity and the connectivity of populations on Georges Bank and in the Gulf of Maine for important biological uncertainties. They included scientific uncertainty of the survey indices because populations are at the southern extent of the species range and may exhibit wide changes in distribution. Uncertainties from fisheries data include unknown harvest by foreign fleets and the extent of unreported catches and discards. The Review Panel believed that process uncertainty resulted from the lack of size truncation in commercially harvested fish, which indicated that fishing effort alone may not be responsible for changes in abundance. They suggest lack of preferable habitat may be considered as a viable alternative hypothesis. Model uncertainties include high survey catchability coefficients for pre and fully recruited sizes and the sensitivity of BRPs to maturity ogives and fishery selectivity curves. The Review Panel concluded that stock projections would be unreliable and should not be conducted because of the interpretation of zero catches in the survey data.

Section 8. If applicable, consider developing BRPs for species groups
NA

Section 9. Comment on what can be done to improve the information, proxies or assessments for each species.

Much work could be done to improve information on the basic biology of Atlantic wolffish in the Gulf of Maine. Age and growth data from both commercial and fishery independent sources needs to be collected to improve life history information, specifically L infinity. Conduct a maturity study based on egg size or first generation eggs in female wolffish to improve size at maturity estimates. Estimate fecundity for Gulf of Maine wolffish. Conduct tagging studies to confirm populations are sedentary and localized. Collect fishery observer data from more fishery sectors including the offshore lobster fishery. Comparative studies on wolffish catchability in multiple habitats, including complex rock habitat, with NEFSC survey gear and commercial gear types. A fishery independent index for wolffish should be developed for assessing potential biomass located in rocky habitats.

The Review Panel prioritized a list of research recommendations, including those mentioned above, to reduce uncertainty surrounding the biology, population dynamics and biological reference points of Atlantic wolffish.

1. Exploration of the relationship between survey catch per tow and habitat complexity and environmental signals should continue. These studies will aid understanding of the relationship between survey estimates and population abundance.
2. Age and growth studies for wolffish in the NE/GOM region should be conducted to refine estimates of L∞.
3. Maturity ogive data are currently based on simple presence of eggs in females, and do not account for functional maturity which requires presence of larger eggs. The review team believed the current approach is inadequate. Regional maturity ogives should be developed.
4. The review team recommended that a fixed gear survey be considered to assess abundance in non trawlable habitats.
5. Tagging studies should be conducted to explore and quantify the vagility of wolffish to help improve understanding of population structure and connectivity.

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Atlantic wolffish: Tables

Table 1. Summary table of total catch, commercial landings, recreational catch, discards and NEFSC survey indices.

YEAR	MRFSS (mt)	CFDBS (mt) US Only	Discard OT LL GN (mt) US Only	Total Catch (mt) US Only	Total Catch (1000 mt) US Only	Spring Biomass Index (kg/tow) US Only	Spring Exploitation Index US Only	Fall Biomass Index (kg/tow) US Only	Fall Exploitation Index US Only	Spring Abundance Index US Only	Fall Abundance Index US Only
1963	--	--	--	--	--	--	--	0.003	--	--	0.03
1964	--	114.32	--	114.32	0.114	--	--	0.18	0.62	--	0.09
1965	--	166.51	--	166.51	0.167	--	--	0.30	0.56	--	0.31
1966	--	174.42	--	174.42	0.174	--	--	0.17	1.03	--	0.33
1967	--	149.58	--	149.58	0.150	--	--	0.23	0.64	--	0.09
1968	--	116.22	--	116.22	0.116	0.38	0.31	0.41	0.29	0.07	0.15
1969	--	163.28	--	163.28	0.163	1.11	0.15	0.03	4.83	0.15	0.01
1970	--	154.83	--	154.83	0.155	1.12	0.14	0.36	0.43	0.18	0.08
1971	--	172.80	--	172.80	0.173	0.60	0.29	0.16	1.07	0.14	0.12
1972	--	243.94	--	243.94	0.244	0.51	0.48	0.16	1.51	0.34	0.13
1973	--	242.63	--	242.63	0.243	0.87	0.28	0.13	1.83	0.14	0.34
1974	--	352.79	--	352.79	0.353	1.11	0.32	0.10	3.67	0.53	0.23
1975	--	313.12	--	313.12	0.313	0.92	0.34	0.03	9.68	0.14	0.04
1976	--	401.93	--	401.93	0.402	0.53	0.76	0.05	8.68	0.10	0.07
1977	--	393.76	--	393.76	0.394	0.62	0.64	0.08	4.64	0.22	0.04
1978	--	605.24	--	605.24	0.605	1.17	0.52	0.54	1.13	0.30	0.47
1979	--	656.49	--	656.49	0.656	0.71	0.92	0.10	6.41	0.21	0.05
1980	--	826.46	--	826.46	0.826	0.70	1.19	0.18	4.59	0.30	0.14
1981	0.81	671.61	--	672.42	0.672	0.63	1.07	1.14	0.59	0.31	0.26
1982	23.12	760.40	--	783.52	0.784	0.68	1.15	0.19	4.08	0.19	0.05
1983	11.90	1099.92	--	1111.83	1.112	0.74	1.51	0.33	3.33	0.13	0.25
1984	13.18	935.31	--	948.50	0.948	0.47	2.00	0.07	13.30	0.12	0.04
1985	15.95	879.96	--	895.91	0.896	0.74	1.21	0.32	2.81	0.28	0.19
1986	7.24	789.79	--	797.03	0.797	1.44	0.55	0.37	2.16	0.24	0.10
1987	37.71	665.13	--	702.83	0.703	0.91	0.77	0.06	11.10	0.25	0.04
1988	9.03	505.59	--	514.62	0.515	0.54	0.95	0.10	5.12	0.20	0.11
1989	20.49	466.84	26.98	514.31	0.514	0.40	1.27	0.11	4.83	0.27	0.14
1990	29.17	378.16	2.63	409.95	0.410	0.17	2.46	0.21	1.91	0.06	0.11
1991	16.86	446.56	1.95	465.37	0.465	0.36	1.29	0.30	1.58	0.05	0.13
1992	10.73	430.92	19.18	460.83	0.461	0.11	4.02	0.18	2.51	0.14	0.13
1993	20.11	467.22	13.38	500.71	0.501	0.42	1.19	0.41	1.22	0.13	0.19
1994	18.54	455.39	0.11	474.04	0.474	0.14	3.41	0.28	1.69	0.21	0.11
1995	20.45	449.81	5.77	476.02	0.476	0.20	2.42	0.27	1.79	0.12	0.15
1996	12.33	347.98	4.53	364.84	0.365	0.17	2.18	0.01	25.90	0.11	0.01
1997	20.21	301.77	7.82	329.79	0.330	0.04	8.02	0.21	1.59	0.05	0.07
1998	16.84	286.84	2.25	305.92	0.306	0.10	2.92	0.01	42.64	0.04	0.01
1999	8.54	242.75	0.35	251.64	0.252	0.06	4.23	0.19	1.35	0.04	0.05
2000	12.40	191.34	0.54	204.29	0.204	0.21	0.98	0.03	8.17	0.03	0.01
2001	16.67	236.00	6.47	259.14	0.259	0.06	4.11	0.12	2.11	0.03	0.04
2002	9.82	145.58	13.10	168.50	0.169	0.08	2.01	0.07	2.35	0.06	0.03
2003	24.23	123.05	3.82	151.11	0.151	0.18	0.83	0.08	1.79	0.09	0.08
2004	12.45	116.95	1.58	130.98	0.131	0.00003	4169.42	0.02	6.36	0.02	0.01
2005	10.73	114.04	1.31	126.08	0.126	0.00	0.00	0.02	6.48	0.00	0.05
2006	17.86	80.05	1.45	99.36	0.099	0.00	0.00	0.002	62.94	0.00	0.04
2007	12.87	63.32	0.84	77.03	0.077	0.01	8.32	0.00	0.00	0.02	0.00
2008	--	--	--	--	--	--	--	--	--	--	--

Table 2. Percent US Commercial Landings of Atlantic wolffish by Statistical Area and Year

YEAR	512	513	514	515	521	522	525	526	537	Grand Total
1964	3.12	4.04	37.04	3.23	27.92	19.68	4.20	0.76	0.00	100.00
1965	8.06	3.35	29.81	0.92	29.43	25.04	0.72	2.64	0.04	100.00
1966	1.04	5.00	40.12	0.98	30.95	16.79	1.47	3.60	0.05	100.00
1967	1.45	17.26	35.79	1.27	29.84	13.21	0.49	0.70	0.00	100.00
1968	1.72	10.96	32.65	0.55	37.79	12.71	2.55	0.97	0.10	100.00
1969	0.86	12.90	43.91	1.74	24.19	14.83	1.31	0.26	0.01	100.00
1970	1.12	11.05	41.51	1.25	31.19	13.03	0.19	0.63	0.03	100.00
1971	1.85	8.22	42.60	1.63	26.38	16.63	0.85	1.11	0.73	100.00
1972	1.07	8.43	33.74	0.31	32.11	17.62	2.50	3.95	0.28	100.00
1973	0.74	10.16	42.75	0.80	33.97	8.85	1.32	1.41	0.00	100.00
1974	0.74	8.16	37.03	0.21	37.61	12.80	1.21	2.21	0.02	100.00
1975	1.36	10.36	41.55	2.50	33.34	9.56	0.60	0.50	0.23	100.00
1976	1.70	12.99	34.29	1.53	32.27	13.75	1.06	2.40	0.00	100.00
1977	1.34	10.35	37.32	2.02	41.23	6.41	0.58	0.69	0.06	100.00
1978	3.71	14.34	35.40	2.37	34.21	8.93	0.36	0.53	0.15	100.00
1979	3.10	17.30	28.31	3.09	36.66	10.77	0.16	0.61	0.00	100.00
1980	2.94	21.78	21.63	7.24	33.58	11.75	0.49	0.57	0.00	100.00
1981	3.99	22.82	24.83	6.61	28.63	11.73	0.39	0.80	0.21	100.00
1982	7.88	22.65	23.83	10.27	26.92	7.67	0.35	0.19	0.24	100.00
1983	4.65	25.89	28.51	13.92	19.84	6.35	0.22	0.57	0.06	100.00
1984	4.46	28.29	16.08	16.53	23.95	9.41	0.70	0.49	0.09	100.00
1985	6.17	25.18	14.83	19.47	26.63	7.09	0.21	0.35	0.05	100.00
1986	8.92	25.29	14.59	18.43	24.31	7.10	0.78	0.52	0.06	100.00
1987	5.90	25.25	17.55	18.22	25.56	6.91	0.18	0.42	0.01	100.00
1988	5.82	26.08	15.75	9.69	32.96	8.31	0.26	1.11	0.00	100.00
1989	6.39	22.29	11.78	8.76	41.19	8.01	0.10	1.37	0.13	100.00
1990	7.90	29.96	15.65	8.59	29.71	5.05	0.83	2.02	0.30	100.00
1991	6.08	24.30	16.41	16.68	25.59	9.10	0.33	1.22	0.29	100.00
1992	5.74	24.38	15.56	18.10	23.29	10.64	0.49	1.25	0.55	100.00
1993	3.73	20.35	15.56	20.61	19.51	17.49	0.83	1.49	0.42	100.00
1994	4.32	18.85	15.44	15.27	28.65	15.68	0.39	1.20	0.19	100.00
1995	2.26	14.92	20.65	17.80	28.26	14.39	0.29	1.04	0.39	100.00
1996	2.16	15.06	25.96	13.82	28.98	12.18	0.63	0.97	0.24	100.00
1997	1.82	13.48	24.10	11.09	33.59	13.72	0.54	0.43	1.23	100.00
1998	1.87	9.25	35.34	10.08	29.92	11.24	0.44	1.58	0.28	100.00
1999	1.18	9.34	18.35	7.91	41.27	17.39	0.83	2.66	1.06	100.00
2000	1.53	13.68	29.21	8.72	29.39	14.38	0.90	0.59	1.61	100.00
2001	0.96	9.84	18.99	5.81	34.47	26.30	0.83	0.60	2.21	100.00
2002	1.36	11.77	28.52	6.17	35.49	14.24	1.05	0.28	1.13	100.00
2003	1.91	14.05	35.62	5.81	29.78	7.93	1.18	0.25	3.47	100.00
2004	3.91	16.86	39.49	6.92	24.22	5.78	0.18	0.18	2.46	100.00
2005	2.58	20.06	40.80	12.93	16.14	6.22	0.61	0.64	0.03	100.00
2006	2.56	16.84	42.28	8.33	20.32	8.85	0.31	0.10	0.41	100.00
2007	3.29	14.39	39.78	10.08	23.84	7.30	0.85	0.34	0.12	100.00
Grand Total	4.11	19.26	24.64	10.28	29.20	10.70	0.59	0.94	0.27	100.00

Table 3. Commercial Discard Estimates for Atlantic wolffish US waters only

	Metric Tons				Percent		
YEAR	**LL**	**OT**	**GN**	**Grand Total**	**LL**	**OT**	**GN**
1989	0.00	26.98	0.00	26.98	0.00	100.00	0.00
1990	0.00	2.63	0.00	2.63	0.00	100.00	0.00
1991	0.00	1.95	0.00	1.95	0.00	100.00	0.00
1992	0.51	18.67	0.00	19.18	2.66	97.34	0.00
1993	0.00	13.38	0.00	13.38	0.00	100.00	0.00
1994	0.00	0.11	0.00	0.11	0.00	100.00	0.00
1995	0.00	5.77	0.00	5.77	0.00	100.00	0.00
1996	0.00	4.53	0.00	4.53	0.00	100.00	0.00
1997	0.00	7.11	0.71	7.82	0.00	90.91	9.09
1998	0.00	2.25	0.00	2.25	0.00	100.00	0.00
1999	0.00	0.35	0.00	0.35	0.00	100.00	0.00
2000	0.00	0.49	0.06	0.54	0.00	89.28	10.72
2001	0.00	6.47	0.00	6.47	0.00	100.00	0.00
2002	0.00	13.10	0.00	13.10	0.00	100.00	0.00
2003	0.00	3.67	0.15	3.82	0.00	96.01	3.99
2004	0.00	1.34	0.23	1.58	0.00	85.28	14.72
2005	0.00	1.22	0.09	1.31	0.00	93.37	6.63
2006	0.03	1.42	0.00	1.45	1.90	98.10	0.00
2007	0.01	0.69	0.14	0.84	0.65	82.16	17.19
Grand Total	0.54	112.13	1.39	114.06	0.48	98.31	1.21

Table 4. Atlantic wolffish recreational catch summary from MRFSS database, 1981-2007.

Year	Landed # (A + B1)	Discarded # (live) (B2)	Landed kg (A + B1)	Landed MT	Ave Wt kg	Adjusted Landed kg	Adj Landed MT
1981	334	0	unk	unk		806.38	0.81
1982	9,576	2,789	4,952	4.952	0.52	23,119.43	23.12
1983	4,930	88	16,776	16.776	3.40	11,902.54	11.90
1984	5,461	366	12,740	12.74	2.33	13,184.54	13.18
1985	6,607	0	14,428	14.428	2.18	15,951.34	15.95
1986	3,000	0	unk	unk		7,242.93	7.24
1987	15,618	691	31,733	31.733	2.03	37,706.68	37.71
1988	3,740	574	3,748	3.748	1.00	9,029.52	9.03
1989	8,486	6,956	21,415	21.415	2.52	20,487.83	20.49
1990	12,081	386	9,628	9.628	0.80	29,167.27	29.17
1991	6,984	7,180	14,250	14.25	2.04	16,861.54	16.86
1992	4,446	213	4,985	4.985	1.12	10,734.02	10.73
1993	8,329	1,544	11,969	11.969	1.44	20,108.78	20.11
1994	7,681	820	10,526	10.526	1.37	18,544.31	18.54
1995	8,470	2,027	32,287	32.287	3.81	20,449.20	20.45
1996	5,105	5,841	10,391	10.391	2.04	12,325.05	12.33
1997	8,369	833	37,474	37.474	4.48	20,205.35	20.21
1998	6,974	5,029	19,760	19.76	2.83	16,837.39	16.84
1999	3,538	2,389	4,741	4.741	1.34	8,541.83	8.54
2000	5,138	4,463	11,592	11.592	2.26	12,404.72	12.40
2001	6,905	4,841	15,628	15.628	2.26	16,670.81	16.67
2002	4,069	1,953	17,996	17.996	4.42	9,823.82	9.82
2003	10,035	1,204	42,207	42.207	4.21	24,227.59	24.23
2004	5,158	6,237	9,573	9.573	1.86	12,453.01	12.45
2005	4,445	481	14,955	14.955	3.36	10,731.60	10.73
2006	7,397	9,513	28,614	28.614	3.87	17,858.65	17.86
2007	5,329	8,678	15,253	15.253	2.86	12,865.85	12.87
2008							

Grand Mean Average Weight (kg) = **2.41**

Table 5. Summary Statistics of Commercial Observer Length Samples by Year, 1989-2007.

YEAR	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
1989	72	74.25	5.91	4	70 - 83
1991	77	81.89	13.25	9	70 - 114
1992	45.5	49.14	10.93	70	39 - 80
1993	61.5	64.58	11.01	24	49 - 86
1994	73	72.80	10.36	25	45 - 95
1995	62.5	62.00	18.08	20	21 - 102
1996	75	72.76	10.96	25	42 - 94
1997	81	78.38	12.52	13	47 - 92
1998	89	85.58	9.89	19	67 - 99
1999	83	82.14	11.28	7	65 - 94
2000	77	77.30	7.19	50	60 - 89
2001	76	75.69	10.86	74	52 - 96
2002	82	81.75	10.64	53	63 - 110
2003	77	73.78	13.41	186	31 - 113
2004	75	74.35	12.40	253	41 - 115
2005	81	80.23	11.38	264	29 - 107
2006	82	82.34	12.04	163	54 - 111
2007	83	81.59	12.48	129	44 - 105

Table 6. Summary Statistics of Commercial Observer Length Samples by major gear type.

Gear Type	Gear Code	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
Longline Bottom	10	73.5	71.91	14.04	22	71-96
Otter Trawl Fish	50	78.0	76.21	14.75	1000	21-115
Gillnet Fixed	100	77.0	76.32	11.82	335	36-114
Gillnet Drift	117	78.5	77.71	9.90	14	64-99
Scallop Dredge	132	69.0	67.64	14.66	11	46-94
Offshore Lobster	200	71	66.17	13.83	6	42-79

Table 7. Commercial Port Sample Summary Statistics by Year, 1982-1985 and 2001-2007.

YEAR	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
1982	69	71.71	15.35	354	45-114
1983	78	78.25	14.46	1349	42-128
1984	76	76.10	12.76	445	51-130
1985	77	76.98	11.86	729	47-119
2001	75	76.59	10.11	176	59-110
2002	76	76.34	10.30	297	38-104
2003	76	76.88	11.07	473	52-109
2004	81	80.83	10.72	1159	48-115
2005	82	81.40	9.95	500	54-110
2006	83	83.03	10.36	894	37-111
2007	84	83.55	10.01	800	51-108

Table 8. Commercial Port Samples Summary Statistics by Gear Type

Gear Type	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
Longline	71	71.08	8.84	134	45-92
Handline	80	79.41	10.90	29	62-99
Otter Trawl Fish	80	80.04	12.63	7041	37-130
Gill Net	76	76.36	11.68	211	51-109

Table 9. Commercial Port Samples Summary Statistics by Fishery Statistical Areas

Statistical Area	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
0	83	83.27	6.13	11	75 - 95
512	83	82.16	10.76	421	37 - 108
513	80	79.70	10.99	1745	46 - 110
514	77	77.69	12.04	1357	42 - 130
515	79	78.50	11.67	1956	44 - 112
521	78	79.19	12.53	894	38 - 119
522	77	77.88	12.39	478	50 - 115
525	82	82.70	9.30	47	57 - 102
526	112	110.72	9.67	79	79 - 128
537	68	68.00	15.43	10	48 - 101

Table 10. Observer based CPUE (sum of kept wolffish per year / sum of days fished per year) for Atlantic wolffish, 1989-2007.

YEAR	LLB	OTF	GNF
1989		19.51	5.79
1990		9.47	28.84
1991	52.25	19.64	14.72
1992	54.43	39.68	17.56
1993	262.50	43.05	21.25
1994		54.08	25.77
1995		19.57	62.17
1996		18.94	50.92
1997		30.09	17.75
1998		21.58	19.86
1999		20.47	14.52
2000		19.12	19.37
2001		24.45	18.70
2002	86.70	10.69	18.90
2003	29.60	12.91	32.67
2004	9.36	9.69	17.48
2005	18.98	5.45	19.87
2006	9.91	5.83	16.16
2007	8.20	5.72	8.03

Table 11. Party and Charter Boat CPUE (number of wolffish / million angler days fished) from VTR data for Atlantic wolffish, 1994-2007.

YEAR	CPUE Charter Boats	CPUE Party Boats
1994	71.828	15.080
1995	76.796	9.000
1996	67.966	10.945
1997	82.408	12.949
1998	138.833	12.639
1999	39.482	7.561
2000	16.524	4.559
2001	17.532	3.078
2002	6.906	3.687
2003	8.919	4.477
2004	6.603	3.593
2005	6.737	3.356
2006	5.147	3.430
2007	4.910	2.238

Table 12. Population depiction of distributions around the mean length at age for wolffish used in the SCALE model. Top row shows the input standard deviation at age and the second row has the mean lengths at age.

std	3	3	3.5	4	4.5	5	5.5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
len/age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
122																										1	1	1	1	1
121																								1	1	1	2	2	2	2
120																						1	1	2	2	3	3	4	4	4
119																					1	1	2	4	5	6	7	8	8	8
118																				1	2	3	5	7	9	11	13	14	14	15
117																			1	2	4	7	10	14	18	20	23	24	25	24
116																		1	2	4	8	13	20	26	31	35	38	39	39	39
115																		1	4	9	16	25	35	44	52	57	60	61	60	58
114																	1	3	8	17	30	45	60	73	82	88	90	90	87	82
113																	2	6	17	33	54	76	97	113	123	128	128	125	118	110
112																1	4	14	32	59	90	122	148	165	175	177	172	164	152	140
111																2	9	27	58	100	144	184	213	229	235	230	219	204	186	168
110															1	5	19	50	100	160	217	263	291	301	297	283	263	239	215	190
109															2	11	37	89	163	242	310	355	375	374	357	330	299	266	234	204
108															4	22	68	149	251	347	418	454	458	439	405	364	321	280	242	208
107														1	9	42	119	237	365	471	533	549	529	488	435	380	327	279	236	200
106														3	20	78	197	354	504	604	643	628	579	512	442	375	314	262	218	182
105														6	39	137	307	503	657	734	734	680	598	509	424	350	286	233	191	156
104													1	13	74	226	454	674	811	843	792	696	585	479	386	309	246	197	158	127
103													3	28	132	354	634	855	947	916	809	674	541	426	332	258	200	157	123	98
102													6	54	222	523	838	1,026	1,046	941	782	617	474	358	270	204	154	118	91	71
101												1	14	101	354	732	1,048	1,165	1,092	915	714	535	392	285	208	152	113	84	64	49
100												2	29	177	533	969	1,240	1,251	1,079	842	618	439	307	215	151	107	78	57	42	32
99												4	57	294	761	1,213	1,388	1,271	1,009	732	505	340	228	153	104	72	51	36	26	20
98												9	106	462	1,028	1,437	1,469	1,222	892	603	391	250	159	103	68	45	31	22	16	11
97											1	20	188	687	1,312	1,611	1,471	1,111	746	469	286	173	106	66	42	27	18	12	9	6
96											1	41	315	965	1,585	1,707	1,394	955	590	345	198	114	66	40	24	15	10	7	5	3
95											4	81	499	1,284	1,811	1,712	1,249	777	442	241	130	71	39	23	13	8	5	3	2	2
94											9	149	749	1,615	1,958	1,624	1,059	598	313	159	80	41	22	12	7	4	3	2	1	1
93											19	259	1,063	1,921	2,002	1,457	849	435	209	99	47	23	12	6	3	2	1	1		
92										1	40	426	1,427	2,163	1,936	1,237	644	300	133	58	26	12	6	3	2	1	1			
91										2	78	664	1,812	2,303	1,771	993	462	195	80	33	14	6	3	1	1					
90										4	147	979	2,177	2,319	1,533	754	314	120	45	17	7	3	1	1						
89										10	259	1,365	2,474	2,210	1,255	542	201	70	24	9	3	1	1							
88										23	434	1,801	2,660	1,992	972	368	122	39	12	4	1	1								
87										47	687	2,247	2,704	1,698	712	237	70	20	6	2	1									
86									1	93	1,028	2,652	2,601	1,370	494	144	38	10	3	1										
85									3	174	1,455	2,961	2,367	1,045	324	83	20	5	1											
84									6	307	1,950	3,128	2,037	754	201	45	10	2												
83									14	512	2,470	3,125	1,659	515	118	23	4	1												
82									31	809	2,961	2,953	1,278	333	65	11	2													
81									64	1,209	3,358	2,640	931	203	34	5	1													
80								1	125	1,709	3,602	2,233	642	117	17	2														
79								2	231	2,285	3,654	1,787	418	64	8	1														
78								4	402	2,890	3,508	1,352	258	33	4															
77								9	664	3,459	3,185	968	151	16	1															
76								21	1,035	3,915	2,735	655	83	8	1															
75								45	1,528	4,192	2,222	420	43	3																
74								92	2,132	4,246	1,708	254	21	1																
73								175	2,816	4,069	1,242	146	10	1																
72								318	3,517	3,688	854	79	4																	
71							1	545	4,155	3,162	556	41	2																	
70							2	884	4,644	2,565	342	20	1																	
69							4	1,357	4,910	1,968	199	9																		
68							11	1,970	4,911	1,428	110	4																		
67							27	2,705	4,647	981	57	2																		
66							63	3,514	4,159	637	28	1																		
65							134	4,318	3,521	391	13																			
64							268	5,019	2,820	227	6																			
63							502	5,518	2,136	125	2																			
62							880	5,740	1,531	65	1																			
61							1,445	5,647	1,038	32																				
60						1	2,220	5,256	666	15																				
59						3	3,193	4,628	404	7																				
58						10	4,298	3,854	232	3																				
57						28	5,415	3,037	126	1																				
56						71	6,386	2,263	65																					
55						165	7,049	1,595	31																					
54						354	7,284	1,064	14																					
53						701	7,045	671	6																					
52					1	1,281	6,377	401	3																					
51					5	2,162	5,404	226	1																					
50					17	3,369	4,286	121																						
49					50	4,844	3,182	61																						
48					134	6,431	2,211	29																						
47					328	7,880	1,438	13																						
46					725	8,914	876	6																						
45					1,453	9,308	499	2																						
44					2,638	8,973	266	1																						
43				1	4,341	7,984	133																							
42				4	6,470	6,558	62																							
41				16	8,736	4,973	27																							
40				55	10,688	3,481	11																							
39				169	11,845	2,249	4																							
38				460	11,893	1,342	2																							
37				1,106	10,818	739	1																							
36				2,345	8,915	375																								
35				4,391	6,656	176																								
34			1	7,254	4,502	76																								
33			4	10,575	2,759	31																								
32			21	13,606	1,531	11																								
31			89	15,448	770	4																								
30			310	15,479	351	1																								
29			923	13,688	145																									
28			2,333	10,681	54																									
27			5,010	7,356	18																									
26			9,135	4,470	6																									
25		3	14,150	2,398	2																									
24		20	18,616	1,135																										
23		106	20,801	474																										
22		457	19,743	175																										
21		1,584	15,915	57																										
20	1	4,395	10,897	16																										
19	5	9,765	6,337	4																										
18	35	17,376	3,130	1																										
17	178	24,756	1,313																											
16	730	28,243	468																											
15	2,399	25,801	142																											
14	6,311	18,873	36																											
13	13,295	11,055	8																											
12	22,428	5,185	1																											
11	30,295	1,947																												
10	32,767	586																												
9	28,379	141																												
8	19,681	27																												
7	10,929	4																												
6	4,860	1																												
5	1,730																													
4	493																													
3	113																													
2	21																													
1	3																													

Table 13. Survey area coverage, estimated average survey tow coverage, total area divided by the survey footprint and the survey efficiency q estimates for run 1 and 2.

Wolffish	NEFSC			MDMF
	Spr Age 1	Spr 40+	Fall 40+	40+
survey area (nm^2)	25,911	25,911	25,911	1,833
Avg tow area swept	0.0112	0.0112	0.0112	0.003846
Tow duration	30 min	30 min	30 min	20 min
total area / tow area swept	2,313,482	2,313,482	2,313,482	476,573
Q L50 = 90	0.145	0.195	0.099	0.011
Q Slope = 0.15	0.147	0.188	0.095	0.011

Table 14. Wolffish working group SCALE runs. Run 1 was allowed to hit the L-50 bound on selectivity and run 2 hit the selectivity slope bound of 0.15. Run 3 parameters were identical to Run 2 and were used to develop F50 BRPs.

Run	1			2		
	L_{50} = 90			slope = 0.15		
	weight	qs	Residuals or parameters	weight	qs	Residuals or parameters
total objective function			250.75			254.12
total catch	10		0.22	10		0.22
catch len freq 1+	500		10.14	500		9.92
Variation in recruit penalty (Vrec)	2		14.33	2		15.02
NEFSC Spr 1 Age-1 1968-2007	2	0.145	8.86	2	0.147	9.03
NEFSC Spr 40+ 1968-2007	12	0.195	5.86	12	0.188	5.99
MDMF Spr 40+ 1978-2007	3	0.011	9.64	3	0.011	9.56
NEFSC Fall 40+ 1968-2007	3	0.099	26.67	3	0.095	26.82
NEFSC Spr 40+ len freq	5		12.85	5		12.84
Fstart			0.012			0.001
recruitment year 1 (1968, 000s)			355			361
Selectivity Alpha (L50) 1982-1984			90.00			73.16
Selectivity Beta (slope) 1982-1984			0.09			0.15

Table 15. Estimated biological reference points based on F40 and F50 for three wolffish SCALE runs. A range of knife edge maturity cutoffs were used (40, 65, and 75 cm).

SCALE run	1			2			3		
Selectivity	L50 = 90			slope = 0.15			slope = 0.15		
Length of maturity	40cm	65cm	75cm	40cm	65cm	75cm	40cm	65cm	75cm
F_{MSY} proxy	F40%	F40%	F40%	F40%	F40%	F40%	F50%	F50%	F50%
F_{MSY}	0.686	0.486	0.374	0.319	0.233	0.185	0.197	0.156	0.129
YPR	0.872	0.839	0.799	0.861	0.817	0.771	0.784	0.728	0.679
SSB per Recruit	6.098	5.432	4.846	6.098	5.430	4.838	7.627	6.796	6.050
Initial Recruits (000s)	355	355	355	361	361	361	361	361	361
MSY (mt)	310	298	284	311	295	278	283	264	245
SSB_{MSY} (mt)	2,167	1,931	1,722	2,202	1,961	1,747	2,754	2,448	2,184
SSB_{07} (mt)	890	656	475	998	753	562	998	753	562
F_{07}	0.413	0.413	0.413	0.158	0.158	0.158	0.158	0.158	0.158
SSB_{07}/SSB_{MSY}	41%	34%	28%	45%	38%	32%	36%	31%	26%
F_{07}/F_{MSY}	60%	85%	111%	50%	68%	86%	80%	102%	123%

Table 16. Sensitivity analysis of the delta depletion parameter in the Depletion-Corrected Average Catch model (DCAC) over time.

DCAC model - DCAC Average Catch (mt)
Sensitivity Analysis of % reduction on Several Time Periods

	Delta Depletion Ratio										
	50% DD		**75% DD**		**90% DD**		**95% DD**		Total	Uncorrected	
Base Years	mean	median	mean	median	mean	median	mean	median	Catch	Catch	N Years
1970-1990	378.0	384.7	328.1	332.1	304.5	307.1	297.4	299.4	11714.9	557.9	21
1970-2000	367.3	374.9	328.7	334.8	309.6	314.9	303.8	308.6	15137.3	488.3	31
1970-2005	353.9	361.0	320.1	326.3	303.1	308.7	297.9	303.1	16384.2	455.1	36

	Confidence Intervals							
	5%	95%	5%	95%	5%	95%	5%	95%
1970-1990	254.3	476.2	202.0	439.6	180.0	420.8	174.0	414.6
1970-2000	271.5	436.9	225.5	411.7	204.2	398.1	198.1	393.9
1970-2005	269.6	413.3	227.1	392.3	207.1	380.8	201.3	377.3

assumptions:
M = 0.15 std dev = 0.5
Fmsy to M = 1.0 std dev = 0.2
delta depl std dev = 0.1

Atlantic wolffish: Figures

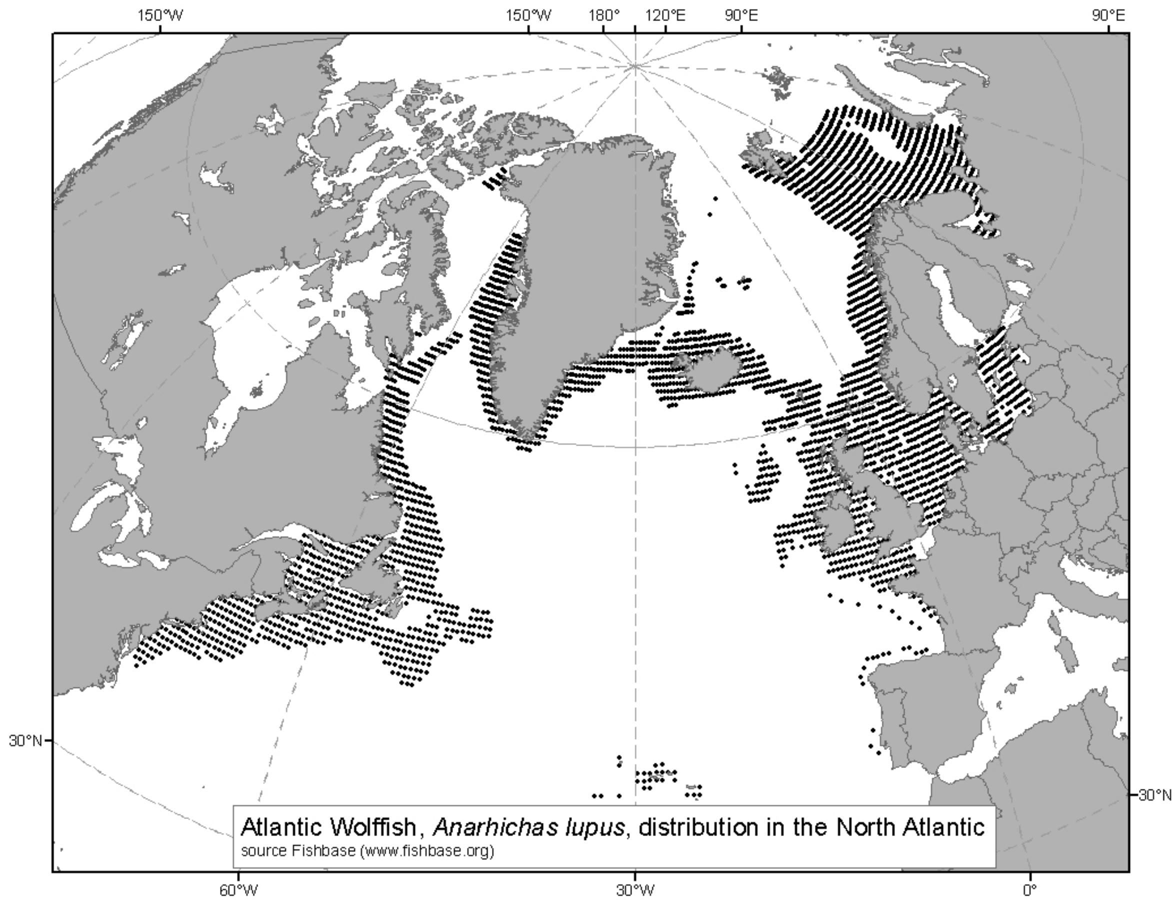


Figure 1. Atlantic wolffish distribution in the North Atlantic Ocean. The US is the southern extent of the geographic range in the western Atlantic.

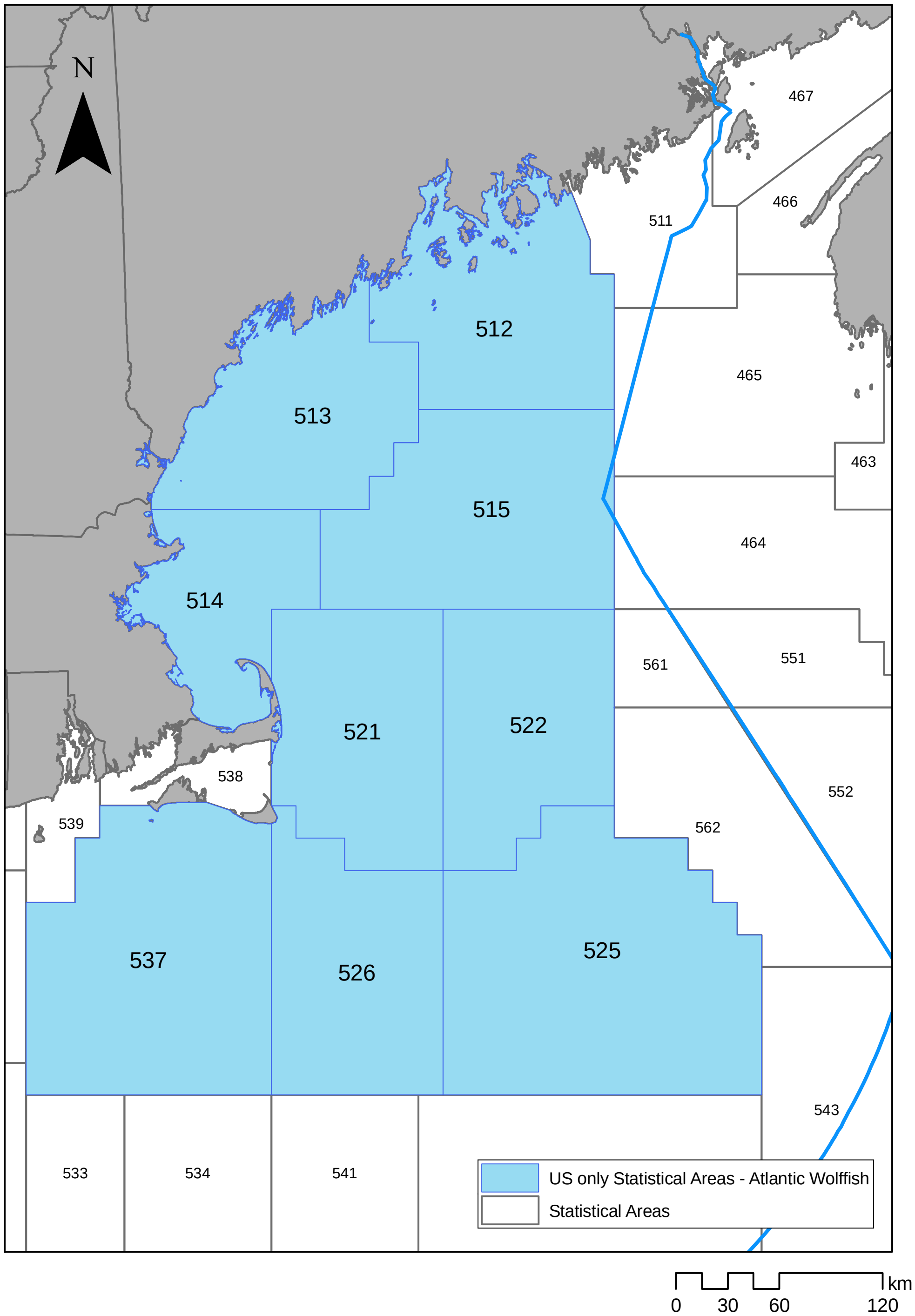


Figure 2. Fishery statistical areas used for Atlantic wolffish landings, catch and discard estimates.

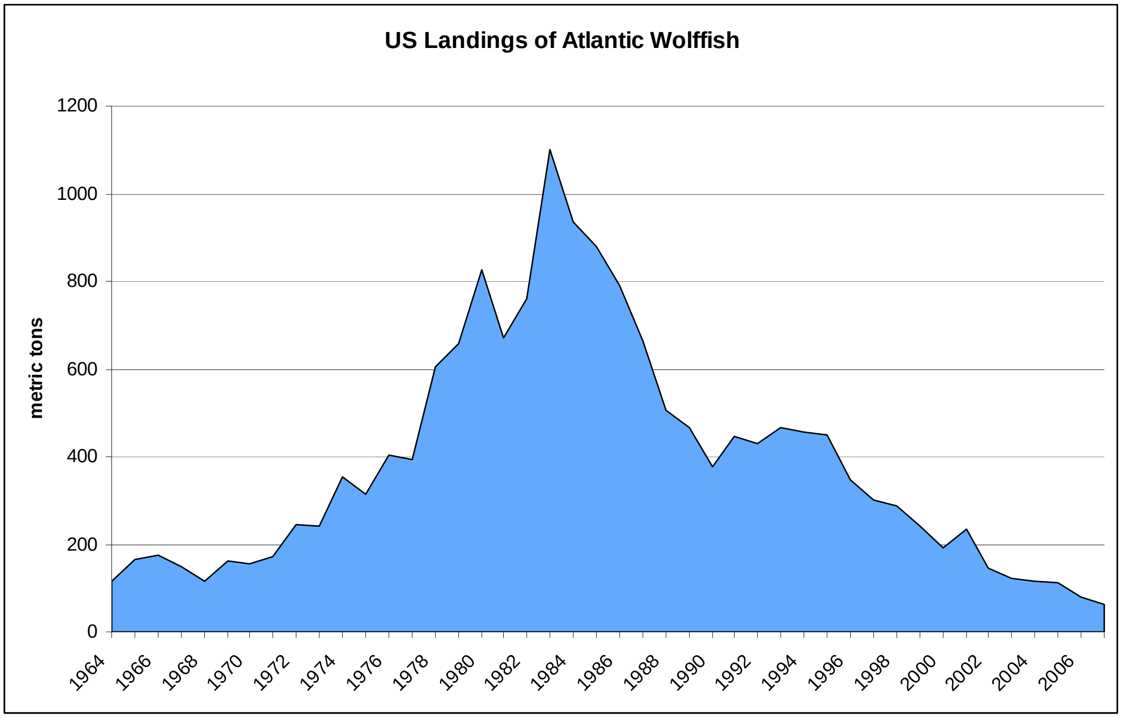


Figure 3. Reported landings of Atlantic wolffish in fishery statistical areas 512-515, 521-522, 525-526 and 537.

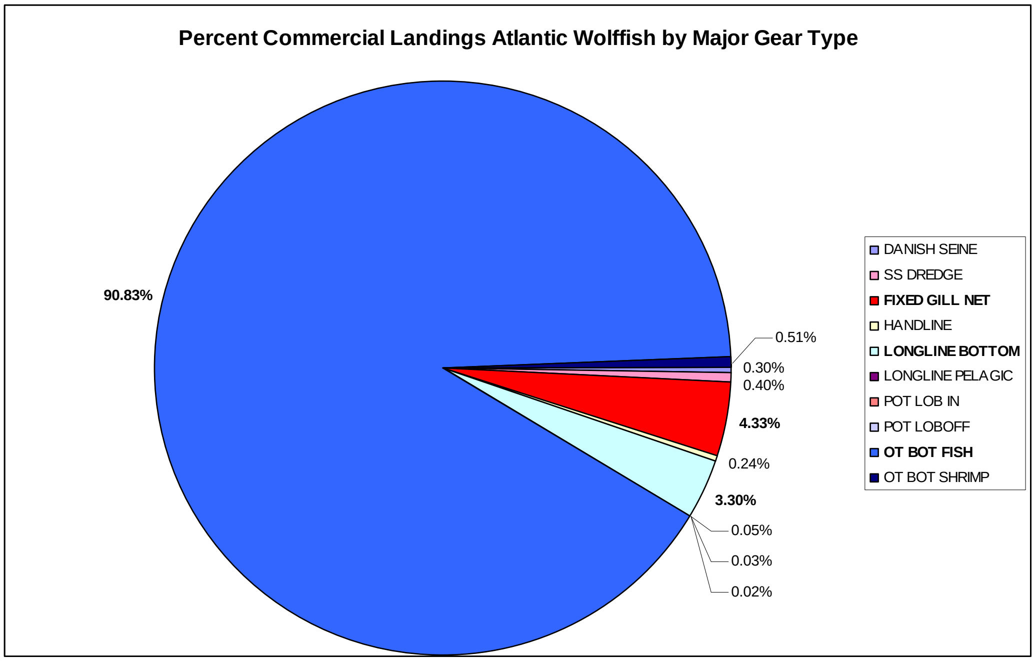


Figure 4. Atlantic wolffish US only landings by gear type for all years, 1964-2007.

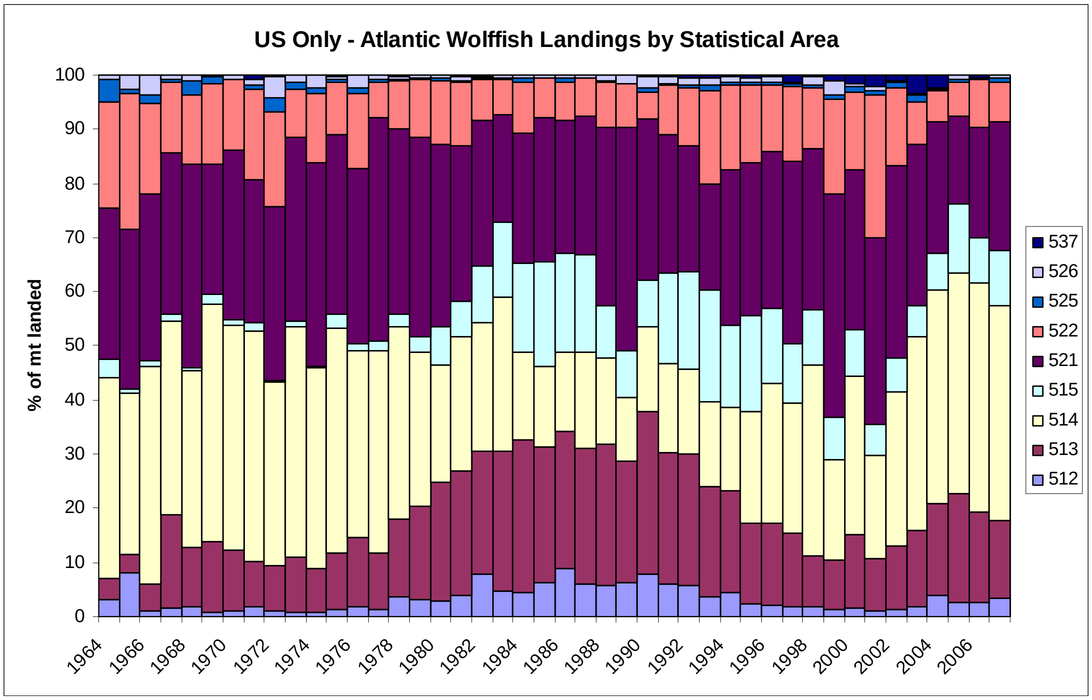


Figure 5. Reported wolffish landings by fishery statistical area in US waters.

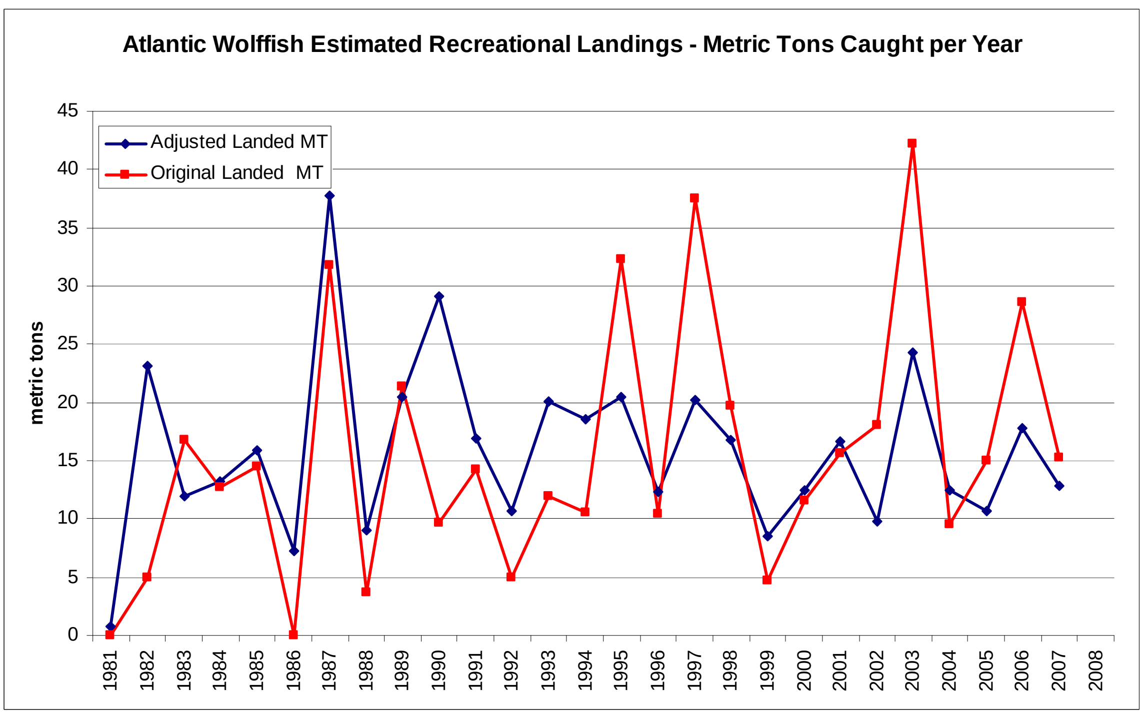


Figure 6. Reported and adjusted recreational landings by year from MRFSS database, 1981-2007.

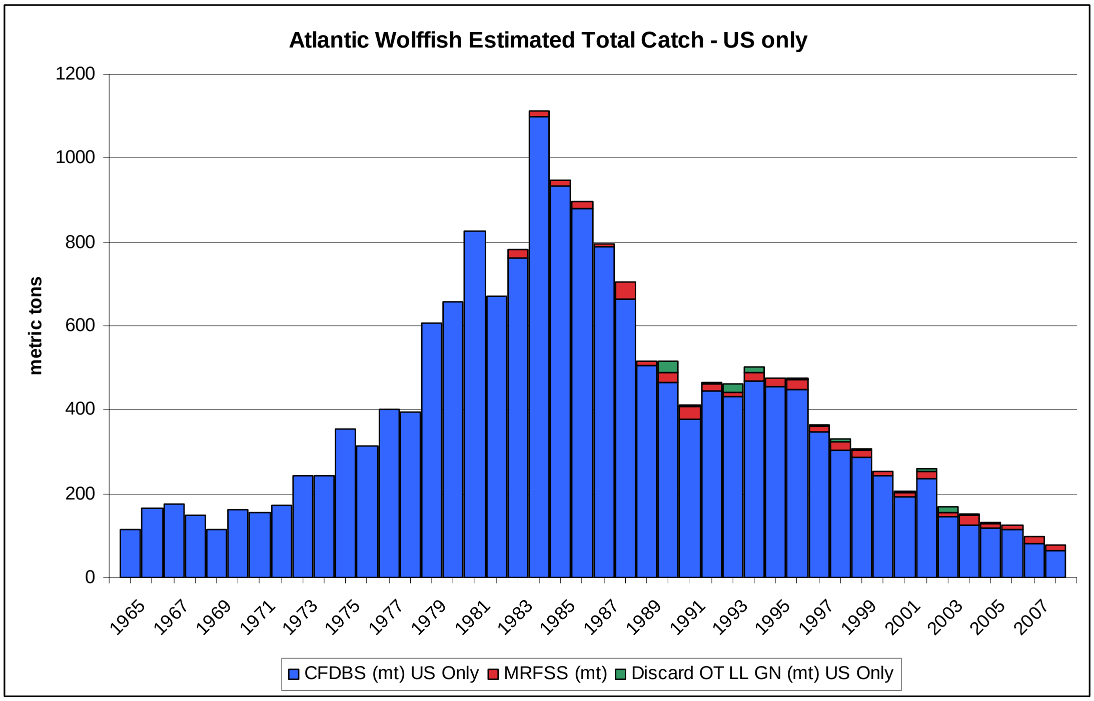


Figure 7. Total catch from reported commercial landings, estimated discards and recreational landings for US only 1964-2007.

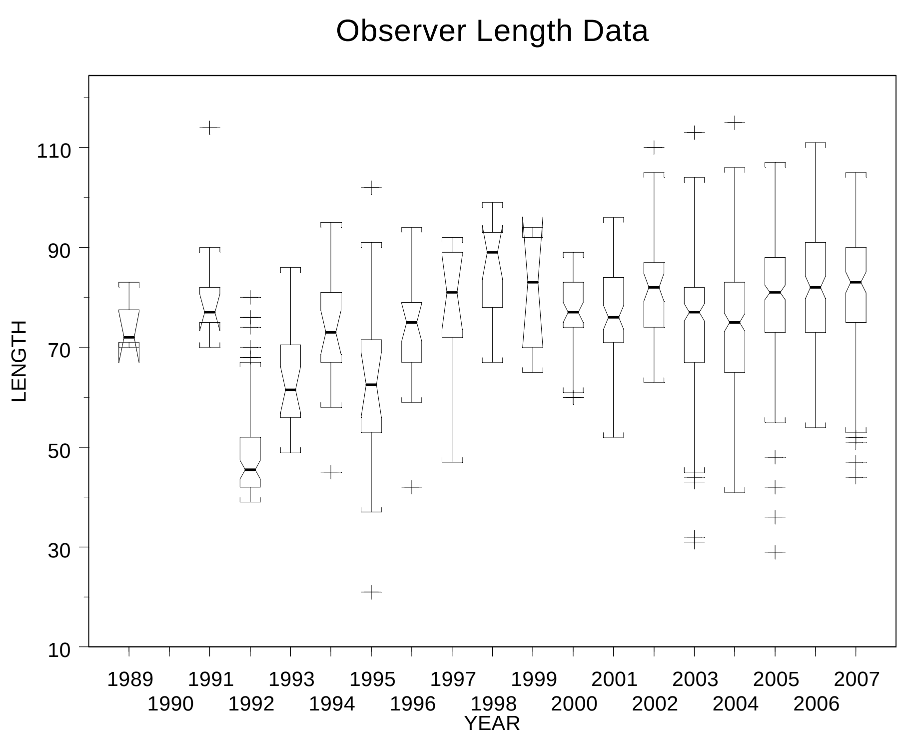


Figure 8. Fishery observer length distribution by year, 1989-2007.

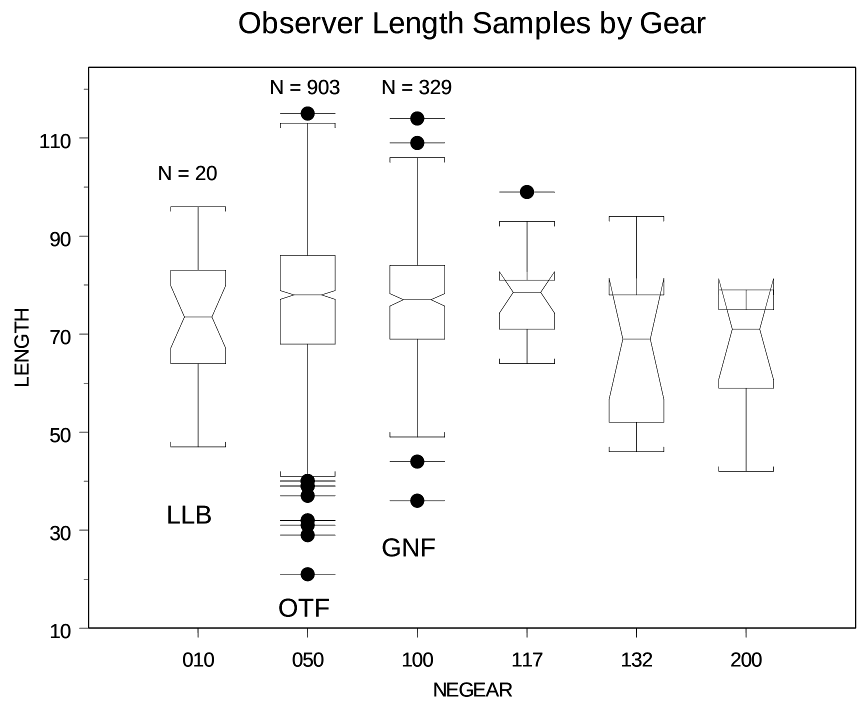


Figure 9. Fishery observer length distribution by major gear type.

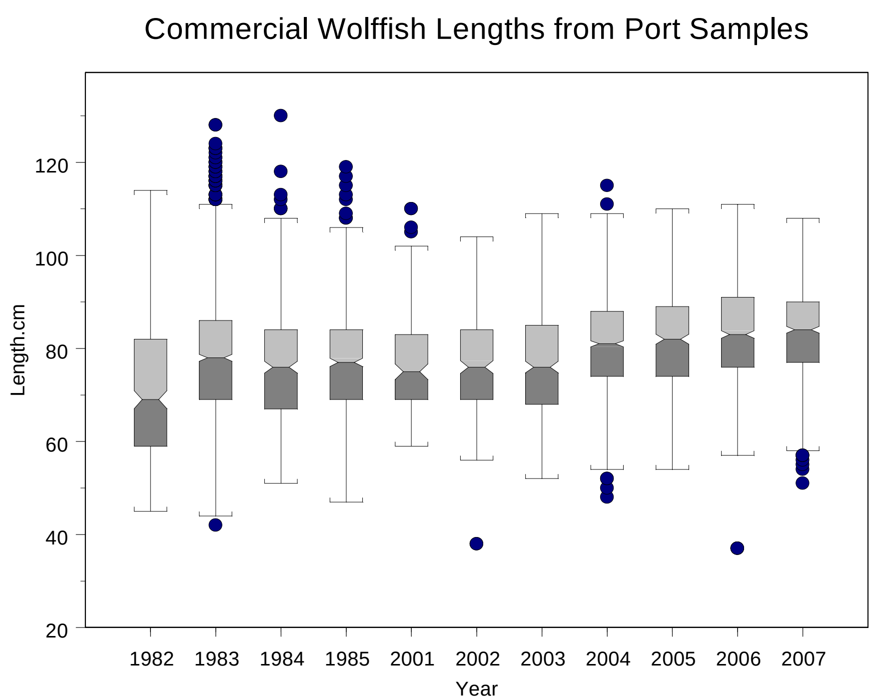


Figure 10. Atlantic wolffish commercial length distributions by year from port samples, 1982-1985 and 2001-2007.

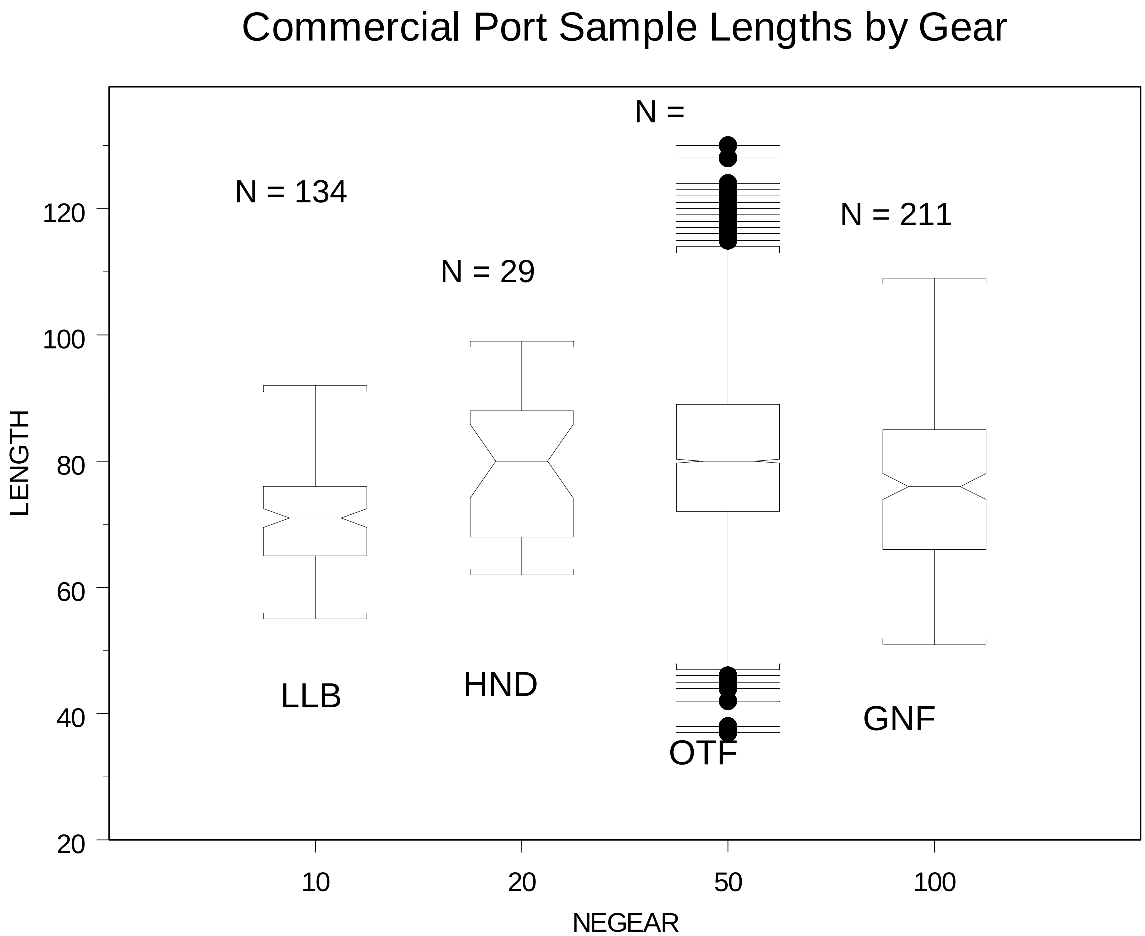


Figure 11. Commercial port sample length distributions by major gear type, all years combined (1982-1985 & 2001-2007).

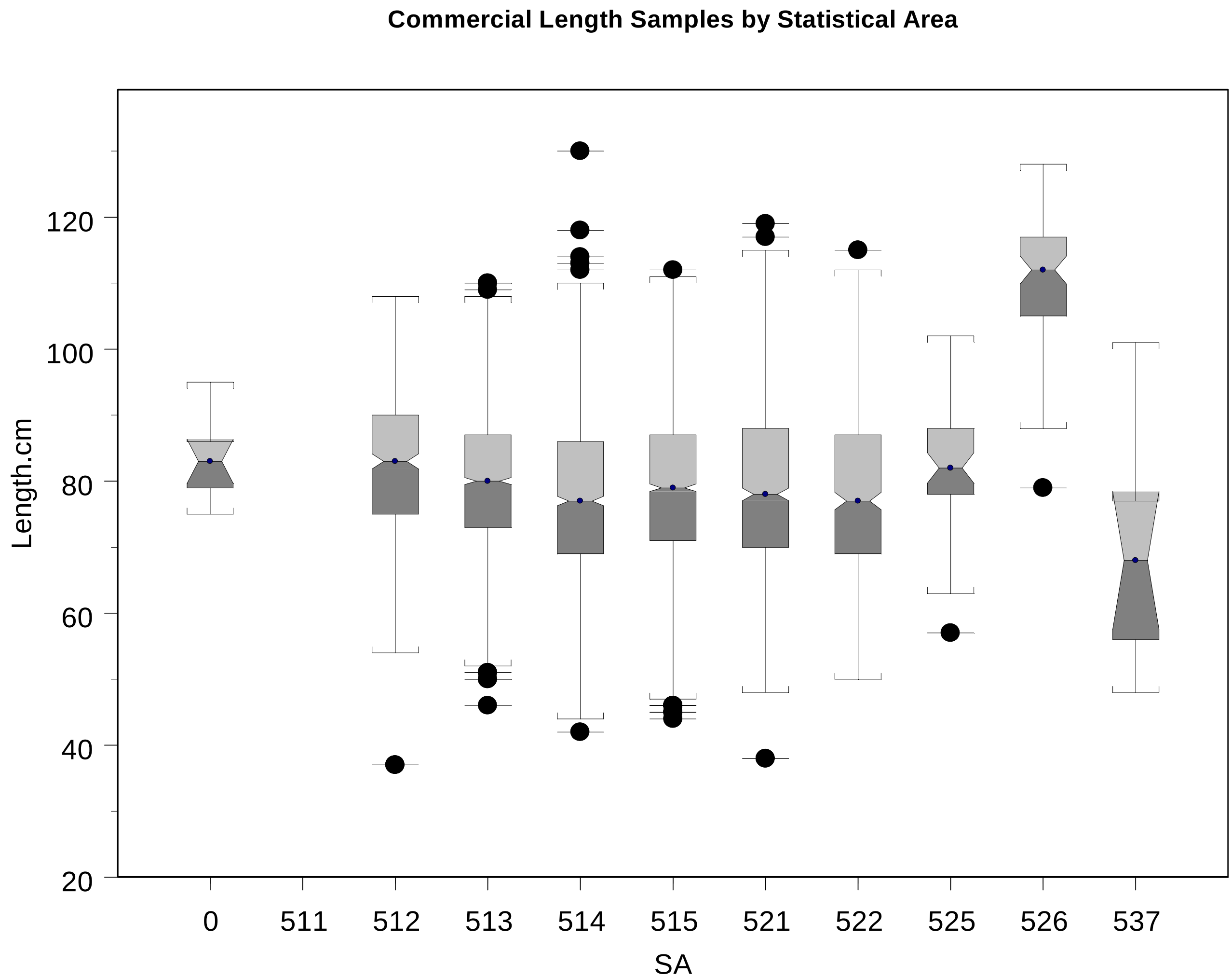


Figure 12. Commercial port sample length distributions by fishery statistical area in US waters, all years combined (1982-1985 & 2001-2007).

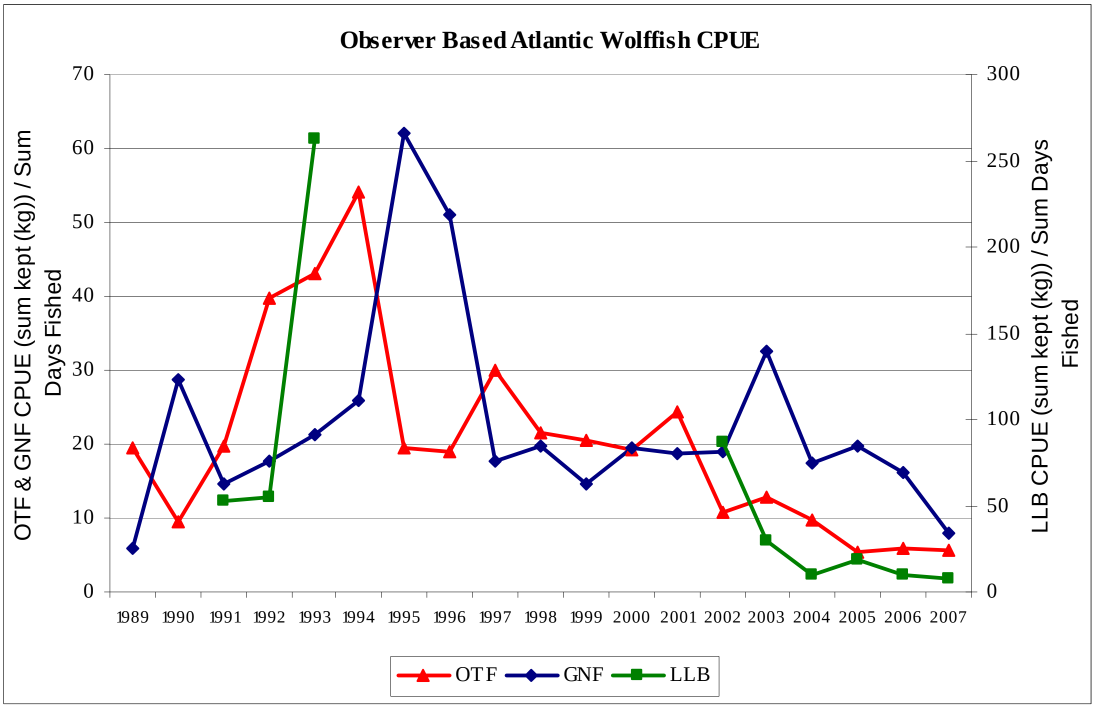


Figure 13. Catch per unit effort of Atlantic wolffish based on observer data in the otter trawl, gillnet and longline fisheries.

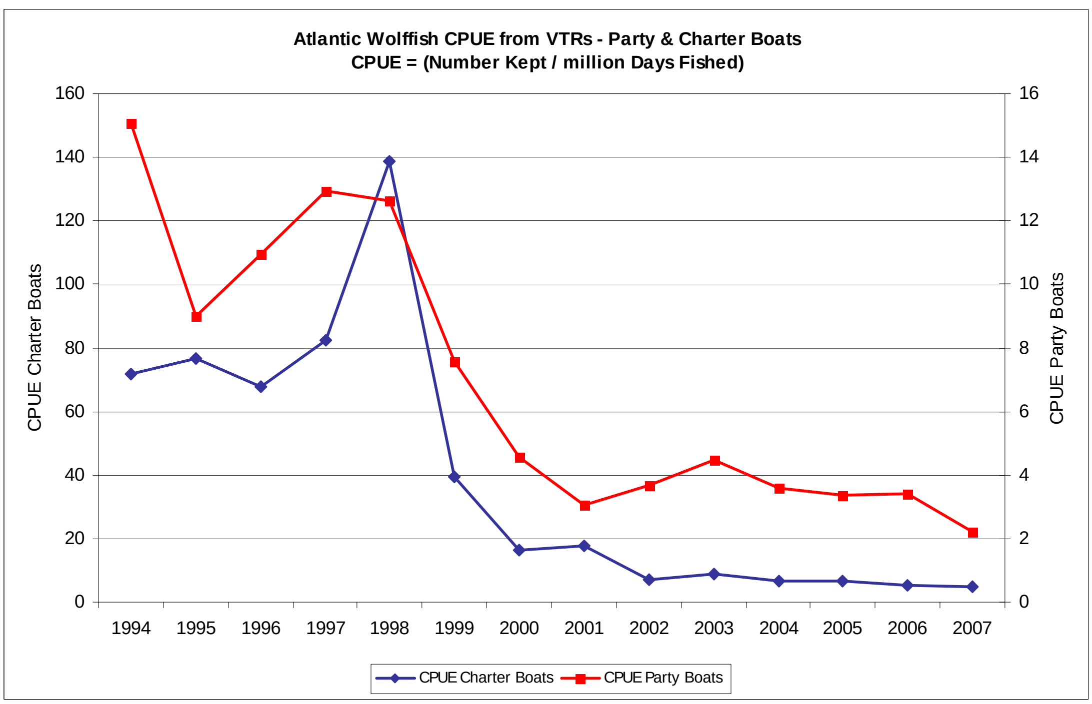


Figure 14. Catch per unit effort of Atlantic wolffish (numbers kept / million days fished) based on VTR data in the party and charter boat sectors.

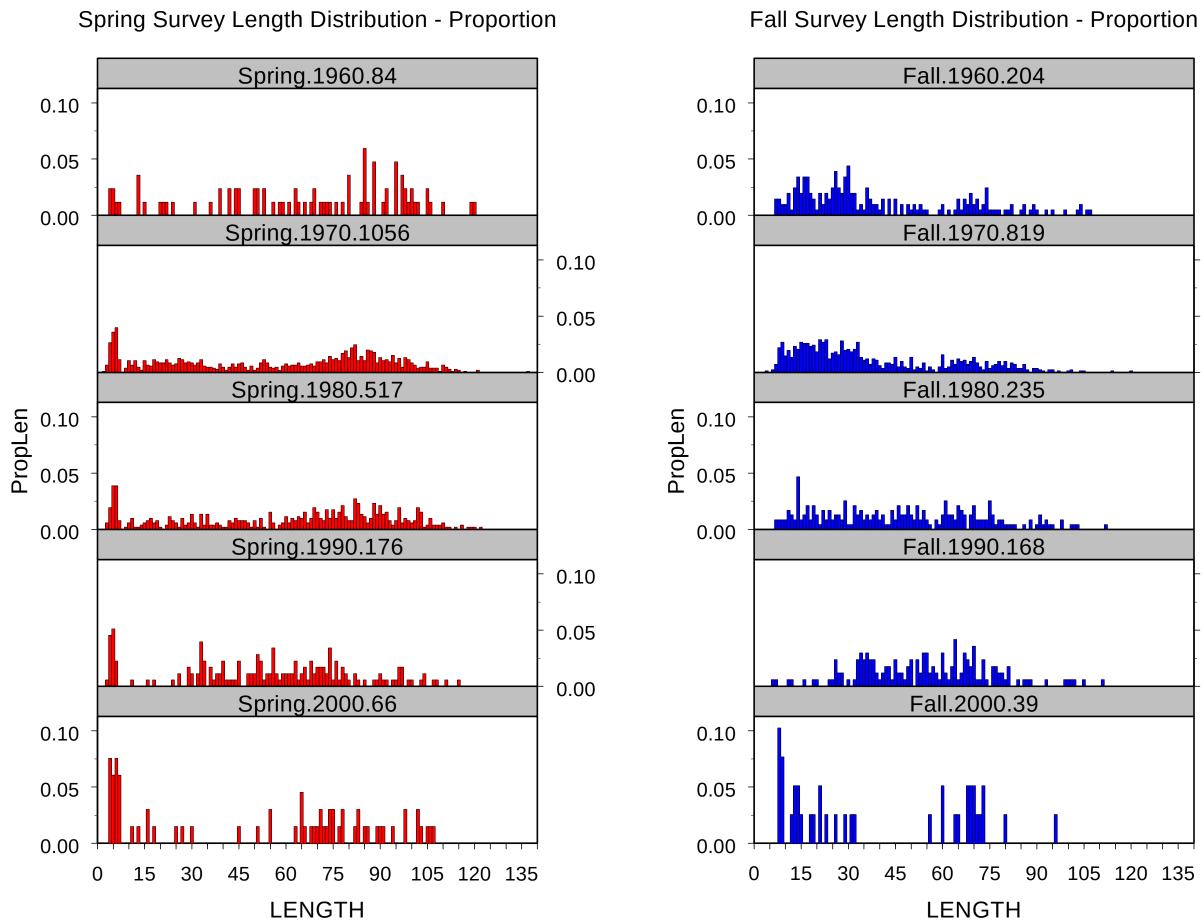


Figure 15. Spring and fall proportional length distributions grouped by decade from NEFSC bottom trawl surveys. Spring and fall time series 1968-2007 and 1963-2007 respectively.

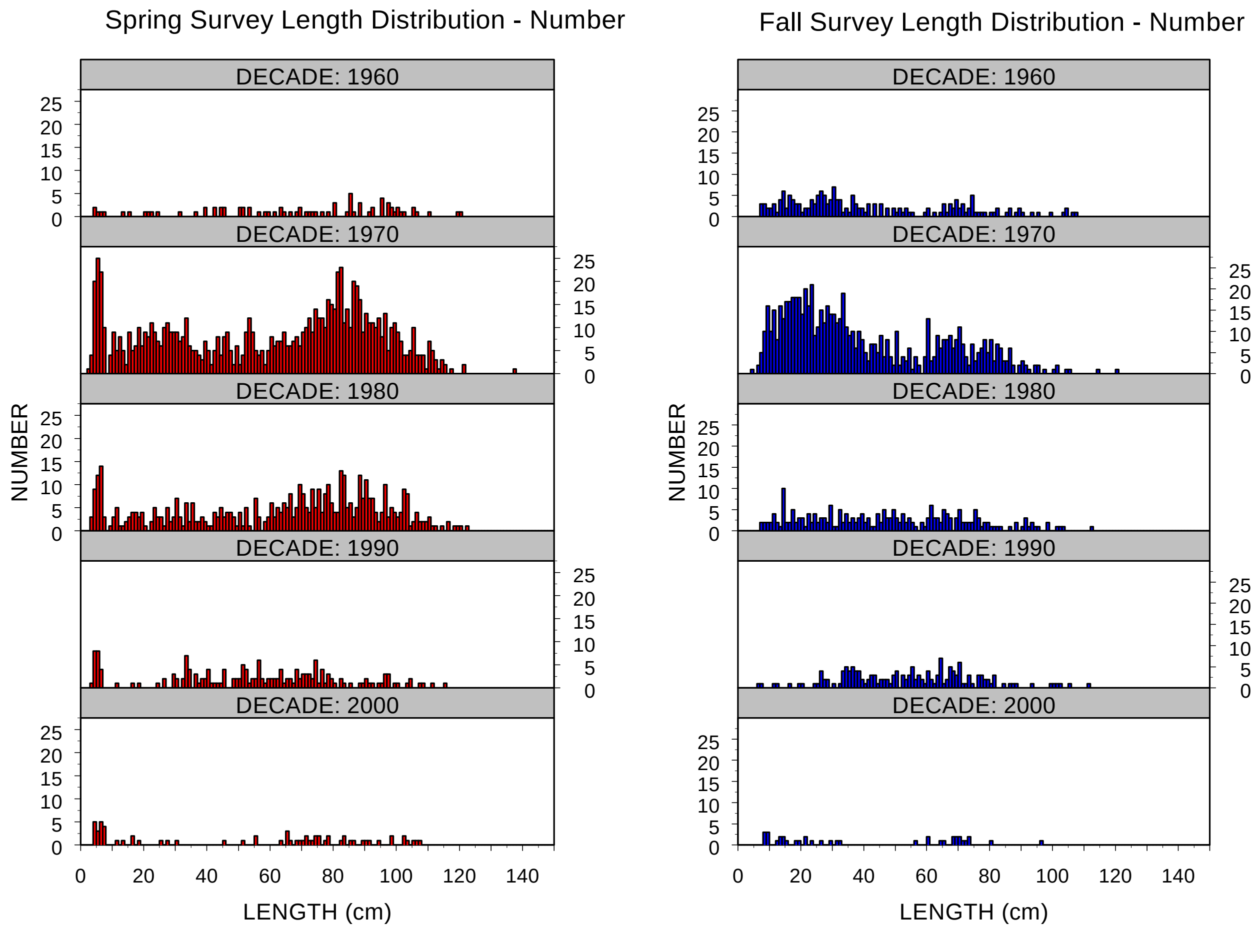


Figure 16. Spring and fall number at length histograms grouped by decade from NEFSC bottom trawl surveys. Spring and fall time series 1968-2007 and 1963-2007 respectively.

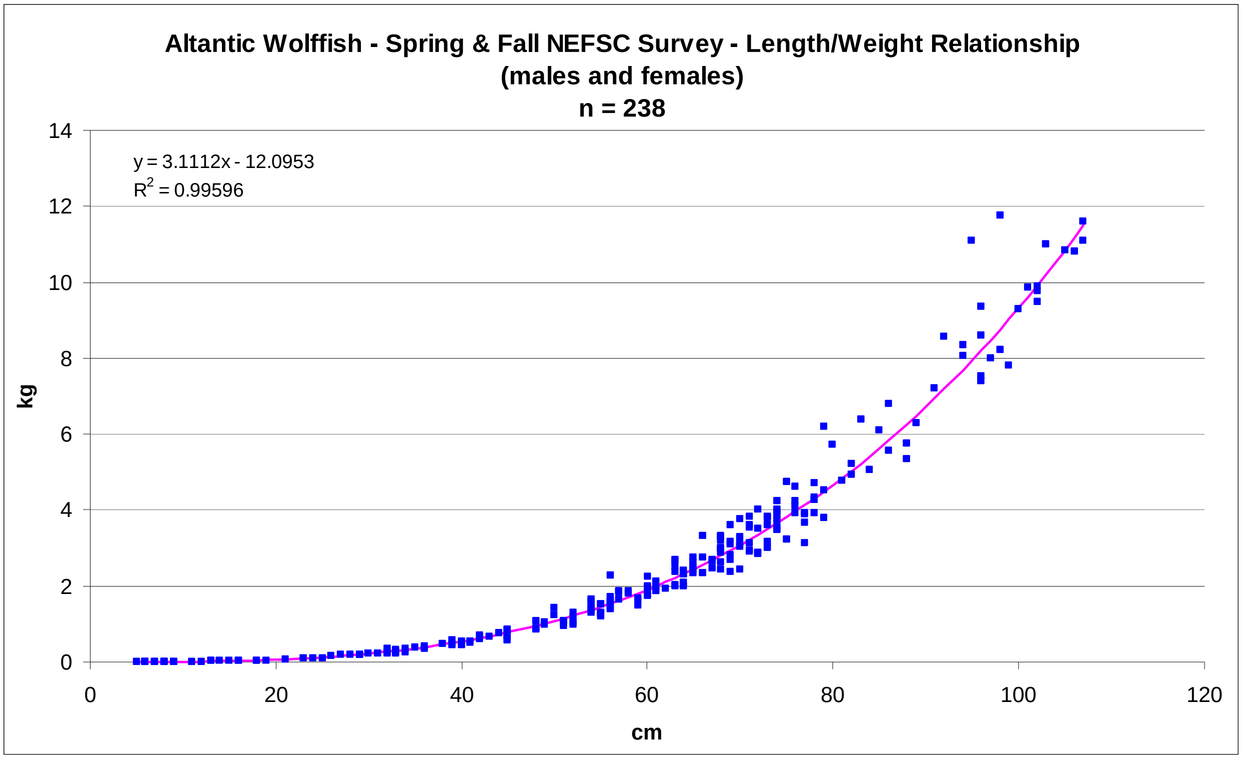


Figure 17. A combined male and female length weight relationship for Atlantic wolffish from NEFSC spring and fall bottom trawl surveys, all years.

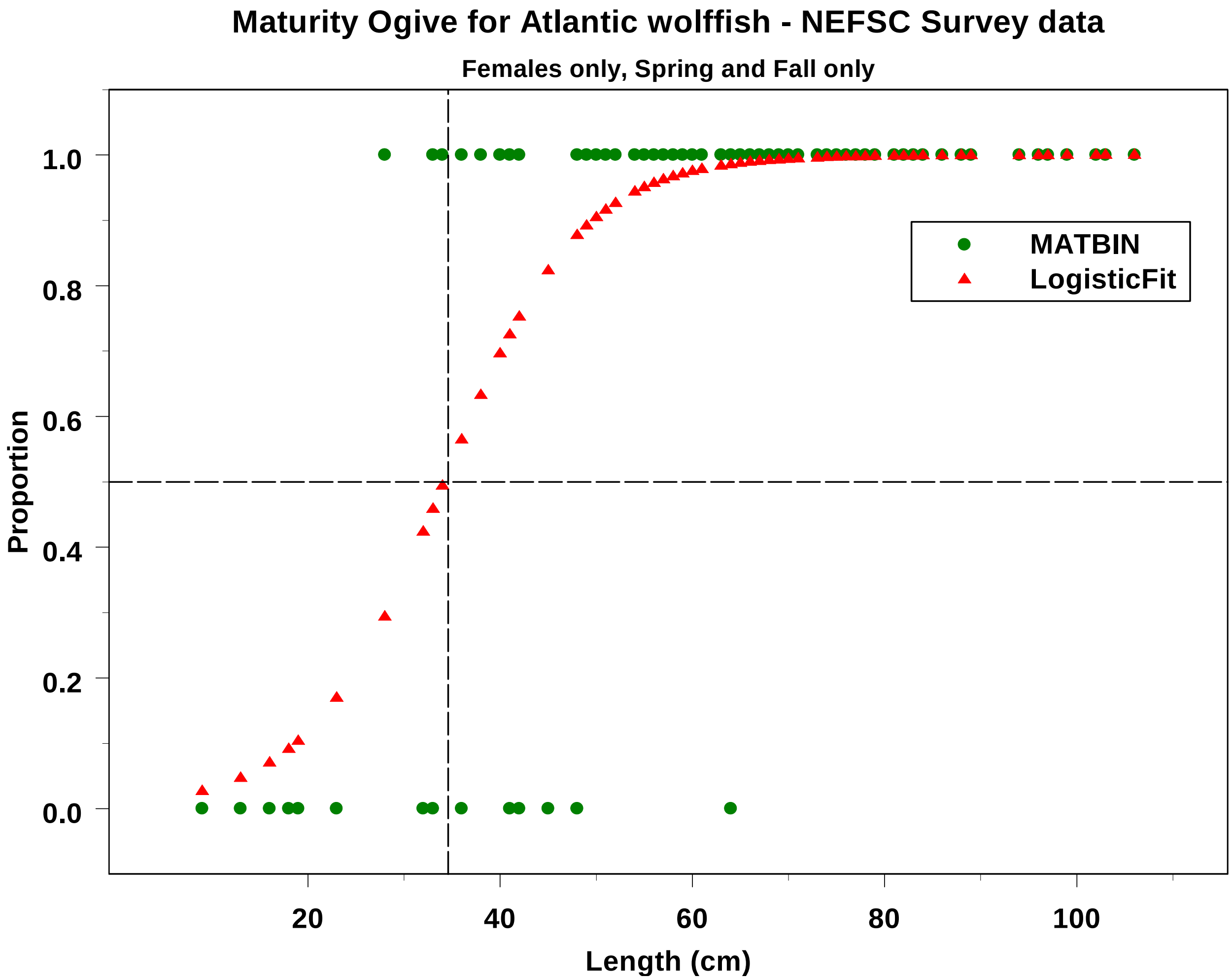


Figure 18. Maturity ogive for female Atlantic wolffish from NEFSC spring and fall data, all years.

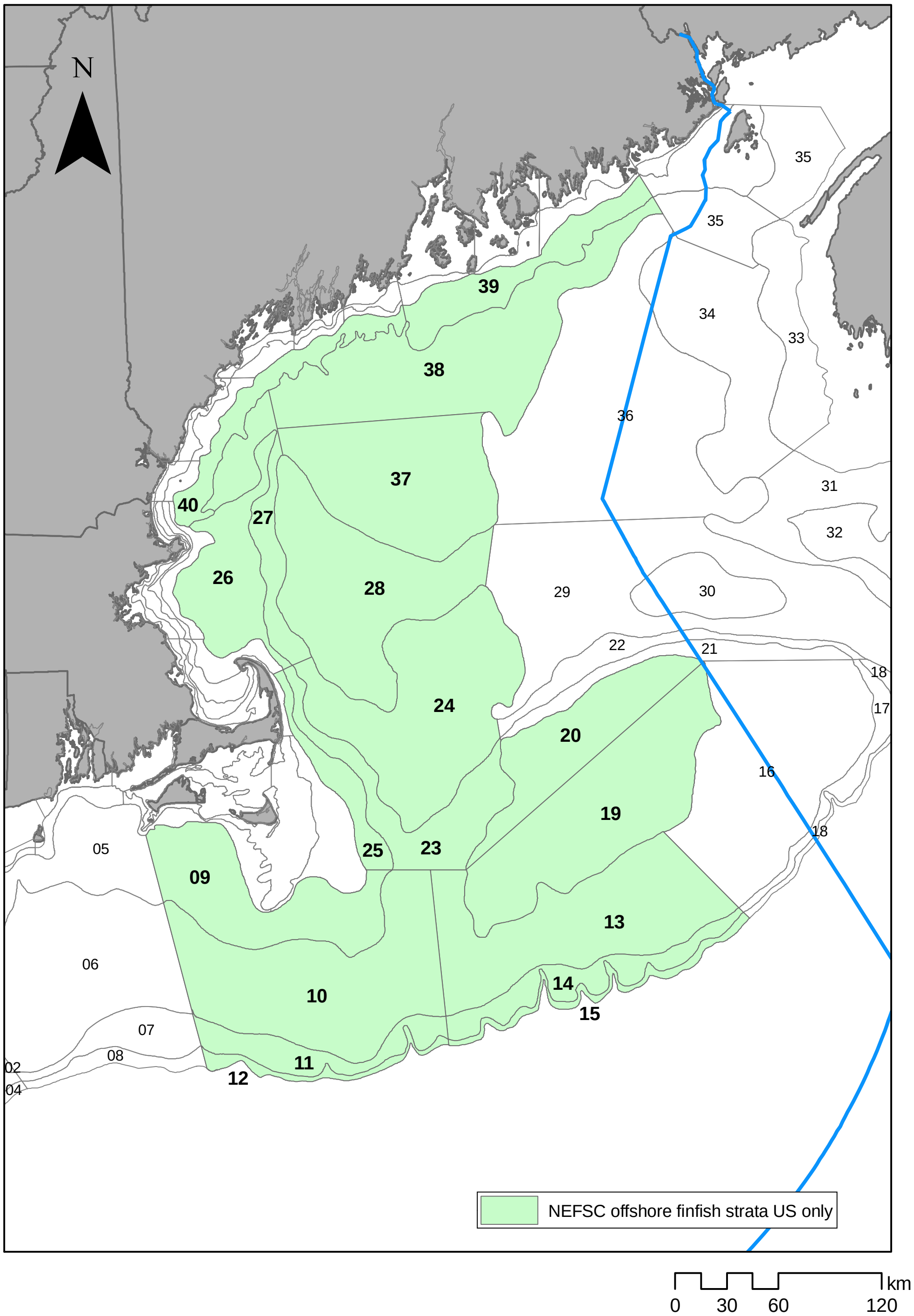


Figure 19. NEFSC survey strata used for Atlantic wolffish abundance and biomass indices.

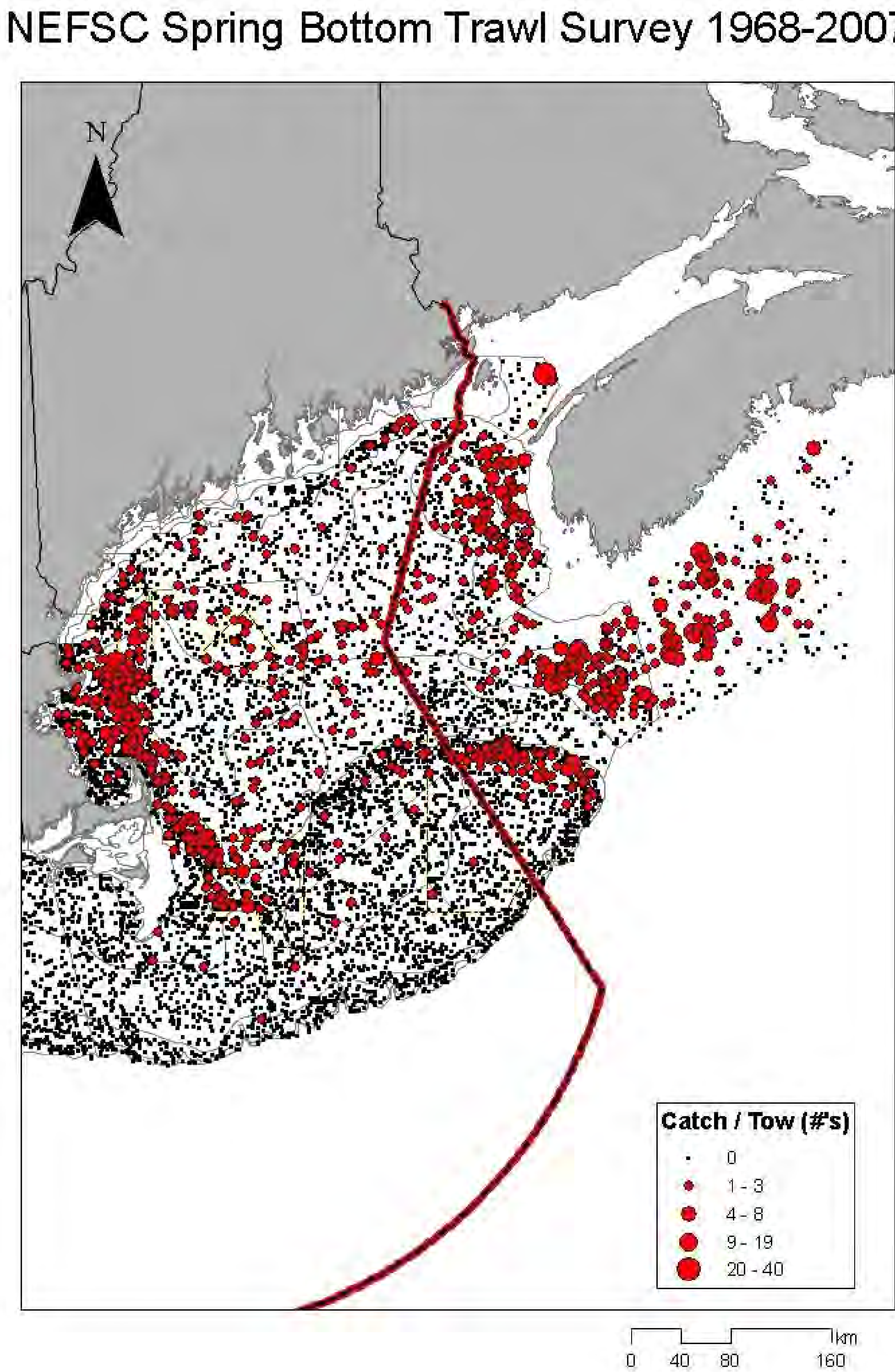


Figure 20. NEFSC spring bottom trawl survey wolffish catches, 1968-2007. Regions east of the Hague line were not included in abundance and biomass estimates.

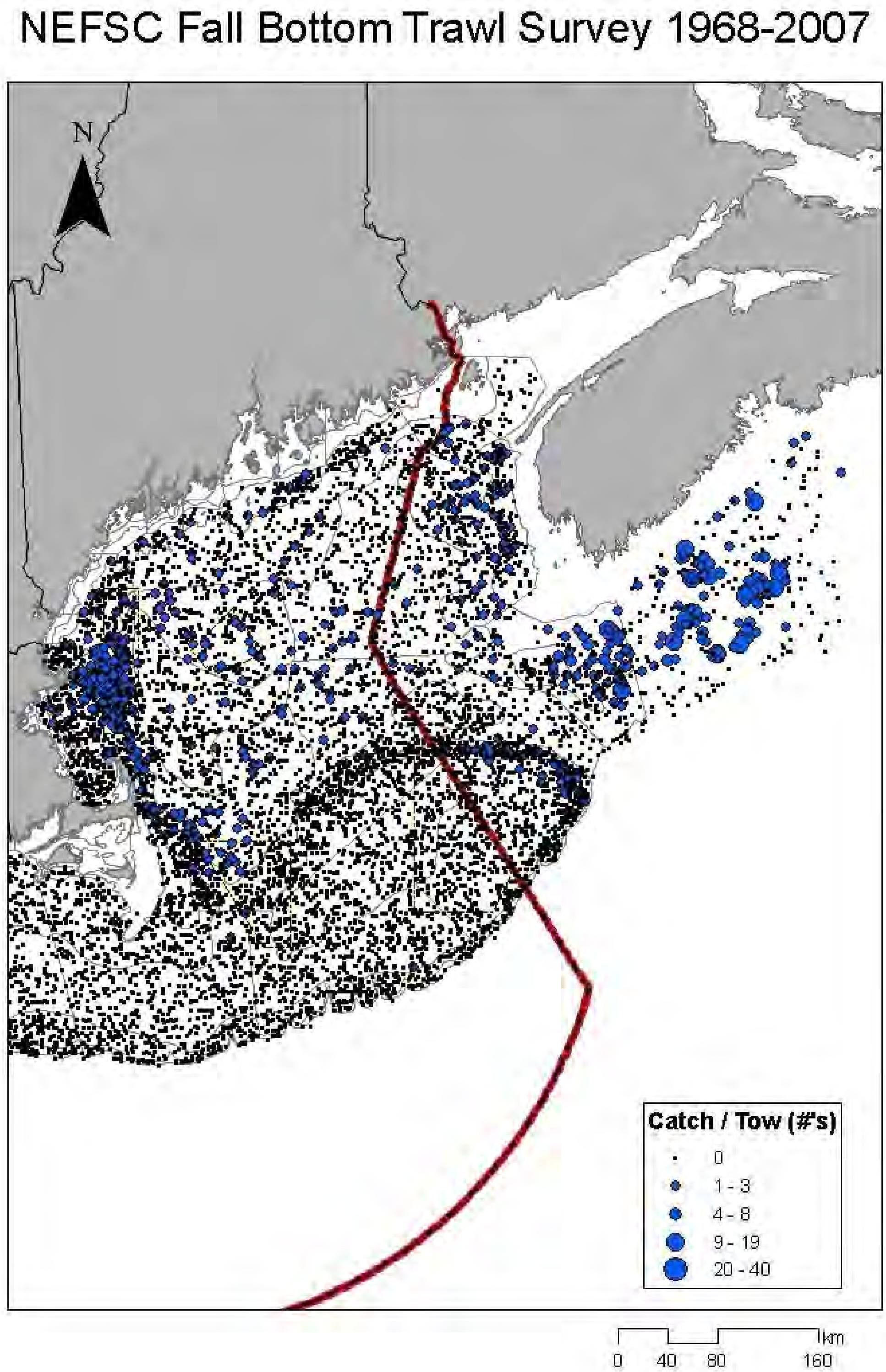


Figure 21. NEFSC fall bottom trawl survey wolffish catches, 1963-2007. Regions east of the Hague line were not included in abundance and biomass estimates.

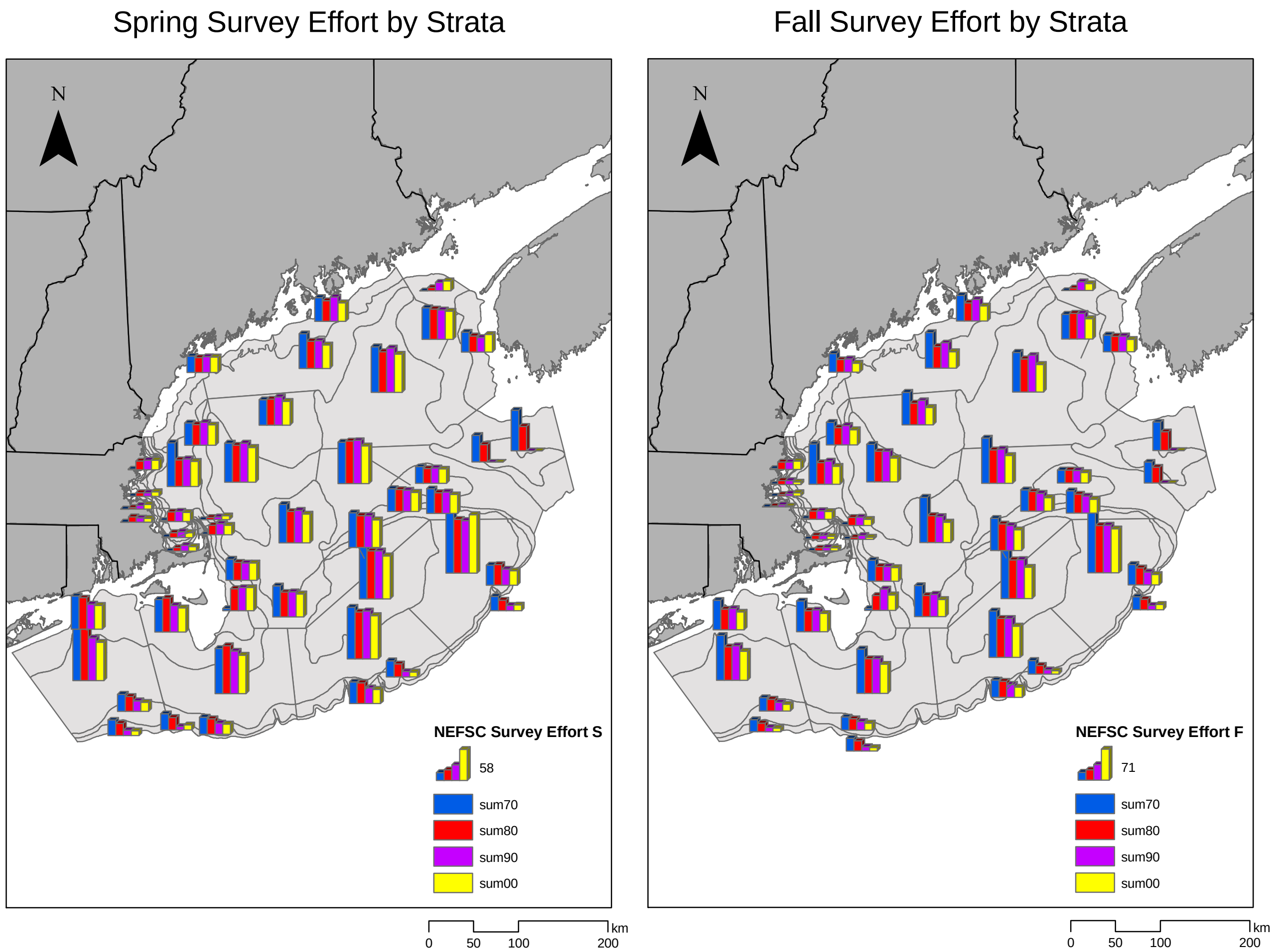
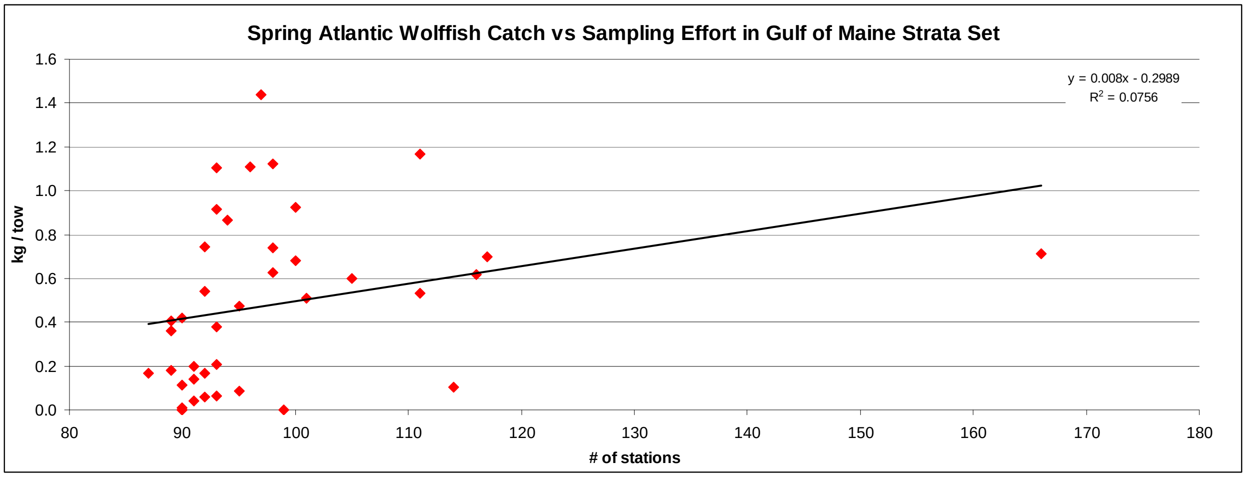


Figure 22. NEFSC spring and fall bottom trawl survey effort by decade per strata. Bars indicate number of stations per strata.



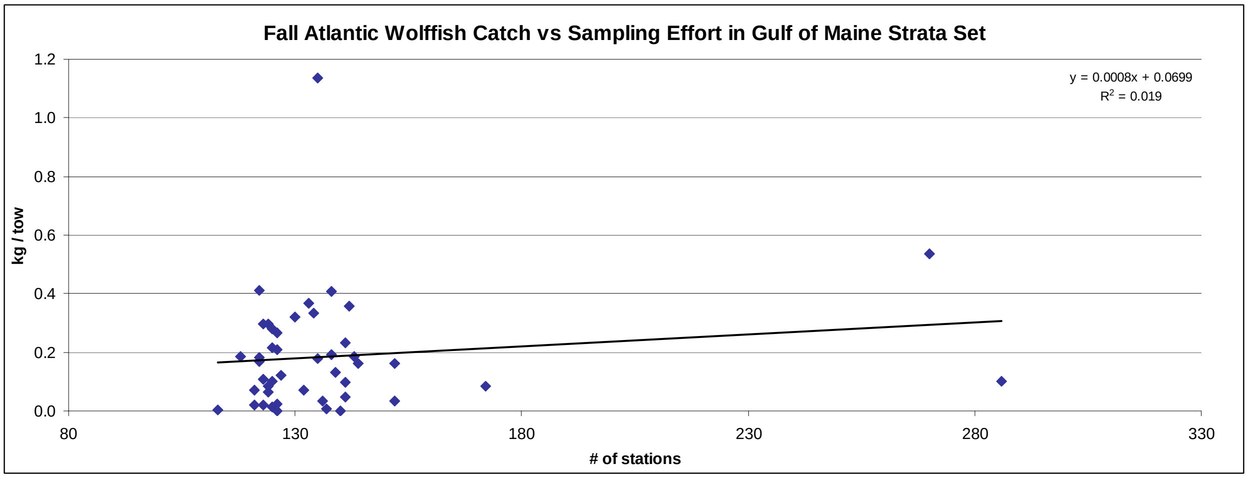
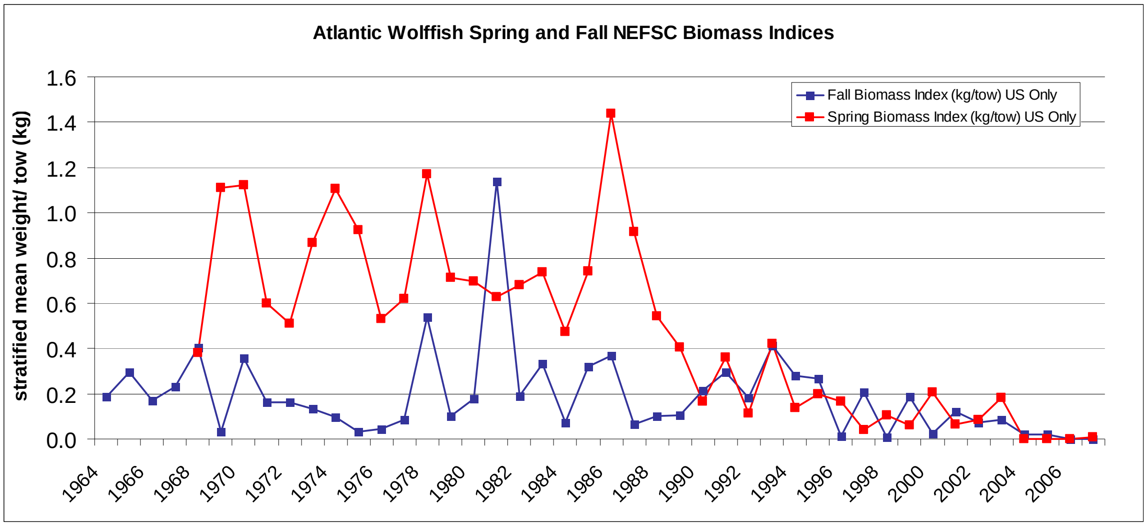


Figure 23. NEFSC sampling effort and biomass of Atlantic wolffish captured.



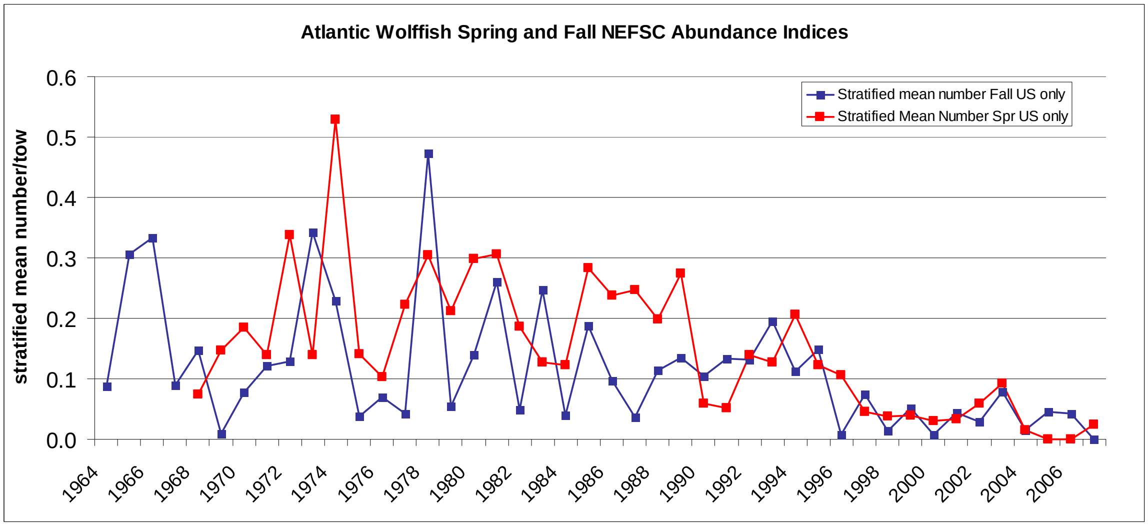
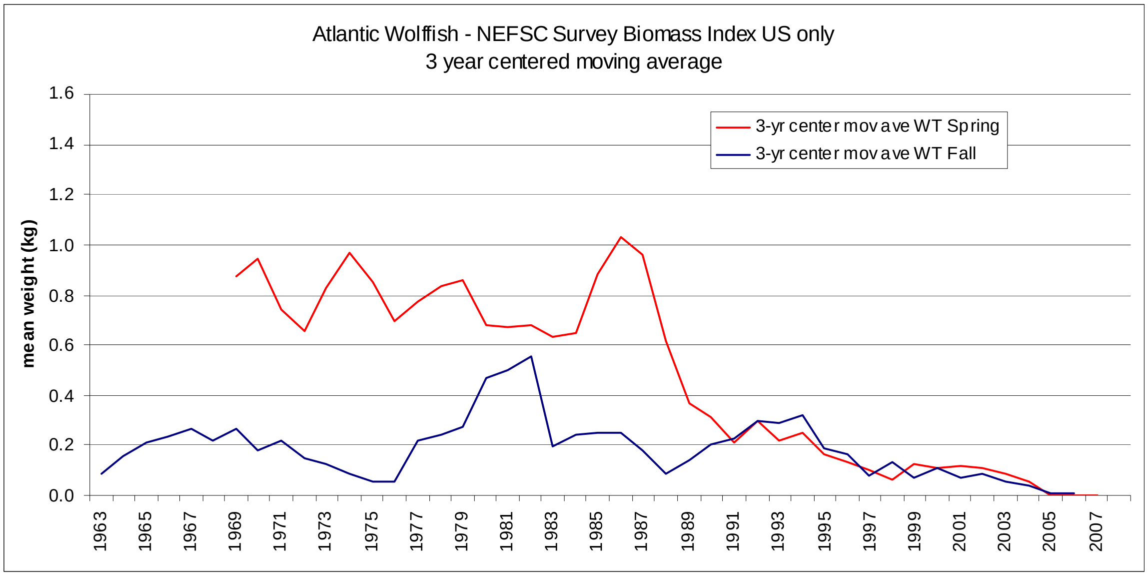


Figure 24. Spring and fall biomass and abundance indices for US only survey strata, 1964-2007.



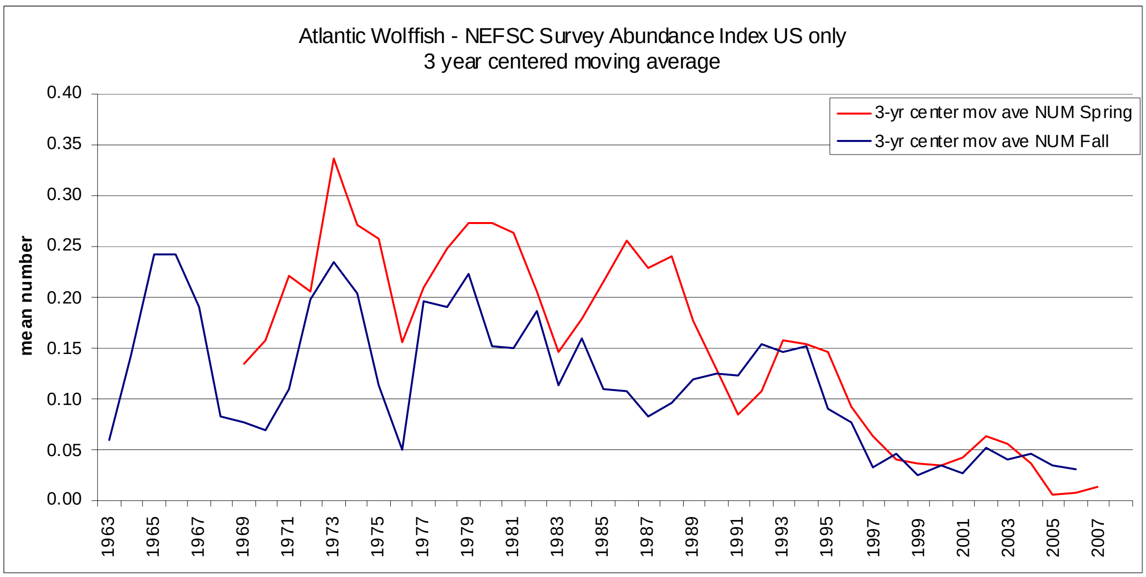
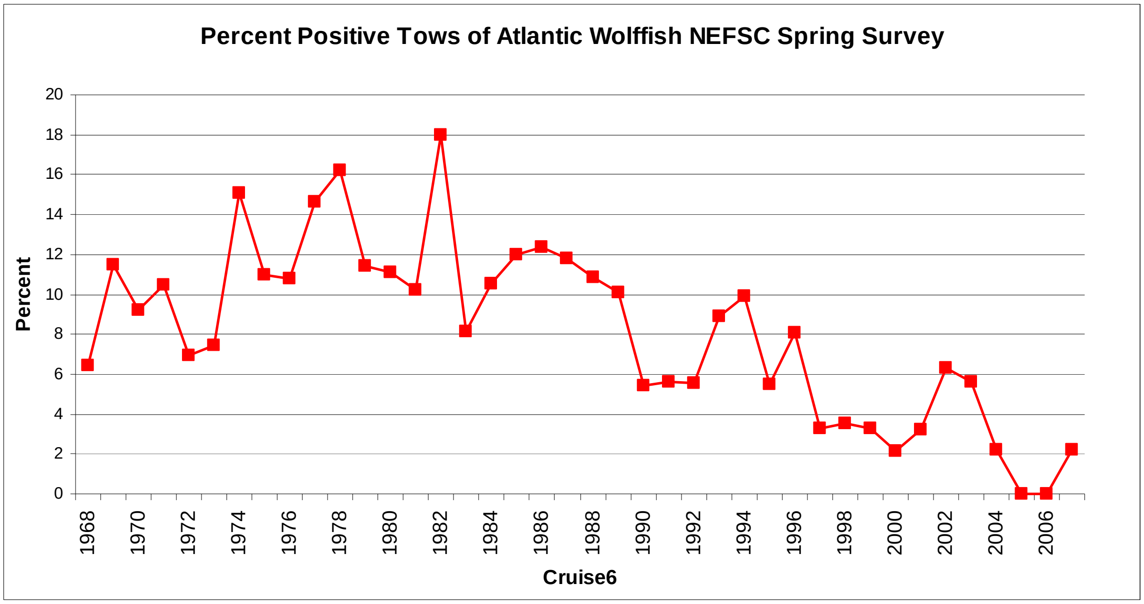


Figure 25. 3 year moving average for NEFSC spring and fall biomass and abundance indices.



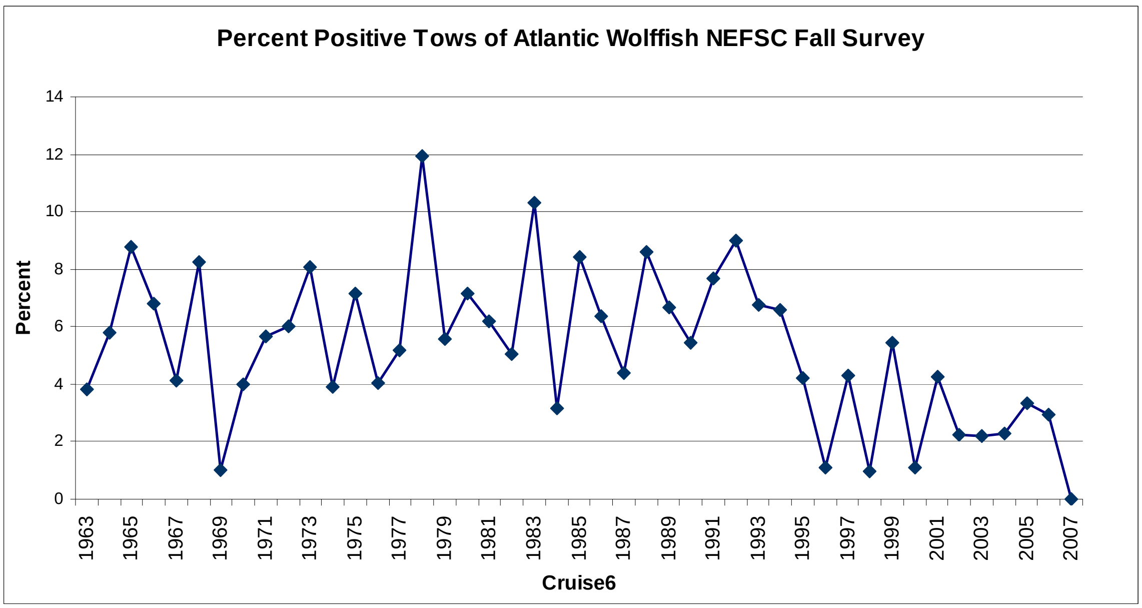


Figure 26. Percent positive Atlantic wolffish catches by year from NEFSC spring and fall bottom trawl surveys.

Spring NEFSC Survey Catches by Decades - US Strata Only

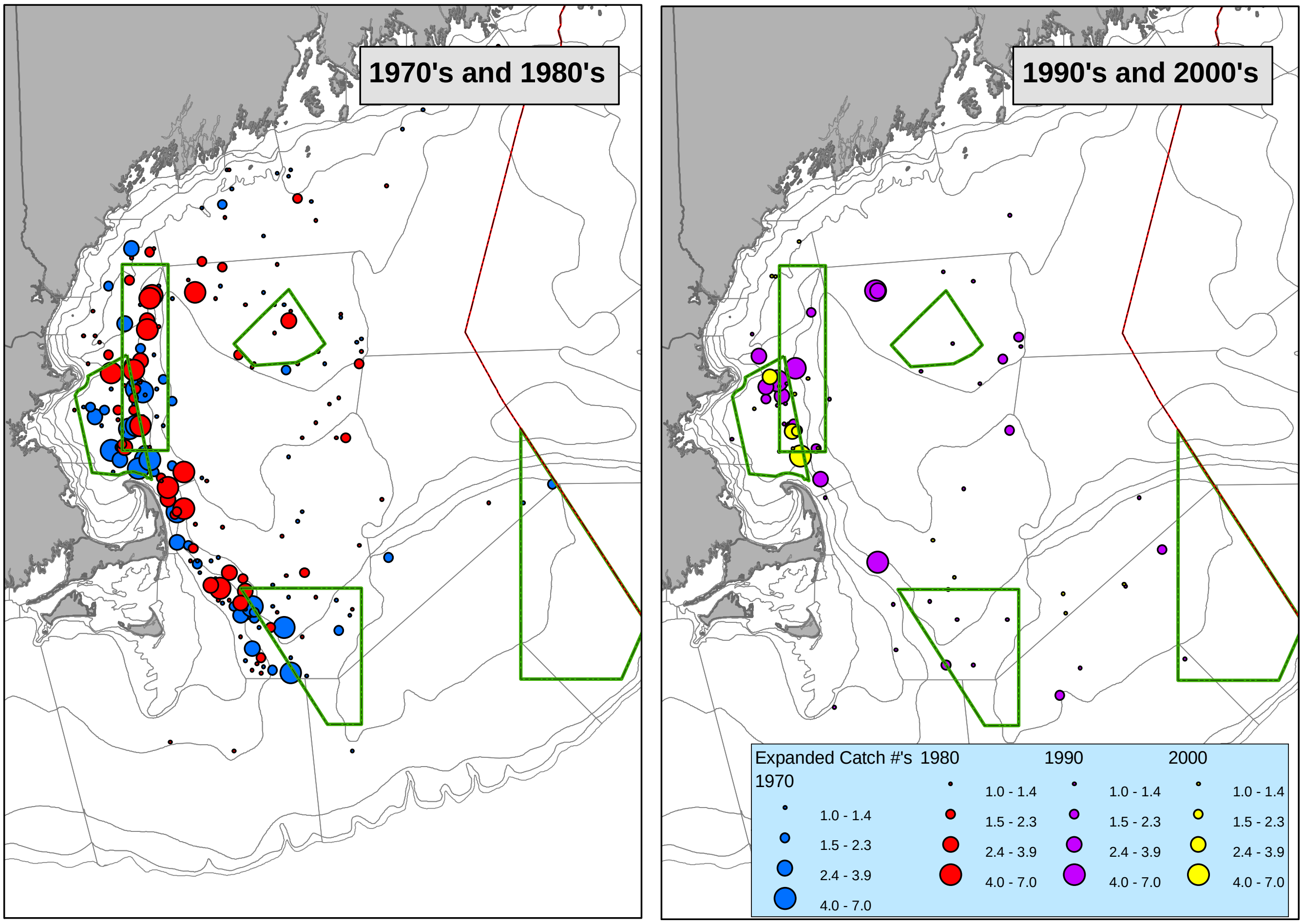


Figure 27. NEFSC spring survey catches by decade.

Fall NEFSC Survey Catches by Decades - US Strata Only

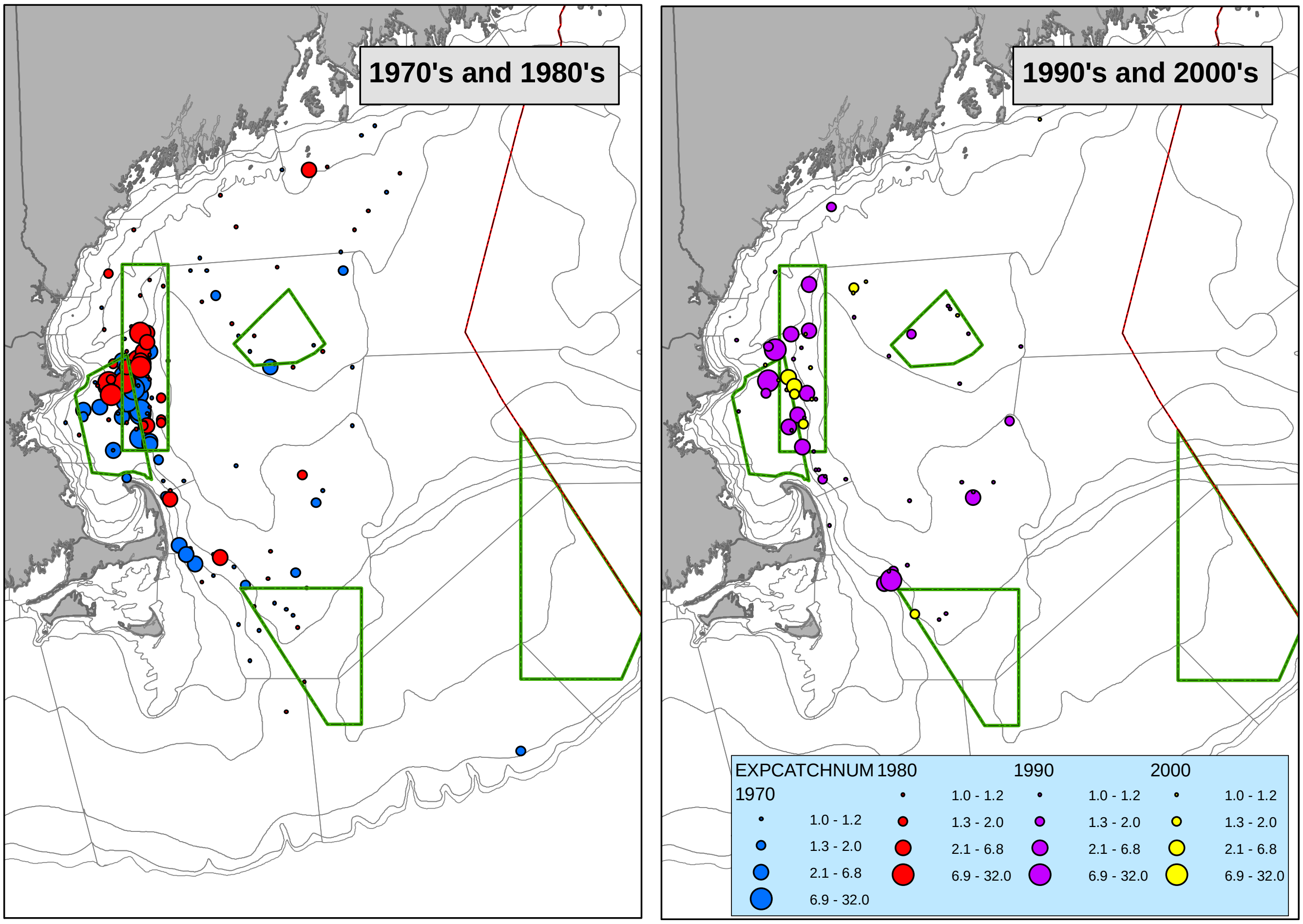


Figure 28. NEFSC fall survey catches by decade.

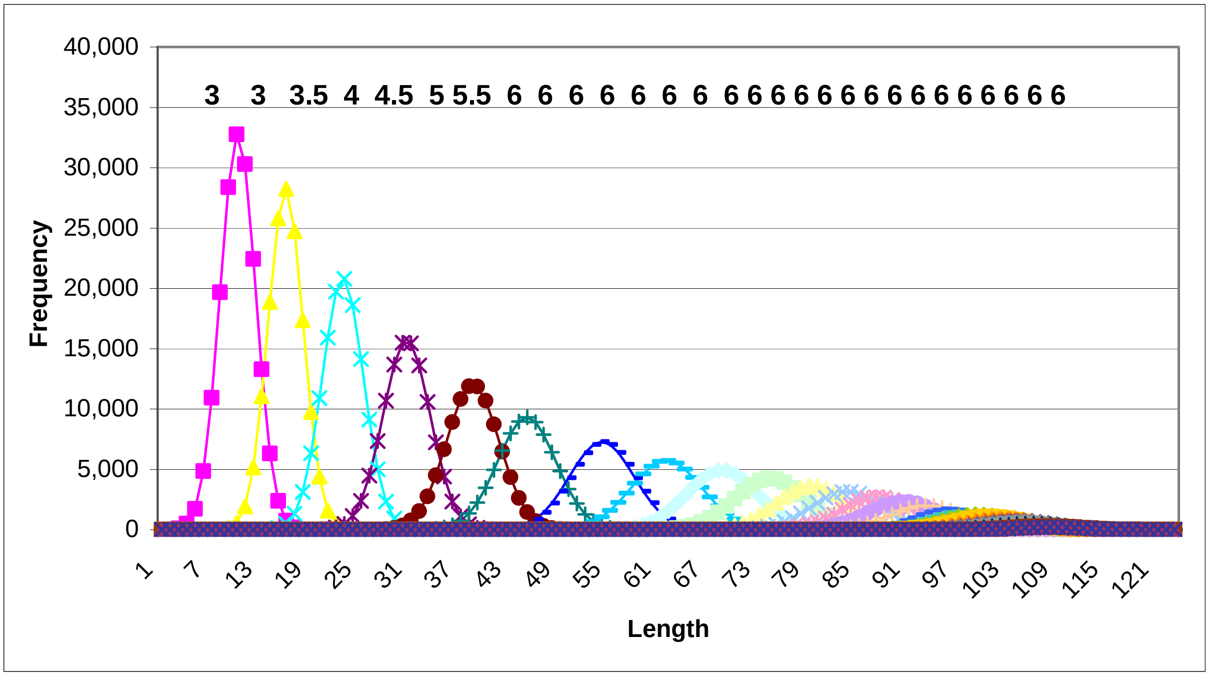


Figure 29. Mean lengths at age distributions assumed for wolffish growth. The input standard deviation is given in the top row of numbers. Ages greater than 7 had a standard deviation of 6.

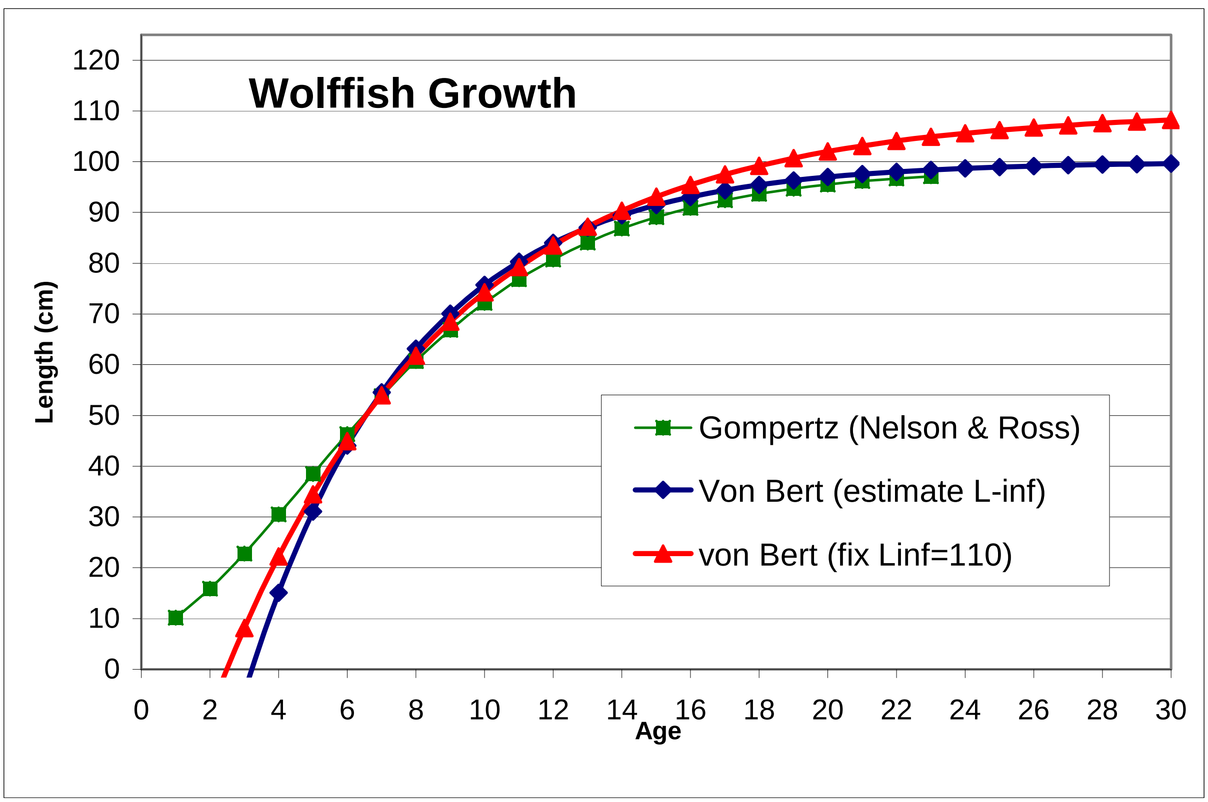


Figure 30. Wolffish estimated growth from Nelson and Ross (1992), von Bertalanffy model limited to 5+ fish, and von Bertalanffy model limited to 5+ fish with fixed L-infinity at 110 cm.

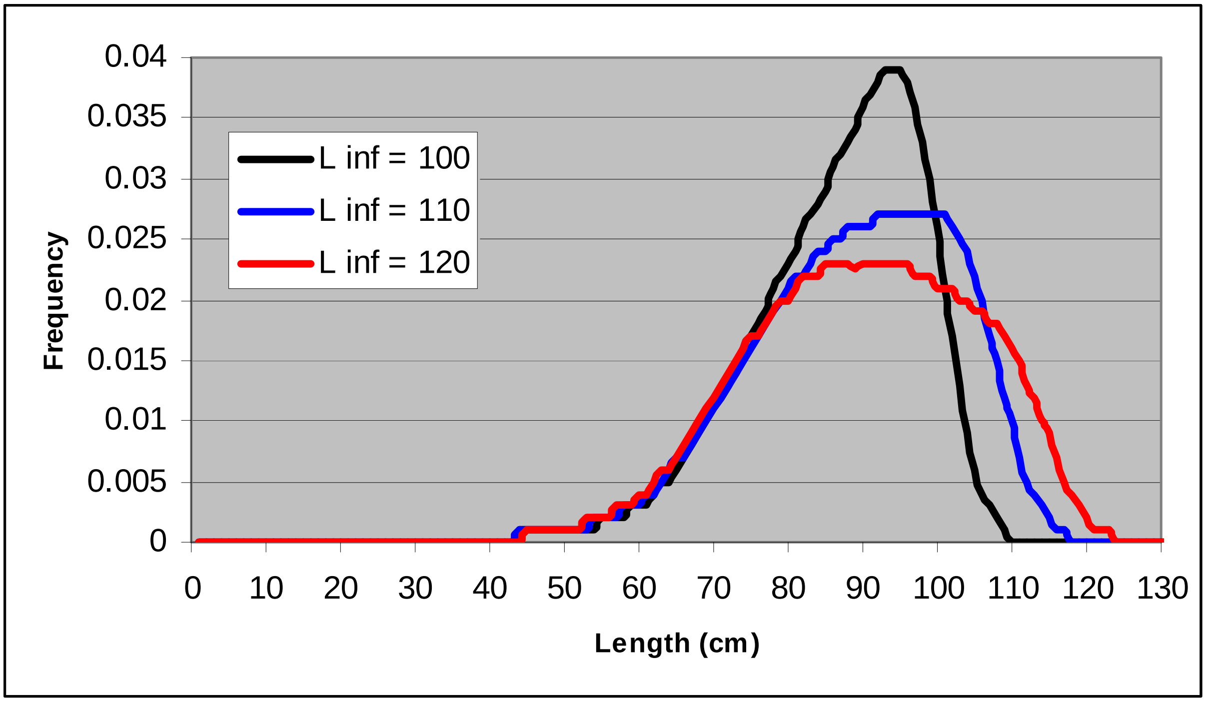


Figure 31. Predicted catch length frequency distributions at low fishing mortality (F = 0.001) with different assumed L-infinity values for growth.

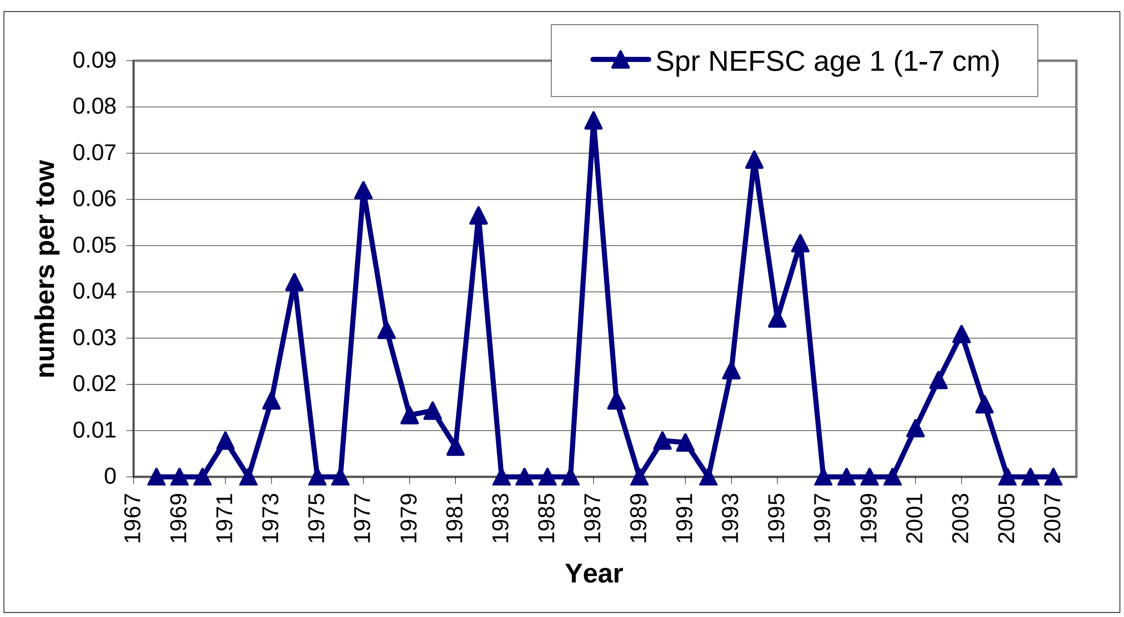


Figure 32. NEFSC spring age-1 stratified mean numbers per tow index. Lengths 1-7 cm was used as a proxy for age-1.

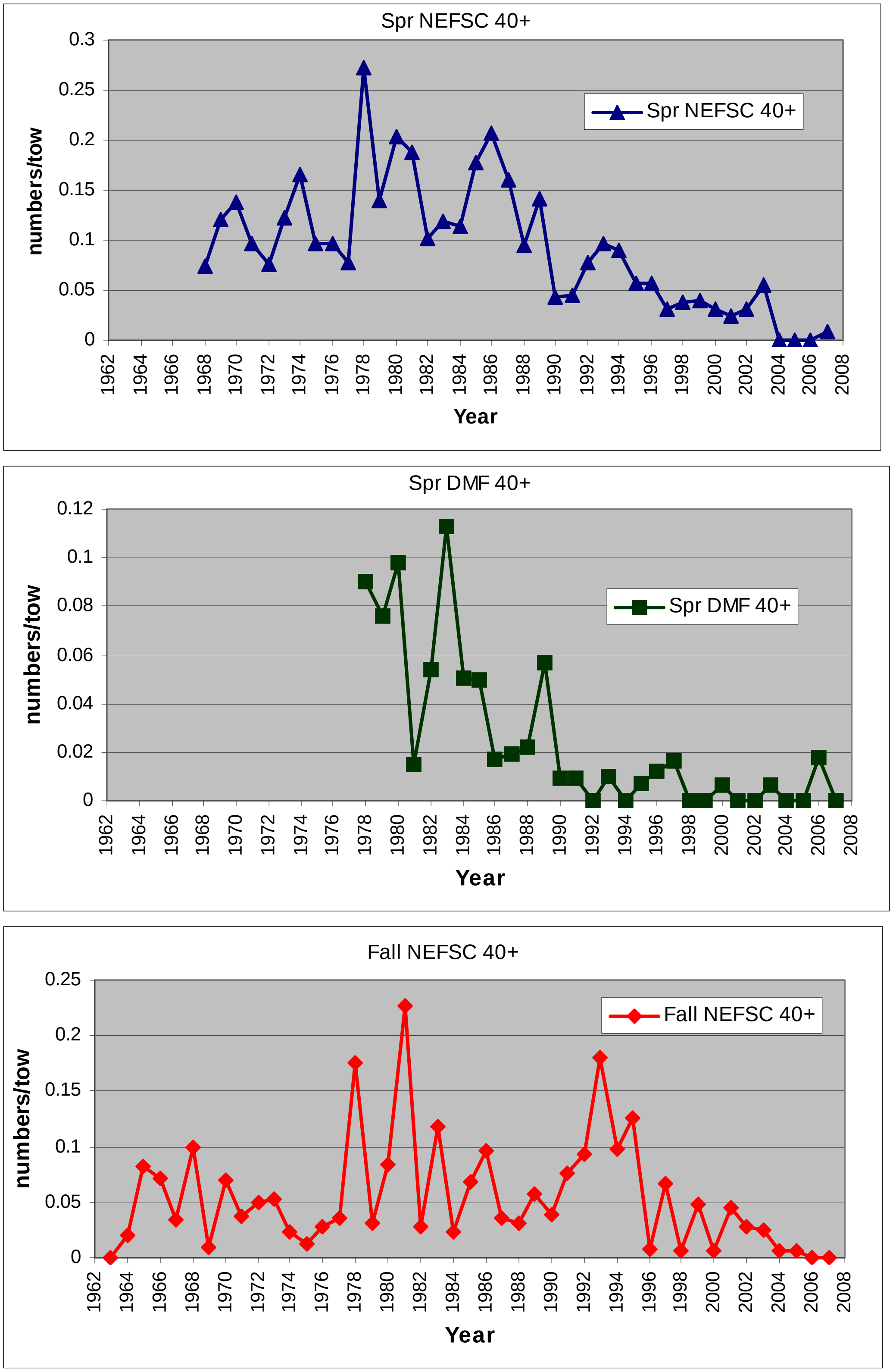


Figure 33. NEFSC spring 40+ cm, MDMF spring 40+ cm, and NEFSC fall 40+ cm stratified numbers per tow survey indices for wolffish.

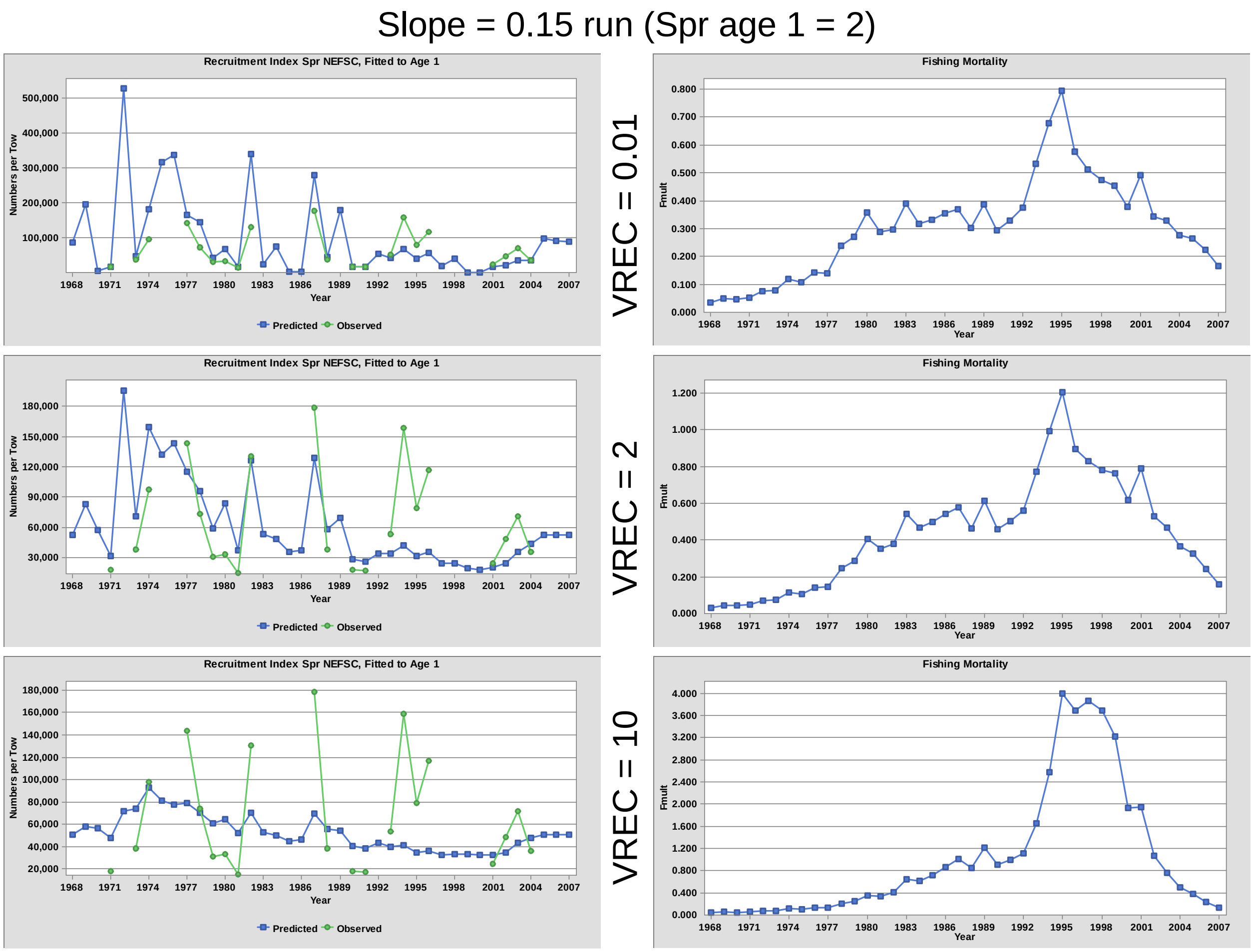


Figure 34. SCALE model sensitivity of fitting the recruitment index and the estimated fishing mortality with different penalty weights on recruitment variation (0.01, 2, 10). The weight on the age-1 recruitment index was fixed at 2.

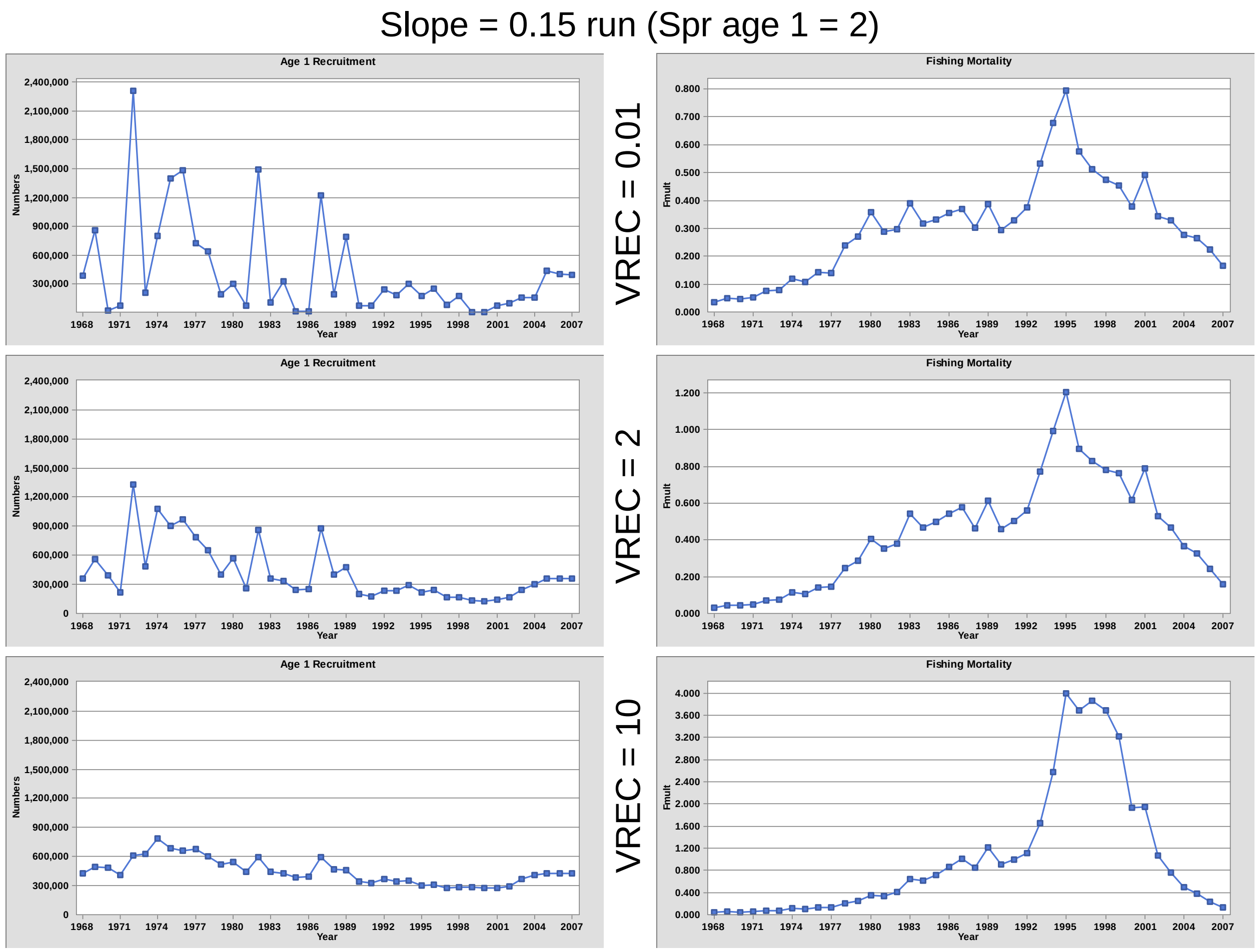


Figure 35. SCALE model sensitivity of estimated recruitment and fishing mortality with different penalty weights on recruitment variation (0.01, 2, 10). The weight on the age-1 recruitment index was fixed at 2.

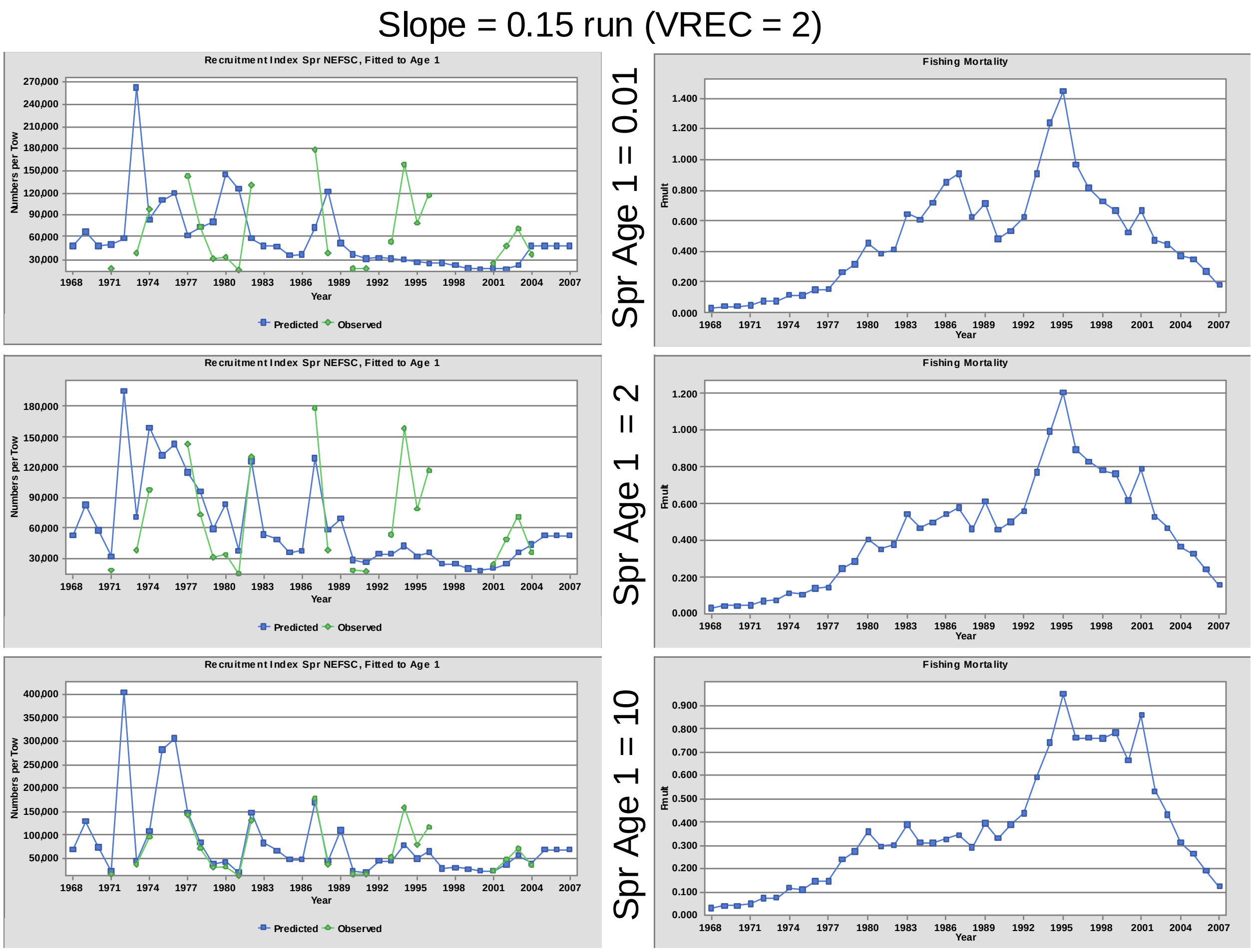


Figure 36. SCALE model sensitivity of fitting the recruitment index and the estimated fishing mortality with different weights on the recruitment index (0.01, 2, 10). The weight on recruitment variation penalty was fixed at 2.

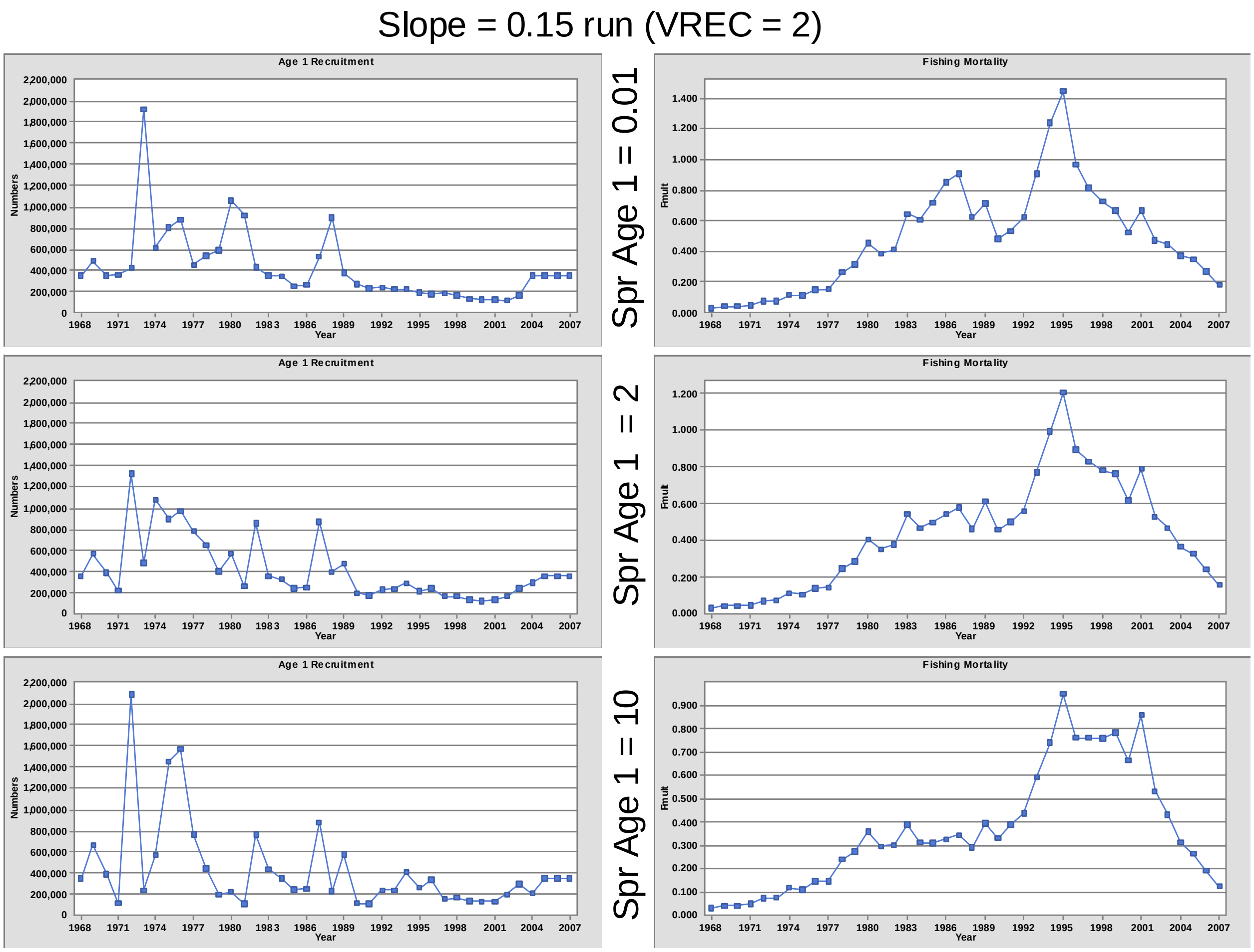


Figure 37. SCALE model sensitivity of estimated recruitment and fishing mortality with different weights on the recruitment index (0.01, 2, 10). The weight on recruitment variation penalty was fixed at 2.

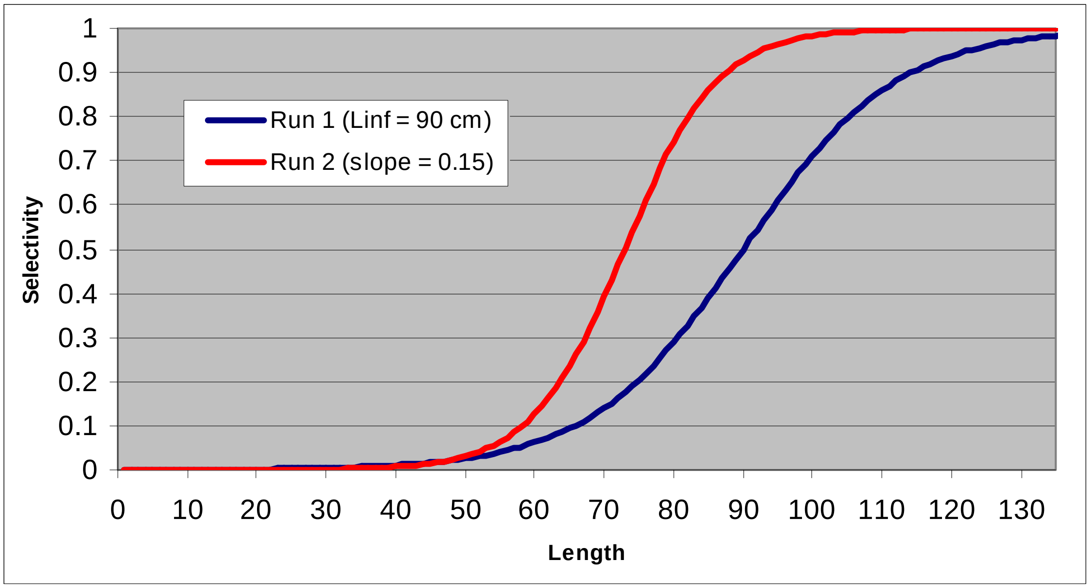


Figure 38. SCALE run 1 selectivity was allowed to hit the L-infinity bound of 90 cm which estimates a relatively flat selectivity curve. SCALE run 2 hits the slope bound of 0.15 which estimated a lower L-infinity.

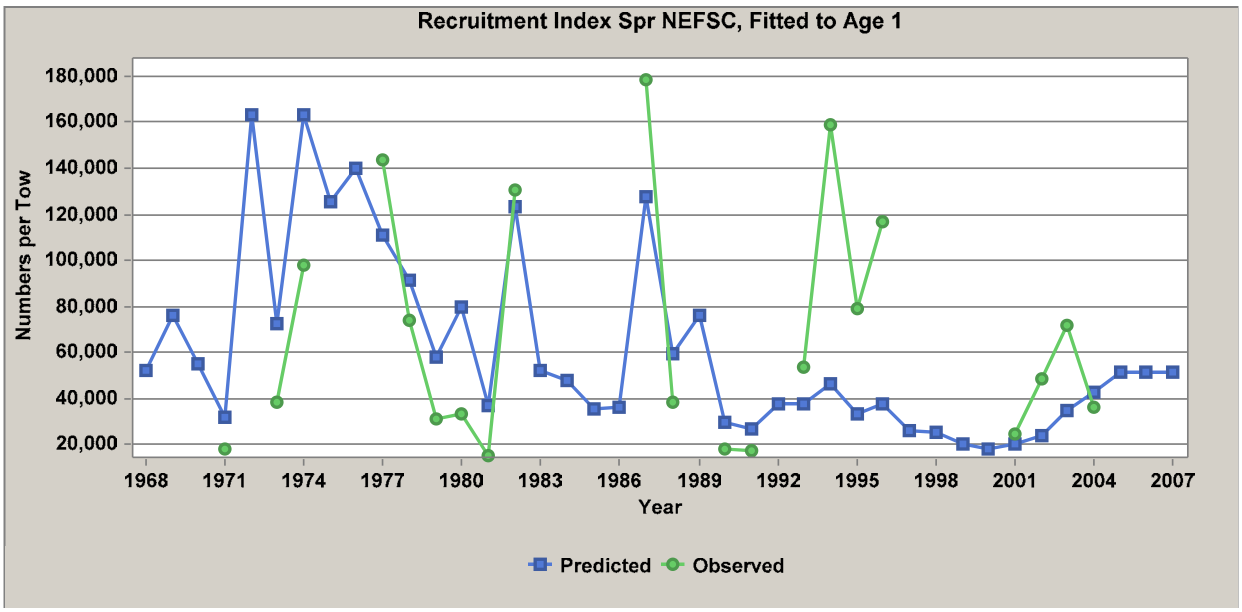


Figure 39. SCALE run 1 (L-infinity = 90 cm) fit to the NEFSC spring age-1 recruitment index.

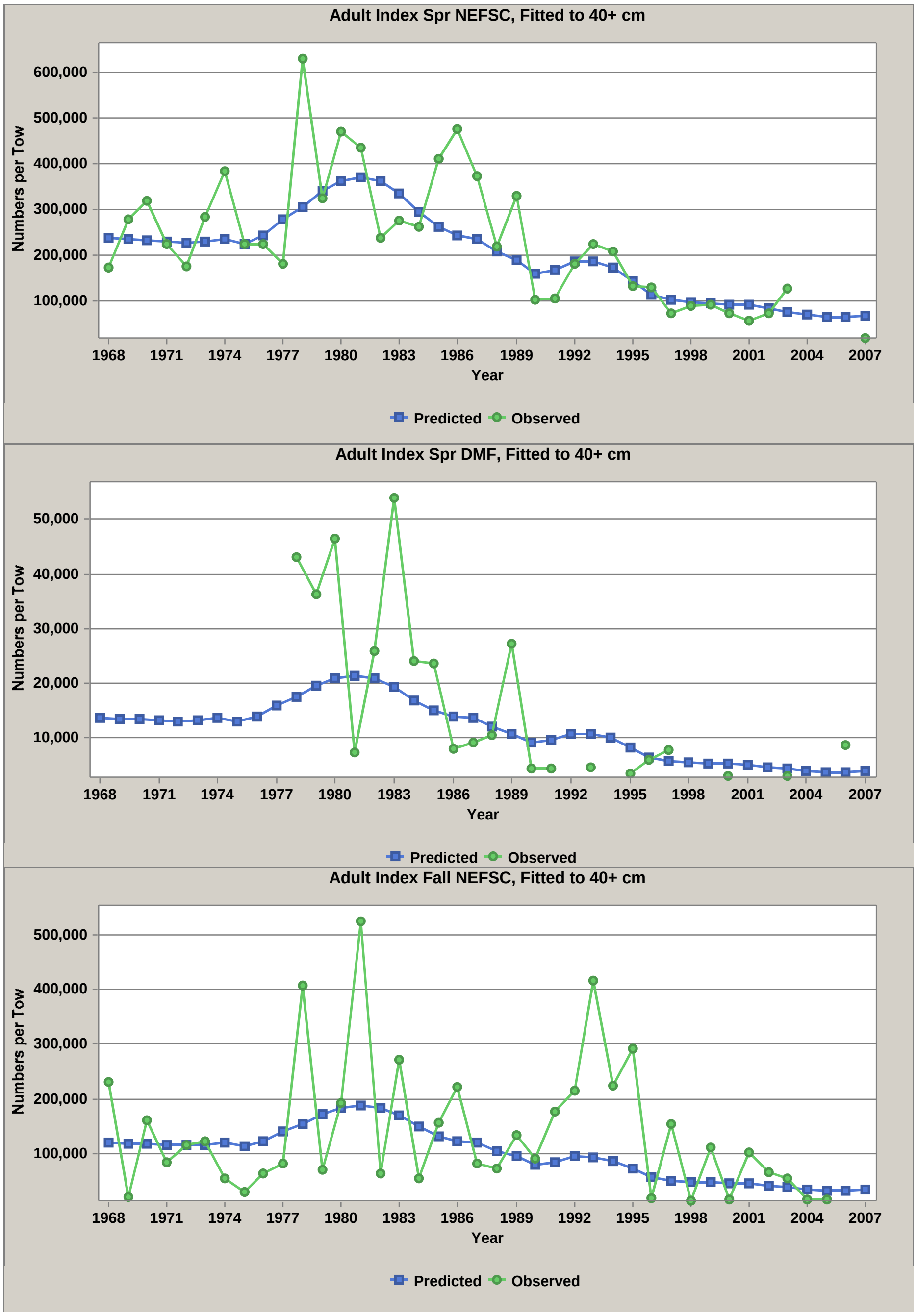


Figure 40. SCALE run 1 (L-infinity = 90 cm) fit to the NEFSC spring 40+ cm, MDMF 40+ cm, and NEFSC fall 40+ cm indices.

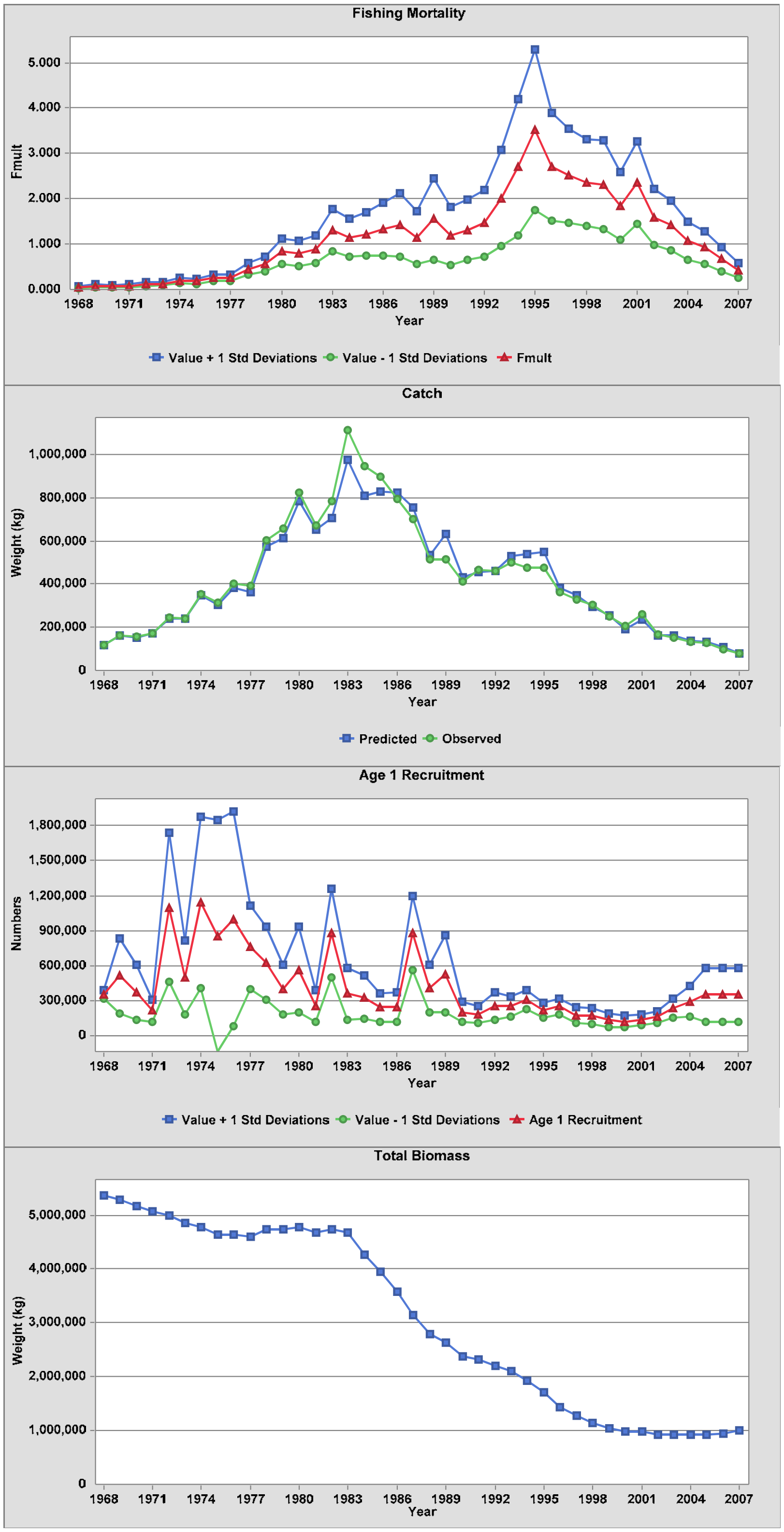


Figure 41. Run 1 (L-infinity = 90 cm) F, fit to the catch, recruitment and total biomass. Plus 1 and minus 1 standard deviations are shown on F and recruitment.

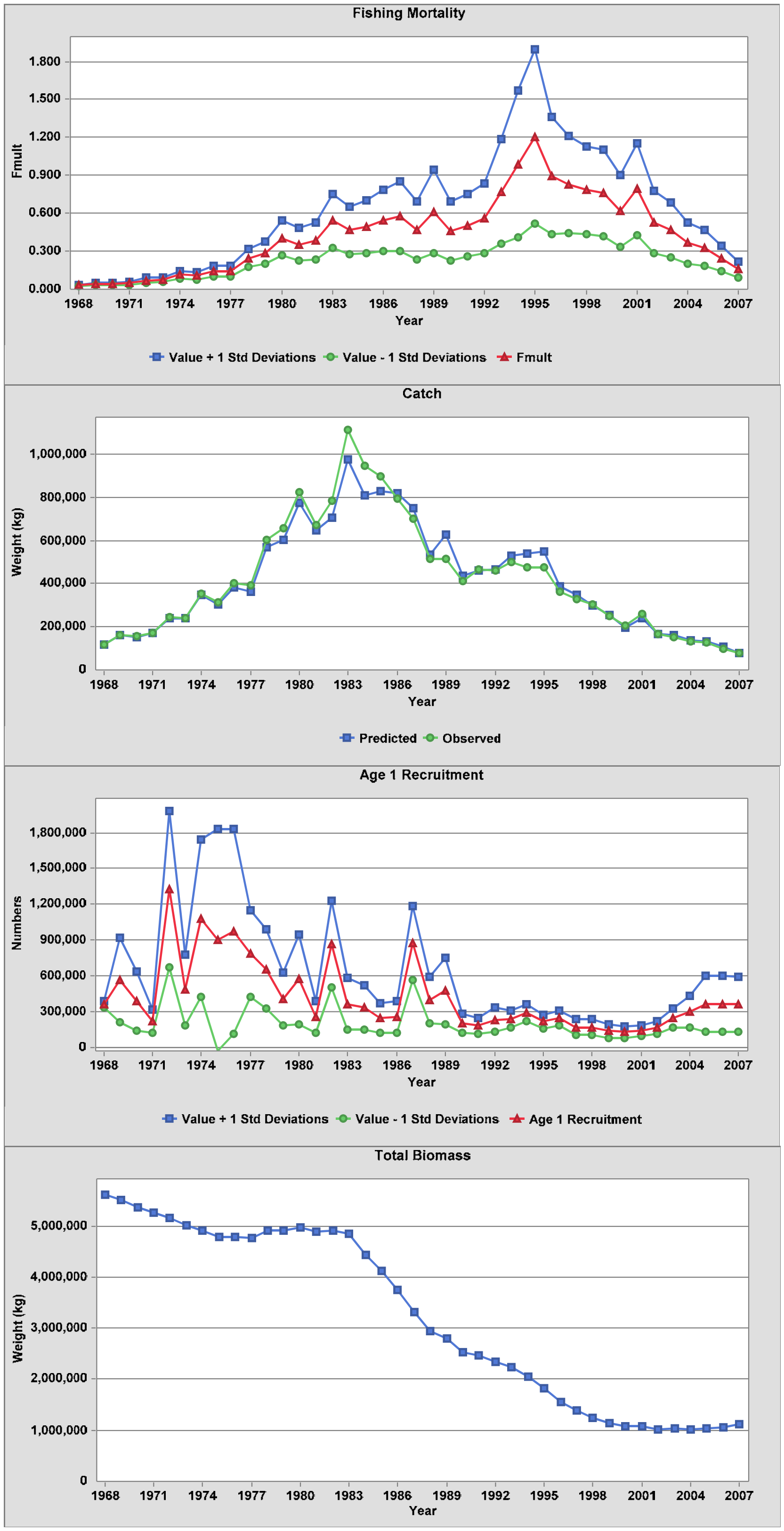


Figure 42. Run 2 (Slope = 0.15) F, fit to the catch, recruitment and total biomass. Plus 1 and minus 1 standard deviations are shown on F and recruitment.

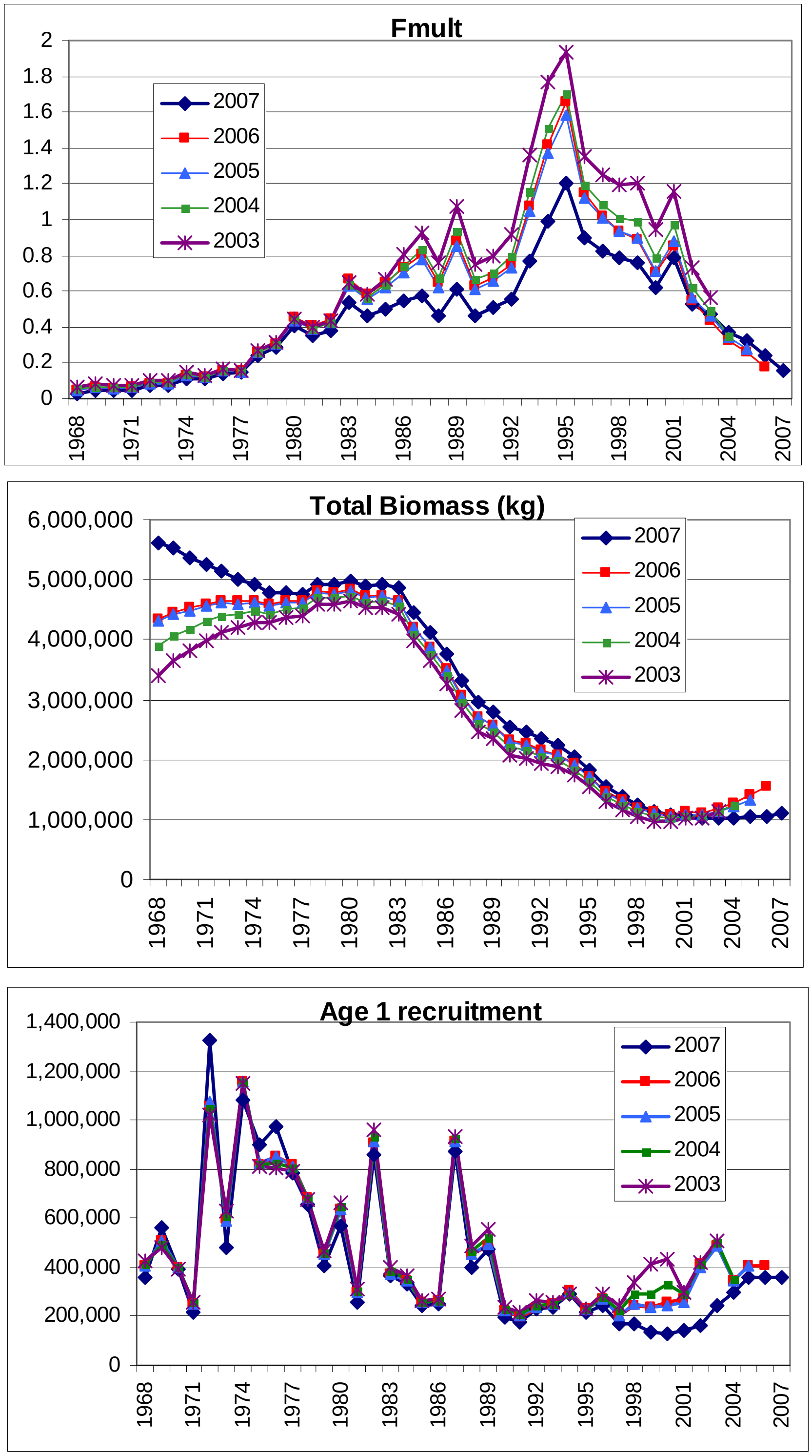


Figure 43. Run 2 (slope = 0.15) retrospective on F, total biomass and age-1 recruitment.

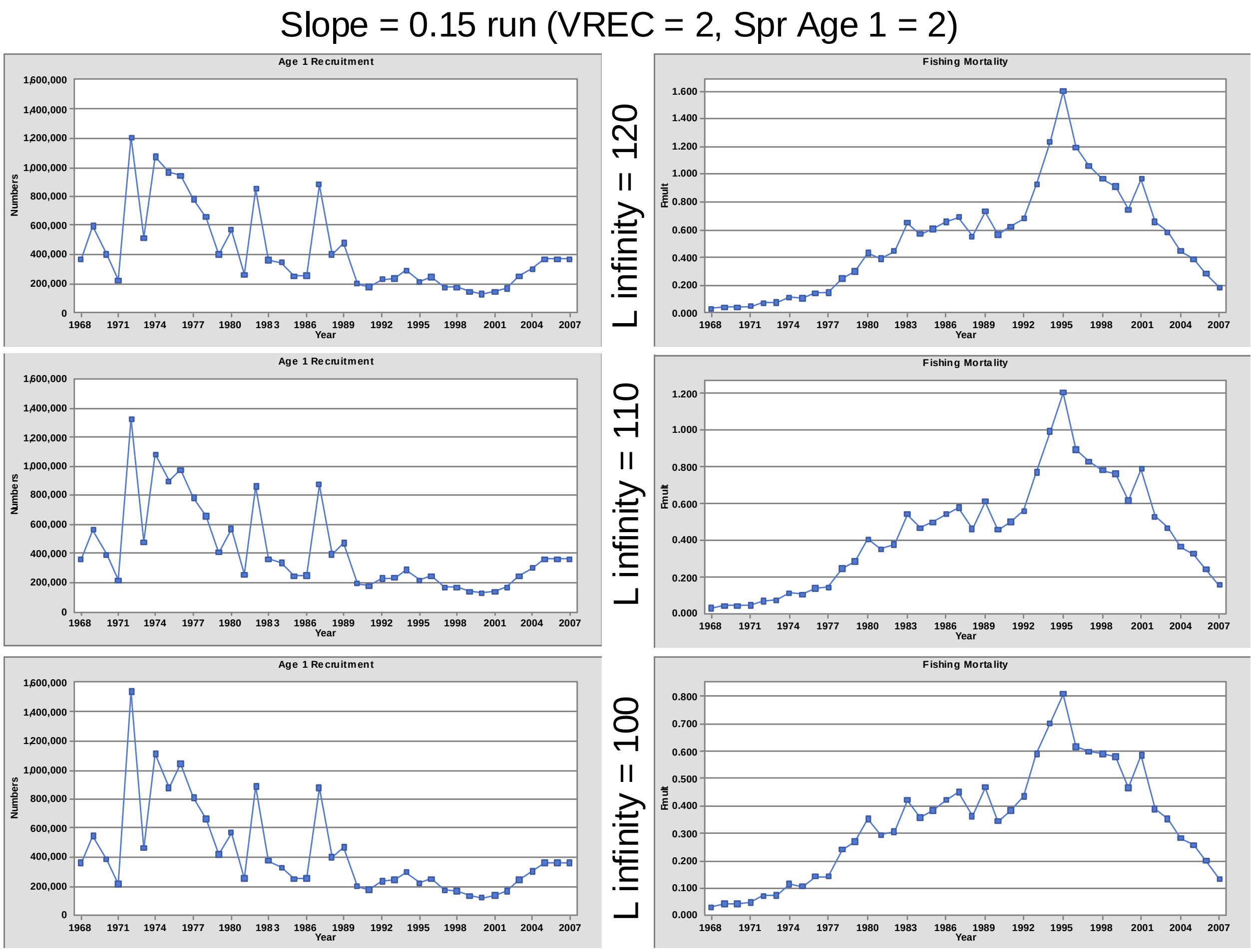


Figure 44. Run 1 (slope = 0.15) sensitivity of recruitment and fishing mortality using three different assumed L-infinity values (100, 110, 120) on growth.

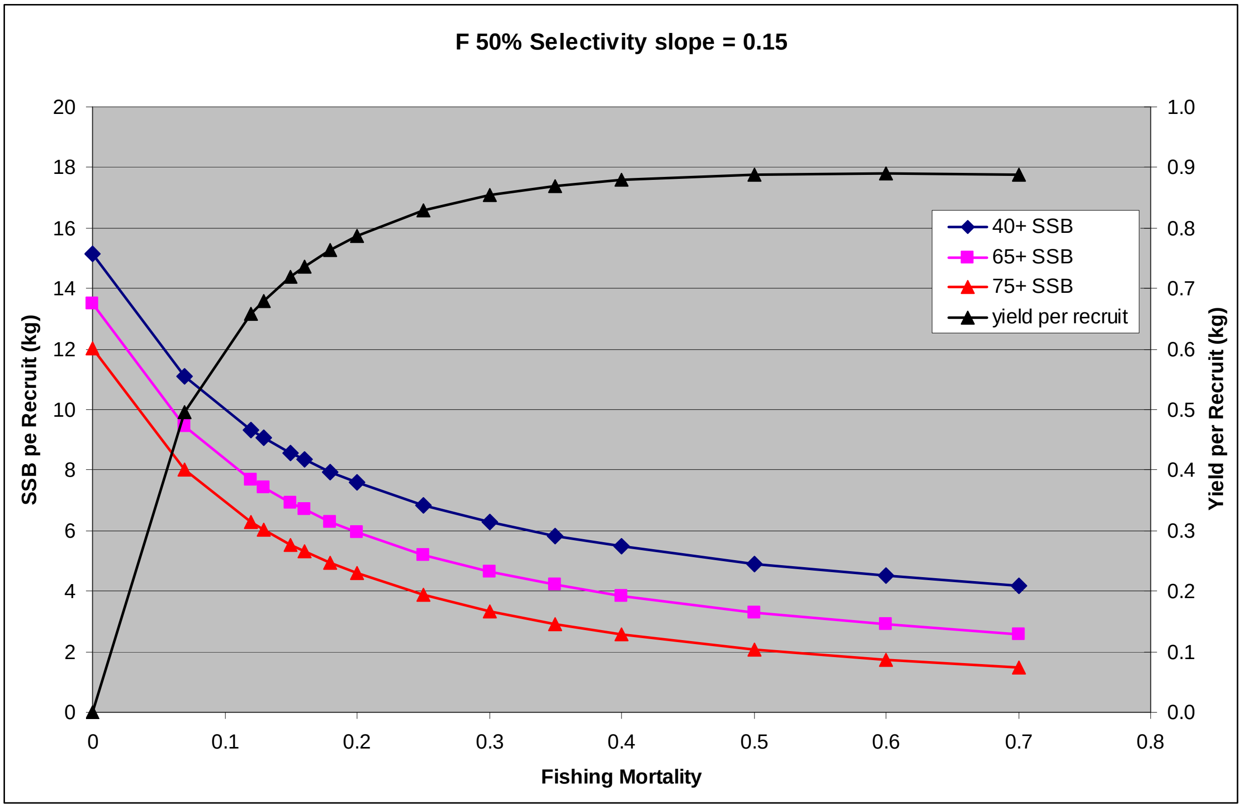
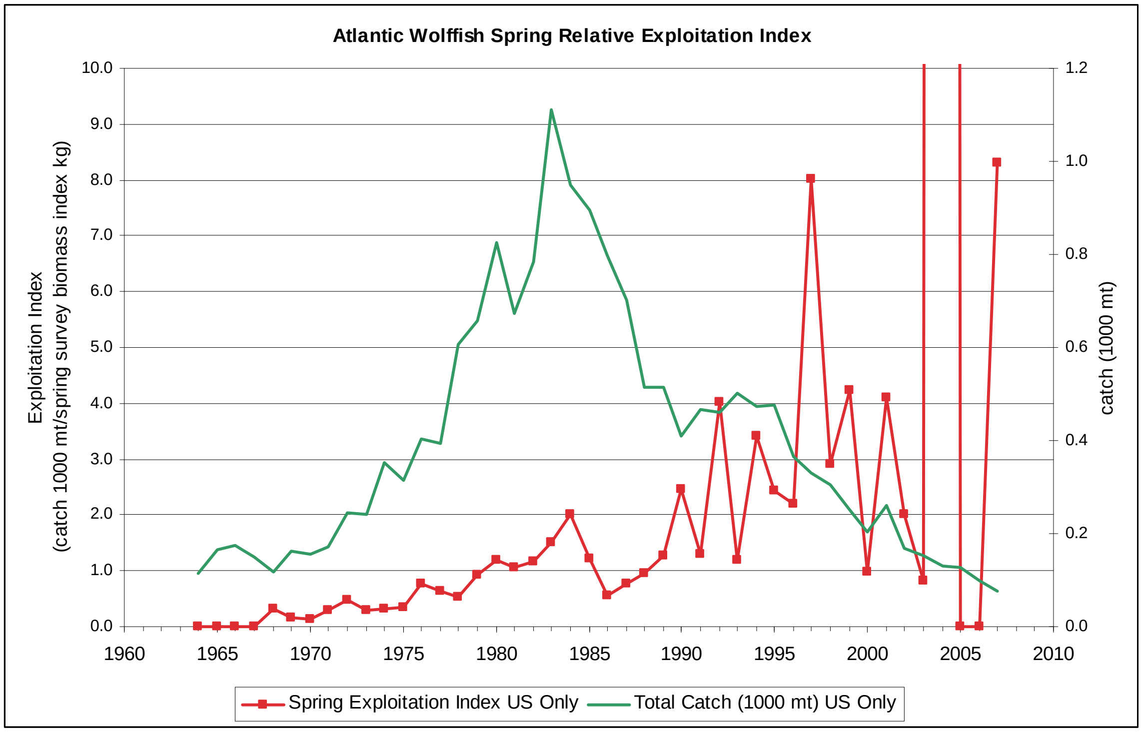


Figure 45. Updated Run 3 SCALE model F50% yield per recruit and spawn stock biomass per recruit curves.



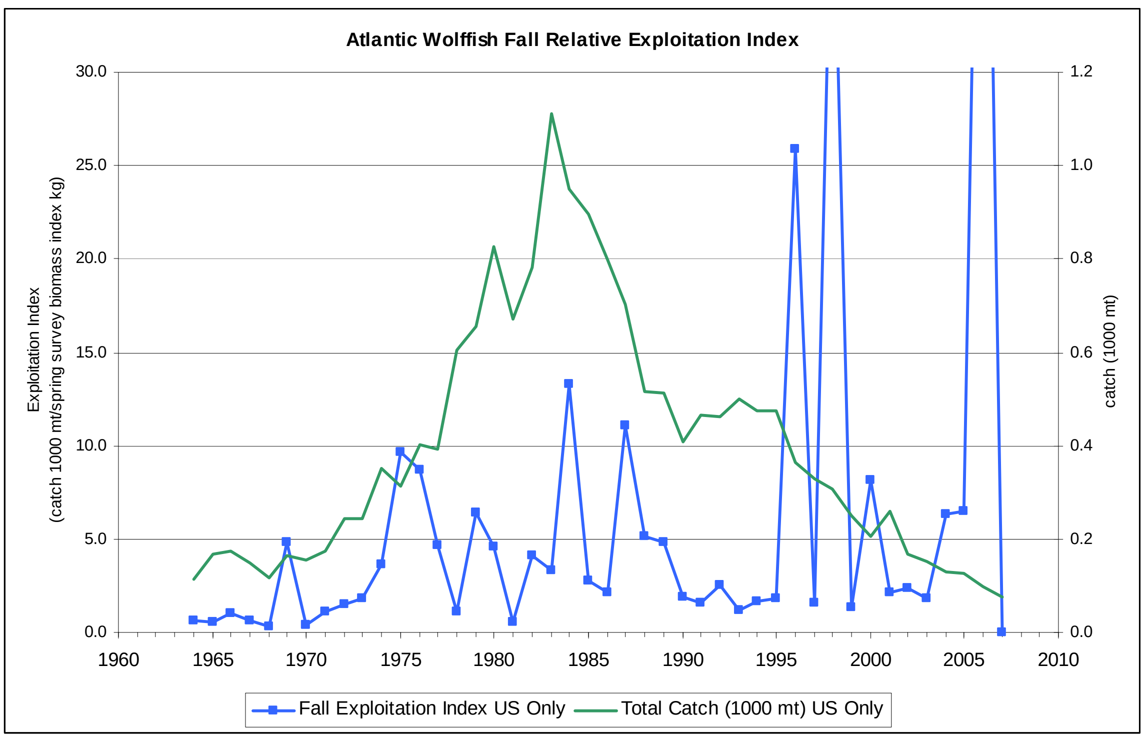


Figure 46. Spring and fall US only exploitation indices with total catch of Atlantic wolffish.

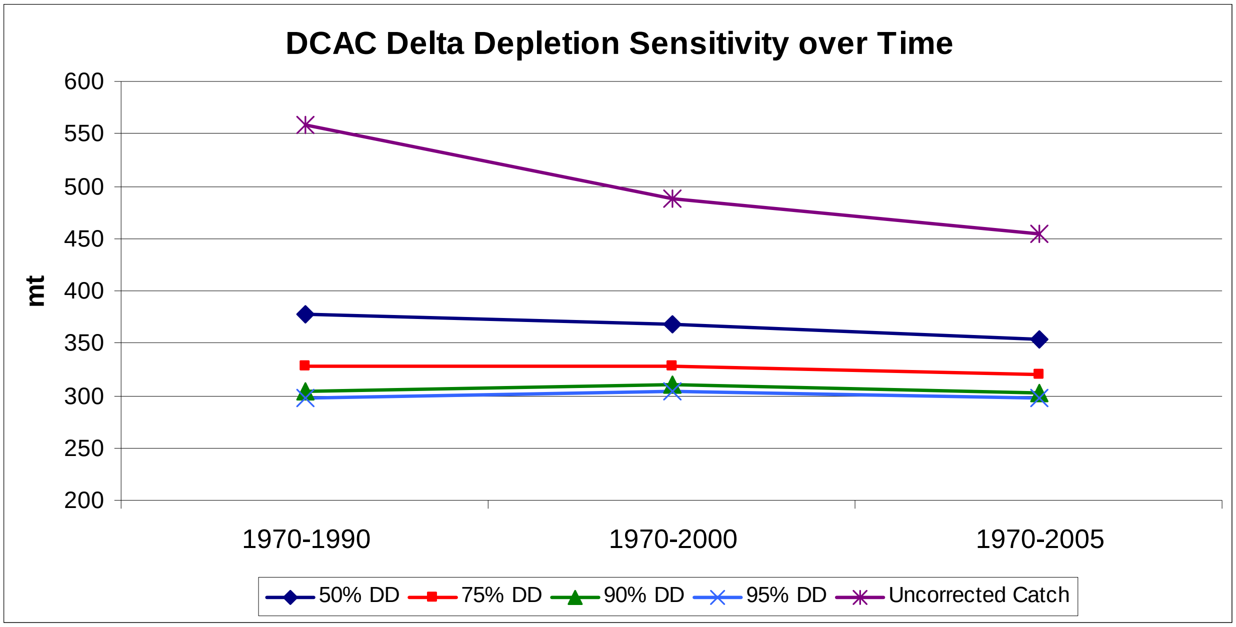


Figure 47. Results of a sensitivity analysis of the depletion ratio from the Depletion-Corrected Average Catch model (DCAC) over time.

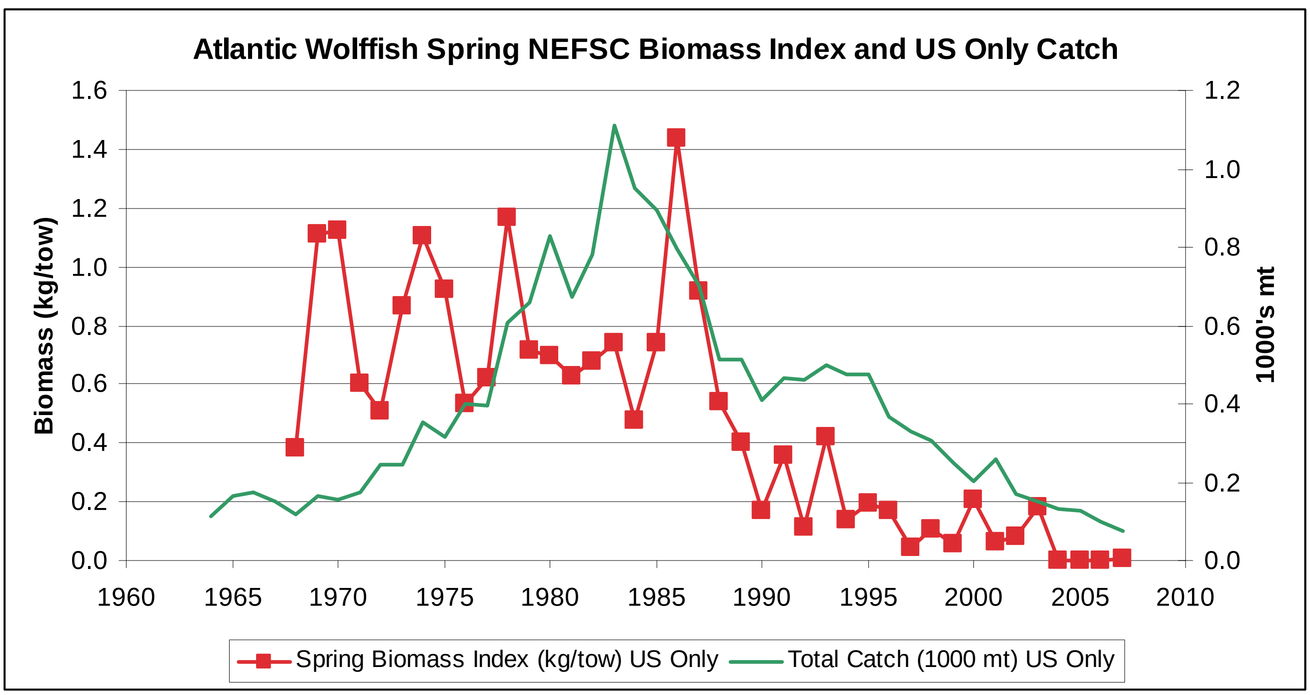
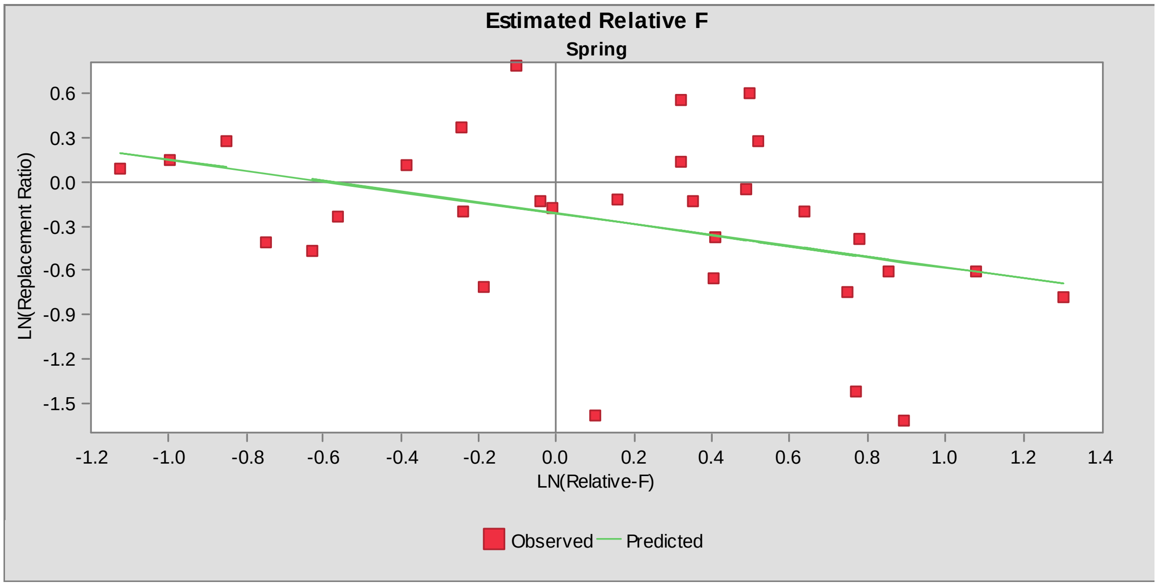


Figure 48. NEFSC spring biomass index and total US catch of Atlantic wolffish used in the AIM (An Index Method) model.

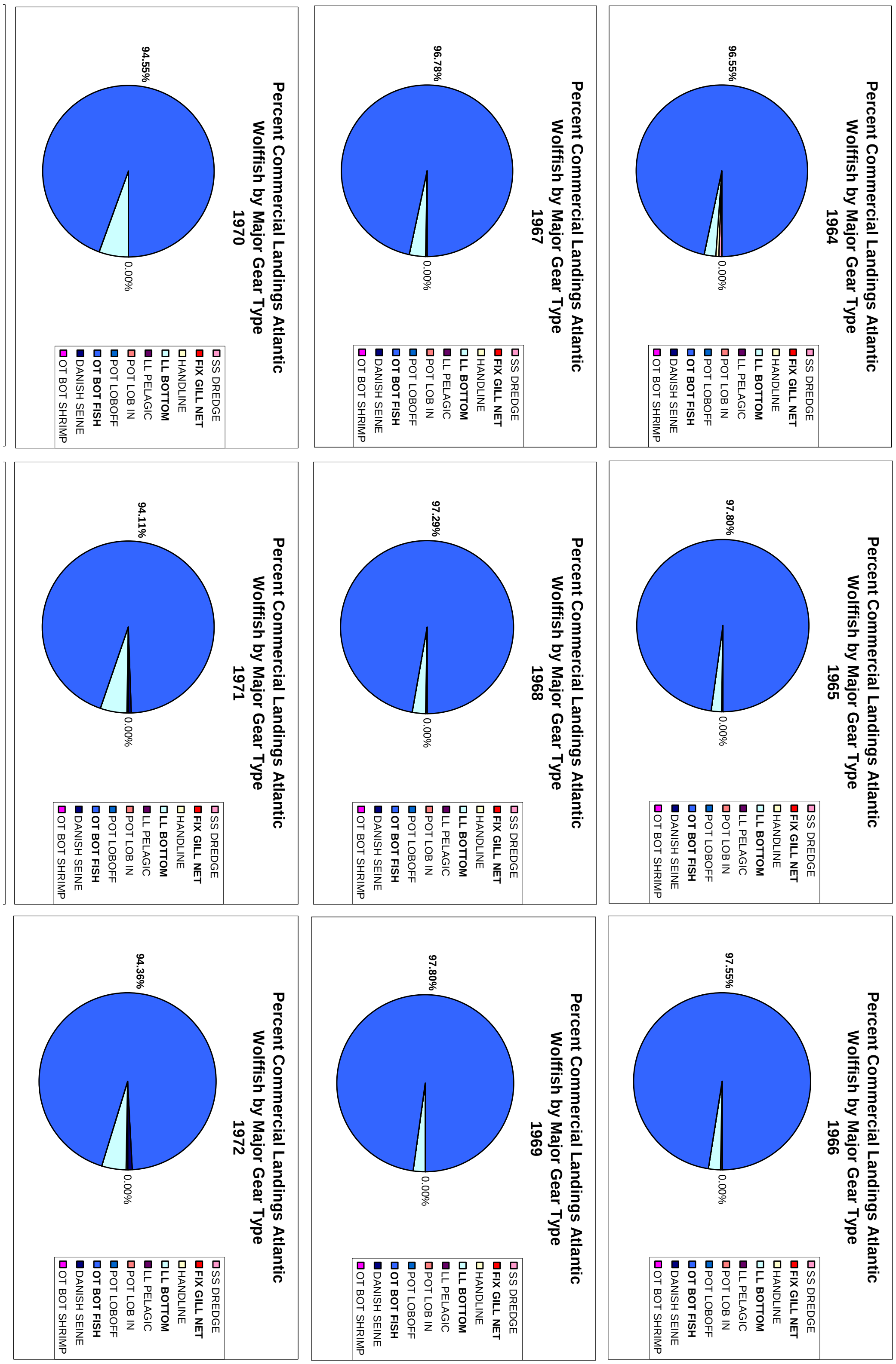


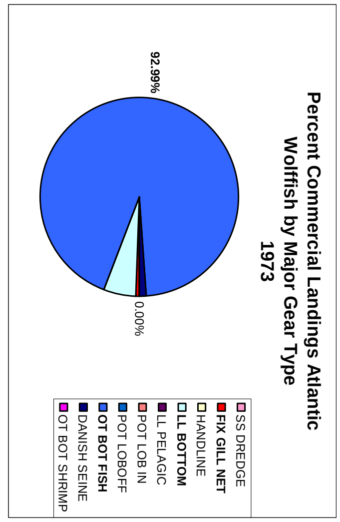
Randomization Test	
	Spring
Critical Value	-0.387470
Significance Level	0.128

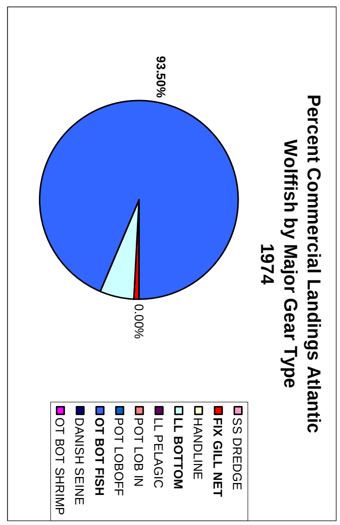
Figure 49. Linear regression of log replacement ratio and log relative F and statistical test results from the AIM model.

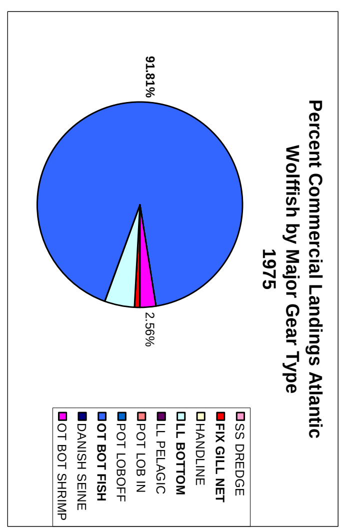
Wolffish Appendix 1

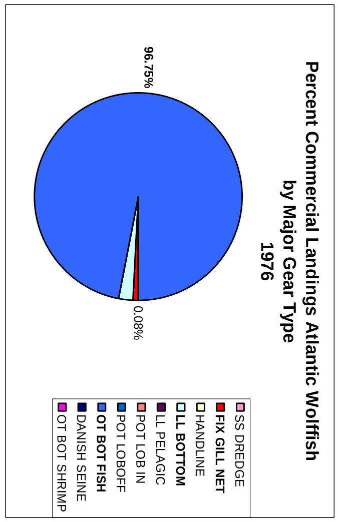
Commercial landings of Atlantic wolffish by gear, 1964-2007.

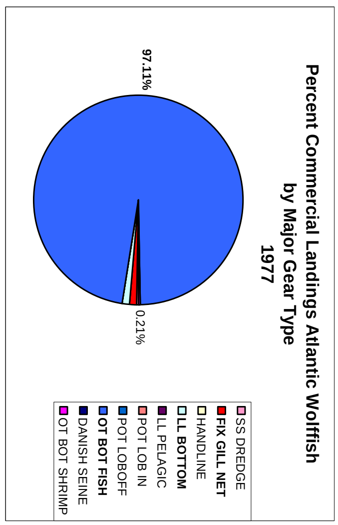


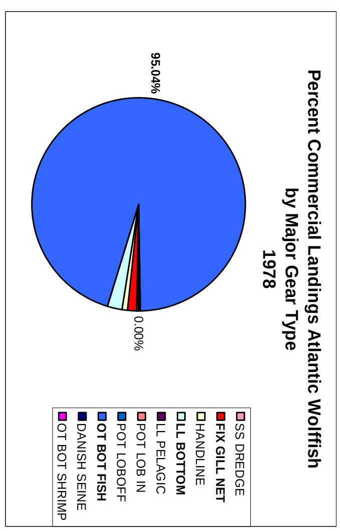

Percent Commercial Landings Atlantic
Wolffish by Major Gear Type
1973
92.99%
0.00%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

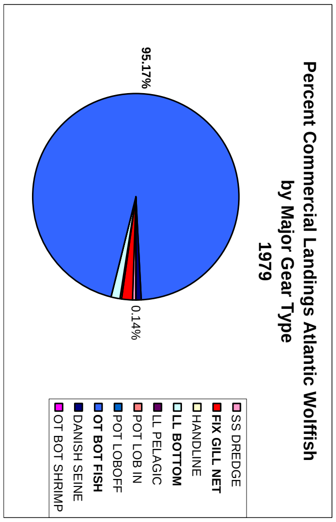

Percent Commercial Landings Atlantic
Wolffish by Major Gear Type
1974
93.50%
0.00%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

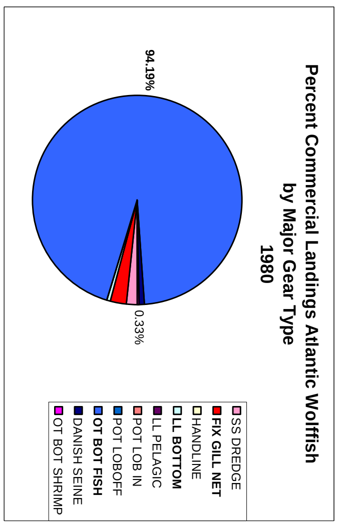

Percent Commercial Landings Atlantic
Wolffish by Major Gear Type
1975
91.81%
2.56%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

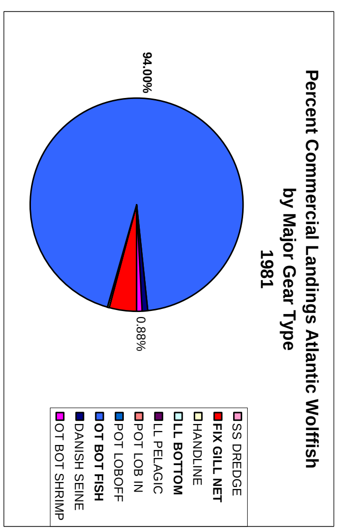

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1976
96.75%
0.08%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

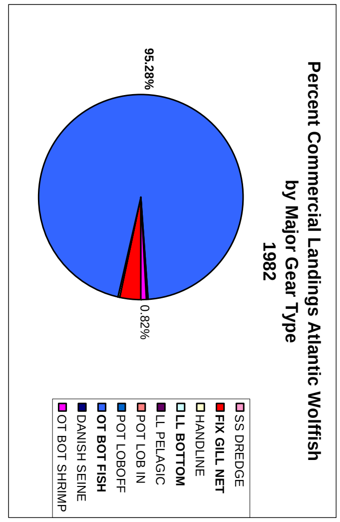

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1977
97.11%
0.21%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

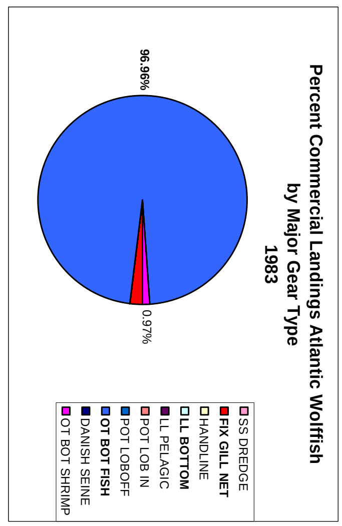

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1978
95.04%
0.00%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

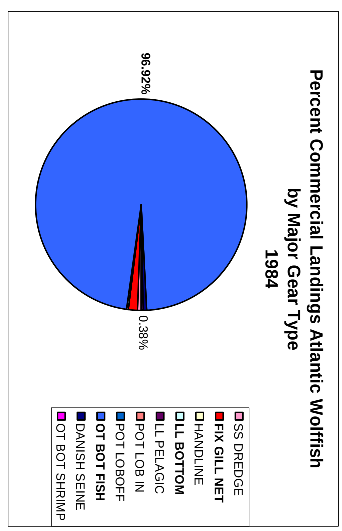

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1979
95.17%
0.14%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

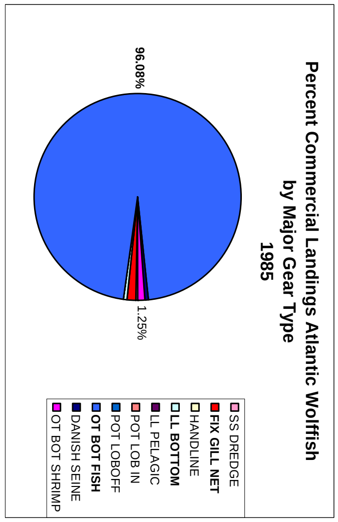

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1980
94.19%
0.33%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

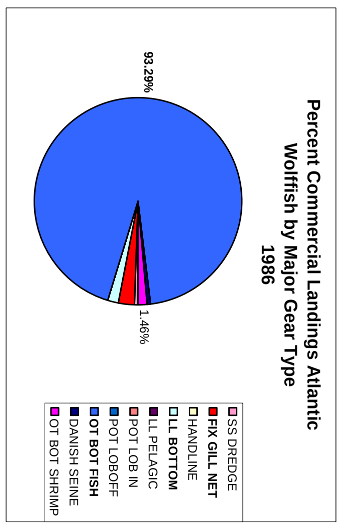

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1981
94.00%
0.88%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

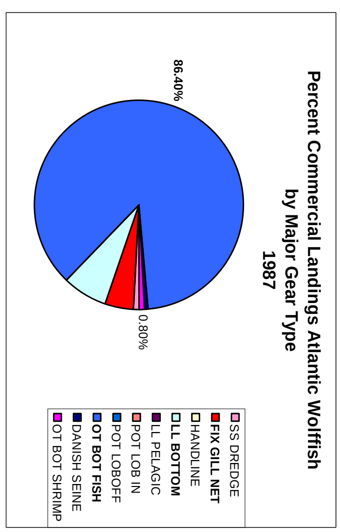

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1982
95.28%
0.82%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

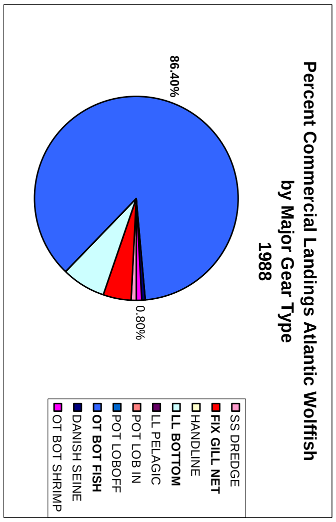

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1983
96.96%
0.97%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

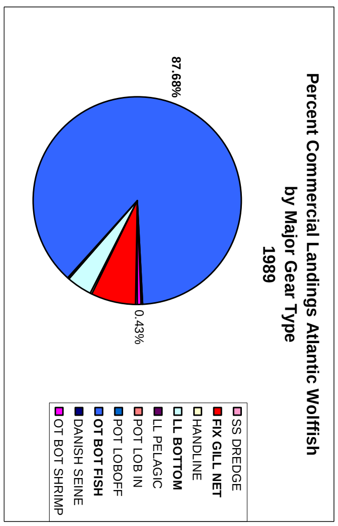

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1984
96.92%
0.38%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

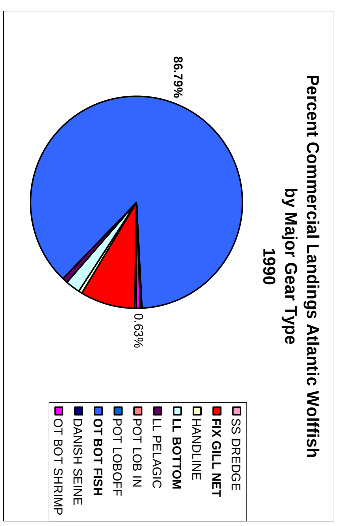

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1985
96.08%
1.25%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

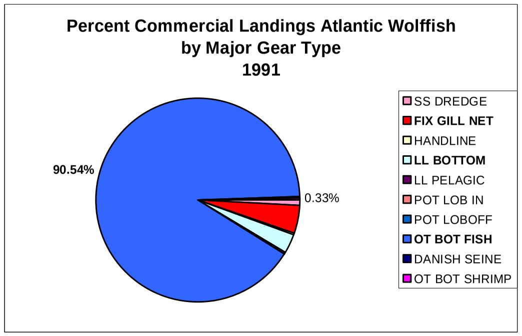

Percent Commercial Landings Atlantic
Wolffish by Major Gear Type
1986
93.29%
1.46%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

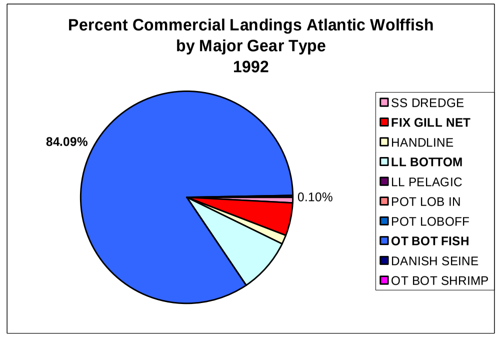

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1987
86.40%
0.80%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

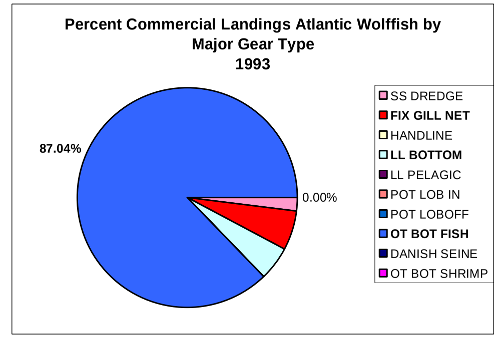

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1988
86.40%
0.80%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

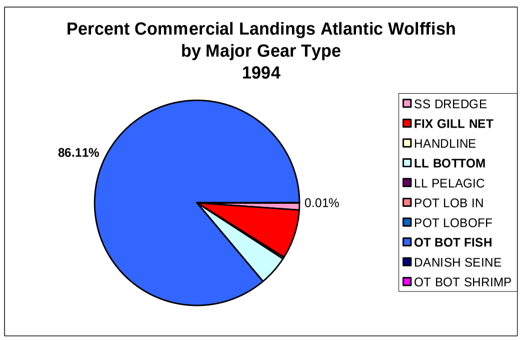

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1989
87.68%
0.43%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

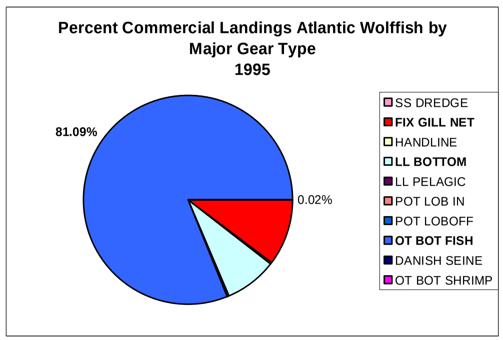

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1990
86.79%
0.63%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

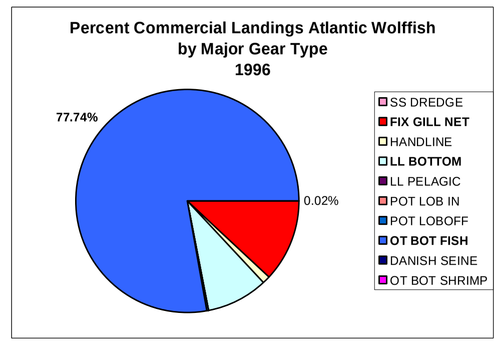

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1991
90.54%
0.33%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

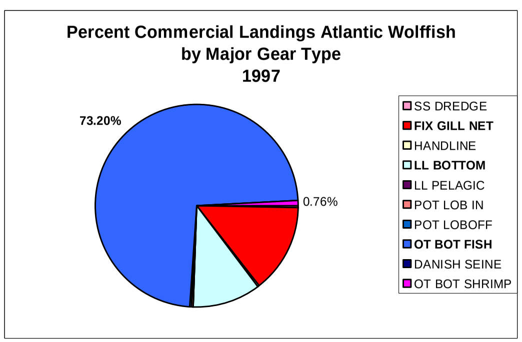

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1992
84.09%
0.10%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

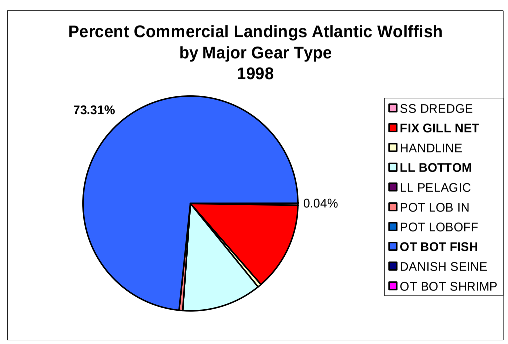

Percent Commercial Landings Atlantic Wolffish by
Major Gear Type
1993
87.04%
0.00%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

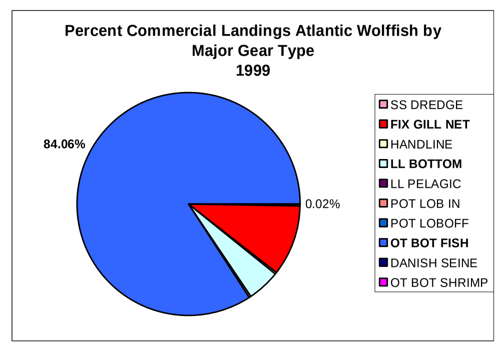

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1994
86.11%
0.01%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

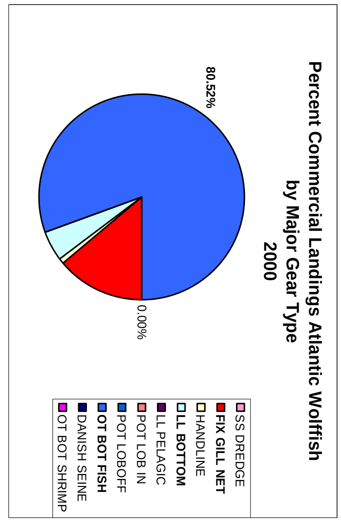

Percent Commercial Landings Atlantic Wolffish by
Major Gear Type
1995
81.09%
0.02%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

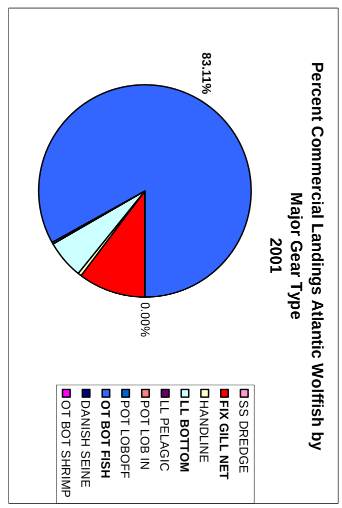

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1996
77.74%
0.02%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

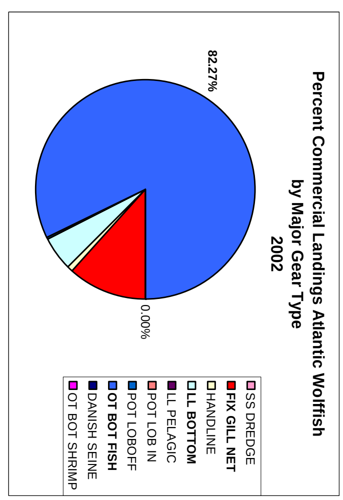

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1997
73.20%
0.76%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

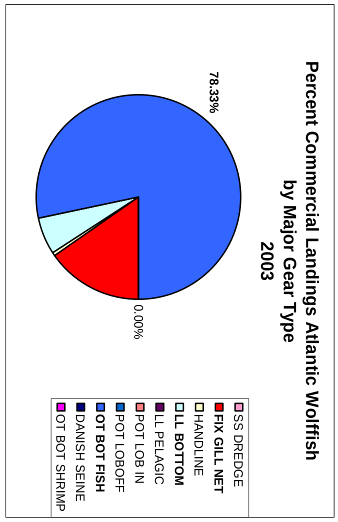

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1998
73.31%
0.04%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

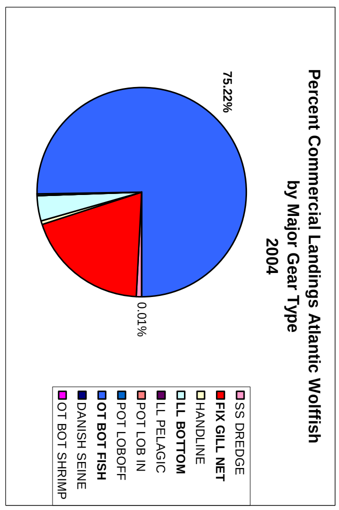

Percent Commercial Landings Atlantic Wolffish by
Major Gear Type
1999
84.06%
0.02%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

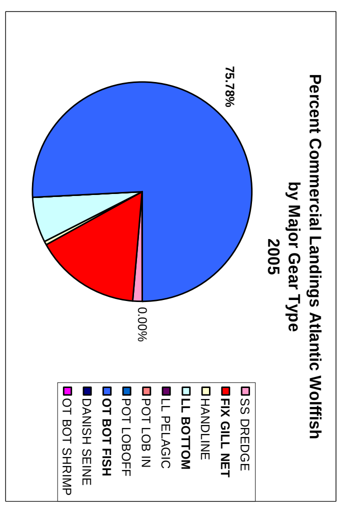

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
2000
80.52%
0.00%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

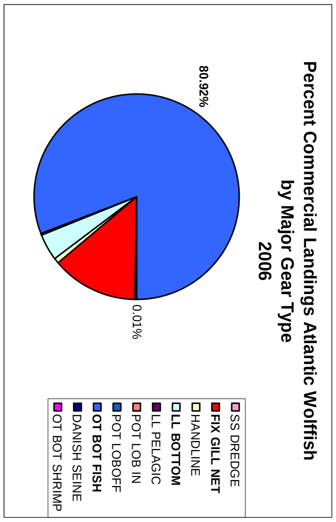

Percent Commercial Landings Atlantic Wolffish by
Major Gear Type
2001
83.11%
0.00%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

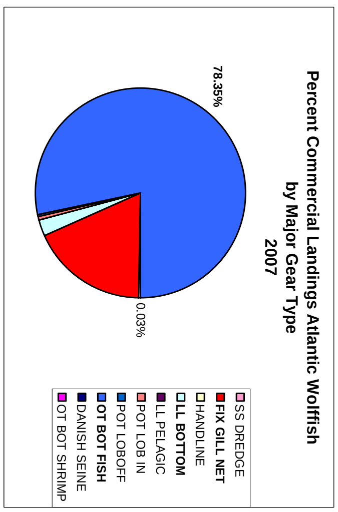

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
2002
82.27%
0.00%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
2003
78.33%
0.00%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
2004
75.22%
0.01%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
2005
75.78%
0.00%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
2006
80.92%
0.01%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
2007
78.35%
0.03%
SS DREDGE
FIX GILL NET
HANDLINE
LL BOTTOM
LL PELAGIC
POT LOB IN
POT LOBOFF
OT BOT FISH
DANISH SEINE
OT BOT SHRIMP

Scup:
Stock Assessment and
Biological Reference Points for 2008

by

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Northeast Data Poor Stocks Working Group Meeting
Woods Hole, MA
December 8-12, 2008

Executive Summary

The current biomass reference point for scup relies on the index of Spawning Stock Biomass (SSB) from the NEFSC spring trawl survey. Previous reviews of the stock assessment have indicated that while this index may be the most reliable fishery independent index of scup SSB, it is subject to a relatively high degree of inter-annual variability that reduces its utility as an indicator of stock status. Managers, scientists, and other stakeholders indicated a desire for a more reliable way to monitor the status of scup and support the annual specification of fishery regulations. The December 2008 Northeast Data Poor Stocks Peer Review Panel accepted a revised stock assessment using a statistical catch at age model (ASAP) as the basis for biological reference points and status determination for scup. The new model of scup population dynamics and the recommended reference points represent a more stable approach for monitoring stock status and specifying annual fishery regulations, compared with the current single index-based model. The new model integrates a broad array of fishery and survey input data and should be less sensitive to inter-annual changes in any single data component than the current model.

The Peer Review Panel recommended $F_{40\%}$ as the proxy for F_{MSY}, and the corresponding $SSB_{F40\%}$ as the proxy for SSB_{MSY}. The $F_{40\%}$ proxy for F_{MSY} = 0.177, the proxy estimate for SSB_{MSY} = 92,044 mt, and the proxy estimate for MSY = 16,161 mt (13,134 mt of landings, 3,027 mt of discards). The stock biomass threshold of ½ SSB_{MSY} = ½ $SSB_{F40\%}$ = 46,022 mt = 101.461 million lbs.

The 2007 SSB estimate of 119,343 mt is 30% above SSB_{MSY} = 92,044 mt, indicating the stock was not overfished. The F_{2007} estimate of 0.054 is 31% of F_{MSY} = 0.177, indicating overfishing was not occurring. Total catch (landings plus discards) was 7,867 mt in 2007, about 49% of MSY. The revised status determination represents a significant change from the recent biomass status update conducted in July 2008, which indicated that the stock was overfished in 2007, although not experiencing overfishing. While the accepted long-term MSY estimate appears feasible given historical evidence from the fishery, managers may wish to take an adaptive approach to the specification of fishery quotas in the short-term. Total fishery landings over the last five years (2003-2007) have averaged 6,214 mt (13.7 million lbs). If the stock is fished at $F_{40\%}$ = 0.177 over the long-term, the corresponding annual total MSY landings would be 13,134 mt (29.0 million lbs), more than double the recent five year average. The Peer Review Panel recommended that "…rapid increases in quota to meet the revised MSY would be unwarranted given uncertainties in recruitments. A more gradual increase in quotas is a preferred approach reflective of the uncertainty in the model estimates and stock status."

Term of Reference

The following components of the Terms of Reference for the Northeast Data Poor Stocks Working Group are relevant for scup:

1. Constitute and convene a Working Group comprising NEFSC assessment scientists, and staff from NERO, NEFMC, MAFMC, and ASMFC to:

    a. Recommend biological reference points (BRPs) and measurable BRP and maximum sustainable yield (MSY) proxies for Scup.

b. Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop allowable biological catches (ABCs) for these stocks.
c. Comment on what can be done to improve the information, proxies or assessments for each species.

Introduction

Scup (*Stenotomus chrysops*) is a schooling continental shelf species of the Northwest Atlantic that is distributed primarily between Cape Cod and Cape Hatteras (Morse 1978). Scup undertake extensive migrations between coastal waters in summer and offshore waters in winter. Scup migrate north and inshore to spawn in spring, with larger scup (age 2 and older) tending to arrive in spring first, followed by smaller scup (Neville and Talbot 1964; Sisson 1974). Larger scup are found during the summer near the mouth of larger bays and in the ocean within 20-fathoms, and often inhabit rough bottom areas. Smaller scup are more likely to be found in shallow, smooth bottom areas of bays during summer (Morse 1978). Scup migrate south and offshore in autumn as the water temperature decreases, arriving in offshore wintering areas by December (Hamer 1970; Morse 1978). Spawning occurs from May through August and peaks in June. About 50% of age-2 scup are sexually mature (about 17 cm total length; Morse 1978), while nearly all scup of age 3 and older are mature. Scup reach a maximum fork length of at least 41 cm and a maximum age of at least 14 years, with a likely maximum of 20 years (Dery and Rearden 1979). Tagging studies (e.g., Neville and Talbot 1964; Cogswell 1960, 1961; Hamer 1970, 1979) have indicated the possibility of two stocks of scup, one in Southern New England waters and another extending south from New Jersey waters. However, the lack of definitive locations for tag return data coupled with distributional data from the NEFSC bottom trawl surveys support the concept of a single unit stock extending from Cape Hatteras north to New England (Mayo 1982).

Overfished and Overfishing Definitions

The Mid-Atlantic Fishery Management Council (MAFMC) and the Atlantic States Marine Fisheries Commission (ASMFC) manage scup under Amendment 8 (1997) to the Summer Flounder, Scup, and Black Sea Bass (SFSCBSB) Fishery Management Plan (FMP). The FMP management unit includes all scup from Cape Hatteras, NC northward to the US-Canada border.

Amendment 8 also established a recovery plan for scup under which exploitation rates were to be reduced to 47% (F=0.72) during 1997-1999, to 33% (F=0.45) during 2000-2001, and to 21% (F=0.26) during 2002-2007. These goals were to be attained through implementation of a Total Allowable Catch (TAC) that included a commercial quota and recreational harvest limit, and other regulations including commercial fishery minimum net mesh, trap vent and fish sizes, closed areas, and recreational fishery minimum fish sizes, possession limits, and open seasons.
Amendment 12 (1998) to the FMP established a biomass threshold (a proxy for one-half BMSY) for scup based on the three-year moving average of the NEFSC spring bottom trawl survey index of Spawning Stock Biomass (SSB) during 1977-1979, which was perceived to be a period when the stock was near one-half BMSY (2.77 SSB kg per tow). The scup stock is overfished when the spawning stock biomass index falls below this value. Amendment 12 defined overfishing for

scup to occur when the fishing mortality rate exceeds the threshold fishing mortality of Fmax = 0.26 (proxy for FMSY).

Broad scale Gear Restricted Areas (GRAs) for scup were implemented in November 2000 under the framework provisions of the FMP as a measure to reduce discards of scup in the small mesh fisheries for *Loligo* squid and silver hake. The regulations restricted the use of small mesh trawl gear in areas with high concentrations of small scup during the late fall and winter months. Two Northern Areas off Long Island were implemented for November through January, while a Southern Area off the mid-Atlantic coast was implemented for January through April. The size and boundaries of the GRAs were modified in December 2000 and again in 2005 in response to commercial fishing industry recommendations.

Amendment 14 (July 2007) to the FMP defined the biomass target and implemented a stock rebuilding plan for scup. The stock must be fully rebuilt to the biomass target by January 1, 2015. The proxy for BMSY is two times the 3-year moving average of the NEFSC spring index of SSB during 1977-1979, or 2*2.77 = 5.54 SSB kg per tow. A constant fishing mortality rate (F) of 0.10 (9% exploitation rate) is to be applied in each year of a 7 year rebuilding period; 2008 was year 1 of rebuilding and F=0.10 was applied as the target F. Total Allowable Catch (TAC) of 4,491 mt (9.90 million lbs) and corresponding Total Allowable Landings (TAL) of 3,329 mt (7.34 million lbs) were established for 2008 to achieve the target F.

The current overfished and overfishing definitions are based on revisions to the SFSCBSB FMP through Framework 7 (October 2007), currently use the values established in Amendments 12 (1998) and 14 (July 2007), and are as follows:

AThe maximum fishing mortality threshold for each of the species under the FMP is defined as FMSY (or a reasonable proxy thereof) as a function of productive capacity, and based upon the best scientific information consistent with National Standards 1 and 2. Specifically, FMSY is the fishing mortality rate associated with MSY. The maximum fishing mortality threshold (FMSY) or a reasonable proxy may be defined as a function of (but not limited to): total stock biomass, spawning stock biomass, total egg production, and may include males, females, both, or combinations and ratios thereof which provide the best measure of productive capacity for each of the species managed under the FMP. Exceeding the established fishing mortality threshold constitutes overfishing as defined by the Magnuson-Stevens Act.@

AThe minimum stock size threshold for each of the species under the FMP is defined as one-half BMSY (or a reasonable proxy thereof) as a function of productive capacity, and based upon the best scientific information consistent with National Standards 1 and 2. The minimum stock size threshold (one-half BMSY) or a reasonable proxy may be defined as a function of (but not limited to): total stock biomass, spawning stock biomass, total egg production, and may include males, females, both, or combinations and ratios thereof which provide the best measure of productive capacity for each of the species managed under the FMP. The minimum stock size threshold is the level of productive capacity associated with the relevant one-half MSY level. Should the measure of productive capacity for the stock or stock complex fall below this minimum threshold, the stock or stock complex is considered overfished. The target for rebuilding is specified as BMSY (or reasonable proxy thereof) at the level of productive capacity associated with the relevant MSY level, under the same definition of productive capacity as specified for the minimum stock size threshold.@

Current Biological Reference Points

The current Biological Reference Points for scup are defined as follows in SFSCBSB FMP Amendment 12:

AOverfishing for scup is defined to occur when the fishing mortality rate exceeds the threshold fishing mortality rate of FMSY. Because FMSY cannot be reliably estimated, Fmax is used as a proxy for FMSY. Fmax is 0.26 under current stock conditions. The maximum value of the spring survey index based on a three year moving average (2.77 kg/tow) would serve as a biomass threshold. BMSY cannot be reliably estimated for scup.@ The original definition under Amendment 12 did not explicitly provide the time frame for the biomass threshold calculation. However, the specifics of the definition were provided in the discussion of the National Standards in another section of Amendment 12 as follows: AY 3-year moving average of the NEFSC spring survey catch per tow of spawning stock biomass (1977-1979 average = 2.77 kg/tow).@

Amendment 14 to the SFSCBSB FMP defined a proxy for BMSY for scup as follows:
AThe current minimum biomass threshold is the NEFSC spring SSB 3-year index value (1977-1979) of 2.77 kg/tow. Assuming the minimum biomass threshold is a proxy for 2 BMSY, doubling that index value would be a proxy for BMSY. Specifically, NEFSC spring 3-year index value of 5.54 kg/tow would be a proxy for BMSY. A

Background and Justification for Current Biological Reference Points

The last peer-reviewed assessment to include an analytical model was accepted in 1995 by SAW 19 (NEFSC 1995). The assessment featured a Virtual Population Analysis (VPA) modeled in the ADAPT framework (Conser and Powers 1990), included commercial and recreational landings and discards at age estimates, and used state and NEFSC abundance indices for calibration. The 1995 SAW 19 assessment indicated that the instantaneous fishing mortality rate (F) in 1993 was 1.3, and spawning stock biomass was 4,600 mt. A yield per recruit (YPR) analysis indicated that Fmax = 0.236.

The VPA was updated through 1996 and reviewed by SAW 25 (NEFSC 1997), but due to concerns over the low intensity of fishery sampling in the 1990s, uncertainty about the magnitude of commercial discards in the late 1990s, and the ongoing variability of survey indices, the VPA was not accepted as a basis for management decisions. Assessment conclusions were therefore based primarily on trends in NEFSC and state agency survey indices and catch curve analyses using those survey data. The 1997 SAW 25 was able to conclude that in 1996 scup were Aover-exploited and near record low abundance levels.@

The scup assessment was next updated through 1997 and reviewed by SAW 27 (NEFSC 1998). Several configurations of a surplus production model (ASPIC; Prager 1994) were reviewed in addition to an updated VPA, but like the VPA, the ASPIC model results were not accepted due to concerns over the validity of the input fishery and survey data. An updated YPR analysis was accepted and indicated that F_{max} = 0.26. SAW 27 concluded that AA VPA or other analytical model formulation for scup will not be feasible until the quality of the input data, particularly the precision of discard estimates, is significantly improved.@ The 1998 SAW 27 also concluded the scup was Aover exploited and at a low biomass level.@

The 1998 SAW27 Panel recommended the scup assessment be based on the long-term time series of NEFSC trawl survey indices and fishery catches. The Panel noted that commercial landings were sustained near 19,000 mt annually during the mid-1950s to mid-1960s, and concluded that the stock was likely near BMSY during that period (Figure 1). The nearest subsequent peak in NEFSC survey indices occurred in the late 1970s. Commercial and total fishery catches in the late 1970s were about one-half of those in the 1950s to 1960s, and so the late 1970s were identified as a period when the stock was likely to be near one-half of BMSY (Figures 1-2). The Panel considered the NEFSC spring survey series to be most representative of spawning stock biomass, since older ages were better represented in the age structure than in the NEFSC fall survey or other state agency surveys. The 1998 SAW27 Panel recommended that the three-year moving average of the NEFSC spring bottom trawl survey index of Spawning Stock Biomass (SSB) during 1977-1979 (2.77 SSB kg per tow) be used as the proxy biomass threshold (one-half BMSY) and that Fmax = 0.26 be used as the proxy fishing mortality threshold (FMSY). Those recommendations were subsequently adopted for the BRPs in FMP Amendment 12.

The scup assessment was next updated through 1999 and reviewed by SAW 31 (NEFSC 2000). The assessment continued to be based on trends in research survey indices and fishery catches and indicated that the stock was Aoverfished@ (the NEFSC spring SSB index was much lower than the biomass threshold specified in FMP Amendment 12) and that Aoverfishing@ was occurring (catch curve analyses indicated that F exceeded 1.0, much greater than the FMP Amendment 12 threshold of Fmax = 0.26).

The most recent peer-reviewed assessment of scup included fishery data through 2001 and was reviewed by SAW 35 (NEFSC 2002). The assessment was again based on trends in research survey indices and fishery catches, but indicated that the stock was no longer Aoverfished@ (the NEFSC spring SSB index was above the biomass threshold specified in FMP Amendment 12), although the SAW 35 Panel concluded that Astock status with respect to the overfishing definition cannot currently be evaluated,@ due to the uncertainty of F estimates derived from research survey catch curve calculations. The 2002 SAW 35 Panel found sufficient evidence to conclude that AThe relative exploitation rates have declined in recent years...@ and that ASurvey observations indicated strong recruitment and some rebuilding of age structure.@

Since 2002, the status of the stock has been monitored by the MAFMC Monitoring Committee using trends in research survey indices and fishery catches. A Relative Exploitation Index (REI) based on the annual total fishery landings and the NEFSC spring three-year average SSB index has been used as a proxy for F to monitor status with respect to overfishing and provide guidance to the specification of annual TACs. A projection of the NEFSC spring survey SSB index using assumptions about maturity, partial recruitment to the survey, and the level of future recruitment as indexed by the NEFSC spring survey at age 1 was used in FMP Amendment 14 to forecast stock rebuilding and set the Frebuild target for 2008-2105.

An update to the status monitoring metrics was completed in July 2008 to aid in the specification of fishery regulations for 2009. The update indicated that while the stock was overfished in 2007 (NEFSC spring SSB three-year average index = 1.16 kg per tow, 21% of the biomass target of 5.54 kg per tow), the exploitation rate was at the rebuilding target rate (9%, or about F = 0.10), suggesting that overfishing was not occurring in 2007. However, the stock rebuilding rate was slower than indicated by the Amendment 14 projection, with the NEFSC spring 2007 SSB index (three-year average = 1.16 kg per tow) at only 56% of the forecast 2007 index (2.08 kg per tow).

Need for Revision of the Current Biological Reference Points

The current stock biomass reference point relies on the index of SSB from the NEFSC spring trawl survey. Previous reviews of the scup stock assessment have indicated that while this index may be the most reliable fishery independent metric of scup SSB, it is subject to a relatively high degree of inter-annual variability and the possibility that positive and negative Aavailability@ events will reduce the utility of the index in monitoring the status of the stock for any given year, in spite of the three-year smoothing protocol (Figure 2). An example of this phenomenon took place in 2002, when an unusually high value of the NEFSC spring SSB index was recorded that did not seem to result from high abundance in 2001, nor translate into a correspondingly high value in 2003. Subsequent reviews concluded that the high 2002 index resulted mainly from an increased availability of fish to the survey, rather than due to a true increase in abundance of the recorded magnitude. However, the high 2002 index lead to a change in official stock status to Anot overfished@ when incorporated into the three-year average SSB index calculation, and then a change back to Aoverfished@ when the 2002 index passed out of the three-year average in 2005 (Figure 2), with accompanying volatility in the annual specification of fishery regulations.

The last four peer reviews of the assessment have rejected analytical models for scup, and indicated that estimates of F based on research survey catch curve analyses are not valid. The Relative Exploitation Index (REI; total fishery landings divided by the NEFSC spring three-year SSB index) used as a proxy for F is also volatile and potentially unreliable if inter-annual changes in the SSB index are suspected to be biologically unrealistic. Finally, the NEFSC survey series using NOAA Ship *Albatross IV* sampling, on which the stock status monitoring is based, ended in November 2008. While efforts are underway to calibrate the *Albatross IV* indices to new indices collected by the NOAA Ship *Henry B. Bigelow*, those efforts may not provide a reliable basis for stock monitoring in the short term. Managers, scientists, and other stakeholders have therefore indicated a desire for a more reliable way to monitor the status of the scup stock and support the annual specification of fishery regulations.

Proposed Biological Reference Points

The following section details the sequence of work that was performed in the series of Data Poor Stocks Working Group meetings during the fall of 2008 to develop the analytical model that is the basis for the accepted BRPs. The section details the two analytical modeling approaches for scup that were pursued. The first was a relatively simple approach, the AIM model, which fits relationships between single abundance index time series and fishery catch time series. The second was a statistical catch at age model incorporating many data components, ASAP. Because the accepted model requires the use of significantly more complex input fishery and research survey data than the current BRPs, a description of those data precedes the model descriptions.

Commercial Landings

US commercial landings averaged over 18,000 mt per year from 1950 to 1965 (peaking at over 22,000 mt in 1960) and declined to less than 10,000 mt per year in the late 1960s. Landings fluctuated between about 5,000 and 10,000 mt from 1970 to the early 1990s and then declined to about 1,200 mt in 2000, less than 6% of the peak observed in 1960. Commercial landings have since increased to average about 4,200 mt during 2003-2007 (Figure 1).

About eighty percent of the commercial landings of scup for the period 1979-2007 were in Rhode Island (38%), New Jersey (26%), and New York (16%; Table 1). The otter trawl is the principal commercial fishing gear, accounting for about 75% of the total catch during 1979-2007 (Table 2). The remainder of the commercial landings is taken by floating trap (11%) and hand lines (7%), with paired trawl, pound nets, and pots and traps each contributing between 1 and 4%.

Commercial Discards

The NEFSC Observer Program has collected information on landings and discards in the commercial fishery for 1989-2007. Northeast Region (ME-VA) discard estimates were raised to account for North Carolina landings. A discard mortality rate of 100% was assumed because there are no published estimates of scup discard mortality rates. This assumption is based on limited observations and is an important element of uncertainty in the assessment. Past SAW panels have recommended that research be conducted to better characterize the discard mortality rate of scup in different gear types in order to more accurately quantify the absolute magnitude of scup discard mortality (NEFSC 1995, 1997, 1998, 2000, 2002; see also Section 7 of this report AResearch Recommendations@).

Quantifying discards from the commercial fishery is necessary for a reliable scup assessment, but low sample sizes in the past have resulted in uncertain estimates. Concern regarding the uncertainty of discard estimates due to inadequate observer sampling has been expressed in at least five previous SAW reviews of the scup assessment, and those reviews have recommended increases in sampling intensity to increase the accuracy and precision of discard estimates (NEFSC 1995, 1997, 1998, 2000, 2002). Despite the uncertainty of the discard data, recent SAW panels have concluded that commercial discarding of scup has been high during most of the last 20 years, generally approaching or exceeding commercial landings (i.e., about 50% or more of the total commercial catch). Since the implementation of GRAs in 2000, estimated discards as a proportion of the total commercial catch have decreased, averaging about 35%.

Given the uncertainty associated with estimating commercial discards for scup, three different methods for calculating discard estimates have been considered in assessments since 1998:

1) Geometric Mean Discards-to-Landings Ratio (GMDL): Ratios of discards to landings by trip landings level (for trip landings < 300 kg [661 lbs], the Abycatch fishery@; or => 300 kg, the Adirected fishery@) and half year period were calculated and multiplied by the corresponding observed landings from the NEFSC Dealer Report database to provide estimates of discards. Geometric mean rates (re-transformed, uncorrected, mean ln-transformed Discards to Landings [D/L] per trip) were used because the distributions of landings and discards and the ratio of discards to landings on a per-trip basis in the scup fishery are highly variable and positively skewed. Observed trips with both scup landings and discard were used to calculate the per trip discard to landings ratios. Only trips with both non-zero landings and discards could be used for this approach to avoid division by zero. The number of trawl gear trips used to calculate geometric mean discard-to-landings ratios (GMDL) by half year for 1997-2007 ranged from 1 to 104 for trips < 300 kg and from 1 to 35 for trips =>300 kg, with the best sampling occurring since 2003. No trawl gear trips were available for half year two in 1997 and 1999 for trips < 300 kg and for half year two in 1997-2001 for trips => 300 kg. The GMDL calculated for half year one was used to estimate discards for half year two when no trawl gear trips were available in half year two. The GMDL ratios ranged from 0.03 in 2004 (half year two, trips => 300 kg) to 121.71 in 1998 (half year one, trips => 300 kg; Table 3).

The large 1998 Adirected fishery@ discard ratio and subsequent very high annual discard estimate (111,973 mt) was based on one trawl gear trip. About 93% of the discard from that trip was attributable to a single tow in which an estimated 68.2 mt (150,000 lbs) of scup were captured. This tow was not lifted from the water and the captain of the vessel estimated the weight of the catch. There has been debate concerning the validity of the catch weight estimate and whether or not it was representative of other vessels or trips in the fishery. However, the observation was reported by a trained NEFSC observer and was therefore included in the initial calculation of the GMDL estimate of scup discards (Tables 3-4).

2) Aggregate Discards-to-Landings Ratio (AGDL): The second approach for estimating discards considered aggregate discards to landings ratios (summed D/summed L for all trips catching scup in stratum). As in the GMDL method, trips are stratified by trip landings level and half year period. The number of trawl gear trips used to calculate AGDL by half year for 1997-2007 ranged from 14 to 254 for trips < 300 kg and from 1 to 35 for trips => 300 kg, with the best sampling occurring since 2003. There are more trips available for the AGDL calculation for trips < 300 kg than in the GMDL approach, since trips with zero landings can be used. The lowest AGDL ratio calculated was 0.00 in 2001 (no discard observed in 4 trips, half year two, trips => 300 kg). The highest AGDL was 121.71 in 1998 (half year one, trips => 300 kg), the same as that calculated in the GMDL method. The AGDL approach generally provides higher annual estimates of scup discards, with greater inter-annual variability, than the GMDL approach.

3) Mean Differences between Landings and Discards (DELTA): Mean differences (kg) between landings and discard (D = landings - discard, per trip) were also calculated using the same strata as for the other methods. Observed trips in the stratum were used to calculate the mean difference in stratum, which was then applied to the scup landings of trips in the NEFSC Dealer Report database to calculate a discard for each trip (discard = landings -(D)). Calculating differences allows use of trips that had discards but no landings, whereas D/L ratios cannot be calculated in these situations (i.e. zero in the denominator). When discards exceed landings, the difference (D) is negative. As the magnitude of discards is of primary interest, the absolute values of D are used. The number of trawl gear trips used in the DELTA method calculations ranged from 6 to 254 for trips < 300 kg and from 1 to 35 for trips => 300 kg, with the best sampling occurring since 2003. The magnitude of the DELTA values ranged from 10.7 in 2001 (half year two, trips < 300 kg) to 72707 in 1998 (half year one, trips => 300 kg). As before, this large discard estimate is the result of one large discarding event in the Adirected fishery@ that was discussed above. The DELTA approach generally provides lower estimates of scup discards for the Adirected fishery @ but slightly higher estimates for the Abycatch fishery@ compared to the GMDL approach.

Since 2002 the GMDL approach discard estimates have been adopted by the MAFMC Monitoring Committee to monitor trends in fishery catch and evaluate the status of the stock, since the year-to-year trends among the three approaches differed in magnitude but followed similar trends. The large discard event in 1998 affected calculations from each method, resulting in extremely high D/L rates and subsequent discard estimates in 1998 for each approach. The DELTA method yielded estimates that were fairly consistent with the GMDL rates, while the AGDL estimates exhibited generally higher discard estimates with more variability. Previous SAW Working Groups and review panels have expressed most confidence in the estimates produced using the GMDL approach and considered the estimates to be supported by the DELTA rates. The GMDL estimates were used for all subsequent modeling approaches considered in the assessment. The 1998 estimates from all 3 computational methods was considered infeasible, and replaced by the mean of the 1997 and 1999 GMDL estimates (3,331 mt) in subsequent tabulations of catch and in subsequent modeling (Tables 3-5, and 9).

Recreational Catch

Scup is an important recreational species, with the greatest proportion of catches taken in the states of Massachusetts, Rhode Island, Connecticut and New York. Estimates of the recreational catch in numbers were obtained from the NMFS Marine Recreational Fishery Statistics Survey (MRFSS) for 1981-2007. These estimates were available for three categories: type A - fish landed and available for sampling, type B1 - fish landed but not available for sampling, and type B2 - fish caught and released alive. The estimated recreational landings (types A and B1) in weight during 1981-2007 averaged about 2,000 mt per year (Table 5). Since 1981, the MRFSS data indicate that the recreational landings have averaged 29% of the commercial and recreational landings total.

The estimated recreational discard in weight during 1984-2007 ranged from 6 mt in 1999 to a high of 185 mt in 2006, while averaging about 72 mt per year (Table 5). The weight of discards has been directly calculated only for those years (1984 and later) for which recreational catch at age has been compiled. In compilations of total fishery catch for earlier years, the recreational discards was assumed to be approximately 2% of the estimated recreational landings, based on the mean discard percentage for 1984-1996 (directly calculated discard weights for years prior to implementation of FMP regulations). No length frequency samples of the scup discard were collected under the MRFSS program before 2005, so recreational discards were assumed to be fish aged 0 and 1, in the same relative proportions and with the same mean weight as the landed catch less than state regulated minimum fish sizes. An inspection of discard length frequency samples from the New York recreational fishery for 1989-1991 indicated that this assumption was reasonable. Since 2005, length samples of the recreational fishery discard have been collected in the MRFSS For Hire Survey sampling. The mortality rate due to discarding in the recreational fishery has been reported to range from 0-15% (Howell and Simpson 1985) and from 0-13.8% (Williams, pers. comm.). Howell and Simpson (1985) found mortality rates were positively correlated with size, due mainly to the tendency for larger fish to take the hook deep in the esophagus or gills. Williams more clearly demonstrated increased mortality with depth of hook location, as well as handling time, but found no association with fish size. Based on these studies, a discard mortality rate in the recreational fishery of 15% appears reasonable and has been used in previous and the current assessments.

Commercial Fishery Landings at Length and Age

The intensity of commercial fishery biological sampling is summarized in Table 6. Annual sampling intensity varied from 27 to 687 mt per 100 lengths, with sampling exceeding the informal threshold criterion of 200 mt per 100 lengths sampled since 1994. For this assessment, commercial fishery landings at age beginning in 1984 have been updated through 2007, with samples generally pooled by market category (pins/small, medium, large/mix, jumbo, and unclassified) and half year period (January-June, July-December), with market category samples pooled on a quarterly basis for 2004-2007. Estimates of commercial fishery landings at age (Figure 3) and mean weights at age are presented in Tables 7-8.

Commercial Fishery Discards at Length and Age

The intensity of length frequency sampling of discarded scup from the NEFSC Observer Program declined in 1992-1995 relative to 1989-1991 (Table 9). Sampling intensity ranged from 489 to 335 mt per 100 lengths sampled in 1992-1995, failing to meet the informal criterion of 200 mt per100 lengths sampled. Sampling intensity improved to 100 mt per 100 lengths in 1996, but then declined to over 200 mt per 100 lengths in 1997-1999. Sampling intensity has generally met the 200 mt per 100 length threshold since 1999. The mean weight of the discard was estimated from length frequency data and a length-weight equation, with the total numbers discarded then estimated by dividing total discard weight by mean fish weight, and the numbers at length then calculated from the length-frequency distribution. Discards at length were aged using a combination of commercial and survey age-length keys, with discards at age dominated by fish aged 0, 1, or 2, depending on the year under consideration. Estimates of commercial fishery discards at age (Figure 4) and mean weights at age are presented in Tables 10-11.

Recreational Fishery Landings at Length and Age

In the recreational fishery, landings sampling intensity varied from 45 to 471 mt per 100 lengths. Sampling in all years except one (1984) during 1981-1987 failed to satisfy the above criterion, but since 1987 the criterion has been met except for 1999-2000 (Table 12). Numbers at length for recreational landings were determined based on available recreational fishery length frequency samples pooled by half year period over all regions and fishing modes, and were converted to numbers at age by applying half year period age-length keys constructed from NEFSC commercial and survey samples. Age-length keys from spring surveys and first and second quarter commercial samples were applied to numbers at length from the first half of the year, while age-length keys from fall surveys and third and fourth quarter commercial samples were applied to numbers at length from the second half of the year. Estimates of recreational fishery landings at age (Figure 5) and mean weights at age are presented in Tables 13-14.

Recreational Fishery Discards at Length and Age

As noted earlier, no length frequency distribution data on scup discard are routinely collected under the MRFSS program prior to 2005, so recreational discards were assumed to be fish less than state minimum sizes, in the same relative proportions at age as the landed catch less than the respective state minimum sizes (i.e., sub-legal fish of ages 0 and 1). This assumption for the coastwide fishery is supported by discard length frequency samples from the New York recreational fishery (1989-1991) and samples collected since 2005 by the MRFSS For-Hire Survey. Since 2005, the MRFSS For-Hire Survey discard samples have been used in concert with the MRFSS sub-legal landed lengths to directly characterize the length frequency of the recreational discard. As noted earlier, a 15% discard mortality rate is assumed. Estimates of recreational fishery discards at age (Figure 6) and mean weights at age are presented in Tables 15-16.

Total Fishery Catch

Estimates of the total fishery catch at age and mean weights at age for 1984-2004 (the time series is limited by the availability of sampled fishery ages) are presented in Tables 17-18.

An extended time series of the total catch of scup has been estimated to provide an historical perspective of the exploitation of scup in the years before fishery aging data were available (Table 19). These estimates include commercial and recreational landings and discards. The catches before 1981 are the least reliable due to uncertainty about a) the level of domestic commercial fishery discards, b) distant water fleet (DWF) catch, and c) assumptions to estimate the recreational catch (50% reduction from interpolations made in Mayo 1982 for 1960-1978; recreational discards assumed to be 2% of the adjusted recreational landings). For years in which no observer data were collected (prior to 1989), commercial discards were estimated using the mean of GMDL approach ratios for 1989-2001.

Research Vessel Survey Indices

NEFSC

The NEFSC spring and fall surveys provide long time series of fishery-independent indices for scup. The NEFSC spring and fall surveys are conducted annually during March-May and September-November, ranging from just south of Cape Hatteras, NC to Canadian waters. NEFSC spring and fall abundance and biomass indices for scup exhibit considerable inter-annual variability (Table 20). The 2002 spring SSB index (9.24 kg/tow) was about twice the second highest spring SSB index, which was observed in 1977 (4.35 kg/tow)(Figure 7). The spring numeric abundance indices are similar; in 2002, the estimated index of spring abundance is the highest observed in the series (154.86 fish/tow) and about twice the 1970 index (78.50 fish/tow). These dramatic increases were evident across all ages in the estimated 2002 spring numbers at age (Table 21; Figure 8). Fall survey estimates of numbers at age in 2001 did not reflect relatively large values from which corresponding 2002 spring numbers at age might be expected to derive (Table 22, Figure 9) , nor did they translate to exceptional indices of biomass or SSB in fall 2002 or spring 2003. Spring survey SSB and abundance indices decreased subsequent to 2002, but are still above the low values of the late 1990s. Fall survey abundance and biomass have been highly variable since 2002.

The NEFSC winter survey was started in 1992 primarily as a flatfish survey (used a different trawl net than the spring and fall surveys), was conducted during February, and ranged from Cape Hatteras, NC to the southwestern part of Georges Bank. The winter survey 2002 abundance and biomass indices were, like the spring survey, the largest of the time series (Table 23). Similar to the spring estimates, numbers at age estimated for the 2002 winter survey were also exceptionally large (Table 24, Figure 10). Winter survey abundance and biomass decreased subsequent to 2002, but were still above the low values of the late 1990s. The winter trawl series ended in 2007.

As noted in Sections 1-4, indices of scup SSB per tow were developed from the NEFSC spring offshore strata series for use as proxy biomass reference points. The 1998 SAW 27 panel (NEFSC 1998) selected a three-year moving average of the NEFSC spring SSB index as a representative measure of scup SSB, based on the characteristics of the survey age structure, the magnitude of the survey catch, and the trend in the extended series of commercial and total fishery catch estimated back to 1960 (Table 19, Figures 1-2). FMP Amendment 12 defined the biomass threshold reference point as the maximum (at the time) observed value of this three-year moving average: the 1978 value (mean of 1977-1979) of 2.77 SSB kg/tow (Table 20, Figure 2). FMP Amendment 14 defined the target biomass BRP as twice the threshold value of this three-year moving average, or 2 times 2.77 = 5.54 SSB kg/tow.

Massachusetts DMF

The Massachusetts Division of Marine Fisheries (MADMF) has conducted a semi-annual bottom trawl survey of Massachusetts territorial waters in May and September since 1978. Survey coverage extends from the New Hampshire to Rhode Island boundaries and seaward to three nautical miles including Cape Cod Bay and Nantucket Sound. The study area is stratified into geographic zones based on depth and area. Trawl stations are allocated in proportion to stratum area and are chosen randomly within each stratum. A 20 minute tow at 2.5 knots is made at each station with a 3/4-size North Atlantic two- seam otter trawl (11.9 m headrope, 15.5 m footrope) rigged with a 19.2 m chain sweep with 7.6 cm rubber discs. The net contains a 6.4 mm mesh codend liner to retain small fish. Approximately 95 stations are sampled during each survey. Standard bottom trawl survey techniques are used to process the catch of each species. Generally, the total weight (nearest 0.1 kg) and length frequency (nearest cm) are recorded for each species on standard trawl logs. Collections of age and growth structures, maturity observations, and pathology observations are taken. The MADMF spring survey catches are characterized mainly by scup of ages 1 and 2, while the fall survey often captures large numbers of age 0 fish. The spring biomass and abundance indices dropped sharply from a high in the early 1980s to relatively low levels through the remainder of the time series, with the exception of spikes in 1990, 2000, and 2002, the latter event in common with the NEFSC spring trawl survey (Table 25, Figure 11). The MADMF fall indices can include large numbers of age 0 fish, and on a numeric basis are more variable than the spring indices. The fall biomass index is less variable than the spring, however, and exhibits an increasing trend since the mid 1990s (Figure 12).

Rhode Island DFW

The Rhode Island Division of Fish and Wildlife (RIDFW) has conducted autumn and spring surveys since 1979 based on a stratified random sampling design. Three major fishing grounds are considered in the spatial stratification, including Narragansett Bay, Rhode Island Sound, and Block Island Sound. Stations are either fixed or randomly selected for each stratum. To maintain continuity in the number of stations sampled per stratum each season, an alternate list is generated for substitution in the event of an unexpected hang-up or questionable bottom type. At each station, a 3/4-scale High Rise bottom trawl is towed for 20 minutes at an average speed of 2.5 knots. The net average vertical opening is estimated at 10 feet. The otter trawl doors are 2 ft by 4 ft in dimension, set 7.5 fathoms ahead of the wings of the net. The RIDFW spring survey mainly catches scup of ages 1 and 2. The spring indices show relatively levels of scup abundance and biomass through 1999 followed by a steep increase during 2000-2002, in common with the NEFSC and MADMF indices. No scup were caught in the spring 2003 survey, but the index has since rebounded to pre-2000 levels (Table 26; Figure 11). The RIDFW fall survey is dominated by age 0 scup. Fall abundance indices show a general increase to its 1993 peak, followed by a steep decline until 1998, and a general increase since then, reaching a time series peak in 2007 (Figure 12).

Connecticut DEP

The Connecticut Department of Environmental Protection (CTDEP) trawl survey program was initiated in May 1984 and encompasses both New York and Connecticut waters of Long Island Sound. The stratified random design survey is conducted in the spring (April-June) and fall (September-October). Each survey consists of three cruises, with 40 stations sampled during each cruise, providing a sampling density of one station per 20 square nautical miles per cruise. Prior to 1990, the survey was conducted monthly from April to November. The CTDEP spring indices exhibit relatively low levels through most of the survey period, but have increased substantially since 1999 (Table 27, Figures 11 & 13). The CTDEP fall survey, which often catches large numbers of age-0 scup, indicates that recruitment was relatively stable during most of the survey period, but fall indices have also increased substantially since 1999 (Table 28, Figures 12 & 14). The age compositions of the CTDEP spring and fall surveys generally include a higher proportion of age 2 and older fish than the other state or NEFSC surveys (Figures 13-14).

New York DEC

The New York Department of Environmental Conservation (NYDEC) initiated a small mesh trawl survey in 1985 to collect fisheries-independent data on the age and size composition of scup in local waters. This survey is conducted in the Peconic Bays, the estuarine waters which lie between the north and south forks of eastern Long Island. Tows are 20 min in duration. The net used has a 16 ft headrope and a 19 ft footrope and is constructed of polypropylene netting with 1.5 in stretch mesh in the body and 1.25 in stretch mesh in the codend. No survey data are available for 2005. The NYDEC survey provides age 0, 1, and 2+ indices of scup abundance. The age 0 indices are generally low over the survey period, with peaks in 2000, 2002, 2003, 2006, and 2007 that may indicate recruitment of strong cohorts in those years (Table 29). In the early years of the survey there often has not been a strong correspondence between the age 0 indices and age 1 and 2+ indices in the following years (Figure 15).

New Jersey BMF

The New Jersey Bureau of Marine Fisheries (NJBMF) conducts a stratified random bottom trawl survey of New Jersey coastal waters from Ambrose Channel south to Cape Henlopen Channel. Latitudinal strata boundaries correspond to those in the NEFSC trawl survey; longitudinal boundaries correspond to the 30, 60, and 90 foot isobaths. Each survey includes two tows per stratum plus one additional tow in each of nine larger strata for a total of 39 tows. A three-in-one trawl with a 100 ft footrope, an 82 ft headrope, 3- 4.7 in mesh throughout most of the body and a 0.25 in mesh codend liner is used. From 1991 to present, the area has been surveyed in January, April, June, August, and October; from 1988-1990, February and December surveys were incorporated instead of the January survey. The NJBMF abundance and biomass indices exhibit variable patterns over the early part of the time series. The index reached a minimum in 1996, and has generally increased since then, reaching time series highs in numbers and biomass in 2007 (Table 29; Figure 11).

Virginia Institute of Marine Science (VIMS)

The Virginia Institute of Marine Science (VIMS) has conducted a juvenile scup survey in lower Chesapeake Bay during June-September since 1988. The VIMS age-0 scup survey shows a general decline in recruitment from relatively high levels with peaks in 1990 and 1993 to relatively low levels from 1994 to 2004, and the indication of stronger year classes in 2006 and 2007 (Table 29).

University of Rhode Island Graduate School of Oceanography (URIGSO)

University of Rhode Island Graduate School of Oceanography (URIGSO) has conducted a standardized, two-station trawl survey in Narragansett Bay and Rhode Island Sound since the 1950s, with consistent sampling since 1963. Irregular length-frequency samples for scup indicate that most of the survey catch is of fish from ages 0 to 2. The aggregate numbers-based index reached a peak in the late 1970s, was relatively low during the late 1990s, reached a second peak in 2002 in common with the NEFSC, MADMF, RIDFW spring biomass indices, and has since been variable at relatively high level (Table 30, Figure 11).

Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP)

The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) trawl survey is designed to support bay-specific stock assessment activities at both a single and multispecies scale. While no single gear or monitoring program can collect all of the data necessary for quantitative assessments, ChesMMAP was designed to fulfill data gaps by maximizing the biological and ecological data collected for several recreationally and commercially important species in the bay. Total abundance and biomass indices for scup mainly of age 0 and 1 are available since 2002, and indicate strong recruitment in 2005 and 2006 (Table 31).

Natural Mortality

Instantaneous natural mortality (M) for scup was assumed to be 0.20 (Crecco *et al.* 1981, Simpson *et al.* 1990). The largest/oldest scup sampled in NEFSC surveys (1973, 1978) were fish 38-41 cm (fork length) and 14 years old. The largest/oldest scup in NEFSC commercial fishery samples (1974) was 40 cm (fork length) and 14 years old.

Models of Fishing Mortality and Stock Size

Background Information

The 1998 SAW 27 Panel (NEFSC 1998) rejected an ADAPT VPA for scup as the basis for assessing stock status or as the basis for projections. The panel indicated that the amount of variance in the scup catch at age, particularly for the commercial discards, was unreasonably large. The Panel concluded that the precision of estimates of fishing mortality and stock size from the VPA was unacceptably low and would provide an unreliable basis for any estimates of stock size and fishing mortality rates (NEFSC 1998). The SAW 27 Panel also reviewed a surplus production model for scup developed in the ASPIC framework. The Panel noted that the inability to directly estimate historical commercial fishery discards (1968-1988) and recreational catch (1968-1978) cast uncertainty on the validity of the ASPIC absolute estimates of stock biomass, fishing mortality rates, and biological reference points. Since the ASPIC analysis suffered from many of the same input data inadequacies as the VPA, the SAW 27 Panel rejected the ASPIC analysis as a basis for stock status, projections, or reference points (NEFSC 1998).
State and NEFSC survey indices at age for scup are highly variable. The patterns in proportions at age in survey indices and survey catchability coefficients at age estimated in the VPA suggested that all ages of scup may not be equally available or susceptible to capture by survey trawl gear. As a result, the SAW 27 Panel noted that mortality estimates derived from survey catch at age indices are highly variable and may be positively biased, and are probably not a reliable basis for evaluating fishing mortality rates (NEFSC 1998). These conclusions about the lack of reliability of surplus production, VPA, or catch curve analyses for scup, due mainly to an inability to evaluate the uncertainty of results, have been supported by subsequent SAW Panel reviews of the scup assessment (NEFSC 2000, 2002).

In the absence of reliable analytical model results for scup, the 2000 SAW 31 Panel (NEFSC 2000) developed and the MAFMC Monitoring Committee has subsequently used a Relative Exploitation Index (REI) as a metric for the instantaneous fishing mortality rate (F). The scup REI is computed as the ratio of total fishery landings to the NEFSC spring trawl survey

SSB three year average index. Landings, rather than total catch, are used in the REI because of the relatively high uncertainty of commercial fishery discard estimates. The REI is therefore assumed to reflect the fishing mortality on age 2 and older scup because fishery landings and survey catch in the NEFSC spring SSB index are generally scup of ages 2 and older. The low REI values in the early 1980s were consistent with the Mayo (1982) assessment of scup (Figure 16; note that the REI is plotted on a log scale). There was a general increasing trend in the REI through the mid-1990s followed by a steady decline through 2001, with an increasing trend since 2001.

The 2000 SAW 31 Panel (NEFSC 2000) concluded that A ...catch curve analyses of survey indices indicate that F for ages 0-3 exceeds 1.0...for the 1994-1998 year classes.@ The 2002 SAW 35 Panel (NEFSC 2002) concluded, however, that AThough the relative exploitation rates have declined in recent years, the absolute value of F cannot be determined.@ In recent years, the MAFMC Monitoring Committee has used the REI as part of the assessment information used to recommend an annual Total Allowable Landings (TAL) for the stock. The MAFMC Monitoring Committee has assumed that F in 1999 was equal to 1.0 (NEFSC 2000), equating to an annual exploitation rate of 58%, which in turn equates to the 1999 REI = 62.4. An estimate of the current year exploitation rate has then been developed by assuming the same ratio between the current REI and exploitation rate, to provide advice on an appropriate level for the next year TAL.

The SAW 35 Panel (NEFSC 2002) reviewed an application of the NOAA Fisheries Toolbox model called AAn Index Method,@ or AIM, to scup fishery and survey catch data. That work used the extended total catch series noted earlier, and found that the NEFSC fall survey series provided a better model fit than the NEFSC spring series used as the basis for the biomass reference point and as input to the REI described earlier. The SAW 35 Panel (NEFSC 2002) noted that for scup, the AIM approach had A...considerable promise as a monitoring tool to evaluate stock trajectories and provide valuable information in interim years between analytical assessments@ and A...utility in presenting an integrated picture of stock dynamics for resources where only catch statistics and survey trends are available.@ While this approach was not adopted by the 2002 SAW 35 Panel to monitor the status of the stock, further research using the AIM model was recommended.

As noted earlier, the most recent update of the current stock assessment approach was completed in July 2008 to support the specification of fishery regulations for 2009. The update indicated that while the stock was overfished in 2007 (1.16 kg per tow, 21% of the biomass target of 5.54 kg per tow; Figure 16), the exploitation rate was at about the rebuilding target rate (9%; F = 0.10), suggesting that overfishing was not occurring in 2007. However, the stock rebuilding rate was slower than indicated by the FMP Amendment 14 projection, with the actual 2007 index (2006-2008 three-year average = 1.16 kg per tow) at only 56% of the forecast 2007 index (2.08 kg per tow).

An Index Method (AIM)

The AIM model (NFT 2008a) fits a relationship between time series of relative stock abundance, such as survey indices of abundance or biomass, and fishery catch data that might include landings and discards. Underlying the approach is a linear model of population growth, which characterizes the population response to varying levels of fishing mortality. If the underlying model is valid over the range of densities observed, AIM can be used to estimate the level of relative fishing mortality at which the population is likely to be stable (e.g., a proxy for

FMSY). The approach can be used to construct reference points based on relative abundance indices and catches, and to perform deterministic and stochastic projections to achieve a target stock size.

The basic calculations of the AIM model are two derived quantities, the Replacement Ratio (RR) and Relative F (RF). Replacement ratio is the ratio between the current year observed index and a smoothed value of the index over a given number of the current and previous years (typically 3 to 5), and is a measure of the trend in abundance or biomass of the population. Relative F is the ratio of the observed catch to a centered average index over a given number of years (typically 2 to 3). It should be noted that the application of any smoothing technique reflects a choice between signal and noise, with a greater degree of smoothing eliminating noise but possibly failing to detect a true change in signal (Rago 2001).

When fishing mortality rates exceed to capacity of a population to replace itself the population is expected to decline over time; likewise the population is expected to increase if fishing mortality rates are less than the capacity of a population to replace. In the AIM approach, the RR will have a stable point = 1 when the fishing mortality rate is in balance with recruitment and growth, resulting in a stable population. Robust regression techniques are used in AIM to estimate the RF ($RF_{threshold}$) corresponding to RR = 1. Values of RF in excess of $RF_{threshold}$ are therefore expected to lead to stock decline (i.e., fishing mortality exceeds FMSY), while RF values less than $RF_{threshold}$ would be expected to allow populations to increase. Randomization tests are used to test the null hypothesis that the input fishery catch and survey index time series represent a random ordering of observations with no underlying association, and that in turn the relationship between RR and RF is not spurious.

The AIM approach was tested with data for scup in the 2002 SAW 35 review (NEFSC 2002). An extended series of total catch beginning in 1963 and the NEFSC spring and fall biomass indices through 2001 were used as inputs. In the SAW 35 work, only the NEFSC fall series provided a statistically significant regression between the RR and RF, and results indicated that the RR first increased above 1.0 in 1996, and that the RF during 2000 was lowest of the time series. The SAW 35 work also indicted that re-examination of the reliance on the NEFSC spring survey series as the primary signal of stock abundance was warranted (NEFSC 2002).

The current AIM implementation for scup was tested over a range of degree of smoothing of both the RR and RF to explore the sensitivity of results to those inputs. Also, three different lengths of the extended catch time series (Table 19) were tested: beginning in 1963 (advent of the NEFSC trawl surveys), beginning in 1974 (to include the peak in NEFSC Surveys used as the basis for the current biomass reference point), and beginning in 1981 (to include the least number of assumptions for catch estimates). All of the available NEFSC and state agency survey series of stock biomass and abundance were initially tested for their utility in the AIM approach.

The best (i.e., a significant model at the p = 0.10 level) simple regression fits in AIM were provided by the NEFSC fall, URIGSO, NJBMF annual, and MADMF spring survey series (Figures 17-20). The MADMF and NJBMF series are too short to serve as the sole stock index for scup in the AIM model - neither series captures the historical peaks and trends in biomass. The 1974 and 1981 AIM run configurations suffer from the same shortcoming. The URIGSO, MADMF and NJBMF series also failed to satisfy the randomization test at the p = 0.10 level. These initial results indicated that only the NEFSC fall survey biomass index (Figures 17 and 19) provided acceptable fit statistics and other diagnostics within the AIM model framework.

In an attempt to include the recent information content of the multitude of state agency surveys as well as the historical perspective provided by the long-term NEFSC and URIGSO series, a model-based index including all of the index series in a GLM framework was developed. Alternative configurations included lognormal, Poisson, and negative binomial error distribution assumptions; Asurvey@ was used as the classification variable, with the Ayear@ classification variable coefficient acting as the index of abundance. The Working Group adopted the GLMALL index with Poisson error (Figure 21) for input to AIM based on the GLM model fit statistics and diagnostics. AIM results for the GLMALL index with Poisson error showed a significant regression model ($p < 0.10$) and feasible Relative F and Replacement Ratio results (Figure 22), but a failed randomization test.

These results suggest that the most appropriate AIM model would include only the NEFSC fall survey biomass index. However, the NEFSC spring and fall *Albatross IV* time series have ended, and even if reliably calibrated indices from the *Henry B. Bigelow* series can be developed (Figure 23), they will likely not be available for at least a few years. Thus, the Working Group concluded that the AIM results provided the impetus to explore a more complex statistical catch at age model (such as ASAP) that is better able to accommodate the numerous sources and relatively high uncertainty of both fishery and survey data for scup.

Age Structured Assessment Program (ASAP) Model

The fishery and research survey data for scup described earlier were used as input for the Age Structured Assessment Program (ASAP) statistical catch at age model in NFT version 2.0.17 (NFT 2008b). NEAMAP survey data were considered by the Data Poor Working Group but were not used to calibrate the scup population model. It was not clear that the NEAMAP data could serve as an abundance index yet given the very short survey time series and the high variance between seasons.

The ASAP model is able to estimate residuals (error) for the fishery catch components as well as for the survey indices used for calibration. The ASAP model also allows control in specifying the selection (partial recruitment) characteristics for both the fisheries and the surveys, in specifying the underlying stock-recruitment relationship, and in the relative emphasis of the different likelihood components that influence the model estimation results.

Initial Runs

The fishery catch data (aggregate catches in weight for 1963-2007; catches at age in number for 1984-2004) were input as four component fisheries (commercial landings, commercial discards, recreational landings, recreational discards; in aggregate weight and as number at age) and associated mean weights at age. Natural mortality (M) was set equal to 0.2, and maturity at age was set as in the SAW 27 assessment (NEFSC 1998) with proportions mature as follows: age 0 = 0.00, age 1 = 0.13, age 2 = 0.75, age 3 = 0.99, and age 4 and older = 1.00. In the initial ALL configuration, the following research survey abundance indices at age were used: NEFSC spring ages 1-4, NEFSC fall ages 0-4, NEFSC winter ages 1-4, CTDEP spring ages 1-6+, CTDEP fall ages 0-5+, NYDEC ages 0-1, and VIMS age 0. Aggregate biomass or abundance indices from the NEFSC winter, spring, and fall, MADMF spring and fall, RIDFW spring and fall, CTDEP spring and fall, NJBMF annual, and VIMS surveys were also used as input in initial runs. Fishery selectivity was estimated for two time periods: 1984-1996 and 1997-2007, with the break roughly coinciding with the advent of substantial regulatory changes in the fisheries (Amendment 8 in 1997 and Amendment 12 in 1998). Other model options (survey CVs, stock-recruit function CVs and lambdas, etc.) were configured to provide stable and feasible results. Alternative input data model configurations tested included a) only NEFSC surveys, b) only STATE surveys, and c) only NEFSC and URIGSO (NEC-URI) surveys.

The four initial model configurations (ALL, NEFSC, STATE, and NEC-URI) provided comparable time series trends in SSB and F through the late 1990s: high abundance and low F in the early 1960s, a decline and then rebuilding to a period of abundance in the late 1970s, and then a decline in abundance under high Fs in the mid-1980s to mid-1990s resulting in a period of low abundance in the late 1990s. The alternatives differed substantially in the development of the stock since 2000, and in the estimate of current abundance with respect to the previous peak in the late 1970s, mainly as a result of differing estimates of recruitment since the late 1990s (Figures 24-26). The STATE run provided the highest recent estimates of SSB, due to the scaling of recent large year classes (with the notable exception of 2006) about 50% higher than the ALL run and 100% higher than the NEFSC and NEC-URI runs. Comparison of the alternative estimates of SSB and F with ASAP internally calculated BRPs indicates that the stock in 2007 was about two to four times SSBMSY, with Fs at about 20-50% of FMSY (Figure 27).

Modifications to Survey Input Data

The initial runs indicated that the stock should be considered to be fully rebuilt with no overfishing. With a stock at that level of abundance, there is an expectation that both fishery and survey catches would reflect a robust age structure with significant numbers of older fish. There is evidence of expansion of the age structure of the fishery catch since about 2000 (Figures 3-6), likely reflecting the combined effects of a) increasing minimum retention sizes b) more restrictive trip limits in the fisheries, c) recent decreases in quotas/harvest limits and d) real increases in recruitment and subsequently SSB.

However, there is little evidence of substantial expansion of the age structure of the stock in the survey catches (Figures 8-10, 15), except for the CTDEP survey catches (Figures 13-14). Previous and current reviews of the scup research trawl survey data have noted that the catchability and/or availability of age 3 and older fish is likely reduced compared to age 0-2 fish. The NEFSC survey catches likely reflect this higher catchability of ages 0-2 relative to older fish (ages 3 and older), and so the aggregate biomass indices likely reflect mainly the abundance of ages 0-2, but not of ages 3 and older. Examination of the available length and age frequencies suggests the same properties likely apply to the MADMF, RIDFW, URIGSO, NYDEC, and ChesMMAP indices for scup. The CTDEP survey catches, however, are distributed across ages more in line with realistic total mortality rates, suggesting that the CTDEP survey older age indices (ages 3 and older) may be reflective of true abundance, with aggregate indices in turn more reflective of total stock biomass (Figures 13-14).

In an attempt to resolve the inconsistent signals provided by the fishery and survey catches, a number of modifications were made to the input survey data and to the manner in which the survey data are modeled in ASAP. For the NEFSC survey indices at age, input data were limited to the age 0-2 indices. The NEFSC long-term aggregate biomass indices were recompiled with a length cut-off at age 2 (winter = 22 cm; spring = 20 cm; fall = 23 cm; Figures 28-30), and selectivity (selex) within the ASAP model limited to ages 0/1 to 2. The consistency of rank order and trends between the original and modified NEFSC aggregate indices indicates that those series best index the abundance and biomass of ages 0/1 to 2.

For the MADMF, RIDFW, NJBMF, and URIGSO aggregate indices, selectivity within the ASAP model was also limited to ages 0/1 to 2. Alternative runs were made with different inputs and assumptions for the CTDEP indices, to test the inclusion of age 3 and older indices and aggregate indices, and correspondingly varying the selectivity of the aggregate indices. The newly modified runs are identified as:

Sep08_ALL: All indices, all ages, aggregate index selex for ages 0/1 to 7+
SV0to2: Use only age 0-2 indices, no aggregate indices
SV0to2_AGG0to2 Use only age 0-2 indices, aggregate indices selex for age 0/1 to 2
SV0to2_AGG0to2_CTALL: Use all CT indices, CT aggregate indices selex for ages 0/1 to 7+

The modified runs generally provided a different recent pattern of stock biomass in relation to the early 1960s and late 1970s peaks compared to the four initial runs, and also higher recent biomass in absolute terms. The four initial run estimates of SSB in 2007 ranged from 55,000 mt to 140,000 mt (Figure 24); the four modified run estimates ranged from 90,000 mt to 180,000 mt (Figure 31). The Sep08_ALL run, which includes some additional input data series (URIGSO, ChesMMAP and updated NYDEC) and some modifications to initial settings, provided results closest to the initial ALL run.
The two modified runs with older ages excluded from both the at-age and aggregate indices (SV0to2 and SV0to2_AGG0to2) estimated higher recent recruitment and thus lower recent F and higher recent SSB than the Sept08_ALL run (Figures 31-33). The run including all ages in the CTDEP indices (SV0to2_AGG0to2_CTALL) estimated extremely high recent recruitments (three year classes > 300 million age 0 fish) and correspondingly low F and high SSB. The SV0to2_AGG0to2_CTALL run had the poorest diagnostics of the four runs, in terms of a) large residuals for many of the survey indices, b) relatively poor fits to the estimated commercial and recreational fishery aggregate discards, and c) relatively poor fits to the estimated commercial and recreational fishery discards at age. For those reasons, the SV0to2_AGG0to2_CTALL configuration was not considered further.

The other three runs had comparable residual patterns and fits to the estimated catches. Four objective function components, a) fishery total catch, b) fishery age compositions, c) survey indices (age compositions plus aggregate indices), and d) recruitment deviations, account for 99% of the total objective function for all four modified runs. With the SV0to2_AGG0to2_CTALL excluded, the remaining three runs had comparable objective function distribution and fit diagnostics. Figure 34 shows that restricting the input survey data to only the age 0-2 indices (run SV0to2) shifts more of the influence on the model solution to the fishery catch (total and age composition) components, compared to the other runs that also include aggregate indices (whether restricted to ages 0-2 or allowed to include older ages). The SV0to2 run does not include the long-term aggregate indices that are included in the Sep08_ALL and SV0to2_AGG0to2 runs, fishery independent data that increases the precision of historical stock size estimates in those runs. However, run Sep08_ALL includes indices at age 3 and older that are less likely to be reflective of true abundance than indices for ages 0-2. Therefore, by elimination of configurations with diagnostic or data fit concerns, the SV0to2_AGG0to2 run was carried forward for further examination of the sensitivity of the model to changes in configuration.

The next step was to examine the retrospective performance of the SV0t2_AGG0to2 run to judge its= potential utility to reliably monitor the stock. Six retrospective peels (a seventh, terminal year 2001 retrospective peel did not converge) indicated that the SV0to2_AGG0to2 run was stable with little retrospective pattern evident in SSB, F, or R (Figure 35).

Sensitivity to Fishery Catch Lambdas (Weighting Factors) and Time Series Length

Next, model sensitivity to fishery catch lambdas (the weighting or emphasis factors on the four aggregate fishery catch components) was examined. The initial and modified runs described earlier were made with lambdas set at 0.10 (i.e., CV = 10%) for all four aggregate fishery catch components. Further sensitivity runs were made with lambda set at 0.10 for commercial landings and 0.20 for the commercial discards, recreational landings, and recreational discards (run CAT20); with 0.10 for commercial landings and 0.30 for the commercial discards, recreational landings, and recreational discards (run CAT30); with 0.10 for commercial landings and 0.60 for the commercial discards, recreational landings, and recreational discards (run CAT60); with 0.10 for commercial landings and lambda changing from 0.30 to 0.10 in 1981 for the commercial discards, recreational landings, and recreational discards (run CAT30to10); and with 0.10 for commercial landings and lambda changing from 0.60 to 0.30 in 1981 for the commercial discards, recreational landings, and recreational discards (run CAT60to30). The 1980/1981 time split coincides with the more reliable estimation of recreational catches.

The results of the SV0to2_AGG0to2 run configuration were sensitive to the catch lambda specifications. The 1980/1981 time split in the CAT30to10 and CAT60to30 runs did not have an important effect on the results. However, the change from lambdas of 0.10 to lambdas of 0.20 and higher did have an important effect on SSB results, as reflected by the Ashift@ from the initial SV0to2_AGG0to2 and CAT30to10 runs (all recent catch lambdas set at 0.10) to the runs with recent commercial discards, recreational landings, and recreational discards lambdas set at 0.20 or higher. Results for F and R were less strongly affected. Lambdas reflecting greater uncertainty of the magnitude of commercial discards and recreational catch resulted in lower recent estimates of SSB and a different relationship between current estimates and previous peaks in SSB in the 1960s and late 1970s (Figure 36-38). This result occurs because the influence of the survey indices in these run configurations is mainly restricted to ages 0-2, and so the magnitude and uncertainty of the input fishery catches has the strongest influence on estimates of recent SSB.

The input assumptions for the age range for which the survey indices can be considered reliable, and the estimate or assumption for the uncertainty of the input fishery catch, both have strong influence on the model results. Based on the work presented earlier, an assumption that most survey indices are likely to be reflective of true abundance only for ages 0 to 2 is appropriate - hence the subsequent work using run SV0to2_AGG0to2 as a basis. Further investigation of the empirical precision of the commercial fishery discards and recreational catches indicated that the precision of commercial fishery discards averaged (unweighted average of annual PSE) 39% for 1997-2007 (Table 4) and 32% for the entire NEFSC Observer Program sample period (1989-2007). The precision of recreational fishery landings (catch types A+B1 numbers) during 1981-2007 averaged 10%; the precision of recreational fishery discards (catch type B2 numbers) during 1981-2007 averaged 12%. A new run, BASE_Nov08, was configured to reflect this empirical information about the uncertainty of the fishery catch for scup, with commercial landings lambda assumed to be 0.10, commercial discards lambda set at 0.32, recreational landings lambda set at 0.10, and recreational discards lambda set at 0.12; for all years 1963-2007. The results of the BASE_Nov08 run were similar to the sensitivity runs with commercial discard and recreational catch lambdas of 0.20 and greater, indicating that the current magnitude of SSB is about the same as in the 1960s and higher than in the late 1970s, with very low current F and several very large year classes recruiting to the stock since 2000 (Figure 39-41).

A sensitivity exercise was conducted to test the influence of the length of the catch time series modeled. The BASE_Nov08 time series includes a time series of fishery catches extended back to 1963, using ratios to extend the commercial discards (1963-1988) and recreational landings and discards (1963-1980; Table 19). The BASE81_Nov08 run was configured to include only fishery and survey data from 1981-2007, the time period for which most of the fishery catches are reported or estimated from sampling, rather than extrapolated from ratios. The shorter time series provided 10-30% lower estimates of SSB during the early 1980s, and 10-20% higher estimated of SSB since 2003, when compared to the 1963-2007 BASE_Nov08 run (Figure 42). Patterns and levels of F and R were very similar, however (Figures 43-44). The BASE_Nov08 run SSB varied from about 103,000 mt in 1963 to a time-series low of 4,100 mt in 1995 to a time-series high of 107,100 mt in 2007; Fs varied from a high of 1.13 in 1993 to a low of 0.06 in 2007; recruitment varied from a low of 32 million age 0 fish in 1996 to a high 367 million in 2007. The BASE81_Nov08 run SSB varied from a low of 4,200 mt in 1995 to a high of 122,700 mt in 2007; Fs varied from a high of 1.14 in 1994 to a low of 0.06 in 2007; recruitment varied from a low of 35 million age 0 fish in 1996 to 308 million in 2007. Biological Reference Points calculated from the BASE_Nov08 and BASE81_Nov08 runs are presented in Figure 45. Given the similarity of the results, the November 2008 Working Group decided to use to the BASE_Nov08 runs with the full 1963-2007 time series as the basis for further model development.

Sensitivity to 2002 Survey and Commercial Discard Estimates

The next step in model development was to add preliminary fishery catch at age estimates for the four fishery fleets for 2004-2006, which provided model run configuration BASE_C2006. The November 2008 Working Group reviewed the diagnostics of the BASE_C2006 run in detail, and noted that some components of the calendar year 2002 survey data and the 2002 commercial fishery discard aggregate estimate provided large residuals (Figure 46-48). The unusually high values for many survey indices in 2002 has been noted previously, and is presumed to result mainly from increased availability of fish to the surveys, especially during the first half of 2002, rather than true increases in abundance (e.g., Figures 7-8, 11). The same type of availability event may have affected the 2002 commercial fishery discard sampling, resulting in higher than usual discard rates and increased estimated discards at age in 2002 (Figure 4). To explore the sensitivity of the ASAP model for scup to these data, two new runs were configured. The first, BASE_C2006_No02SV, dropped all the calendar year 2002 survey indices (at age and aggregate) from the model fit. The second, BASE_C2006_No02SV_NoCD02, also dropped the 2002 commercial fishery discard estimates at age and used the average of the 2001 and 2003 estimates as a substitute for the 2002 aggregate discard weight.

Figures 49-51 summarize the results of these BASE_C2006 runs. The BASE_C2006 run with fishery catch at age through 2006 provided results very similar to the BASE_Nov08 run with fishery catch at age through 2004, with SSB in 2007 estimated at just over 100,000 mt, F in 2007 estimated at about 0.05, and the large recent recruitments in 2000 and 2007 estimated at 300-400 million fish. Dropping the 2002 survey indices in the BASE_C2006_No02SV run increased the SSB in 2007 to about 125,000 mt, substantially reduced the 2002 recruitment estimate from about 296 million to 156 million fish, changed the pattern of recruitment so that the 1999 year class (212 million) was larger than the new estimate of the 2000 year class, and increased the estimated of recruitment in 2007 to about 376 million fish. Dropping the 2002 Commercial Discards at age and substituting for the high 2002 aggregate discard in weight in the BASE_C2006_No02SV_No02CD run had relatively little additional effect on results, other than eliminating the large residual for the 2002 estimate, and so the November 2008 Working Group decided to retain the original 2002 commercial fishery discard estimates in subsequent model runs.

The November 2008 Working Group extensively debated whether it was appropriate to exclude the 2002 survey data in a BASE case run for subsequent development. It was noted that the model Acompensated@ for the missing data, changing the rank order of recruitments over the last decade, and increasing the size of the 2007 year class. It was also noted that there may have been other abrupt, but substantial Apositive availability@ events that have occurred in the past (e.g., NEFSC spring survey in 1977, NEFSC fall survey in 1976, 1989, and 1999; Table 20, Figure 7), that were not being considered for exclusion from the analysis. Likewise, there may have been several abrupt, but substantial Anegative availability@ events that have occurred (e.g., NEFSC spring 2003, 2005, and 2007, NEFSC fall 2005), and no exclusion was being considered for those possible events. The November 2008 Working Group found it difficult to develop an objective justification for the exclusion of the 2002 survey data, and so they were retained in subsequent model runs.

Alternative Assumptions for Natural Mortality (M)

A range of alternative assumptions for the instantaneous natural mortality rate (M) was tested in a series of runs derived from the BASE_C2006 run. The values ranged from 0.10 to 0.40, in runs BASE_C2006_M10 to BASE_C2006_M40. A sensitivity profile indicated that the ASAP model for scup fit best (lowest total likelihood value) at M = 0.10 (Figure 52). This was considered a counter-intuitive result, as most members of the November 2008 Working Group expected a higher value of M (e.g., in the 0.3-0.4 range) to perform better, given the maximum observed age in survey and fishery samples of 14 years, and configuration of the model with an oldest age group of 7-plus. Those expectations were not born out by the results, however, and so the November 2008 Working Group retained the initial assumption of M = 0.2 for all ages in subsequent model runs.

Update with final 2004-2007 Catches: BASE_C2007 runs

Final fishery catch at age estimates for 2004-2007 became available in mid-November 2008, after the November 2008 Working Group meeting, and model runs including these data were called BASE_C2007 runs. In the BASE_C2007 and all previous runs, the same mid-year mean weights at age were used for the total catch, January 1 total stock biomass, and June 1 SSB mean weights at age. Once the fishery catches at age were finalized through 2007, mean weights for the January 1 and SSB biomass were re-calculated using the Rivard method (NFT 2008c), to provide run BASE_C2007_RIV. As a final model tuning step, the ratio of the estimated Effective Sample Sizes (ESS) to the input ESS was calculated for the four fishery fleets, and the ratio used to adjust the ESS for the final run, BASE_C2007_T1.

Figures 53-55 summarize comparative results for the runs configured during and since the November 2008 Working Group meeting. The addition of the preliminary 2004-2006 fishery catches at age to the BASE_Nov08 run to create the BASE_C2006 run had a very minor effect on the results. The addition of the final 2004-2007 catches at age to create the BASE_C2007 run had a slightly larger effect on recent trends, increasing the SSB in 2007 from 103,000 mt to about 113,000 mt, and increasing recruitment in 2000 (from 297 million to 302 million) while decreasing recruitment in 2007 (from 364 million to 305 million). Re-calculation of the mean weights at age in the BASE_C2007_RIV run affected only the SSB estimates by increasing the recent estimates by a few percent, with the SSB in 2007 increasing from 113,000 mt to 121,000 mt. The final tuning of the ESS created the final run BASE_C2007_T1, with a slight decrease in SSB and R in recent years compared to the previous run, and an estimate of SSB in 2007 of 119,000 mt, F of 0.054, and recruitment in 2007 of 308 million fish. The December 2008 Northeast Data Poor Stocks Peer Review Panel accepted the BASE_C2007_T1 ASAP run as the basis for subsequent calculation of biological reference points and status evaluation. Run BASE_C2007_T1 did not exhibit substantial retrospective patterns in SSB, F, or R (Figures 56-58).

Summary estimates, estimated January 1 stock size at age in numbers, and estimated fishing mortality (F) at age from the accepted BASE_C2007_T1 run for 1984-2007 (the years with input fishery catches at age) are provided in Tables 32-34. Spawning stock biomass (SSB) decreased from about 102,000 mt in 1963 to about 50,000 mt in 1969, then increased to about 75,000 mt during the late 1970s (Figure 53). SSB declined through the 1980s and early 1990s to only 4,000 mt in 1995. With greatly improved recruitment and low fishing mortality rates since 2000, SSB has steadily increased since to about 113,000 mt in 2007 (Table 32, Figure 53). There is an 80% chance that SSB in 2007 was between 111,204 and 130,120 mt (Figure 59). Fishing mortality varied between F = 0.100 and F = 0.274 during the 1960s and 1970s (Figure 54). Fishing mortality increased steadily during the 1980s and early 1990s, peaking at F = 1.120 in 1994. Fishing mortality decreased rapidly after 1994, falling to less than F = 0.100 since 2004, with F in 2007 = 0.054 (Table 32, Figure 54). There is an 80% chance that F in 2007 was between 0.048 and 0.060 (Figure 60). Recruitment at age 0 averaged 91.4 million fish during 1963-1983, the period during which recruitment estimates are influenced mainly by the internal ASAP stock-recruitment relationship (Figure 55). Since 1984, recruitment estimates are influenced mainly by the fishery and survey catches at age, and recruitment at age 0 averaged 119.6 million fish during 1984-2007, with the 2000 and 2007 year classes estimated to be the largest of the time series, at 311.2 and 307.9 million age 0 fish (Table 32, Figures 55 and 61).

Recommended Biological Reference Points and Status Determination

The December 2008 Northeast Data Poor Stocks Peer Review Panel accepted the BASE_C2007_T1 ASAP run as the basis for biological reference points and status determination for scup. Biological reference points were calculated using the non-parametric yield and SSB per recruit/long-term projection approach recently adopted for summer flounder (NEFSC 2008a) and New England groundfish stocks (NEFSC 2008b). In the yield and SSB per recruit calculations, the most recent five year averages were used for mean weights and fishery partial recruitment pattern (Table 35). For the projections, the cumulative distribution function of the 1984-2007 recruitments (corresponding to the period of input fishery catches at age) was re-sampled to provide future recruitment estimates (mean = 117.2 million age 0 fish).

The Peer Review Panel recommended $F_{40\%}$ as the proxy for F_{MSY}, and the corresponding $SSB_{F40\%}$ as the proxy for SSB_{MSY}. The F40% proxy for F_{MSY} = 0.177, the proxy estimate for SSB_{MSY} = 92,044 mt, and the proxy estimate for MSY = 16,161 mt (13,134 mt of landings, 3,027

mt of discards). The stock biomass threshold of ½ SSB_{MSY} = ½ $SSB_{40\%}$ = 46,022 mt = 101.461 million lbs.
The 2007 F estimate of 0.054 is 31% of F_{MSY} = 0.177, indicating no overfishing was occurring. The 2007 SSB estimate of 119,343 mt is 30% above SSB_{MSY} = 92,044 mt, indicating the stock was not overfished. Total catch (landings + discards) was 7,867 mt in 2007, about 49% of MSY (Table 36). Estimates of biomass and catch reference points corresponding to F_{MAX} and $F_{35\%}$ are also listed in Table 36 for comparison.

Uncertainty and Risk for Scientific and Statistical Committees (SSCs) to Consider

The accepted ASAP model of scup population dynamics and recommended BRPs provides a more stable tool for monitoring stock status and specifying annual fishery regulations than the current single index-based model. The ASAP model integrates a broad array of fishery and survey input data and should be less sensitive to inter-annual changes in any single data component than the current model. The accepted model results and recommended BRPs indicate that the stock was above the SSB_{MSY} proxy and being fished at below the F_{MSY} proxy in 2007. This status represents a significant change from the July 2008 biomass status update, which indicated that the stock was overfished in 2007 (NEFSC spring SSB three-year average index = 1.16 kg per tow, 21% of the biomass target of 5.54 kg per tow) and rebuilding more slowly than indicated by the Amendment 14 projection (see Section 3). The current REI proxy for F did indicate that F in 2007 was low (about 0.10) and therefore was not experiencing overfishing, in accord with the accepted ASAP model.

The 2007 stock abundance indicated by the accepted model is the result of historically low fishing mortality rates and historically high levels of recruitment since about 2000 (Figures 53-55). Age 0 fish accounted for about 40% of the stock size in 2007 due to the large size of the 2007 year class, but the relative percentages of the age 1 and older fish are within of few percent of what might be expected in the stock if it was fished at Fmax = 0.283 over the long-term (Figure 62). The age 7+ fish accounted for about 6% of the stock size in 2007. The model results indicate that stock has not been fished at low levels of F long enough to accumulate as high a percentage in the age 7+ group (16%) as would be expected if fished at F = 0.05 over the long-term (Figure 62). Since 2000, a high proportion of the SSB has accumulated at ages 3 and older (those expected to be fully mature). The percentage of SSB in 2007 at fully mature ages 3-6 (56%) is near what would be expected if the stock were fished at F = 0.050 over the long-term (46%), while the age 7+ fish accounted for about 35% of the SSB in 2007 (Figure 63).

A retrospective look at historical stock assessments for scup shows that the accepted ASAP model estimates of SSB and R are comparable to those previously estimated for the same time period in the 1995, 1997 and 1998 assessments using ADAPT VPA; estimates of F are somewhat higher in the VPA assessments (NEFSC 1995, 1997, 1998) (Figures 64-66). The 1995 SAW19 assessment was the last accepted peer-reviewed analytical assessment. The analytical components of the 1997 and 1998 assessments were not accepted as valid bases for assessing the stock. The historical analyses used input fishery and research survey data time series beginning in 1984.

The recommended MSY proxy for scup in terms of total catch is 16,161 mt (35.6 million lbs), with total landings of 13,134 mt (29.0 million lbs) and total discards of 3,027 mt (6.7 million lbs). The extended catch series estimated for scup (Table 19) indicates that this MSY proxy is a feasible estimate. Total fishery catch is estimated to have averaged about 34,000 mt

(75.0 million lbs) during 1960-1965, while reported commercial landings alone averaged about 19,000 mt (41.9 million lbs) in that period (Table 19 and Figure 1).

While the accepted long-term MSY estimate appears feasible given historical evidence from the fishery, managers may wish to take an adaptive approach to the specification of fishery quotas in the short-term. Total fishery landings over the last five years (2003-2007) have averaged 6,214 mt (13.7 million lbs). If the stock is fished at F40% = 0.177 over the long-term, the corresponding annual total MSY landings would be 13,134 mt (29.0 million lbs), more than double the recent five year average. The Peer Review Panel recommended that "…rapid increases in quota to meet the revised MSY would be unwarranted given uncertainties in recruitments. A more gradual increase in quotas is a preferred approach reflective of the uncertainty in the model estimates and stock status."

Research Recommendations

Short term analytical tasks

a) Evaluation of indicators of potential changes in stock status that could provide signs to management of potential reductions of stock productivity in the future would be helpful.

b) A management strategy evaluation of alternative approaches to setting quotas would be helpful.

Long term data and analytical needs

a) Current research trawl surveys are likely adequate to index the abundance of scup at ages 0 to2. However, the implementation of new standardized research surveys that focus on accurately indexing the abundance of older scup (ages 3 and older) would likely improve the accuracy of the stock assessment.

b) Continuation of at least the current levels of at-sea and port sampling of the commercial and recreational fisheries in which scup are landed and discarded is critical to adequately characterize the quantity, length and age composition of the fishery catches.

c) Quantification of the biases in the catch and discards, including non-compliance, would help confirm the weightings used in the model. Additional studies would be required to address this issue.

d) The commercial discard mortality rate was assumed to be 100% in this assessment. Experimental work to better characterize the discard mortality rate of scup captured by different commercial gear types should be conducted to more accurately quantify the magnitude of scup discard mortality.

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Scup; Tables

Table 1. Commercial landings (mt) of scup by state. One mt was landed in DE in 1995, included with MD 1995 total. Eight mt was landed in PA in 2004 included with MD 2004 total. Landings include revised Massachusetts landings for 1986-1997.

Year	ME	MA	RI	CT	NY	NJ	MD	VA	NC	Total
1979		782	3,123	92	1,422	2,159	21	397	589	8,585
1980	1	706	2,934	17	1,294	2,310	32	531	599	8,424
1981		523	2,959	44	1,595	2,990	9	1,054	682	9,856
1982		545	3,203	25	1,473	1,746	2	1,042	668	8,704
1983		672	2,583	49	1,103	2,536	13	536	302	7,794
1984		540	2,919	32	904	2,217	6	673	478	7,769
1985		387	3,583	41	861	1,493	17	74	271	6,727
1986		875	2,987	67	893	1,895	14	273	172	7,176
1987	5	735	2,162	301	911	1,817		232	113	6,276
1988	9	536	2,832	359	687	1,334	1	127	58	5,943
1989	32	579	1,401	89	603	1,219	1	45	15	3,984
1990	4	696	1,786	165	755	1,005	4	75	81	4,571
1991	16	553	2,902	287	1,223	1,960	15	56	69	7,081
1992		655	2,676	193	1,043	1,475	17	73	127	6,259
1993		556	1,332	148	729	1,822	10	76	53	4,726
1994		354	1,514	142	688	1,456	7	92	139	4,392
1995		310	1,045	90	511	1,084	2	20	11	3,073
1996		436	773	99	377	1,141	20	72	27	2,945
1997		676	486	50	376	596	1	2	1	2,188
1998		435	361	44	282	758	5	4	7	1,896
1999		300	581	44	206	361		13		1,505
2000		161	461	65	287	232		1		1,207
2001		149	734	45	297	479	1	24		1,729
2002		330	1,668	4	714	419		25	13	3,173
2003		407	1,730	64	839	1,033	21	253	58	4,405
2004		353	1,562	116	865	862	21	203	249	4,231
2005		515	1,553	149	989	880	1	130	50	4,266
2006		493	1,653	135	1,096	632	0	36	17	4,062
2007		501	1,785	118	1,054	714	1	10	13	4,196
mean	11	509	1,906	106	830	1,332	10	212	187	5,074

Table 2. Commercial landings (mt) of scup by major gear types. Midwater paired trawl landings are combined with other gears during 1994 and later. Landings include revised Massachusetts landings for 1986-1997.

Year	Otter trawl	Paired trawl	Floating trap	Pound net	Pots and traps	Hand lines	Other gear	Total mt
1979	6,387	146	1,305	429	26	215	77	8,585
1980	6,192	160	1,559	194	8	303	8	8,424
1981	7,836	79	1,291	246	49	306	49	9,856
1982	6,563	104	1,514	244	9	226	44	8,704
1983	5,861	398	850	390	8	265	22	7,794
1984	5,617	272	1,266	295	8	287	24	7,769
1985	4,856	417	1,022	229	5	182	16	6,727
1986	5,163	540	629	332	9	493	10	7,176
1987	4,607	237	590	193	213	423	13	6,276
1988	4,142	166	1,052	53	44	396	90	5,943
1989	3,174	89	193	74	104	334	16	3,984
1990	3,205	200	505	60	239	340	22	4,571
1991	5,217	152	988	40	258	395	31	7,081
1992	4,371	94	934	67	303	450	40	6,259
1993	3,865	46	166	25	202	402	20	4,726
1994	3,416		331	79	76	340	150	4,392
1995	2,204		331	42	57	215	224	3,073
1996	2,196		229	8	120	374	18	2,945
1997	1,491		86	12	104	489	6	2,188
1998	1,379		11	4	98	390	14	1,896
1999	1,005		140	30	77	184	69	1,505
2000	773		56		78	205	95	1,207
2001	1,088		229	65	52	215	80	1,729
2002	2,084		220		221	450	198	3,173
2003	2,777		723		168	445	292	4,405
2004	3,767		20		121	196	127	4,231
2005	3,475		117		174	448	52	4,266
2006	3,422		106		201	291	42	4,062
2007	3,332		181		279	373	31	4,196
mean	3,775	207	574	141	114	332	65	5,074

Table 3. Summary NEFSC Domestic Observer program data for scup. Geometric mean discards to landings ratios (GMDL; retransformed, mean ln-transformed D/L per trip) are stratified by half-year period (HY1, HY2) and trip landings level (< 300 kg, => 300 kg). N is the number of observed trips with both scup landings and discard, which are used to calculate the per-trip discard to landings ratios. Corresponding dealer landings are from the NEFSC database.

1997		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.8957	17	258	231	0.8221	4	1,244	1,023
HY 2	0.8957	0	279	250	0.8221	0	413	340
Total			537	481			1,657	1,362

1998		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	2.401	7	196	471	121.71	1	920	111,973
HY 2	3.126	10	281	878	121.71	0	496	60,368
Total			477	1,349			1,416	172,341

1999		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	1.742	6	245	427	3.766	2	785	2,956
HY 2	1.742	0	178	310	3.766	0	299	1,126
Total			423	737			1,084	4,082

Table 3 continued .

2000		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	4.5818	13	196	898	0.6018	2	655	394
HY 2	3.5001	1	292	1,022	0.6018	0	63	38
Total		14	488	1,920		2	718	432

2001		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.8916	10	180	160	0.9185	4	1,013	930
HY 2	0.4606	2	307	141	0.9185	0	290	266
Total		14	487	302		4	1,303	1,197

2002		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	2.6088	11	423	1,104	0.0653	2	1,484	97
HY 2	3.4522	12	829	2,862	3.6028	3	437	1,574
Total		23	1,252	3,965		5	1,921	1,671

Table 3 continued .

2003		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.1371	9	315	43	0.2560	2	2,473	633
HY 2	1.4299	4	921	1,317	0.2304	5	696	160
Total		13	1,236	1,360		7	3,169	793

2004		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.3370	40	344	116	0.1685	25	2,353	396
HY 2	0.4200	64	868	365	0.0309	10	550	17
Total		104	1,212	480		35	2,903	413

2005		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.7354	31	292	215	0.0732	7	2,390	175
HY 2	0.2740	67	850	233	0.0563	2	694	39
Total		98	1,142	448		9	3,084	214

Table 3 continued .

2006		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.6621	37	472	313	0.0740	10	1,814	134
HY 2	0.8573	40	814	698	0.2631	10	921	242
Total		77	1,286	1,010		20	2,735	377

2007		Trips <300 kg				Trips =>300 kg		
Period	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)	GM D/L	N	Dealer Landings (mt)	Estimated Discard (mt)
HY 1	0.4821	41	461	222	0.2628	10	2,177	572
HY 2	0.9404	54	892	839	0.3389	7	666	226
Total		95	1,353	1,061		17	2,843	798

Table 4. A summary of landings, discards, and geometric mean discards to landings ratio (GMDL), 1997-2007.

Year	Landings (mt)	GMDL Discards (mt)	GMDL D:L ratio	GMDL Discards PSE (%)
1997	2,188	1,843	0.84	61
1998	1,896	173,690	91.61	32
1999	1,507	4,819	3.20	9
2000	1,207	2,352	1.95	48
2001	1,729	1,499	0.87	32
2002	3,173	5,636	1.78	95
2003	4,405	2,153	0.49	41
2004	4,231	893	0.21	25
2005	4,226	662	0.16	29
2006	4,062	1,387	0.34	27
2007	4,196	1,859	0.44	26

Table 5. Total catch (mt) of scup from Maine through North Carolina. Landings include revised Massachusetts landings for 1986-1997. Commercial discards for 1984-1988 calculated as the geometric mean ratio of discards to landings numbers at age for 1989-1993. Commercial discards estimate for 1998 is the mean of 1997 and 1999 estimates.

Year	Commercial Landings	Commercial Discards	Recreational Landings	Recreational Discards	Total Catch
1981	9,856	n/a	2,636	n/a	12,492
1982	8,704	n/a	2,361	n/a	11,065
1983	7,794	n/a	2,836	n/a	10,630
1984	7,769	2,158	1,096	30	11,053
1985	6,727	4,184	2,764	54	13,729
1986	7,176	2,005	5,264	87	14,532
1987	6,276	2,537	2,811	38	11,662
1988	5,943	1,657	1,936	31	9,567
1989	3,984	2,229	2,521	39	8,773
1990	4,571	3,909	1,878	38	10,396
1991	7,081	3,530	3,668	78	14,357
1992	6,259	5,668	2,001	47	13,975
1993	4,726	1,436	1,450	28	7,640
1994	4,392	807	1,192	37	6,428
1995	3,073	2,057	609	13	5,752
1996	2,945	1,522	978	20	5,465
1997	2,188	1,843	543	8	4,582
1998	1,896	3,331	397	14	5,638
1999	1,505	4,819	856	6	7,186
2000	1,207	2,352	2,469	55	6,083
2001	1,729	1,499	1,933	165	5,326
2002	3,173	5,636	1,644	137	10,590
2003	4,405	2,153	3,848	158	10,564
2004	4,231	893	1,923	134	7,181
2005	4,266	662	1,153	165	6,246
2006	4,062	1,387	1,331	185	6,965
2007	4,196	1,859	1,655	157	7,867
mean	4,820	2,506	1,991	72	9,102

Table 6. Summary of the landed fish sampling intensity for scup in the Northeast Region (NER; ME-VA) commercial fishery.

Year	No. of samples	No. of lengths	NER Landings (mt)	Sampling intensity (mt/100 lengths)
1979	10	1,250	8,585	687
1980	26	3,478	8,424	242
1981	16	2,005	9,856	492
1982	81	9,896	8,704	88
1983	72	7,860	7,794	99
1984	60	6,303	7,769	123
1985	31	3,058	6,727	220
1986	54	5,467	7,176	131
1987	61	6,491	6,276	97
1988	85	8,691	5,943	68
1989	46	4,806	3,984	83
1990	46	4,736	4,571	97
1991	31	3,150	7,081	225
1992	33	3,260	6,259	192
1993	23	2,287	4,726	207
1994	22	2,163	4,392	203
1995	22	2,487	3,073	124
1996	61	6,544	2,945	45
1997	37	3,732	2,188	59
1998	41	4,022	1,896	47
1999	56	6,040	1,505	25
2000	22	2,352	1,207	51
2001	40	3,934	1,729	44
2002	26	2,587	3,173	123
2003	78	6,681	4,405	66
2004	144	13,172	4,231	32
2005	124	9,324	4,266	46
2006	152	12,506	4,062	32
2007	198	15,704	4,196	27

Table 7. Commercial fishery scup landings (000s) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	1	2691	6114	7090	5793	1418	536	251	1	0	0	23895
1985	79	3245	6767	7696	2640	346	520	159	0	0	0	21452
1986	9	301	12321	4773	1004	75	106	337	5	0	0	18931
1987	2	1679	9952	10399	1725	177	124	21	18	0	1	24098
1988	17	423	7709	9526	2424	58	127	39	0	0	0	20323
1989	17	1484	4943	7071	685	22	69	24	0	0	0	14315
1990	0	247	10203	6781	1022	355	149	2	0	0	0	18759
1991	0	2412	12956	10202	2161	409	193	0	0	0	0	28334
1992	21	1577	10883	3737	3797	1243	138	0	0	0	0	21396
1993	1	230	6558	6877	1500	1143	124	0	0	0	0	16432
1994	0	1052	13544	6358	836	82	39	0	0	0	0	21911
1995	0	2198	8345	2878	891	248	31	0	0	0	0	14591
1996	0	346	6343	1640	770	469	62	0	0	0	0	9630
1997	0	131	2080	4089	732	84	97	0	0	0	0	7213
1998	0	340	1453	2373	1092	381	2	0	0	0	0	5641
1999	0	1	1148	2688	527	117	0	0	0	0	0	4481
2000	0	0	661	2144	511	15	0	0	0	0	0	3331
2001	0	31	1635	3033	695	46	6	1	1	0	0	5448
2002	0	124	1219	5051	2132	392	5	0	0	0	0	8922
2003	0	185	863	4627	3323	856	34	0	0	0	0	9889
2004	0	1	844	2406	2826	2089	296	40	4	14	0	8520
2005	0	31	683	1558	2361	2515	807	92	3	3	0	8053
2006	0	89	2233	2231	1119	1477	1219	366	28	3	0	8765
2007	0	91	2787	1390	680	940	590	124	12	0	0	9275

Table 8. Commercial fishery scup landings mean weights (kg) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	0.033	0.155	0.190	0.293	0.344	0.398	0.767	1.044	1.545	0.000	0.000	0.288
1985	0.043	0.134	0.197	0.293	0.409	0.517	0.739	1.042	0.000	0.000	0.000	0.272
1986	0.036	0.140	0.219	0.357	0.676	0.670	1.010	1.246	1.616	0.000	0.000	0.302
1987	0.034	0.136	0.203	0.244	0.407	0.544	0.747	1.194	1.068	0.000	0.000	0.237
1988	0.044	0.123	0.201	0.263	0.441	0.636	0.715	0.982	0.000	0.000	0.000	0.263
1989	0.025	0.144	0.188	0.275	0.367	0.651	0.721	1.036	0.000	0.000	0.000	0.240
1990	0.000	0.140	0.189	0.246	0.367	0.518	0.842	0.846	0.000	1.096	0.000	0.230
1991	0.000	0.187	0.194	0.263	0.389	0.511	0.729	0.000	0.000	0.000	0.000	0.241
1992	0.039	0.173	0.199	0.325	0.419	0.503	0.859	0.000	0.000	1.096	0.000	0.280
1993	0.031	0.140	0.197	0.261	0.442	0.510	0.782	0.000	0.000	0.000	0.000	0.272
1994	0.000	0.203	0.193	0.259	0.430	0.663	0.742	0.000	0.000	0.000	0.000	0.224
1995	0.000	0.161	0.209	0.295	0.396	0.480	0.724	0.000	0.000	0.000	0.000	0.236
1996	0.000	0.206	0.200	0.325	0.468	0.554	0.784	0.000	0.000	0.000	0.000	0.264
1997	0.000	0.227	0.253	0.300	0.386	0.529	0.749	0.000	0.000	0.000	0.000	0.303
1998	0.000	0.200	0.254	0.313	0.459	0.556	0.748	0.000	0.000	0.000	0.000	0.336
1999	0.000	0.075	0.220	0.323	0.497	0.748	0.000	0.000	0.000	0.000	0.000	0.328
2000	0.000	0.000	0.221	0.367	0.504	0.674	0.000	0.000	0.000	0.000	0.000	0.360
2001	0.000	0.229	0.265	0.346	0.476	0.562	0.779	1.003	1.003	0.000	0.000	0.340
2002	0.000	0.231	0.281	0.339	0.465	0.577	0.748	0.000	0.000	0.000	0.000	0.370
2003	0.000	0.228	0.308	0.402	0.505	0.635	0.844	0.000	0.000	0.000	0.000	0.447
2004	0.000	0.182	0.313	0.398	0.518	0.591	0.812	1.002	1.370	1.674	0.000	0.496
2005	0.000	0.196	0.269	0.362	0.471	0.652	0.809	1.044	1.099	1.311	0.000	0.529
2006	0.000	0.213	0.283	0.344	0.460	0.591	0.727	0.915	1.108	1.314	0.000	0.463
2007	0.000	0.217	0.265	0.353	0.470	0.646	0.768	0.894	1.077	1.697	0.000	0.452

Table 9. Summary of sampling for scup in the NEFSC Observer Program. OT =number of otter trawl trips sampled with scup discard lengths. HY1 = first half year; HY2 = second half year. GMDL reflects the estimate of discard based on applying geometric mean observed ratios of discards to landings by trip, stratified by landings level (< 300 kg per trip, = > 300 kg per trip) to reported dealer landings (from Table 4).

Year	OT	Lengths			GMDL Discard	Intensity
	trips	HY1	HY2	Total	(mt)	(mt/100 lengths)
1989	61	4,449	2,910	7,359	2,229	30
1990	52	2,582	781	3,363	3,909	116
1991	91	1,237	1,780	3,017	3,530	117
1992	53	1,158	0	1,158	5,668	489
1993	29	275	154	429	1,436	335
1994	7	99	119	218	807	370
1995	18	162	383	545	2,057	377
1996	27	1,093	435	1,528	1,522	100
1997	45	750	1	751	1,843	245
1998	33	618	64	682	3,331	488
1999	35	586	89	675	4,819	714
2000	62	3,981	762	4,743	2,352	50
2001	67	1,231	229	1,460	1,499	103
2002	65	1,422	866	2,288	5,636	246
2003	72	925	284	1,209	2,153	178
2004	80	1,948	1,051	2,999	893	30
2005	73	797	1,159	1,956	662	34
2006	47	1,486	777	2,263	1,387	61
2007	59	1,313	1,058	2,371	1,859	78

Table 10. Commercial fishery scup discards (000s) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	78	10847	6367	924	21	0	0	0	0	0	0	18237
1985	52773	13093	6534	1060	10	0	0	0	0	0	0	73470
1986	78	1180	14040	602	3	0	0	0	0	0	0	15903
1987	78	6814	12215	1366	5	0	0	0	0	0	0	20478
1988	1552	1698	9242	1339	10	0	0	0	0	0	0	13841
1989	387	8943	13603	813	28	0	0	0	0	0	0	23774
1990	822	8269	17249	2801	0	0	0	0	0	0	0	29141
1991	1794	17231	5397	1733	5	0	0	0	0	0	0	26160
1992	38804	10023	26380	72	0	0	0	0	0	0	0	75279
1993	5386	1549	6960	224	0	0	0	0	0	0	0	14119
1994	6858	3099	3422	74	0	0	0	0	0	0	0	13453
1995	1855	50174	335	108	14	0	0	0	0	0	0	52486
1996	199	3009	5990	691	21	1	0	0	0	0	0	9911
1997	1	618	8250	1871	0	0	0	0	0	0	0	10740
1998	18	17524	11849	1127	247	57	0	0	0	0	0	30822
1999	1338	2563	18123	3139	691	201	0	0	0	0	0	26055
2000	853	11206	4890	1475	55	57	0	0	0	0	0	18536
2001	3536	4232	2647	355	281	207	57	0	0	0	0	11315
2002	9561	22393	5834	4431	518	571	75	0	0	0	0	43383
2003	1480	1578	3779	937	752	503	93	0	0	0	0	9122
2004	545	1397	1423	1176	220	187	8	0	0	0	0	4956
2005	480	893	1879	516	79	47	15	0	0	0	0	3909
2006	4809	8083	2354	642	53	13	16	0	0	0	0	15970
2007	1412	3936	5370	1420	94	41	87	0	0	0	0	12360

Table 11. Commercial fishery scup discards mean weights (kg) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	0.033	0.108	0.125	0.198	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.118
1985	0.033	0.108	0.125	0.198	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.057
1986	0.033	0.108	0.125	0.198	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.126
1987	0.033	0.108	0.125	0.198	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.124
1988	0.033	0.108	0.125	0.198	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.120
1989	0.039	0.060	0.111	0.198	0.217	0.000	0.000	0.000	0.000	0.000	0.000	0.094
1990	0.026	0.121	0.137	0.187	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.134
1991	0.057	0.127	0.163	0.207	0.252	0.000	0.000	0.000	0.000	0.000	0.000	0.135
1992	0.033	0.078	0.136	0.243	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.075
1993	0.026	0.106	0.154	0.269	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.102
1994	0.024	0.068	0.122	0.198	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.060
1995	0.038	0.037	0.229	0.310	0.331	0.000	0.000	0.000	0.000	0.000	0.000	0.039
1996	0.033	0.110	0.169	0.240	0.268	0.532	0.000	0.000	0.000	0.000	0.000	0.154
1997	0.020	0.028	0.137	0.362	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.170
1998	0.092	0.069	0.147	0.224	0.418	0.564	0.000	0.000	0.000	0.000	0.000	0.108
1999	0.010	0.037	0.158	0.398	0.599	0.690	0.000	0.000	0.000	0.000	0.000	0.183
2000	0.044	0.076	0.195	0.299	0.486	0.768	0.000	0.000	0.000	0.000	0.000	0.127
2001	0.015	0.063	0.168	0.345	0.500	0.670	0.944	0.000	0.000	0.000	0.000	0.108
2002	0.035	0.064	0.201	0.361	0.524	0.757	1.071	0.000	0.000	0.000	0.000	0.123
2003	0.022	0.091	0.212	0.315	0.537	0.784	0.878	0.000	0.000	0.000	0.000	0.236
2004	0.029	0.109	0.166	0.268	0.371	0.453	0.750	0.000	0.000	0.000	0.000	0.180
2005	0.019	0.090	0.154	0.267	0.416	0.652	0.912	0.000	0.000	0.000	0.000	0.153
2006	0.026	0.086	0.166	0.217	0.313	0.549	0.755	0.000	0.000	0.000	0.000	0.087
2007	0.041	0.094	0.163	0.282	0.342	0.597	0.770	0.000	0.000	0.000	0.000	0.148

Table 12. Summary of the landed fish sampling intensity for scup in the recreational fishery (MRFSS sampling).

Year	No. of lengths	Estimated landings (A + B1; mt)	Sampling intensity (mt/100 lengths)
1981	642	2,636	411
1982	1,057	2,361	223
1983	1,384	2,836	205
1984	943	1,096	116
1985	741	2,764	373
1986	2,580	5,264	204
1987	777	2,811	362
1988	2,156	1,936	90
1989	4,111	2,521	61
1990	2,698	1,878	70
1991	4,230	3,668	87
1992	4,419	2,001	45
1993	2,206	1,450	66
1994	1,374	1,192	87
1995	822	609	74
1996	526	978	186
1997	399	543	136
1998	286	397	139
1999	265	856	323
2000	524	2,469	471
2001	1,038	1,933	186
2002	1,006	1,644	163
2003	2,508	3,848	153
2004	1,802	1,923	107
2005	1,794	1,153	64
2006	2,217	1,331	60
2007	2,262	1,655	73

Table 13. Recreational fishery scup landings (000s) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	23	3036	1353	570	182	219	442	86	51	30	66	6058
1985	431	4478	3054	1330	788	441	137	33	0	0	115	10807
1986	538	4353	15570	2617	845	431	87	5	4	57	315	24822
1987	77	2299	4686	1261	824	598	112	0	0	11	46	9914
1988	9	1001	2229	1824	460	216	123	92	20	0	86	6060
1989	311	3978	3371	823	86	235	154	13	0	50	148	9169
1990	169	1352	5091	1102	147	112	36	7	2	3	22	8043
1991	299	4838	3797	3319	700	210	19	0	2	20	68	13272
1992	99	1850	4457	530	672	84	12	6	8	7	30	7755
1993	46	1245	3051	908	254	133	2	2	0	2	7	5650
1994	31	1473	1840	691	95	88	21	6	0	0	0	4245
1995	15	613	1399	225	89	20	3	3	0	0	0	2367
1996	9	351	1467	812	365	54	10	15	0	0	0	3083
1997	32	52	983	562	168	63	33	17	6	0	0	1916
1998	13	223	257	415	248	19	13	23	0	0	0	1211
1999	61	469	2169	359	182	11	0	0	0	0	0	3251
2000	6	912	3443	2113	641	129	0	0	0	0	0	7244
2001	0.3	514	1511	1705	806	244	101	218 0		0	0	5099
2002	7	70	688	1635	1005	179	24	39	0	0	0	3647
2003	0.3	75	1723	2655	3127	1407	350	115	0	0	0	9452
2004	0.9	45	284	1551	1441	1166	470	32	0	0	0	4990
2005	0	13	100	513	700	845	349	26	0	0	0	2546
2006	1	50	658	819	404	431	541	46	0	1	0	2951
2007	3	47	456	1347	775	378	605	206	26	1	0	3844

Table 14. Recreational fishery scup landings mean weights (kg) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	0.044	0.117	0.266	0.373	0.472	0.557	0.678	0.825	0.912	1.002	1.145	0.274
1985	0.038	0.125	0.253	0.340	0.573	0.718	0.913	1.087	0.000	0.000	1.673	0.270
1986	0.052	0.101	0.234	0.374	0.534	0.654	0.801	0.912	1.003	1.003	1.638	0.261
1987	0.029	0.105	0.242	0.381	0.548	0.698	0.737	0.000	0.000	1.003	3.808	0.302
1988	0.026	0.142	0.240	0.325	0.497	0.663	0.794	1.144	1.099	0.000	1.532	0.330
1989	0.035	0.123	0.234	0.376	0.433	0.653	0.696	0.657	0.000	1.003	1.332	0.235
1990	0.057	0.128	0.208	0.325	0.461	0.567	0.761	0.939	1.088	1.202	1.947	0.225
1991	0.064	0.150	0.275	0.361	0.474	0.714	0.675	0.000	1.003	1.003	1.305	0.271
1992	0.092	0.140	0.240	0.373	0.454	0.598	0.804	0.859	1.311	1.003	2.117	0.256
1993	0.087	0.135	0.226	0.336	0.460	0.524	0.912	0.827	0.000	1.026	1.100	0.242
1994	0.054	0.180	0.281	0.357	0.467	0.674	0.905	1.430	0.000	0.000	0.000	0.274
1995	0.065	0.155	0.279	0.450	0.557	0.756	1.044	1.311	0.000	0.000	0.000	0.279
1996	0.093	0.171	0.231	0.368	0.540	0.772	0.876	1.383	0.000	0.000	0.000	0.314
1997	0.083	0.110	0.253	0.299	0.510	0.684	0.819	1.342	0.779	0.000	0.000	0.318
1998	0.072	0.121	0.211	0.312	0.491	0.866	1.066	1.950	0.000	0.000	0.000	0.337
1999	0.095	0.173	0.274	0.451	0.635	0.900	0.000	0.000	0.000	0.000	0.000	0.298
2000	0.075	0.138	0.296	0.424	0.544	0.825	0.000	0.000	0.000	0.000	0.000	0.345
2001	0.092	0.220	0.344	0.485	0.637	0.776	0.875	1.127	0.000	0.000	0.000	0.490
2002	0.110	0.152	0.296	0.427	0.618	0.795	0.932	1.427	0.000	0.000	0.000	0.481
2003	0.092	0.161	0.314	0.416	0.536	0.720	0.908	1.499	0.000	0.000	0.000	0.512
2004	0.094	0.151	0.325	0.437	0.523	0.575	0.858	0.748	0.000	0.000	0.000	0.527
2005	0.000	0.112	0.270	0.384	0.516	0.679	0.881	1.098	0.000	0.000	0.000	0.588
2006	0.092	0.151	0.304	0.411	0.525	0.695	0.883	0.999	0.000	1.311	0.000	0.536
2007	0.111	0.152	0.313	0.418	0.509	0.672	0.882	0.935	1.056	1.322	0.000	0.551

Table 15. Recreational fishery scup discards (000s) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total	Metric tons
1984	2	255	0	0	0	0	0	0	0	0	0	257	30
1985	40	417	0	0	0	0	0	0	0	0	0	457	54
1986	100	807	0	0	0	0	0	0	0	0	0	907	87
1987	12	357	0	0	0	0	0	0	0	0	0	369	38
1988	2	219	0	0	0	0	0	0	0	0	0	221	31
1989	24	308	0	0	0	0	0	0	0	0	0	332	39
1990	36	284	0	0	0	0	0	0	0	0	0	320	38
1991	31	505	0	0	0	0	0	0	0	0	0	536	78
1992	17	325	0	0	0	0	0	0	0	0	0	342	47
1993	8	204	0	0	0	0	0	0	0	0	0	212	28
1994	4	203	0	0	0	0	0	0	0	0	0	207	37
1995	63	135	0	0	0	0	0	0	0	0	0	198	13
1996	44	222	0	0	0	0	0	0	0	0	0	266	20
1997	163	10	0	0	0	0	0	0	0	0	0	173	8
1998	80	139	0	0	0	0	0	0	0	0	0	219	14
1999	208	0	0	0	0	0	0	0	0	0	0	208	6
2000	20	561	25	0	0	0	0	0	0	0	0	606	55
2001	0.3	484	325	0	0	0	0	0	0	0	0	809	165
2002	14	199	381	55	0	0	0	0	0	0	0	649	137
2003	1	168	550	63	0	0	0	0	0	0	0	782	158
2004	7	232	242	211	0	0	0	0	0	0	0	692	134
2005	5	88	232	135	44	46	11	0	0	0	0	561	165
2006	1	143	644	66	0	0	0	0	0	0	0	854	185
2007	20	185	375	124	20	2	1	0	0	0	0	727	

Table 16. Recreational fishery scup discards mean weights at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	0.044	0.117	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.116
1985	0.038	0.125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.117
1986	0.052	0.101	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.096
1987	0.029	0.105	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.103
1988	0.026	0.142	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.141
1989	0.035	0.123	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.117
1990	0.057	0.128	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.120
1991	0.064	0.150	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.145
1992	0.092	0.140	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.138
1993	0.087	0.135	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.133
1994	0.054	0.180	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.178
1995	0.063	0.065	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.064
1996	0.075	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.075
1997	0.043	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.045
1998	0.061	0.068	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.065
1999	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.028
2000	0.075	0.087	0.189	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.091
2001	0.092	0.194	0.218	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.204
2002	0.110	0.155	0.238	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.211
2003	0.092	0.141	0.215	0.251	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.202
2004	0.094	0.149	0.206	0.233	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.194
2005	0.035	0.114	0.215	0.311	0.481	0.698	0.810	1.110	0.000	0.000	0.000	0.294
2006	0.092	0.148	0.229	0.243	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.216
2007	0.067	0.127	0.220	0.322	0.408	0.567	0.000	0.000	0.000	0.000	0.000	0.215

Table 17. Total fishery scup catch (000s) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	104	16829	13834	8584	5996	1637	978	337	52	30	66	48447
1985	53323	21233	16355	10086	3438	787	657	192	0	0	115	106186
1986	725	6641	41931	7992	1852	506	193	342	9	57	315	60563
1987	169	11149	26853	13026	2554	775	236	21	18	11	47	54859
1988	1580	3341	19180	12689	2894	274	250	131	20	0	86	40445
1989	739	14712	21917	8707	799	257	223	37	0	50	148	47590
1990	1027	10152	32543	10684	1169	467	185	9	2	3	22	56263
1991	2124	24986	22150	15254	2866	619	212	0	2	20	68	68302
1992	38941	13775	41720	4339	4469	1327	150	6	8	7	30	104772
1993	5441	3228	16569	8009	1754	1276	126	2	0	2	7	36414
1994	6893	5827	18806	7123	931	170	60	6	0	0	0	39816
1995	1933	53120	10079	3211	994	268	34	3	0	0	0	69642
1996	252	3928	13800	3143	1156	524	72	15	0	0	0	22890
1997	196	811	11313	6522	900	147	130	17	6	0	0	20042
1998	111	18226	13559	3915	1587	457	15	23	0	0	0	37893
1999	1607	3033	21440	6186	1400	329	0	0	0	0	0	33995
2000	879	12679	9019	5732	1207	201	0	0	0	0	0	29717
2001	3537	5261	6118	5093	1782	497	164	219	1	0	0	22671
2002	9582	22786	8122	11172	3654	1142	104	39	0	0	0	56601
2003	1481	1823	7007	6629	8432	3041	564	156	5	14	0	29152
2004	553	1675	2793	5344	4487	3442	774	72	4	14	0	19158
2005	465	1025	2894	2722	3184	3453	1182	119	3	3	0	15050
2006	4811	8365	5889	3758	1576	1921	1776	412	28	4	0	28540
2007	1435	4259	8988	5552	2279	1101	1633	796	150	13	0	26206

Table 18. Total fishery scup catch mean weights (kg) at age.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
1984	0.036	0.117	0.168	0.288	0.348	0.419	0.727	0.988	0.924	1.002	1.145	0.222
1985	0.033	0.116	0.179	0.289	0.446	0.629	0.775	1.050	0.000	0.000	1.673	0.122
1986	0.050	0.104	0.193	0.351	0.611	0.656	0.916	1.241	1.344	1.003	1.638	0.236
1987	0.031	0.112	0.174	0.253	0.452	0.663	0.742	1.194	1.068	1.003	3.727	0.206
1988	0.033	0.122	0.169	0.265	0.449	0.657	0.754	1.096	1.099	0.000	1.532	0.223
1989	0.037	0.087	0.147	0.277	0.369	0.653	0.704	0.903	0.000	1.003	1.332	0.165
1990	0.032	0.123	0.164	0.239	0.379	0.530	0.826	0.918	1.088	1.195	1.947	0.179
1991	0.058	0.138	0.201	0.278	0.409	0.580	0.724	0.000	1.003	1.003	1.305	0.206
1992	0.033	0.099	0.164	0.329	0.424	0.509	0.854	0.859	1.311	1.004	2.117	0.131
1993	0.027	0.121	0.184	0.270	0.445	0.512	0.784	0.827	0.000	1.026	1.100	0.200
1994	0.024	0.125	0.189	0.267	0.434	0.669	0.799	1.430	0.000	0.000	0.000	0.174
1995	0.039	0.044	0.219	0.306	0.409	0.501	0.752	1.311	0.000	0.000	0.000	0.088
1996	0.042	0.122	0.190	0.317	0.487	0.577	0.796	1.327	0.000	0.000	0.000	0.221
1997	0.049	0.066	0.168	0.318	0.409	0.595	0.767	1.342	0.779	0.000	0.000	0.231
1998	0.067	0.072	0.160	0.287	0.458	0.570	1.024	1.950	0.000	0.000	0.000	0.149
1999	0.016	0.058	0.173	0.368	0.565	0.718	0.947	1.538	0.000	0.000	0.000	0.212
2000	0.045	0.081	0.235	0.371	0.524	0.798	0.947	1.538	0.000	0.000	0.000	0.205
2001	0.015	0.091	0.240	0.392	0.553	0.712	0.896	1.126	0.000	0.000	0.000	0.253
2002	0.035	0.066	0.223	0.360	0.515	0.701	1.024	1.427	0.000	0.000	0.000	0.186
2003	0.022	0.099	0.247	0.376	0.501	0.708	0.893	1.337	1.241	0.000	0.000	0.396
2004	0.030	0.116	0.230	0.374	0.512	0.578	0.839	0.889	1.370	1.674	0.000	0.412
2005	0.019	0.096	0.190	0.346	0.480	0.659	0.832	1.056	1.099	1.311	0.000	0.433
2006	0.026	0.089	0.233	0.335	0.472	0.614	0.775	0.924	1.108	1.313	0.000	0.253
2007	0.042	0.099	0.205	0.350	0.477	0.653	0.810	0.905	1.073	1.668	0.000	0.316

Table 19. Extended time series of total fishery catch (mt). To estimate commercial discards for 1960-1988, the discards to landings ratio for 1989-1997 = 0.504 was applied to commercial landings. To estimate recreational catch for 1960-1980, 50% of the Mayo 1982 estimates were included.

Year	Comm. Land.	Comm. Disc.	DWF Land.	Rec Catch	Total Catch
1960	22236	11198	0	3765	37,199
1961	20944	10548	0	3716	35,208
1962	20831	10491	0	3667	34,989
1963	18884	9510	5863	3528	37,785
1964	17204	8664	459	3341	29,668
1965	15785	7950	2089	3265	29,089
1966	11960	6023	823	2474	21,280
1967	8748	4406	896	1879	15,929
1968	6630	3339	2251	1473	13,693
1969	5149	2593	485	1107	9,334
1970	4493	2263	288	1003	8,047
1971	3974	2001	889	853	7,717
1972	4203	2117	1647	796	8,763
1973	5024	2530	1783	1118	10,455
1974	7106	3579	958	1,388	13,031
1975	7623	3839	685	1,403	13,550
1976	7302	3677	87	1,183	12,249
1977	8330	4195	28	1,398	13,951
1978	8936	4500	3	1,256	14,695
1979	8585	4324	0	1,198	14,107
1980	8424	4242	16	3,109	15,791
1981	9,856	4964	1	2,636	17,457
1982	8,704	4383	0	2,361	15,448
1983	7,794	3925	0	2,836	14,555
1984	7,769	2158	0	1,126	11,053
1985	6,727	4184	0	2,818	13,729
1986	7,176	2005	0	5,351	14,532
1987	6,276	2537	0	2,849	11,662
1988	5,943	1657	0	1,967	9,567
1989	3,984	2229	0	2,560	8,773
1990	4,571	3909	0	1,916	10,396
1991	7,081	3530	0	3,746	14,357
1992	6,259	5668	0	2,048	13,975
1993	4,726	1436	0	1,478	7,640
1994	4,392	807	0	1,229	6,428
1995	3,073	2,057	0	622	5,752
1996	2,945	1,522	0	998	5,465
1997	2,188	1,843	0	551	4,582
1998	1,896	3,331	0	411	5,638
1999	1,505	4,819	0	862	7,186
2000	1,207	2,352	0	2,524	6,083
2001	1,729	1,499	0	2,098	5,326
2002	3,173	5,636	0	1,781	10,590
2003	4,405	2,153	0	4,006	10,564
2004	4,231	893	0	2,057	7,181
2005	4,266	662	0	1,318	6,246
2006	4,062	1,387	0	1,516	6,965
2007	4,196	1,859	0	1,812	7,867

Table 20. NEFSC spring and fall trawl survey indices for scup. Strata set includes only offshore strata 1-12, 23, 25, and 61-76 for consistency over entire time series. The Fall series strata set excludes inshore strata 1-61 that are included in the 1984 and later indices at age in Table 22.

Year	Spring No./tow	Spring Kg/tow	Spring SSB kg/tow	Spring SSB 3-yr avg	Fall No./tow	Fall Kg/tow
1963					2.12	1.21
1964					118.70	2.23
1965					3.84	0.62
1966					2.00	0.41
1967					29.38	1.46
1968	59.21	2.25	0.94		14.35	0.54
1969	2.26	0.40	0.39	0.88	99.41	4.48
1970	78.50	3.01	1.30	1.09	10.34	0.22
1971	70.91	2.41	1.57	1.28	7.730	0.25
1972	49.80	2.30	0.98	1.21	40.56	2.34
1973	3.62	1.19	1.09	1.38	22.82	0.93
1974	30.28	3.24	2.06	1.92	9.94	1.01
1975	14.01	3.12	2.61	1.73	52.21	3.40
1976	4.09	0.63	0.53	2.50	161.14	7.35
1977	42.46	4.48	4.35	2.49	32.69	1.71
1978	39.85	3.49	2.59	2.77	12.17	1.32
1979	22.42	1.95	1.38	1.69	15.77	0.61
1980	9.31	1.31	1.09	1.12	11.05	0.92
1981	14.72	1.16	0.89	1.00	67.14	3.01
1982	7.88	1.16	1.02	0.65	25.47	1.17
1983	0.80	0.29	0.03	0.46	4.59	0.34
1984	8.52	0.51	0.33	0.24	24.03	1.22
1985	14.67	0.80	0.37	0.68	68.30	3.56
1986	11.74	1.30	1.33	0.98	46.19	1.66
1987	10.82	1.21	1.24	1.10	5.76	0.15
1988	25.41	1.26	0.73	0.66	5.75	0.09
1989	1.63	0.12	0.00	0.35	94.05	3.37
1990	1.17	0.39	0.34	0.26	16.53	0.83
1991	12.61	0.75	0.45	0.32	9.52	0.43
1992	6.79	0.40	0.21	0.32	16.19	1.12
1993	2.93	0.33	0.31	0.18	0.43	0.04
1994	1.54	0.09	0.03	0.15	3.59	0.11
1995	2.90	0.22	0.12	0.06	24.72	0.91
1996	0.53	0.03	0.02	0.08	4.46	0.23
1997	0.91	0.11	0.11	0.06	16.92	0.88
1998	40.04	0.87	0.05	0.08	25.35	0.69
1999	1.70	0.12	0.09	0.08	85.23	2.07
2000	6.71	0.33	0.11	0.25	99.33	4.79
2001	13.03	0.80	0.54	3.30	20.28	1.11
2002	154.86	13.46	9.24	3.31	95.62	3.79
2003	6.01	0.28	0.15	3.74	28.18	0.80
2004	57.58	2.84	1.82	0.69	10.38	0.27
2005	19.22	0.55	0.10	1.32	4.50	0.07
2006	5.71	2.10	2.04	0.76	96.41	1.92
2007	10.60	0.36	0.14	1.16	41.52	2.21
2008	9.68	1.44	1.30			

Table 21. NEFSC spring trawl survey stratified mean number of scup per tow at age. Strata set includes only offshore strata 1-12, 23, 25, and 61-76, corresponding to the spring survey indices in Table 20.

Spring					Age										
Year	0	1	2	3	4	5	6	7	8	9	10	11	Total	age 2+	age 3+
1977		6.62	32.08	3.54	0.16	0.04	0.01	0.01					42.46	35.84	3.76
1978		26.90	4.67	6.50	1.31	0.32	0.12	0.03					39.85	12.95	8.28
1979		15.63	4.04	0.88	1.28	0.37	0.06	0.13	0.02	0.01			22.42	6.79	2.75
1980		2.39	5.61	0.57	0.17	0.25	0.15	0.08	0.08	0.01			9.31	6.92	1.31
1981		10.78	2.16	1.15	0.17	0.14	0.05	0.15	0.12				14.72	3.94	1.78
1982		3.80	1.77	1.39	0.38	0.17	0.13	0.07	0.07	0.10			7.88	4.08	2.31
1983		0.70	0.03	0.06				0.01					0.80	0.10	0.07
1984		6.14	1.97	0.22	0.12	0.07							8.52	2.38	0.41
1985		12.11	2.32	0.20	0.04								14.67	2.56	0.24
1986		1.05	10.26	0.43									11.74	10.69	0.43
1987		4.57	3.60	1.81	0.74	0.04	0.02	0.03	0.01				10.82	6.25	2.65
1988		16.74	8.36	0.17	0.03	0.01	0.03	0.07					25.41	8.67	0.31
1989		0.79	0.74	0.09	0.01								1.63	0.84	0.10
1990		0.12	0.30	0.30	0.18	0.09	0.13	0.05					1.17	1.05	0.75
1991		10.61	0.70	1.11	0.19								12.61	2.00	1.30
1992		5.72	0.88	0.07	0.05	0.06	0.01						6.79	1.07	0.19
1993		0.61	2.02	0.17	0.11	0.02							2.93	2.32	0.30
1994		1.34	0.16	0.04									1.54	0.20	0.04
1995		2.29	0.44	0.11	0.05	0.01							2.90	0.61	0.17
1996		0.44	0.05	0.03	0.01								0.53	0.09	0.04
1997		0.17	0.64	0.10									0.91	0.74	0.10
1998		39.90	0.12	0.02									40.04	0.14	0.02
1999		1.03	0.67										1.70	0.67	0.00
2000		5.93	0.71	0.07									6.71	0.78	0.07
2001		7.90	5.03	0.08		0.02							13.03	5.13	0.10
2002		109.01	15.60	26.67	3.27	0.31							154.86	45.85	30.25
2003		5.08	0.79	0.07	0.06								6.01	0.92	0.14
2004		38.69	16.15	1.31	0.82	0.60							57.58	18.89	2.74
2005		18.26	0.81	0.13	0.02								19.22	0.96	0.15
2006		1.56	0.51	0.80	0.35	0.70	1.69	0.10					5.71	4.15	3.64
2007		9.73	0.41	0.44	0.00	0.01	0.01						10.60	0.87	0.46

Table 22. NEFSC fall trawl survey stratified mean number of scup per tow at age. Strata set includes offshore strata 1-12, 23, 25, 61-76, and inshore strata 1-61.

Fall					Age										
Year	0	1	2	3	4	5	6	7	8	9	10	11	Total	age 2+	age 3+
1984	47.64	9.20	0.34	0.03	0.01		0.01						59.96	0.39	0.05
1985	61.22	11.53	1.10	0.26	0.06	0.05							74.71	1.47	0.37
1986	70.19	6.58	0.57		0.01								77.36	0.58	0.01
1987	49.93	29.85	0.46	0.01									80.45	0.47	0.01
1988	47.44	15.95	0.67	0.10									64.22	0.77	0.10
1989	176.37	25.92	0.66	0.03									202.99	0.69	0.03
1990	77.45	9.21	0.75	0.04									87.46	0.79	0.04
1991	151.62	12.51	0.07	0.02									164.24	0.09	0.02
1992	25.92	14.51	1.66	0.04	0.02								42.15	1.72	0.06
1993	46.78	9.76	0.32										56.86	0.32	0.00
1994	39.54	3.92	0.04	0.01									43.52	0.05	0.01
1995	33.04	2.61	0.08	0.01									35.74	0.09	0.01
1996	24.42	2.86	0.43	0.01									27.73	0.44	0.01
1997	46.91	0.61	0.02		0.01								47.66	0.03	0.01
1998	57.73	9.64	0.09	0.03	0.01								67.50	0.13	0.04
1999	96.06	9.77	1.37	0.07	0.01								107.28	1.45	0.08
2000	98.72	20.60	3.14	0.48	0.11	0.07							123.12	3.80	0.66
2001	91.84	10.32	1.82	0.12	0.04	0.01							104.15	1.99	0.17
2002	180.09	43.31	0.90	0.35	0.04	0.01							224.70	1.30	0.40
2003	53.70	5.66	2.30	1.33	0.82	0.20	0.02						64.02	4.67	2.37
2004	41.83	33.46	1.14	1.70	0.39	0.12	0.04	0.01					78.69	3.40	2.26
2005	27.26	7.94	1.02	0.14	0.04	0.04							36.43	1.23	0.21
2006	146.85	20.08	0.92	0.07	0.05	0.01	0.03	0.01					168.02	1.09	0.17
2007	113.95	40.28	0.60	0.24	0.05	0.03	0.05	0.02					155.22	0.99	0.39

Table 23. NEFSC 1992-2007 Winter trawl survey indices of abundance for scup, offshore survey strata 1-12 and 61-76.

Year	Mean number per tow	Mean kg per tow
1992	65.56	2.87
1993	25.71	2.73
1994	17.09	0.66
1995	69.50	2.26
1996	18.28	1.19
1997	13.90	0.32
1998	46.92	1.20
1999	15.04	0.71
2000	24.21	1.33
2001	55.49	1.58
2002	267.83	7.56
2003	24.16	0.49
2004	380.59	3.82
2005	84.74	1.96
2006	201.96	3.72
2007	101.08	2.95
Mean	88.25	2.21

Table 24. NEFSC 1992-2007 winter trawl survey stratified mean number of scup per tow at age, offshore survey strata 1-12 and 61-76. The 1992, 1993, and 1996 lengths are aged with the corresponding annual spring survey age-length key.

Winter	Age											
Year	0	1	2	3	4	5	6	7	8	Total	age 2+	age 3+
1992		59.78	4.93	0.20	0.09	0.10	0.46			65.56	5.78	0.85
1993		2.51	22.05	0.56	0.57	0.02				25.71	23.19	1.15
1994		16.31	0.73	0.02	0.02	0.01				17.09	0.78	0.05
1995		67.35	1.94	0.15	0.01	0.01	0.02	0.01		69.50	2.15	0.21
1996		12.94	5.31	0.03	0.01					18.28	5.34	0.04
1997		13.27	0.52	0.11						13.90	0.64	0.11
1998		45.62	0.75	0.22	0.21	0.08	0.03	0.01		46.92	1.30	0.55
1999		12.48	2.41	0.12	0.02	0.01				15.04	2.56	0.15
2000		20.28	3.21	0.68	0.03			0.01		24.21	3.93	0.72
2001		48.54	6.48	0.36	0.09	0.02				55.49	6.95	0.47
2002		257.08	7.44	2.96	0.33	0.01	0.01			267.83	10.75	3.31
2003		23.77	0.28	0.07	0.03		0.02			24.16	0.39	0.11
2004		380.22	0.29	0.07	0.01					380.59	0.37	0.08
2005		80.03	4.62	0.09						84.74	4.71	0.09
2006		198.52	2.64	0.66	0.03	0.04	0.07			201.96	3.44	0.80
2007		99.18	1.86	0.02	0.02					101.08	1.90	0.04

Table 25. MADMF trawl survey mean number of scup per tow and mean weight (kg) per tow for spring (survey regions 1-3) and fall (survey regions 1-5). Time series revised in 2008 to account for stratum area changes effective in 2006.

	Spring		Fall	
Year	No./Tow	Kg/tow	No./Tow	Kg/Tow
1978	90.08	31.71	1859.40	14.82
1979	76.14	18.05	1150.16	12.20
1980	189.82	41.39	1183.02	12.53
1981	298.53	17.63	971.87	14.34
1982	10.46	0.98	2153.76	9.17
1983	25.29	3.51	1623.13	12.90
1984	17.90	6.53	963.49	12.29
1985	67.02	3.40	647.63	12.09
1986	44.17	7.35	773.61	9.15
1987	6.05	1.37	561.61	7.72
1988	13.98	2.09	1396.86	14.15
1989	13.32	2.02	580.73	7.77
1990	144.06	21.45	1128.07	7.21
1991	28.73	6.05	1150.71	10.18
1992	14.49	2.52	2440.96	11.54
1993	19.13	4.23	1023.11	10.06
1994	9.71	2.85	820.31	9.84
1995	49.29	2.76	507.02	4.11
1996	5.18	0.68	1019.96	9.15
1997	3.22	0.71	921.21	7.25
1998	1.37	0.21	709.61	6.94
1999	11.61	1.93	1212.23	18.07
2000	307.00	18.02	867.00	11.63
2001	7.28	2.37	1205.60	9.89
2002	281.36	18.77	1137.64	8.32
2003	0.22	0.07	3209.61	14.87
2004	41.71	13.04	1483.56	10.07
2005	9.32	3.25	4005.89	21.53
2006	92.97	22.41	1231.49	9.46
2007	13.30	2.03	1774.23	11.65
2008	145.72	27.89		
Mean	65.76	9.27	1323.78	11.03

Table 26. RIDFW trawl survey mean number of scup per tow and mean weight (kg) per tow for spring and fall.

	Spring		Fall	
Year	No./Tow	Kg/tow	No./Tow	Kg/Tow
1981	12.49	0.40	196.22	2.54
1982	0.43	0.04	63.87	0.70
1983	3.59	0.32	173.63	2.75
1984	13.24	0.88	589.68	10.57
1985	8.30	0.41	74.27	1.51
1986	1.78	0.33	340.06	4.20
1987	0.04	0.01	314.20	4.73
1988	0.23	0.04	804.00	7.10
1989	0.17	0.04	326.86	6.62
1990	0.64	0.15	527.31	5.66
1991	2.93	0.57	655.69	16.62
1992	1.88	0.61	1105.51	9.10
1993	1.12	0.06	1246.35	8.90
1994	2.08	0.53	236.12	3.66
1995	4.33	0.53	423.02	5.03
1996	0.52	0.07	184.73	3.83
1997	1.93	0.15	597.90	6.04
1998	0.15	0.03	150.38	1.89
1999	0.38	0.07	832.22	12.39
2000	84.05	3.54	588.73	9.11
2001	29.68	5.08	1139.17	11.07
2002	174.80	10.28	716.12	9.27
2003	0.00	0.00	1181.83	11.38
2004	2.59	0.45	1616.24	9.58
2005	2.95	1.63	2216.72	21.35
2006	53.12	3.90	765.90	11.26
2007	1.95	0.24	2410.00	23.76
2008				
Mean	15.01	1.12	721.36	8.17

Table 27. CTDEP spring trawl survey mean number of scup per tow at age, total mean number per tow, and total mean weight (kg) per tow.

						Age								Total	Total	Age
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	No./Tow	Kg/Tow	2+
1984	0.49	1.31	0.59	0.30	0.08	0.00	0.00	0.00	0.00	0.03	0.02	0.00	0.00	0.00	2.80	0.64	2.31
1985	2.94	2.00	0.33	0.24	0.05	0.02	0.05	0.00	0.00	0.01	0.00	0.00	0.00	0.00	5.61	1.22	2.71
1986	4.44	1.65	0.99	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.40	0.78	2.79
1987	0.43	1.65	0.07	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.17	0.37	1.76
1988	1.18	0.30	0.51	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.11	0.32	0.88
1989	5.63	0.56	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.77	0.63	0.62
1990	2.56	2.06	0.21	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.25	0.61	2.30
1991	4.25	1.44	1.26	0.09	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.09	0.94	2.80
1992	0.39	1.21	0.09	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.75	0.48	1.36
1993	0.04	2.29	0.19	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.32	0.49	2.49
1994	0.81	2.03	0.93	0.10	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.88	0.58	3.09
1995	12.94	0.39	0.20	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.24	0.65	0.64
1996	5.20	2.48	0.07	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.25	0.73	2.56
1997	3.16	2.61	1.68	0.06	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.23	0.75	4.39
1998	10.07	0.58	0.12	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.25	0.75	0.76
1999	2.71	1.75	0.16	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.22	0.56	2.02
2000	124.51	17.18	4.24	0.20	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.46	4.56	21.71
2001	1.65	18.99	1.57	0.25	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.20	2.85	20.84
2002	49.15	66.61	123.25	17.44	1.29	0.10	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	257.91	13.16	208.76
2003	0.14	4.05	3.28	4.96	0.61	0.07	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	13.12	2.28	12.98
2004	0.01	3.97	8.96	4.90	8.21	0.76	0.08	0.02	0.01	0.00	0.00	0.00	0.00	0.00	26.92	3.93	26.90
2005	1.16	1.28	1.06	1.51	1.27	1.94	0.22	0.05	0.00	0.00	0.00	0.00	0.00	0.00	8.49	1.65	7.33
2006	18.48	23.72	5.63	2.07	2.56	3.16	2.90	0.53	0.01	0.00	0.00	0.00	0.00	0.00	59.06	10.41	40.58
2007	7.51	15.86	5.84	1.49	0.55	0.54	0.54	0.39	0.07	0.01	0.00	0.00	0.00	0.00	32.80	3.32	25.29

Table 28. CTDEP fall trawl survey mean number of scup per tow at age, total mean number per tow, and total mean weight (kg) per tow.

						Age						Total	Total	Age
Year	0	1	2	3	4	5	6	7	8	9	10	No/Tow	Kg/Tow	2+
1984	7.99	1.04	0.78	0.52	0.28	0.09	0.02	0.00	0.00	0.00	0.00	10.72	1.36	1.69
1985	25.01	4.71	0.40	0.59	0.19	0.04	0.03	0.00	0.00	0.00	0.00	30.97	2.50	1.25
1986	13.06	9.98	2.50	0.19	0.01	0.01	0.01	0.00	0.00	0.00	0.00	25.76	2.95	2.72
1987	12.47	4.17	1.25	0.58	0.06	0.01	0.01	0.00	0.00	0.00	0.00	18.55	1.79	1.91
1988	31.89	5.71	1.82	0.24	0.03	0.00	0.00	0.00	0.00	0.00	0.00	39.69	2.27	2.09
1989	40.88	22.60	1.51	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00	65.08	3.65	1.60
1990	54.34	7.74	6.95	0.40	0.03	0.01	0.01	0.00	0.00	0.01	0.00	69.49	5.00	7.41
1991	291.58	17.03	1.76	1.04	0.15	0.01	0.00	0.00	0.00	0.00	0.00	311.57	8.30	2.96
1992	50.91	26.58	5.54	0.40	0.29	0.01	0.01	0.00	0.00	0.00	0.00	83.74	4.96	6.25
1993	74.06	1.83	1.02	0.12	0.01	0.01	0.00	0.00	0.00	0.00	0.00	77.05	3.72	1.16
1994	90.76	1.12	0.46	0.18	0.01	0.00	0.00	0.00	0.00	0.00	0.00	92.53	3.33	0.65
1995	32.46	26.52	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	59.13	4.63	0.15
1996	51.50	8.56	1.37	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	61.47	3.68	1.41
1997	31.79	8.68	0.63	0.17	0.01	0.00	0.00	0.00	0.00	0.00	0.00	41.28	2.49	0.81
1998	90.40	12.24	0.54	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	103.27	4.50	0.63
1999	498.18	30.93	8.35	0.19	0.02	0.01	0.00	0.00	0.00	0.00	0.00	537.68	22.72	8.57
2000	250.39	261.45	8.32	0.79	0.14	0.01	0.00	0.00	0.00	0.00	0.00	521.10	30.76	9.26
2001	140.51	16.90	18.42	1.61	0.19	0.03	0.00	0.00	0.00	0.00	0.00	177.66	11.28	20.25
2002	259.90	47.62	23.32	16.81	0.67	0.33	0.05	0.00	0.01	0.00	0.00	348.70	23.69	41.18
2003	52.91	15.35	32.07	22.39	26.44	2.49	0.54	0.02	0.02	0.00	0.00	152.23	28.95	83.96
2004	251.05	4.13	8.34	15.08	5.98	6.25	0.53	0.07	0.01	0.02	0.00	291.46	16.31	36.28
2005	373.32	32.56	8.14	2.44	4.01	1.50	1.69	0.33	0.06	0.00	0.00	424.05	13.79	18.17
2006	52.16	51.02	9.52	2.34	0.26	0.35	0.38	0.68	0.04	0.00	0.00	116.75	10.49	13.57
2007	319.89	118.06	29.34	5.93	0.90	0.23	0.30	0.31	0.31	0.03	0.00	475.30	24.15	37.35

Table 29. NYDEC trawl survey indices at ages 0, 1 and 2 and older (2+); NJBMF trawl survey mean number of scup per tow and mean weight (kg) per tow; VIMS age 0 index.

	NYDEC Trawl			NJBMF Trawl		VIMS
Year	Age 0	Age 1	Age 2+	No/tow	Kg/tow	Age 0
1987	0.33	3.43	0.09			
1988	1.19	1.96	0.05			2.07
1989	0.67	11.02	0.04	72.75	2.75	3.07
1990	5.32	1.30	0.14	74.72	3.77	4.92
1991	13.17	2.31	0.22	200.61	6.17	1.90
1992	15.25	1.54	0.06	227.70	7.16	0.65
1993	0.29	0.72	0.04	256.91	5.21	3.36
1994	6.11	0.36	0.06	86.45	3.30	0.90
1995	0.61	7.49	0.03	27.13	2.08	0.39
1996	0.42	0.94	0.15	30.81	1.04	0.54
1997	20.23	0.74	0.20	52.09	3.82	0.21
1998	73.22	1.46	0.05	220.05	4.88	0.50
1999	35.85	2.25	0.03	209.10	10.30	0.27
2000	186.07	16.73	1.02	260.97	6.56	0.13
2001	83.01	2.99	1.22	163.37	4.32	1.34
2002	346.32	5.47	6.01	565.96	25.65	0.24
2003	266.56	0.38	1.35	804.08	10.19	0.96
2004	40.82	0.92	0.70	449.12	11.70	0.46
2005	n/a	n/a	n/a	147.98	4.19	1.11
2006	122.23	3.12	0.35	943.63	16.52	1.58
2007	109.47	4.18	0.61	1185.54	38.27	2.99
Mean	66.36	3.47	0.62	314.68	8.84	1.38

Table 30. University of Rhode Island Graduate School of Oceanography (URIGSO) trawl survey indices for scup (total catch number).

Year	Number
1963	80
1964	181
1965	100
1966	124
1967	686
1968	217
1969	142
1970	146
1971	523
1972	345
1973	689
1974	543
1975	1243
1976	2591
1977	1806
1978	1112
1979	1033
1980	510
1981	952
1982	478
1983	1477
1984	1374
1985	1411
1986	1062
1987	809
1988	762
1989	2386
1990	953
1991	1841
1992	654
1993	1775
1994	471
1995	682
1996	628
1997	516
1998	551
1999	1830
2000	3978
2001	3225
2002	5380
2003	2047
2004	468
2005	857
2006	4473
2007	2889

Table 31. VIMS ChesMMAP trawl survey indices for scup. Indices are maximum seasonal values (usually July or September) minimum swept area estimates.

Year	Total N	Total B	Age 0 N	Age 1 N
2002	477,359	77,307	324,291	154,625
2003	624,210	61,501	93,089	500,176
2004	2,166,993	146,627	89,384	1,975,035
2005	3,402,832	197,762	1,864,624	673,437
2006	1,318,855	109,652	1,180,618	566,905
2007	894,289	23,183	0	894,289
2008	52,317	3,488	n/a	n/a
Mean	1,480,756	102,672	592,001	794,078

Table 32. Summary results for 1984-2007 from the 2008 assessment accepted model BASE_C2007_T1.

Year	SSB (mt)	Recruits (Age 0; 000s)	F
1984	18,151	108,158	0.533
1985	17,010	78,360	0.608
1986	15,953	60,241	0.779
1987	13,531	48,392	0.676
1988	10,621	91,460	0.701
1989	8,894	66,774	0.695
1990	9,438	114,796	0.673
1991	9,211	100,966	1.027
1992	7,928	39,496	1.068
1993	6,147	45,406	1.109
1994	4,428	75,827	1.120
1995	3,993	36,349	0.920
1996	5,103	30,377	0.758
1997	5,609	87,276	0.487
1998	6,772	123,306	0.329
1999	12,367	217,853	0.206
2000	25,727	311,243	0.149
2001	51,511	194,937	0.080
2002	72,536	114,487	0.186
2003	76,533	108,778	0.111
2004	81,638	171,236	0.079
2005	93,754	116,828	0.061
2006	105,645	219,752	0.057
2007	119,343	307,943	0.054

Table 33. January 1 population number (N, 000s) estimates for 1984-2007 from the 2008 assessment accepted model BASE_C2007_T1.

	Age							
Year	0	1	2	3	4	5	6	7+
1984	108158	61923	30650	8353	3465	3014	4824	13099
1985	78360	80287	40534	14126	4100	1637	1423	8775
1986	60241	56693	49486	16395	6531	1780	710	4704
1987	48392	44866	36176	21410	6555	2350	641	2148
1988	91460	36323	29465	16671	9319	2643	947	1201
1989	66774	69016	24120	13772	7049	3672	1041	887
1990	114796	49652	44341	10620	5925	2780	1448	794
1991	100966	84717	31624	19059	4624	2402	1127	935
1992	39496	72016	49032	10527	5990	1289	670	611
1993	45406	26601	37486	12722	3136	1615	347	365
1994	75827	31708	14804	11151	3641	810	417	196
1995	36349	55377	19198	5296	3162	929	207	163
1996	30377	25410	31416	6090	1802	999	293	122
1997	87276	22335	15998	12939	2438	670	371	158
1998	123306	65699	14356	8195	6455	1218	335	268
1999	217853	94257	44254	8205	4802	3786	714	358
2000	311243	170265	67634	28464	5449	3191	2515	716
2001	194937	247527	128258	47186	20013	3832	2244	2280
2002	114487	156810	192914	96113	35619	15111	2893	3428
2003	108778	68584	55407	47367	65005	24205	10264	4313
2004	171236	86609	51990	39723	34636	47549	17705	10695
2005	116828	138009	67886	39371	30017	26177	35936	21519
2006	219752	94532	109412	52530	30297	23101	20146	44303
2007	307943	177299	74375	83856	40578	23407	17848	49939

Table 34. Fishing mortality (F) estimates for 1984-2007 from the 2008 assessment accepted model BASE_C2007_T1.

	Age							
Year	0	1	2	3	4	5	6	7+
1984	0.098	0.224	0.575	0.512	0.550	0.551	0.551	0.501
1985	0.124	0.284	0.705	0.571	0.634	0.635	0.636	0.564
1986	0.095	0.249	0.638	0.717	0.822	0.822	0.823	0.710
1987	0.087	0.220	0.575	0.632	0.708	0.709	0.709	0.623
1988	0.082	0.209	0.561	0.661	0.731	0.732	0.732	0.649
1989	0.096	0.242	0.620	0.643	0.730	0.731	0.731	0.637
1990	0.104	0.251	0.644	0.632	0.703	0.703	0.704	0.622
1991	0.138	0.347	0.900	0.957	1.077	1.078	1.079	0.945
1992	0.195	0.453	1.149	1.011	1.111	1.112	1.113	0.994
1993	0.159	0.386	1.012	1.051	1.154	1.154	1.155	1.032
1994	0.114	0.302	0.828	1.061	1.166	1.166	1.167	1.040
1995	0.158	0.367	0.948	0.878	0.952	0.953	0.955	0.861
1996	0.108	0.263	0.687	0.715	0.789	0.789	0.790	0.703
1997	0.084	0.242	0.469	0.495	0.494	0.494	0.490	0.460
1998	0.069	0.195	0.359	0.335	0.334	0.334	0.331	0.311
1999	0.046	0.132	0.241	0.209	0.209	0.209	0.207	0.193
2000	0.029	0.083	0.160	0.152	0.152	0.152	0.151	0.139
2001	0.018	0.049	0.089	0.081	0.081	0.081	0.081	0.075
2002	0.312	0.840	1.204	0.191	0.186	0.187	0.185	0.180
2003	0.028	0.077	0.133	0.113	0.113	0.113	0.112	0.104
2004	0.016	0.044	0.078	0.080	0.080	0.080	0.079	0.074
2005	0.012	0.032	0.056	0.062	0.062	0.062	0.061	0.058
2006	0.015	0.040	0.066	0.058	0.058	0.058	0.058	0.054
2007	0.016	0.044	0.073	0.055	0.055	0.055	0.055	0.051

Table 35. 2008 assessment Biological Reference Point input data.

Natural Mortality (M) = 0.20

Proportion of mortality before spawning = 0.417

Age	Selectivity on F	Selectivity on M	1-Jan Stock Weights	Catch Weights	1-Jun SSB Weights	Maturity
0	0.21	1.00	0.017	0.028	0.025	0.00
1	0.58	1.00	0.051	0.100	0.089	0.13
2	1.00	1.00	0.142	0.221	0.205	0.75
3	0.91	1.00	0.283	0.356	0.343	0.99
4	0.90	1.00	0.418	0.488	0.476	1.00
5	0.90	1.00	0.564	0.642	0.629	1.00
6	0.90	1.00	0.735	0.830	0.813	1.00
7+	0.90	1.00	1.041	1.041	1.041	1.00

Table 36. Proposed biological reference points and status evaluation for scup from 2008 accepted assessment model BASE_C2007_T1. The Northeast Data Poor Stocks Peer Review Panel adopted F40% = 0.177 as the proxy for FMSY, and SSBF40% = 92,044 mt as the proxy for SSBMSY (in **bold**).

BRP	F	Y/R	SSB/R	SSBproxy	MSYproxy	Landproxy	Discproxy
Fmax	0.283	0.146	0.499	57,759	16,903	12,764	4,139
F35%	0.207	0.142	0.683	80,280	16,615	13,236	3,379
F40%	**0.177**	**0.138**	**0.780**	**92,044**	**16,161**	**13,134**	**3,027**

BRP	SSBproxy	SSB07	%SSBproxy		MSYproxy	Catch07	%MSYproxy
Fmax	57,759	119,343	207%		16,903	7,867	47%
F35%	80,280	119,343	149%		16,615	7,867	47%
F40%	**92,044**	**119,343**	**130%**		**16,161**	**7,867**	**49%**

Scup; Figures

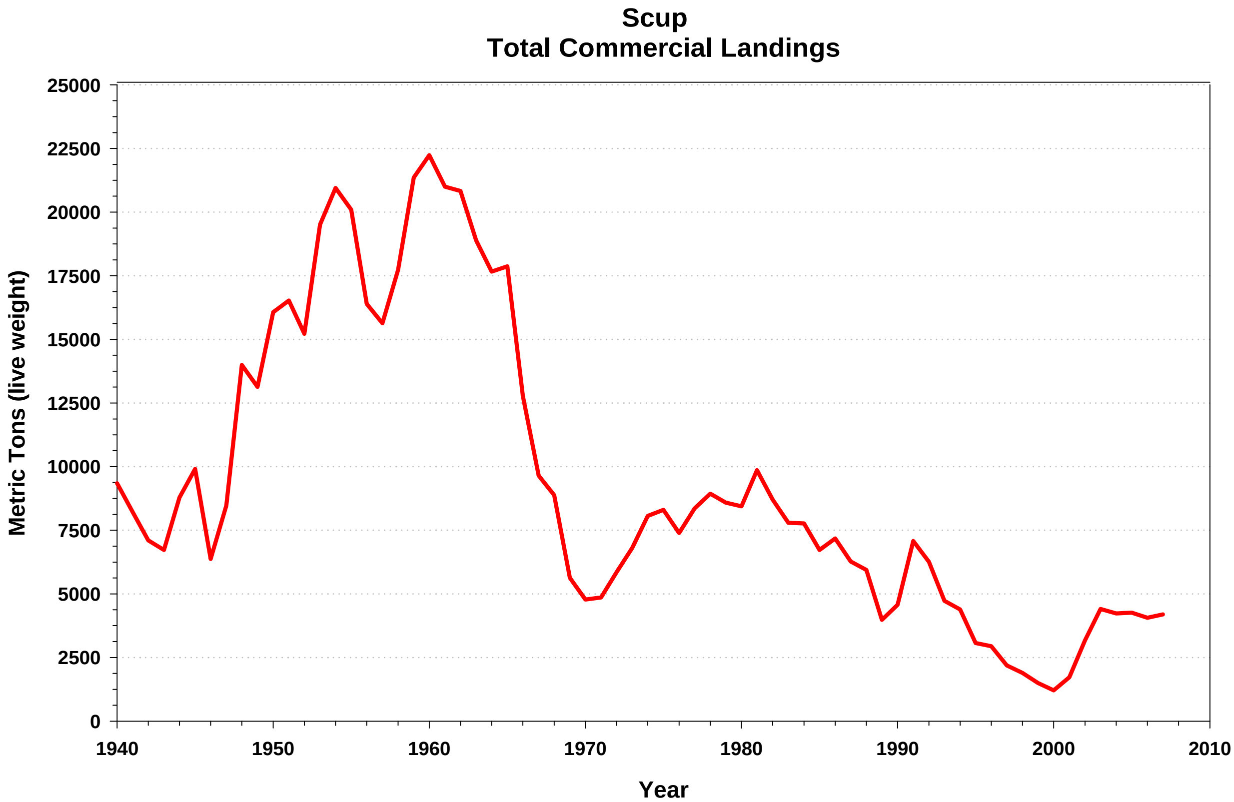


Figure 1. Total commercial fishery landings for scup.

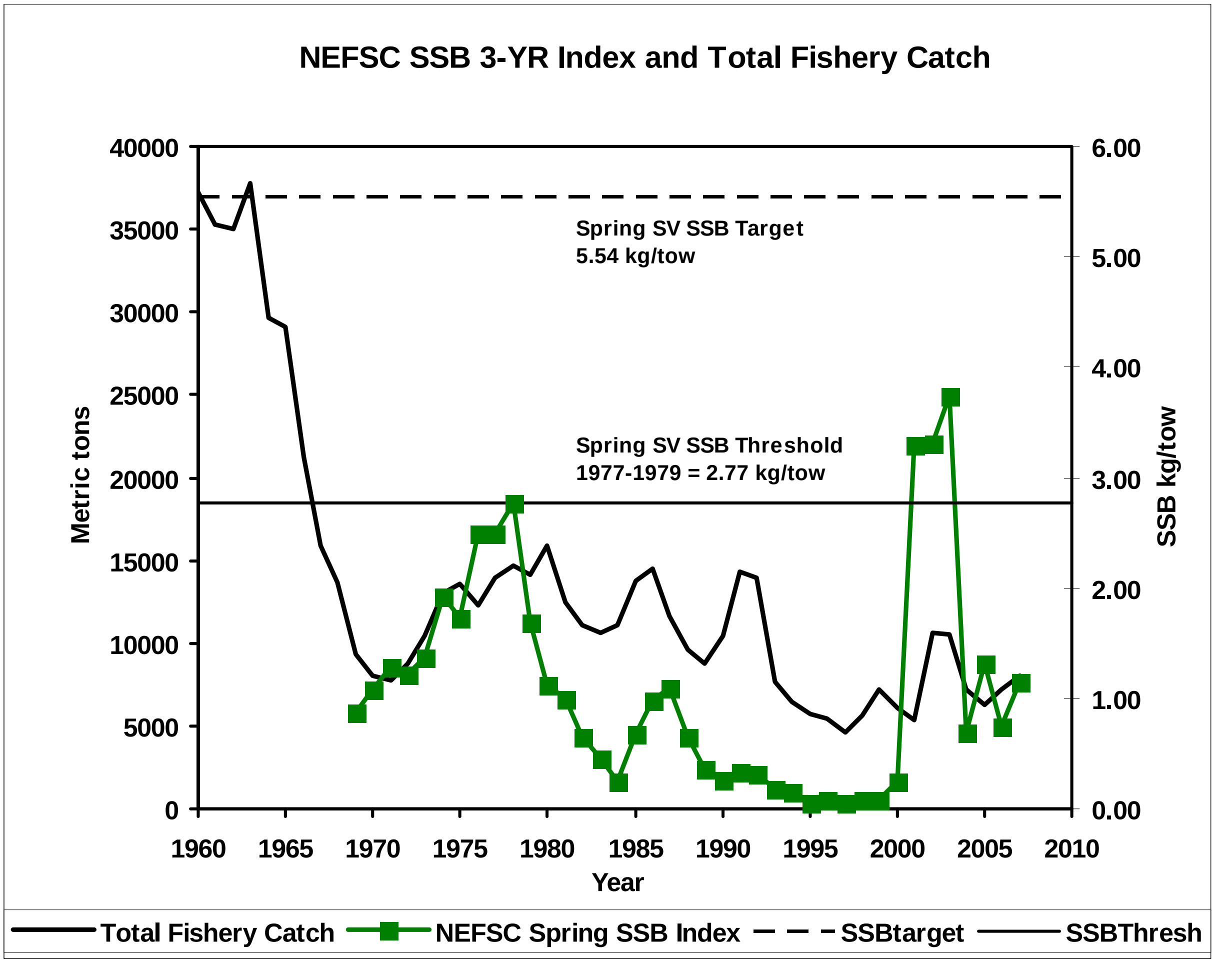


Figure 2. NEFSC Spring survey indices of scup spawning stock biomass per tow (SSB kg/tow) used as proxy target and threshold biomass Biological Reference Points.

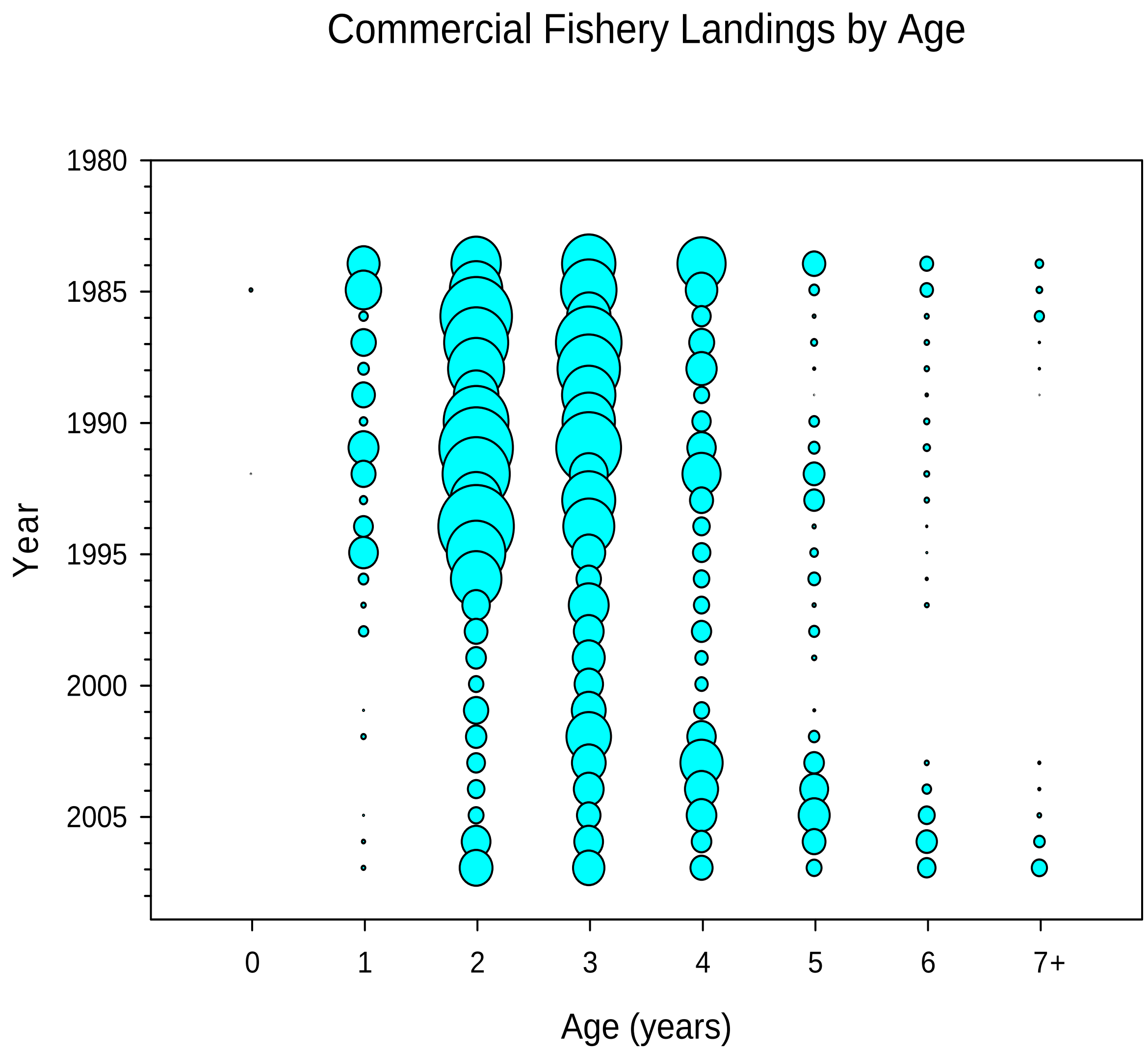


Figure 3. Commercial fishery landings by age for scup.

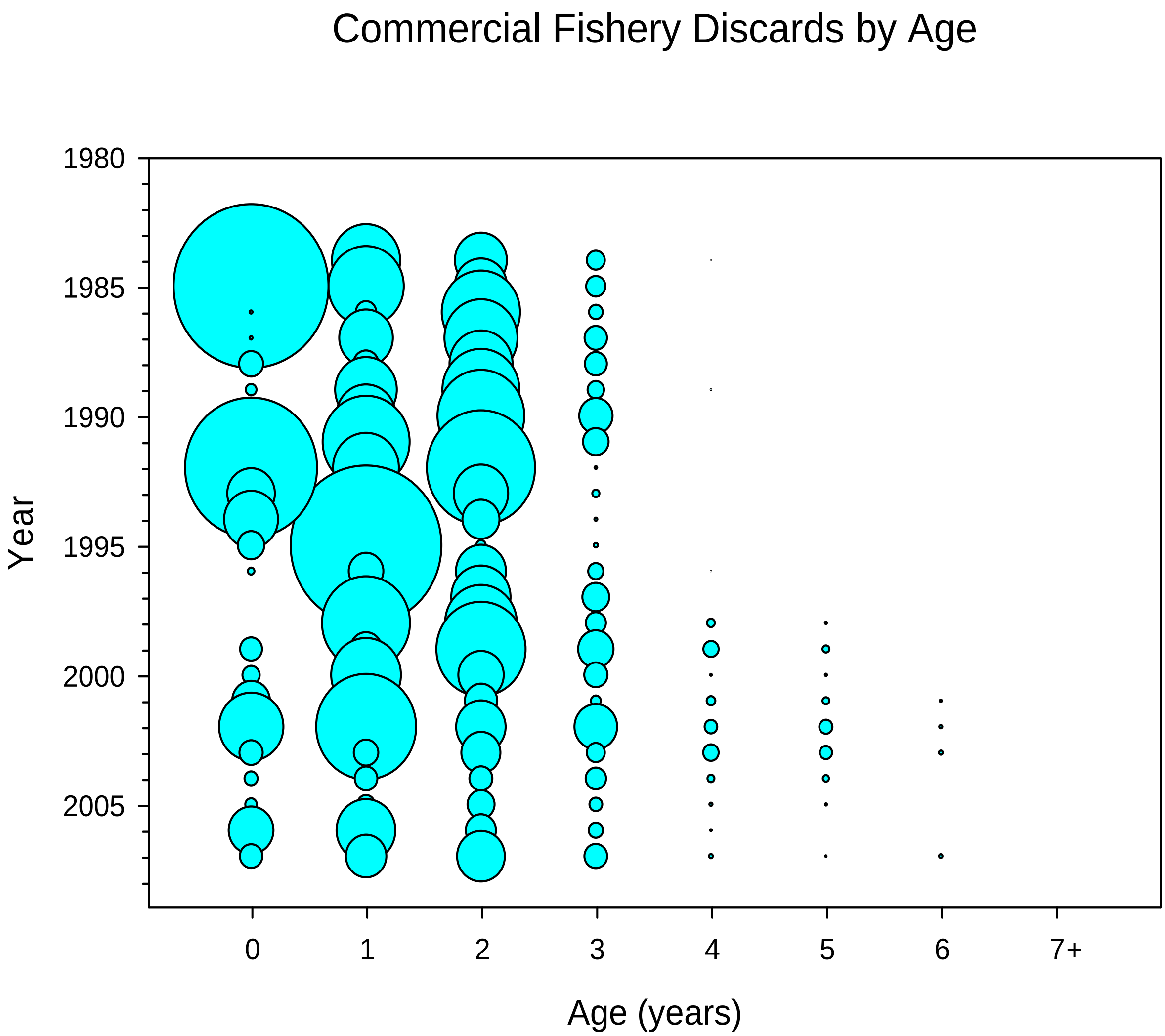


Figure 4. Commercial fishery discards by age for scup.

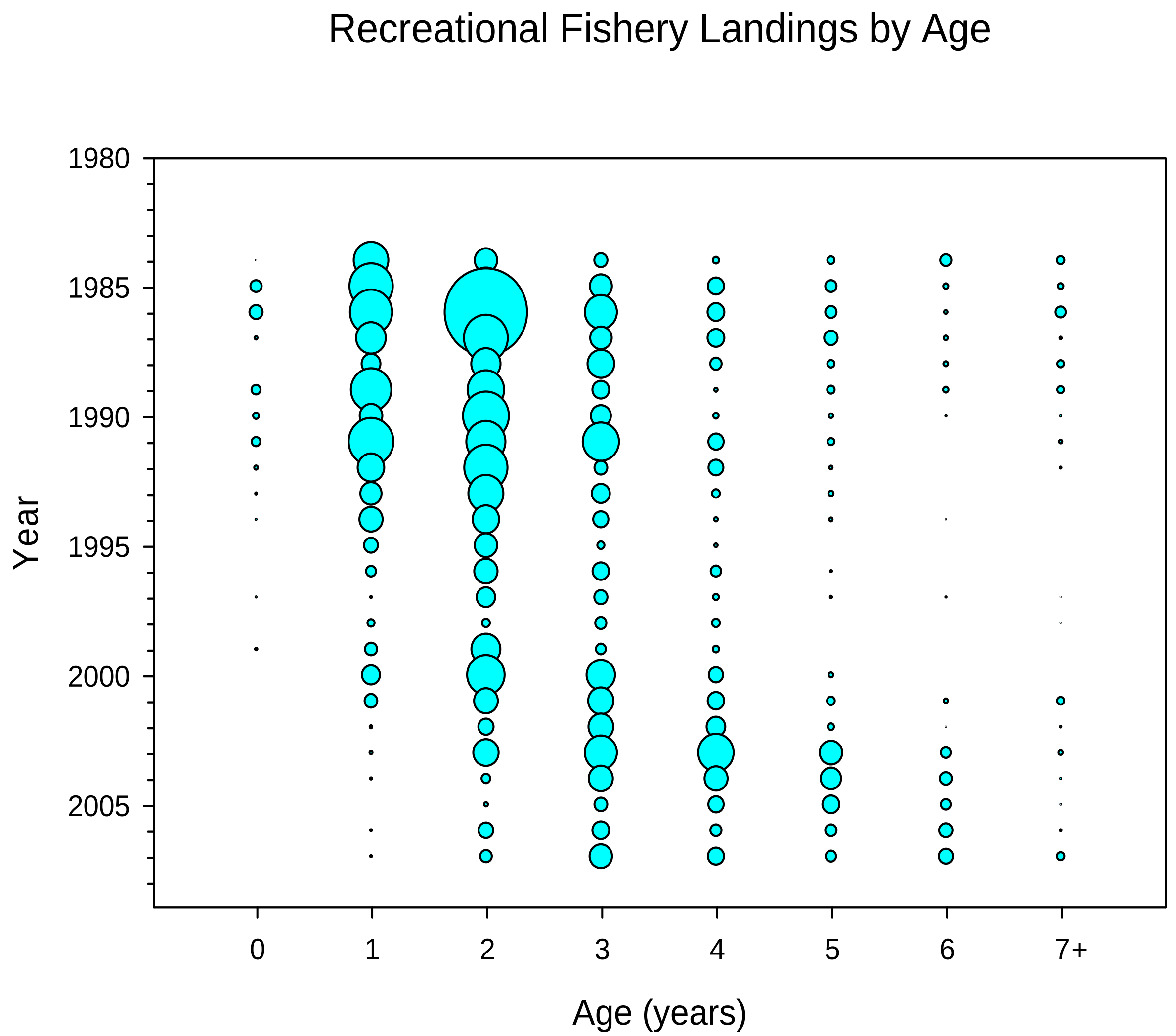


Figure 5. Recreational fishery landings by age for scup.

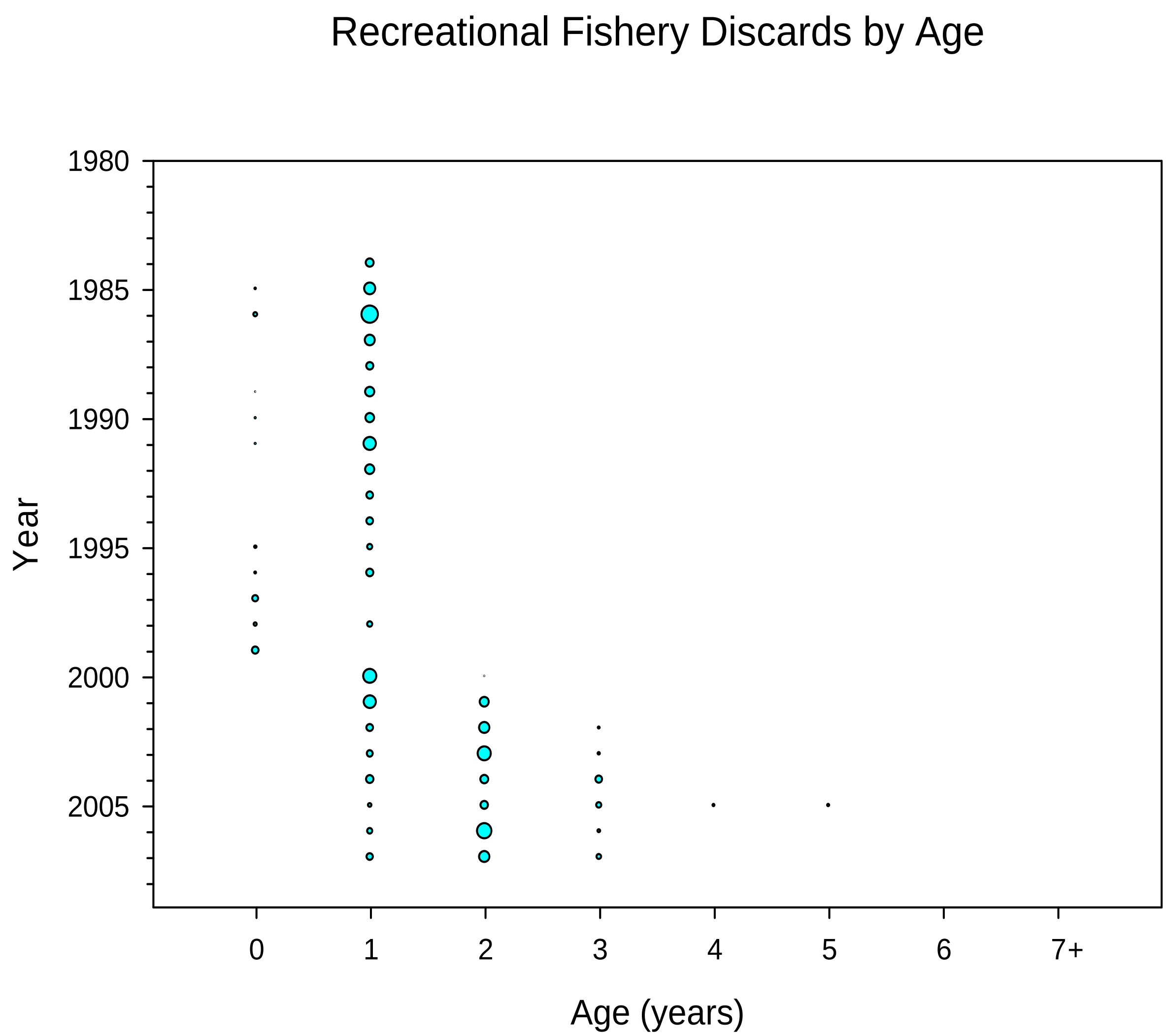


Figure 6. Recreational fishery discards by age for scup.

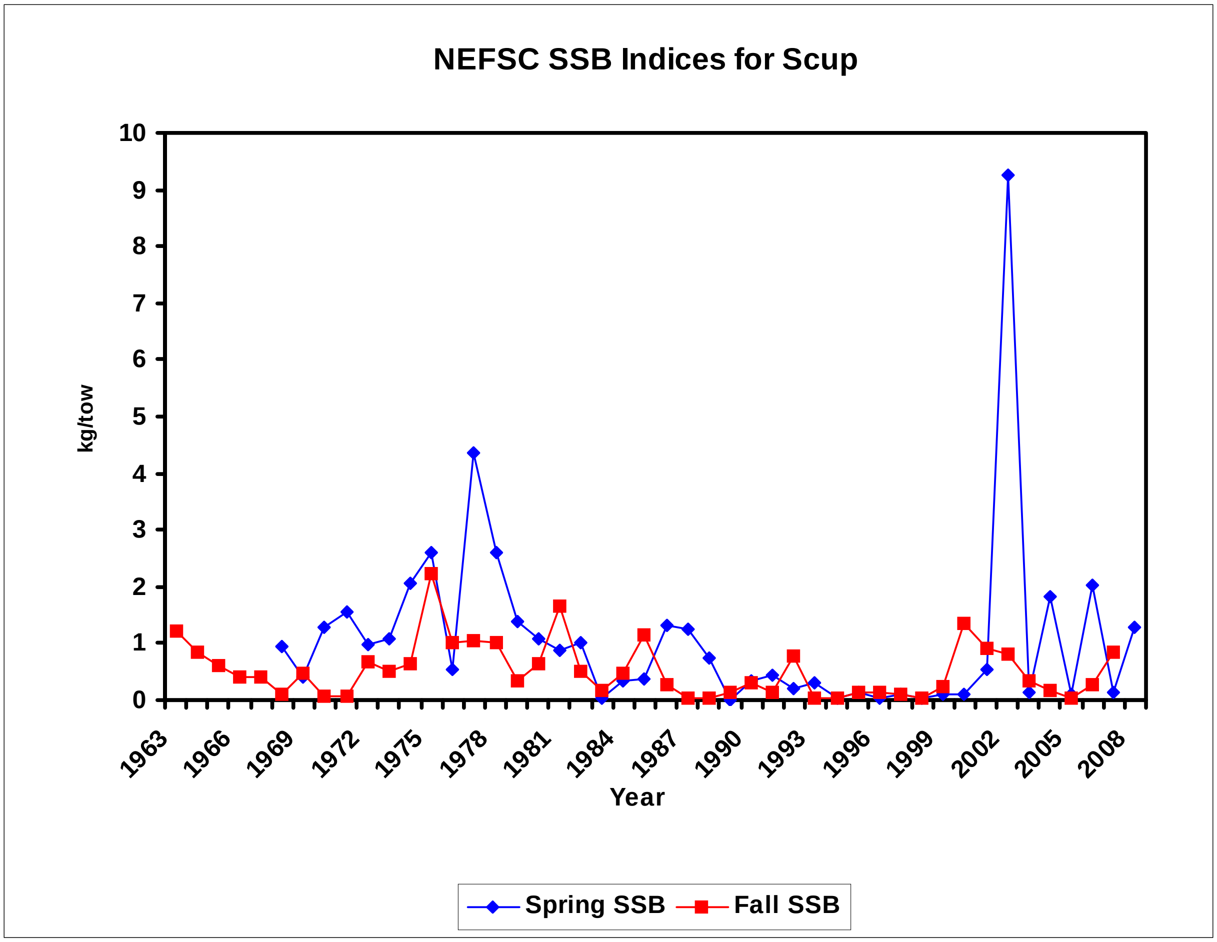


Figure 7. NEFSC spring and fall annual SSB indices for scup.

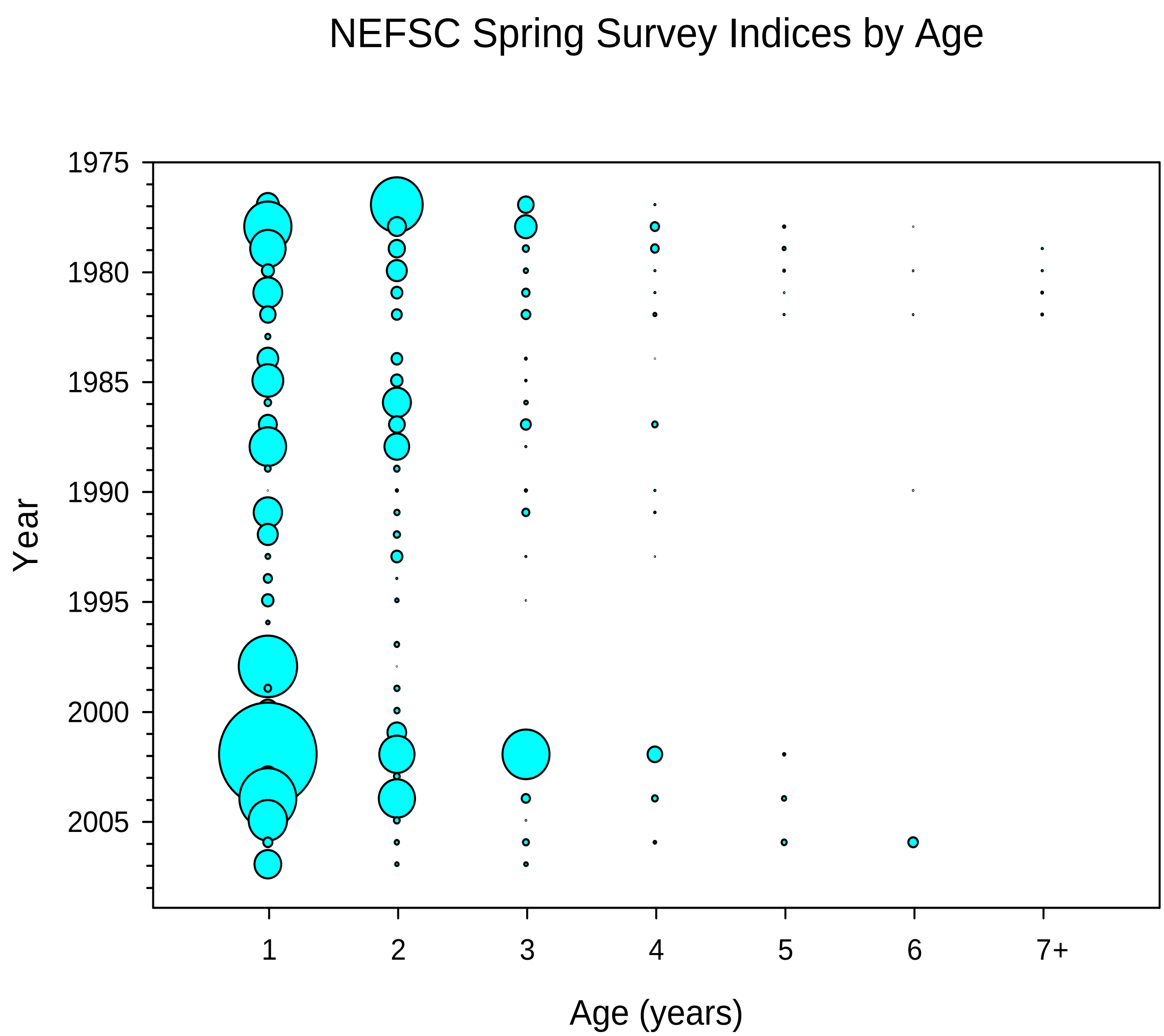


Figure 8. NEFSC Spring survey indices by age for scup.

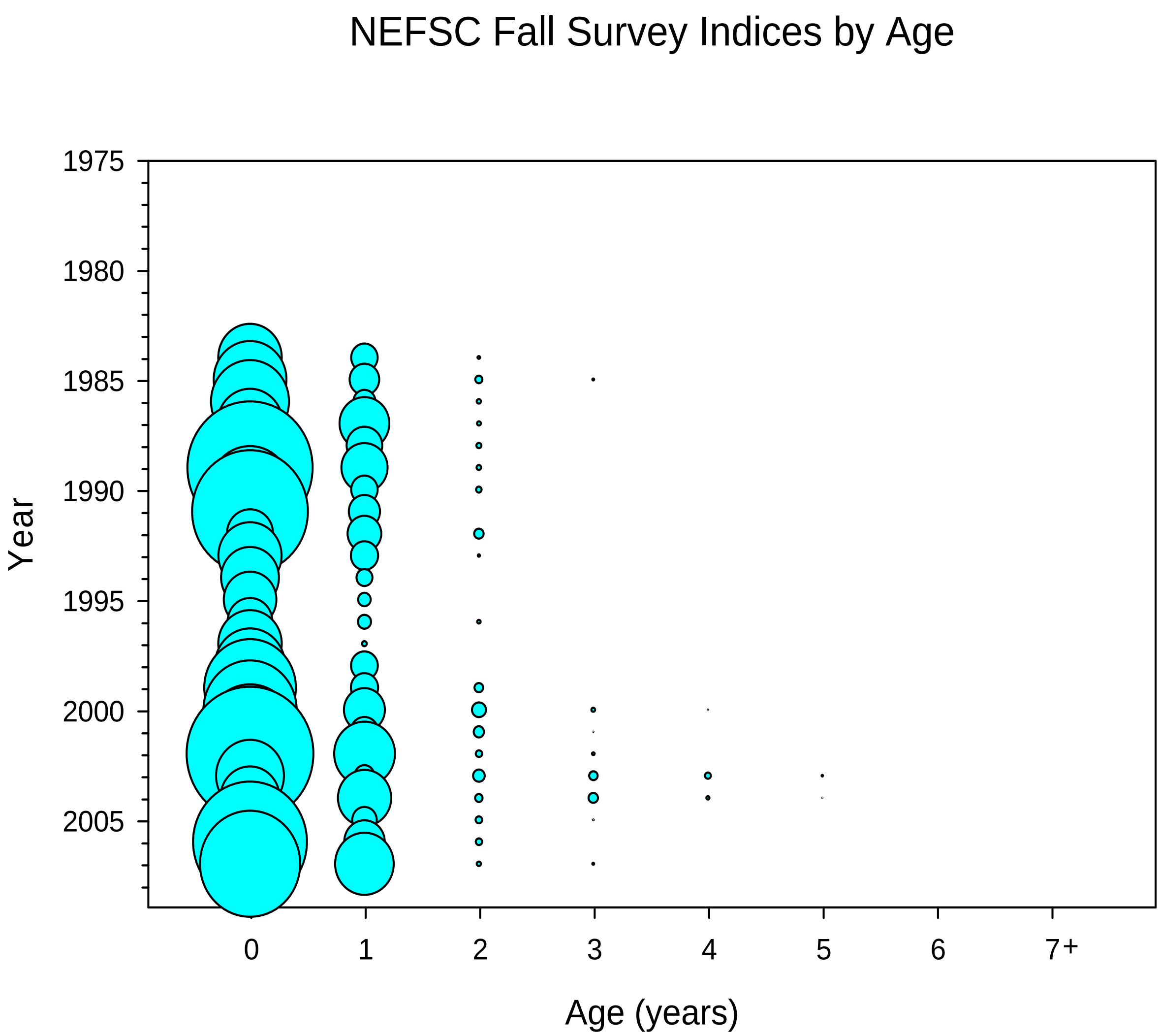


Figure 9. NEFSC Fall survey indices by age for scup.

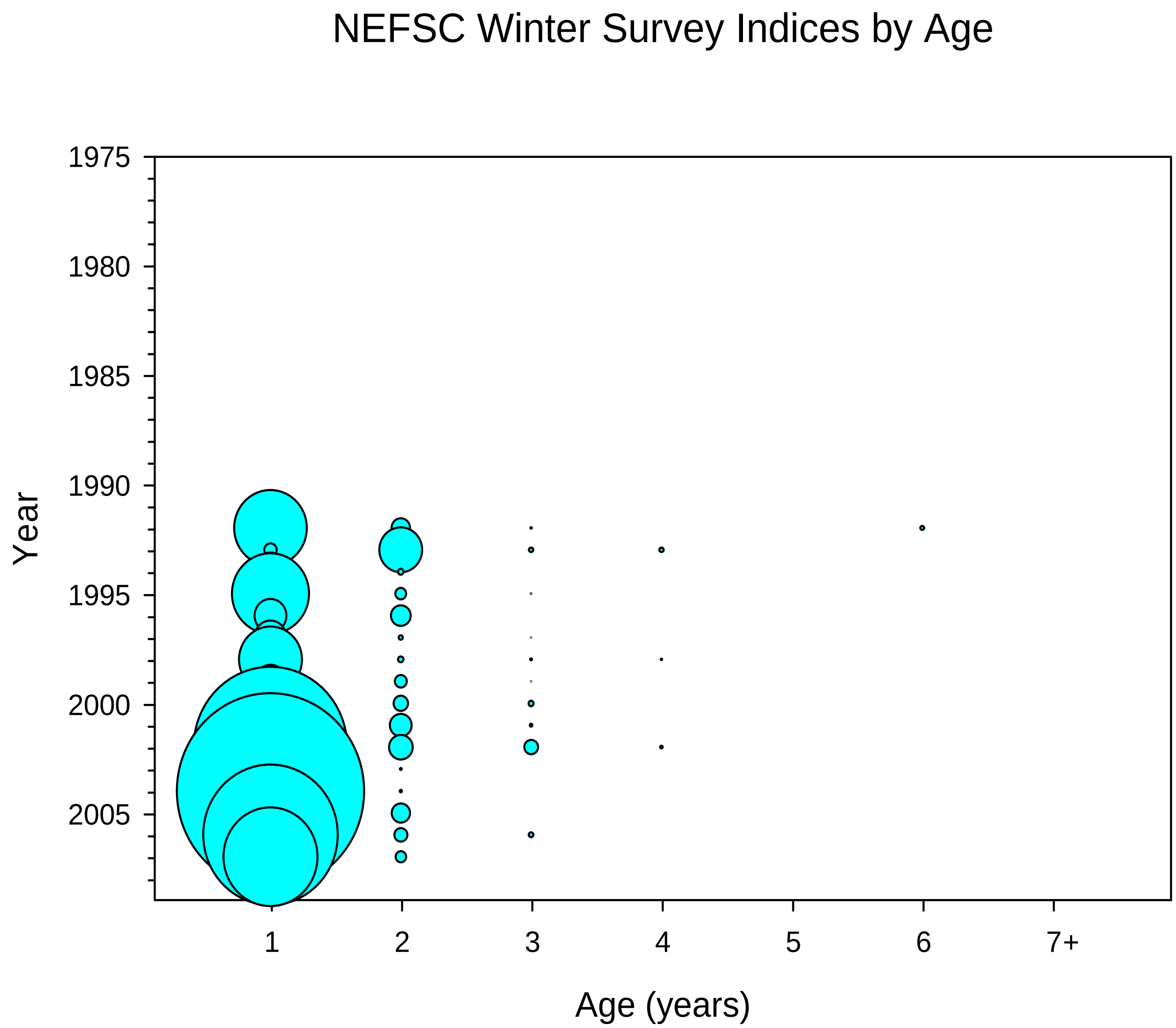


Figure 10. NEFSC Winter survey indices by age for scup.

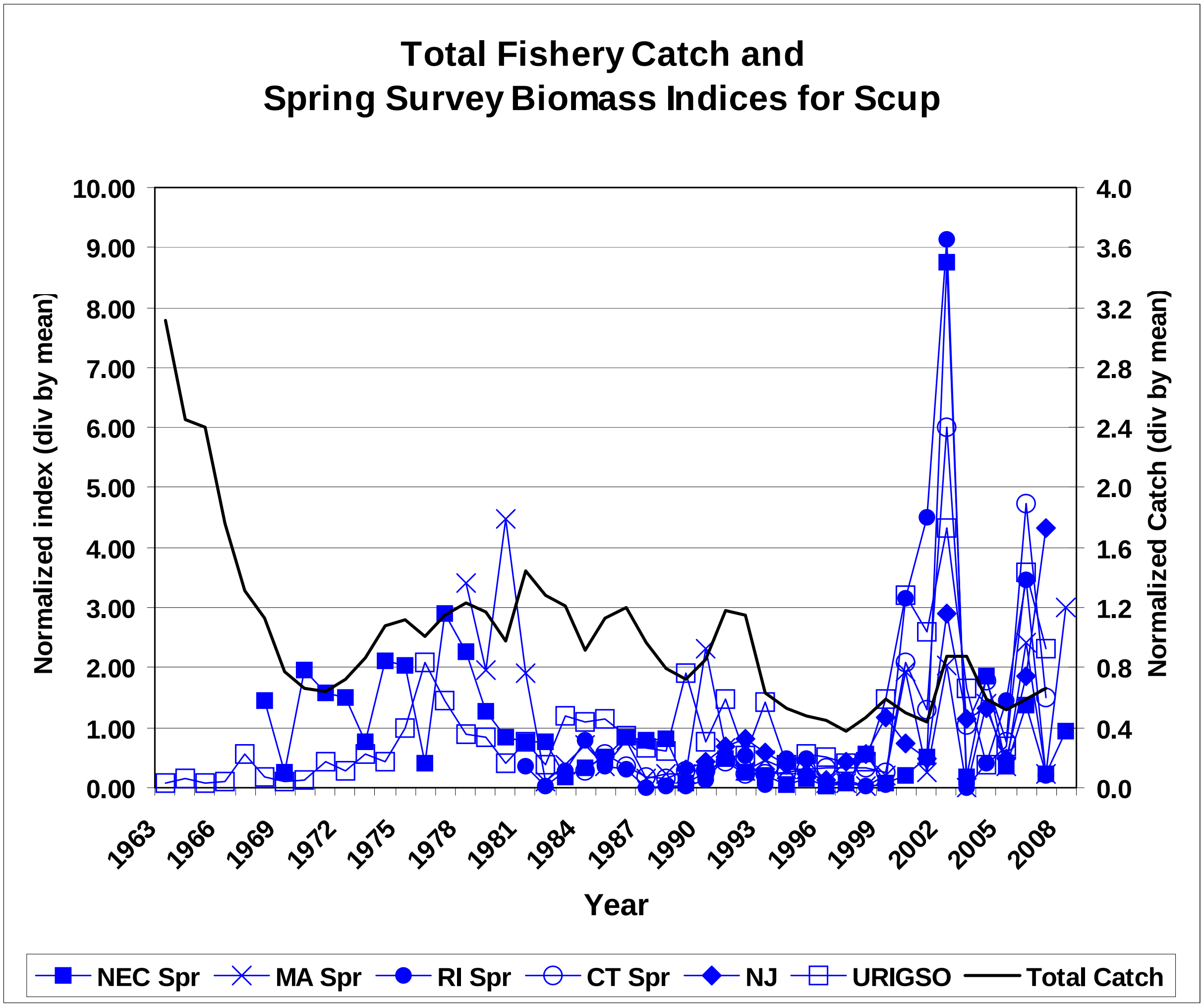


Figure 11. Research survey indices for scup: Spring

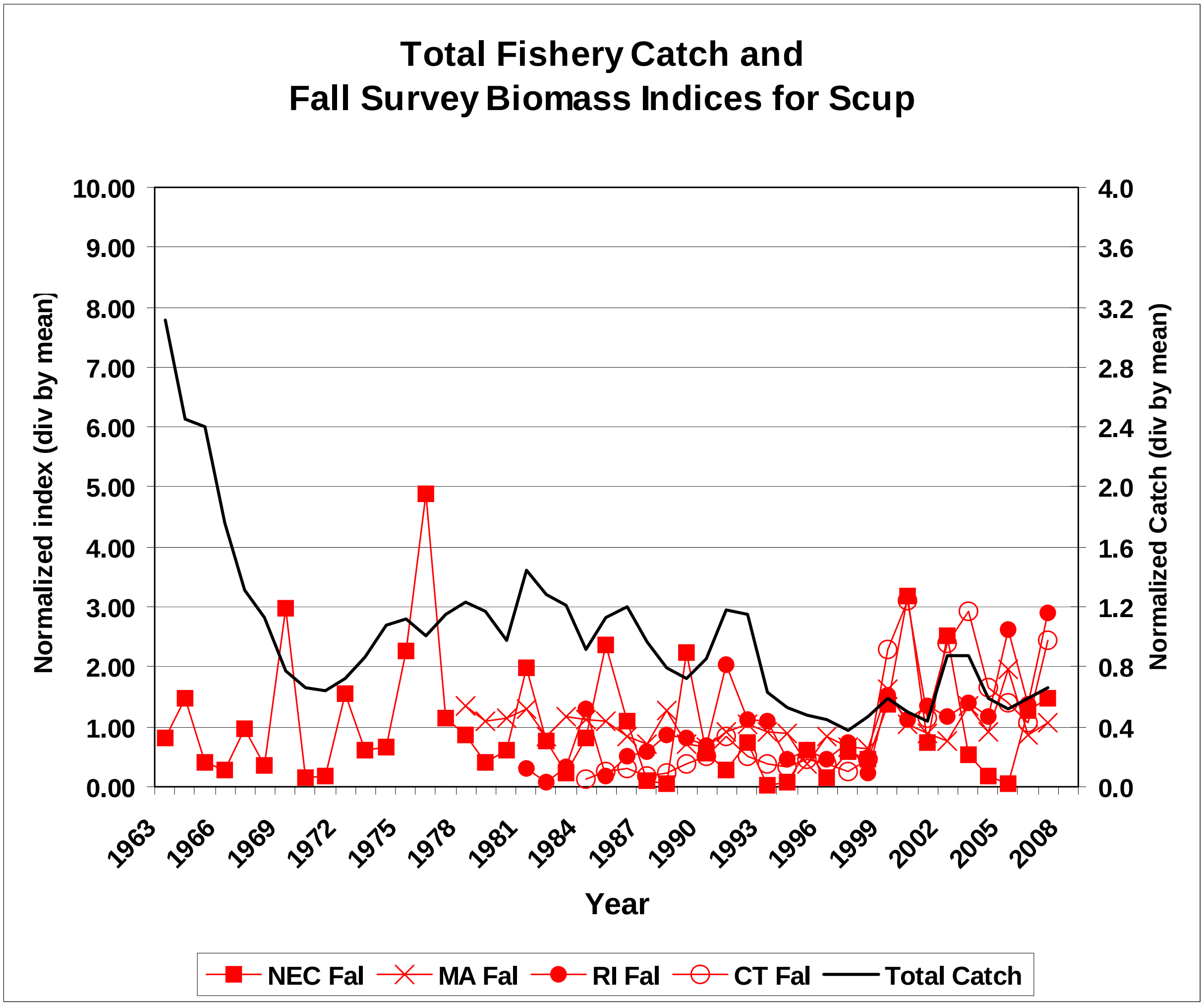


Figure 12. Research survey indices for scup: Fall

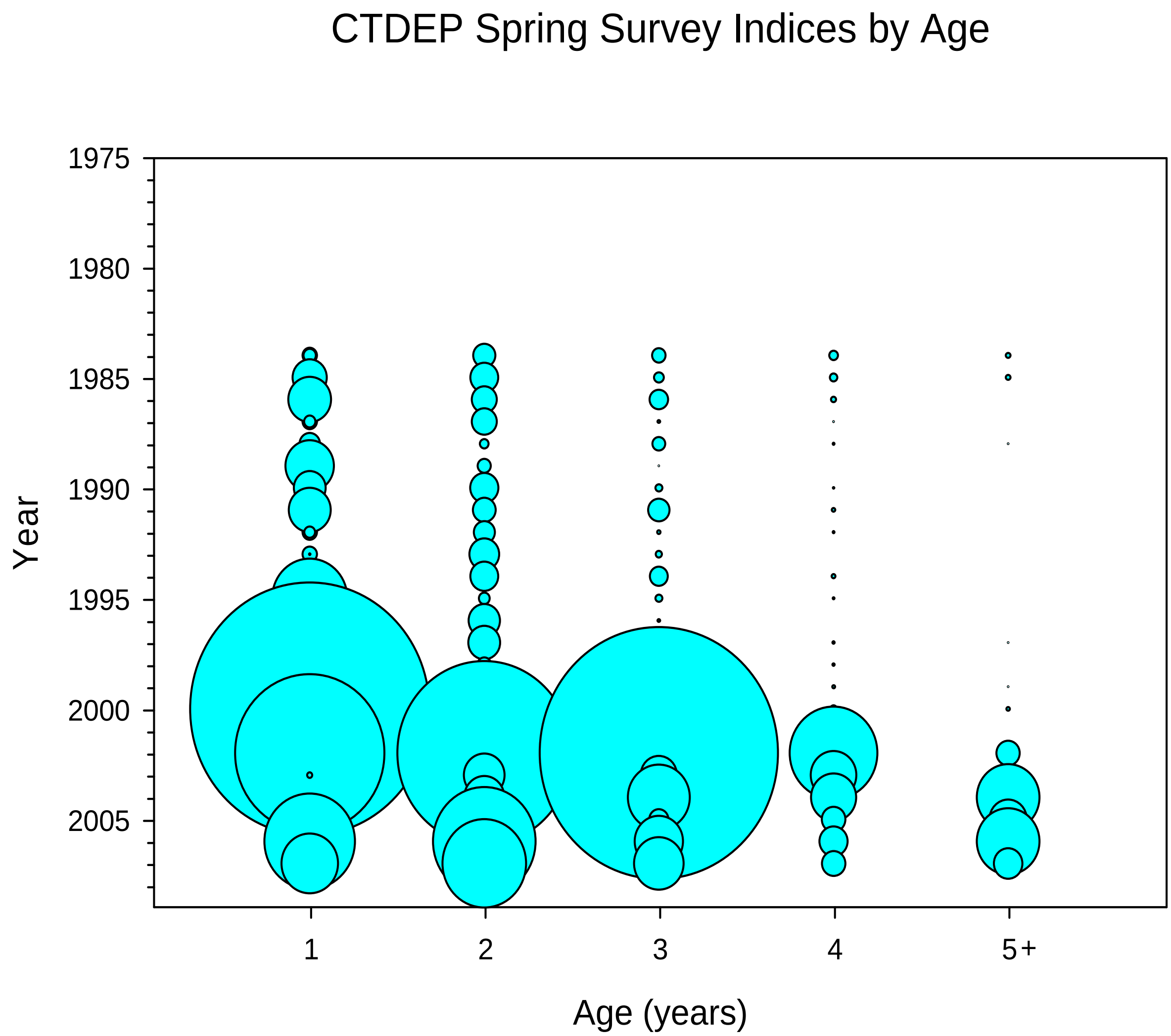


Figure 13. CTDEP Spring survey indices by age for scup.

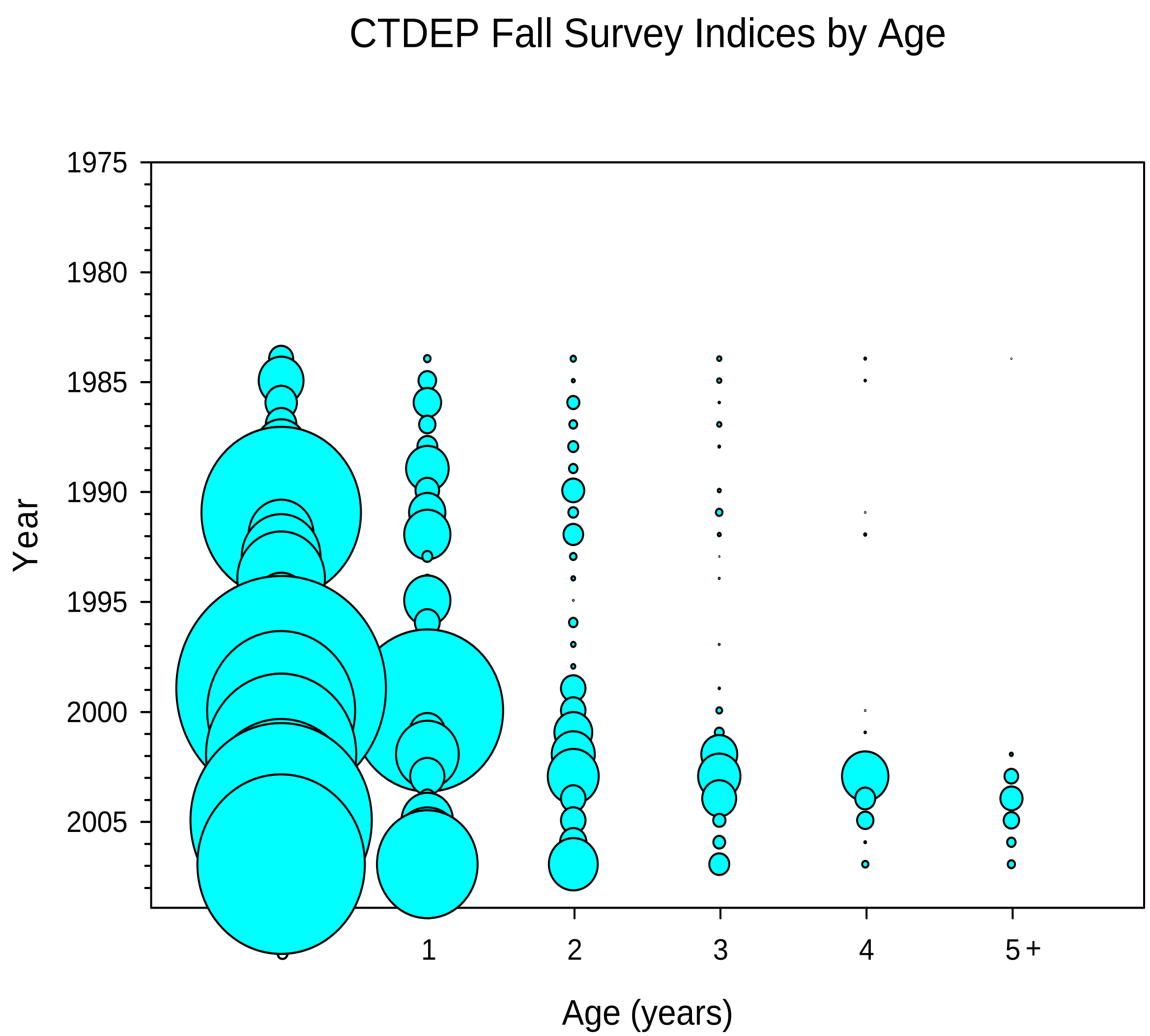


Figure 14. CTDEP Fall survey indices by age for scup.

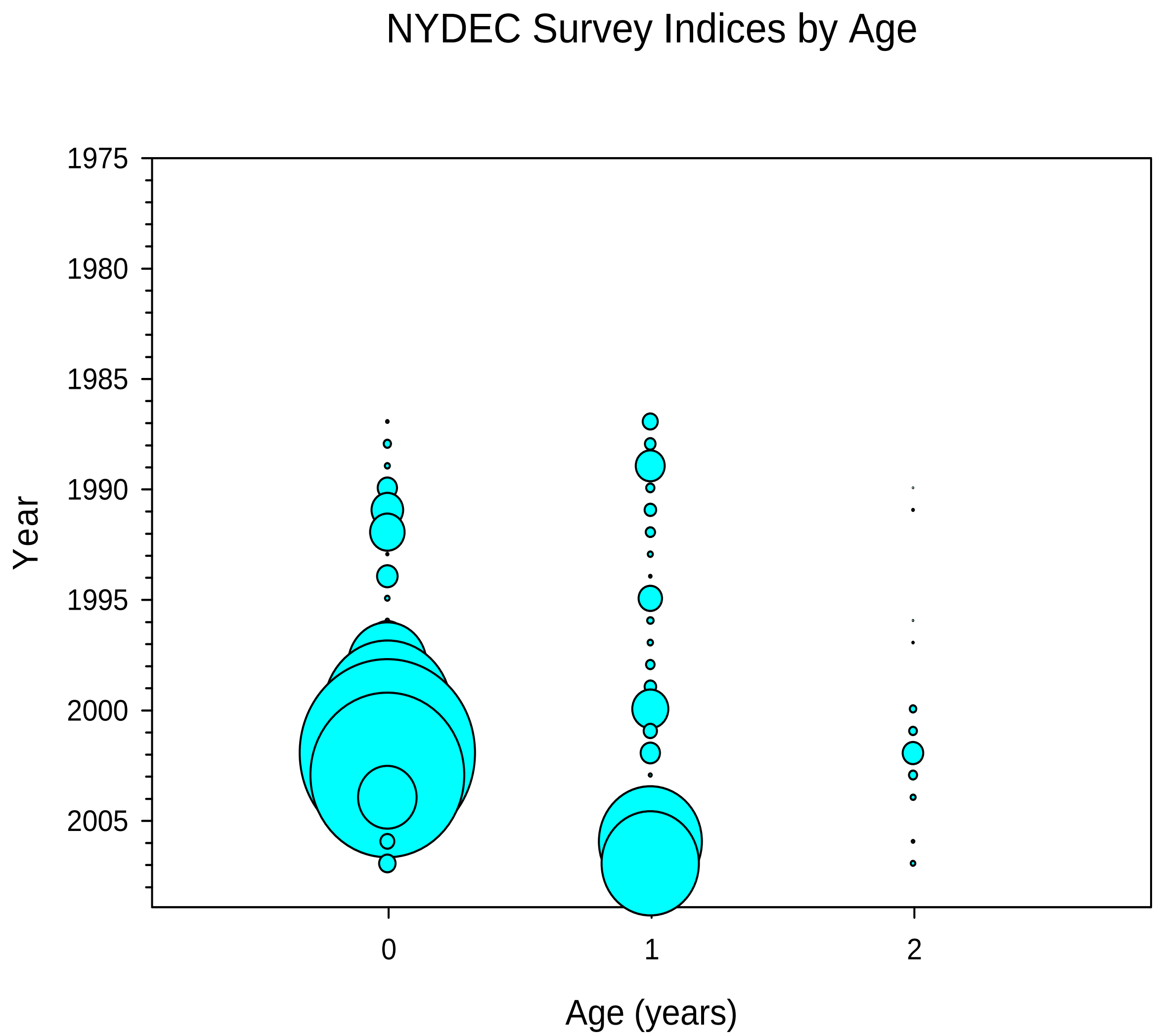


Figure 15. NYDEC survey indices by age for scup.

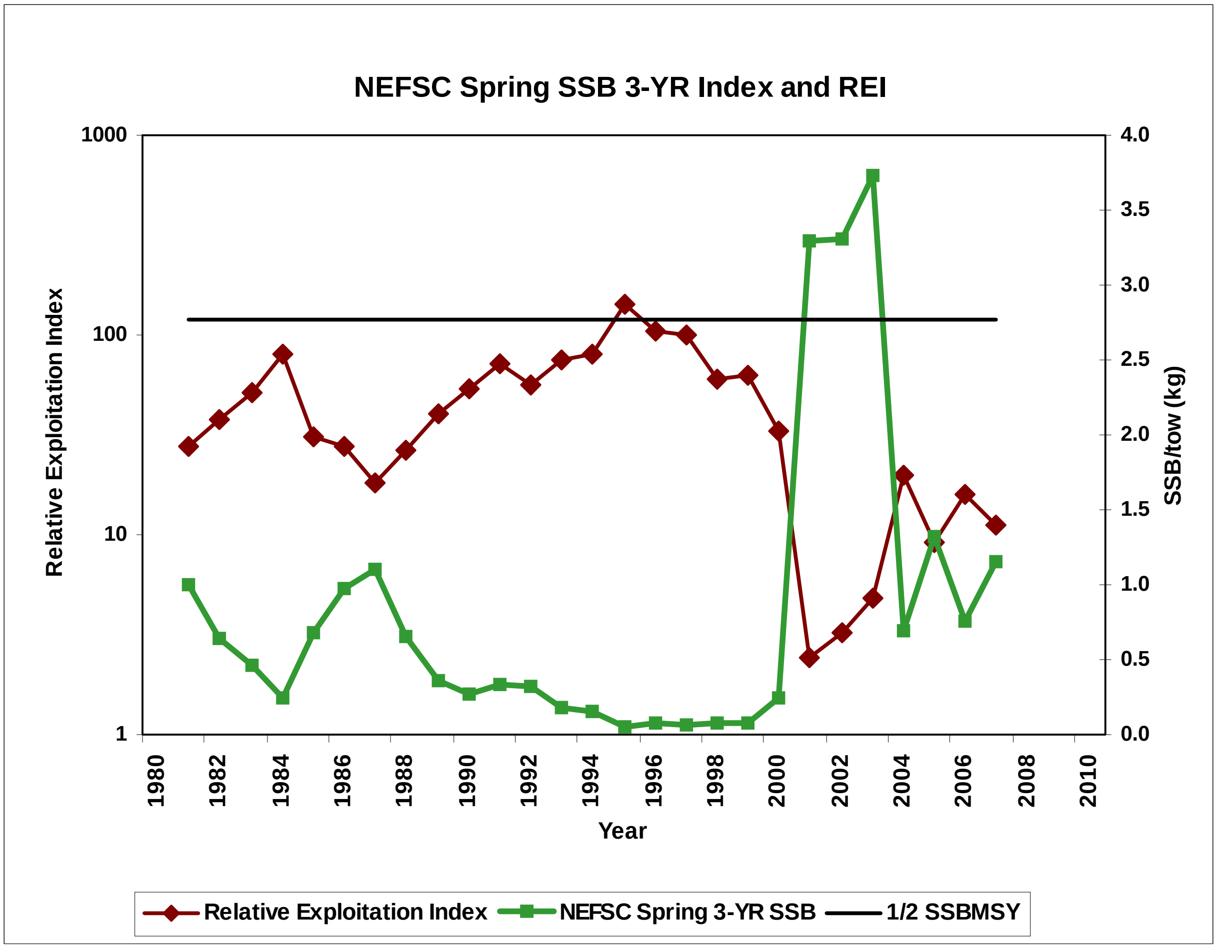
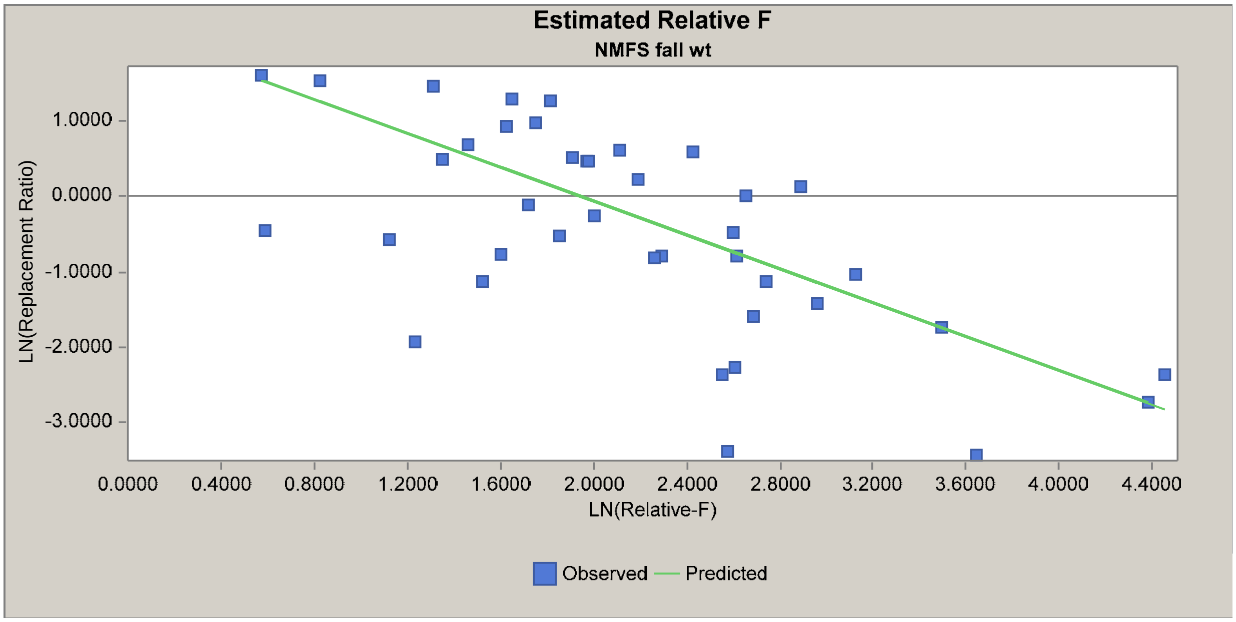


Figure 16. NEFSC Spring survey 3-year average SSB index (biomass metric) and Relative Exploitation Index (REI; fishing mortality rate metric).



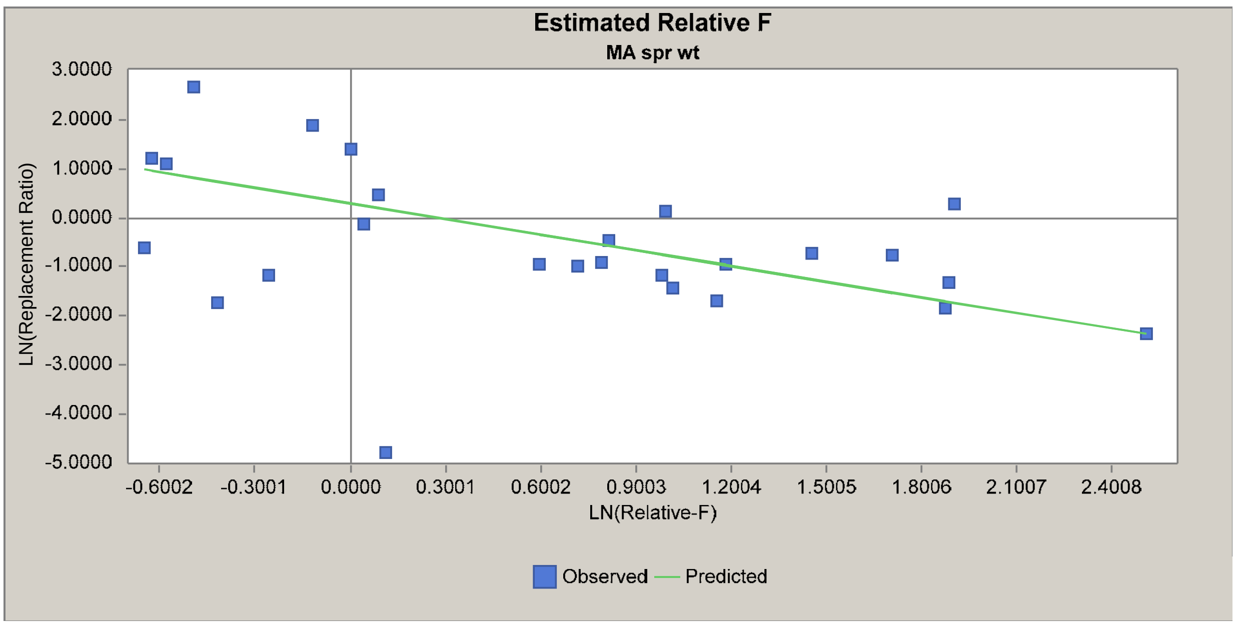
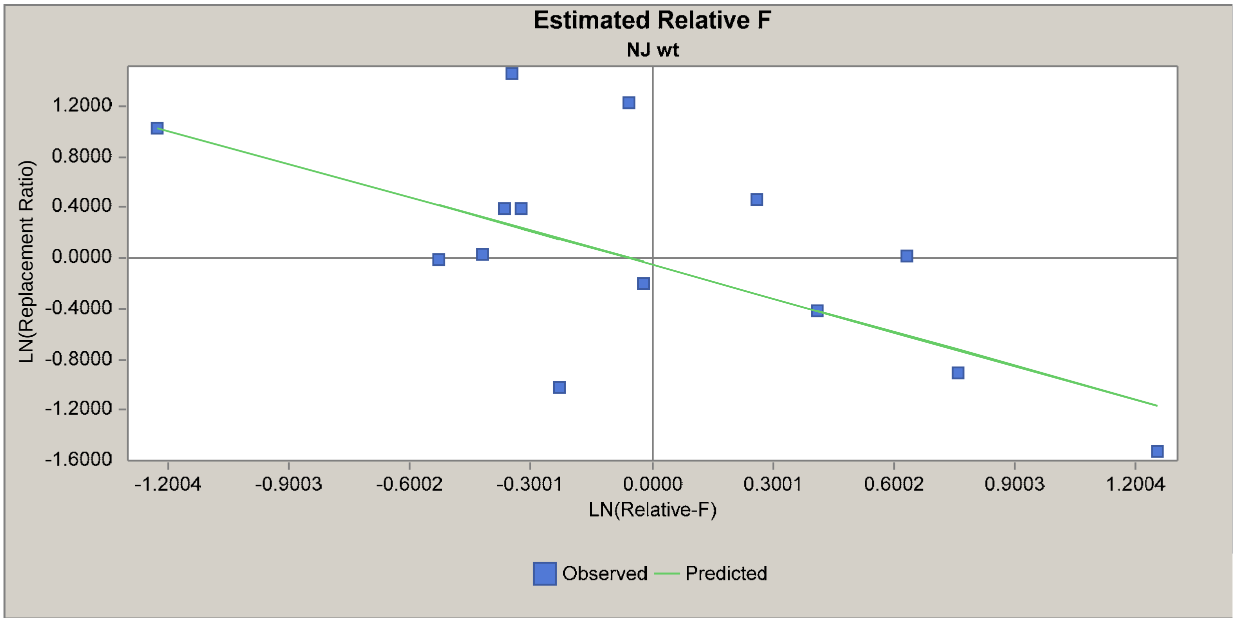


Figure 17. AIM relative F results for the NEFSC Fall and MADMF Spring survey indices.



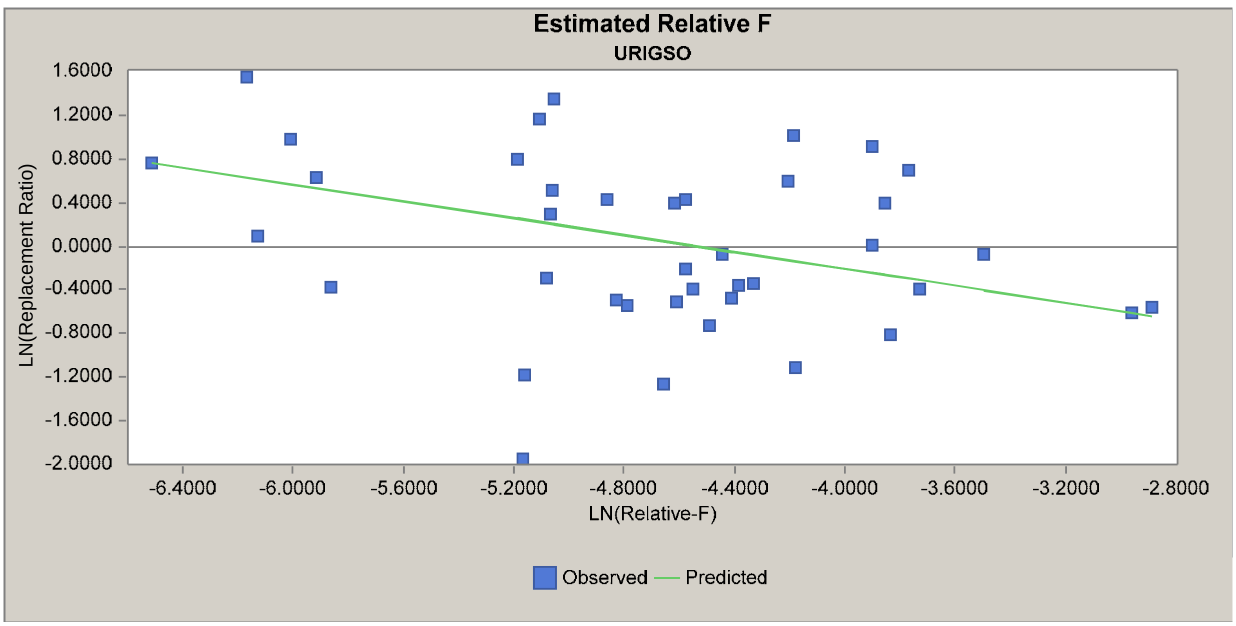
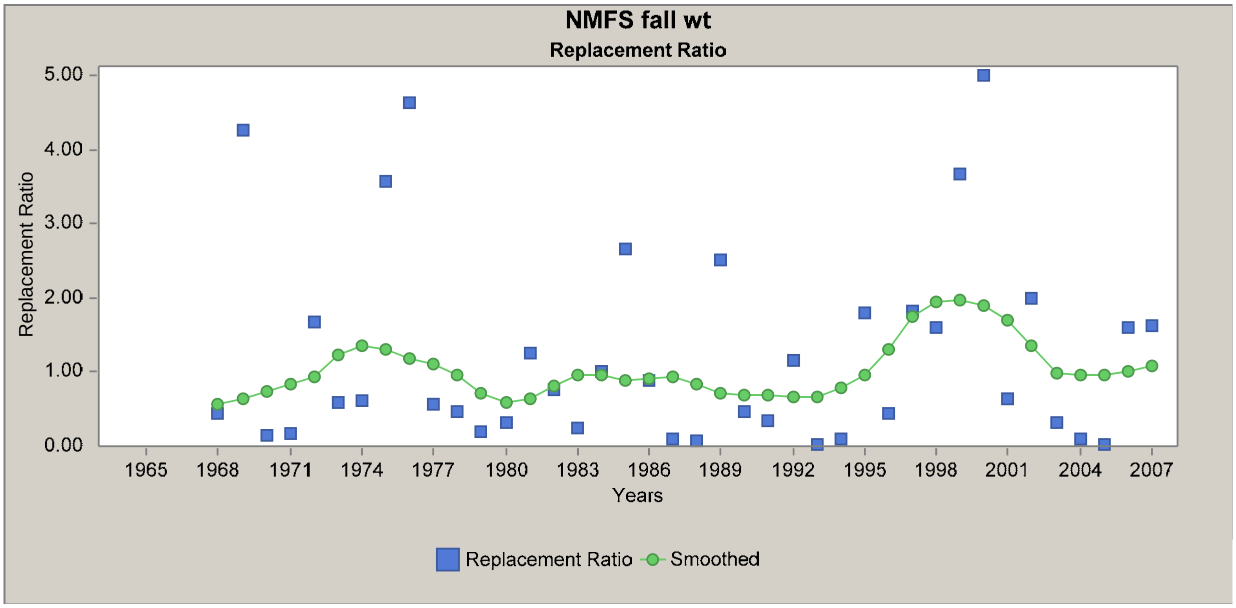


Figure 18. AIM relative F results for the NJBMF Annual and URIGSO indices.



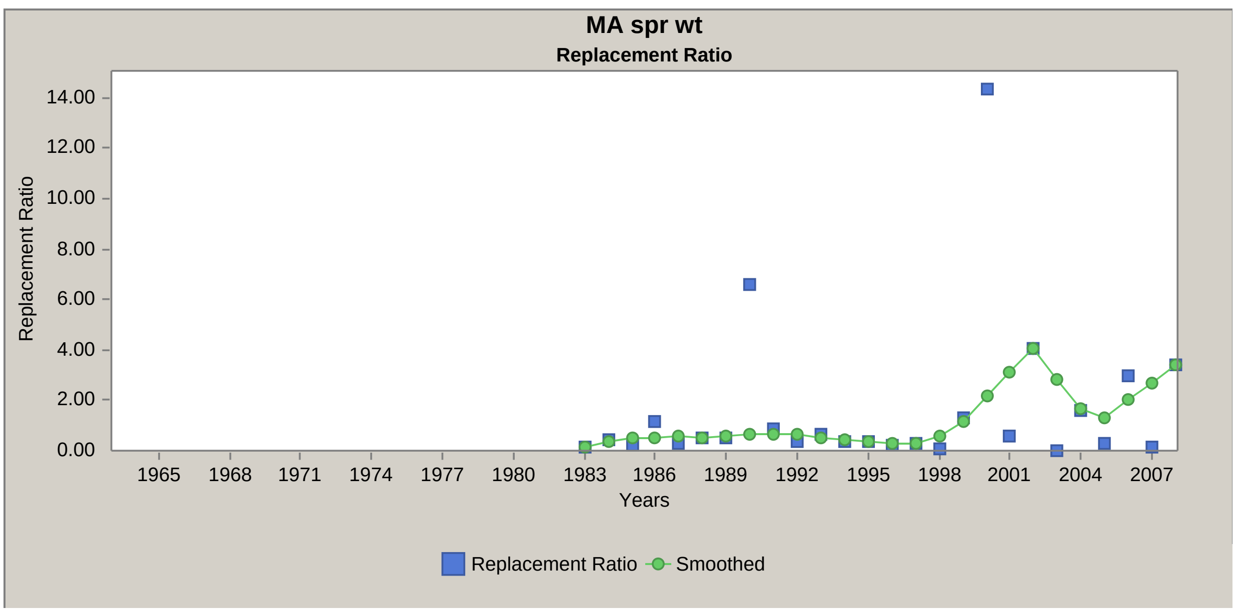


Figure 19. AIM replacement ratio results for NEFSC Fall and MADMF Spring indices.

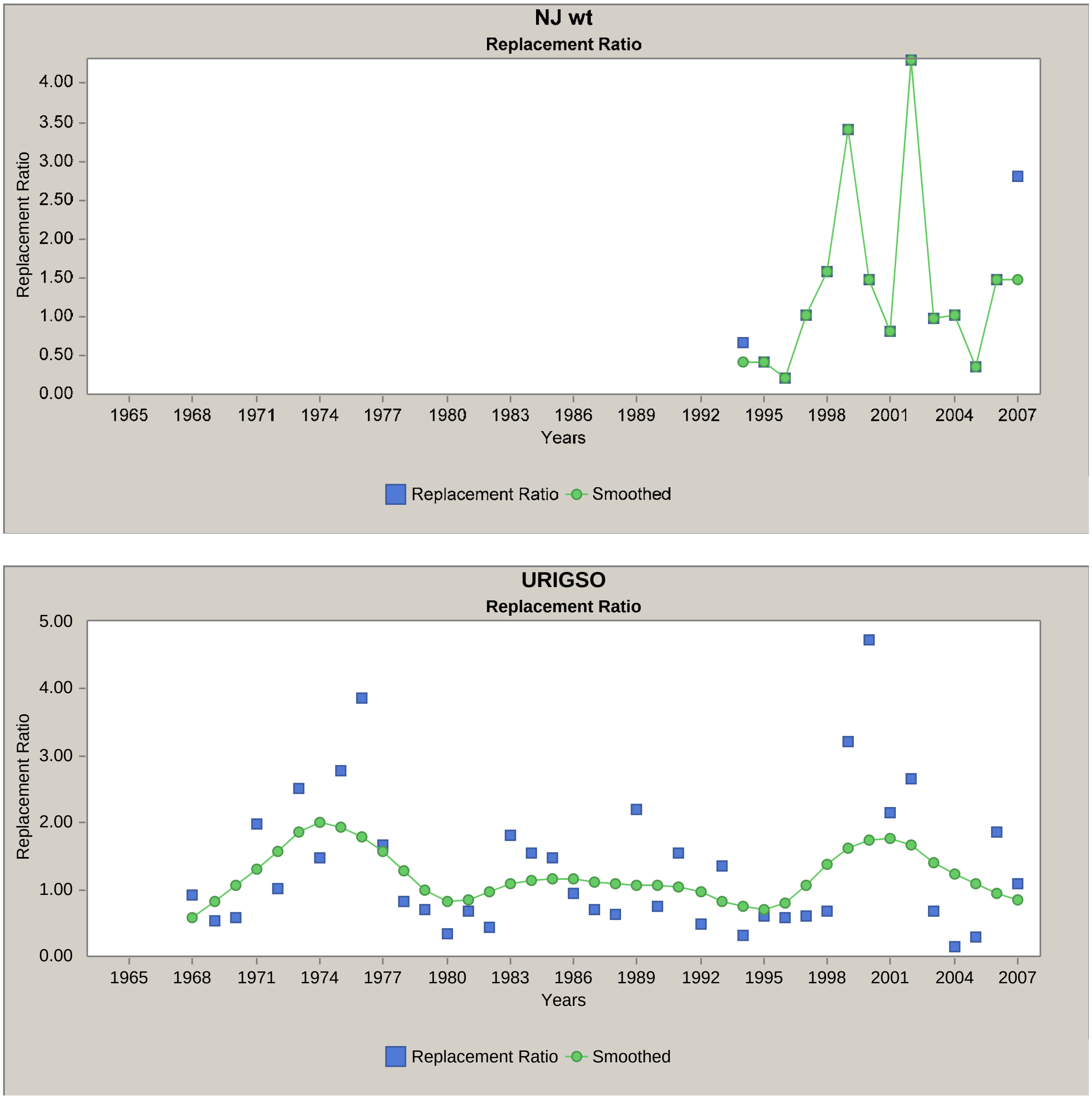


Figure 20. AIM replacement ratio results for NJBMF Annual and URIGSO indices.

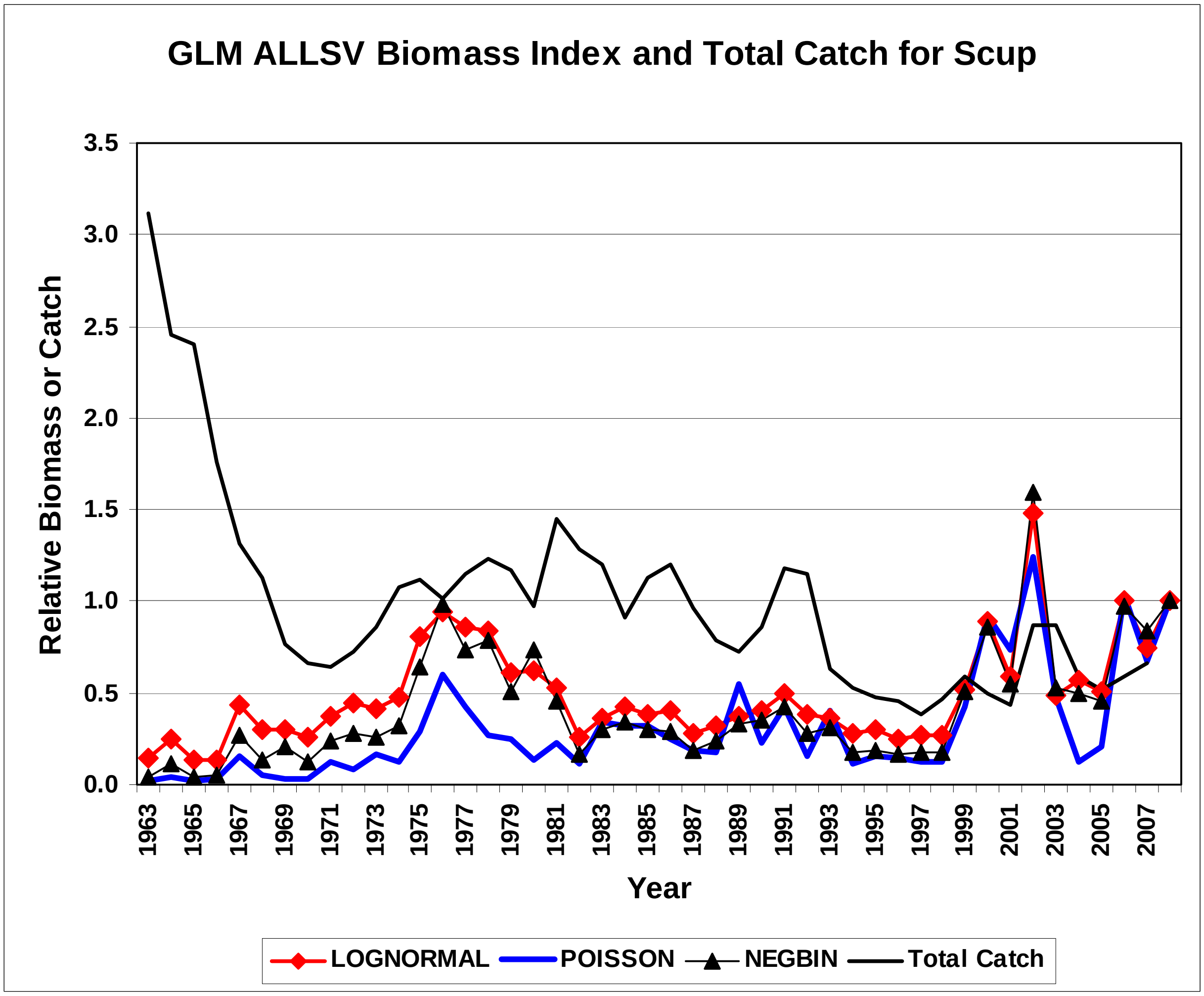
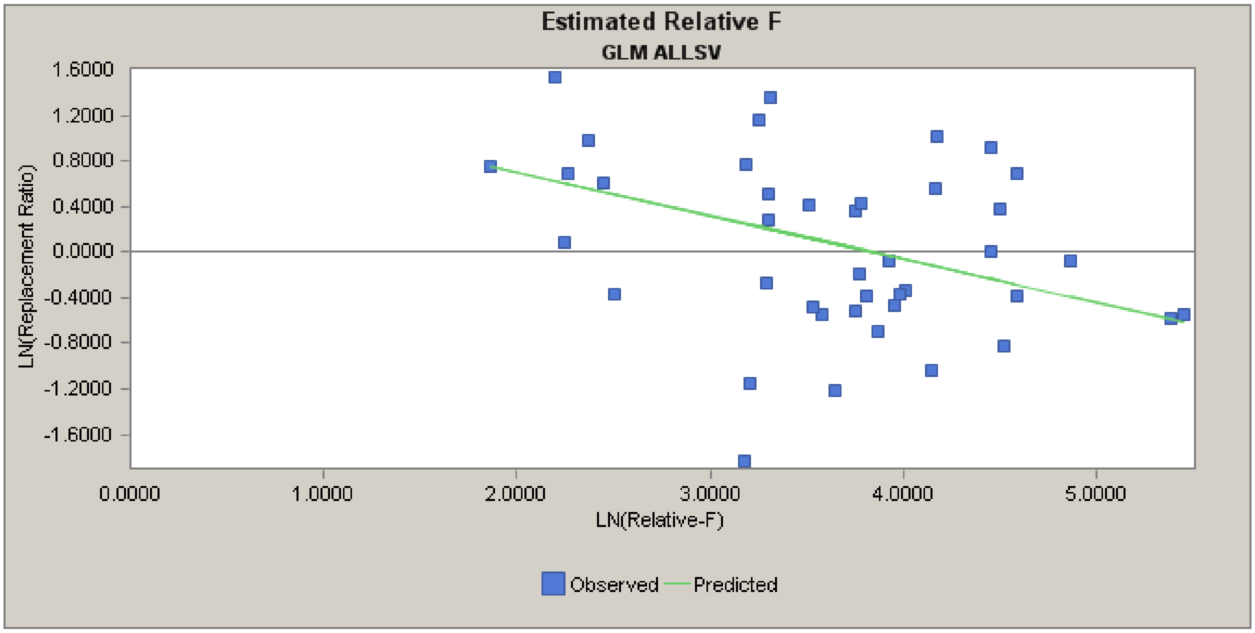


Figure 21. GLM-based biomass index for scup. The Poisson-assumption index was adopted as AIM input.



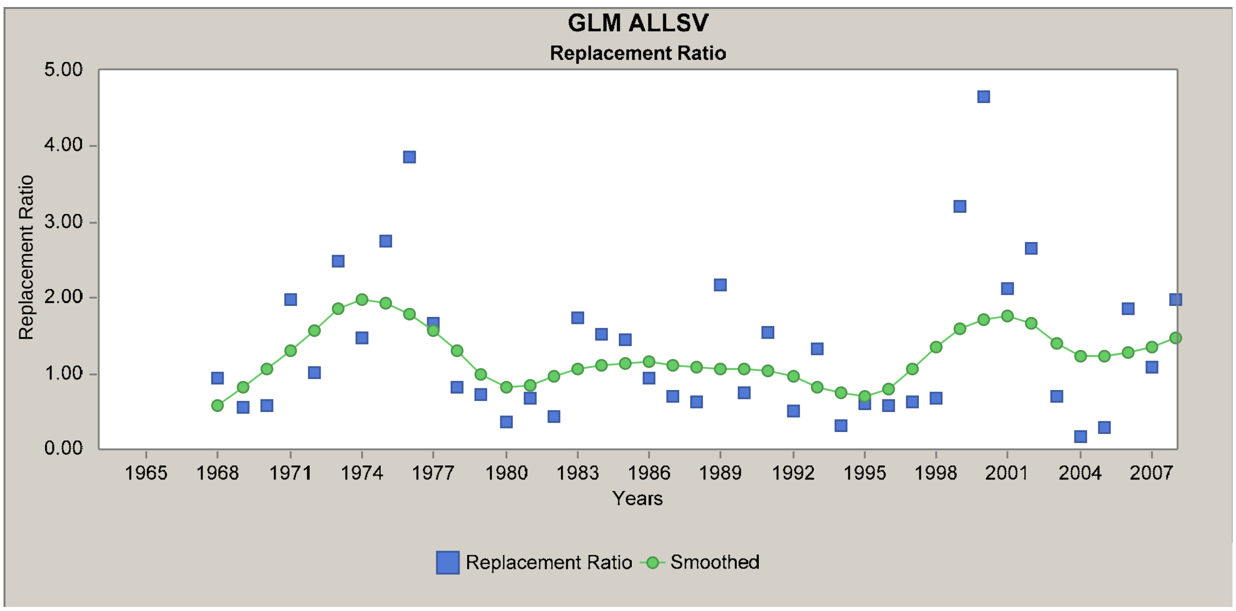


Figure 22. AIM results for the GLM based biomass index for scup.

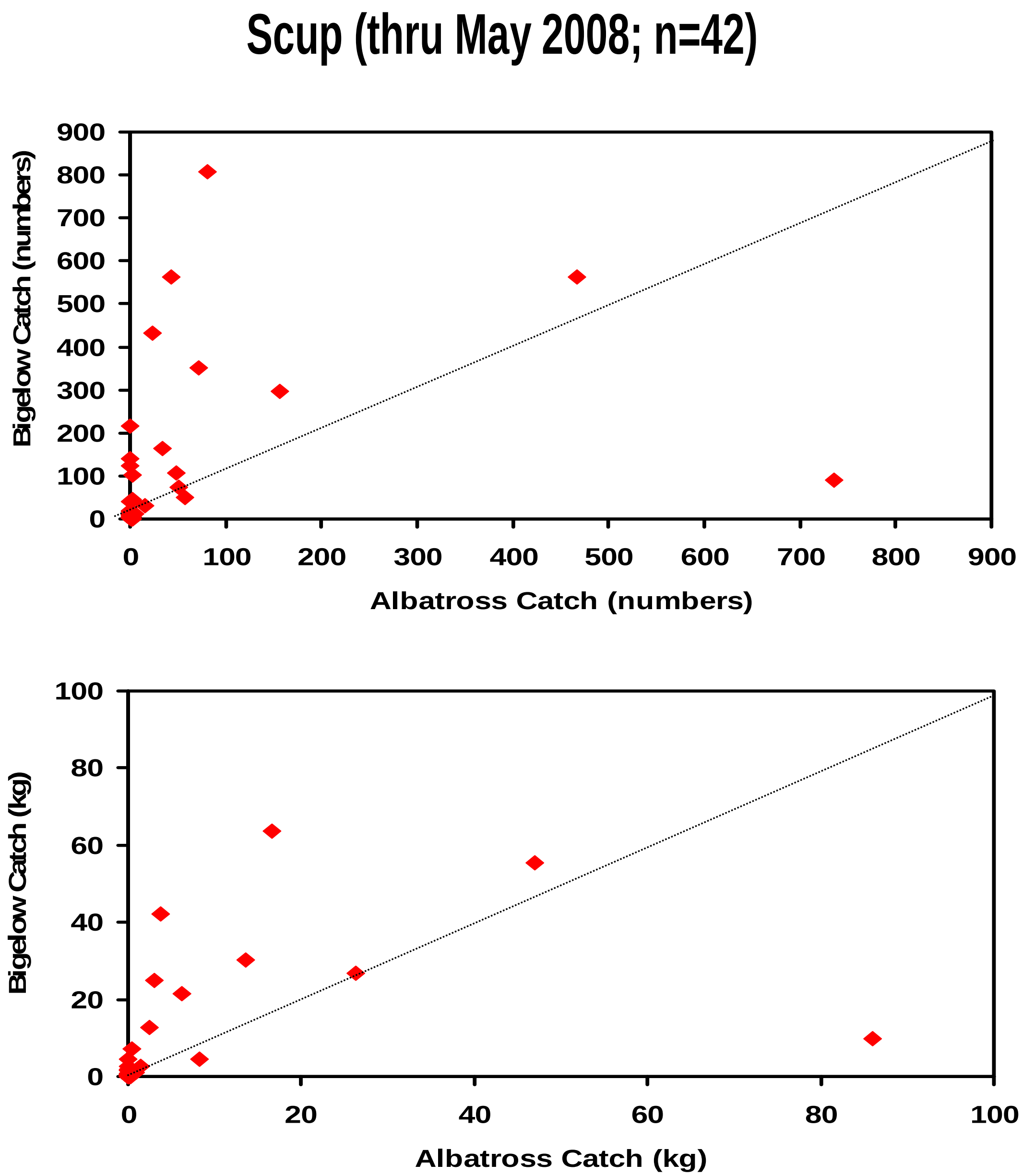


Figure 23. Preliminary NEFSC Survey calibration results for scup.

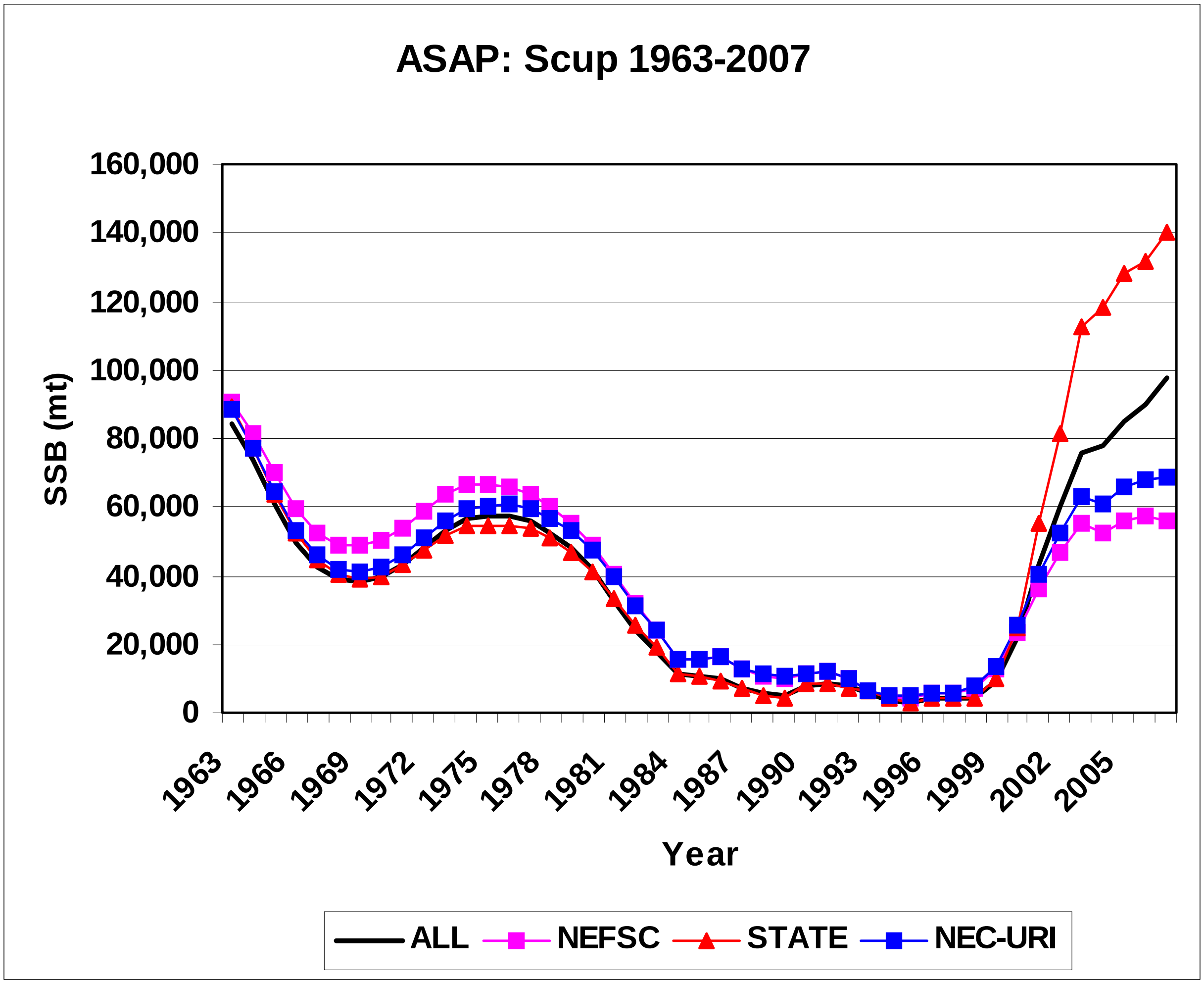


Figure 24. ASAP SSB estimates for the initial four alternative model configurations.

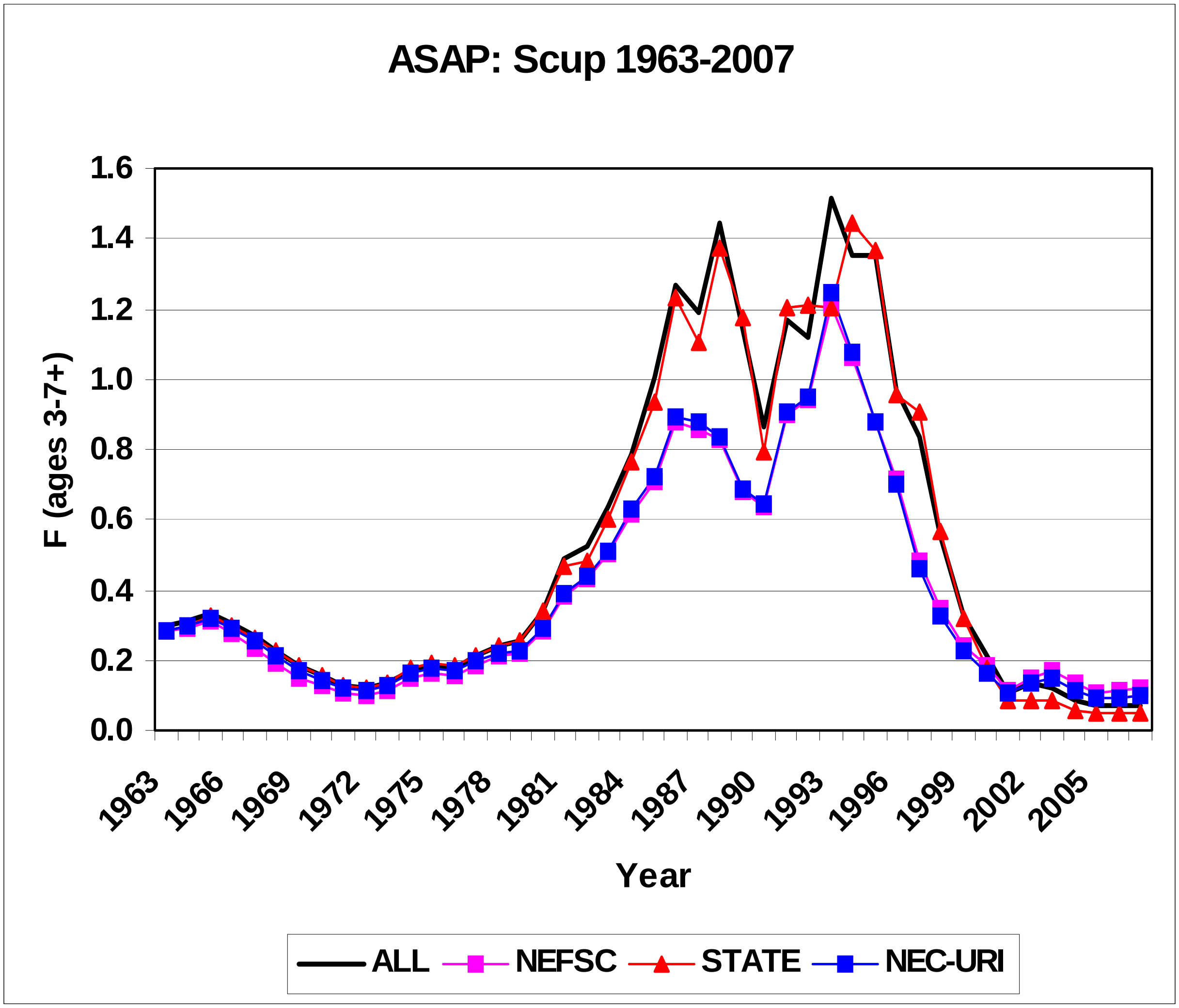


Figure 25. ASAP F estimates for the initial four alternative model configurations.

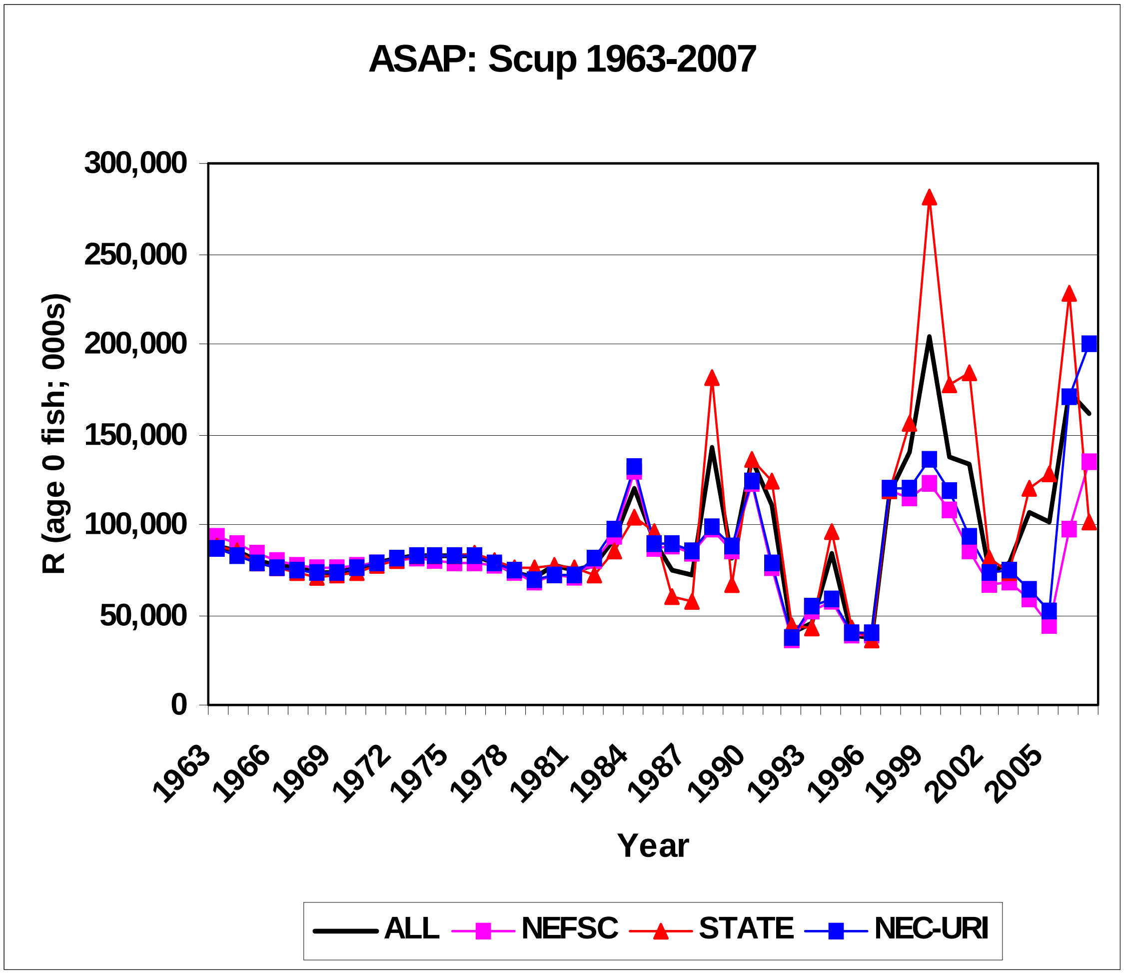


Figure 26. ASAP R (recruitment at age 0) estimates for the initial four alternative model configurations.

RUN ID	SSB63	SSB07	Fhighest	F07	Rhighest	R07	SSBMSY	MSY	FMSY	CATCH07
ALL	84,300	97,700	1.5	0.07	205	161	35600	12300	0.27	8026
NEFSC	90,500	56,300	1.21	0.12	135	135	33000	11000	0.25	8026
STATE	89,000	140,300	1.44	0.05	281	101	35900	12500	0.27	8026
NEC-URI	88,400	68,600	1.25	0.10	200	200	33300	11600	0.27	8026

	SSB07/SSBMSY	F07/FMSY	CAT07/MSY
ALL	2.74	0.26	0.65
NEFSC	1.71	0.48	0.73
STATE	3.91	0.19	0.64
NEC-URI	2.06	0.37	0.69

Figure 27. Initial ASAP results for four alternative run configurations.

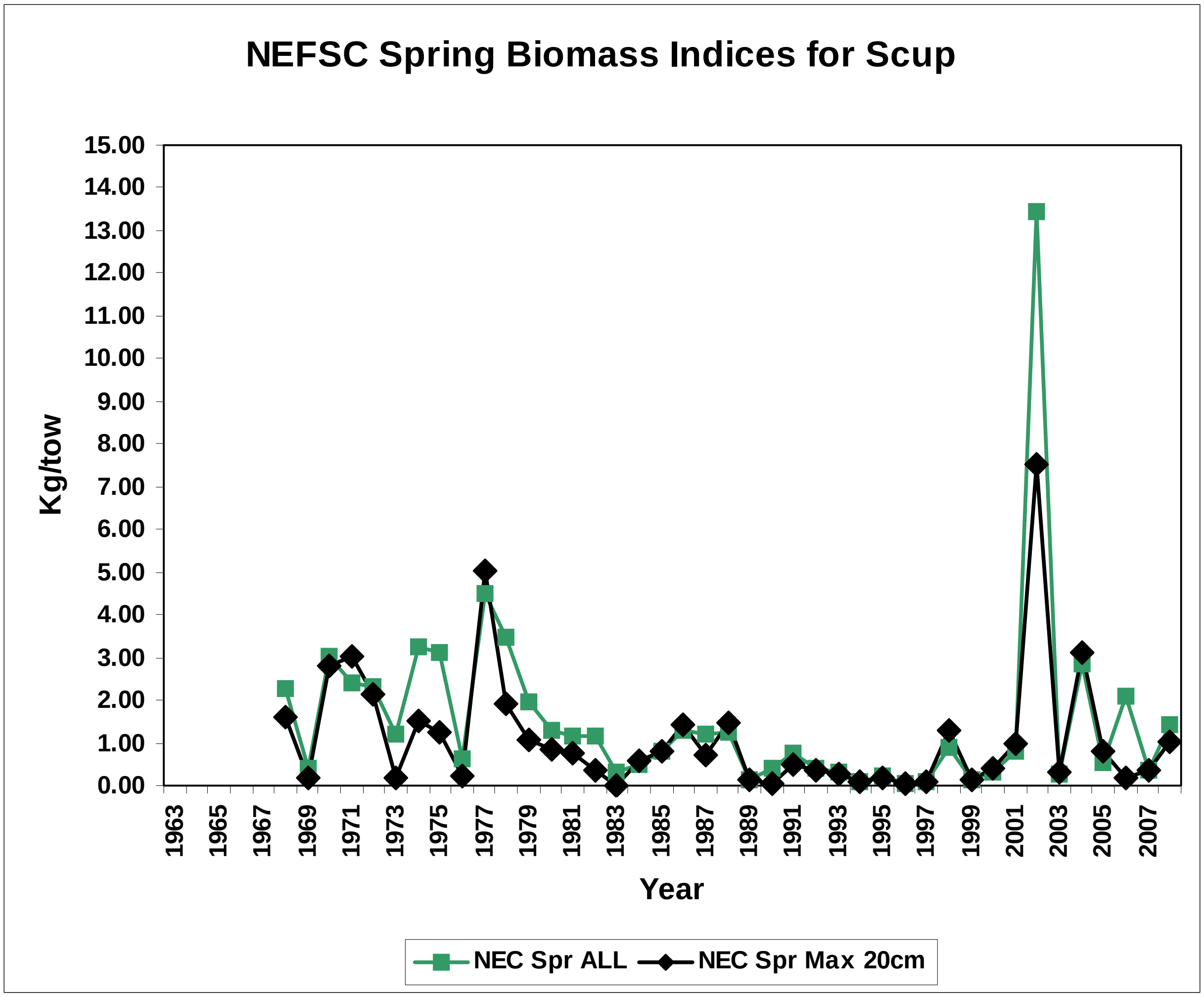


Figure 28. NEFSC Spring trawl survey biomass indices for scup: all sizes, and with a maximum length of 20 cm.

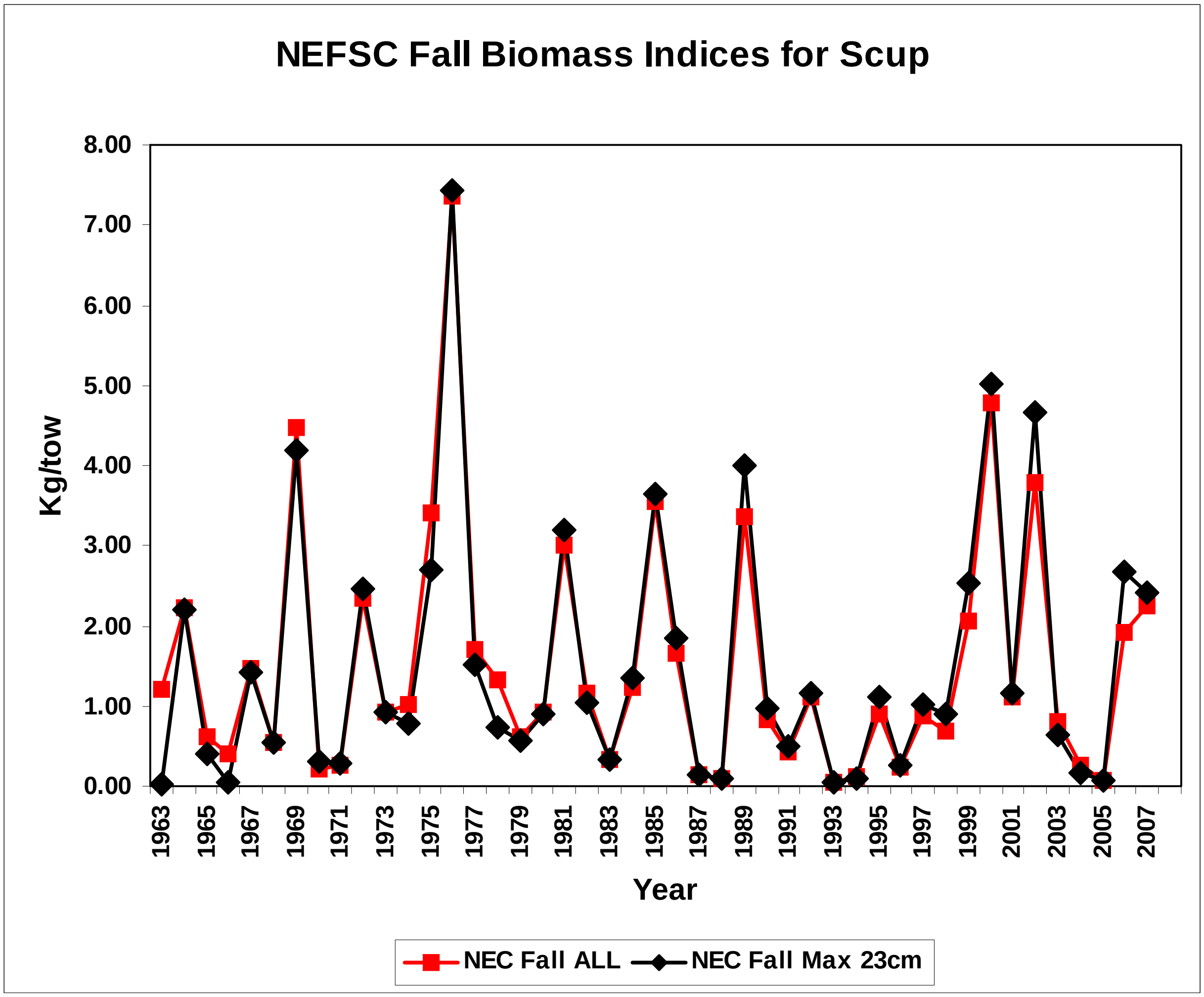


Figure 29. NEFSC Fall trawl survey biomass indices for scup: all sizes, and with a maximum length of 23 cm.

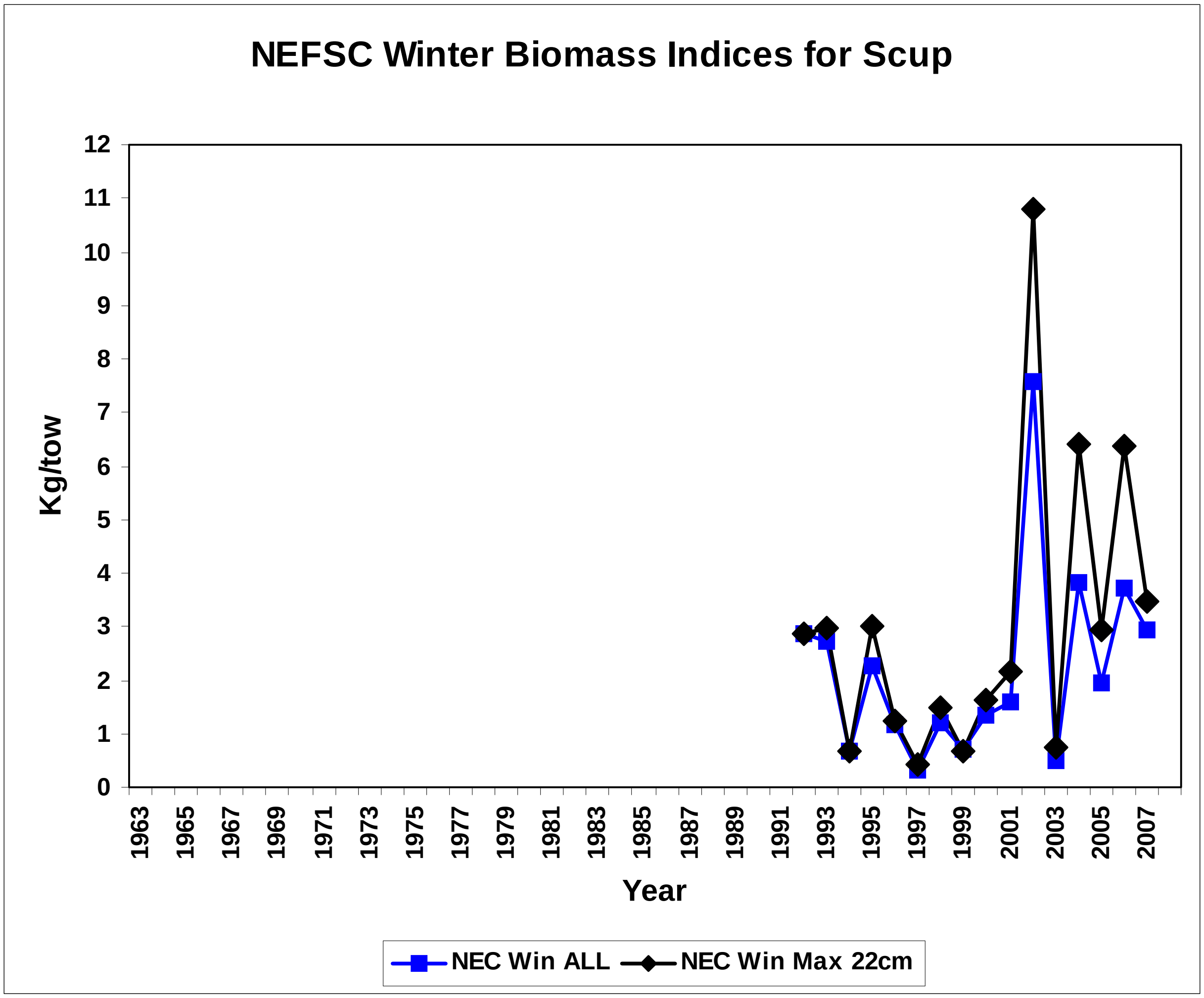


Figure 30. NEFSC Winter trawl survey biomass indices for scup: all sizes, and with a maximum length of 22 cm.

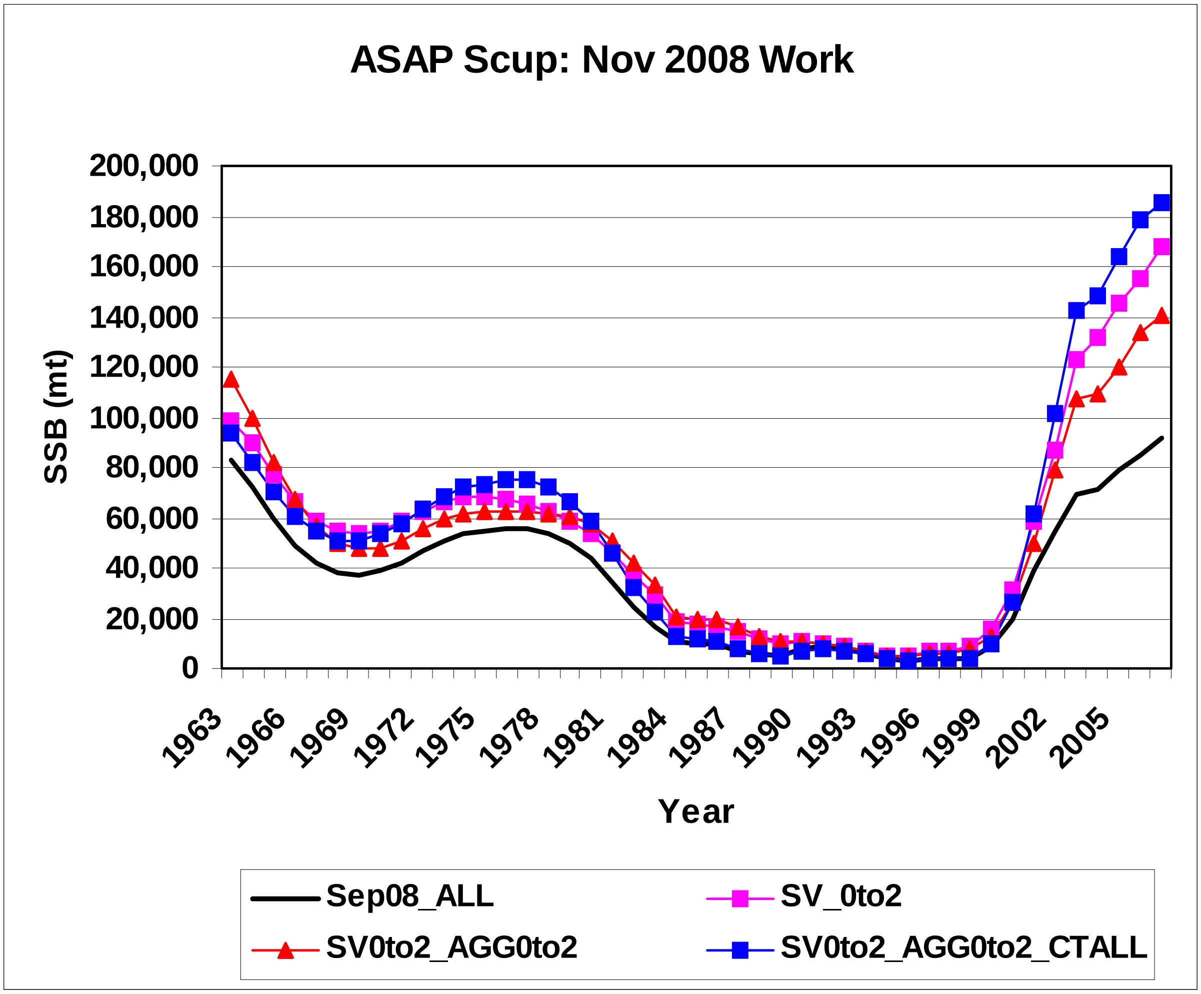


Figure 31. ASAP SSB estimates for the modified survey input model configurations.

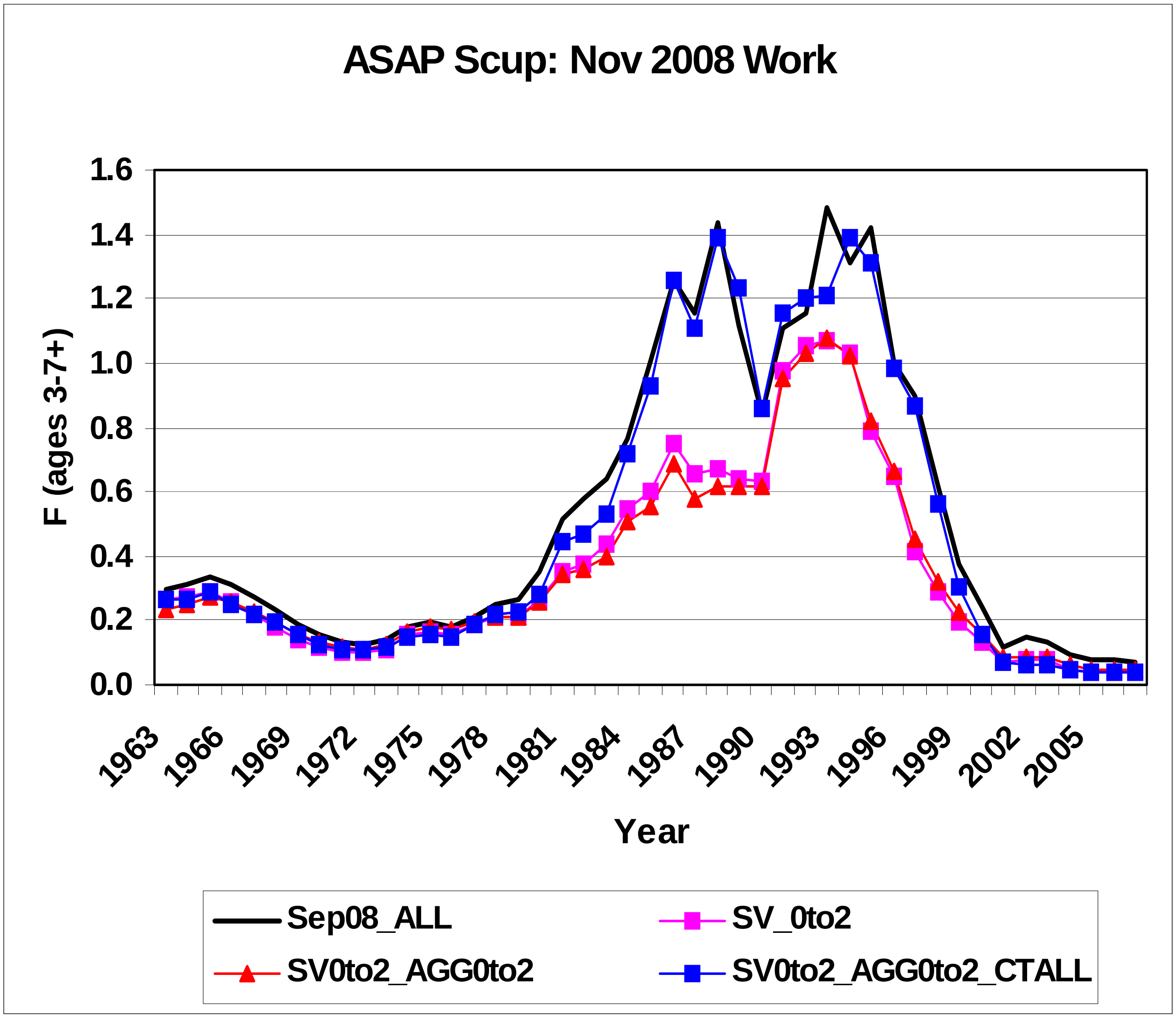


Figure 32. ASAP F estimates for the modified survey input model configurations.

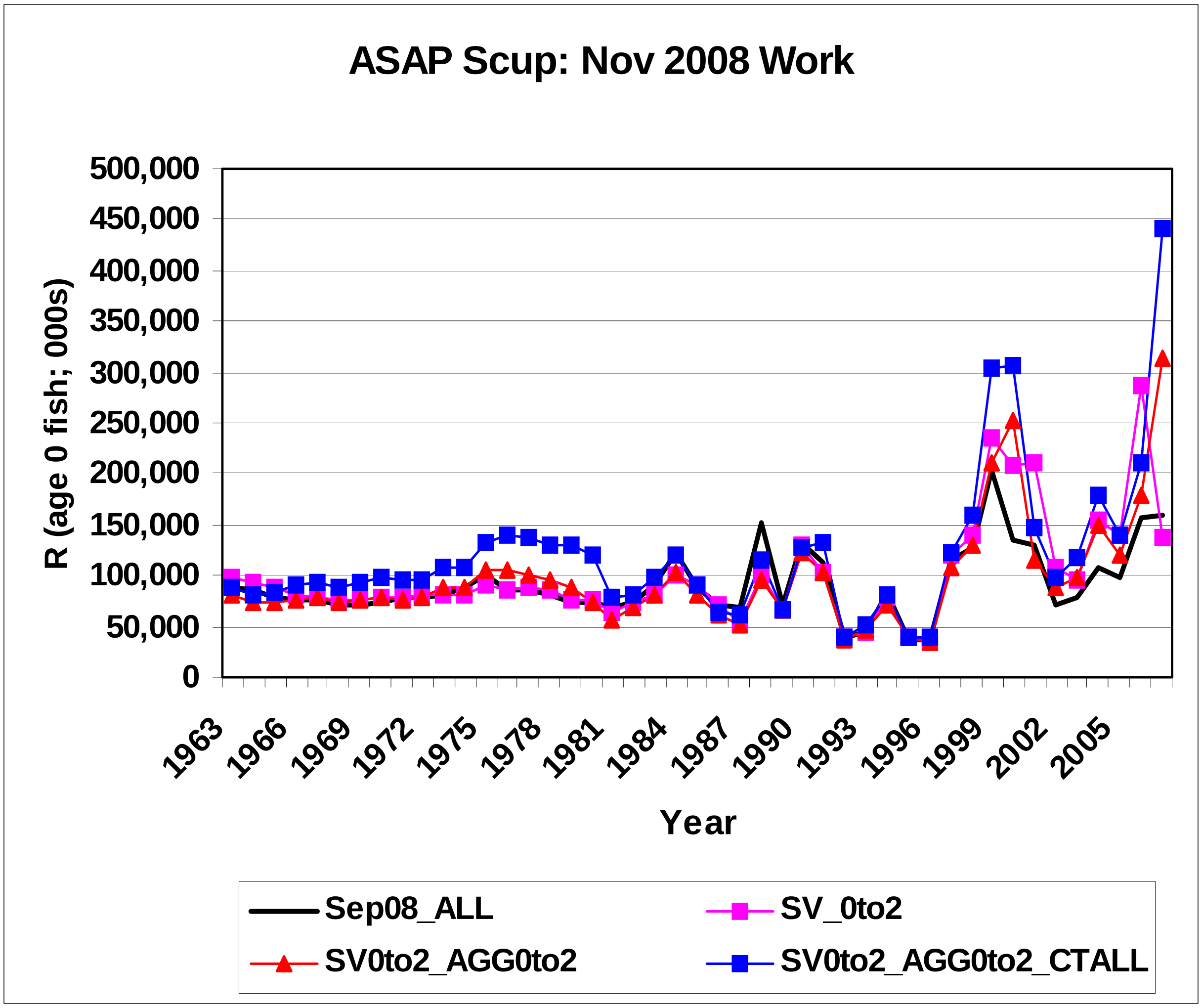


Figure 33. ASAP R (recruitment at age 0) estimates for the modified survey input model configurations.

Objective Function Summary

Absolute RUN ID	Fishery Total Catch	Fishery Age Comp	Survey Indices	Rec Devs	Total
Sep08_ALL	1052	1997	6354	518	9921
SV0to2	1013	1929	2473	528	5943
SV0to2_AGG0to2	1025	1967	5403	537	8932
SV0to2_AGG0to2_CTALL	1159	1996	5597	553	9305

Percent RUN ID	Fishery Total Catch	Fishery Age Comp	Survey Indices	Rec Devs	Total
Sep08_ALL	11%	20%	64%	5%	100%
SV0to2	17%	32%	42%	9%	100%
SV0to2_AGG0to2	11%	22%	60%	6%	100%
SV0to2_AGG0to2_CTALL	12%	21%	60%	6%	100%

Figure 34. Objective function summary for the ASAP modified survey input runs.

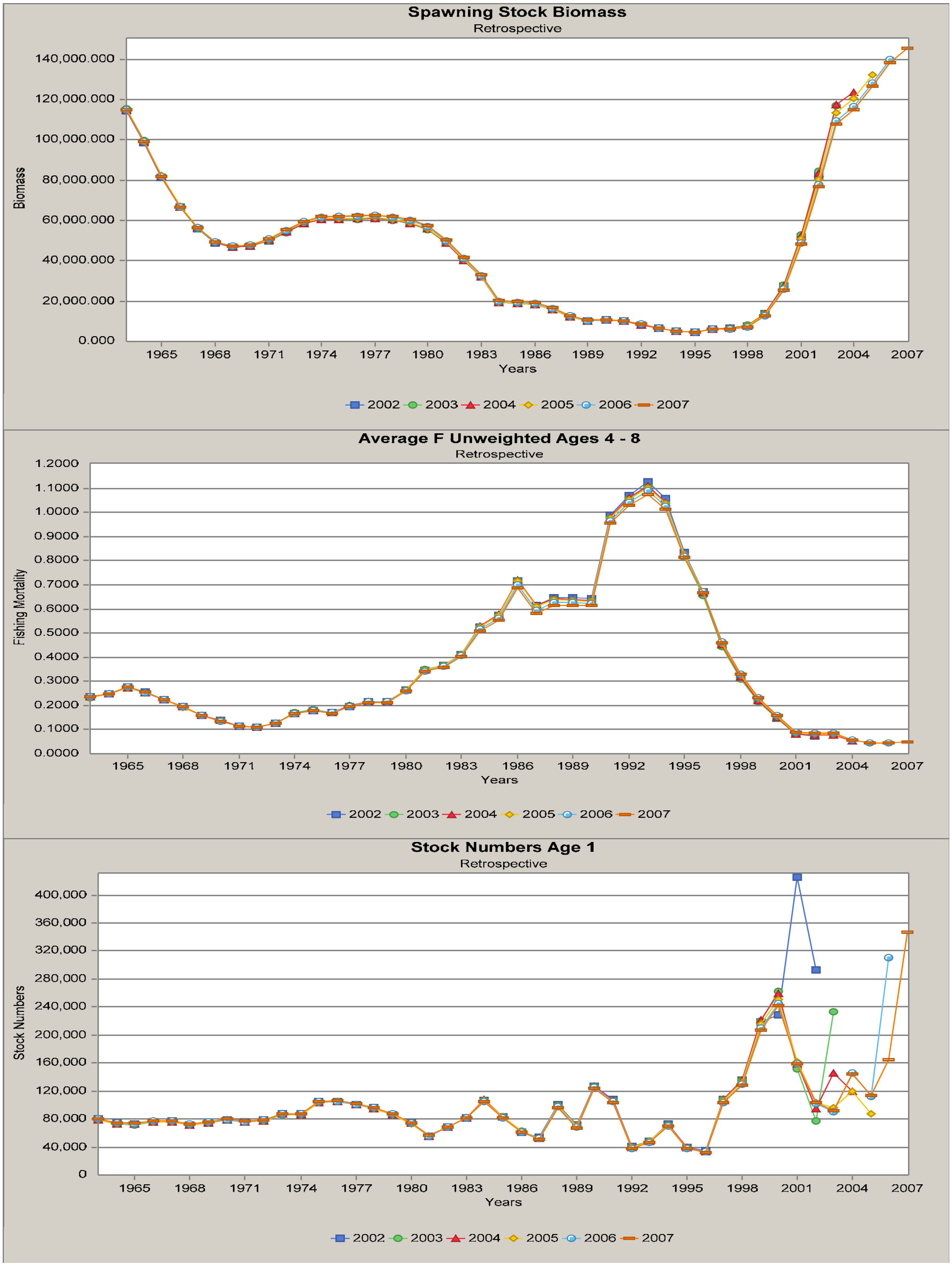


Figure 35. Retrospective results for run SV0to2_AGG0to2.

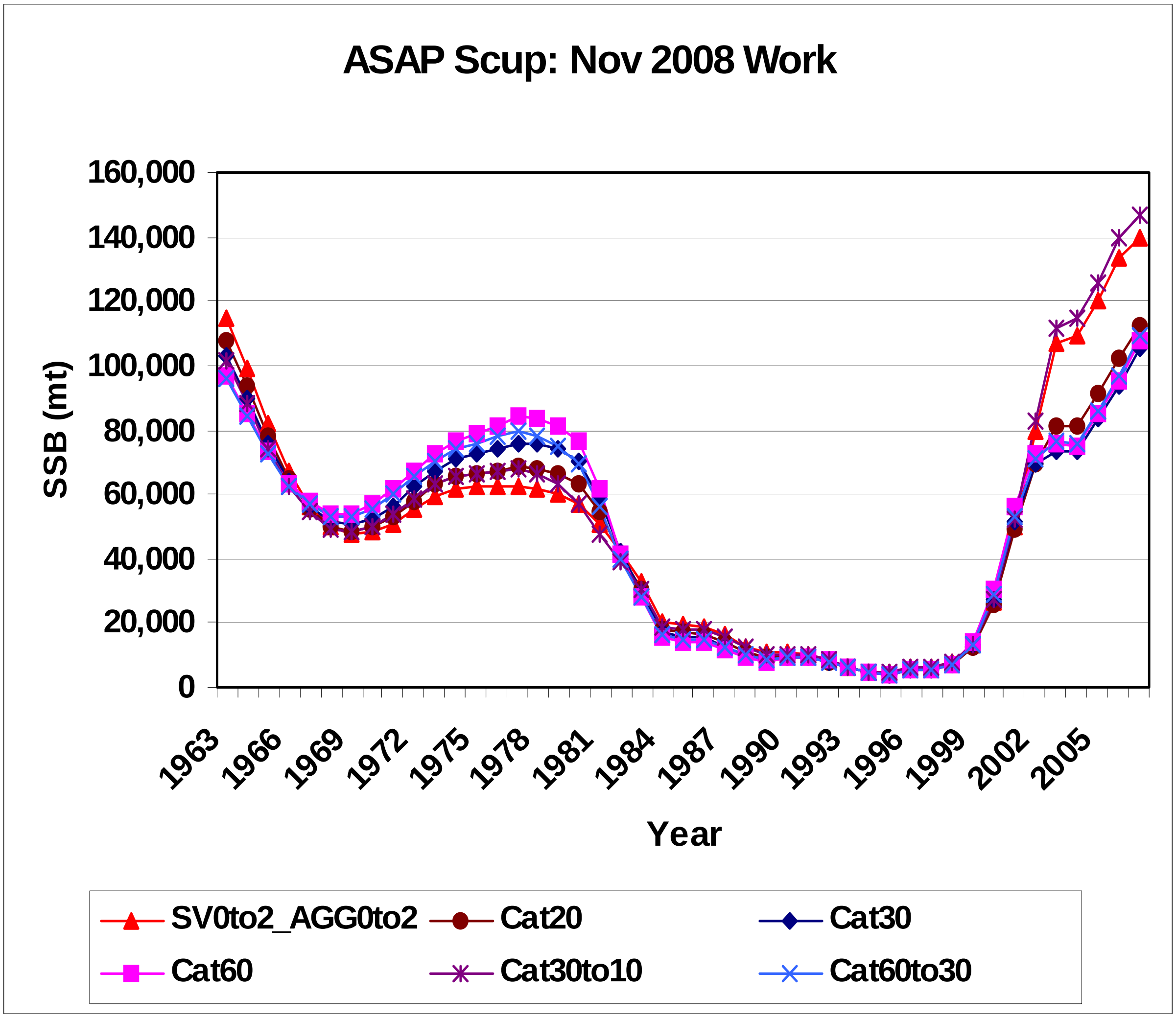


Figure 36. Sensitivity of the SV0to2_AGG0to2 ASAP results to different assumptions about the uncertainty of fishery catch estimates: estimates of SSB.

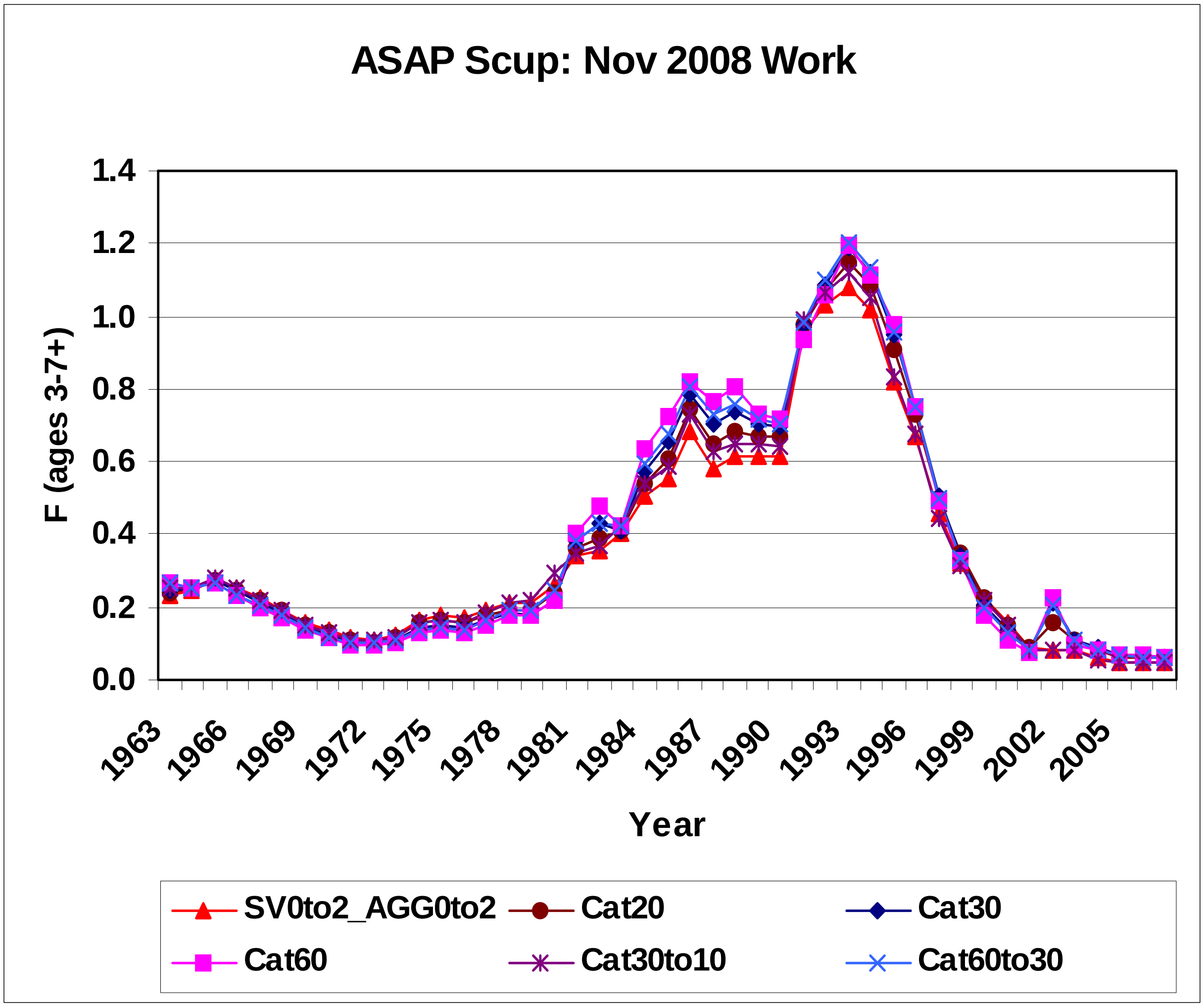


Figure 37. Sensitivity of the SV0to2_AGG0to2 ASAP results to different assumptions about the uncertainty of fishery catch estimates: estimates of F.

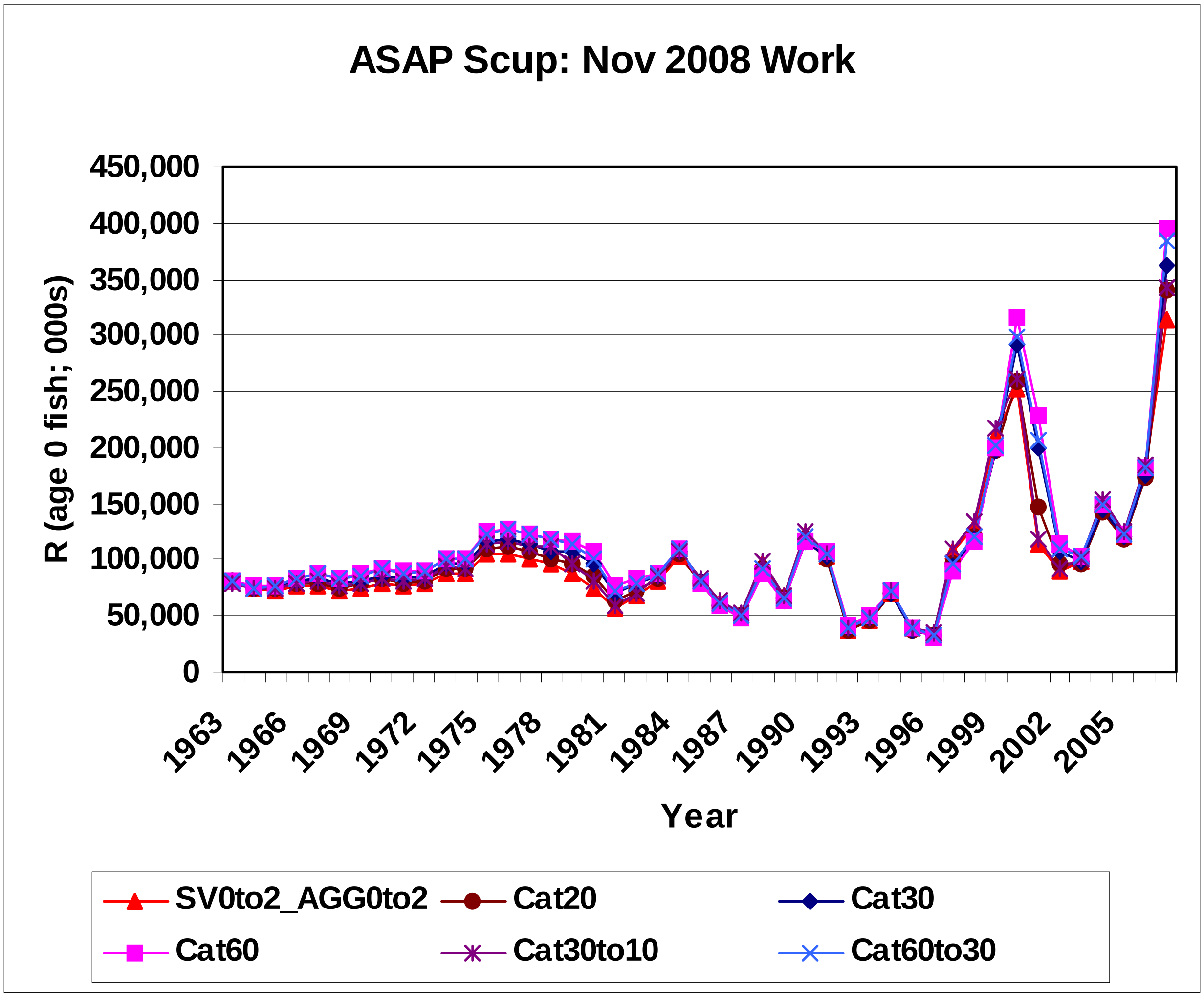


Figure 38. Sensitivity of the SV0to2_AGG0to2 ASAP results to different assumptions about the uncertainty of fishery catch estimates: estimates of F.

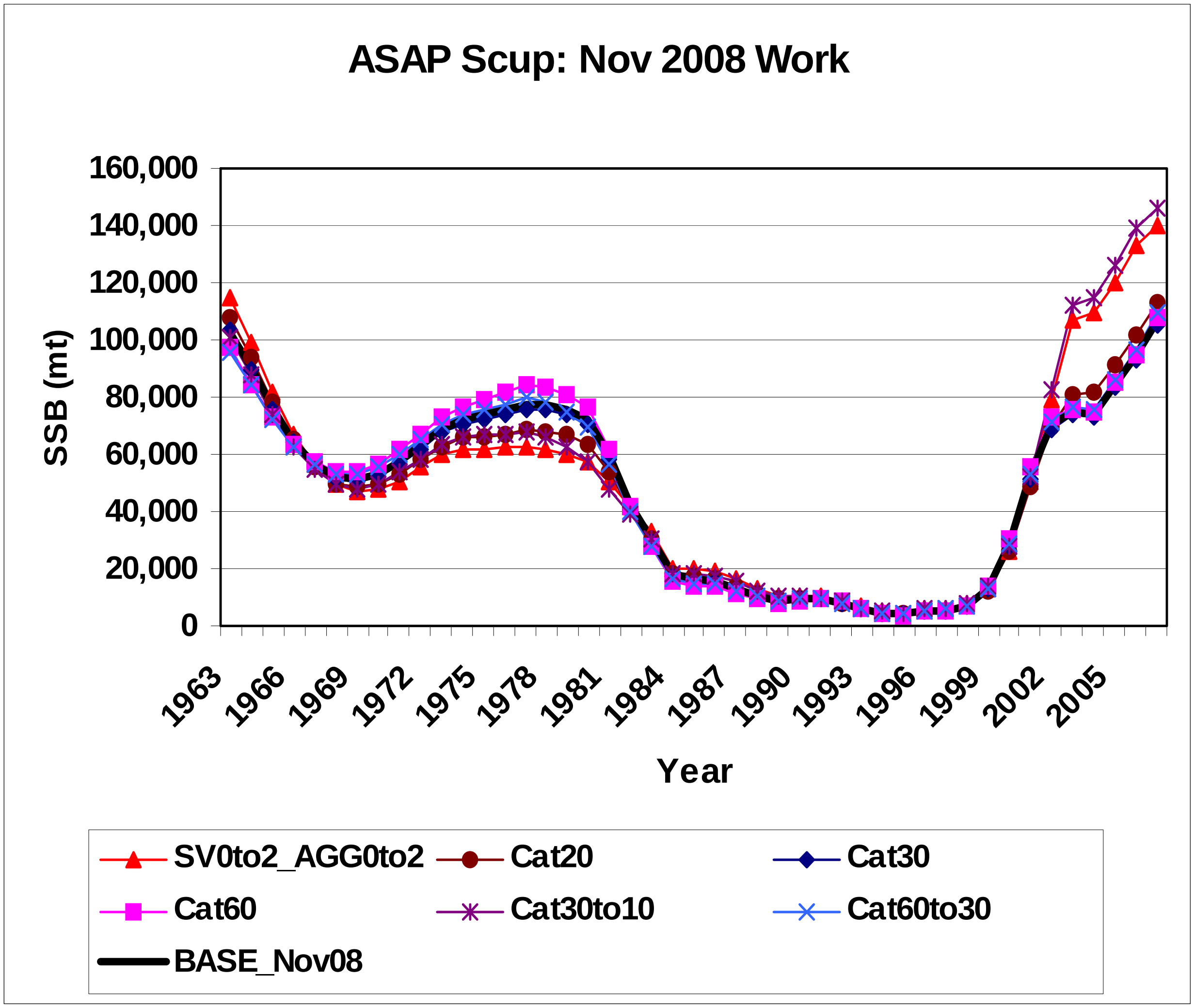


Figure 39. Comparative ASAP results for different assumptions about the uncertainty of fishery catch estimates: estimates of SSB from the BASE_Nov08 run.

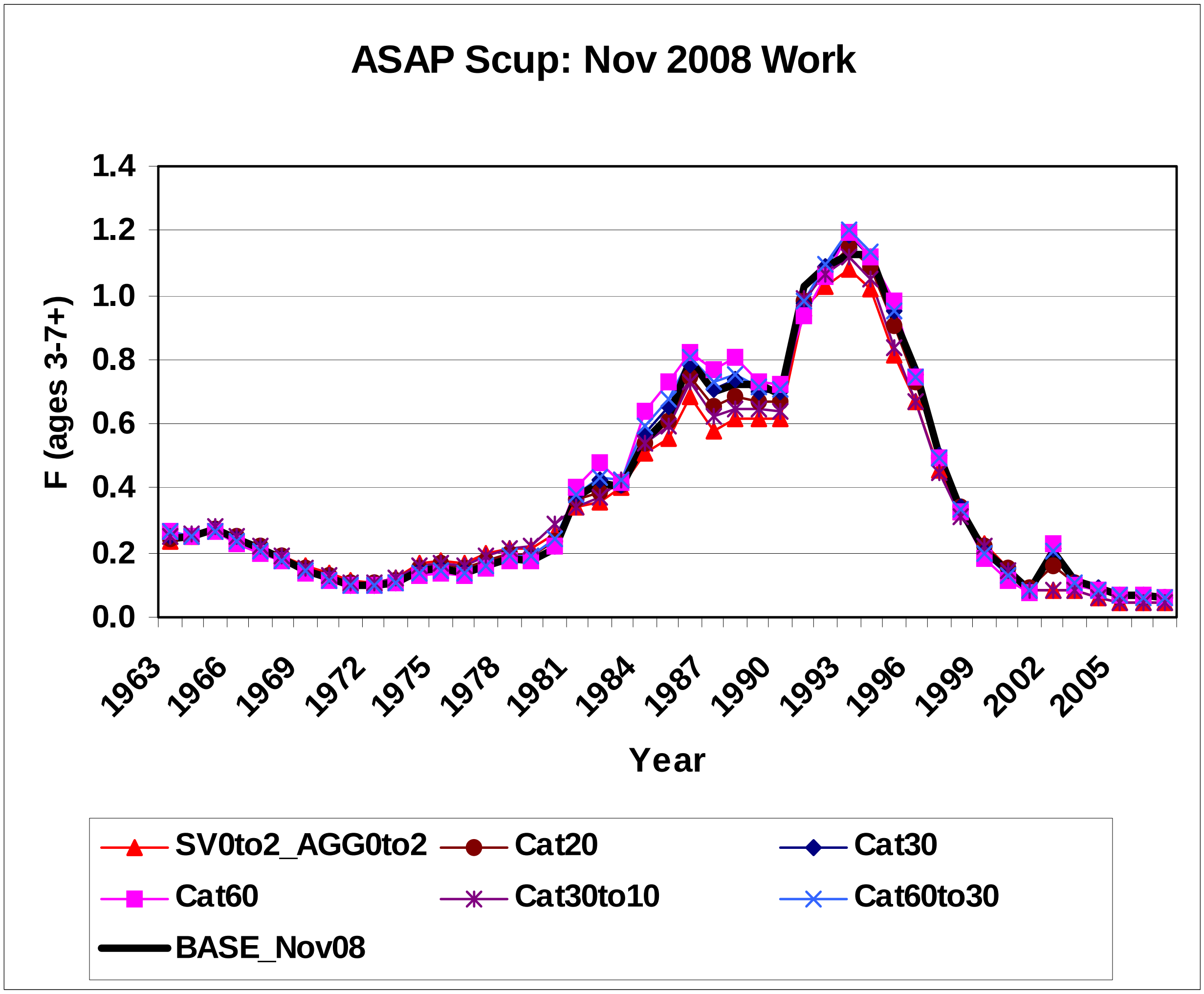


Figure 40. Comparative ASAP results for different assumptions about the uncertainty of fishery catch estimates: estimates of F from the BASE_Nov08 run.

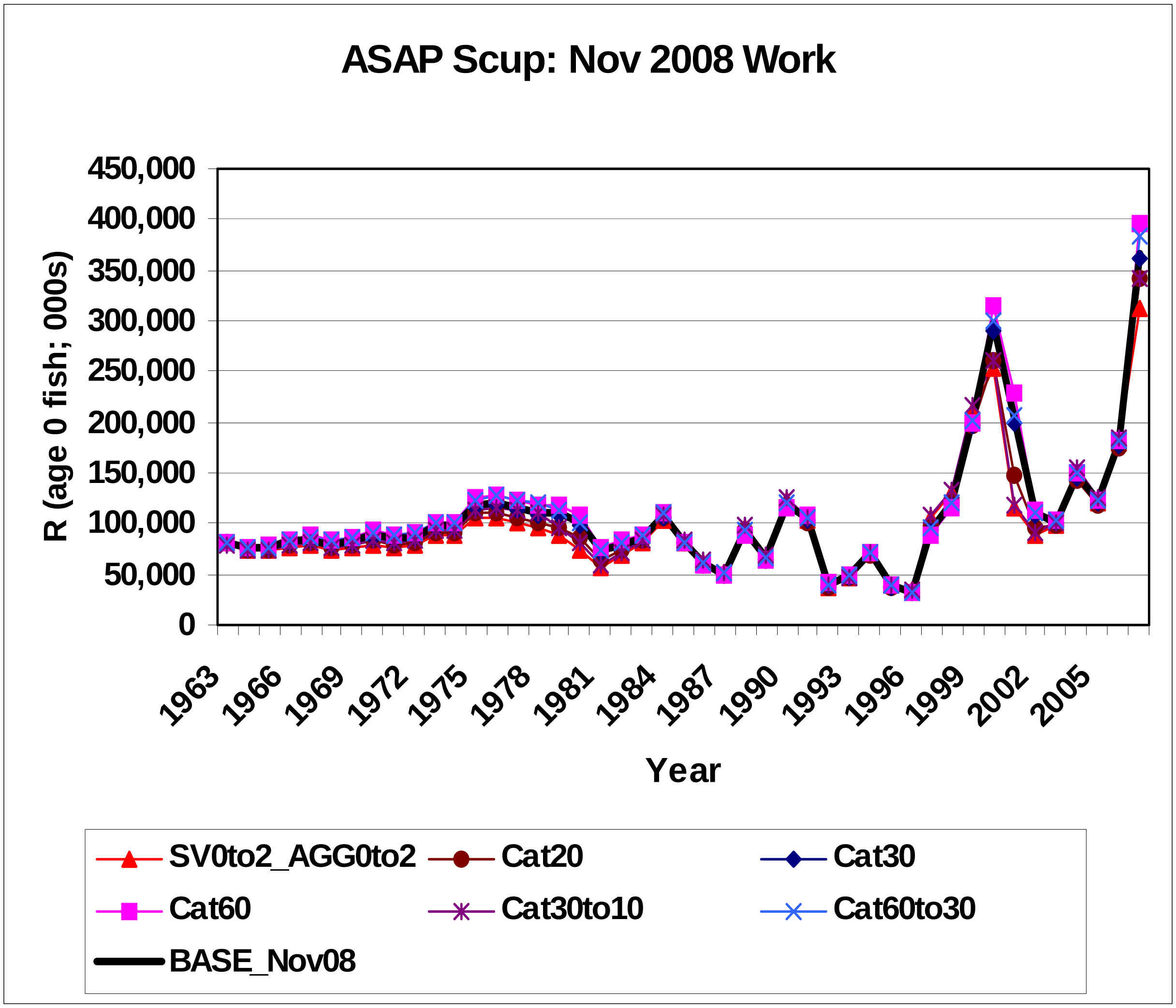


Figure 41. Comparative ASAP results for different assumptions about the uncertainty of fishery catch estimates: estimates of R from the BASE_Nov08 run.

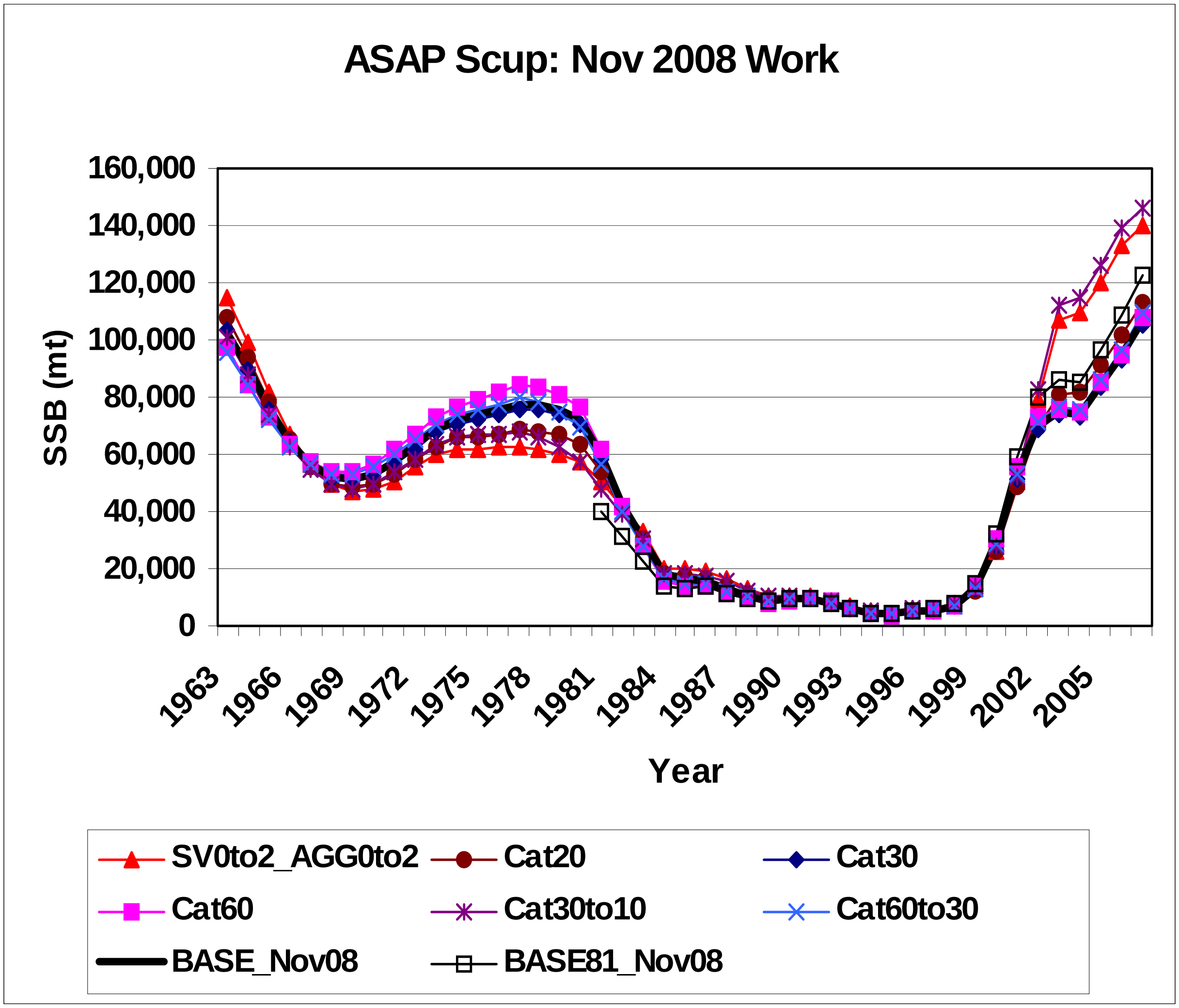


Figure 42. Comparative ASAP results for effect of 1981-2007 time series in run BASE81_Nov08: estimates of SSB.

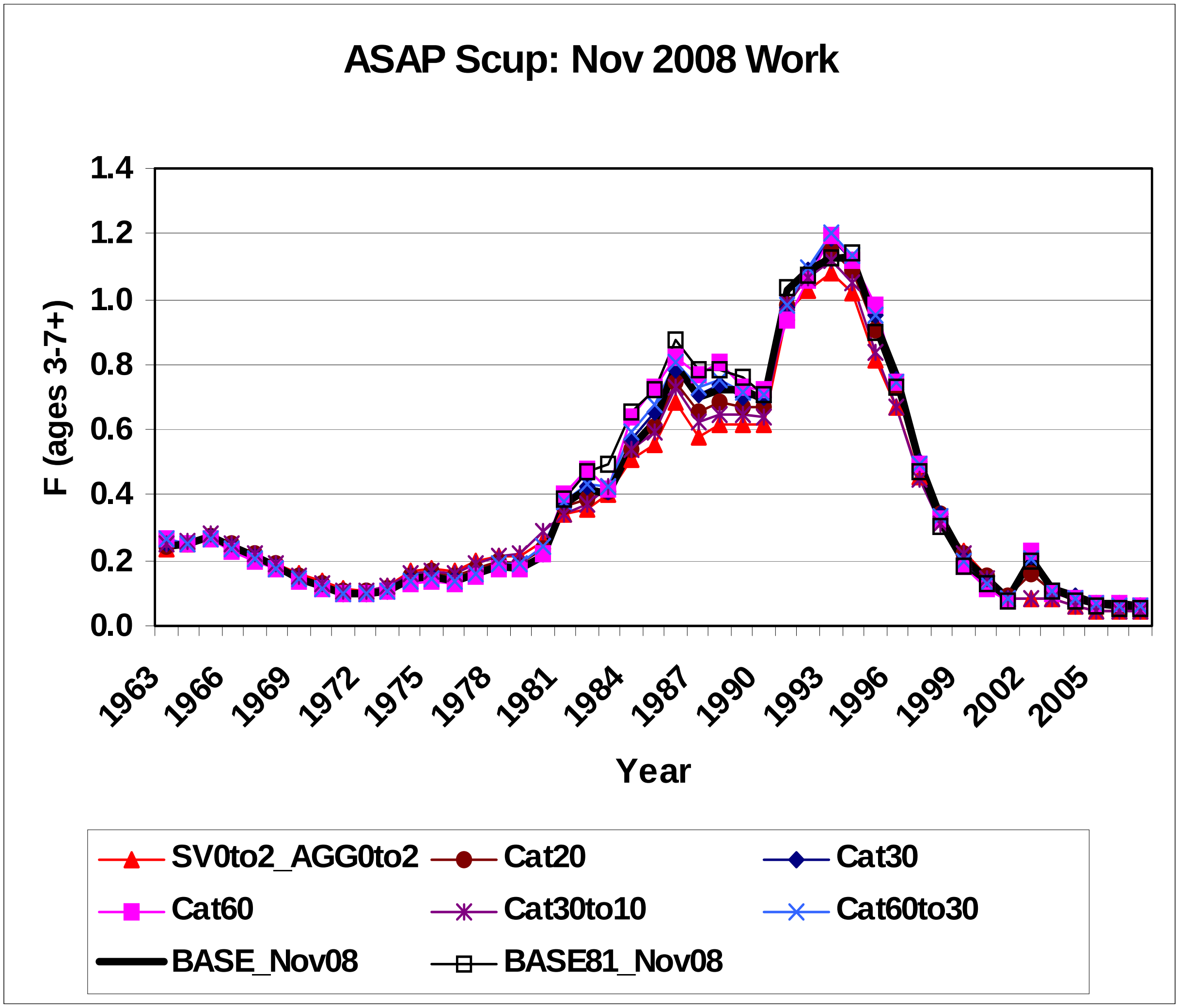


Figure 43. Comparative ASAP results for effect of 1981-2007 time series in run BASE81_Nov08: estimates of F.

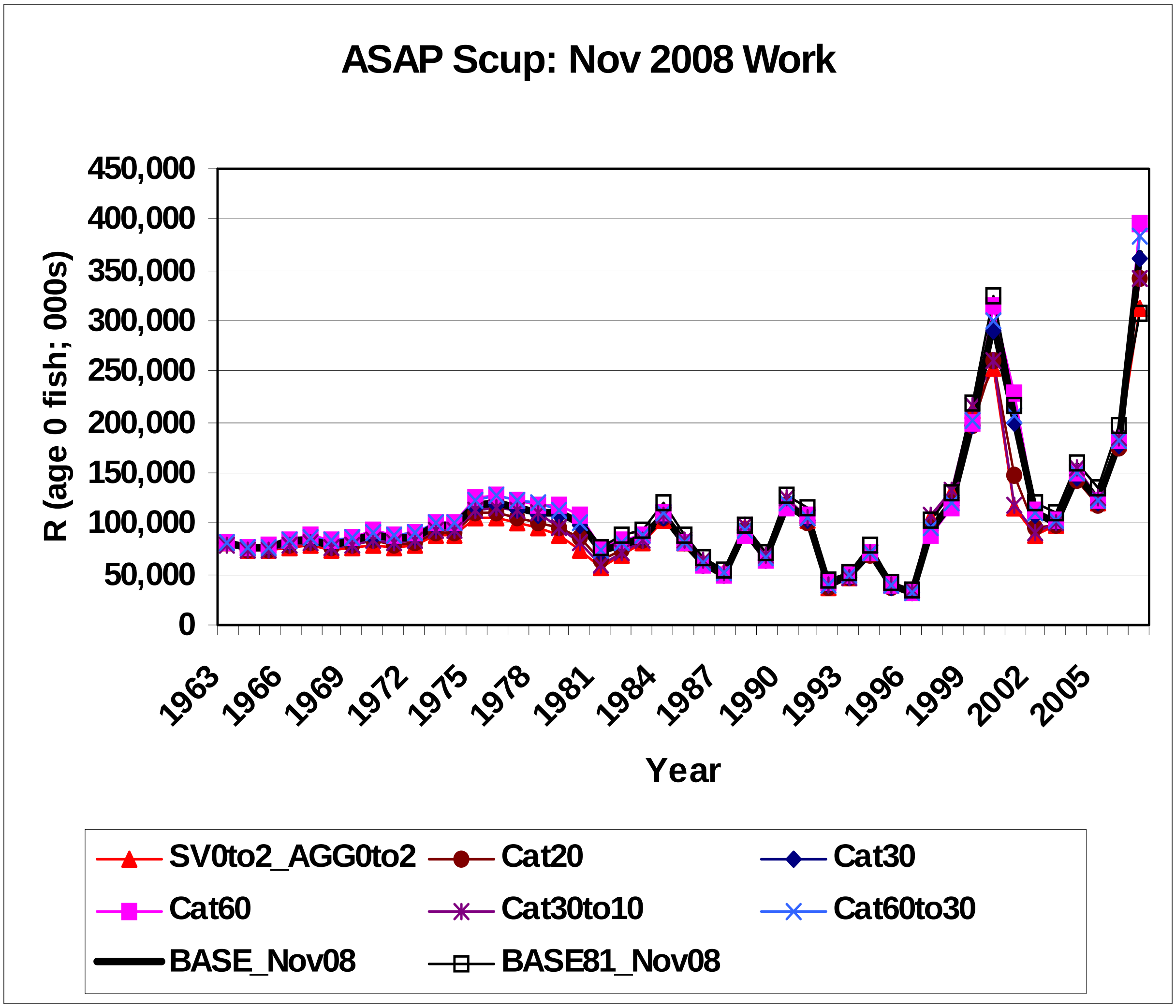


Figure 44. Comparative ASAP results for effect of 1981-2007 time series in run BASE81_Nov08: estimates of R.

SCUP: ASAP "BASE_Nov08" model **Mean R = 119.2 million age 0 fish**

BRP		Y/R	SSB/R	SSB	Catch	Land	Disc
Fmax	0.272	0.155	0.552	62,630	17,601	13,330	4,271
F35%	0.202	0.151	0.745	85,425	17,349	13,823	3,526

SCUP: ASAP "BASE81_Nov08" model **Mean R = 125.4 million age 0 fish**

BRP		Y/R	SSB/R	SSB	Catch	Land	Disc
Fmax	0.292	0.163	0.547	66,142	19,743	15,202	4,541
F35%	0.213	0.158	0.746	91,119	19,440	15,735	3,705

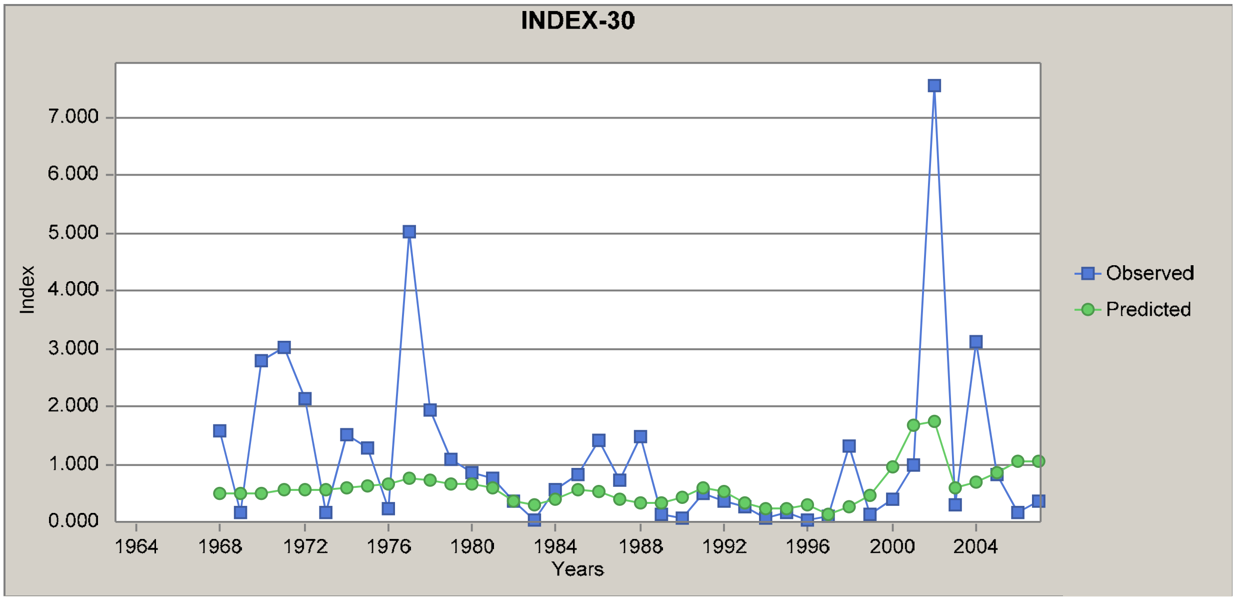
SCUP: ASAP "BASE_Nov08" model

BRP	SSB	SSB07	%SSBMSY	Catch	Catch07	%MSY
Fmax	62,630	107,129	171%	17,601	8,026	46%
F35%	85,425	107,129	125%	17,349	8,026	46%

SCUP: ASAP "BASE81_Nov08" model

BRP	SSB	SSB07	%SSBMSY	Catch	Catch07	%MSY
Fmax	66,142	122,671	185%	19,743	8,026	41%
F35%	91,119	122,671	135%	19,440	8,026	41%

Figure 45. Biological reference points and stock status from ASAP model results, for the full 1963-2007 time series (BASE_Nov08 run) and shorter 1981-2007 time series (BASE81_Nov08 run). Fishing mortality rates (F) for both models were about 0.06, about one-quarter of the Fmax proxy for FMSY.



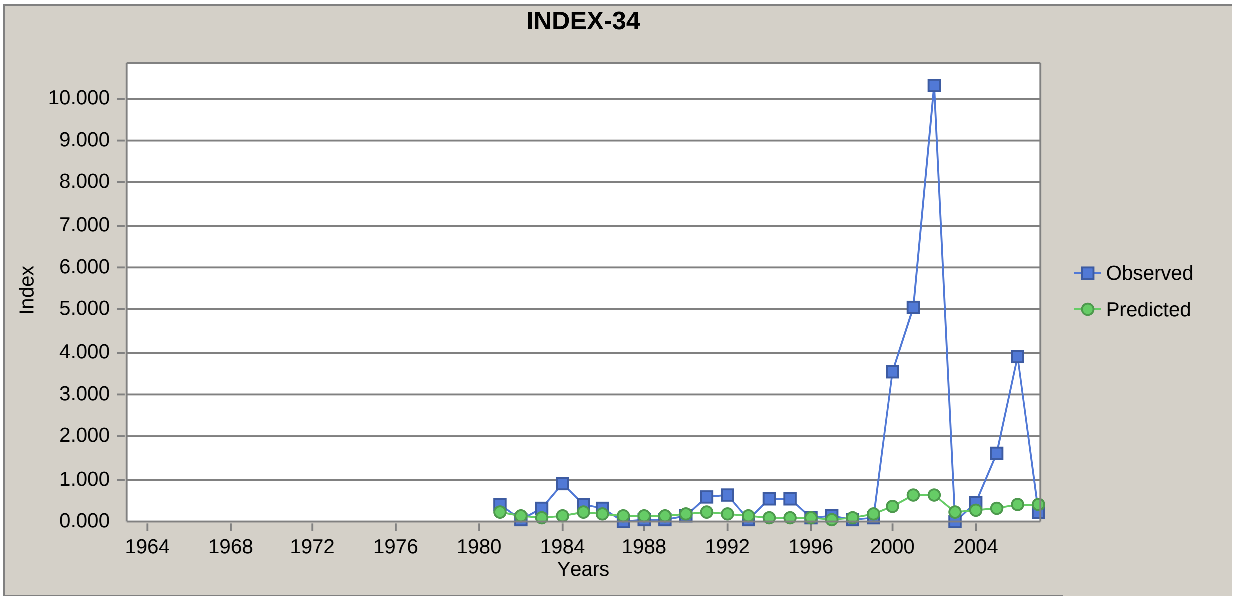


Figure 46. ASAP model BASE_C2006 run fits for the NEFSC Spring survey aggregate biomass index for ages 1-2 (top - Index 30) and RIDFW Spring survey biomass index for ages 1-2 (bottom - Index 34) showing the large residuals for the 2002 indices.

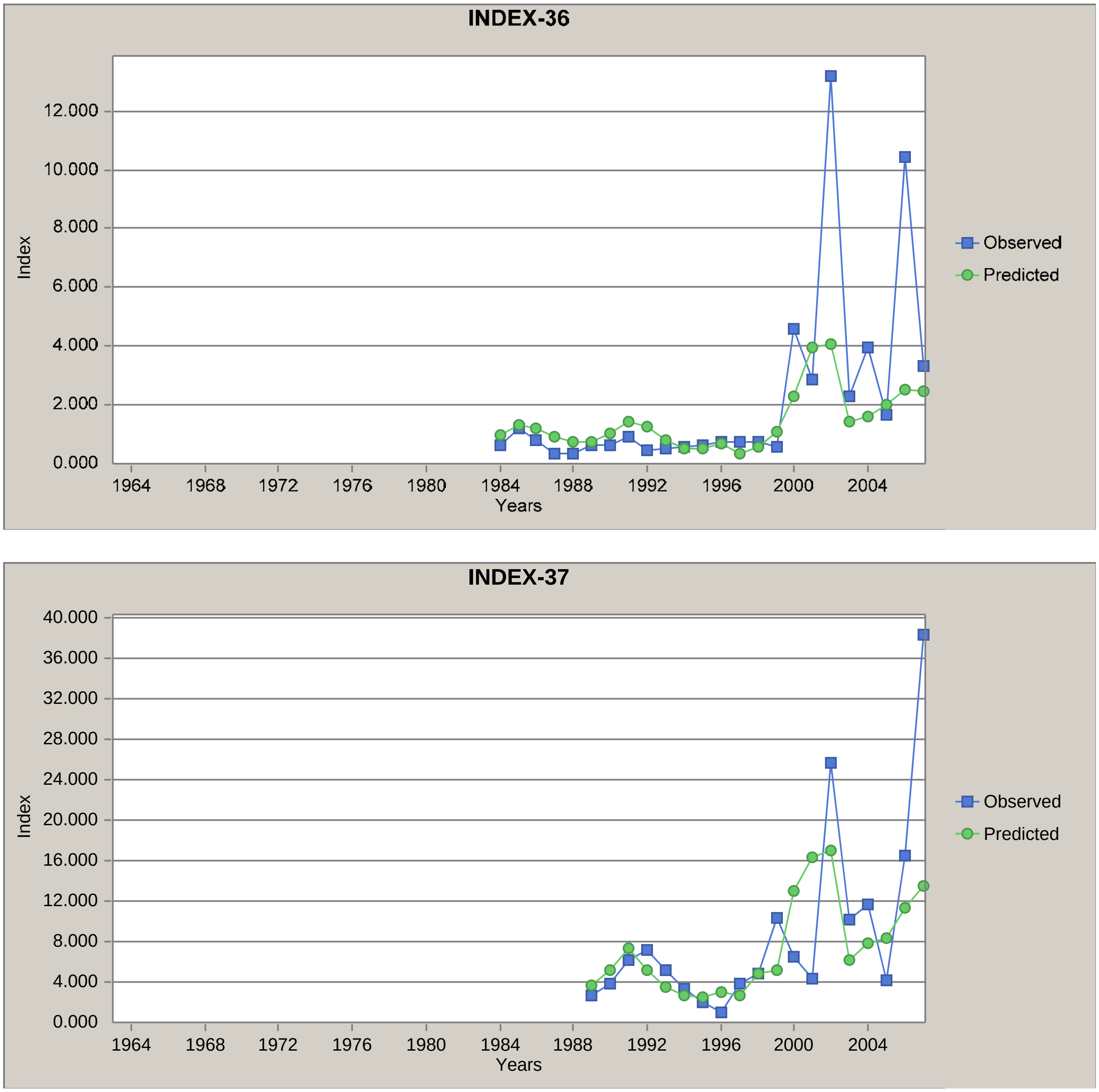


Figure 47. ASAP model BASE_C2006 run fits for the CTDEP Spring survey aggregate biomass index for ages 1-2 (top - Index 36) and NJBMF Annual survey biomass index for ages 1-2 (bottom - Index 37) showing the large residuals for the 2002 indices.

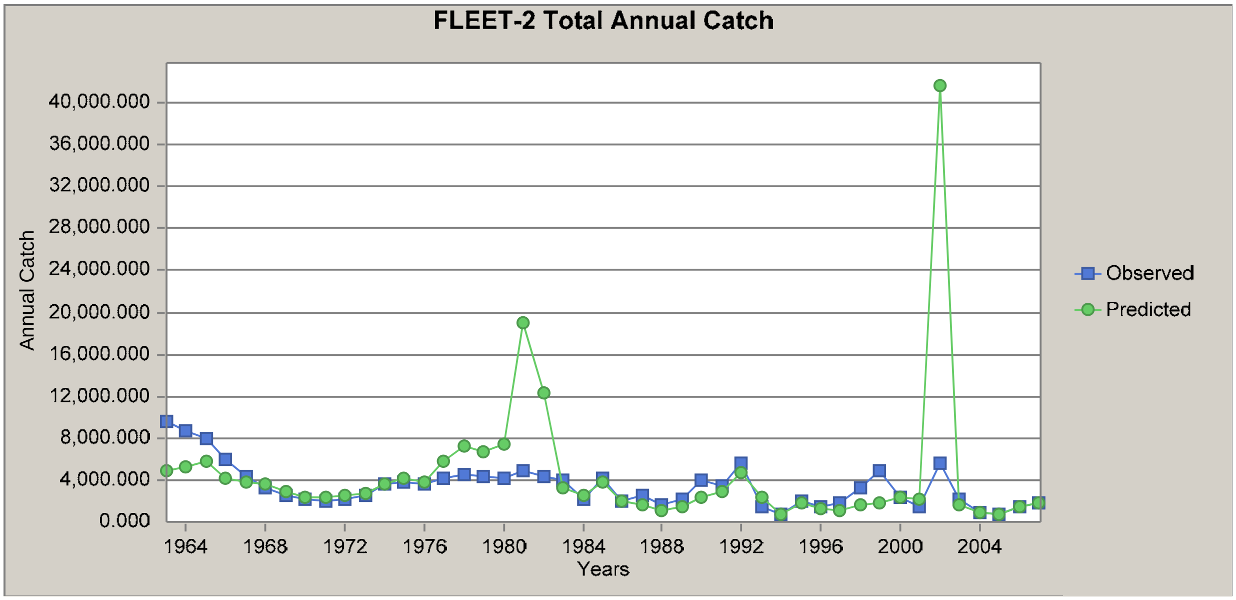


Figure 48. ASAP model BASE_C2006 run fit for Commercial Fishery Aggregate Discards showing the large residual for the 2002 estimate

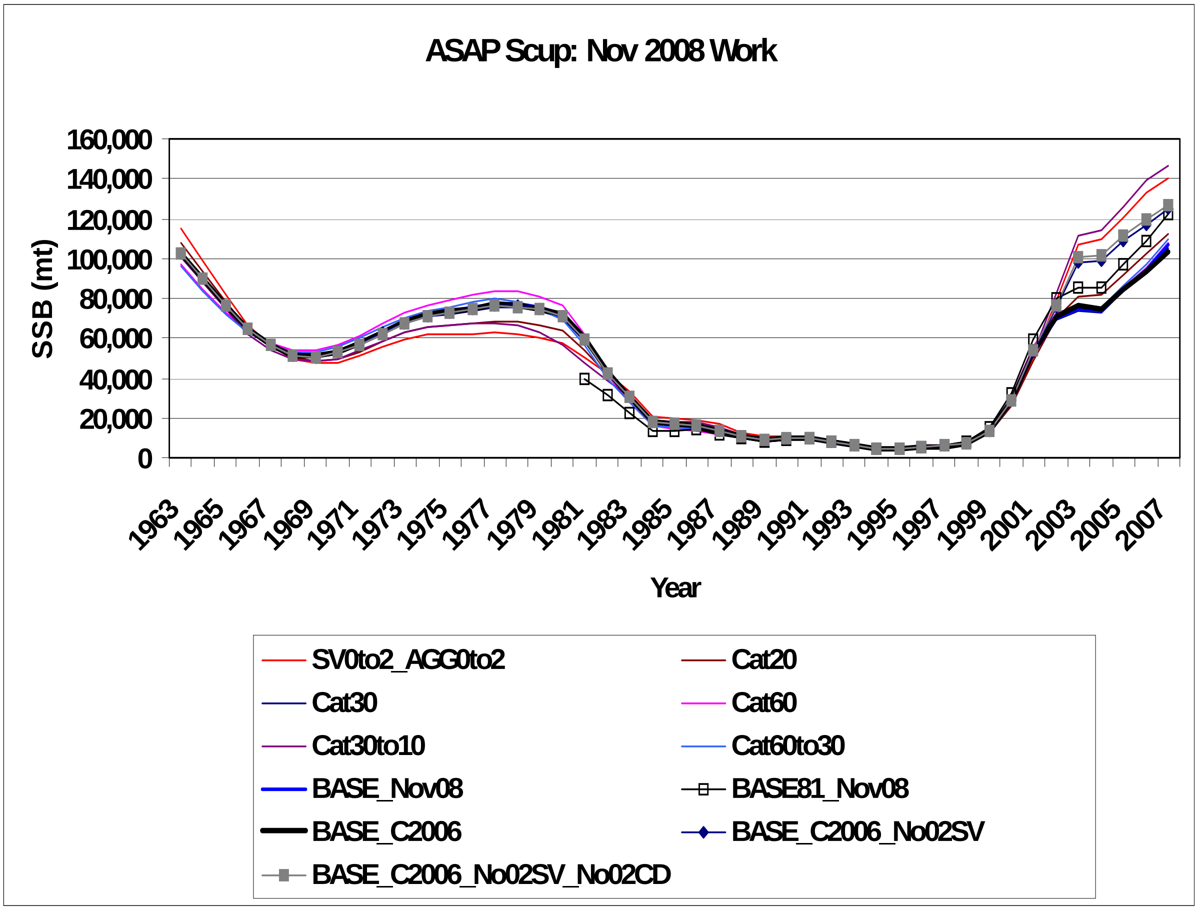


Figure 49. Comparative results for estimated SSB in ASAP runs for scup: effect of 2002 survey and commercial discard input data.

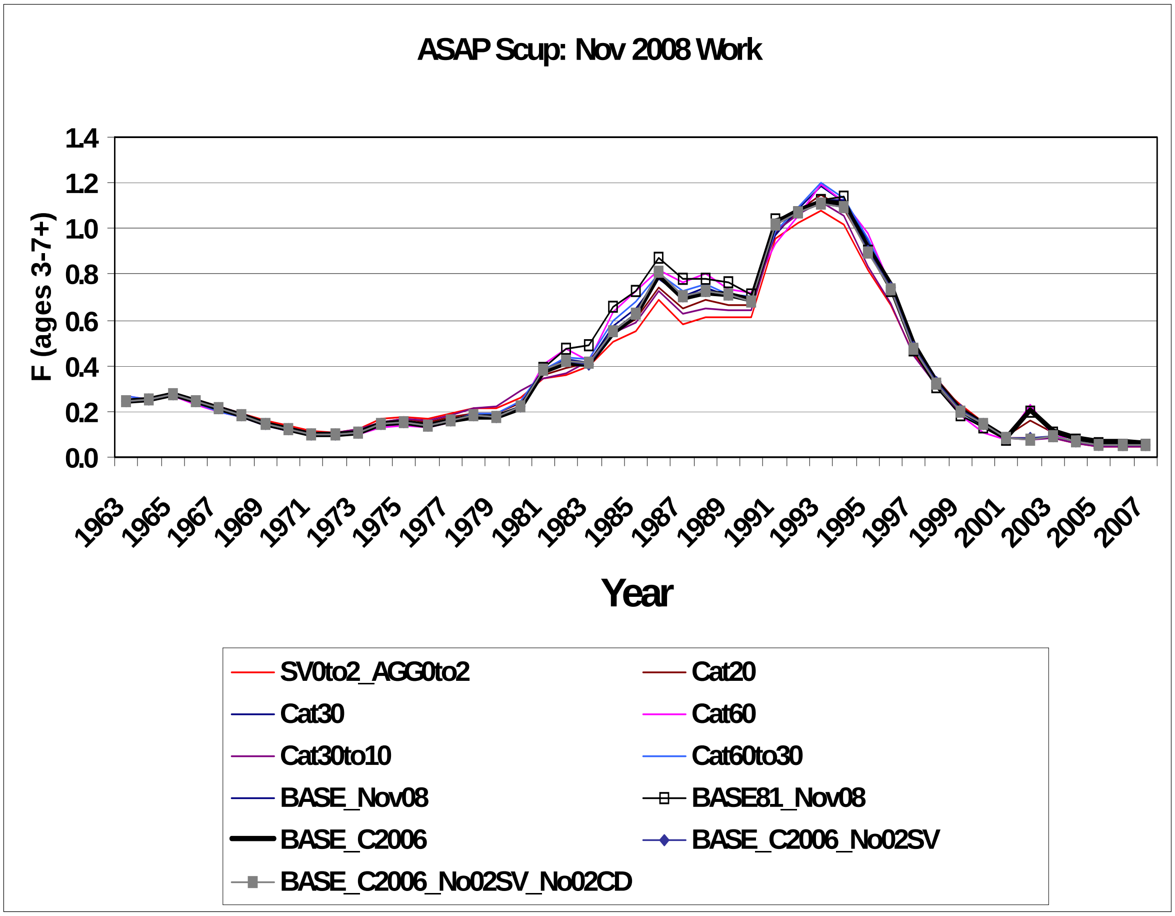


Figure 50. Comparative results for estimated F in ASAP runs for scup: effect of 2002 survey and commercial discard input data.

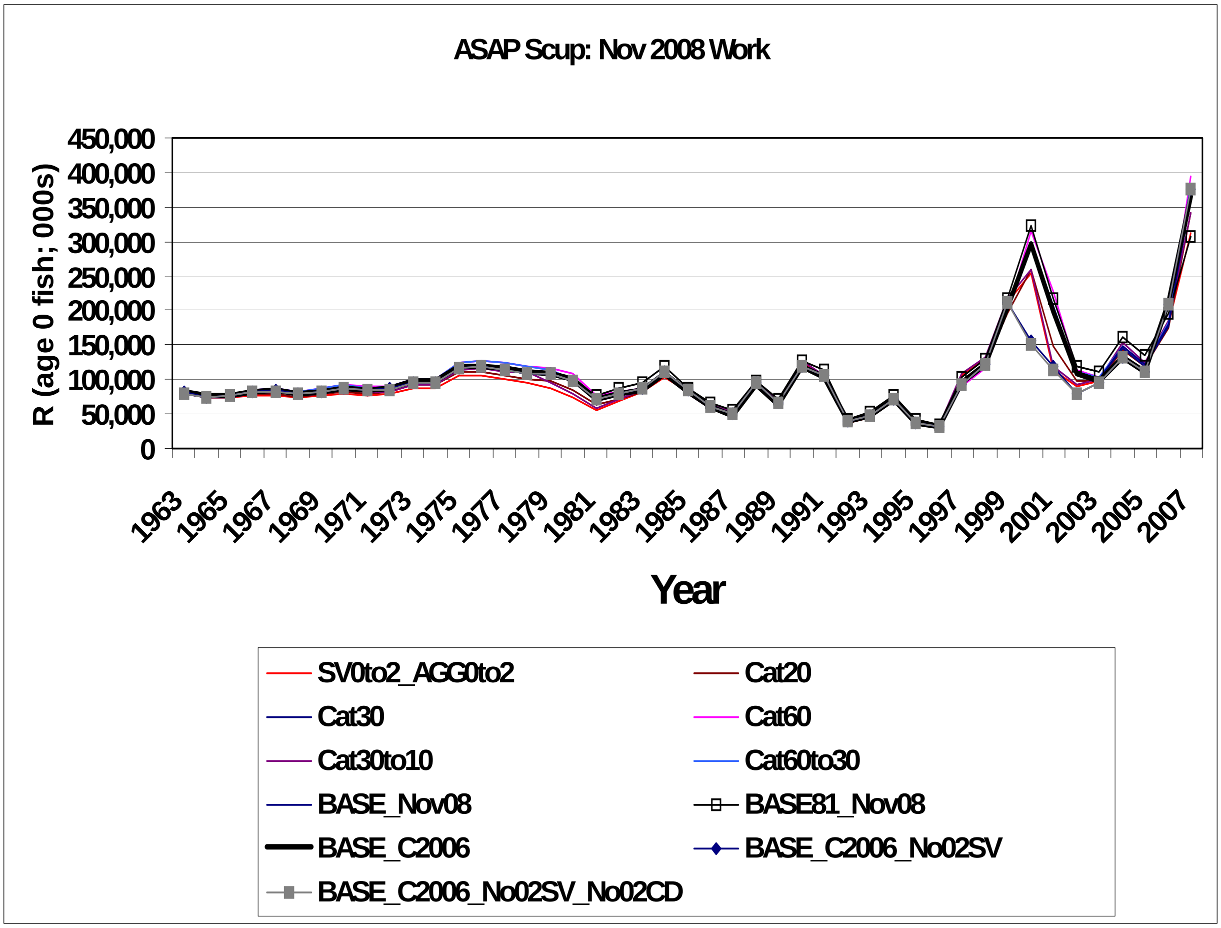


Figure 51. Comparative results for estimated recruitment in ASAP runs for scup: effect of 2002 survey and commercial discard input data.

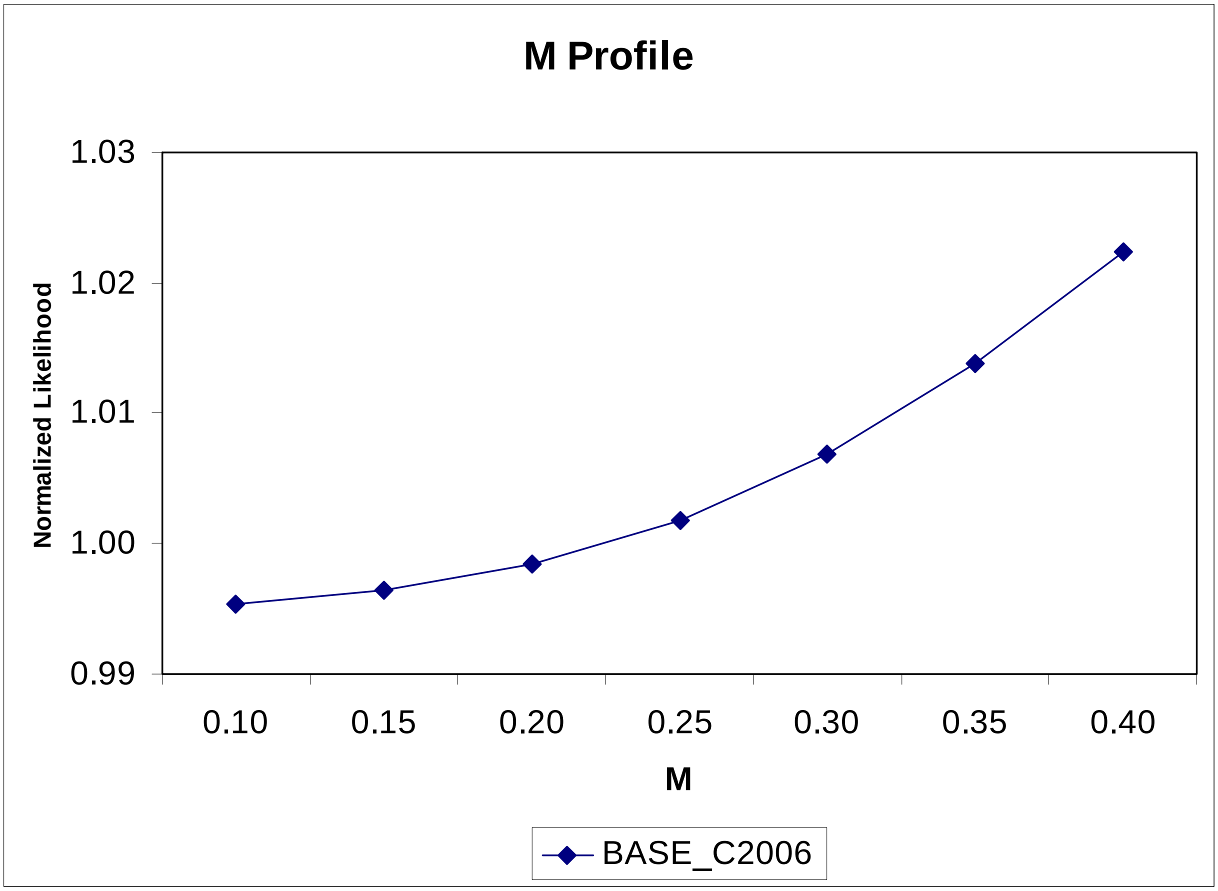


Figure 52. Sensitivity profile of the assumption for natural mortality (M) for the ASAP BASE_C2006 model configuration.

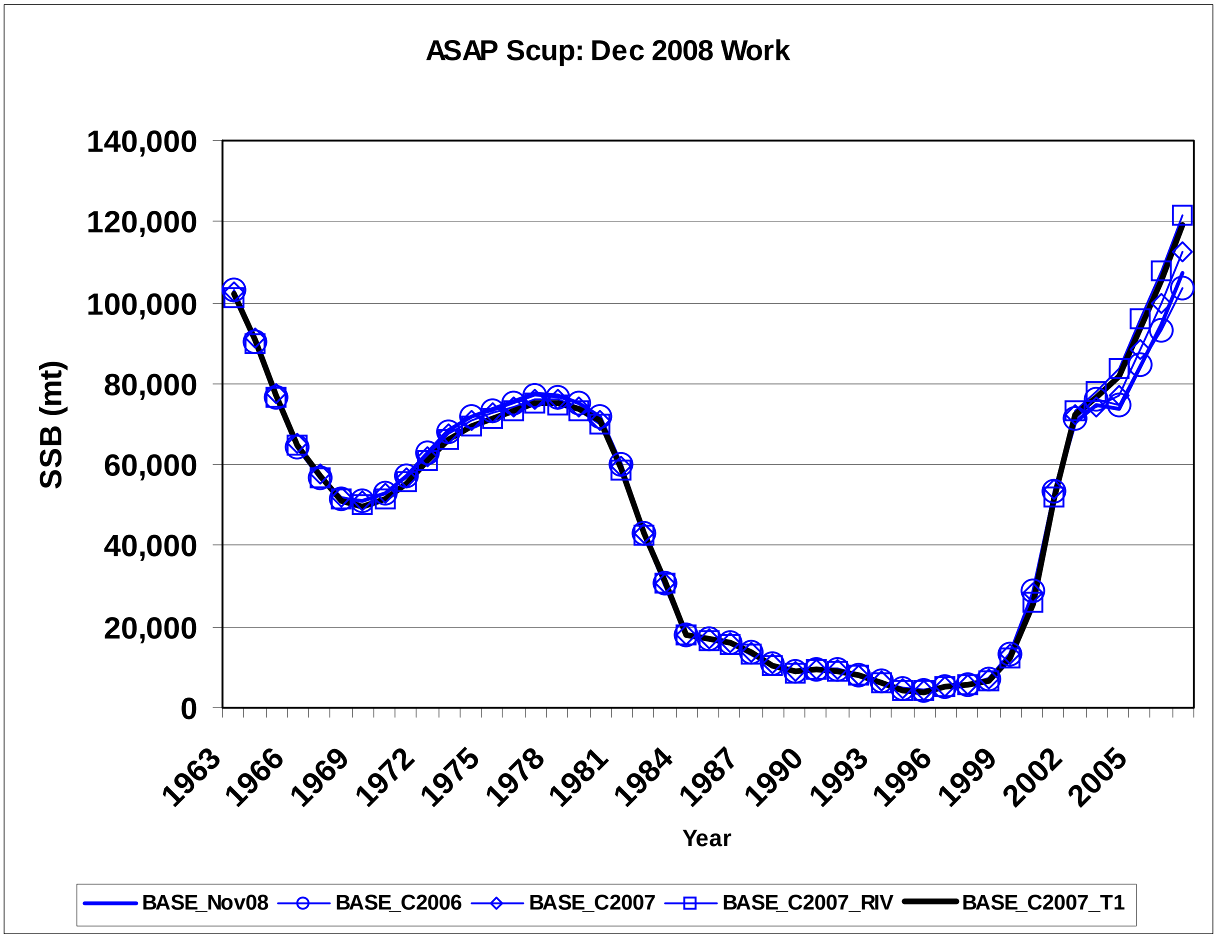


Figure 53. Comparative results for estimated SSB in ASAP runs for scup: run BASE_C2007_T1 (solid black line) is the accepted basis for biological reference points and status evaluation.

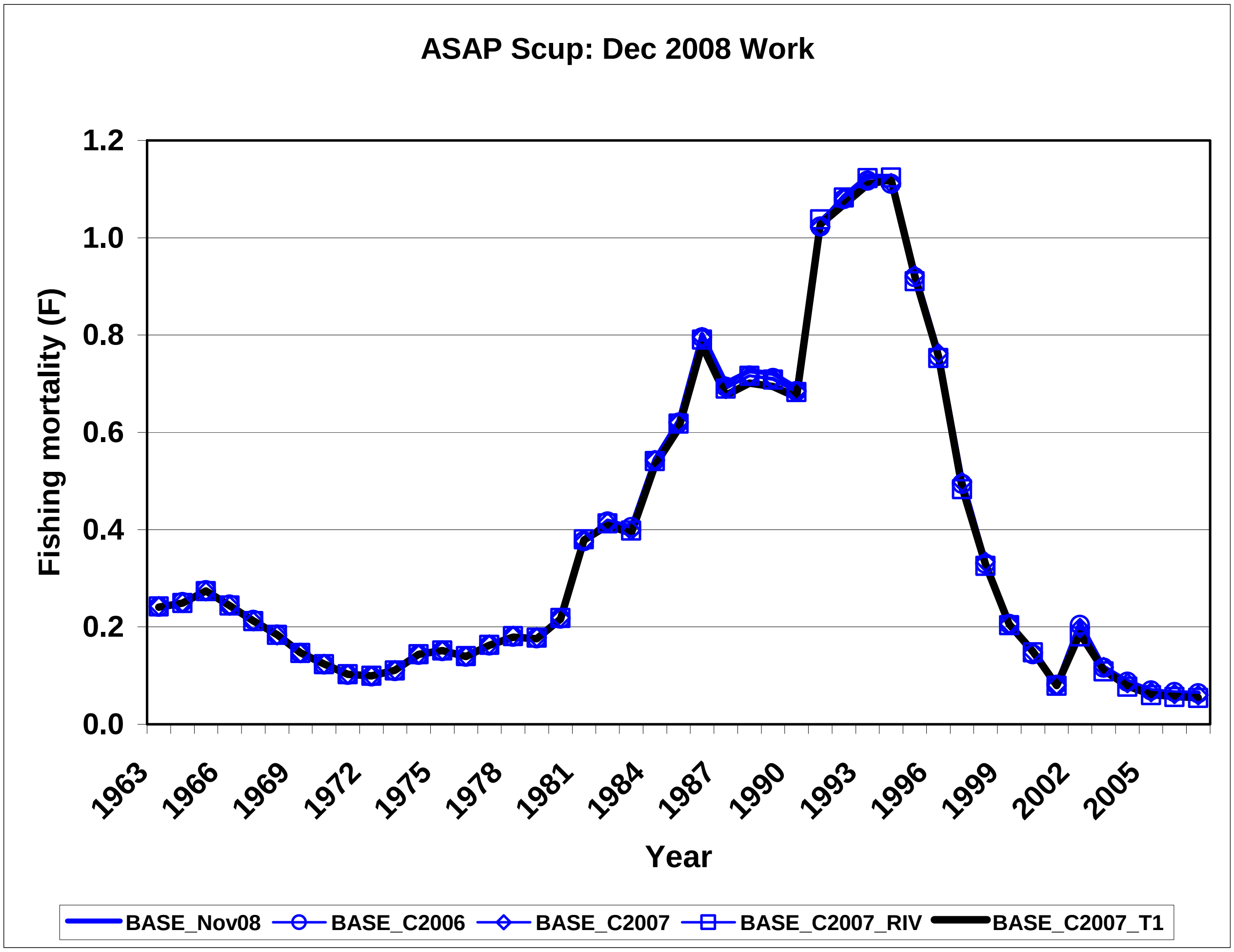


Figure 54. Comparative results for estimated F in ASAP runs for scup: run BASE_C2007_T1 (solid black line) is the accepted basis for biological reference points and status evaluation.

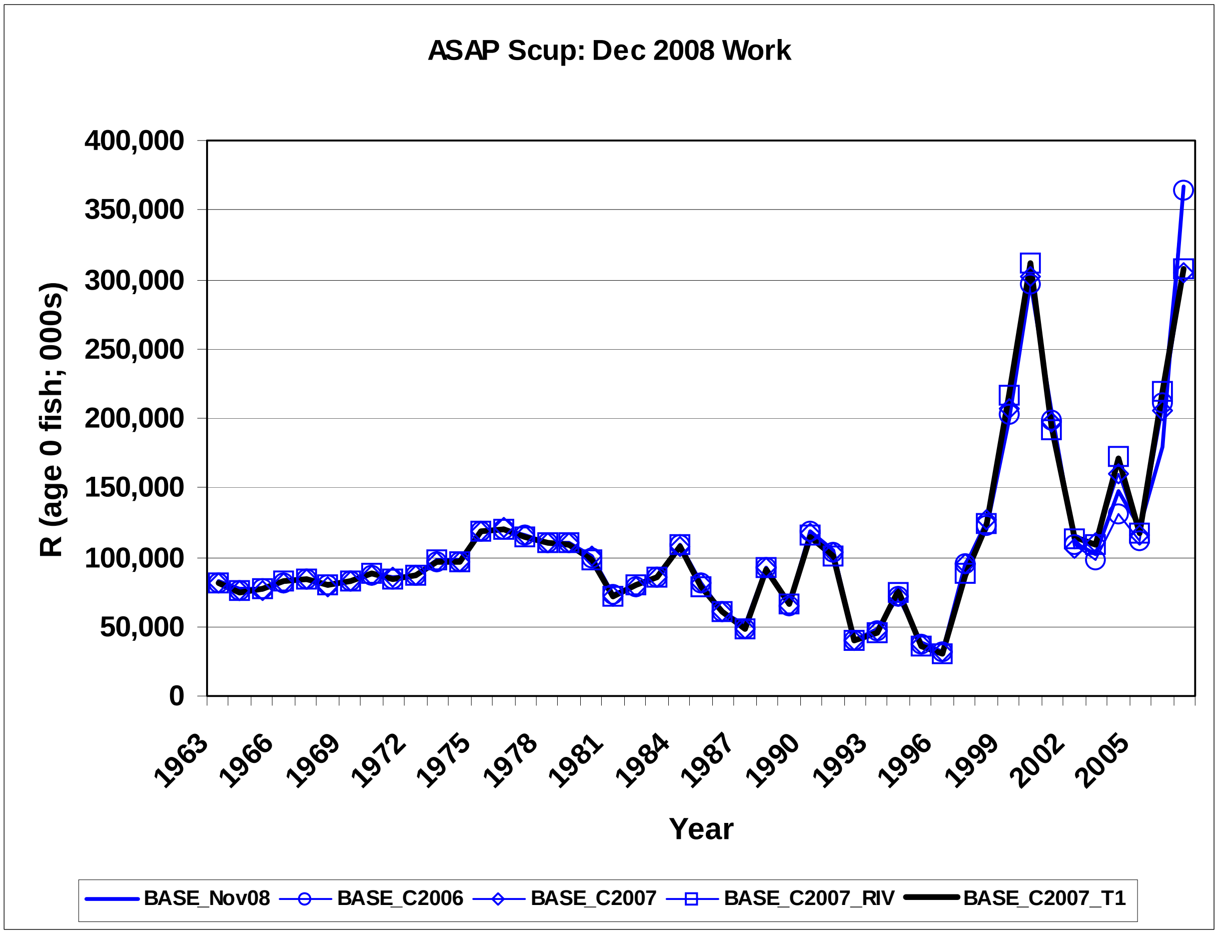


Figure 55. Comparative results for estimated recruitment in ASAP runs for scup: run BASE_C2007_T1 (solid black line) is the accepted basis for biological reference points and status evaluation.

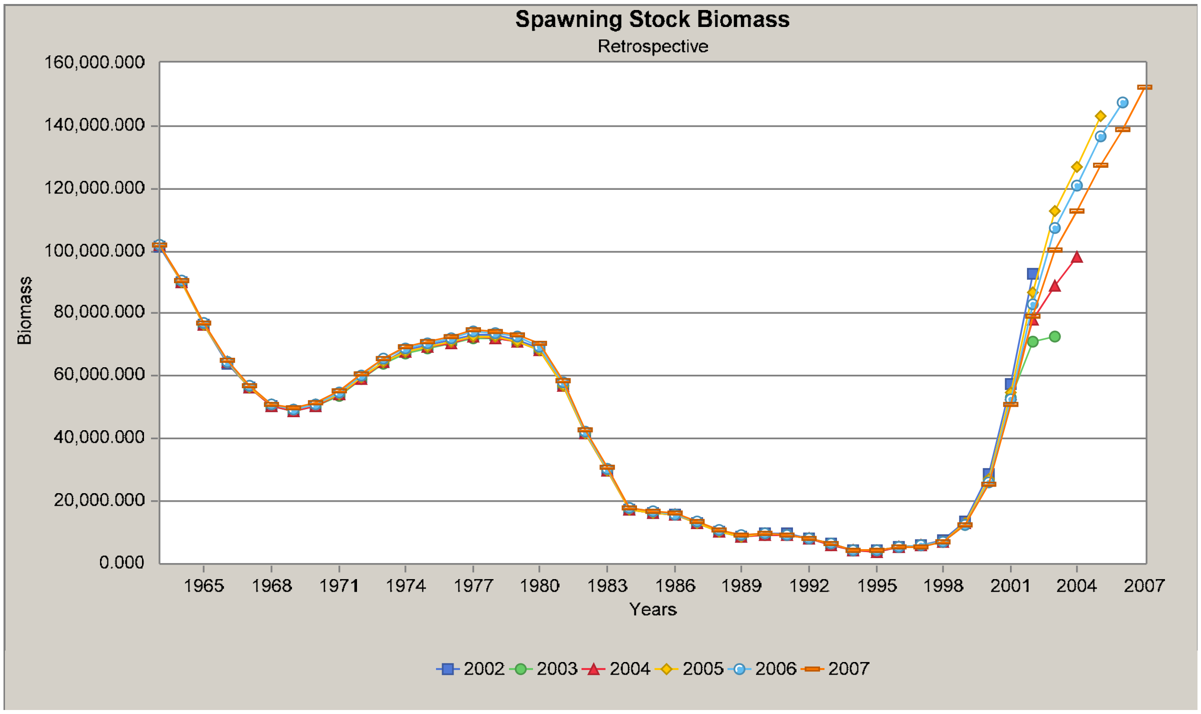


Figure 56. Retrospective analysis for SSB from Scup ASAP accepted model BASE_C2007_T1.

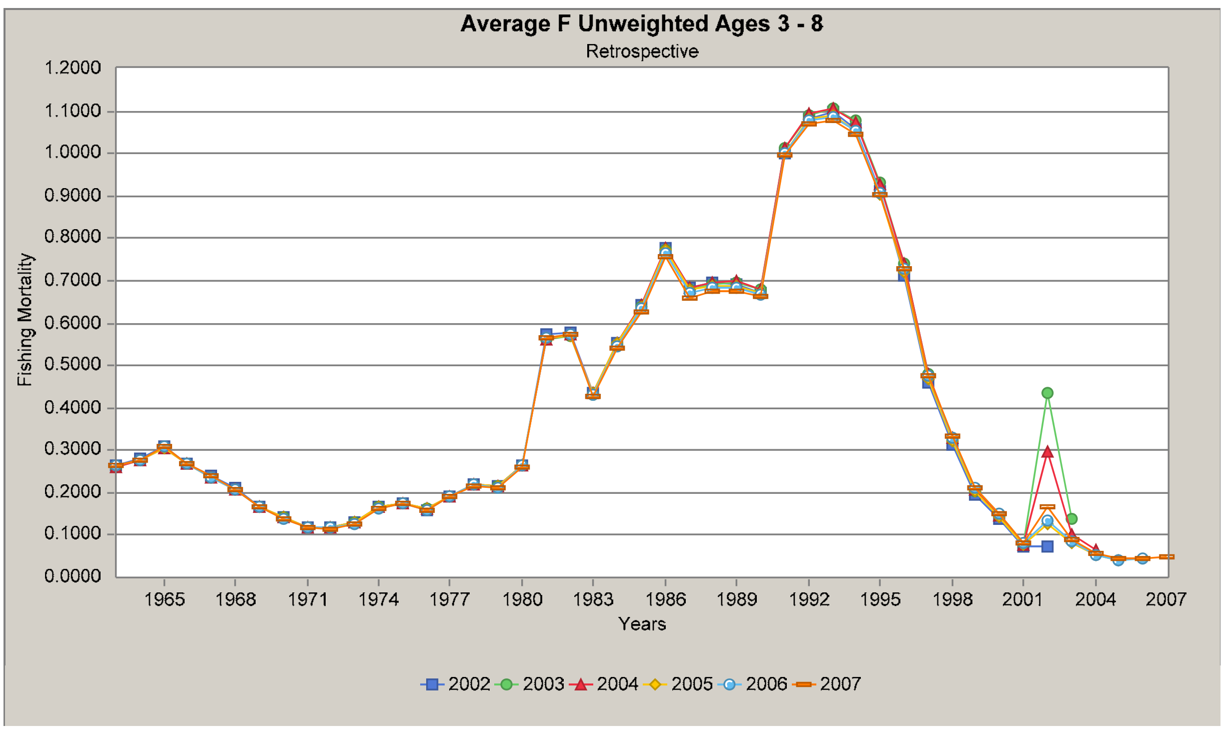


Figure 57. Retrospective analysis for fishing mortality (F) from Scup ASAP accepted model BASE_C2007_T1. Note that model coded ages 3-8 are true ages 2-7+.

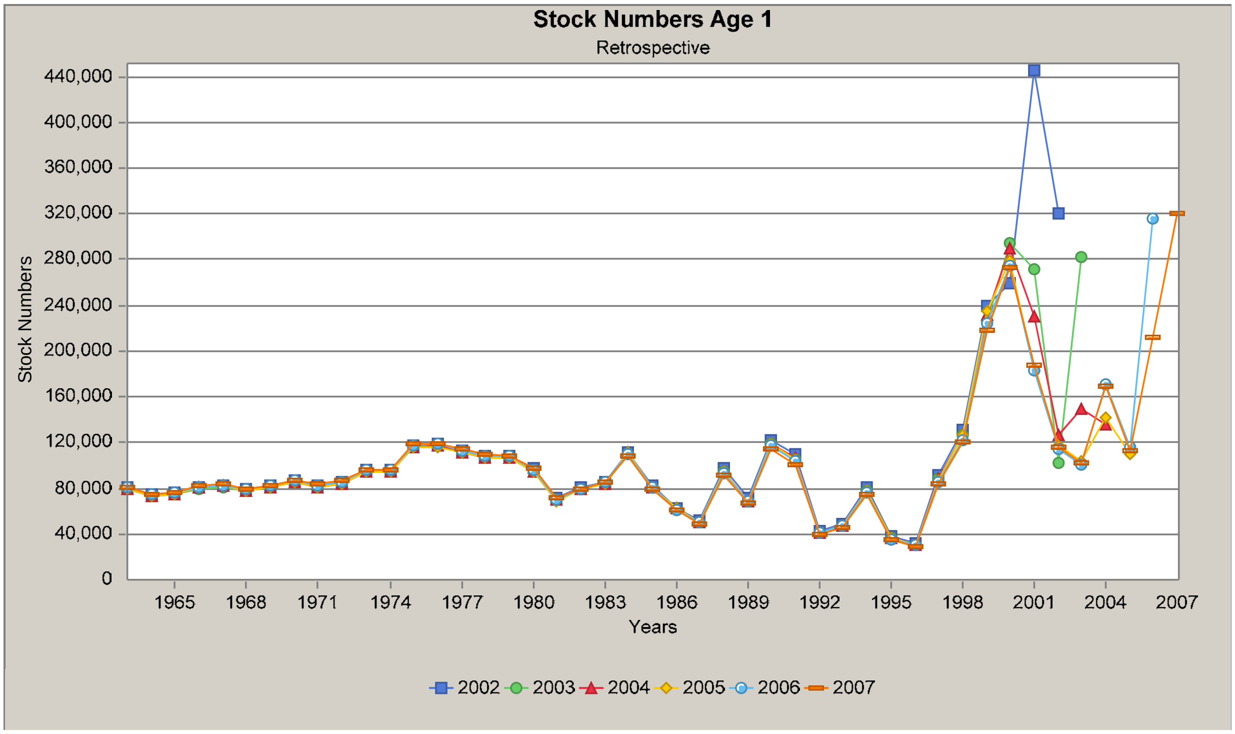


Figure 58. Retrospective analysis for recruitment at age 0 from Scup ASAP accepted model BASE_C2007_T1. Note that model coded age 1 is true age 0.

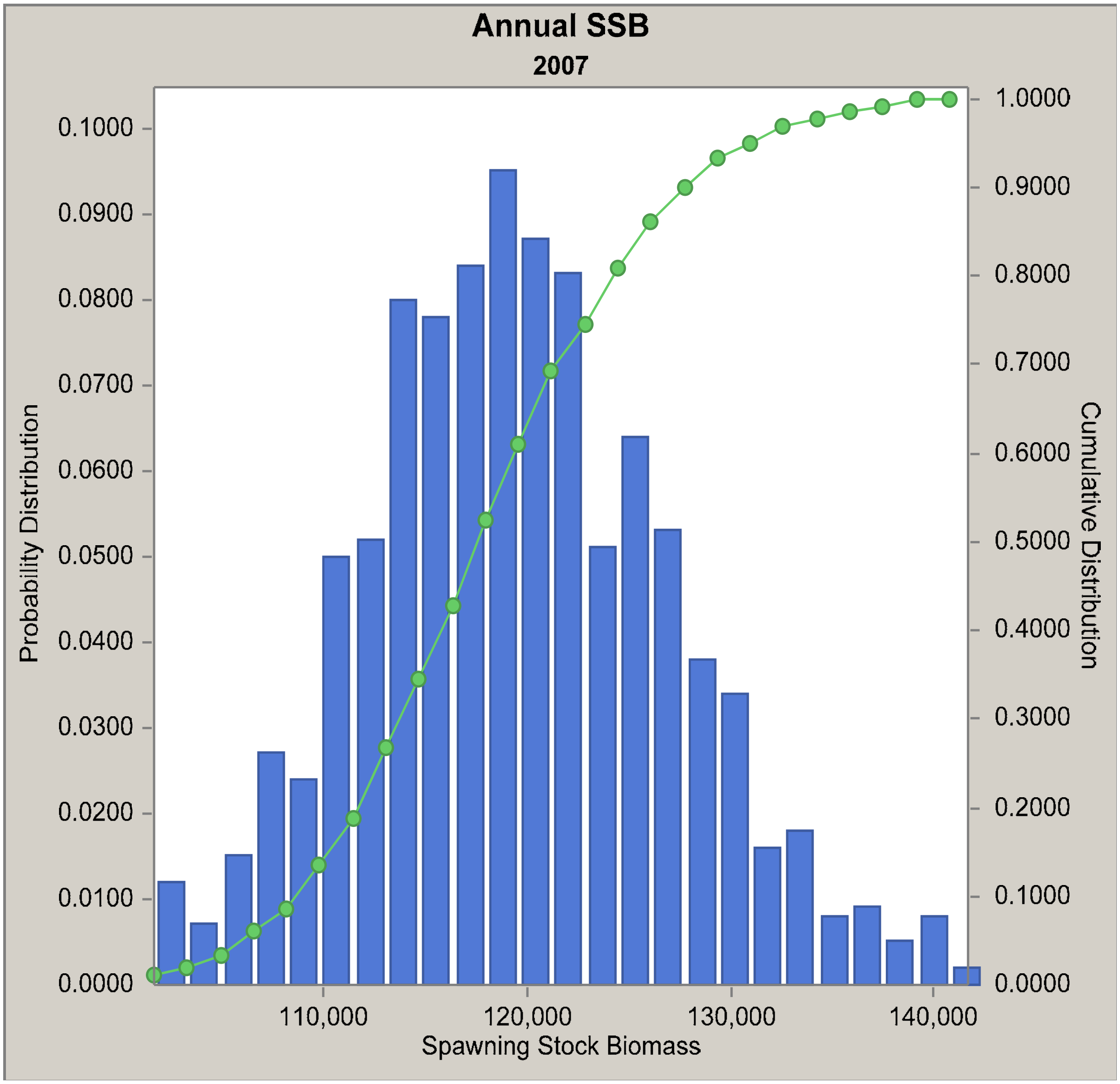


Figure 59. MCMC distribution of SSB in 2007 from the 2008 assessment accepted model BASE_C2007_T1.

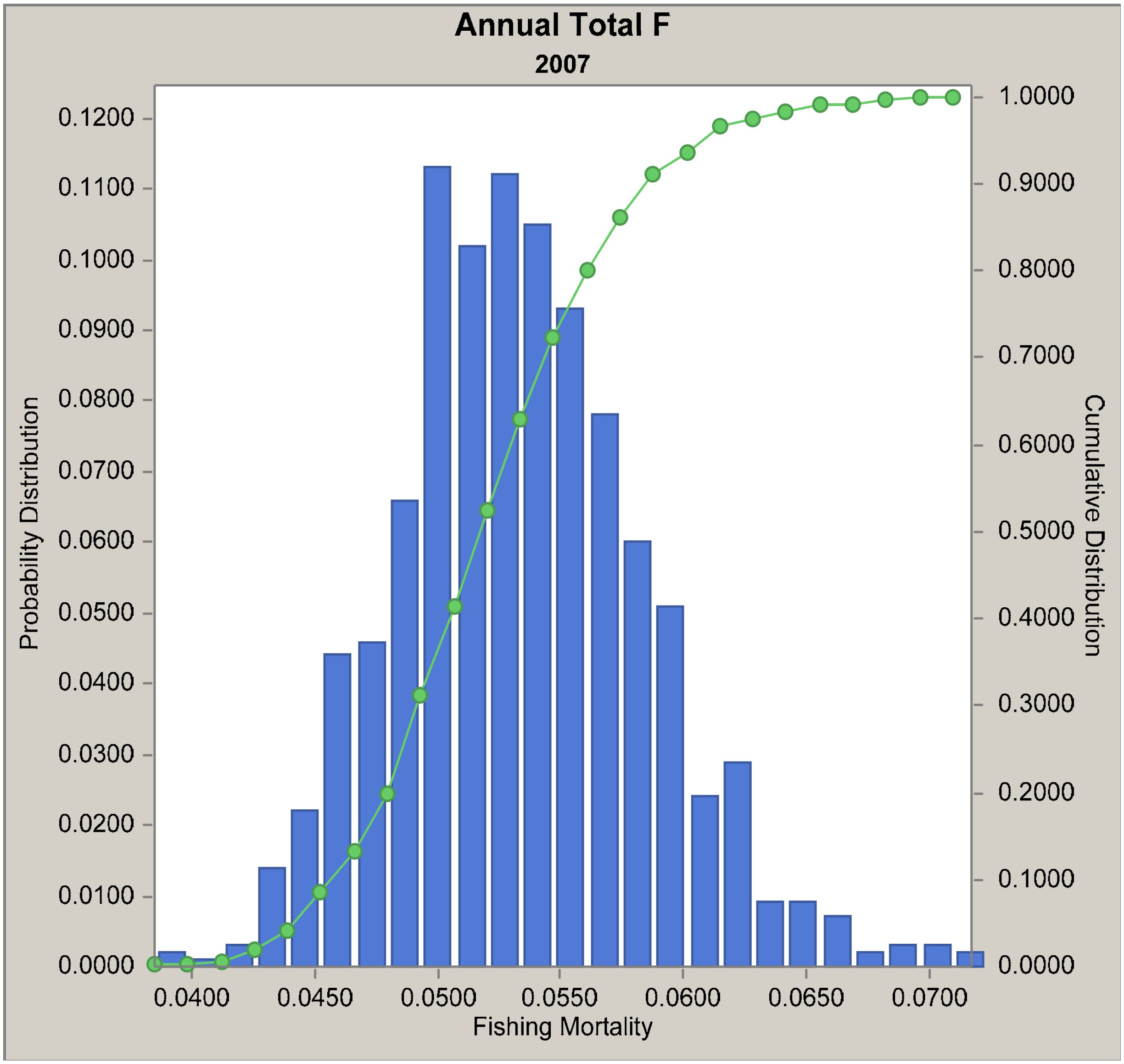


Figure 60. MCMC distribution of F in 2007 from the 2008 assessment accepted model BASE_C2007_T1.

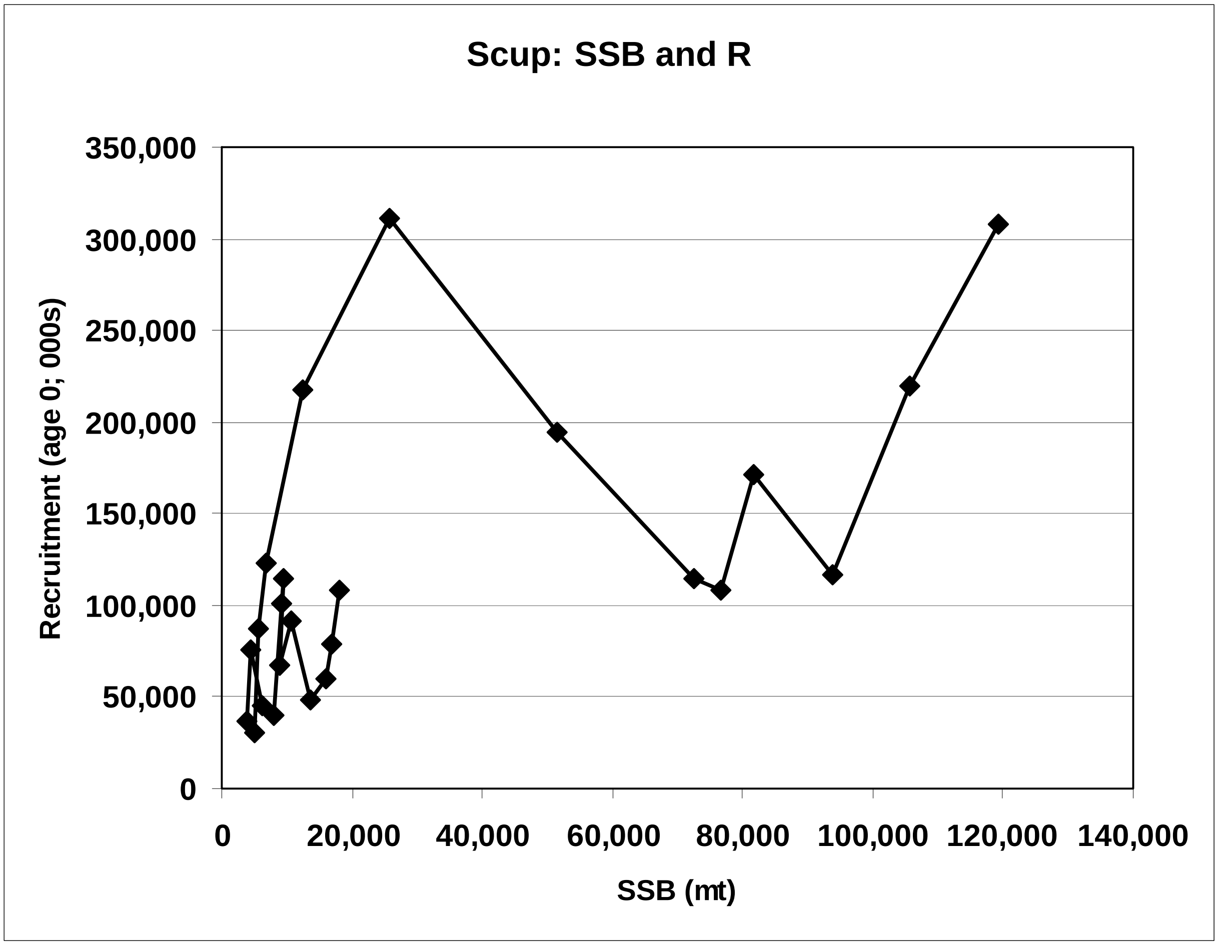


Figure 61. Spawning stock biomass (SSB; metric tons) and recruitment (age 0; 000s) estimates for scup from the 2008 assessment accepted model BASE_C2007_T1.

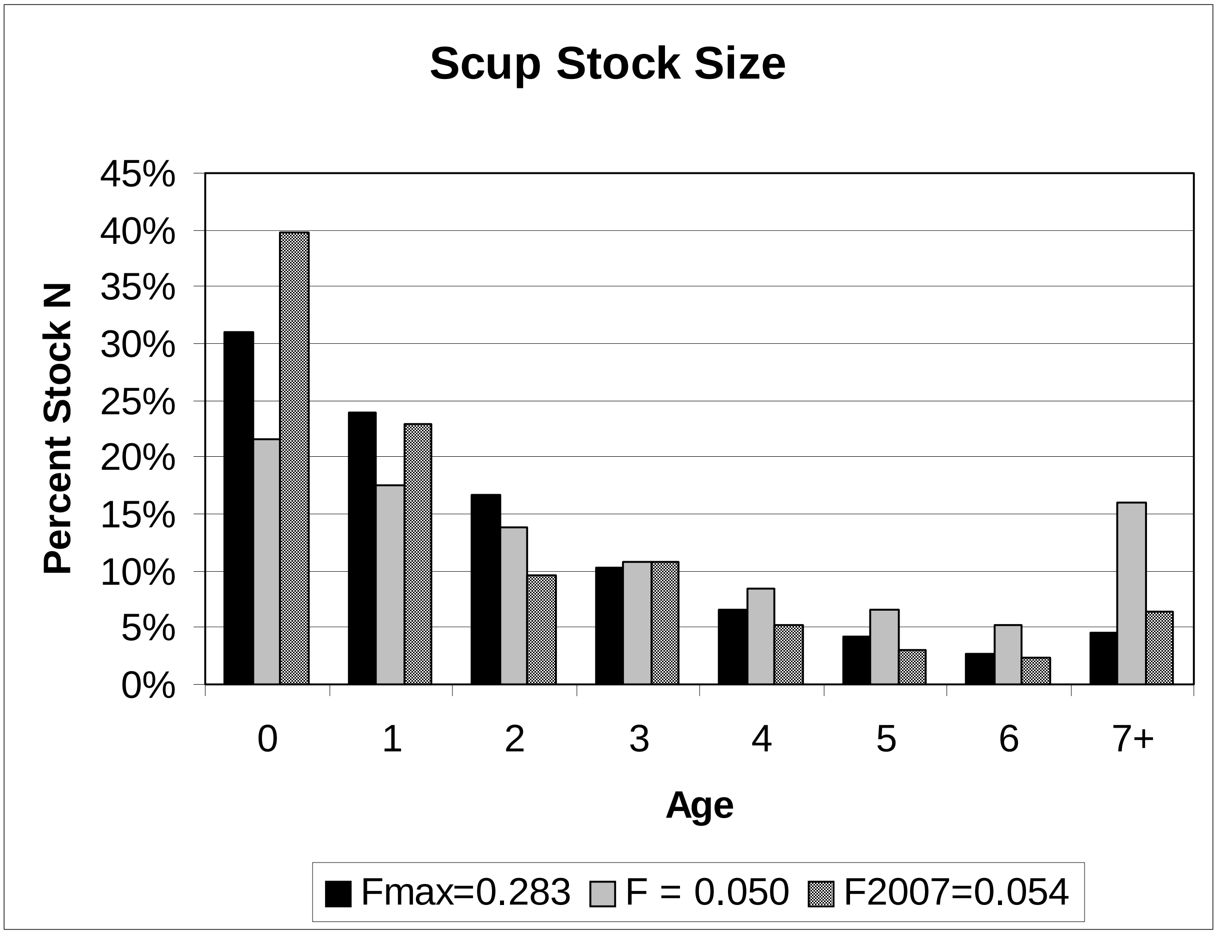


Figure 62. Percentage of scup stock size in numbers expected if the stock were fished at Fmax = 0.283 or F = 0.050 over the long-term, compared with stock size percentages estimated for 2007 at F = 0.054.

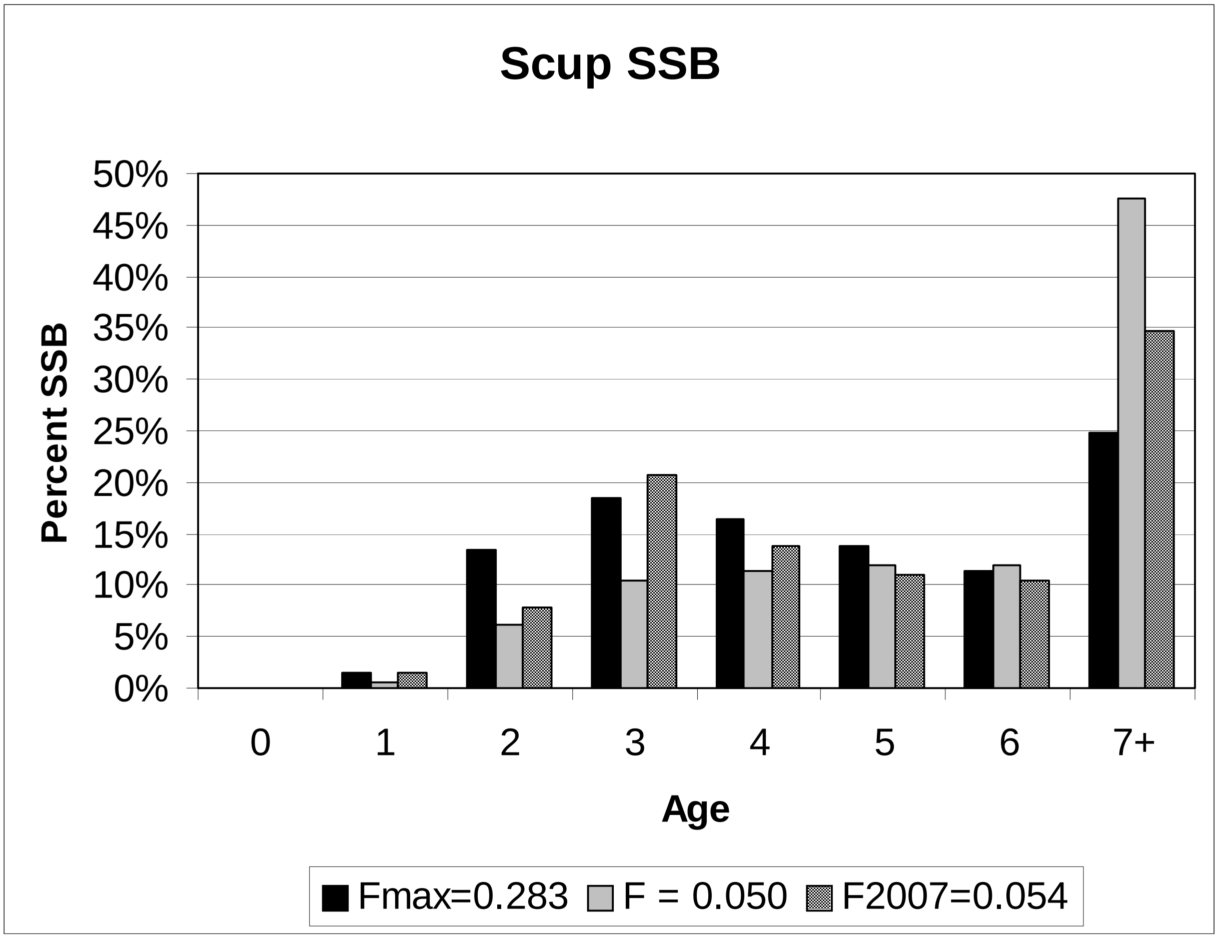


Figure 63. Percentage of SSB in weight expected if the stock were fished at Fmax = 0.283 or F = 0.050 over the long-term, compared with SSB percentages estimated for 2007 at F = 0.054. Fish at ages 3 and older are fully (>99%) mature.

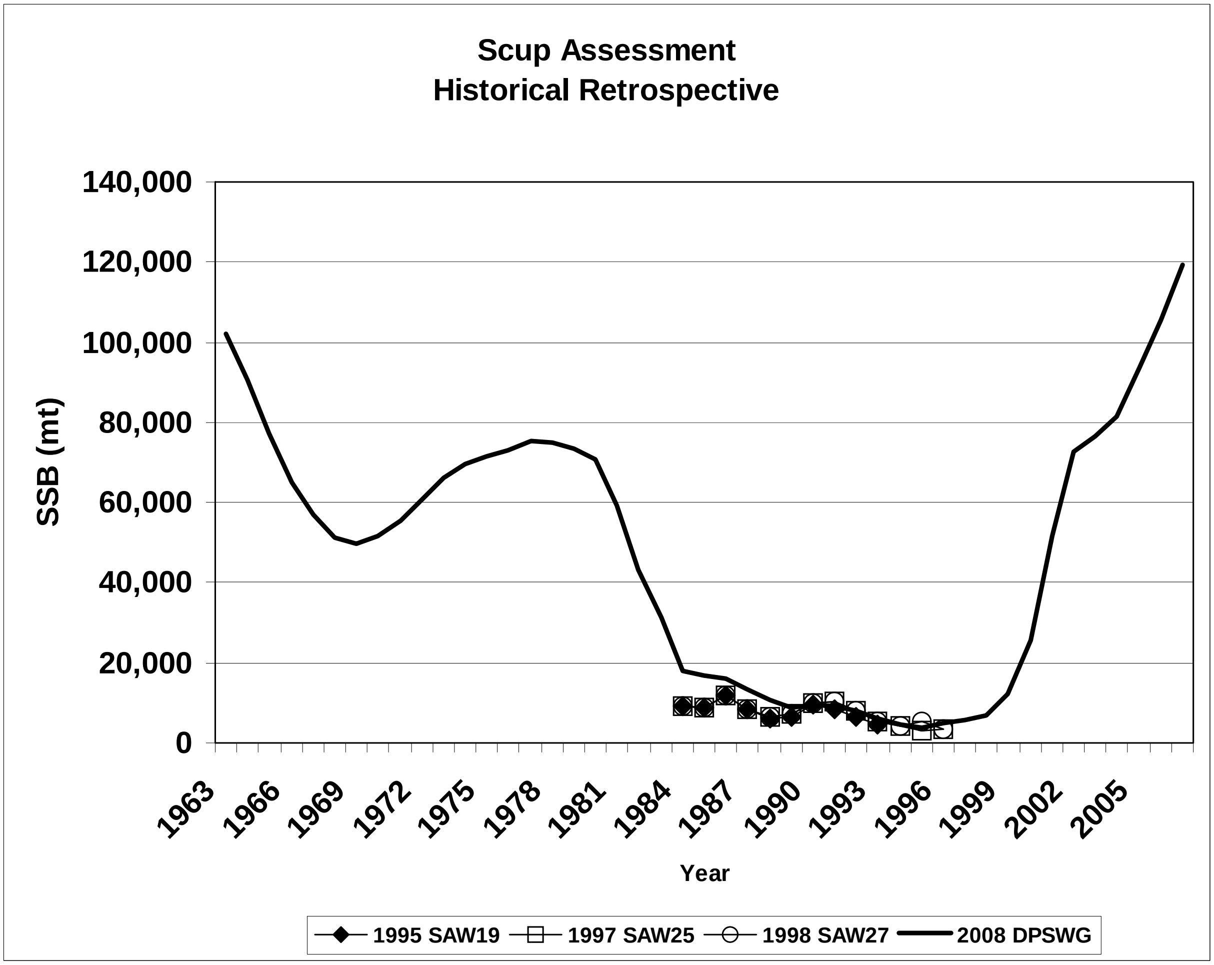


Figure 64. Historical retrospective of previous analytical assessments for scup: SSB. The 1995 SAW19 assessment was the last accepted peer-reviewed assessment. For the 1997 SAW25 and 1998 SAW27 assessments, the analytical components were not accepted as valid bases for assessing stock status. The SAW19, SAW25, and SAW27 analyses used the ADAPT VPA model for data beginning in 1984, while the 2008 DPSWG assessment uses the ASAP accepted model for data beginning in 1963.

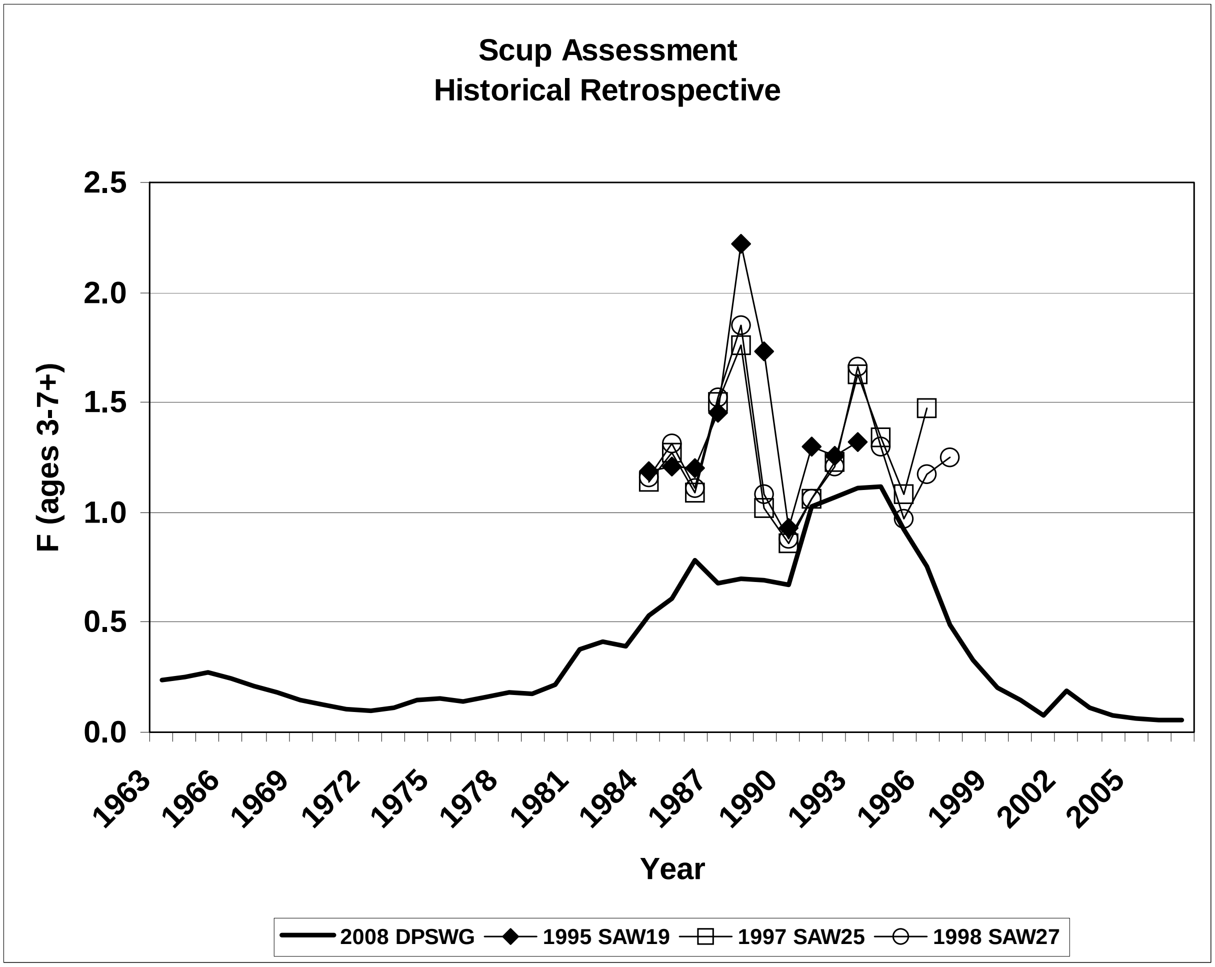


Figure 65. Historical retrospective of previous analytical assessments for scup: Fishing mortality (F). The 1995 SAW19 assessment was the last accepted peer-reviewed assessment. For the 1997 SAW25 and 1998 SAW27 assessments, the analytical components were not accepted as valid bases for assessing stock status. The SAW19, SAW25, and SAW27 analyses used the ADAPT VPA model for data beginning in 1984, while the 2008 DPSWG assessment uses the ASAP accepted model for data beginning in 1963.

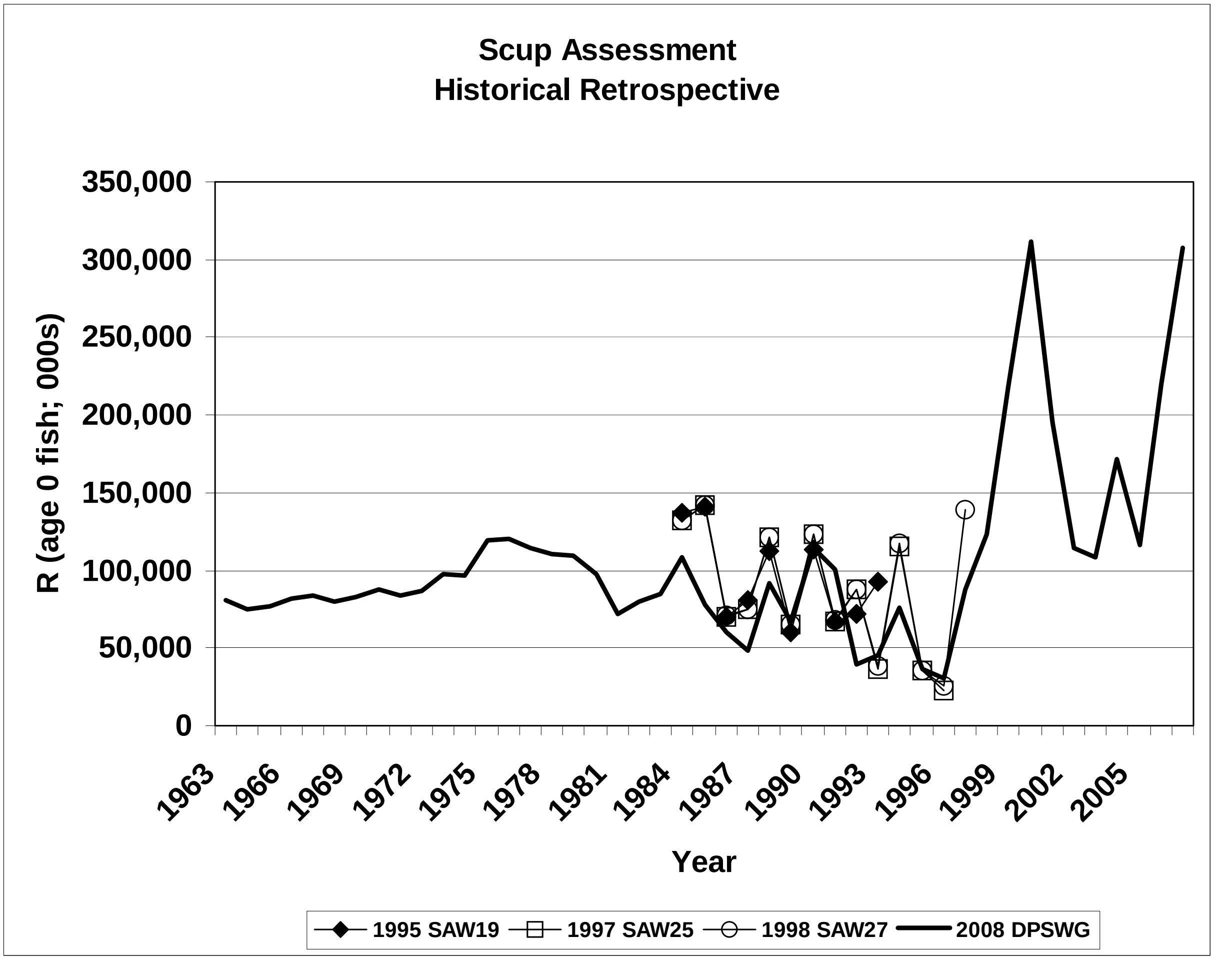


Figure 66. Historical retrospective of previous analytical assessments for scup: Recruitment at age 0 (R). The 1995 SAW19 assessment was the last accepted peer-reviewed assessment. For the 1997 SAW25 and 1998 SAW27 assessments, the analytical components were not accepted as valid bases for assessing stock status. The SAW19, SAW25, and SAW27 analyses used the ADAPT VPA model for data beginning in 1984, while the 2008 DPSWG assessment uses the ASAP accepted model for data beginning in 1963.

Black Sea Bass

by

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Northeast Data Poor Stocks Working Group Meeting
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Executive Summary

The northern stock of black sea bass (*Centropristis striata*) was evaluated using length-based population models. Under the existing fishery management plan (FMP), black sea bass has been regulated based on annual changes in the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey index. Fishing mortality resulting in maximum sustainable yield was considered equal to F_{MAX} equal to 0.33. Overfishing status was evaluated only with an approximation of F, based on a relative exploitation rate. A new approach was presented to the Data Poor Workshop review panel (December 2008) which involved estimates of fishing mortality and population size determined from changes in the size composition of the population (SCALE model). In addition, a length based yield per recruit model was developed to determine the associated biological reference points. An array of natural mortality estimates was considered, ranging from 0.2 to 0.9, and they were modeled as either a constant value or in the form of a logistic function where M varied with body length. The panel adopted results using a constant M=0.4 as the preferred model. The resulting $F_{40\%}$, as a proxy for F_{MSY}, was equal to 0.42 with an associated SSB equal to 12,537 mt and MSY of 3,903 mt. Assuming a catch of 2,685 mt, F_{2007} was estimated to be 0.48 and SSB equal to 11,478 mt. Therefore the conclusions are that overfishing is occurring, but the stock is not overfished (assuming a biomass threshold equal to ½ B_{MSY}). These new reference points and stock status determinations should be used with caution due to the uncertainty in the natural mortality estimate, the model input parameters, residuals patterns in model fit, and significant uncertainty associated with managing a protogynous species (i.e., individuals change sex from female to male).

Terms of Reference

1. Recommend biological reference points (BRPs) and measurable BRP and maximum sustainable yield (MSY) proxies.
2. Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop fishing level recommendations for these stocks.
3. Comment on what can be done to improve the information, proxies or assessments for each species.

Life History

Black sea bass (*Centropristis striata*) are distributed from the Gulf of Maine to the Gulf of Mexico, however, fish north of Cape Hatteras, NC are considered part of a single fishery management unit. Sea bass are generally considered structure oriented, preferring live-bottom and reef habitats. Within the stock area, distribution changes on a seasonal basis and the extent of the seasonal change varies by location. In the northern end of the range (New York to Massachusetts), sea bass move offshore crossing the continental shelf, then south along the edge of the shelf. By late winter, northern fish may travel as far south as Virginia, however most return to the northern inshore areas by May. Sea bass originating inshore along the Mid-Atlantic coast (New Jersey to Maryland) head offshore to the shelf edge during late autumn, travelling in a southeasterly direction. They return inshore in spring to the general area from which they originated. Black sea bass in the southern end of the stock (Virginia and North Carolina) move offshore in late autumn/early winter. Given the proximity of the shelf edge, they transit a relatively short distance, due east, to reach over-wintering areas.

Fisheries also change seasonally with changes in distribution. Inshore commercial fisheries are prosecuted primarily with fish pots (baited and unbaited) and handlines. Recreational fisheries generally occur during the period that sea bass are inshore. Once fish move offshore in the winter, they are caught in a trawl fishery targeting summer flounder, scup and *Loligo* squid (Shepherd and Terceiro, 1994). Handline and pot fisheries in the southern areas may still operate during this offshore period. Additionally a small sector of the NJ charter fleet target sea bass offshore during the winter.

Black sea bass are protogynous hermaphrodites and can be categorized as temperate reef fishes (Steimle et al. 1999, Drohan et al. 2007). Transition from female to male generally occurs between the ages of two and five (Lavenda 1949, Mercer 1978). Based on sex ratio at length from NMFS surveys, males constitute approximately 30% of the population by 20 cm, with increasing proportions of males with size (Figure 1). Following transition from female to male, sea bass can follow one of two behavioral pathways; either becoming a dominant male, characterized by a larger size and a bright blue nuccal hump during spawning season, or subordinate males which have few distinguishing features. The initiation of sexual transition appears to be based on visual rather than chemical cues (Dr. David Berlinsky, UNH, Personal communication). In studies of protogny among several coral reef fish species, transition of the largest female to male may occur quickly if the dominate male is removed from the reef, however, similar studies have not been published for black sea bass.

Spawning in the Middle Atlantic peaks during spring (May and June) when the fish reside in coastal waters (Drohan et al. 2007). The social structure of the spawning aggregations is poorly known although some observations suggest that large dominant males gather a harem of females and aggressively defend territory during spawning season (Nelson et al. 2003). The bright coloration of males during spawning season suggests that visual cues may be important in structuring of the social hierarchy.

Black sea bass attain a maximum size around 60 cm and 4 kg. Although age information is limited for the northern stock of black sea bass, growth curves are available from one published study as well as several unpublished studies. Lavenda (1949) suggests a maximum age for females of 8 and age 12 for males. However he noted the presence of large males (>45 cm) in deeper water that may have been older. Available growth curves are listed in Table 1. The Von Bertalanffy parameters were averaged across studies for input to models used in this analysis. (The growth parameters from Caruso, MADMF, appeared to be unique, possibly due to geographic growth differences and were not included in the model average). Although growth information was available for use in models, annual age length keys were not, therefore sea bass modeling efforts are length based rather than age based.

Maturity data is routinely collected on Northeast Fisheries Science Center survey cruises. Proportion mature for all years and sexes combined (n=10,318) was fitted to a logistic model (Figure 2). The model estimate for length at 50% maturity was 20.4 cm with 95% maturity attained by 28 cm.

Fisheries

In the Northwest Atlantic, black sea bass support commercial and recreational fisheries. Prior to WWII in 1939 and 1940, 46-48% of the landings were in New England, primarily in

Massachusetts. After 1940 the center of the fishery shifted south to New York, New Jersey and Virginia. Landings increased to a peak in 1952 at 9,883 mt with the bulk of the landings from otter trawls, then declined steadily reaching a low point in 1971 of 566 mt (Table 2). Historically, trawl fisheries for sea bass have focused on the over-wintering areas near the shelf edge. Inshore pot fisheries, which were primarily in New Jersey, showed a similar downward trend in landings between the peak in 1952 and the late 60s. The large increase in landings during the 1950's appears to be the result of increased landings from otter trawlers, particularly from New York, New Jersey and Virginia (Figure 3). During the same period, a large increase in fish pot effort, and subsequent landings, occurred in New Jersey (Figure 4). In recent years, fish pots and otter trawls account for the majority of commercial landings with increasing contributions from handline fisheries. Landing since 1974 have remained relatively steady around 1400 mt. (Table 2). Recreational landings, available from MFRSS data since 1982, average about 1,600 mt annually (Table 2). Estimates for recreational sea bass landings in1982 and 1986 (4,485 mt and 5,618 mt, respectively) are unusually high, as they are for other species for those years. Similarly, recreational landings for 1998 and 1999 are lower than expected. Although the estimates have been confirmed by MRFSS, they remain suspect.

The species affinity for bottom structure during its seasonal period of inshore residency increases the availability to hook and line or trap fisheries compared to the decreasing susceptibility to bottom trawl gear commonly used for scientific surveys. In autumn when water temperatures decline, black sea bass migrate offshore to areas along the edge of the continental shelf (Moser and Shepherd 2009). During this offshore period, sea bass are vulnerable to otter trawls as part of a multispecies fishery (Shepherd and Terceiro 1994).

Stock assessment history summary

Black sea bass stock assessments have been reviewed in the SARC/SAW process (SAWs 1, 9, 11, 20, 25, 27, 39 and 43) beginning with an index based assessment in 1991. In 1995 a VPA model was approved and the results generally showed fishing mortalities exceeding 1.0 (estimated using an M=0.2). The VPA was reviewed again in 1997 and at this time was considered too uncertain to determine stock status but indicative of general trends. In 1998, another review was conducted and both VPA and production models were rejected as either too uncertain or inappropriate for use with an hermaphroditic species. A suggestion was made to use an alternative method such as a tag/recapture approach. The NEFSC survey remained the main source of information regarding relative abundance and stock status. A tagging program was initiated in 2002 and the first year results were presented for peer review in 2004. The review panel concluded that a simple tag model using the proportion recovered in the first year at large, as well as an analysis of survey indices, produced acceptable results to determine exploitation rate and stock status. The release of tags continued through 2004 and results of tag models as well as indices were presented for SARC review in 2006. Their findings were that the tag model did not meet the necessary assumptions and the variability in the survey indices created uncertainty which prevented determination of stock status. The panel did not recommend any alternative reference points, however they did recommend continued work on length based analytical models.

Existing Biological Reference Points

Based on revision through Framework 7 to the Summer Flounder, Scup and Black Sea Bass (SFSCBSB) FMP, the status determination criteria is defined for each of the species managed under the FMP. The maximum fishing mortality threshold for each of the species under the FMP is defined as F_{MSY} (or a reasonable proxy thereof) as a function of productive capacity, and based upon the best scientific information consistent with National Standards 1 and 2. Specifically, F_{MSY} is the fishing mortality rate associated with MSY. The maximum fishing mortality threshold (F_{MSY}) or a reasonable proxy may be defined as a function of (but not limited to): total stock biomass, spawning stock biomass, total egg production, and may include males, females, both, or combinations and ratios thereof which provide the best measure of productive capacity for each of the species managed under the FMP. Exceeding the established fishing mortality threshold constitutes overfishing as defined by the Magnuson-Stevens Act.

The minimum stock size threshold for each of the species under the FMP is defined as ½ B_{MSY} (or a reasonable proxy thereof) as a function of productive capacity, and based upon the best scientific information consistent with National Standards 1 and 2. The minimum stock size threshold (½ B_{MSY}) or a reasonable proxy may be defined as a function of (but not limited to): total stock biomass, spawning stock biomass, total egg production, and may include males, females, both, or combinations and ratios thereof which provide the best measure of productive capacity for each of the species managed under the FMP. The minimum stock size threshold is the level of productive capacity associated with the relevant ½ MSY level. Should the measure of productive capacity for the stock or stock complex fall below this minimum threshold, the stock or stock complex is considered overfished. The target for rebuilding is specified as B_{MSY} (or reasonable proxy thereof) at the level of productive capacity associated with the relevant MSY level, under the same definition of productive capacity as specified for the minimum stock size threshold.

The best scientific information consistent with National Standards 1 and 2, has not recommended revising the definitions for biological reference points set forward under Amendment 12 to the SFSCBSB FMP. Therefore, these reference points and values are defined as follows in Amendment 12: Overfishing for black sea bass is defined to occur when the fishing mortality rate exceeds the threshold fishing mortality rate of F_{MSY}. Because F_{MSY} cannot be reliably estimated, F_{MAX} (0.33) is used as a proxy for F_{MSY}.

The current biomass reference points are a function of the NEFSC spring bottom trawl survey. The current definitions were adopted as a way to measure stock status in the absence of an analytical age-based stock assessment. Commercial landings of black sea bass reached a peak in 1952 at nearly 9900 mt. From that peak through 1965, the landings averaged nearly 4600 mt whereas from 1966 through 1980 commercial landings averaged 1200 mt. The rationale behind the existing reference point was that the substantial landings prior to 1966 likely represented potential yield at B_{MSY}. The landings in the late 1960s-80s were likely more representative of ½ B_{MSY}. NEFSC spring survey indices began in 1968 and it was concluded that the maximum survey indices coinciding with landings in the 1970s were around ½ B_{MSY} and would therefore represent a biological threshold. To limit year to year variation, the spring offshore survey indices were calculated as a 3 point moving average. The 1977-1979 three year moving average of the spring survey value of exploitable stock biomass (index of black sea bass $\geq$ 22 cm = 0.98 kg/tow), would serve as a biomass threshold. B_{MSY} cannot be reliably estimated for black sea bass.

Without an analytical stock assessment, no current fishing mortality estimates are available to compare to the F_{MAX} proxy of F_{MSY} (0.33). A relative index of exploitation is calculated as total landings /spring survey index of exploitable biomass (defined as sea bass $\geq$ 22 cm). Changes in the relative exploitation index are evaluated for development of management advice. The current definition suffers from the inability to accurately measure fishing mortality relative to F_{MSY}. In addition, reviewers at SARC 43 concluded that the use of the spring offshore survey was not an appropriate measure of relative abundance and was not a valid basis of a biomass reference point. From the SARC 43 reviewer's summary:

"The perception of the status of the stock relative to biomass thresholds is very sensitive to the method used to calculate the survey indices. Not only are the confidence intervals very large, meaning the current biomass is probably indistinguishable from the BRP, but calculating both current biomass and the BRP on a consistent scale (i.e always arithmetic or always logged) can lead to a divergent perceptions of current stock size relative to the BRP. The definition of the biomass threshold was not considered satisfactory. One reviewer questioned whether it was consistent with F_{MAX}. The other pointed out that establishing the biomass threshold as the period of low biomass from which the stock recovered is as plausible as setting the BRP to the early period of high biomass. Given the uncertainty over growth, mortality and selectivity, the estimation of F_{MAX} is uncertain and there is no credible estimate of current fishing mortality with which to compare it. Hence the evaluation of status relative to fishing mortality reference points is not possible."

New analyses

Development of updated biological reference points for black sea bass is hampered not only by a lack of annual age data but also by limited understanding of how black sea bass productivity responds to exploitation. Traditional fisheries models, generally developed for gonochoristic species, may not apply to a protogynous hermaphrodite (Hamilton et al. 2007). Simulation studies of populations exhibiting protogny suggest that conservation of large terminal males is critical for sustainability (Alzono et al. 2008, Brooks et al. 2008, Hamilton et al. 2007, Heppell et al. 2006, Huntsman and Schaaf 1994). The implication is that removal of the terminal male will not only hamper male fertilization success but will induce transitioning of the larger females into males. The consequence is not only removal of male biomass but removal of potential egg production in the larger females. Reduction of dominant males in a population may, in effect, have a similar effect as increasing natural mortality on females.

Tag Release/Recapture model

To evaluate mortality rates, a tag release/recapture study was conducted with 13,794 tagged black sea bass (12,310 legal-size) released between Massachusetts and Cape Hatteras, NC from 2002 to 2004. Of these legal-size releases, 1,683 were recaptured during 2002 to 2007. An instantaneous rates configuration of a Brownie band recovery model was used to estimate both fishing and natural mortality. A seasonal model of fishing mortality, adjusted for non-mixing, and a constant natural mortality best explained the tag recoveries (Shepherd and Moser 2008, *Appendix I*). Fishing mortality estimates ranged between 0.3 and 0.4 whereas the natural mortality estimate was equal to 1.08 (Table 3). The estimate of natural mortality includes the effects of all unaccounted tag losses which could be influenced by an over-estimate of reporting rate (resulting from violation of the assumption that the return rate of high reward tags equaled 100%) or tag attrition (resulting from decreasing legibility of the tags, expulsion of the tags, etc.). An alternative model assuming only 75% reporting of $100 tags and a 9% attrition of tags per season over the recovery period resulted in a decreased estimate of natural mortality of 0.66. Despite uncertainty in the tag model, the results imply that natural mortality of the black sea bass population exceeds 0.2 as used in previous assessments.

Tag recovery data also indicates that extensive seasonal movements occur and are not homogeneous throughout the stock (Moser and Shepherd 2009). During summer months fish throughout the stock remain stationary in coastal areas with very little mixing among adjacent areas. In autumn, offshore migration toward the edge of the continental shelf begins in the north and progresses southward. During the offshore overwintering period on the continental shelf out to the shelf edge, intermixing of fish from various inshore areas is more frequent. Recaptures following spring inshore migrations demonstrate a high degree of site-fidelity with occasional straying to adjacent areas.

Length-based Analytical model

Since annual age information was unavailable, a length based model (SCALE developed by Paul Nitschke, NEFSC) was explored as a method for evaluating sea bass population dynamics. The model details are described in *Appendix II.* SCALE data input included catch time series (mt), NEFSC spring and winter survey recruit and adult indices, growth information, survey length frequencies and catch length frequencies. The model covered the period 1968 to 2007 based on the times series of NEFSC spring offshore surveys.

Commercial length frequencies were compiled beginning with samples in 1984. Sampling was done randomly by market categories and expanded as the ratio of sample weight to total landings, by calendar quarter. Black sea bass were culled as small, medium, large, jumbo or unclassified. In the rare cases where fish were categorized as extra small and extra large, they were combined with small and large, respectively. Total annual length measurements ranged from 300 to 7768 fish with an average of 2956 per year (Table 4).

Commercial discards were estimated since 1989 using a standard approach developed for national standardized by-catch reporting. (Wigley et al., 2008). Observer samples for sea bass were limited to otter trawl trips since 1989. Discard estimates were developed from the ratio of discarded black sea bass in mt to total landings (mt) of all fish species in the comparable statistical area, by half-year periods. Discards from pot and handline fisheries were estimated using the annual ratio of reported discards to landings in vessel trip reports, expanded to total annual landings. Since a component of the pot fishery is prosecuted solely in state waters without a requirement to submit VTR logs, they are not included in the total. A 50% discard survival rate was applied across all commercial gears. Total discards averaged 111 mt annually and represented 17% of reported commercial landings (Table 2). Discards in 1993 and 2004 were well above average at 35% and 62% of landings, respectively.

Complete recreational landings were available from the Marine Recreational Fisheries Statistics Survey (MRFSS) since 1981. Landings for 1968 to 1980 were hindcast based on the relationship between inshore commercial pot and handline landings and recreational landings between 1981 and 1997 (Table 2). In 1998 management regulations were imposed which controlled landings based on quota. The two abnormally large recreational landings in 1982 and 1986 were excluded. The ratio between average recreational landings and pot/handline landings was 2.63. This ratio applied to the commercial pot landings produced the 1968 to 1980 recreational landings. Length frequencies of sea bass were based on dockside sampling by MRFSS staff.

Recreational discard mortalities beginning in 1981 were calculated from MRFSS B2 estimates using a 25% discard mortality rate (Table 2). Discard number was converted to weight assuming comparable mean weight as landings. Between 1981 and 1998 the ratio of discards to landings was relatively constant with an average of 50%. Since 1999, the proportion discarded has increased dramatically averaging 179% of landed sea bass by weight. With a 25% mortality applied, the weight of discards was approximately 50% of landed weight. Length frequencies for recreational discards were not available for the time series.

Fishery Independent Indices

The NEFSC spring bottom trawl survey conducted since 1968 provided indices of relative abundance in number and weight. The review panel in SARC 43 questioned the use of NEFSC bottom trawl survey indices as an index of relative abundance. During autumn, sea bass are generally inshore on structured bottom that is not conducive to sampling with an otter trawl. Consequently those survey results are not considered indicative of sea bass abundance. However, since the 1930's commercial trawl fisheries have had significant landings of sea bass caught offshore during the winter and early spring on the continental shelf. The spring offshore bottom trawl survey takes place in the same areas suggesting that the use of trawl gear for sampling sea bass at this time of year is no less limited by habitat than commercial trawlers. Comparison of survey length frequencies and length frequencies of commercial landings suggest the selectivity at length is comparable (Figure 5). Additionally, the winter survey time series of relative abundance from 1992 to 2007, which uses a trawl with a chain sweep rather than roller gear, was highly correlated to the spring abundance. Although the catch per tow in the spring survey was low, the correlation to the winter survey as well as the comparable length frequency to the commercial fishery suggests that the survey adequately samples sea bass. Finally, the index of abundance from the spring survey also closely resembles the time series of recreational catch per angler trip estimated from MRFSS dockside sampling (Figure 6).

Concern has been raised in the past that environmental conditions significantly influence catchability of black sea bass in the survey. The relationship between catch and environmental anomalies (water temperature and salinity) was evaluated for the survey time series. There was no apparent pattern in deviations of annual survey catches around the time series mean and anomalous temperature or salinity conditions (Figure 7). Local conditions may alter distributions but the influence on the spring index time series appears to be minimal.

The use of $\log_e$ transformation of the survey indices was also criticized by the SARC 43 review panel. A plot of the mean number per tow by strata against the associated variance shows that the variance increases non-linearly (Figure 8). To reduce the influence of over-dispersion on the estimation of the stratified mean, $\log_e$-transform indices (followed by re-transformation) were used in the model. NEFSC spring survey indices with and without transformation are presented in figures 9a and 9b.

The index of exploitable biomass (defined as fish $\geq$ 22 cm presented as the $\log_e$ re-transformed stratified mean weight per tow) beginning in 1968 increased to a peak value in 1976, followed by a decline to the series low in 1982 (Figure 10). A slight rise in abundance was evident in the late 1980s but was followed by a decade of fluctuations around low levels of abundance. Between 1999 and 2002 the index increased again, peaking with the series high in 2002 (1.07 kg per tow), followed by a steady decline through 2008 when the index dropped to 0.18 kg per tow. The 2008 value of 0.19 is below the long-term average of 0.27 fish per tow. The NEFSC winter survey, initiated in 1992, follows a similar pattern with a peak in the $\log_e$ re-transformed index value for 2003 (1.83 kg/tow) followed by declining indices to 0.40 kg/tow in 2007 (Figure 10).

Juvenile indices of black sea bass from the winter and spring surveys provide some insight into cohort strength. The juveniles appear as clearly defined modes at sizes $\leq$ 14 cm in the autumn surveys (Figure 11). There appears to be little growth during the winter, as the same distinct size mode appears in the winter and spring survey length frequencies. In the spring, fish $\leq$ 14 cm would be considered one year old. Indices were calculated as the sum of $\log_e$ re-transformed mean #/tow at length for sea bass less than or equal to 14 cm. The indices in both the winter and spring surveys suggest large 1999 and 2001 cohorts (peaks in the 2000 and 2002 surveys) (Figure 12). Both of these modes in the length frequency appear the following year as increases in a mode above 20 cm, which is consistent with known growth rates. The winter and spring surveys show an above average 2002 year class and the spring survey shows a strong 1998 cohort that was below average in the winter survey. The 2007 juvenile index in the winter survey was above average.

SCALE Model input

A critical issue in development of new biological reference points is the choice of natural mortality. In the case of black sea bass this becomes particularly difficult due to the unique life history. Methods have been proposed for estimating M based on longevity (Hoenig 1983, Hewitt and Hoenig 2005). Maximum age has been reported by Lavenda (1949) as 12, although he suggests sea bass may survive for up to 20 years, while the oldest fish in a study by Mercer (1978) was age 9. NMFS spring survey age data collected in the 1980s found a sea bass at age 10. More recently, a trawl caught sea bass of 61 cm and 4 kg was taken in the winter of 2007 off the mouth of the Chesapeake Bay and aged as 9 years using otoliths (Chris Batsavage, pers. comm.). Additionally, a study at VIMS repeating the work of Mercer identified a fish as age 12 (R. Pemberton, pers. comm.) while Caruso (1995) found the oldest fish to be age 7. Applying the Hoenig regression method for maximum age suggests that M could possibly be between 0.37 (age 12) and 0.55 (age 8) (Figure 13). The results of the tag model previously noted suggest a much higher natural mortality of 1.08 for the period 2003-2007. If M were really greater than 1.0 at all sizes, it would be equivalent to a maximum age of 4 in the Hoenig model. However, if the tagging model assumptions of 100% reporting of high reward tags were relaxed to equal 75% and tag attrition of 9% applied, the estimate of M decreases to 0.66. It is clear from multiple approaches that natural mortality of the population is greater than 0.2. As an alternative to a constant natural mortality across sizes, M was also modeled as a logistic function of size (Figure 14). This was an attempt to include both a high natural mortality and a subgroup with a longer potential life expectancy. The point of inflexion corresponded to the approximate age when transition occurs.

Included as input to the SCALE model were spring and winter offshore indices of adult and juvenile abundance. The spring series of stratified $\log_e$ re-transformed mean number per tow included 1968 to 2008 while the comparable indices from the winter survey were 1992 to 2007 (Figure 15). Mean lengths at age were predicted from a growth curve averaged from available studies and length-weight equation parameters were from fitted length-weight data collected on NMFS surveys. Total catch (mt) was commercial landings since 1968, recreational landings since 1981 estimated by MRFSS and 1968 to 1980 estimates derived from commercial inshore fishery landings, recreational discard losses since 1981 and commercial discard estimates since 1989. The model was not restricted to fitting the catch exactly by assuming error in the catch estimates. The model was fitted to survey length frequencies greater than 30 cm to counter the lack of discard length data in the fishery length frequencies. Selectivity periods were chosen based on regulatory changes in the fisheries. The three periods were 1968 to 1997, 1998 to 2000 and 2001 to 2007. The model was allowed to fit the initial fishing mortality in phase two.

Models were developed with a range of natural mortalities under an assumption of either a constant or logistic pattern. Within the logistic model assumption, a variety of logistic model parameters were used to generate a suite of M estimates. A total of 26 various M patterns were evaluated and the SCALE model results are presented in Table 5 and Figures 16-21.

In general, the SCALE model adequately described the length frequency data from the fisheries and the associated catch. The general pattern in the spring and winter survey indices were adequately predicted by the model, although the magnitude of some recruitment events was somewhat reduced. With constant M the model fit as defined by the objective function improved with increasing M until M exceeded 0.8. Similarly the value of the objective function declined with increasing M for the logistic M model. However, reduction in the objective function with increasing M may also be a result of faster removal of fish in the model which ultimately limits variation in model fit. Alternative models using higher M with different values at length are also possible. Within the output for each model run, SCALE produces values for selectivity at length, fishing mortality estimates, biomass and abundance estimates. Annual spawning biomass estimates were developed outside of the model software using population numbers at length multiplied by mean weight at length and proportion mature at length from NEFSC survey data.

New Biological Reference Points

The current overfishing definition for black sea bass is based on F_{MAX} as a proxy for F_{MSY}. The F_{MAX} value was calculated using an M=0.2 and a maximum age of 15 and predicts an F_{MAX}=0.33. The biomass reference point is a 3 year moving average of stratified mean weight per tow of exploitable biomass for 1977-1979. The proposed new reference point incorporates additional fishery and biological information in addition to the NEFSC spring and winter bottom trawl survey indices. Evaluation of natural mortality suggests that M is likely greater than 0.2.

A length based yield per recruit model from the NOAA Fisheries Toolbox was used to develop estimates of reference points. From each of the 26 SCALE models run, the associated M and fishery selectivity parameters were input to the YPR model. Per recruit values from each model run were expanded to population values using the average recruitment from the 1968-2007 time series as estimated by SCALE. Average von Bertalanffy growth parameters from among several studies were used to define growth (Figure 19) and an average selectivity curve from 2001-2007 (Figure 20) was incorporated into the yield per recruit model. Resulting yield per recruit and SSB per recruit at F40% were multiplied by average long-term recruitment (1968-2007) to produce total yield, spawning biomass (sexes combined). These values and F at $F_{40\%}$ were compared to the 2007 SCALE model results (Figures 21 and 22) to evaluate stock status.
Selection of the preferred model for black sea bass was based on a decision matrix using information from recent trends in NEFSC survey indices, comparison of MSY to long term yield and the ratio of 2007 F and total biomass to F and biomass at $F_{40\%}$. The reference point in the existing FMP for sea bass was predicated on the assumption that MSY occurred at some point midway through the decline in landings experienced in the 1950s and 1960s. However, since the decline leveled off in the late 1960s, catch has remained relatively stable around 3,100 mt (the period following implementation of quotas in 1998 was not included in this average). This implies that catches around 3,100 mt may be sustainable, although not necessarily maximum (landings greater than 10,000 mt in 1952 suggests an upper bound of potential landings). Recent trends in survey indices of the entire stock show a steady decline in abundance and biomass since 2003 and 2002, respectively. This declining trend despite restrictive quotas would suggest that

the stock is unlikely at or above any optimal biomass level. Therefore the suite of 26 model runs were judged using the proximity of predicted optimal yield relative to average yield since the 1960s which was assumed to be near MSY and the 2007 model estimates of fishing mortality and biomass relative to the associated biomass and F reference points. Among candidate models, only those with both 2007 F to $F_{40\%}$ ratios between 0.8 and 1.4, and predicted equilibrium yield between 3,900 and 4,200 mt were considered candidates as preferred models. Only three models fulfilled the selection criteria: constant M at 0.4 and two logistic models with starting F=0.6 (Table 6). Since there is currently no empirical evidence to suggest that natural mortality declines as a logistic function of size, the model using constant M=0.4 was chosen as the best model.

The preferred model option with a constant M=0.4 has an F at 40% of maximum spawning potential equal to 0.42 and $F_{0.1}$ of 0.37. F_{MAX} equals 0.975 and is poorly defined. The associated spawning stock biomass per recruit at $F_{40\%}$=0.45 and total biomass per recruit= 0.50 (Figure 23). Applying age 1 recruitment (averaged from 1968 to 2007) of 27,875,990 recruits to per recruit values, total biomass at F=0 is 32,816 mt and at $F_{40\%}$ is 13,977 mt. Spawning biomass (sexes combined) at $F_{40\%}$ equals 12,537 mt. The 2007 estimates of F from the SCALE model using the constant M for 0.4 is 0.48 with an estimated total biomass of 12,892 mt and a spawning stock biomass of 11,478 mt. Using $F_{40\%}$ as a proxy for F_{MSY}, the implication is that 2007 fishing mortality (0.48) exceeds F_{MSY} by 15% and 2007 spawning biomass (11,478 mt) is 8% below B_{MSY}. However, the biomass is above the threshold (1/2 B_{MSY}) and would not be considered overfished. The reference points for M = 0.4 are presented in Table 7.

As a check on the scale of the stock size estimates, yield associated with $F_{40\%}$ (a proxy for MSY) under average recruitment would be 3,903 mt. This compares with the estimated average catch since 1968 of 3,100 mt. In addition, the peak landings in the early 1950s of between 10,000 and 12,000 mt would be well above optimal yield and would expected to result in a declining abundance, as was observed.

Although predicted adult survey indices from model results using a constant M=0.4 followed the general trend of the observed values, residuals patterns show predicted indices greater than observed indices for 2004 to 2007 (Figure 24). This would suggest that the predicted abundance was greater than observed and consequently the model may overestimate predicted abundance. Additionally, the sensitivity of the yield per recruit at length and catch at length models has not been fully evaluated for sensitivity to input values.

Developing biological reference points for hermaphroditic species requires consideration of the unique life history characteristics. Simulation modeling studies have shown that protogyny has little effect on yield per recruit if growth rates between sexes are comparable (Shepherd and Idoine 1993). In contrast, the effect of transitioning can have a significant effect on the calculation of female spawning biomass. However, without information about spawning efficiency the optimal approach is to consider spawning biomass as combined male and female biomass (Brooks et al. 2008). In addition, if the efficiency of spawning is a function of the presence of a dominant male, then conservation of the large males may be critical (Alonzo,S.H. 2008, Heppell et al. 2006). However, the effect of removal of males on the sex ratio, and consequently transition rate from female to male, remains unknown for black sea bass.

Suggested improvements

In order to improve the stock assessment of black sea bass and corresponding biological reference points, additional fishery independent surveys for black sea bass may be necessary. An alternative survey gear for sea bass may be fish pots or hand lines. Since pots could cover a wider area, a stock wide fish trap survey should be developed to evaluate relative abundance. Additionally, experimental and field evaluation of spawning behavior is necessary to better understand the implication of exploitation on sea bass.

Age analysis of NEFSC survey samples is currently underway in cooperation with MA DMF and could potentially improve the assessment models. There is some evidence of regional differences in growth that should be further explored.

Tagging data suggests regional differences in migration pathways and possible sub-populations. Although the assessment model results suggest the overall stock is near F_{MSY} and B_{MSY}, local groups of sea bass could vary from this overall status. Consequently, increased catch in some areas may exacerbate already declining abundance. Consideration should be given to evaluating alternative management approaches that account for regional differences in recruitment patterns and abundance.

Acknowledgements

Michele Traver compiled historical commercial landing records for this report. Paul Nitschke modified the code for the SCALE model to accommodate natural mortality at length and the change was implemented into the graphical user interface by Mike Jones.

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Black sea bass; Tables

Table 1. Black sea bass growth model results and calculated mean lengths at age.

	Caruso	Pemberton	Mercer	NMFS winter	NMFS spring	
L_{inf}	71.0	61.8	65.9	46.2	47.7	
K	0.20	0.21	0.16	0.36	0.35	
t_0	-0.2	0	0	0.40	0.04	
age	Mean lengh (cm)					avg (w/o Caruso)
1	15.14	**11.89**	**9.79**	**9.01**	**13.51**	11.05
2	25.26	**21.49**	**18.13**	**20.23**	**23.56**	20.85
3	33.55	**29.25**	**25.23**	**28.08**	**30.66**	28.30
4	40.34	**35.51**	**31.27**	**33.55**	**35.67**	34.00
5	45.89	**40.57**	**36.42**	**37.38**	**39.21**	38.39
6	50.44	**44.66**	**40.80**	**40.05**	**41.71**	41.80
7	54.17	**47.96**	**44.53**	**41.91**	**43.47**	44.47
8	57.22	**50.63**	**47.71**	**43.21**	**44.72**	46.57
9	59.71	**52.79**	**50.41**	**44.12**	**45.60**	48.23
10	61.76	**54.53**	**52.72**	**44.76**	**46.22**	49.56
11	63.43	**55.93**	**54.68**	**45.20**	**46.66**	50.62
12	64.80	**57.07**	**56.35**	**45.51**	**46.97**	51.47

Table 2. Commercial and recreational landings and discards (total) of black sea bass. Italicized landing estimated. Recreational discard losses estimated as 25% of total discards and commercial as 50% of totals presented in the table.

YEAR	Comm landings (mt)	Rec landings (mt)	Rec dicards (mt)	Comm discards (mt)	Total catch (mt)
1939	2,910	*727*			3,637
1940	3,097	*774*			3,871
1941	1,427	*357*			1,784
1942	1,129	*282*			1,411
1943	1,565	*391*			1,956
1944	3,307	*827*			4,133
1945	2,483	*621*			3,103
1946	2,232	*558*			2,790
1947	3,593	*898*			4,492
1948	6,832	*1,708*			8,540
1949	4,555	*1,139*			5,694
1950	5,736	*1,434*			7,170
1951	8,361	*2,090*			10,451
1952	9,883	*2,471*			12,354
1953	6,521	*1,630*			8,151
1954	5,141	*1,285*			6,426
1955	5,130	*1,283*			6,413
1956	5,247	*1,312*			6,559
1957	4,319	*1,080*			5,399
1958	5,241	*1,310*			6,551
1959	3,654	*914*			4,568
1960	3,101	*1,551*			4,652
1961	2,459	*1,230*			3,689
1962	3,554	*1,777*			5,331
1963	3,705	*1,853*			5,558
1964	3,143	*1,572*			4,715
1965	3,481	*1,741*			5,222
1966	1,537	*769*			2,306
1967	1,154	*577*			1,731
1968	1,079	*851*			1,930
1969	1,097	*772*			1,869
1970	970	*1,058*			2,028
1971	566	*540*			1,106
1972	727	*846*			1,573
1973	1,115	*1,145*			2,260
1974	1,023	*1,325*			2,348
1975	1,680	*1,791*			3,471

Table 2 (cont'd). Commercial and recreational landings and discards (total) of black sea bass. Italicized landing estimated. Recreational discard losses estimated as 25% of total discards and commercial as 50% of totals presented in the table.

YEAR	Comm landings (mt)	Rec landings (mt)	Rec dicards (mt)	Comm discards (mt)	Total catch (mt)
1976	1,557	*1,895*			3,452
1977	1,985	*2,267*			4,252
1978	1,662	*1,697*			3,359
1979	1,241	*560*			1,801
1980	977	*1,002*			1,979
1981	1,129	546	65		1,740
1982	1,177	4,485	74		5,735
1983	1,513	1,839	137		3,489
1984	1,965	558	65		2,589
1985	1,551	945	90		2,587
1986	1,901	5,618	229		7,748
1987	1,890	870	79		2,839
1988	1,879	1,295	252		3,426
1989	1,324	1,488	94	217	3,122
1990	1,588	1,248	209	128	3,173
1991	1,272	1,875	247	28	3,421
1992	1,364	1,179	170	246	2,960
1993	1,433	2,189	136	505	4,263
1994	925	1,327	176	46	2,475
1995	935	2,809	373	77	4,194
1996	1,524	1,804	280	770	4,378
1997	1,186	1,926	296	56	3,464
1998	1,163	509	213	238	2,122
1999	1,315	726	393	84	2,517
2000	1,208	1,804	822	96	3,930
2001	1,296	1,545	739	246	3,826
2002	1,571	1,961	818	96	4,447
2003	1,361	1,481	507	139	3,489
2004	1,398	760	314	864	3,335
2005	1,290	846	475	165	2,776
2006	1,271	886	492	57	2,706
2007	1,016	1,026	601	169	2,811

Table 3. Annualized fishing and natural mortality rates determined from tagging model.

	F	M
2002	*	*
2003	0.32	1.08
2004	0.39	1.08
2005	0.41	1.08
2006	0.38	1.08
2007	0.37	1.08

Table 4. Length measurements and landings (mt) from commercial fisheries 1984-2007.

Year	# lengths	Landings (mt)
1984	3841	1965
1985	2509	1551
1986	2922	1901
1987	1545	1890
1988	1376	1879
1989	883	1324
1990	1142	1588
1991	735	1272
1992	605	1364
1993	300	1412
1994	3166	896
1995	3233	925
1996	5295	1472
1997	4414	1186
1998	4171	1163
1999	4650	1315
2000	2196	1208
2001	2196	1296
2002	2196	1571
2003	3684	1361
2004	3684	1398
2005	5265	1290
2006	6000	1271
2007	7768	1016
min	300	
avg	3074	
max	7768	

Table 5. Parameters of natural mortality models and associated objective function from SCALE model.

Base M	alpha	beta	Obj Function
0.40	Constant	Constant	253.14
0.50	Constant	Constant	247.75
0.60	Constant	Constant	243.51
0.40	7.5	-0.175	255.66
0.50	7.5	-0.175	250.40
0.60	7.5	-0.175	245.26
0.70	7.5	-0.175	241.27
0.80	7.5	-0.175	238.60
0.90	7.5	-0.175	237.02
0.60	7.0	-0.175	247.29
0.60	8.0	-0.175	243.92
0.60	7.5	-0.150	243.32
0.60	7.5	-0.200	249.22
0.60	7.0	-0.150	244.17
0.60	7.0	-0.200	252.07
0.60	8.0	-0.150	242.85
0.60	8.0	-0.200	246.71
0.90	7.0	-0.175	237.82
0.90	8.0	-0.175	236.80
0.90	7.5	-0.175	237.02
0.90	7.5	-0.150	236.97
0.90	7.5	-0.200	239.24
0.90	7.0	-0.150	242.36
0.90	7.0	-0.200	242.36
0.90	8.0	-0.150	237.06
0.90	8.0	-0.200	237.51

Table 6. M values, Biological reference points and fishing mortality from SCALE and length-based yield per recruit models.

Base M	alpha	beta	F0.1	Fmax	F40%	YPR 40%	avg recruit	yield (mt)	F2007	F ratio
0.40	Constant	Constant	0.37	0.98	0.42	0.14	27,875,990	3,903	0.48	1.15
0.50	Constant	Constant	0.48	1.60	0.59	0.10	39,765,975	4,133	0.41	0.69
0.60	Constant	Constant	0.60	-	0.85	0.08	57,574,343	4,645	0.38	0.45
0.40	7.5	-0.175	0.15	0.27	0.17	0.19	25,052,388	4,770	0.73	4.30
0.50	7.5	-0.175	0.17	0.36	0.19	0.13	33,945,355	4,301	0.56	2.97
0.60	7.5	-0.175	0.19	0.93	0.22	0.09	47,261,598	4,090	0.47	2.16
0.70	7.5	-0.175	0.23	-	0.25	0.06	66,796,863	4,069	0.41	1.61
0.80	7.5	-0.175	0.28		0.31	0.04	95,096,515	4,240	0.37	1.18
0.90	7.5	-0.175	0.35	-	0.41	0.03	139,831,700	4,786	0.32	0.80
0.60	7.0	-0.175	0.16	0.31	0.11	0.11	43,255,263	4,546	0.52	4.74
0.60	8.0	-0.175	0.25	1.70	0.28	0.08	50,832,843	3,914	0.44	1.58
0.60	7.5	-0.150	0.37	-	0.41	0.08	53,187,988	4,095	0.42	1.03
0.60	7.5	-0.200	0.14	0.22	0.16	0.13	40,430,965	5,286	0.60	3.82
0.60	7.0	-0.150	0.28	1.61	0.31	0.08	50,266,135	3,968	0.44	1.43
0.60	7.0	-0.200	0.13	0.20	0.15	0.17	36,715,080	6,095	0.72	4.90
0.60	8.0	-0.150	0.45	-	0.53	0.08	55,381,775	4,319	0.42	0.79
0.60	8.0	-0.200	0.15	0.28	0.17	0.10	44,361,545	4,627	0.51	2.96
0.90	7.0	-0.175	0.22	-	0.26	0.04	116,861,675	4,410	0.36	1.39
0.90	8.0	-0.175	0.56	-	0.73	0.04	163,941,275	5,987	0.30	0.41
0.90	7.5	-0.175	0.35	-	0.41	0.03	139,831,700	4,786	0.32	0.80
0.90	7.5	-0.150	0.77	-	1.33	0.04	181,211,800	7,448	0.29	0.22
0.90	7.5	-0.200	0.16	0.35	0.19	0.05	101,782,075	4,768	0.39	2.11
0.90	7.0	-0.150	0.60	-	0.84	0.04	158,543,975	6,145	0.31	0.37
0.90	7.0	-0.200	0.14	0.23	0.16	0.06	84,365,165	5,445	0.46	2.86
0.90	8.0	-0.150	0.88	-	1.80	0.04	200,197,775	8,492	0.27	0.15
0.90	8.0	-0.200	0.20	-	0.24	0.04	122,250,403	4,439	0.35	1.47

Table 7. Biological reference points and 2007 status for preferred option of constant M=0.4.

M=0.4 constant

	F	YPR	SSB/R	B/R
Fzero	0.000	0.000	1.124	1.177
F0.1	**0.368**	0.135	0.486	0.538
Fmax	0.975	0.152	0.268	0.319
F40%	**0.419**	0.140	0.450	0.501

	yield	SSB	Total Biomass
Fzero	-	31,341	32,816
F0.1	3,774	13,555	14,998
Fmax	4,248	7,472	8,882
F40%	3,903	12,537	13,977

2007 Total Biomass (mt)	12,892
2007 SSB (mt)	11,478
2007 SSB / SSB_{MSY}	92%
2007 F	0.48
2007 F / $F_{40\%}$	115%

Black sea bass; Figures

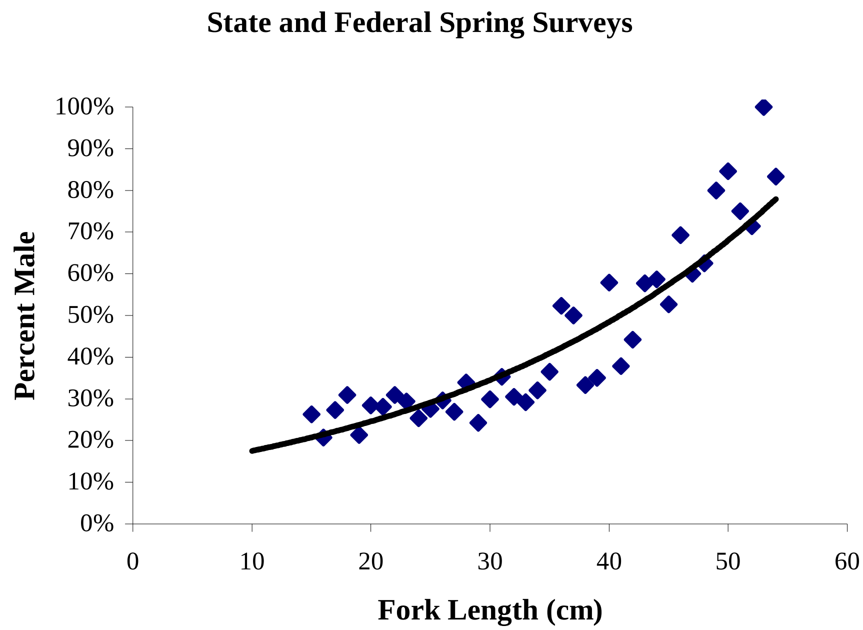

Figure 1. Sex ratio of black sea bass at length (cm) from combined NEFSC and MA DMF spring surveys.

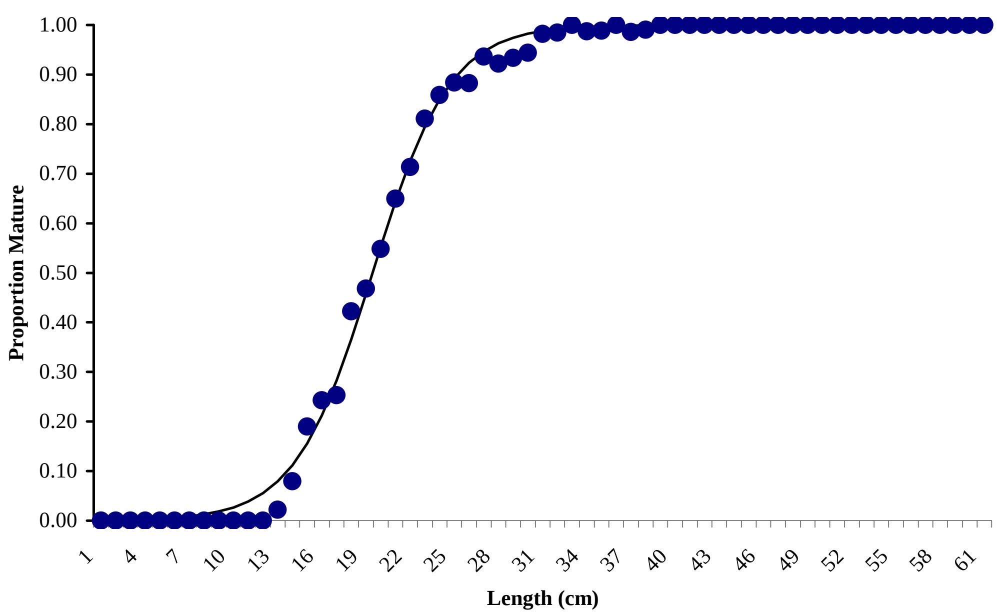

Figure 2. Proportion mature (male and female combined) by length based on samples from NEFSC spring surveys.

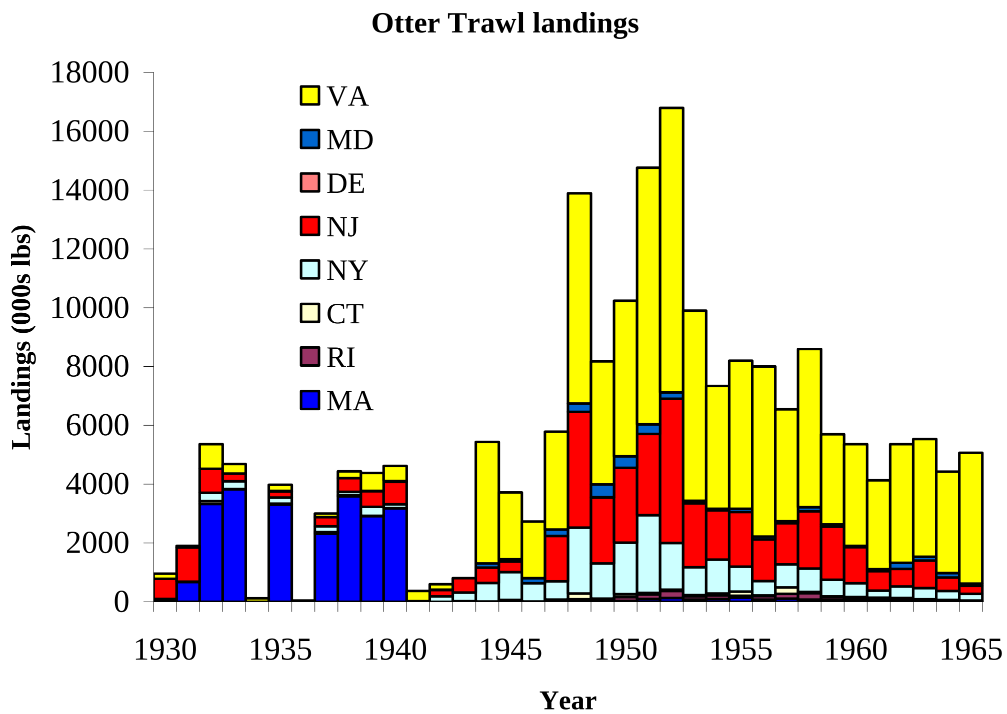

Figure 3. Commercial otter trawl landings (000s lbs) by state for 1930 to 1965. (Source: Fisheries of the U.S.)

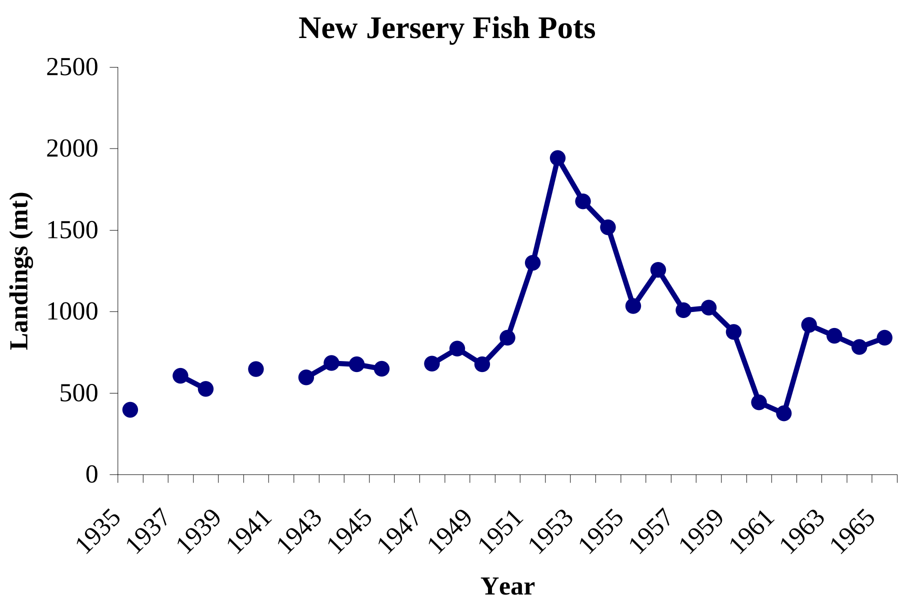

Figure 4. Landings (mt) of sea bass from NJ fish pots, 1935-1965.

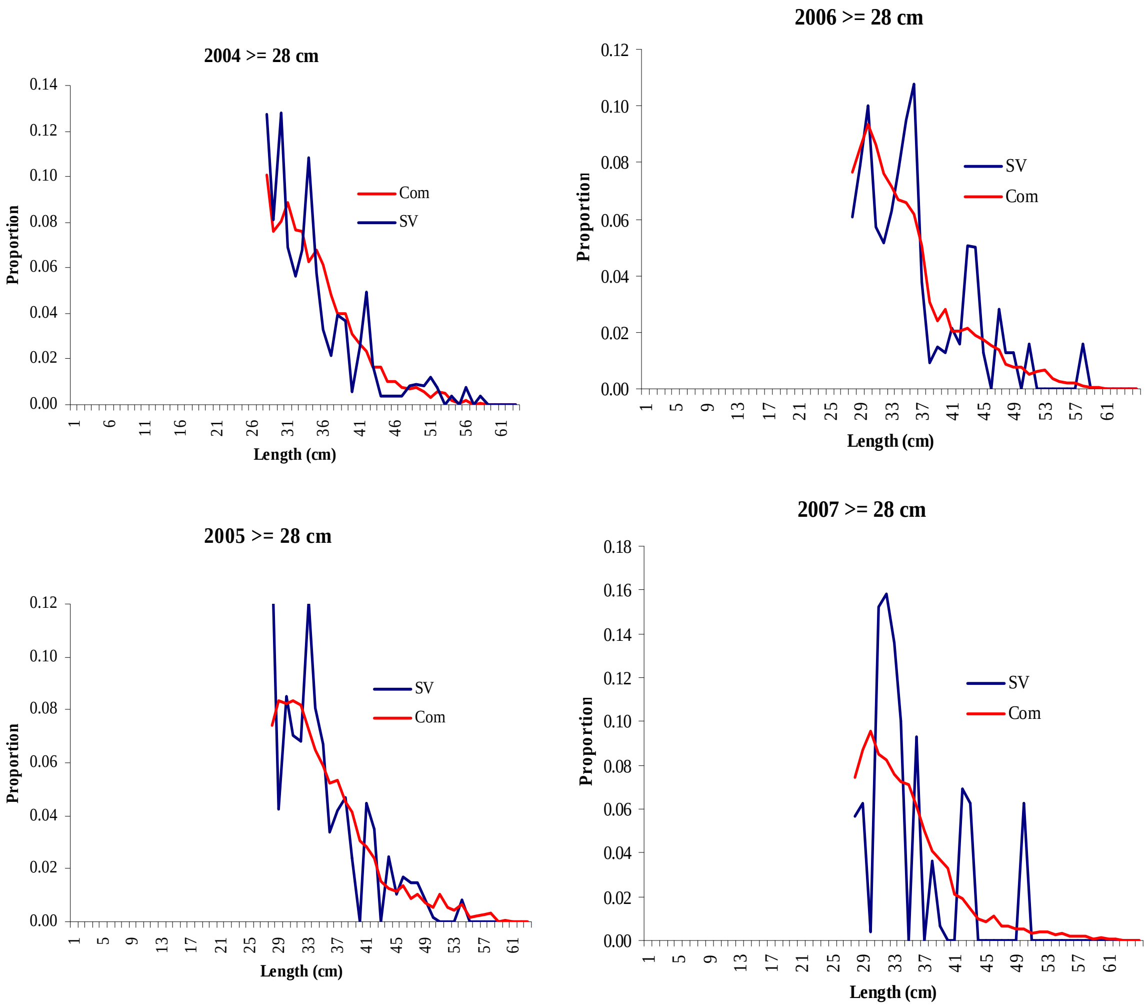

Figure 5. Comparison of proportion at length between commercial fisheries and NEFSC spring offshore survey. Size limited to lengths at full recruitment to the fisheries.

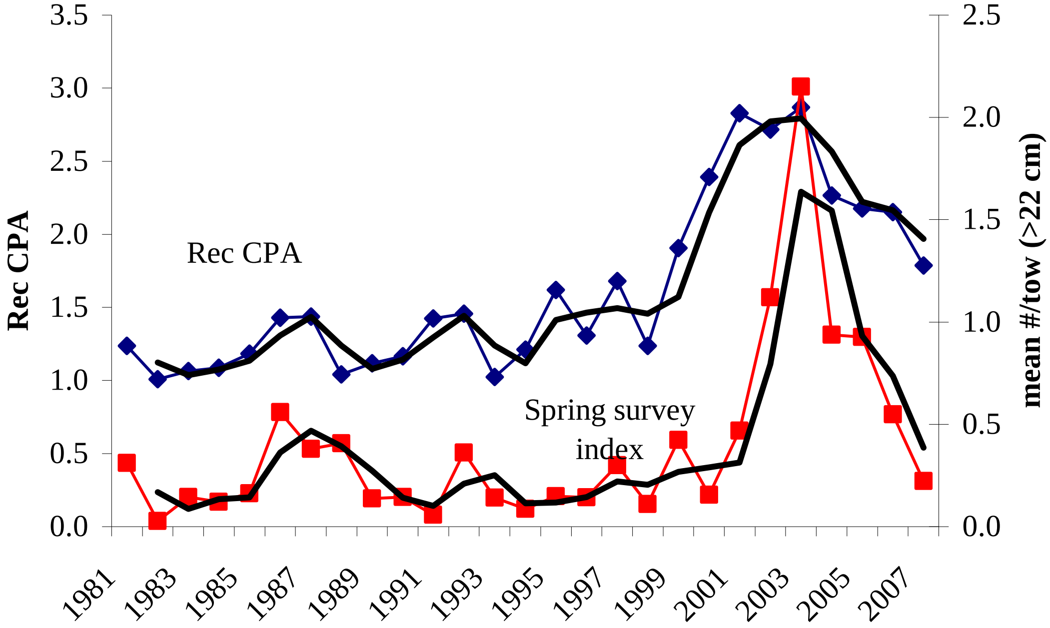

Figure 6. NEFSC Spring offshore survey stratified mean number per tow compared to MRFSS number per angler trip.

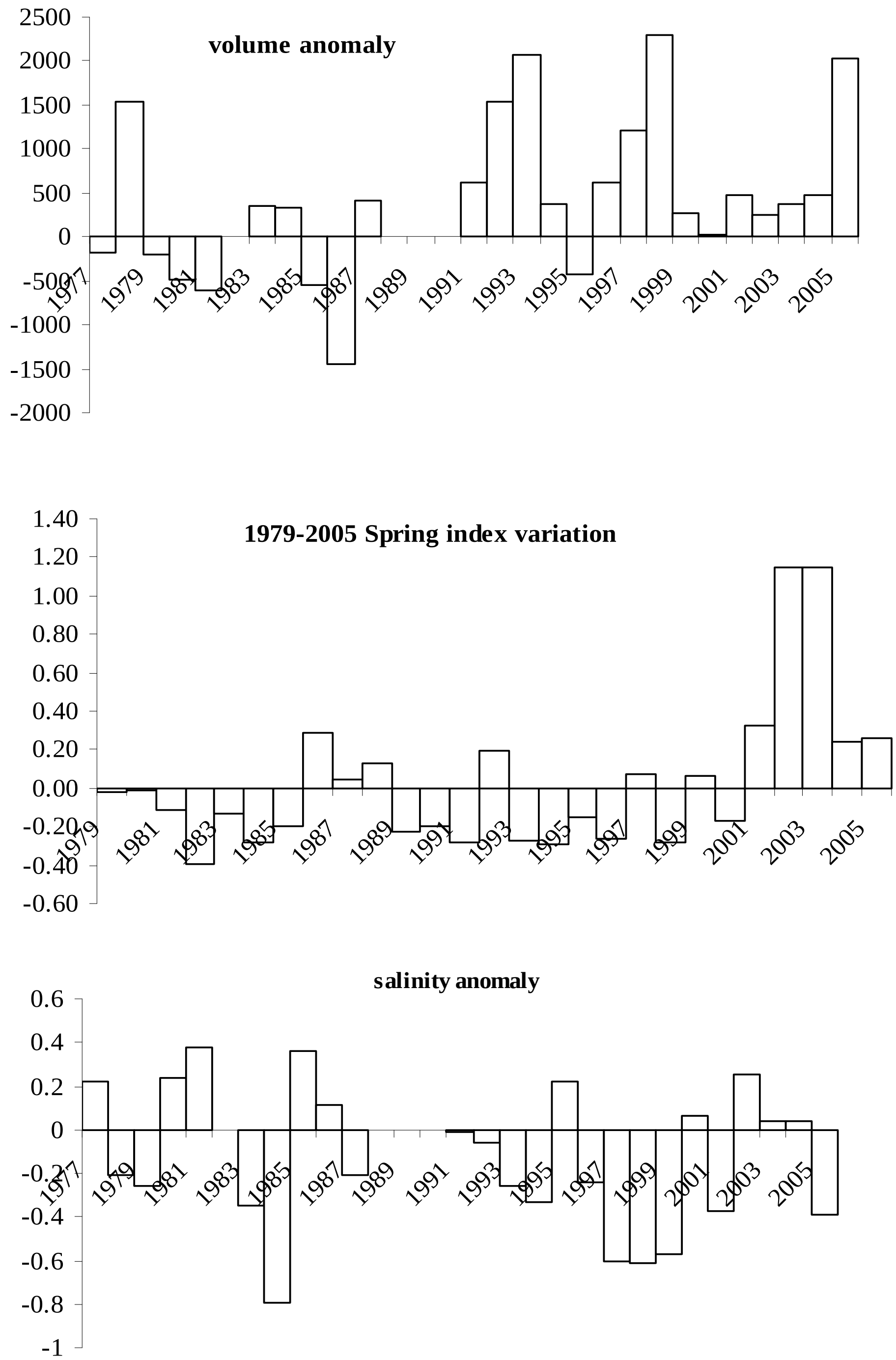

Figure 7. Spring oceanographic anomalies in the mid-Atlantic and variation from the time series mean of NEFSC spring survey indices, 1979-2005.

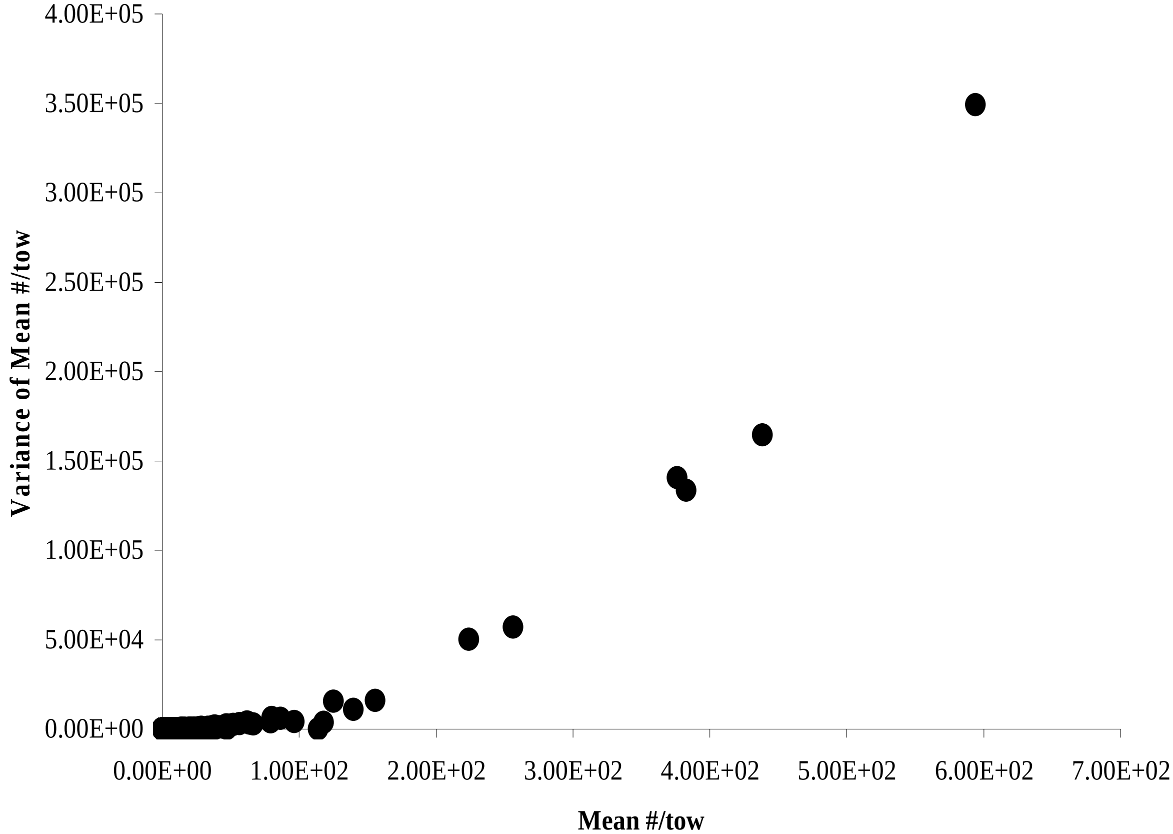

Figure 8. Relationship between black sea bass mean #/tow and associated variance for NEFSC Spring survey.

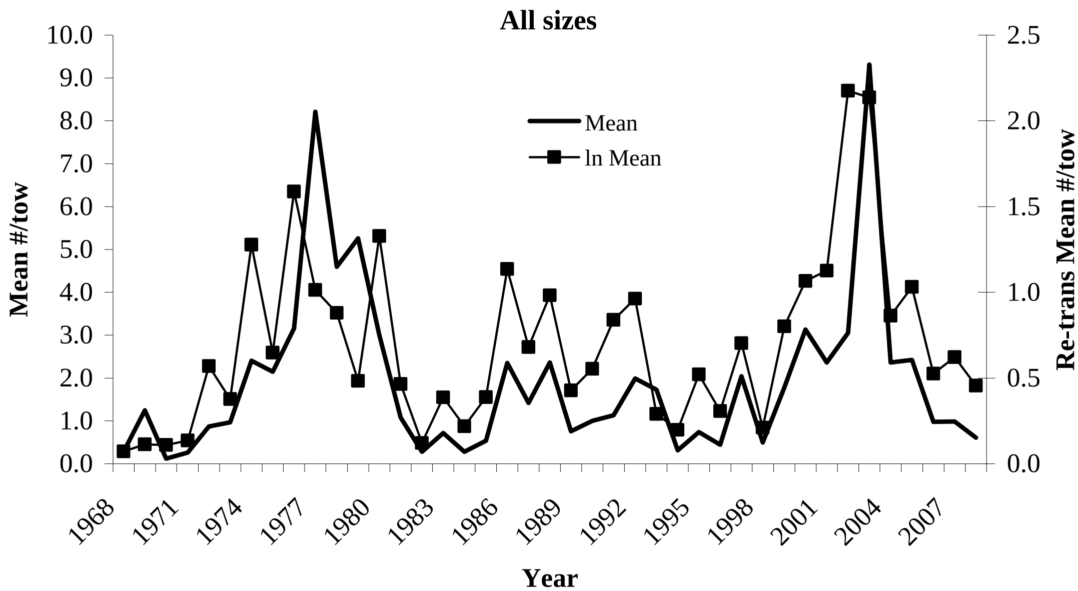

Figure 9a. NEFSC spring offshore stratified mean num/tow and re-transformed $\log_e$ stratified mean num/tow for black sea bass of all sizes.

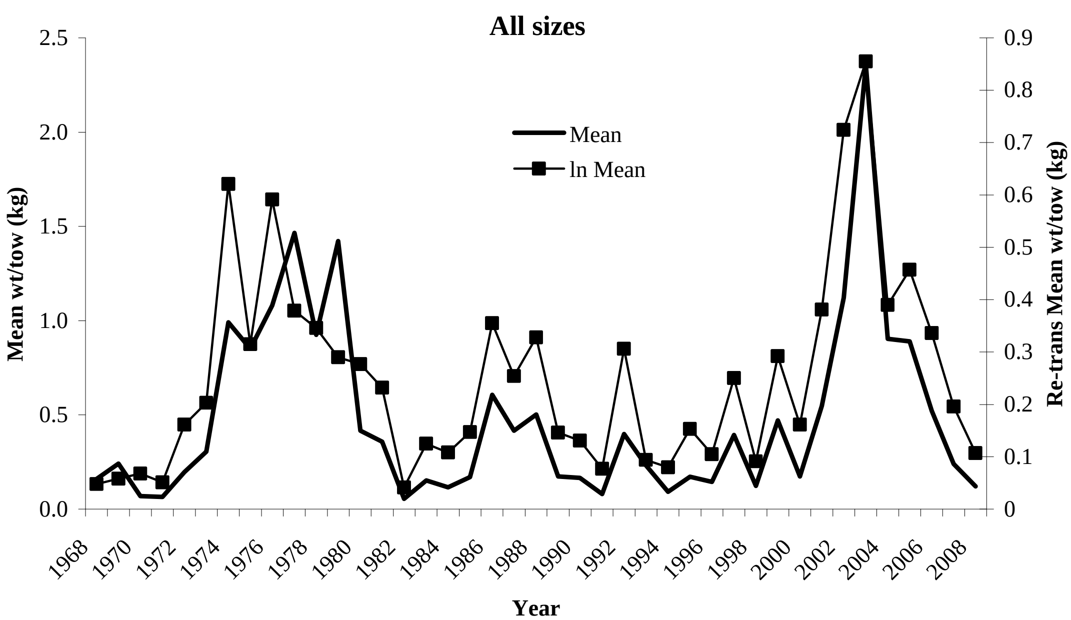

Figure 9b. NEFSC spring offshore stratified mean wt/tow (kg) and re-transformed $\log_e$ stratified mean wt/tow (kg) for biomass of black sea bass, all sizes.

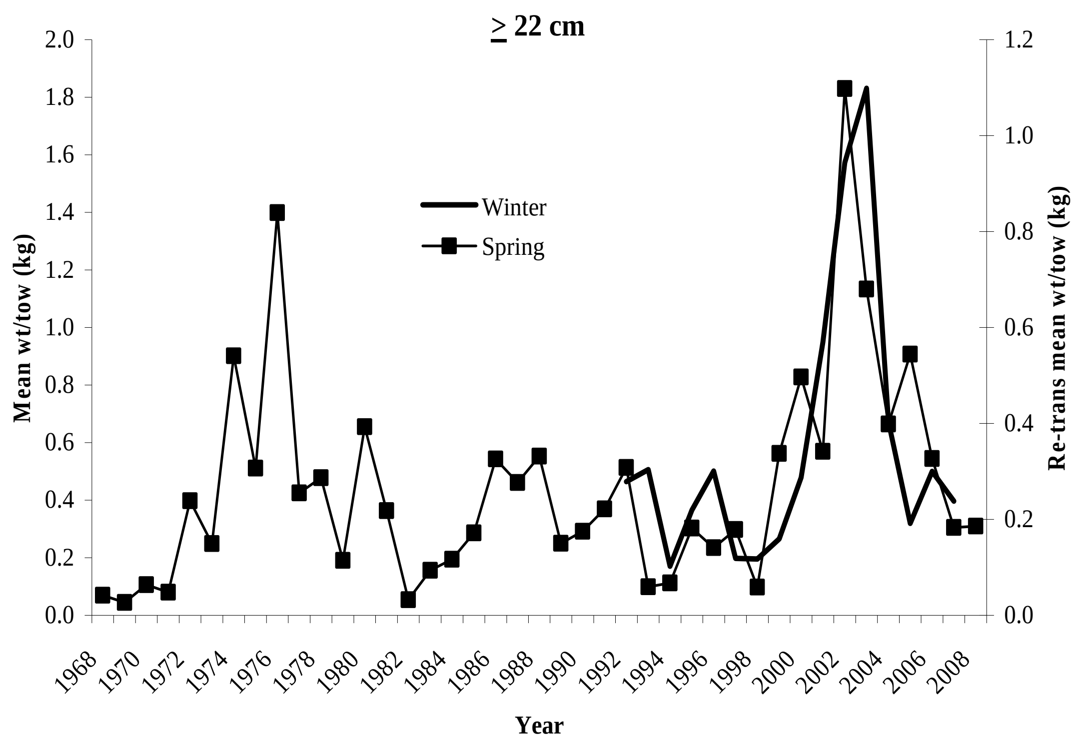

Figure 10. NEFSC spring and winter offshore re-transformed $\log_e$ stratified mean wt/tow (kg) indices for exploitable biomass of black sea bass (≥ 22 cm).

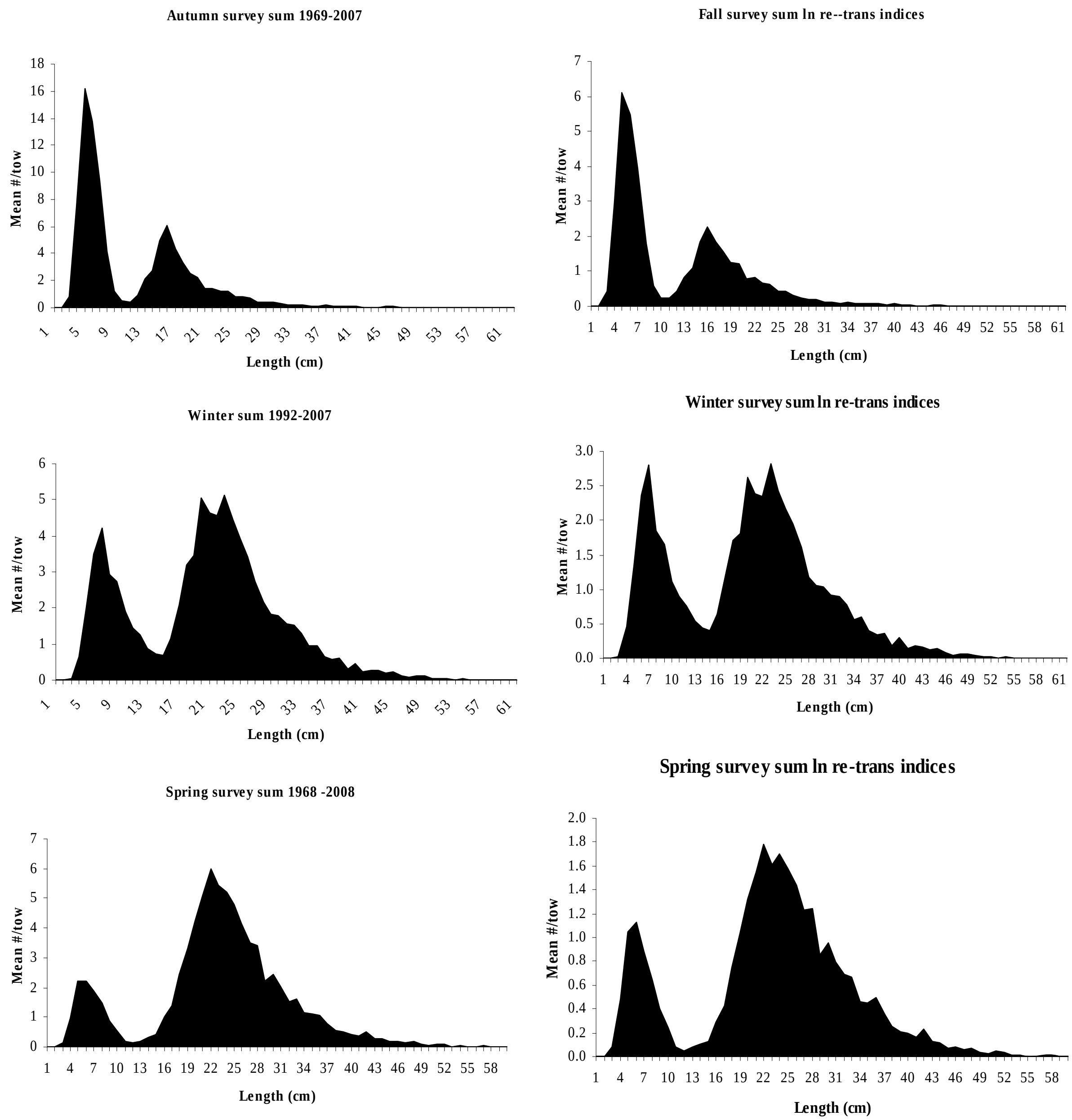

Figure 11. NEFSC spring, winter and autumn length frequencies for combined years showing recruits as first distinctive mode.

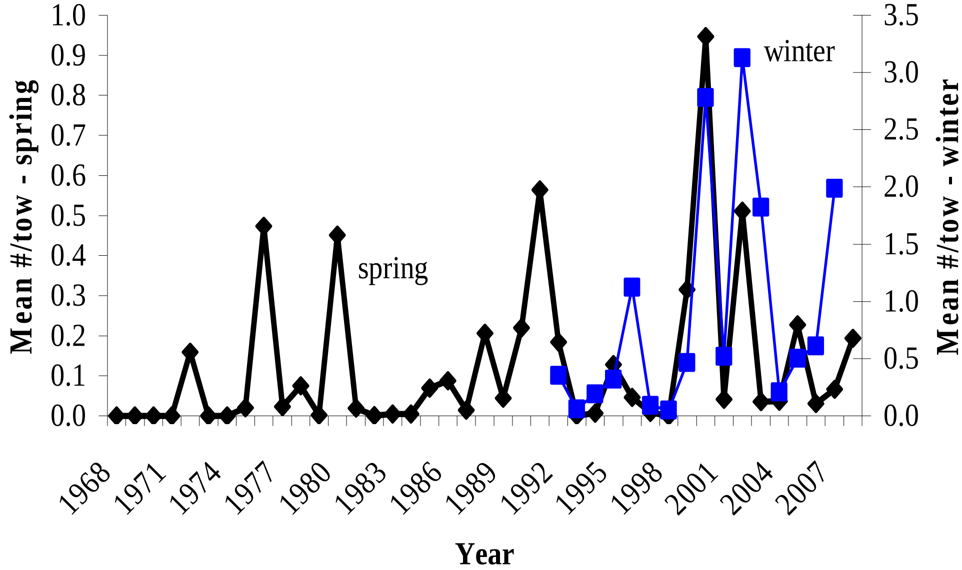

Figure 12. NEFSC spring and winter indices of juvenile abundance (stratified mean #/tow for sea bass ≤ 14 cm).

Figure 13. Relationship between maximum age and natural mortality as determined from Hoenig equation.

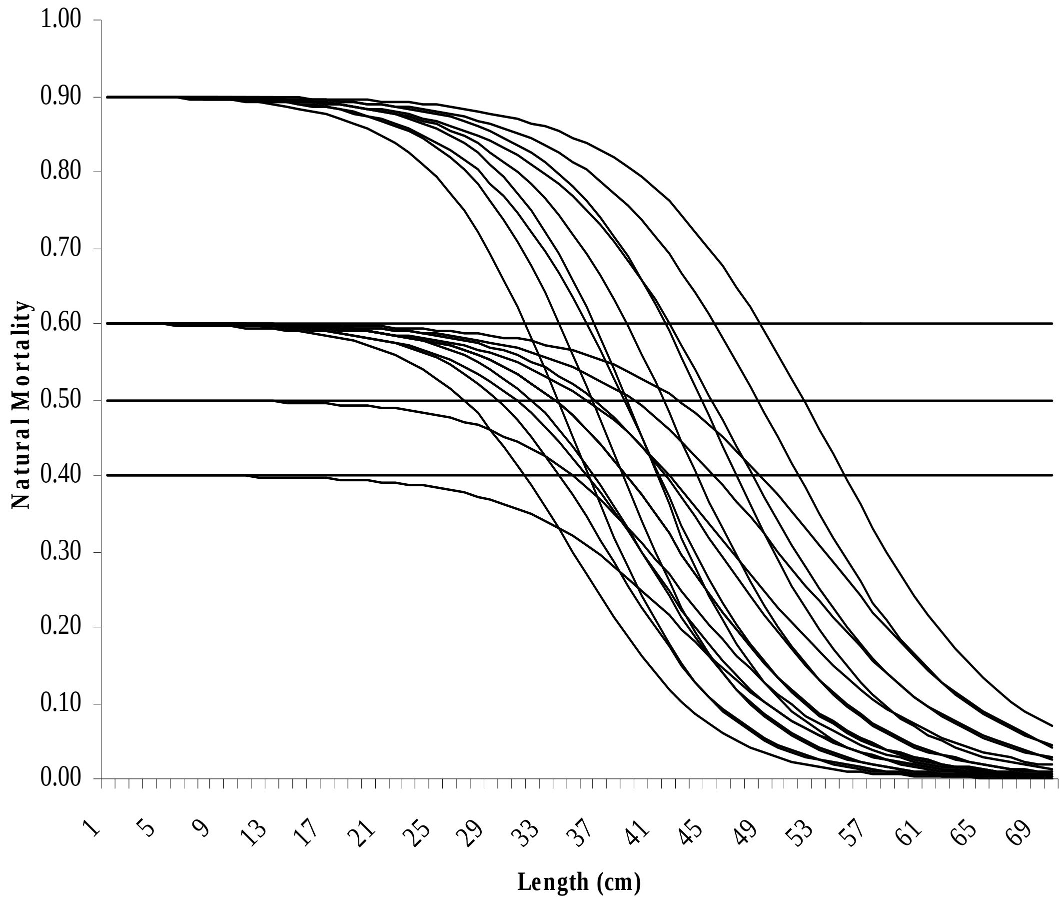

Figure 14. Patterns of natural mortality used in reference point calculations. Logistic models with initial M values of 0.4, 0.5, 0.6 and 0.9 as well as constant M of 0.4, 0.5 and 0.6.

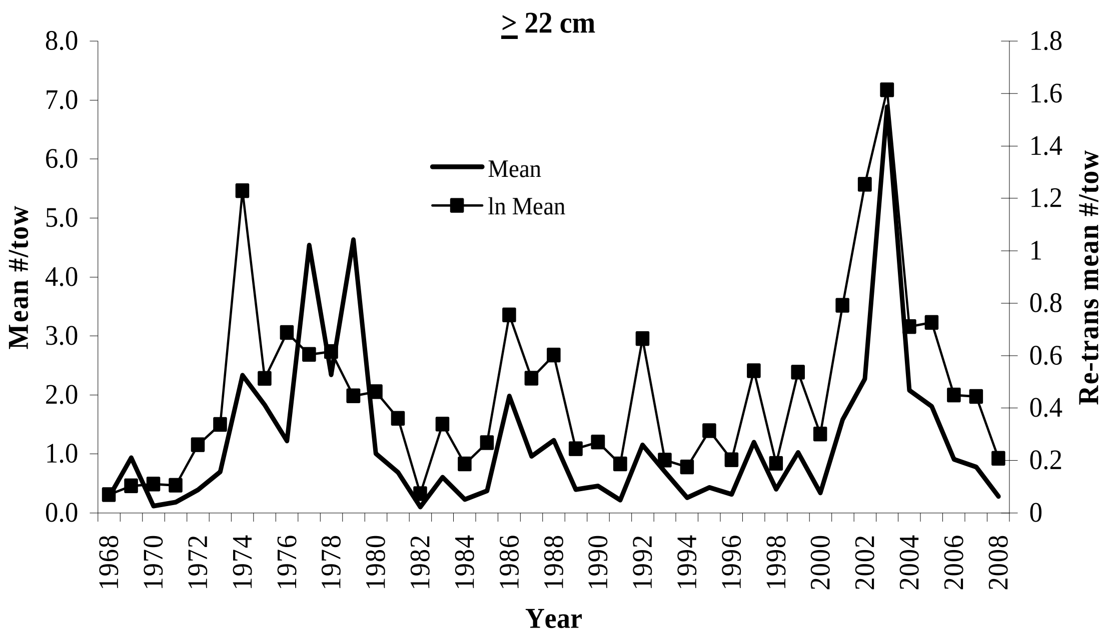

Figure 15. NEFSC spring offshore and winter survey indices (mean #/tow) for black sea bass ≥ 22 cm. Indices of relative abundance used as input to SCALE model.

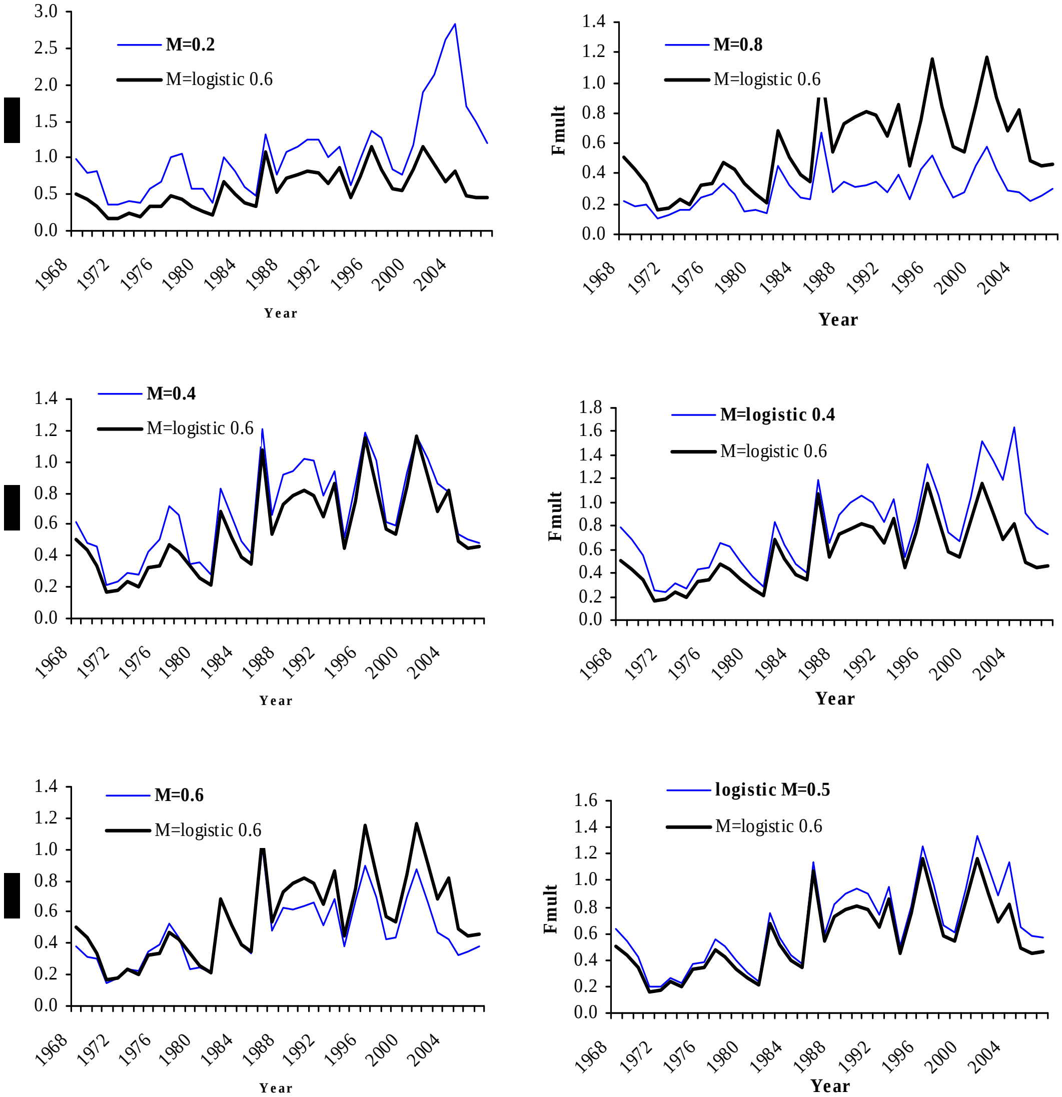

Figure 16. Time series of fishing mortality from the SCALE model under a variety of natural mortality estimates.

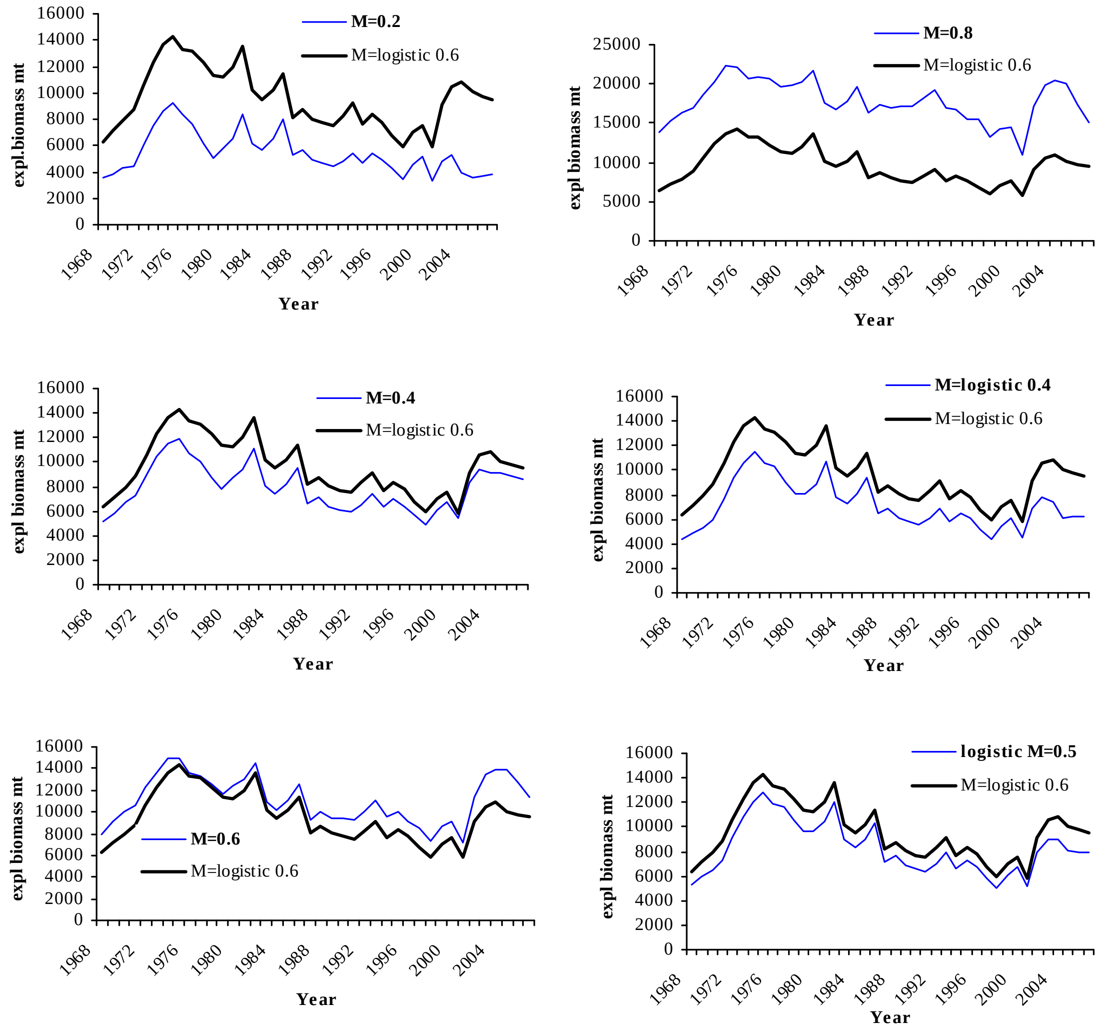

Figure 17. Time series of exploitable biomass (mt) estimates from SCALE under a variety of natural mortalities.

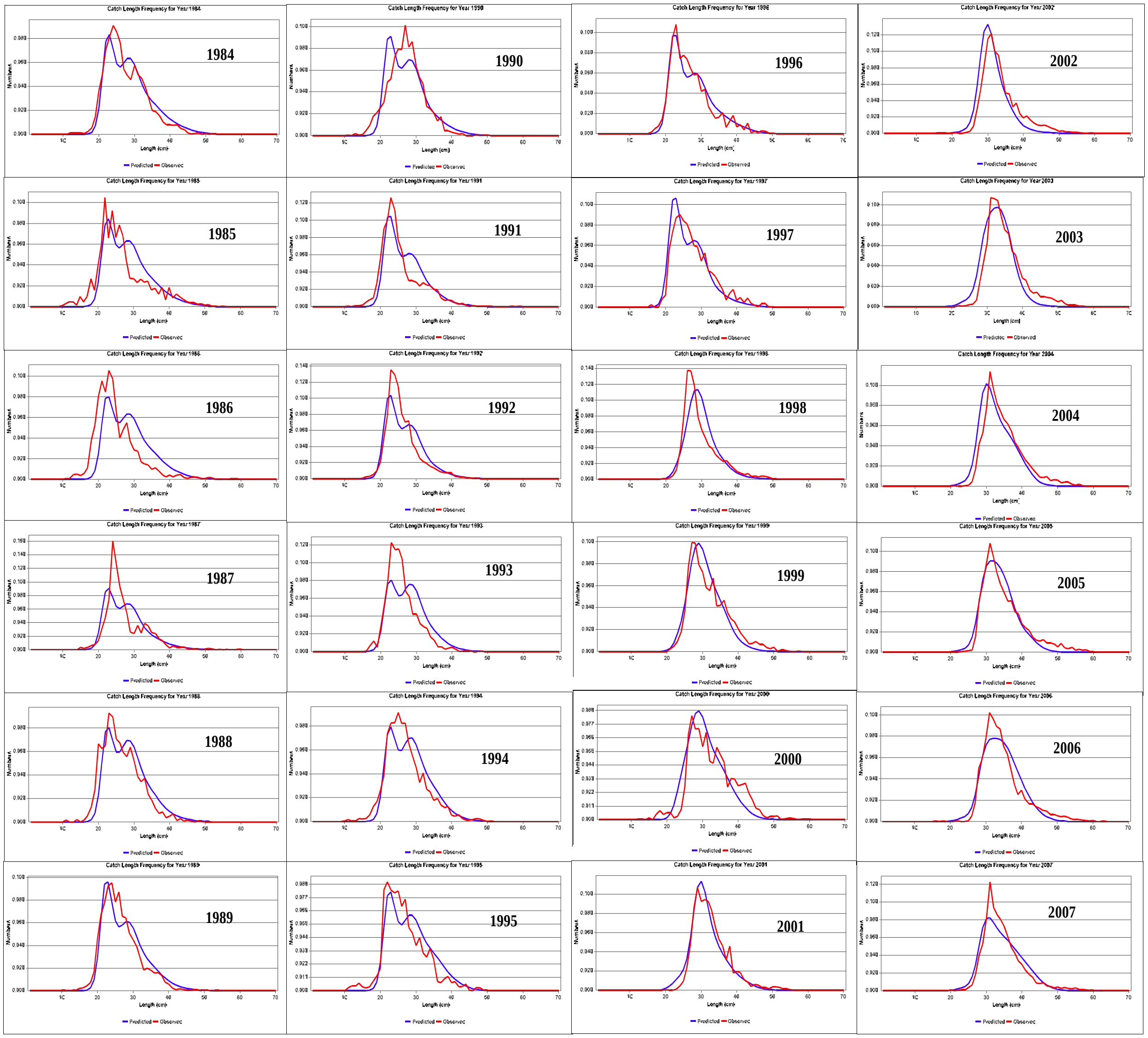

Figure 18. Observed fishery length frequencies 1984-2007 and frequencies predicted by SCALE model using constant M=0.4. Blue equal predicted, red observed.

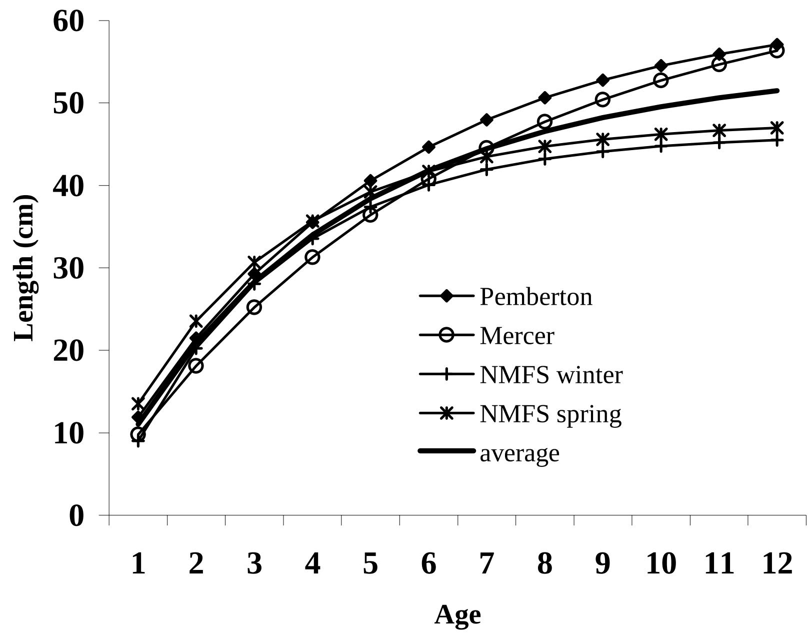

Figure 19. Black sea bass von Bertalanffy growth curves through age 12.

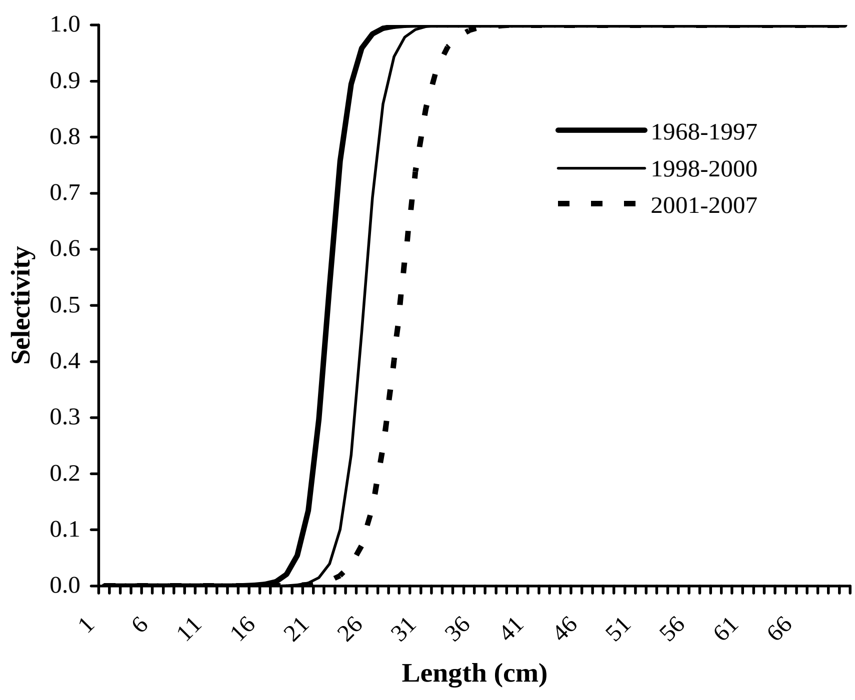

Figure 20. Selectivity patterns for black sea bass from SCALE model, constant M=0.4.

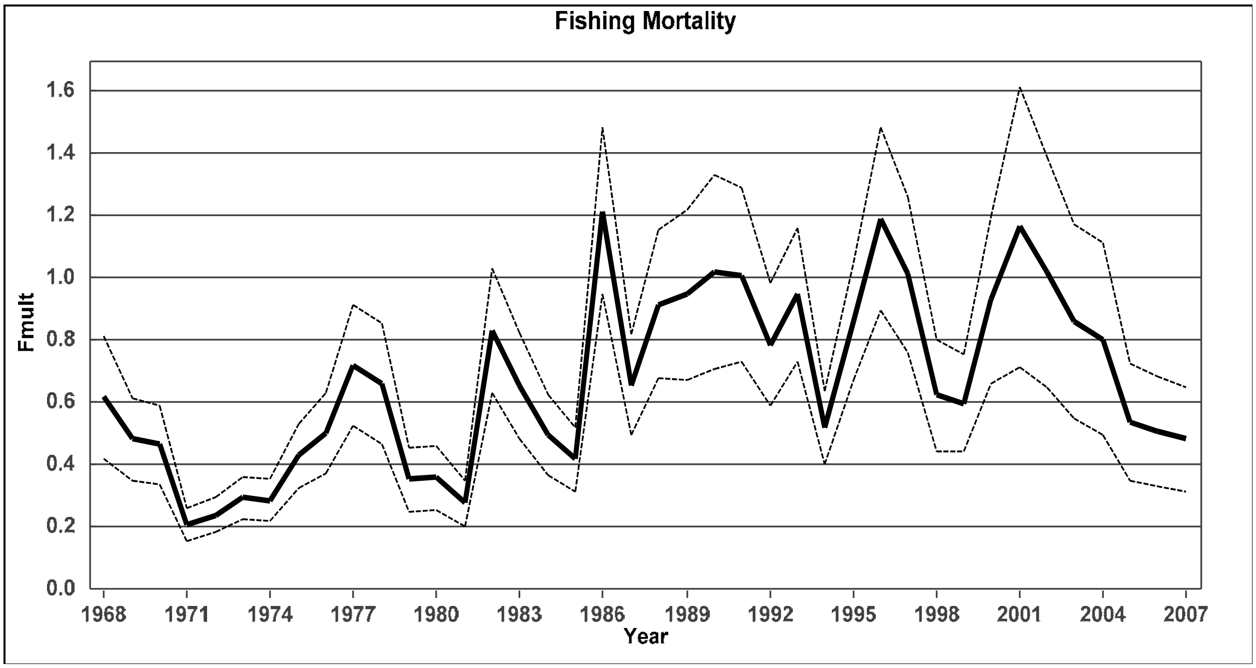

Figure 21. Estimated fishing mortality for black sea bass, 1968-2007 from SCALE model using constant M=0.4.

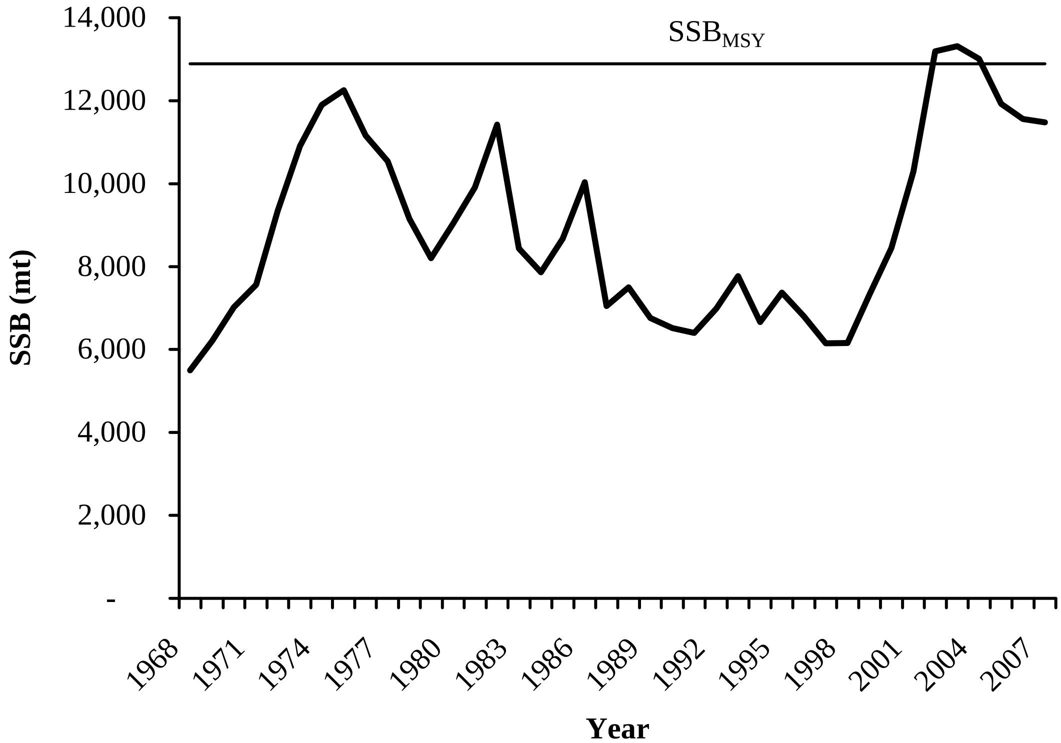

Figure 22. Black sea bass spawning stock biomass from SCALE model using constant M=0.4 and associated SSB$_{MSY}$.

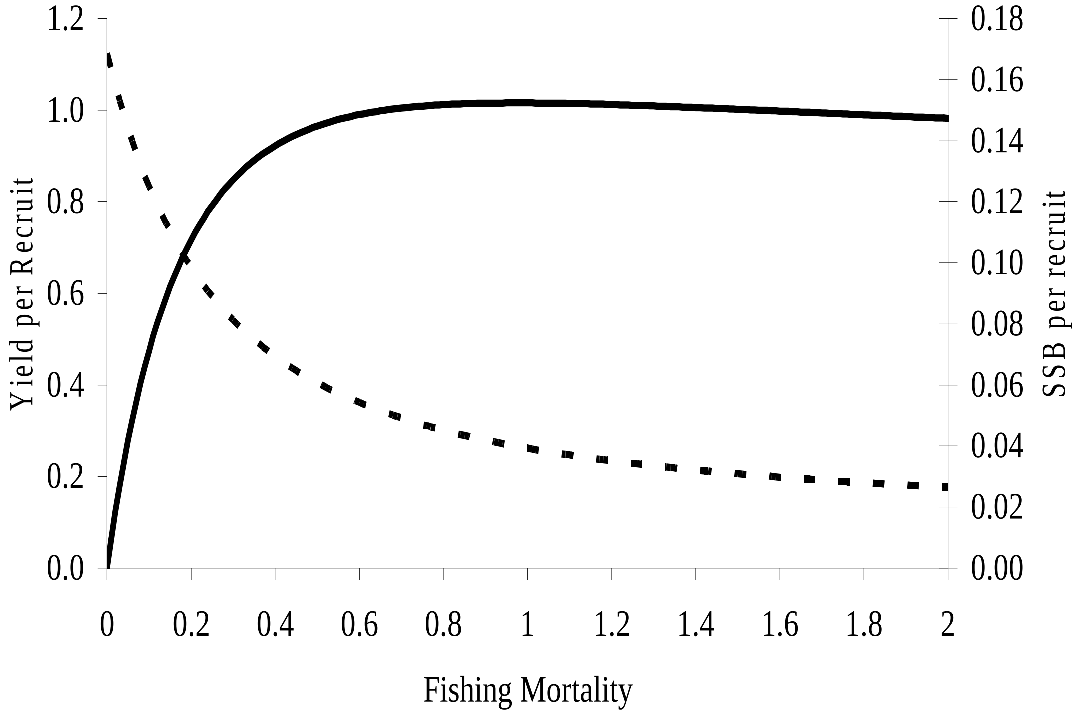

Figure 23. Yield and spawning biomass per recruit for black sea bass at constant M=0.4.

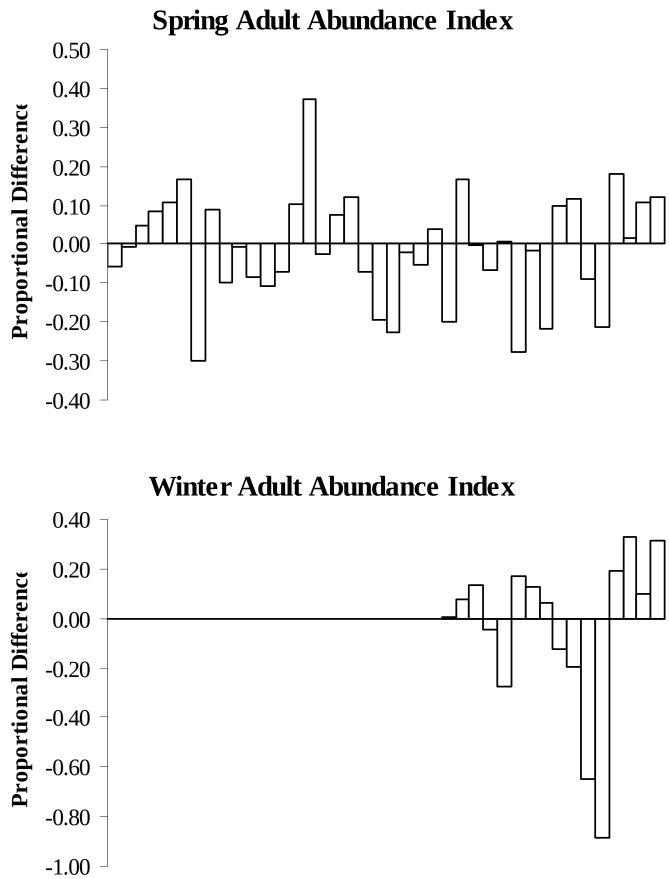

Figure 24. Residual patterns from observed and predicted NEFSC black sea bass survey indices.

Black sea bass
Unpublished manuscript
Appendix 1

Estimates of Fishing and Natural Mortality of Black Sea Bass, *Centropristis striata*, in the Mid-Atlantic based on a Release-Recapture Experiment

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Black sea bass; Appendix 1

Abstract

Black sea bass in the Mid_Atlantic Bight, are exploited by recreational and commercial fisheries. To evaluate mortality rates, a tag release/recapture study was conducted with 13,794 tagged black sea bass (12,310 legal-size) released between Massachusetts and Cape Hatteras, NC from 2002 to 2004. Of these legal-size releases, 1,683 were recaptured during 2002 to 2007. An instantaneous rates configuration of a Brownie band recovery model was used to estimate both fishing and natural mortality. A seasonal model of fishing mortality, adjusted for non-mixing, and a constant natural mortality best explained the tag recoveries. Fishing mortality estimates were between 0.3 and 0.4 whereas the natural mortality estimate was greater than 1.0. The estimate of natural mortality includes the effects of all unaccounted tag losses, however the results suggest that natural mortality is likely greater than 0.2 which has been assumed based on a maximum age of 15. Higher overall rates of natural mortality could result from increased vulnerability at sexual transition in this hermaphroditic species.

Introduction

Stock assessments of marine fish populations have long been a key component in managing fishery resources. Information regarding past rates of exploitation, along with potential productivity, allow managers to determine how much future exploitation can be allowed. Traditionally, catch based population models have been the tool of choice in stock assessments but in recent years tag based models have been increasingly used either as independent estimates of exploitation (Latour et al. 2001; Lambert et al. 2006; Jiang et al. 2007) or in conjunction with catch data (Polacheck et al. 2006). If implemented within the framework of a properly designed experiment, tagging programs are capable of providing estimates of exploitation and population size as accurately as catch at age models (Pine et al. 2003).

In the Northwest Atlantic, black sea bass (*Centropristis striata*), support both commercial and recreational fisheries. Although black sea bass are distributed from the Gulf of Maine to the Gulf of Mexico, fish north of Cape Hatteras, NC are considered part of a single management unit. Commercial landings for this stock have remained relatively steady around 1400 mt since 1970, although landings in 1952 peaked at 9,900 mt (Shepherd 2007). Recreational landings, available since 1982, average about 1,600 mt annually. The species affinity for bottom structure during its seasonal period of inshore residency increases the availability to hook and line or trap fisheries while decreasing the susceptibility to bottom trawl gear commonly used for scientific surveys. In autumn when water temperatures decline, black sea bass migrate offshore to areas along the edge of the continental shelf. During this offshore period, sea bass are vulnerable to otter trawl gear as part of a multispecies fishery (Shepherd and Terceiro 1994).

Black sea bass are protogynous hermaphrodites and can be categorized as temperate reef fishes (Steimle et al. 1999). Transition from female to male generally occurs between the ages of two and five (Lavenda 1949; Mercer 1978). Males can follow one of two behavioral pathways, either becoming dominant males, characterized by a larger size and a bright blue nuccal hump during spawning season, or secondary males which have few distinguishing features. Spawning in the Middle Atlantic peaks during spring (May and June) when the fish reside in coastal waters. The social structure of the spawning aggregations is poorly known although some observations suggest that large dominant males gather a harem of females and aggressively defend territory during spawning season (Nelson et al. 2003). The cue which triggers the transition from females to secondary or dominant male is undocumented, although the bright coloration of males suggests that visual cues may be important in structuring the social hierarchy.

Development of an analytical stock assessment for black sea bass has been hampered by a lack of catch at age information, inadequate fishery independent abundance indices and the unique life history characteristics of this species (NEFSC 2007). A recommendation emanating from an assessment review was to develop a comprehensive coastwide tagging program as an alternative method of determining exploitation on the northern stock and as a way to examine migratory behavior (NEFSC 1998). A secondary goal of the tagging program was to create a cooperative approach to data collection involving both the commercial and recreational industries.

Methods

Tagging protocol

A basic assumption in mark-recapture programs is that the tagged animals will be dispersed equally among untagged animals (Brownie et al. 1985). This can be accomplished either with the tag and release of a single large group, allowing the animals to disperse, or by dispersing the sites of release throughout the tagging area (Ricker 1975). To ensure the greatest geographic dispersal of tagged sea bass throughout the range of the northern stock, we tagged and released fish among coastal states (MA, RI, NY, NJ, DE, MD and VA) relative to state landing quota allocations of the Mid-Atlantic Fishery Management Council (MAFMC). Within each state, tagging sites were distributed at regular spatial intervals.

Sample sizes for releases were determined following the methods of Polacheck and Hearn (2003). A target sample size was 2,500 tags per season based on estimation under a range of exploitation rates (15% to 45%) and assuming a reporting rate of 75%, which demonstrated that any further increase in sample size resulted in minimal reduction in the variance of the exploitation rate. Tagging was conducted annually from 2002 to 2004 within a 30 day period from mid-September to mid-October, as well as a 21day period in May 2003. Several autumn release events occurred within days of this time window, having been delayed by weather. High reward tags ($100) were interspersed among regular tag releases at an approximate rate of 1 per 25 regular tags.

Over the three year period, black sea bass were tagged and released aboard chartered commercial and recreational fishing vessels. Recreational gear was standard hook and line equipment while commercial vessels used fish traps or hook and line gear. Fishing was done in depths ranging from 6 to 46 m and, if necessary, captured fish were placed into a holding tank to await tagging or evaluate condition. The size of fish targeted for tagging were greater than the commercial legal length (28 cm); however, fish as small as 20 cm were tagged. Tag number, date, exact location, total length (to the half-centimeter) and relative condition were recorded for each fish tagged.

The tag type used was a Floy internal anchor tag (FM-84), which has exhibited long term retention in other species (Dunning et al. 1987; Waldman et al. 1991). The tags had a unique identification number, telephone contact number and “Reward” printed on each side and in opposite directions such that the tag number was present at both the base and end of the tag. Tags were either orange, whose reporting was rewarded with a cap, or red which resulted in the $100 reward. In later years of the study, entry into a $250 lottery was offered in lieu of a cap. Tags were inserted into the abdomen below the midpoint of the pectoral fin by removing 2-3 scales and making a 0.5 cm incision into the musculature. Tagged fish were either released immediately or, if necessary, placed into a holding tank for several minutes of observation. Sea bass caught at deeper sites often had extruded swim bladders which were deflated when the abdominal incision was made and tag inserted. Fish judged to be weak or swimming abnormally were not released with a tag.

Recaptured tags were reported by telephone, postal mail, or by an online tag reporting webpage. High reward tags were returned prior to payment. We collected information on the date of capture, fish length, gear type and fishery, port, and longitude and latitude of recapture (or at least some reference point within several miles), condition of the fish at the tag insertion point, and fisherman's contact information.

Tag effects

Tag retention rate and tag induced mortality were determined by holding tagged fish in tanks in three separate studies. The first study was conducted at the Northeast Fisheries Science Center (NEFSC) Woods Hole Aquarium. Fish collected by hook and line were tagged and then placed in a 3,500 L aquarium tank for nine months. A second experiment was conducted in the NEFSC J.J. Howard Laboratory in Sandy Hook, NJ. Fish collected from fish pots were held in 1,500 L for ten to twelve months. A third experiment was conducted by the Rhode Island Department of Environmental Management. Fish collected with fish pots were tagged and held in 1,500 L tanks for twenty-seven days. In each experiment, tag losses and mortality associated with tagging were recorded daily.

Tag Analysis

Black sea bass and their fisheries in the Mid-Atlantic occur during two seasons: May through early October, and late October through April. To account for these seasonal variations and the time of tag releases, the recapture information and subsequent analyses were divided into two periods. One period was May 1st to September 30th and the second period ran from October 1st to April 30th. Tag recapture information was compiled by release cohort and summarized in a recovery matrix as:

$$R = \begin{bmatrix} r_{12} & r_{22} & \cdots & r_{1J} \\ \text{—} & r_{22} & \cdots & r_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ \text{—} & \text{—} & \text{—} & r_{IJ} \end{bmatrix}$$

where r_{IJ} is the number of tags recovered in period J that were released in period I.

An assumption of tag modeling is that the tagged fish are representative of the untagged population. The time series of tag recaptures from a release group can be treated as a catch cohort, and total mortality (F + M or Z) approximated as a catch curve by calculating the slope of the $\log_e$ of recaptures over time (Ricker 1975). The catch curve method was used to evaluate tag recapture consistency across seasons, after adjusting for reporting rate. The negative slopes of the regressions, estimated within Excel, were averaged across all release years for comparison to the full tag model.

Survival estimates from the mark-recapture data were modeled using a variation of the Brownie model parameterized as instantaneous rates (Hoenig et al. 1998a; Hoenig et al. 1998b). The instantaneous rates (IR) model allows for direct estimation of both fishing (F) and natural (M) mortality. Additionally, F in the first recapture interval can be modeled separately to account for incomplete mixing or partial selectivity to the fishery. The model of expected recoveries can be written as:

$$\mathrm{E}(R) = \begin{bmatrix} N_1\phi\lambda_1\mu_1(F_1^*,M) & N_1\phi\lambda_2\mu_2(F_2,M)e^{-(F_1^*+M)} & \cdots & N_1\phi\lambda_J\mu_J(F_J,M)e^{-(F_1^*+\sum_{k=2}^{J-1}F_k+(J-1)M)} \\ — & N_2\phi\lambda_2\mu_2(F_2^*,M) & \cdots & N_2\phi\lambda_J\mu_J(F_J,M)e^{-(F_2^*+\sum_{k=3}^{J-1}F_k+(J-2)M)} \\ \vdots & \vdots & \ddots & \vdots \\ — & — & — & N_I\phi\lambda_J\mu_J(F_J,M)e^{-(F_I^*+\sum_{k=I+1}^{J-1}F_k+(J-I)M)} \end{bmatrix}$$

where ϕ is the rate of tag loss at release, λ is the tag reporting rate, F_k is the instantaneous fishing mortality in period k, F* is F during the initial non-mixing period and M is instantaneous rate of natural mortality. In black sea bass fisheries where F and M occur simultaneously, then:

$$\mu_J(F_J,M) = \frac{F_J}{F_J+M}(1-\exp(-F_J-M))$$

and when $I=J$ then:

$$\mu_J^*(F_J^*,M) = \frac{F_J^*}{F_J^*+M}(1-\exp(-F_J^*-M))$$

Since the results are assumed to be a multinomial distribution, the optimal solution of model parameters was determined using maximum likelihood estimation. Comparisons between observed and predicted tag recovery frequencies were made with a chi-square goodness of fit test and evaluation of the best model was done using the quasi-likelihood Akaike's information criterion, $QAIC_c$, which accounts for over-dispersion in the data (Anderson et al.1994; Burnham and Anderson 2002). Profile likelihoods were developed for each parameter in the final model and used to calculate 95% confidence intervals (Gimenez et al. 2005). The model parameterization was developed using the solver function in Microsoft Excel.

Since tagging occurred in October or May, the resulting mortality estimates were not calendar year values. Annual fishing and natural mortalities were re-calculated using monthly values (seasonal mortality estimate / # months within the season) and these values re-configured to a calendar year rather than tagging year. Fishing mortality estimates in 2002 only included October to December and were not used in an annual mortality estimate. Results from the final three months of 2007 were assumed equal to the mean of the same period in 2006.

Reporting rate

Although it is possible to estimate reporting rate λ within the model (Jiang et al 2007), we used an empirical estimate based on high reward tag returns:

$$\lambda_{J} = \left[\frac{(\sum_{J=1} \text{regular tags returned} / \sum_{J=1} \text{regular tags released})}{(\sum_{J=1} \text{high reward tags returned} / \sum_{J=1} \text{high reward tags released})} \right]$$

The ratio was calculated only for the twelve months at large for each release cohort since the recapture ratio of regular tags to high reward tags in the second year is not independent of the reporting rate in the first year. A constant reporting rate was applied to the recaptures after spring 2005. The monetary award that was thought to ensure that return rates approach 100% was $100 (Murphy and Taylor 1991; Pollock et al. 2001; Taylor et al. 2006). The sensitivity of the model results to the assumption of high reward tag reporting rate was evaluated for rates from 25% to 100%.

Tag induced mortality estimates do not account for mortality associated with the capture and release process during tagging. Hooking mortality in black sea bass has been estimated at 5% (Bugley and Shepherd 1991). To account for potential mortality of tagged fish due to hook and line capture, the tag loss rate was inflated by five percent.

Growth

Growth rate of individuals was calculated as the change in length between release and recapture divided by the number of days at large. Since recapture lengths are provided by the public, these lengths were expected to have a greater measurement error than the release measurements taken by trained personnel. The overall average growth per day was estimated for the entire time series of returns, and for the time series following elimination of data from consecutive days at large. Average growth was calculated from the point where the average growth in the time series remained relatively stable.

Results

Between 2002 and 2004, a total of 13,794 black sea bass of all sizes were tagged and released with either regular or high reward tags. Among those released,12,310 fish were greater than or equal to 26 cm and were tagged with regular reward tags (Table 1, Figure 1). These were considered vulnerable to both recreational and commercial size fisheries within one season following release. From October 2002 to September 2007, 1,683 regular tagged sea bass were recaptured and reported (Figure 2), for an overall recapture rate of 13.7%. Tagged fish were recovered throughout the range from recreational fishermen (57.2%), commercial fishermen (39.2%), research trips (1.0%) and unknown sources (2.6%). The average size at release was 32.2 cm ($\pm$ one std. dev of 4.76) whereas the average size at recapture was 35.8 cm ($\pm$ one std. dev of 5.83). The size distributions of released fish were comparable to the size distributions of sea bass harvested by the recreational and commercial fisheries (Figure 3). Average time-at-large was 257 days and the total distance traveled between tagging and recapture locations averaged 27.0 km or 0.35 km day^{-1}.

Tag retention and tag induced mortality in black sea bass were evaluated in three separate experiments. Sixty-eight (68) fish, ranging in size from 26 to 41 cm, were held in aquaria up to twelve months. No mortalities were observed immediately following tag insertion and over the course of the three experiments, only seven tags were shed (Dr. Mary Fabrizio, NEFSC[2]; Brian Murphy, RIDEM, personal communication). Five of the seven tags were shed within the first several weeks. Tag loss in black sea bass tagged with internal anchor tags was estimated at 10%. In addition, to account for potential hook induced mortalities associated with the initial capture methods, total tag loss and mortality was set at 15%.

Growth of tagged fish was estimated as the difference in size between release and recapture, and the time at large. During the initial days at large, the growth of tagged fish would be expected to be negligible and therefore the difference between length at release and recapture during this period would be due to measurement error. Within the first ten days, the differences in recorded lengths between released and recaptured fish ranged from 0 to 7 cm, averaging 1.1 cm, with the largest discrepancy from legal size fish (≥ 29.5 cm). With increasing time at large, measurement error decreased relative to accumulated growth (Figure 4). Consequently, growth rate declined over the first 90 days but stabilized thereafter. After the initial 90 days, growth averaged 0.012 cm day^{-1} for fish ≥26 cm. Assuming constant growth, fish tagged at 26 cm would be expected to attain legal size of 28 cm within 167 days following release.

Estimation of survival in Brownie-type models requires knowledge of the reporting rate of the tags. Included in the tag releases were 662 high reward tagged fish distributed across release periods. Based on the ratio of regular tags to high reward tag recoveries (N=151), seasonal estimates of tag reporting rate ranged from 53% to 80% (Table 2). The rates for the fall-winter period (76%. 80% and 57%) were generally higher than spring-summer (53%, 59% and 62%). Reporting rates in the years without empirical data were held constant at 60%, the average of the last two periods of empirical data. An assumption in reporting rate estimation was 100% reporting of the high reward tags. In the reporting process not all fishermen were willing to provide complete information necessary for payment. Consequently, true reporting rate was unknown but probably slightly less than 100%. The influence of reduced reporting of high reward tags would be an over-estimation of actual reporting rates (Pollock et al. 2001).

An additional model assumption is constant selectivity once the fish reach the size of full recruitment to the fisheries. This assumption was tested using recovery rates by two cm size categories for all data combined (Figure 5). The selectivity for fish greater than 29 cm was tested for a departure from a slope of zero. Results show no significant difference from 0 (Pr = 0.2) indicating a constant selectivity with size.

A simple estimate of total mortality (fishing plus natural mortality) was calculated as the rate of reduction in tag recoveries over time (Figure 6). The rate of decline in recoveries was consistent among release cohorts and total mortality estimates ranged from 1.33 to 1.54. The overall average total mortality using the catch curve method was 1.41. This approach requires a priori information regarding natural mortality to derive fishing mortality. Alternative tagging models, such as the instantaneous rates model, allow partitioning of the sources of mortality and direct estimation of F.

The instantaneous rates non-mixing model can be configured in a variety of ways. Recaptures of fish ≥ 29.5 cm were evaluated using seven models which included: (1) a fully parameterized model with time specific F, F* and M; (2) constant F and M with time specific F*; (3) constant F, F* and M; (4) time specific estimates of F* by period, time specific F for periods 1 through 6 with constant F across periods 7 to 10 and constant M; (5) constant estimates per period across years for all parameters; (6) constant annual estimates (no seasonal effect); and (7) period F* and F estimates with constant M. The constant F for periods 7 to 10 was chosen to

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account for small sample sizes in the upper right corner of the matrix. Results of the chi-square test indicated that predicted values were not statistically different than those expected, with Pr>0.05 for models 1, 4 and 7. Based on the QAIC value, model 1 provided the best combination of parsimony and fit (Table 3). However, the parameter estimates were not robust to the starting values in the solution algorithm as the F estimates in the final 3 periods converged to different solutions depending on initial values. The reduced model, model 4, provided a more robust solution and was selected as the most appropriate model configuration. A comparison of observed and expected tag recaptures (Figure 7) indicated that recaptures can be adequately predicted using this model. The residuals show a pattern of consistent under-estimation of tag recaptures from the spring 2003 release (Figure 8), although the magnitude of the residuals is very small. The residuals from the three fall releases show no trend.

Comparison of mixing and non-mixing estimates of fishing mortality suggest that black sea bass were more vulnerable to exploitation during the initial release period. In each of the three release cohorts where both a non-mixed and mixed F could be estimated, the non-mixing F was higher (Table 4). The difference was particularly obvious in the spring 2004 release where the non-mixing F for the initial period (F^*_3) was 0.18 whereas subsequent F_3 estimates were 0.10. Fall releases (F_2 and F_4) differed between mixing and non-mixing estimates by 15 and 20%, respectively.

Average seasonal mortality estimates were derived from the model partial Fs. During the October to December/January to April period, fishing mortality averaged 0.16 per month, compared to the partial F from May through September period when fishing mortality averaged 0.22. The annualized fishing mortality standardized to calendar year, increased from 0.32 in 2003 to 0.41 in 2005 but then declined in 2007 to 0.37 (Table 5). Natural mortality, estimated as constant across years and seasons, was 1.08 (Table 4).
The tagging results indicate that fishing mortality has been relatively stable since 2002. Profile likelihoods and the associated 95% confidence intervals for the suite of seasonal F, F* and M estimates are presented in Figures 9 and 10. The distinctiveness of the minimum likelihood decreases for the parameters furthest from the initial release period resulting in a greater uncertainty in the estimates at the end of the recovery time series.

The tag recaptures in the model are influenced by both tag retention and reporting rates. The reporting rate adjustments assume that all high reward tags recaptured are recovered. However, in situations where fish are being quickly discarded, tagged fish may not be recovered and may die soon after discarding. To examine the sensitivity of the natural mortality estimate to under-reporting, we incrementally decreased high reward reporting rates. Overall reporting rate decreased linearly with decreased high reward reporting and the estimate of natural mortality decrease was curvilinear (Figure 11). When the high reward reporting was equal to 28.2%, the model estimate of natural mortality was 0.2.

Discussion

Recent developments in mark-recapture models have advanced their use for evaluating the exploitation of marine fishes. In particular, the parameterization of the Brownie bird banding models into instantaneous rates makes tagging model results similar to traditional catch at age stock assessment models. The lack of an analytical stock assessment was the impetus for developing a tag recapture program for black sea bass. Consequently, the results from the tagging models may help in determining status of black sea bass in the Mid-Atlantic. The most recent estimate of the fishing mortality that produces the maximum yield per recruit (i.e. F_{max})

was calculated to be F=0.33 (NEFSC 2007). The tagging results imply that fishing mortality exceeds this level, although the distribution of the 95% confidence interval shows that there is some probability that F is actually below F_{max}.

Seasonal patterns in fishing mortality reflect differences in the black sea bass fisheries. During the inshore period, sea bass are exposed to a coastwide recreational fishery and a directed pot fishery, whereas the offshore fishery is generally a non-directed trawl fishery targeting species such as summer flounder or *Loligo* squid (Shepherd and Terceiro 1994). The locations of optimal inshore black sea bass habitat, such as artificial reefs, are generally well known to fishermen and are routinely targeted. Among several tag release locations on artificial reefs, the recovery rate was as high as 25 to 35%. Movement of black sea bass is highly seasonal and did not occur until several weeks after tagging. Consequently, the exploitation of tagged fish was greater before they mixed during migration but the non-mixing model was able to adjust for this pre-migration period.

The parameterization of the Brownie model into instantaneous rates allowed potential estimation of natural mortality. Fishing mortality is determined from tag recoveries while the estimation of natural mortality is based on unaccounted tags (Hoenig et al. 1998b). Consequently, the parameter M is true natural mortality but is influenced by biases resulting from tag attrition over time, overestimated reporting rates, changes in selectivity with size, permanent emigration from the study area, increased predation on tagged fish, etc. and any other process which could result in unaccounted for tag losses. Any of these processes could result in an over-estimation of natural mortality in the model.

In fisheries stock assessments, natural mortality is often based on the lifespan of the species (Hewitt and Hoenig 2005) and assuming a life expectancy of 15 years for black sea bass (Musick and Mercer 1977), M has been set at 0.2 in recent stock assessments (NEFSC 2007). The tag based estimate of 1.08 is significantly higher and contradictory to M predicted from maximum age. A biased estimate of M in the tagging model could be the result of model misspecification or biased tag data. However, model misspecification does not appear to be a problem as reflected in the residuals and profile likelihoods. Among tag return biases necessary to overestimate M, it would be difficult to create a scenario resulting in an M equal to 0.2. Initial tag loss (type 1), modeled as 15%, differs from long term attrition of tags (type 2) (Beverton and Holt 1957). Tag attrition can be parameterized similar to M but to reduce M to 0.2 based on misspecification of retention, tag attrition would have to approach 0.88. There is no direct evidence to suggest a loss of this magnitude. Holding studies demonstrated that tags could be retained for at least one year. An immunological response to tags resulting in encapsulation and expulsion has been documented in some species (Vogelbein and Overstreet 1987) but while this may have been possible in sea bass, there would have to be comparable chronic tag loss rates among all release cohorts. Reduction in tag legibility could also create tag attrition problems in the returns (Henderson-Arzapalo et al. 1999). However, there were few reports among fishermen returning tags that legibility was an issue.

Over estimation of reporting rates resulting from violation of the 100% reporting assumption of high reward tags could bias natural mortality estimates. A reporting rate of 30% on high reward tags would have been needed to produce an M of 0.2. This would be highly unlikely and would also imply an unrealistically high exploitation rate. Another possible bias could result from release of tagged fish independent of local abundance followed by non-mixing, but an area based model produced comparable results for M and the use of a non-mixing model should account for initial distribution problems. A potential bias resulting from a dome-shaped selectivity pattern was also discounted after examining the recovery rate by size.

Since tag recovery biases alone do not adequately explain the high natural mortality estimated in the tag models, the possibility exists that M on black sea bass is actually greater than expected. Sea bass are structure oriented, protogynous hermaphrodites with a transition from female to male generally between ages 3 to 5, which was approximately the size of fish tagged and released. During spawning, large dominant males undergo physiological changes and begin aggressively defending territory. The importance of secondary male *C. striata* to spawning success is not documented but in congeneric species the importance of secondary males has ranged from irrelevant to critical contributors to the gene pool (Petersen 1991). If these male *C. striata* only provide a pool of potential dominant males, there would be little evolutionary advantage for the population to maintain a large number of secondary males to compete with smaller females and the large males. The consequence could be a higher natural mortality from such things as senescence, increased aggression by dominant males or higher predation rates if the secondary males are forced into marginal habitats. If life expectancy of tagged fish was only three or four years beyond the age at release, the natural mortality of these fish could be significantly greater than 0.2. This does not imply that a high M was constant across all ages, but rather increases in the post transitional ages.

The tagging program for black sea bass in the Middle Atlantic was designed to simultaneously distribute tagged fish throughout the stock, test for tag induced mortality and tag loss, estimate annual reporting rates, and document recapture information. The release-recapture matrix was examined with an analytical tagging model that incorporated temporal variations in exploitation, and by association, spatial changes in exploitation. The results imply that this stock of black sea bass may be experiencing exploitation above the level currently considered optimal. The tagging results also suggest that our understanding of natural mortality developed from gonochoristic species may not be appropriate for this protogynous hermaphrodite. Biases in parameter estimation due to tag loss, etc. may explain in part the high value for natural mortality, but the magnitude of the value suggests that natural mortality is greater than would be predicted from maximum observed age.

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Table 1. Regular tags release and recapture totals by season for black sea bass ≥ 26 cm marked and released in the Middle Atlantic, 2002-2004.

		Recaptures				
Release Period	Total # Released	Oct 2002-Apr 2003	May 2003-Sept 2003	Oct 2003-Apr 2004	May 2004-Sept 2004	Oct 2004-Apr 2005
Fall 2002	3,391	202	108	40	26	11
Spring 2003	2,314		176	58	55	13
Fall 2003	2,863			253	136	32
Spring 2004	0				-	-
Fall 2004	3,742					223
Total	12,310	202	284	351	217	279

Release Period	May 2005-Sept 2005	Oct 2005-April 2006	May 2006-Sept 2006	Oct 2006-April 2007	May 2007-Sept 2007	never seen again
Fall 2002	14	3	1	0	0	2,986
Spring 2003	15	5	5	0	0	1,987
Fall 2003	20	9	7	1	1	2,404
Spring 2004	-	-	-	-	-	-
Fall 2004	164	49	39	9	8	3,250
Total	213	66	52	10	9	10,627

Table 2. Regular and high reward tag release and recapture totals used in calculation of reporting rates. Totals limited to released sea bass ≥ 29.5 cm and recaptures in the first and second seasons.

	Recaptures					
Total # Released	Oct 2002 - April 2003	May 2003 - Sept 2003	Oct 2003 - April 2004	May 2004 - Sept 2004	Oct 2004 - April 2005	May 2005 - Sept 2005
High Reward tags						
251	21	13				
57		10	2			
208			26	19		
0				-		
146					20	12
Regular tags						
2688	172	76				
1942		173	53			
1941			200	104		
0				-		
2079					163	106
Reporting rate						
Fall 2002	76%	53%				
Spring 2003		51%	78%			
Fall 2003			82%	59%		
Spring 2004				-		
Fall 2004					57%	62%
Average	76%	52%	80%	59%	57%	62%

Table 3. Summary of black sea bass tagging models evaluated.

model	likelihood	QAIC	# parameters	df	T	Pr	c hat
1	-7078.85	8893.50	23	10	14.67	0.145	1.60
2	-7125.06	3526.84	6	27	145.12	<0.001	4.05
3	-7144.74	2908.94	3	30	147.59	<0.001	4.92
4	**-7086.00**	**10142.09**	**11**	**22**	**29.14**	**0.120**	**1.40**
5	-7094.88	8212.20	6	27	46.48	0.011	1.73
6	-7098.60	5211.32	13	20	95.95	<0.001	2.74
7	-7080.46	14122.22	14	19	17.22	0.575	1.00

Table 4. Seasonal estimates of fishing mortality for non-mixing (F*) and following mixing (F). Natural mortality (M) held constant for time series.

F_1*	0.13
F_2*	0.24
F_3*	0.18
F_5*	0.17
F_2	0.20
F_3	0.10
F_4	0.27
F_5	0.15
F_6	0.25
F_7	0.19
F_8	0.19
F_9	0.19
F_{10}	0.19
M_{1-10}	0.54

Table 5. Annualized estimates of instantaneous fishing and natural mortality for black sea bass.

	F	M
2002	*	1.1
2003	0.32	1.08
2004	0.39	1.08
2005	0.41	1.08
2006	0.38	1.08
2007	0.37	1.08

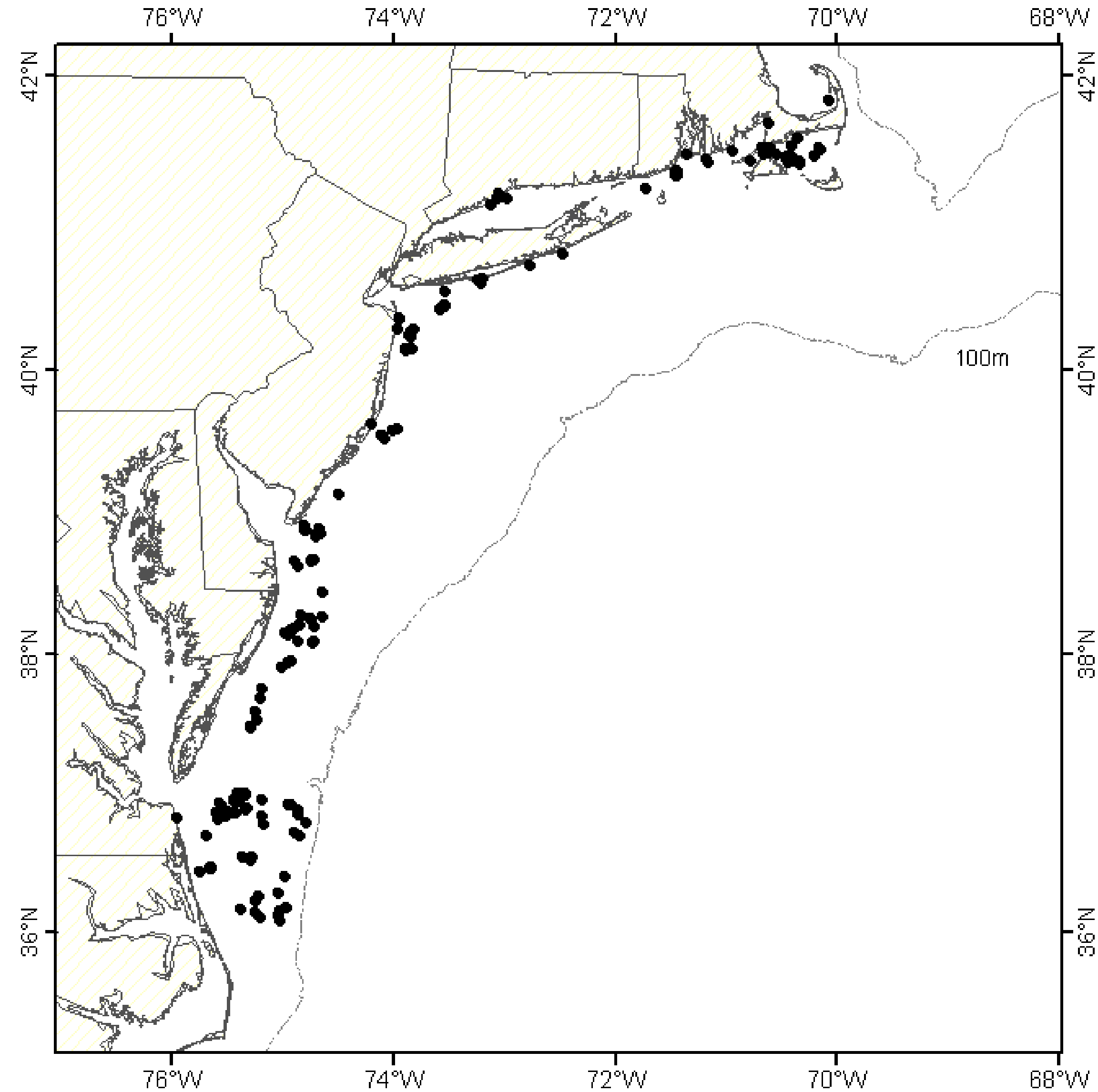

Figure 1. Distribution of black sea bass tag releases, 2002-2004.

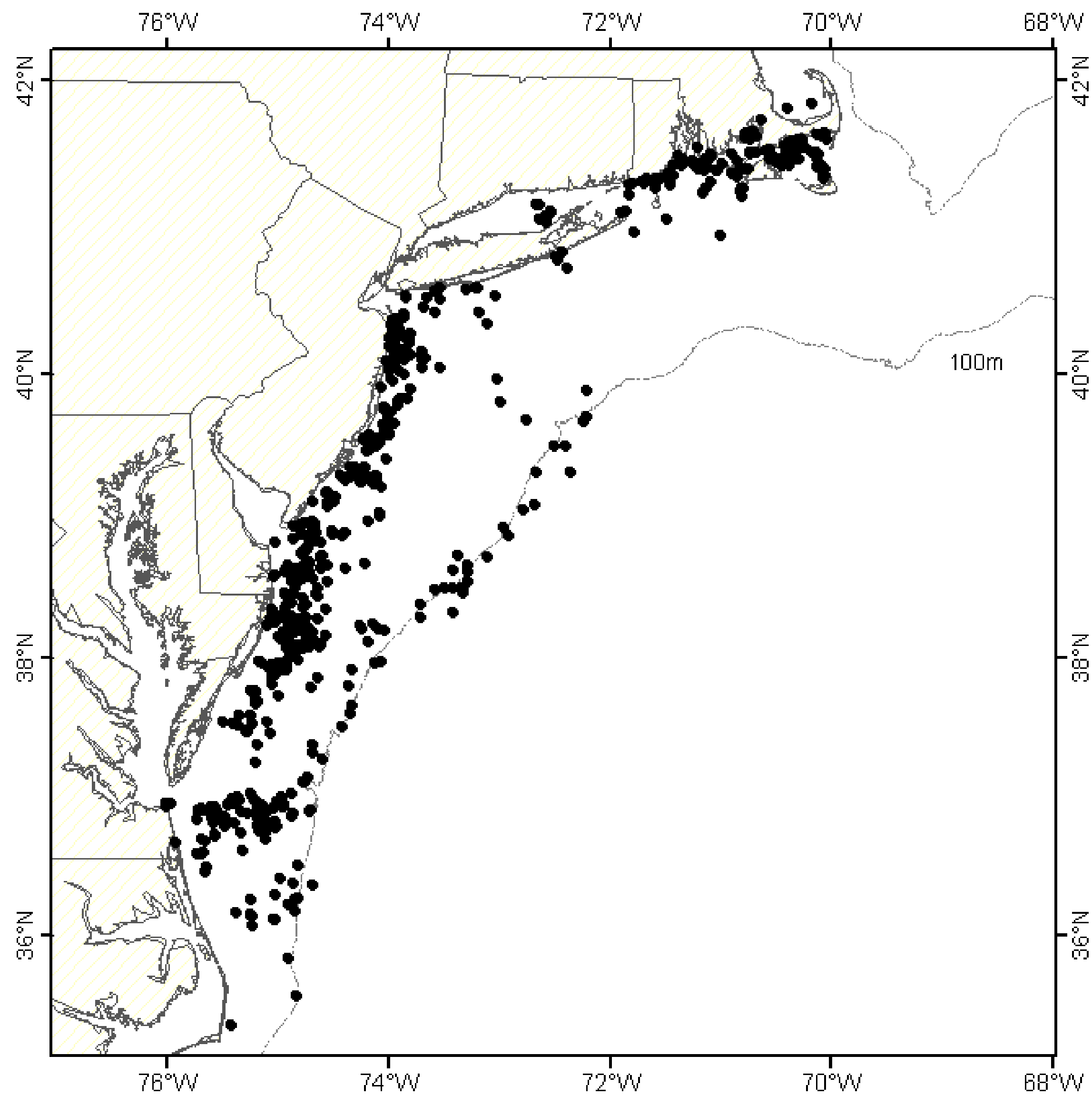

Figure 2. Black sea bass tag recapture locations, 2002-2007.

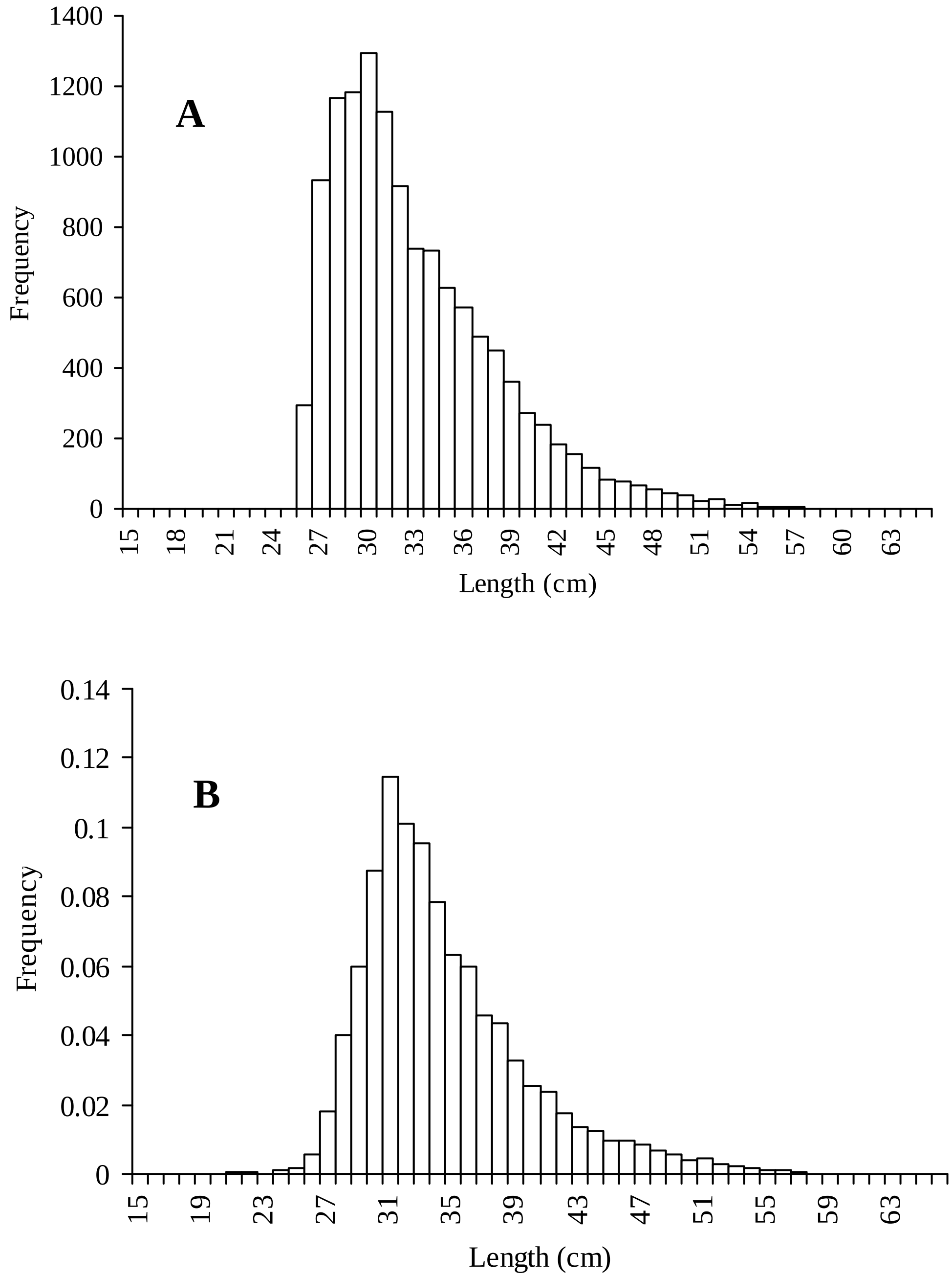

Figure 3. A: Length frequency distribution of marked and released black sea bass (2002-2004) and B: length frequency distribution from recreational and commercial fisheries (2002-2004).

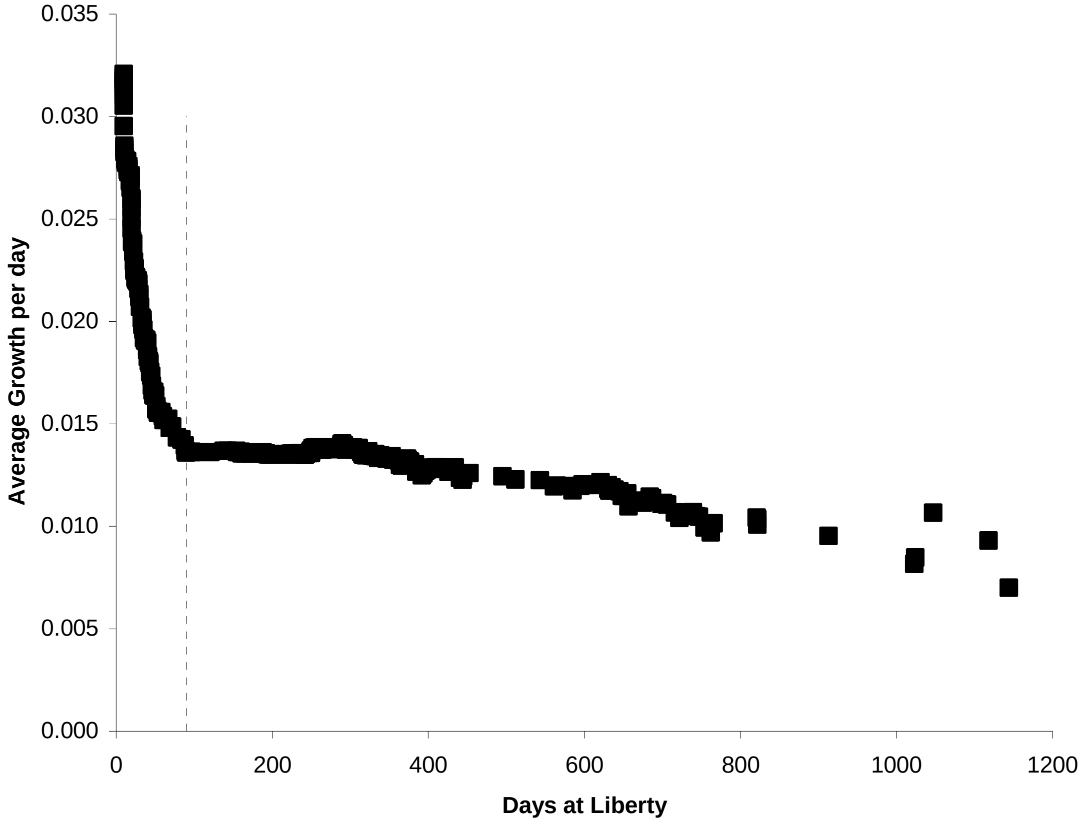

Figure 4. Consecutive moving average growth per day by the days at liberty. The 90 day point indicated by vertical line.

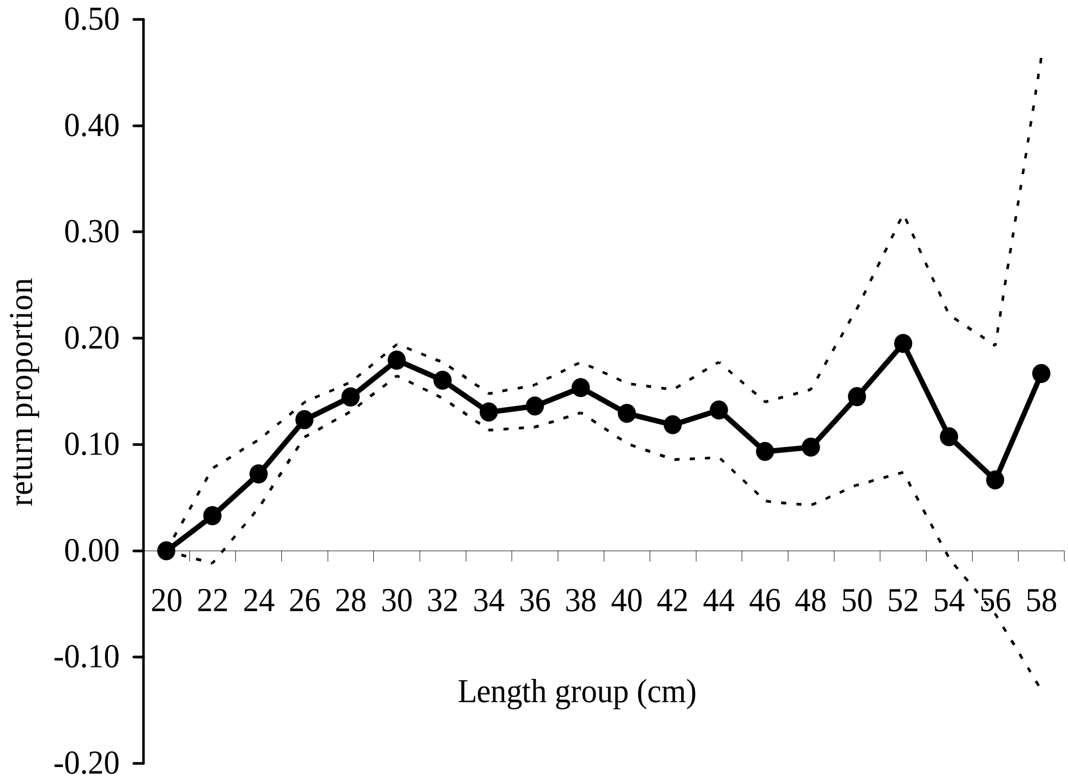

Figure 5. Selectivity by 2 cm length group represented by return proportion among all recoveries.

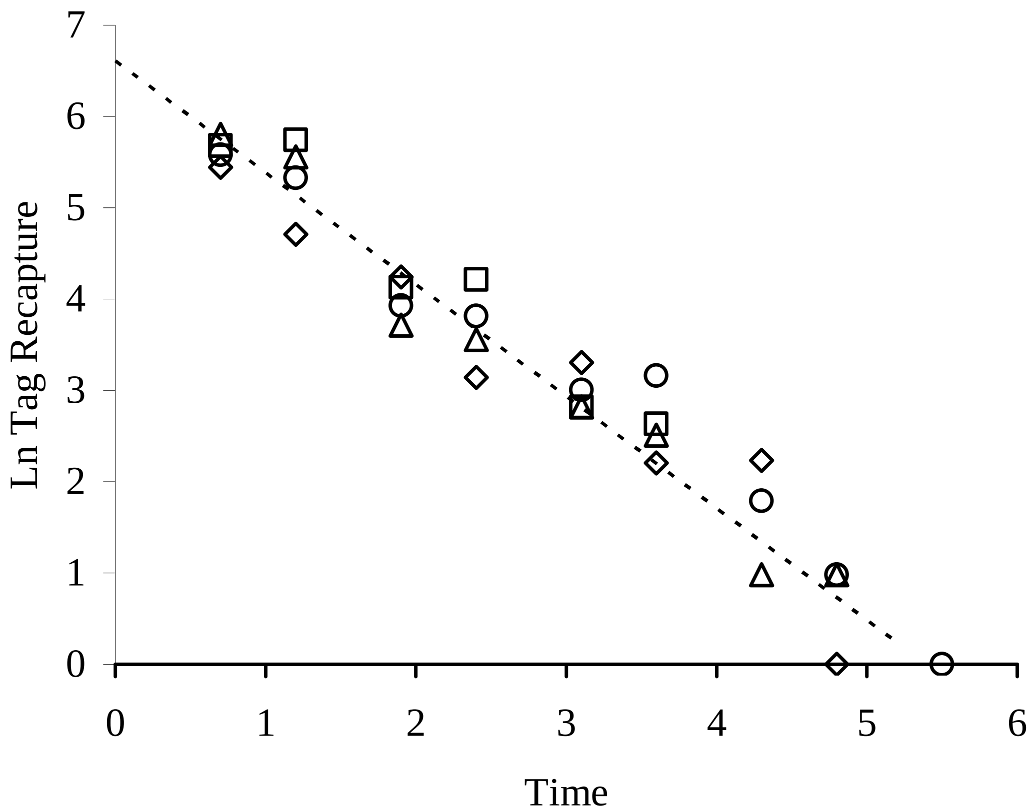

Figure 6. Catch curve equivalent of tag recaptures among all release cohorts. Different symbols represent release cohorts.

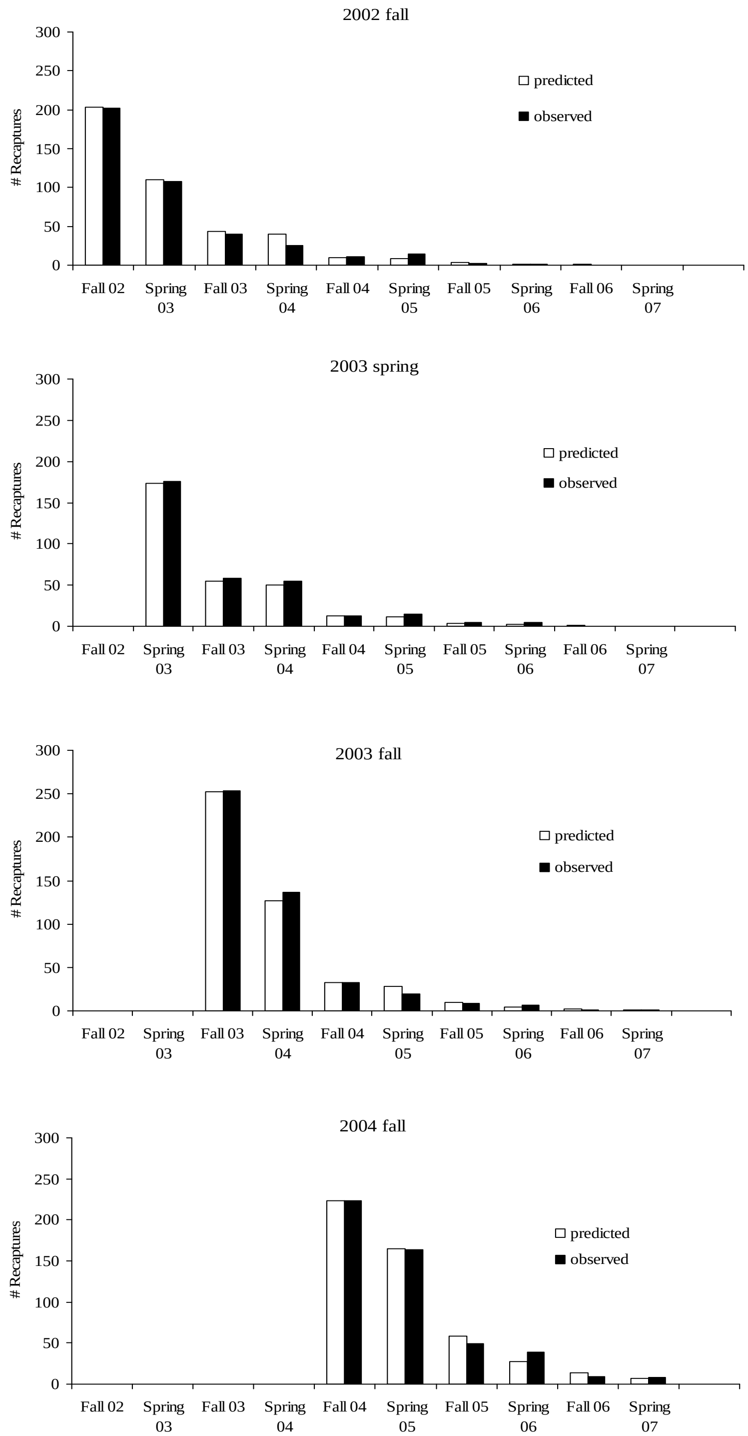

Figure 7. Comparison of observed and predicted tag recaptures by release cohort and season of recapture (model 4).

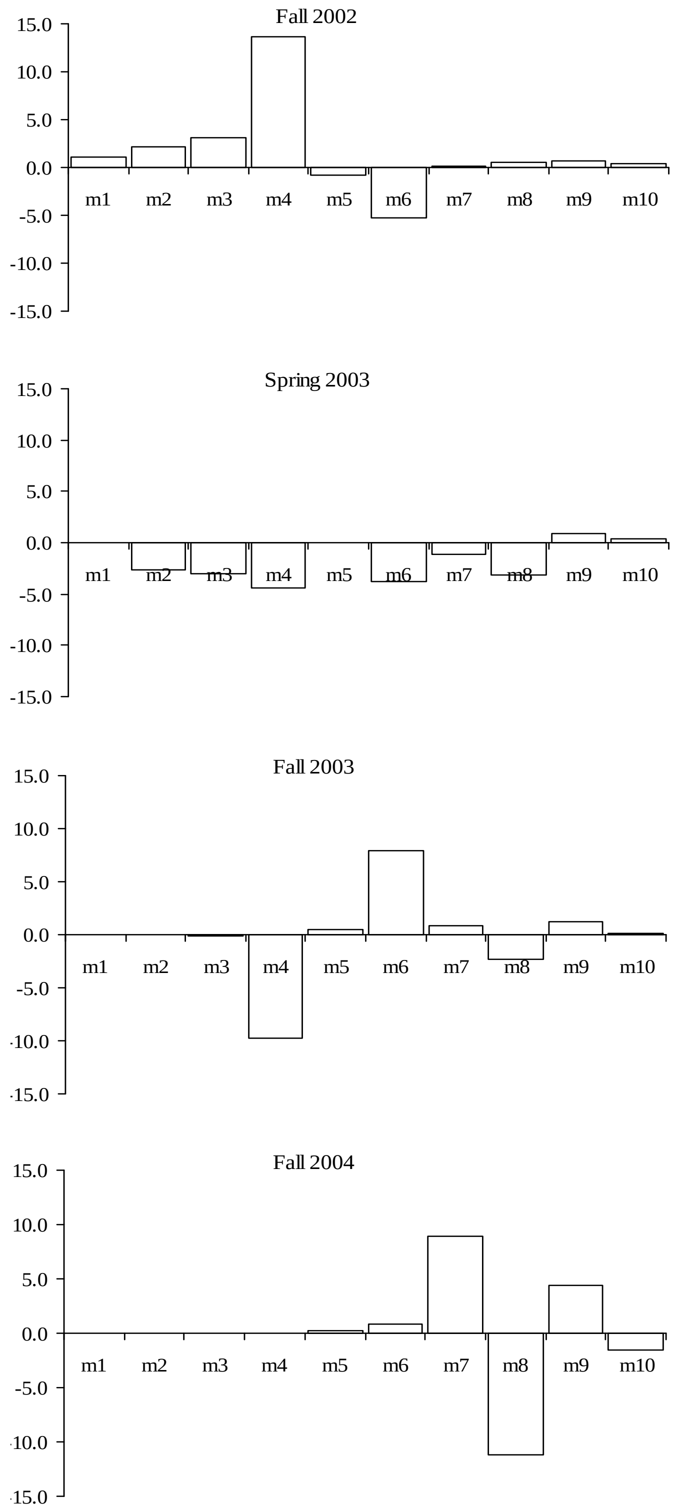

Figure 8. Residual difference between observed and predicted black sea bass tag recaptures, by release cohort and season (model 4).

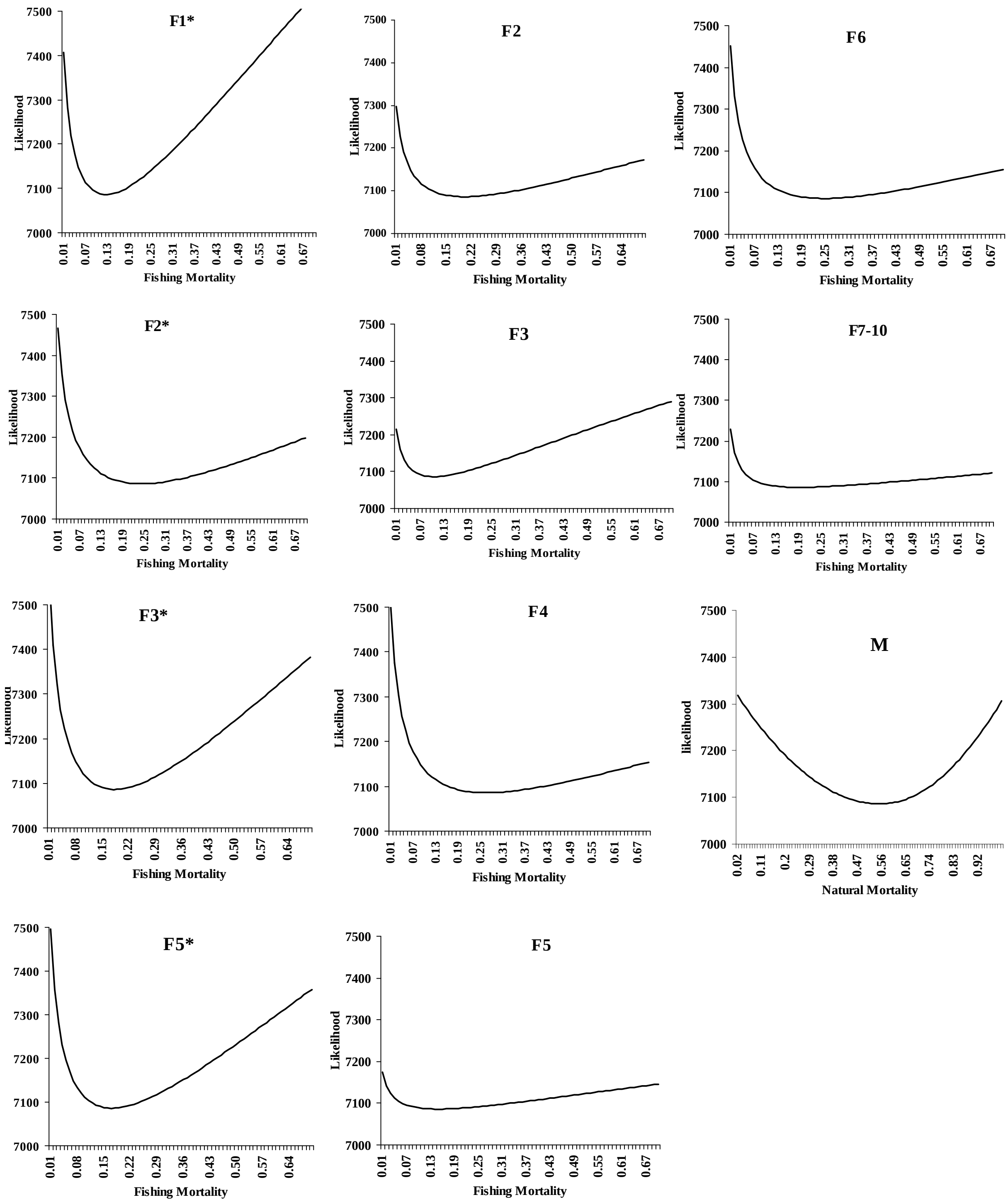

Figure 9. Profile likelihoods of parameter estimates in black sea bass tag model.

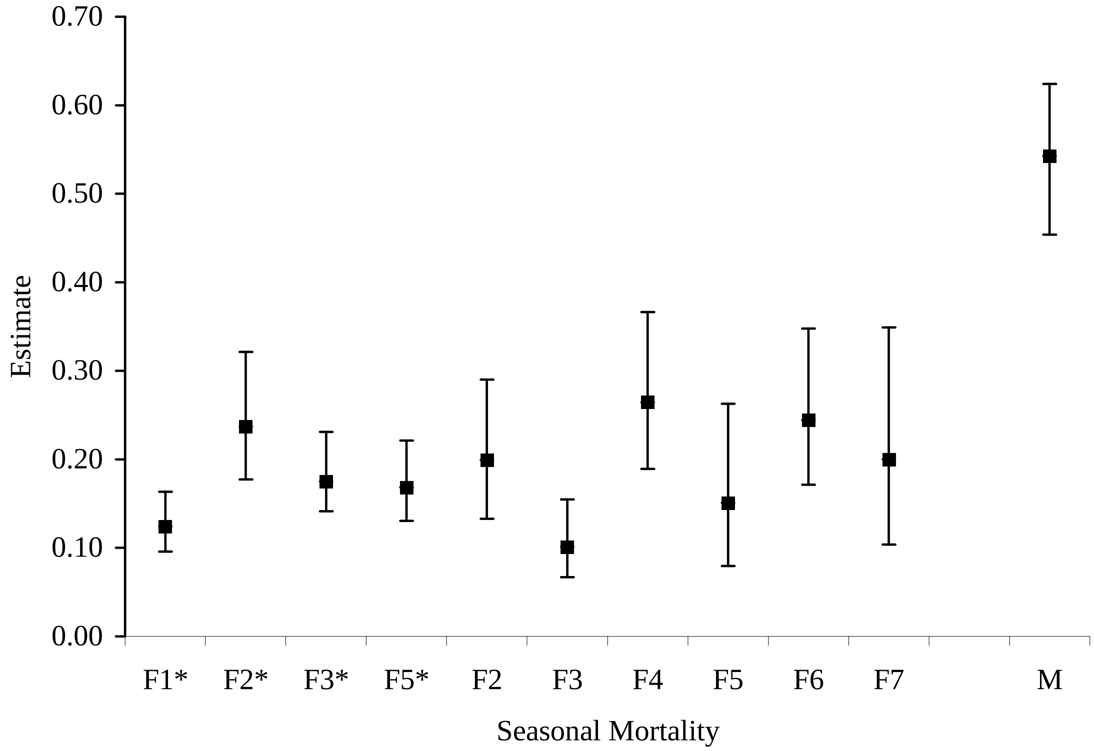

Figure 10. Estimates of fishing mortality for the non-mixed and mixed periods (F* and F) by fishing season and natural mortality (M) (model 4). Values shown with ± 95% confidence intervals derived from profile likelihoods.

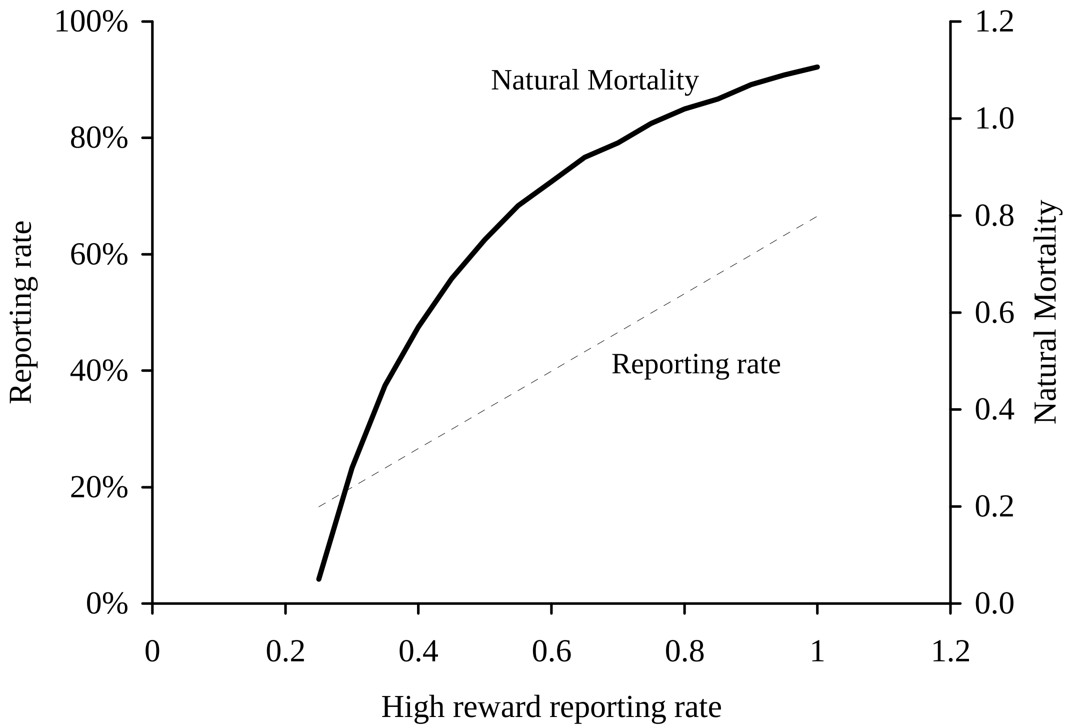

Figure 11. Effect of changes in high reward reporting rate assumption on overall reporting rate and natural mortality estimate.

Black sea bass; Appendix 2

SCALE Model

Introduction

Incomplete or lack of age-specific catch and survey indices often limits the application of a full age-structured assessment (e.g. Virtual Population Analysis and many forward projecting age-structured models). Stock assessments will often rely on the simpler size/age aggregated models (e.g. surplus production models) when age-specific information is lacking. However the simpler size/age aggregated models may not utilize all of the available information for a stock assessment. Knowledge of a species growth and lifespan, along with total catch data, size composition of the removals, recruitment indices and indices on numbers and size composition of the large fish in a survey can provide insights on population status using a simple model framework.

The Statistical Catch At LEngth (SCALE) model, is a forward projecting age-structured model tuned with total catch (mt), catch at length or proportional catch at length, recruitment at a specified age (usually estimated from first length mode in the survey), survey indices of abundance of the larger/older fish (usually adult fish) and the survey length frequency distributions. The SCALE model was developed in the AD model builder framework. The model parameter estimates are fishing mortality and recruitment in each year, fishing mortality to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years and Qs for each survey index.

The SCALE model was developed as an age-structured model that does NOT rely on age-specific information on a yearly basis. The model is designed to fit length information, abundance indices, and recruitment at age which can be estimated by using survey length slicing. However the model does require an accurate representation of the average overall growth of the population which is input to the model as mean lengths at age. Growth can be modeled as sex-specific growth and natural mortality or growth and natural mortality can be model with the sexes combined. The SCALE model will allow for missing data.

Model Configuration

The SCALE model assumes growth follows the mean input length at age with predetermined input error in length at age. Therefore a growth model or estimates of the average mean lengths at age is essential for reliable results. The model assumes static growth and therefore population mean length/weight at age are assumed constant over time.
The SCALE model estimates logistic parameters for a flattop selectivity curve at length in each time block specified by the user for the calculation of population and catch age-length matrices or the user can input fixed logistic selectivity parameters. Presently the SCALE model can not account for the dome shaped selectivity pattern.

The SCALE model computes an initial age-length population matrix in year one of the model as follows. First the estimated populations numbers at age starting with age-1 recruitment get normally distributed at one cm length intervals using the mean length at age with the assumed standard deviation. Next the initial population numbers at age are calculated from the previous age at length abundance using the survival equation. An estimated fishing mortality (Fstart) is also used to produce the initial population. This F can be thought of as the average fishing mortality that occurred before the first year in the model. Now the process repeats itself with the total of the estimated abundance at age getting redistributed according to the mean length at age and standard deviation in the next age (age+1).

This two step process is used to incorporate the effects of length specific selectivities and fishing mortality. The initial population length and age distribution is constructed by assuming population equilibrium with an initial value of F, called F_{start}. Length specific mortality is estimated as a two step process in which the population is first decremented for the length specific effects of mortality as follows:

$$N^{*}_{a,len,y_1} = N_{a-1,len,y_1} e^{-\left(PR_{len}F_{start}+M\right)}$$

In the second step, the total population of survivors is then redistributed over the lengths at age *a* by assuming that the proportions of numbers at length at age *a* follow a normal distribution with a mean length derived from the input growth curve (mean lengths at age).

$$N_{a,len,y_1} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^{*}_{a,len,y_1}$$

where

$$\pi_{len,a} = \Phi\left(len+1 \mid \mu_a, \sigma_a^2\right) - \Phi\left(len \mid \mu_a, \sigma_a^2\right)$$

where

$$\mu_a = L_\infty\left(1 - e^{-K(a-t_0)}\right)$$

Mean lengths at age can be calculated from a von Bertalanffy model from a prior study as shown in the equation above or mean lengths at age can be calculated directly from an age-length key. Variation in length at age a = σ_s^2 can often be approximated empirically from the growth study used for the estimation of mean lengths at age. If large differences in growth exist between the sexes then growth can be input as sex-specific growth with sex-specific natural mortality. However catch and survey data are still fitted with sexes combined.

This SCALE model formulation does not explicitly track the dynamics of length groups across age because the consequences of differential survival at length at age a do not alter the mean length of fish at age a+1. However, it does more realistically account for the variations in age-specific partial recruitment patterns by incorporating the expected distribution of lengths at age.

In the next step the population numbers at age and length for years after the calculation of the initial population use the previous age and year for the estimate of abundance. Here the calculations are done on a cohort basis. Like in the previous initial population survival equation the partial recruitment is estimated on a length vector.

$$N^*_{a,len,y} = N_{a-1,len,y-1} e^{-\left(PR_{len} F_{y-1} + M\right)}$$

second stage

$$N_{a,len,y} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^*_{a,len,y}$$

Constant M is assumed along with an estimated length-weight relationship to convert estimated catch in numbers to catch in weight. The standard Baranov=s catch equation is used to remove the catch from the population in estimating fishing mortality.

$$C_{y,a,len} = \frac{N_{y,a,len}\, F_y\, PR_{len}\left(1 - e^{-\left(F_y PR_{len} + M\right)}\right)}{(F_y \;\; PR_{len}) + M}$$

Catch is converted to yield by assuming a time invariant average weight at length.

$$Y_{y,a,len} = C_{y,a,len} W_{len}$$

The SCALE model results in the calculation of population and catch age-length matrices for the starting population and then for each year thereafter. The model is programmed to estimate recruitment in year 1 and estimate variation in recruitment relative to recruitment in year 1 for each year thereafter. Estimated recruitment in year one can be thought of as the estimated average long term recruitment in the population since it produces the initial population. The residual sum of squares of the variation in recruitment $\sum(\text{Vrec})^2$ is than used as a component of the total objective function. The weight on the recruitment variation component of the objective function (Vrec) can be used to penalize the model for estimating large changes in recruitment relative to estimated recruitment in year one.

The model requires an age-1 recruitment index for tuning or the user can assume relatively constant recruitment over time by using a high weight on Vrec. Usually there is little overlap in ages at length for fish that are one and/or two years of age in a survey of abundance. The first mode in a survey can generally index age-1 recruitment using length slicing. In addition numbers and the length frequency of the larger fish (adult fish) in a survey where overlap in ages at a particular length occurs can be used for tuning population abundance. The model tunes to the catch and survey length frequency data using a multinomial distribution. The user specifies the minimum size (cm) for the model to fit. Different minimum sizes can be fit for the catch and survey data length frequencies.

The number of parameters estimated is equal to the number of years in estimating F and recruitment plus one for the F to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years, and for each survey Q. The total likelihood function to be minimized is made up of likelihood components comprised of fits to the catch, catch length frequencies, the recruitment variation penalty, each recruitment index, each adult index, and adult survey length frequencies:

$$\mathrm{L}_{\mathrm{catch}} = \sum_{years}\left(l\,\mathrm{n}(Y_{\mathrm{obs,y}} + 1) - \ln\left(\sum_{a}\sum_{len} \mathrm{Y}_{\mathrm{pred,len,a,y}} + 1 \right)\right)^2$$

$$L_{catch\_lf} = -N_{eff} \sum_{y}\left(\sum_{inlen}^{L_\infty}\left((C_{y,len}+1)\ln\left(1+\sum_{a} C_{pred,y,a,len}\right) - \ln(C_{y,len}+1)\right)\right)$$

$$\mathrm{L}_{\mathrm{vrec}} = \sum_{y=2}^{Nyears} (Vrec_y)^2 = \sum_{y=2}^{Nyears} (R_1 - R_y)^2$$

$$\sum L_{rec} = \sum_{i=1}^{Nrec}\left[\sum_{y}^{Nyears}\left(\ln\left(I_{rec_i,inage_i,y}\right) - \ln\left(\sum_{len}^{L_\infty} N_{y,inage_i,len} * q_{rec\,i} \right)\right)^2 \right]$$

$$\sum L_{adult} = \sum_{i=1}^{Nadult}\left[\sum_{y}^{Nyears}\left(\ln\left(I_{adult_i,inlen+_i,y}\right) - \left(\sum_{a}\sum_{inlen_i}^{L_\infty} \ln\left(N_{pred,y,a,len} * q_{adult\,i}\right)\right)\right)^2 \right]$$

$$\sum L_{lf} = \sum_{i=1}^{Nlf}\left[-N_{eff}\sum_{y}\left(\sum_{inlen_i}^{L_\infty}\left((I_{lf_i,y,len}+1)\ln\left(1+\sum_{a} N_{pred,y,a,len}\right) - \ln(I_{lf_i,y,len}+1)\right)\right)\right]$$

In equation L_{catch_lf} calculations of the sum of length is made from the user input specified catch length to the maximum length for fitting the catch. Input user specified fits are indicated with the prefix "in" in the equations. LF indicates fits to length frequencies. In equation L_{rec} the input specified recruitment age and in L_{adult} and L_{lf} the input survey specified lengths up to the maximum length is used in the calculation.

$$Obj\ \ fcn = \sum_{i=1}^{N} \lambda_i L_i$$

Lambdas represent the weights to be set by the user for each likelihood component in the total objective function.

Northeast Fisheries Science Center Reference Document 17-05

61st Northeast Regional Stock Assessment Workshop (61st SAW)

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by the Northeast Fisheries Science Center

Northeast Fisheries Science Center Reference Document 17-05

61st Northeast Regional Stock Assessment Workshop (61st SAW) Assessment Report

by the Northeast Fisheries Science Center

NOAA Fisheries, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543

U.S. DEPARTMENT OF COMMERCE
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National Marine Fisheries Service
Northeast Fisheries Science Center
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Contents

1 Atlantic surfclam Assessment

1.1 Foreword

The Northeast Regional Stock Assessment Workshop (SAW) process has three parts: preparation of stock assessments by the SAW Working Groups and/or by ASMFC Technical Committees/Assessment Committees; peer review of the assessments by a panel of outside experts who judge the adequacy of the assessment as a basis for providing scientific advice to managers; and a presentation of the results and reports to the Region's fishery management bodies.

Starting with SAW 39 (June 2004), the process was revised in two fundamental ways. First, the Stock Assessment Review Committee (SARC) became a smaller panel with panelists provided by the Independent System for Peer Review (Center of Independent Experts, (CIE). Second, the SARC provides little management advice. Instead, Council and Commission teams (e.g., Plan Development Teams, Monitoring and Technical Committees, Science and Statistical Committee) formulate management advice after an assessment has been accepted by the SARC. Starting with SAW 45 (June 2007) the SARC chairs were from external agencies, but not from the CIE. Starting with SAW 48 (June 2009), SARC chairs are from the Fishery Management Council's Science and Statistical Committee (SSC), and not from the CIE. Also at this time, some assessment Terms of Reference were revised to provide additional science support to the SSCs, as the SSC's are required to make annual ABC recommendations to the fishery management councils.

Reports that are produced following SAW/SARC meetings include: An *Assessment Summary Report* - a summary of the assessment results in a format useful to managers; an *Assessment Report* - a detailed account of the assessments for each stock; and the SARC panelist reports - a summary of the reviewer's opinions and recommendations as well as individual reports from each panelist. Both the SAW/SARC assessment reports and the CIE review reports are available online at http://www.nefsc.noaa.gov/saw/reports.html.

The 61st SARC was convened in Woods Hole at the Northeast Fisheries Science Center (NEFSC), July 19-21, 2016 to review a benchmark stock assessment of Atlantic surfclam (*Spissula solidissima*). CIE reviews for SARC61 were based on detailed reports produced by NEFSC Assessment Working Groups. This introduction contains a brief summary of the SARC comments, a list of SARC panelists, the meeting agenda, and a list of attendees (Tables 1 - 3). Maps of the Atlantic coast of the USA and Canada are also provided (Figures 1 - 5).

Outcome of Stock Assessment Review Meeting:

Text in this section is based on SARC-61 Review Panel reports (available at http://www.nefsc.noaa.gov/saw/ under the heading "SAW 61 Panelist Reports").

The Atlantic surfclam stock assessment was accepted by the SARC-61 panel. In 2015 overfishing was not occurring and the stock was not overfished. Population projections suggest that the population is unlikely to become overfished and that overfishing is unlikely to occur by 2025. Nine of the ten assessment Terms of Reference were met. The assessment was based on the Stock Synthesis III model (SS3). Commercial LPUE values show mostly declining trends, appearing to contradict increasing survey trends. Stock depletion may be real at a local level, but the limited coverage of the fishery suggests that the LPUE trends are not indicative of the stock as a whole.

The Panel endorsed the redefinition of the Biological Reference Points (BRP) based on relative stock status. The new BRPs can be used to provide catch limit advice. The Panel noted that the fishing mortality threshold calculation uses an estimate of FMSY. This value was derived from a simulation study, the details of which were not discussed by the Panel at the review meeting. The assessment did not determine whether the surfclam resource should be considered as one unit stock throughout the species' range in US federal waters or if regional stocks should be recognized. However, not meeting this ToR did not impact the overall acceptability of the assessment.

Due to the importance of the clam survey in this assessment, the Panel recommends caution in making any changes to the gear and survey vessel.

Table 1: 61st Stock Assessment Review Committee Panel.

SARC Chairman (MAFMC SSC):

Dr. Michael Wilberg
University of Maryland
Email: wilberg@umces.edu

SARC Panelists (CIE):

Dr. Coby Needle
Sea Fisheries Programme Manager
Marine Scotland - Science, Marine Laboratory
Aberdeen, UK
Email: C.Needle@MARLAB.AC.UK

Dr. Michael Bell
Research Associate
International Centre for Island Technology, Heriot-Watt University
Orkney, UK
Email: M.C.Bell@hw.ac.uk

Dr. Martin Cryer
Science Manager, Aquatic Environment
Ministry for Primary Industries
Wellington, NZ
Email: martin.cryer@mpi.govt.nz

Table 2: Agenda, 61st Stock Assessment Review Committee Meeting.

July 19-21, 2016

Stephen H. Clark Conference Room Northeast Fisheries Science Center
Woods Hole, Massachusetts

AGENDA[1] (version: 7/7/2016)

TIME	TOPIC	PRESENTER(S)	RAPPORTEUR
Tuesday, July 19			
10 10:30 AM			
	Welcome	**James Weinberg**, SAW Chair	
	Introduction	**Michael Wilberg**, SARC Chair	
	Agenda Conduct of Meeting		
10:30 12:30 PM	Assessment Presentation (A. Surfclam)	**Dan Hennen**	**Michele Traver**
12:30 1:30 PM	Lunch		
1:30 3:30 PM	Assessment Presentation (A. Surfclam)	**Dan Hennen**	**Michele Traver**
3:30 3:45 PM	Break		
3:45 5:45 PM	SARC Discussion w/ Presenters (A. Surfclam)	**Michael Wilberg**, SARC Chair	**Michele Traver**
5:45 6 PM	Public Comments		
7 PM	(Social Gathering)		

Table 2 cont.

TIME	TOPIC	PRESENTER(S)	RAPPORTEUR
Wednesday, July 20			
9:00 10:45	Revisit with Presenters (A. Surfclam)	**Michael Wilberg**, SARC Chair	**Toni Chute**
10:45 - 11	Break		
11 11:45	Revisit with Presenters (A. Surfclam)	**Michael Wilberg**, SARC Chair	**Toni Chute**
11:45 Noon	Public Comments		
12 1:15 PM	Lunch		
1:15 4 PM	Review/Edit Assessment Summary Report (A. Surfclam)	**Michael Wilberg**, SARC Chair	**Toni Chute**
4 4:15 PM	Break		
4:15 5:00 PM	SARC Report writing		
Thursday, July 21			
9:00 AM 5:00 PM	SARC Report writing		

Table 3: 61st SAW/SARC, List of Attendees.

NAME	AFFILIATION	EMAIL
Michael Wilberg	University of Maryland - CES	wilberg@umces.edu
Coby Needle	Marine Scotland Science, Marine Lab-Aberdeen	C.Needle@MARLAB.AC.UK
Mike Bell	Heriot-Watt University Intl Centre for Island Tech	M.C.Bell@hw.ac.uk
Martin Cryer	Ministry for Primary Industries, Wellington	Martin.Cryer@mpi.govt.nz
Russ Brown	NEFSC	Russell.brown@noaa.gov
Jim Weinberg	NEFSC	james.weinberg@noaa.gov
Larry Jacobson	NEFSC	larry.jacobson@noaa.gov
Dan Hennen	NEFSC	Daniel.hennen@noaa.gov
Jessica Coakley	MAFMC	jcoakley@mafmc.org
Mike Simpkins	NEFSC	Michael.simpkins@noaa.gov
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Sheena Steiner	NEFSC	sheena.steiner@noaa.gov
Michele Traver	NEFSC	Michele.traver@noaa.gov
Toni Chute	NEFSC	toni.chute@noaa.gov
Mark Terceiro	NEFSC	mark.terceiro@noaa.gov
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Tom Alspach	Sea Watch International	talspach@goeaston.net
Eric Powell	University of Southern Mississippi	eric.n.powell@usm.edu
Bob Glenn	Mass. Division of Marine Fisheries	Robert.glenn@state.ma.us
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Wendy Gabriel	NEFSC	wendy.gabriel@noaa.gov
Jon Deroba	NEFSC	jonathan.deroba@noaa.gov
Charles Perretti	NEFSC	Charles.perretti@noaa.gov

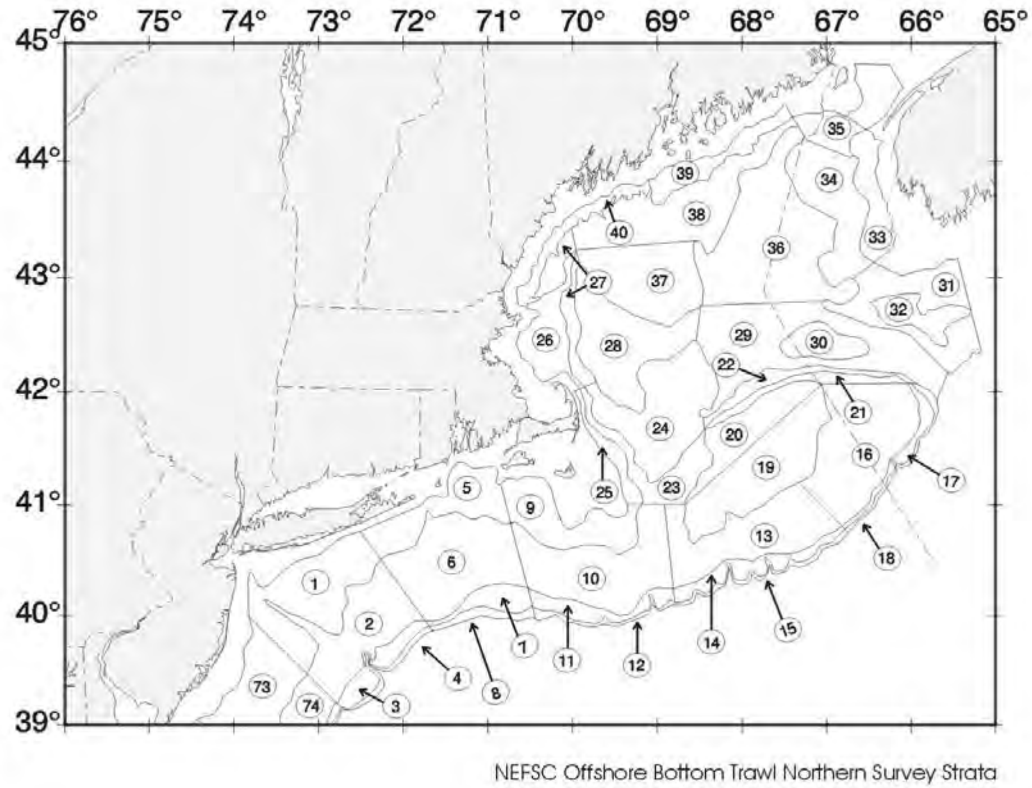


Figure 1: Offshore depth strata that have been sampled during Northeast Fisheries Science Center bottom trawl research surveys. Some of these may not be sampled presently.

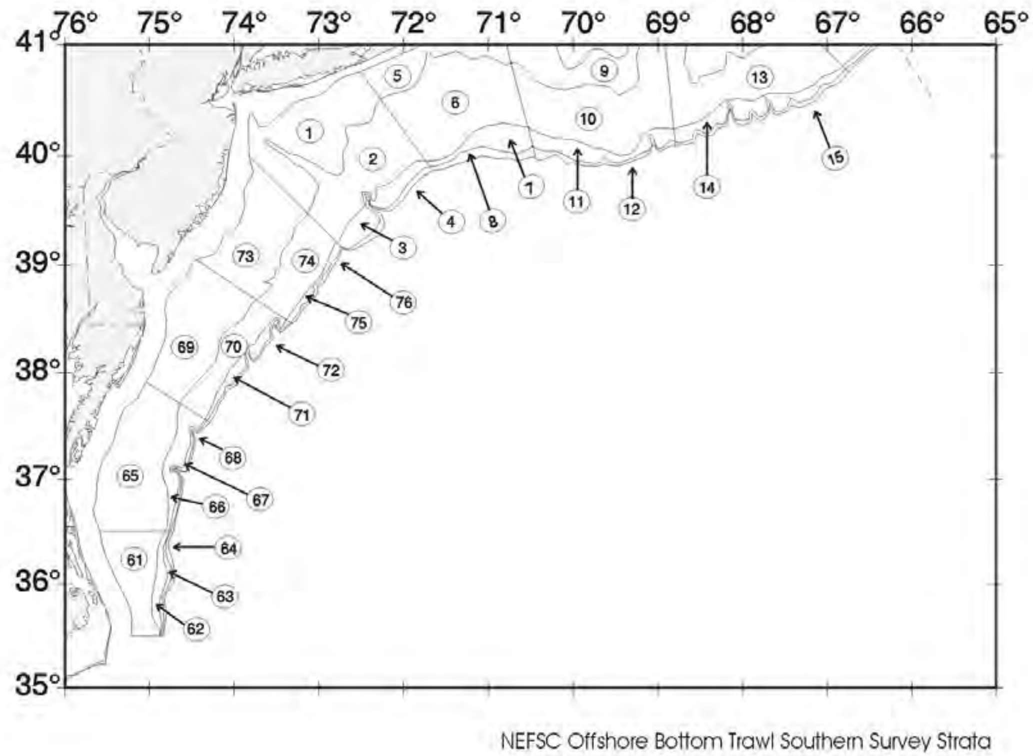


Figure 1 cont.

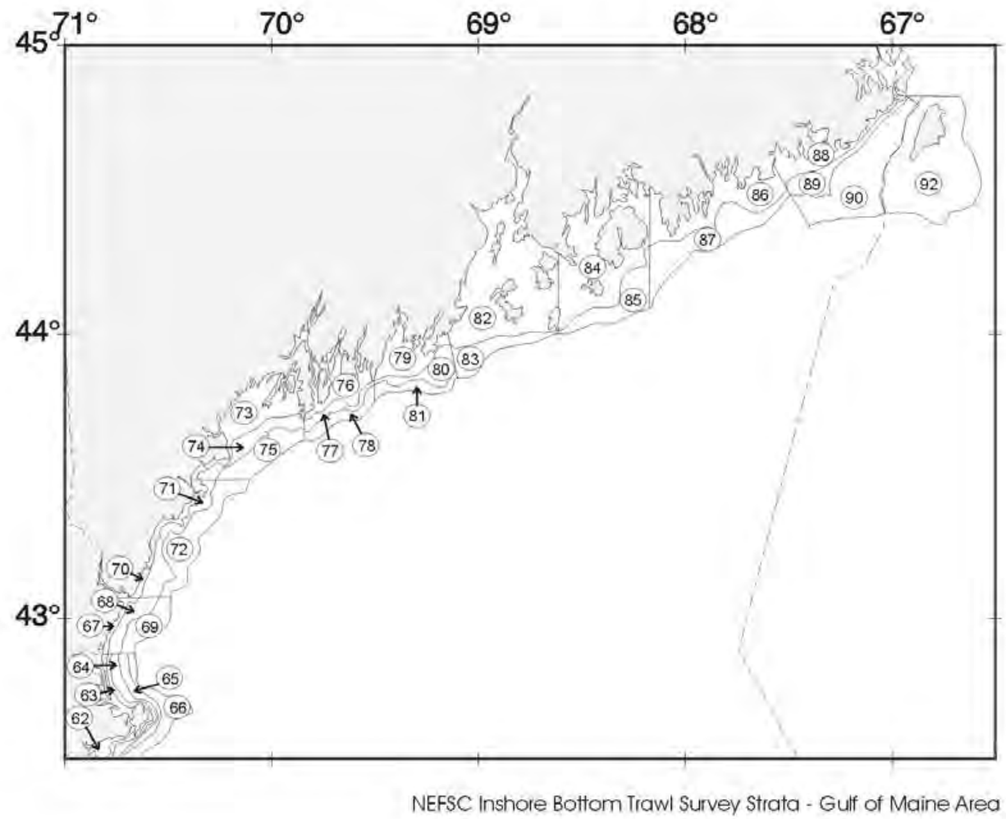


Figure 2: Inshore depth strata that have been sampled during Northeast Fisheries Science Center bottom trawl research surveys. Some of these may not be sampled presently.

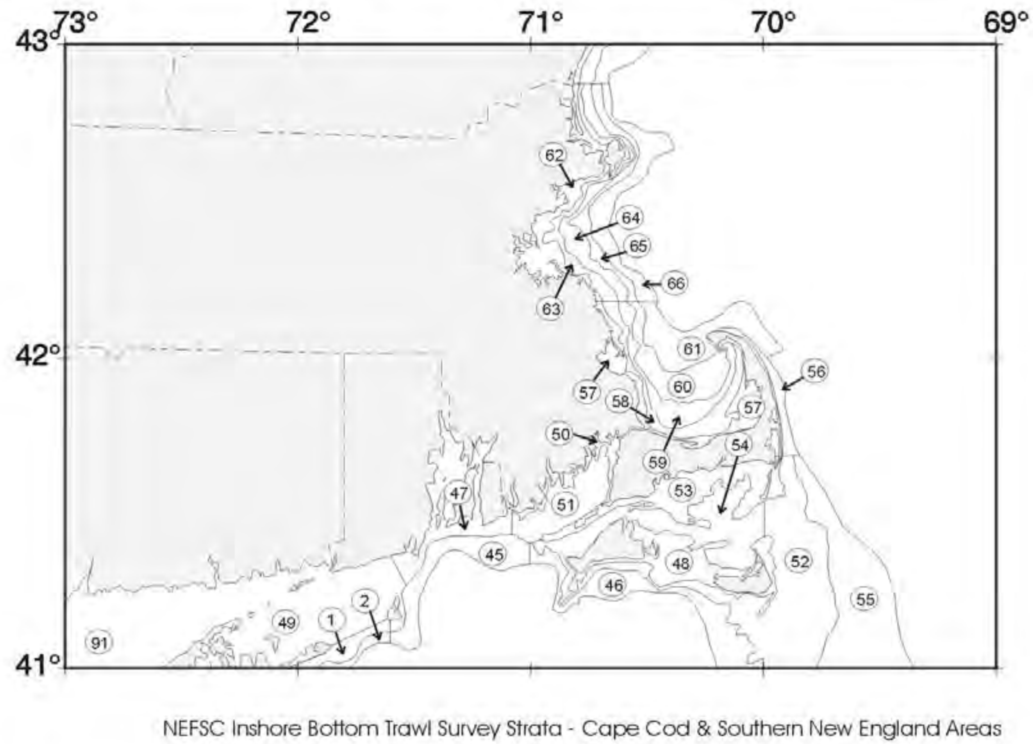


Figure 2 cont.

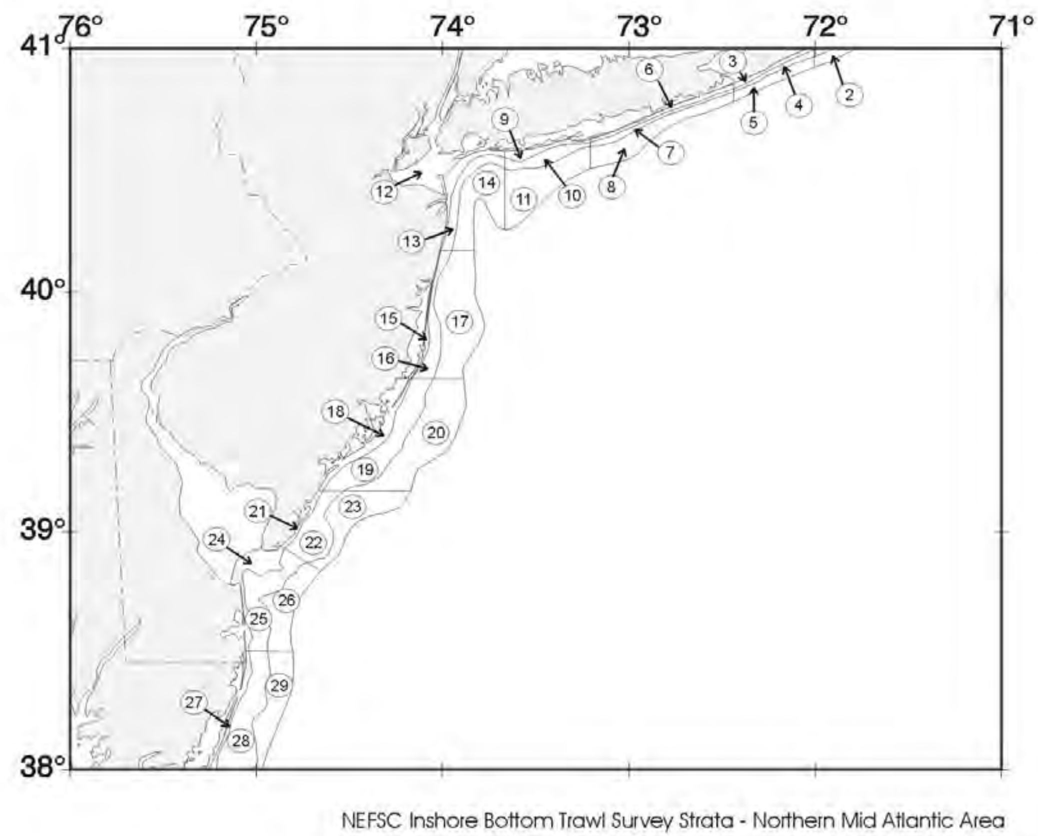
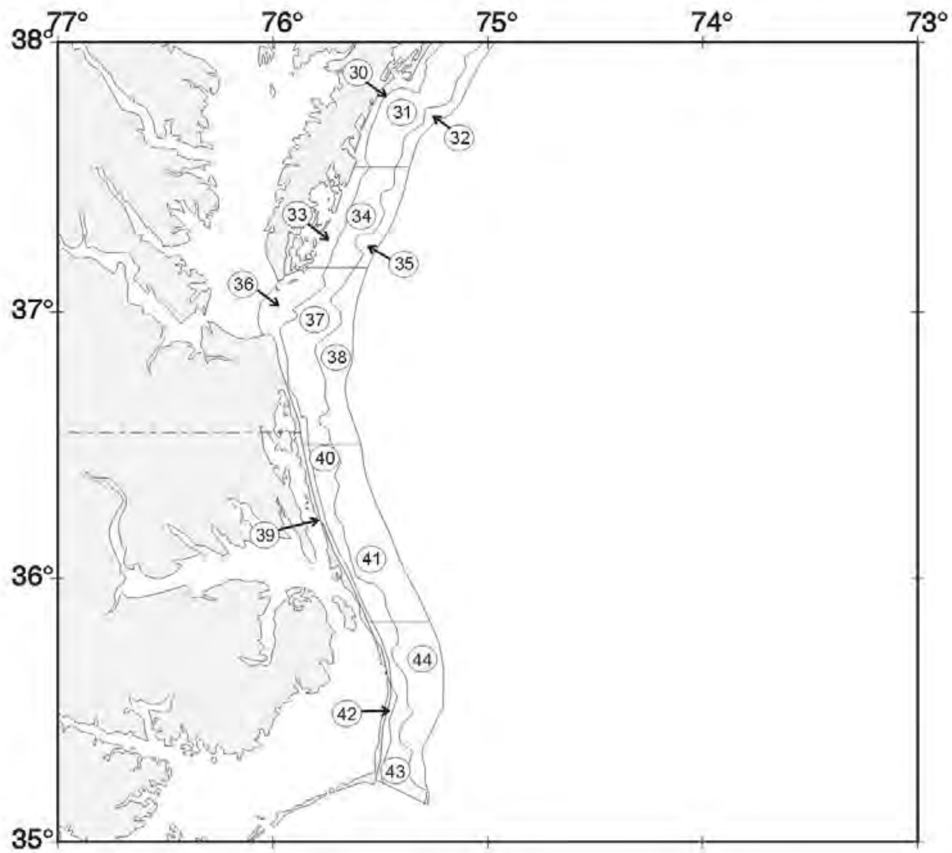


Figure 2 cont.



NEFSC Inshore Bottom Trawl Survey Strata - Southern Mid-Atlantic Area

Figure 2 cont.

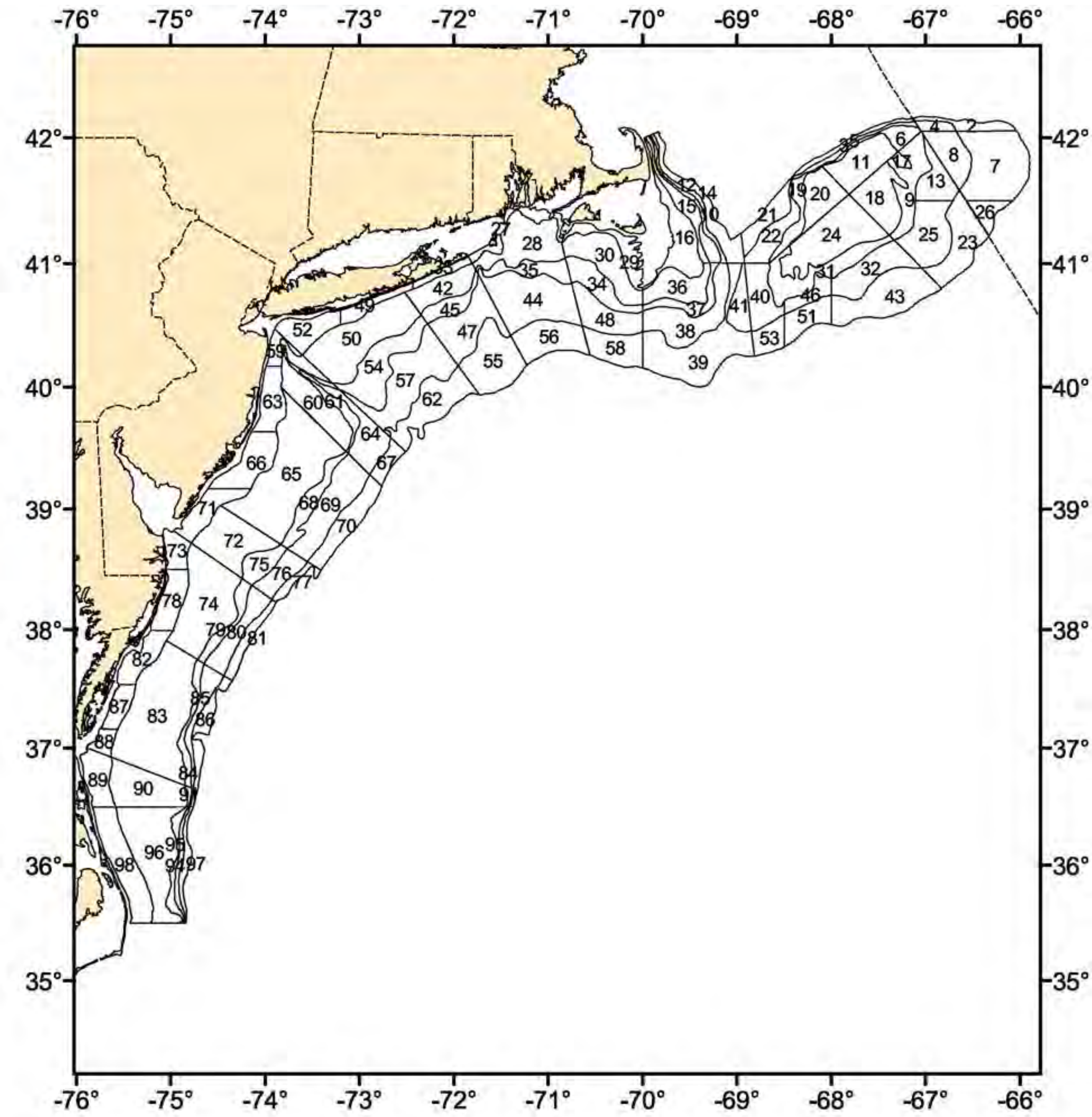


Figure 3: Depth strata sampled during Northeast Fisheries Science Center clam dredge research surveys.

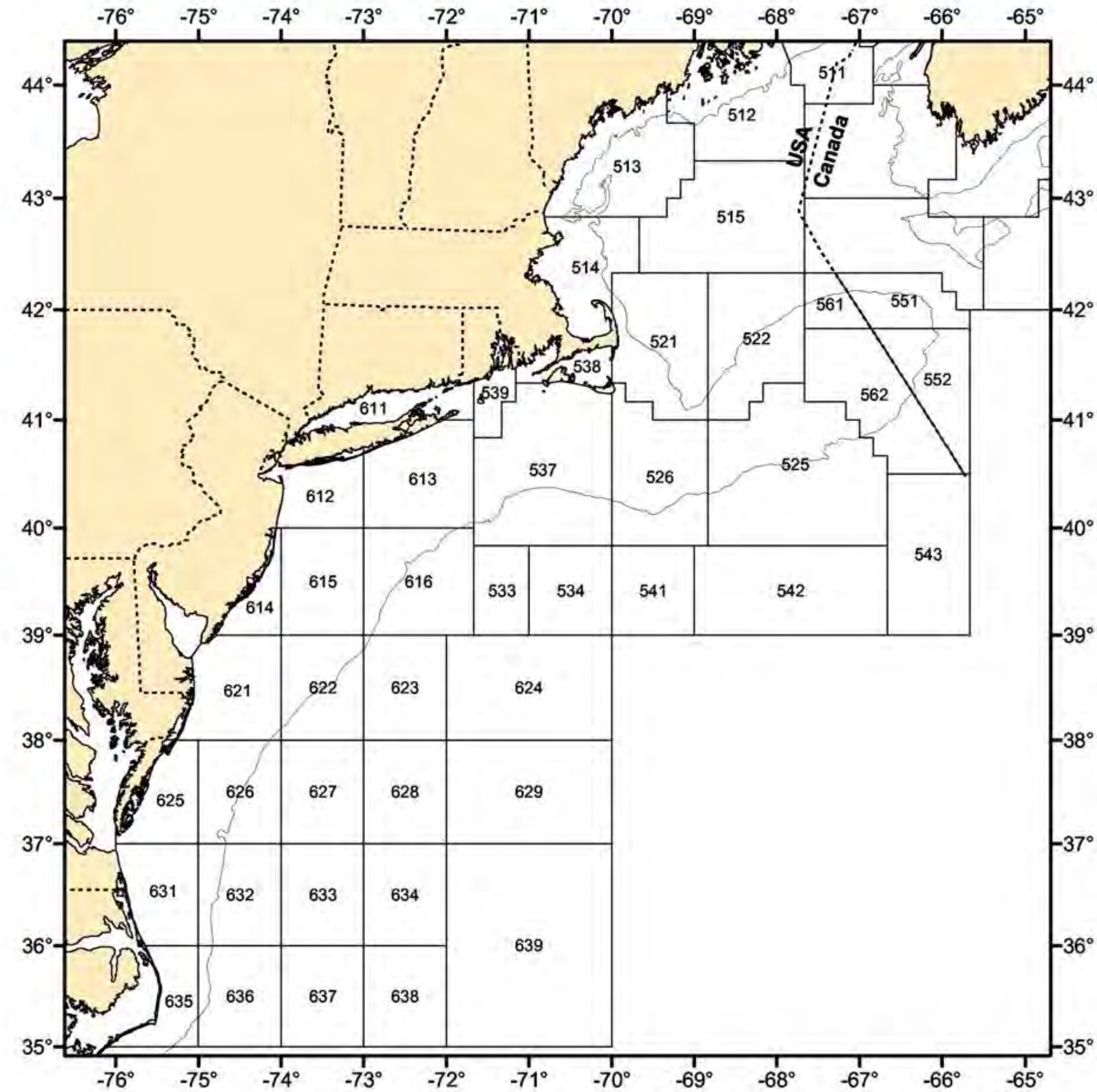


Figure 4: Statistical areas used for reporting commercial catches.

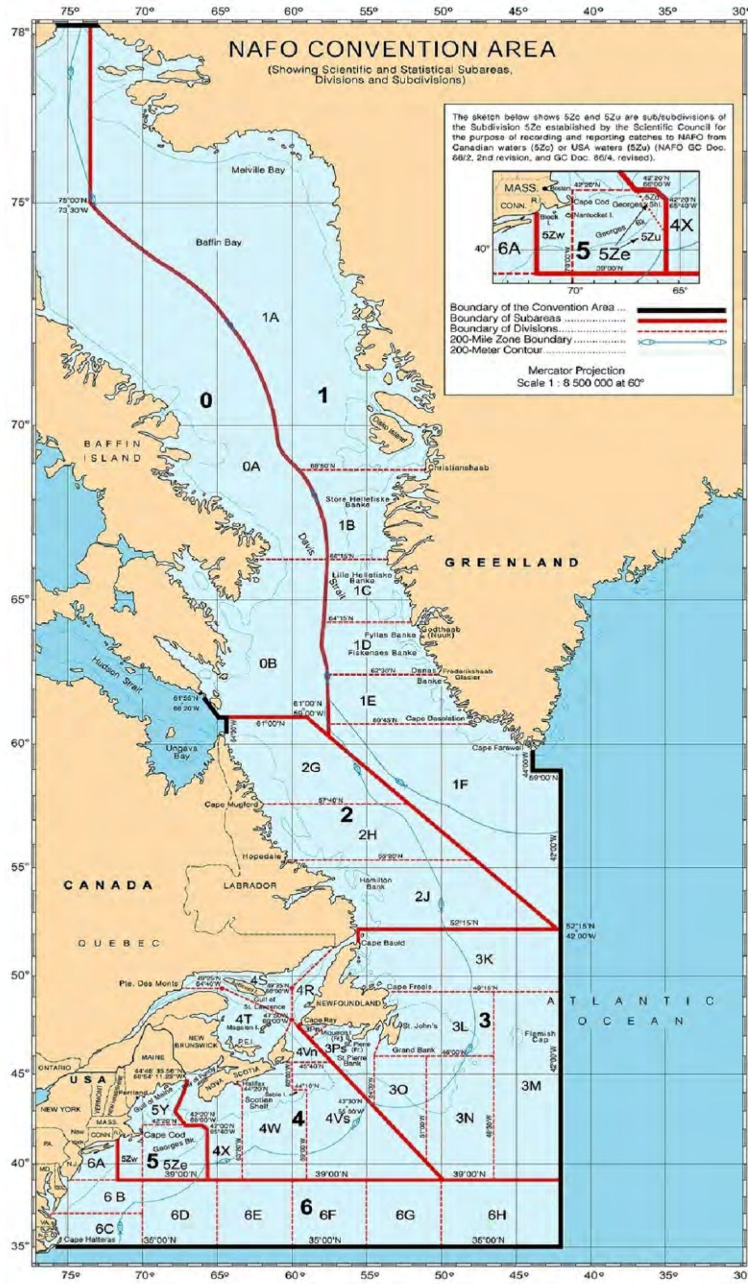


Figure 5: Catch reporting areas of the Northwest Atlantic Fisheries Organization (NAFO).

1.2 Executive summary

This assessment is for Atlantic surfclam in the US EEZ (federal waters, 3-200 nm from shore) individual transferable quota (ITQ) fishery (Appendix 7). The assessment divides the US stock into a northern (Georges Bank or GBK) and a southern area (south of GBK to Cape Hatteras) for modeling purposes (Figures 6 and 7). However, the resource is managed as a single stock so estimates for the north and south are combined for status determination.

TOR 1. Estimate catch from all sources including landings and discards. Map the spatial and temporal distribution of landings, discards, fishing effort, and gross revenue, as appropriate. Characterize the uncertainty in these sources of data.

Commercial landings and fishing effort data are reported by processors based on cage tags, in logbooks by ten-minute square (TNMS) and considered reliable. Catch includes a 12% allowance for incidental mortality. Atlantic surfclam discards were near zero except during 1982-1993 when minimum size regulations were used (Table 3).

Landings, fishing effort and landings per unit effort (LPUE, bu per hour fished) shifted north after 2000 as fishery productivity in the south declined (Figures 13-18). During 2006-2015, total landings declined from about 27 to 18 (mean 21) thousand mt (Tables 4-5 and Figures 8-9). Fishing effort after 2006 varied without trend or declined in the south but is still relatively high. Effort increased dramatically in in the north (Table 6 and Figure 10). Processors prefer large Atlantic surfclam but the sizes of landed Atlantic surfclam have declined in the south (Figures 22-27).

TOR 2. Present the survey data being used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, etc.). Use logbook data to investigate regional changes in LPUE, catch and effort. Characterize the uncertainty and any bias in these sources of data. Evaluate the spatial coverage, precision, and accuracy of the new clam survey.

The NEFSC clam survey used the *RV Delaware II* and a small 5 ft dredge (RD) prior to 2012 and a commercial fishing vessel and modified commercial dredge (MCD) since. The entire resource was surveyed with the RD in 2011 (Tables 10-11). The MCD was used in 2012 and 2015 in the south but only on GBK in 2013. Data from the two periods are not comparable although capture efficiency and size selectivity estimates can be used to calculate relatively consistent swept-area stock size for 1997-2015. Based on two swept-area estimates, biomass declined in the south after 2011 (Figure 39). It is not possible to evaluate recent trends off GBK.

Landings per unit effort declined steadily for the stock as a whole and in the south to near record lows in 2015 but is high on GBK (Table 8 and Figure 12). Survey data and other information indicate that the biological condition of the Atlantic surfclam resource as a whole and in the south is better than fishery conditions would suggest. Landings, effort and LPUE do not reliably measure trends in overall Atlantic surfclam stock size because the fishery operates in relatively few TNMS such that most of the stock and habitat are not accessed by the fishery (Figures 19-21).

TOR 3. Determine the extent and relative quality of benthic habitat for Atlantic surfclam in the Georges Bank ecosystem to refine estimates of stock size based on swept area calculations.

The proportion of untrawlable ground that is potentially poor clam habitat was recalculated to be 14% which is slightly higher than the 12% figure used in this assessment. New information will be available soon for refining these imprecise estimates (Appendix 13).

TOR 4. Quantify changes in the depth distribution of Atlantic surfclam over time. Review changes over time in Atlantic surfclam biological parameters such as length, width, and growth.

The distribution of Atlantic surfclam in the south is shifting towards deeper water due to warming as suitable nearshore habitat areas have decreased and offshore habitats increased (Figures 72-77). Survey data indicate that overlap between Atlantic surfclam and ocean quahogs which inhabit relatively deep water habitat has increased (Figures 78-79). Maximum shell length had declined in the south while the von Bertalanffy growth parameter K increased (Figures 86-87).

TOR 5. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series (integrating results from TOR 3, as appropriate) and estimate their uncertainty. Include a historical retrospective analysis to allow a comparison with previous assessment results and previous projections.

The primary assessment was a statistical catch at age model implemented in SS3. Each of two areas were assessed separately and the results were combined to provide management advice for the stock (Part 1.7). The scale of absolute abundance was uncertain, which is a problem typical of low fishing mortality fisheries. The trend in biomass was relatively well determined. The southern area, where recent recruitment has been strong is near its unfished biomass (B_0). The northern area, where recent recruitment has been poor is at a lower level, but still above $\frac{1}{4}B_0$. Fishing mortality is low for both areas.

TOR 6. State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, F_{MSY} and MSY) and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs, particularly as they relate to stock assumptions.

The current and recommended stock status definitions are listed in Table 4 (Part 1.8). The current stock status definitions were revised based on a management strategy evaluation (Part 8) and assessment model improvements, because the overfishing definition depended on the estimate of absolute abundance in the assessment, which is uncertain. The recommended stock status definitions are trend-based as trend is relatively well estimated in this assessment.

TOR 7. Evaluate stock status with respect to the existing model (from previous peer reviewed accepted assessment) and with respect to any new model or models developed for this peer review.

1. *When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.*
2. *Then use the newly proposed model and evaluate stock status with respect to "new" BRPs and their estimates (from TOR-5).*

The Atlantic surfclam population is not overfished and overfishing is not occurring under either the current or recommended reference point definitions and using either the previous or newly developed models (Part 1.9; Tables 27 - 29).

TOR 8. Develop approaches and apply them to conduct stock projections.

1. *Provide numerical annual projections (five years) and the statistical distribution (e.g., probability density function) of the OFL (overfishing level) (see Appendix 15). Consider cases using nominal as well as potential levels of uncertainty in the model. Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment).*
2. *Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.*
3. *Describe this stock's vulnerability (see 15) to becoming overfished, and how this could affect the choice of ABC.*

Projections indicate that the population is unlikely to be overfished and that overfishing is unlikely to occur by 2025 using a wide range of possible biomass scales and assumed catches (Part 1.10; Tables 30 - 31).

TOR 9. Evaluate the validity of the current stock definition. Determine whether current stock definitions may mask fishery related reductions in sustainable catch on regional spatial scales. Make a recommendation about whether there is a need to modify the current stock definition.

The invertebrate subcommittee did not reach consensus on stock definitions. All members of the workgroup agree that stock definitions are unlikely to affect management, yield, or biological risk in the near term as long as fishing mortality rates remain low and overall abundance and biomass are relatively high in both the northern and southern areas. If fishing mortality increases substantially, or a portion of the stock declines substantially, then the current stock definition has the potential to mask conditions in the affected area and lead to reduced yield and biomass. The single stock assumption also complicates and adds uncertainty to stock status determinations based on current and recommended reference points (Part 1.11).

TOR 10. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in most recent SARC reviewed assessment and review panel reports. Identify new research recommendations.

Research recommendations were reviewed and evaluated and new ones were developed (Part 1.12).

Terms of Reference

A. Atlantic surfclams

1. Estimate catch from all sources including landings and discards. Map the spatial and temporal distribution of landings, discards, fishing effort, and gross revenue, as appropriate. Characterize the uncertainty in these sources of data.

2. Present the survey data being used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, etc.). Use logbook data to investigate regional changes in LPUE, catch and effort. Characterize the uncertainty and any bias in these sources of data. Evaluate the spatial coverage, precision, and accuracy of the new clam survey.

3. Determine the extent and relative quality of benthic habitat for surfclams in the Georges Bank ecosystem to refine estimates of stock size based on swept area calculations.

4. Quantify changes in the depth distribution of surfclams over time. Review changes over time in surfclam biological parameters such as length, width, and growth.

5. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series (integrating results from TOR 3, as appropriate) and estimate their uncertainty. Include a historical retrospective analysis to allow a comparison with previous assessment results and previous projections.

6. State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, F_{MSY} and MSY) and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs, particularly as they relate to stock assumptions.

7. Evaluate stock status with respect to the existing model (from previous peer reviewed accepted assessment) and with respect to any new model or models developed for this peer review.
   (a) When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.
   (b) Then use the newly proposed model and evaluate stock status with respect to "new" BRPs and their estimates (from TOR-5).

8. Develop approaches and apply them to conduct stock projections.
   (a) Provide numerical annual projections (five years) and the statistical distribution (e.g., probability density function) of the OFL (overfishing level) (see Appendix to the SAW TORs). Consider cases using nominal as well as potential levels of uncertainty in the model. Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment).

(b) Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.

(c) Describe this stock's vulnerability (see 15) to becoming overfished, and how this could affect the choice of ABC.

9. Evaluate the validity of the current stock definition. Determine whether current stock definitions may mask fishery related reductions in sustainable catch on regional spatial scales. Make a recommendation about whether there is a need to modify the current stock definition.

10. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in most recent SARC reviewed assessment and review panel reports. Identify new research recommendations.

1.3 TOR 1: Commercial

In this assessment for Atlantic surfclam the northern area was federal waters (3-200 nm from shore) on Georges Bank and the southern area was federal waters from south and west of Georges Bank to Cape Hatteras (Figures 6 and 7). Commercial landings were provided in meat weights for ease of comparison to survey data and in analyses, but were originally reported in units of industry cages. Landings per unit of fishing effort (LPUE) data were reported in this assessment as landings in bushels per hour fished, based on mandatory clam logbook reports. The spatial resolution of the clam logbook reports was usually one ten-minute square.

Unit	Equivalent
1 cage	32 bushels
1 bushel	1.88 ft^3
1 bushel	17 lbs. meats
1 bushel	7.71 kg meats

As in previous stock assessments (Northeast Fisheries Science Center 2013), "catch" was defined as the sum of landings, plus 12% of landings, plus discards. Based on prior calculations (Northeast Fisheries Science Center 2003), Atlantic surfclam catch in previous assessments was assumed to be 12% larger than landings to account for incidental mortality of clams in the path of the dredge. The 12% figure was considered an upper bound or overestimate because the area fished (e.g. 155 km^2 during 2004) is small relative to area covered by the stock (Walace and Hoff 2005). Furthermore, the ITQ (see below) clam fishery operates with little or no regulation induced inefficiency due to area closures, trip limits, size limits, etc. so that fishing effort and incidental mortality are reduced. The support for this estimate was reevaluated in this assessment based on data also used by Northeast Fisheries Science Center (2003), and more realistic algebraic relationships proposed by Dr. Deborah Hart (NEFSC, Woods Hole, MA) for sea scallops in Northeast Fisheries Science Center (2014).

The ratio of Atlantic surfclam in the path of a commercial dredge that are caught relative to those killed but not caught is $R = \frac{e}{c(1-e)}$ where e is capture efficiency and c is the fraction that die but are not caught. Indirect mortality due to contact with a clam dredge is in the range of 5-20% with an extreme upper bound of 50% (Table C10, (Northeast Fisheries Science Center 2003)). If F_L is fishing mortality for landed Atlantic surfclam and F_I is the incidental mortality rate then $F_I = \frac{F_L}{R} = \frac{F_L c(1-e)}{e}$ and $\frac{F_I}{F_L} = \frac{c(1-e)}{e}$. The ratio $\frac{F_I}{F_L}$ is the same as the ratio of numbers landed to numbers killed but not caught. If landed and incidental clams have the same size composition, then the ratio of landed weight to incidental weight is also $\frac{F_I}{F_L}$. The average efficiency of a commercial clam dredge for Atlantic surfclam is about 0.73 (Table A10 in NEFSC 2003). The range of estimates $c = 0.05$, 0.2 and 0.5 indicate that incidental losses are 2%, 7% and 18% of landings which together average about 13%. The Subcommittee concluded that the 12% incidental mortality estimate was reasonable for Atlantic surfclam.

Recreational catch is near zero, although small numbers of Atlantic surfclam are taken recreationally in shallow inshore waters for use as bait. Atlantic surfclam are not targeted recreationally for human consumption.

Discard data

Discards were zero from 2008-2015 since the last assessment. Some discards occurred during 1979-1993; as the result of a minimum size (shell length) requirement for landing that was in place over that period (Table 3). No new information about discards was available for this assessment.

Age and size at recruitment to the fishery

Age at recruitment to the Atlantic surfclam fishery depends on growth rates, which vary both spatially and temporally (see 1.4). The age at recruitment depends on the area being modeled (north vs. south), and the time period in question, as growth may change over time. Size at recruitment depends on the fishery selectivity estimated in the model. This issue is discussed in detail in section (1.7).

Landings, fishing effort and prices

Landings and fishing effort data for 1982-2015 were from mandatory logbook reports (similar but more detailed than standard Vessel Trip Reports used in most other fisheries) with information on the location, duration, and landings of each trip. Data for earlier years were from Northeast Fisheries Science Center (2003) and Mid-Atlantic Fishery Management Council (2006).

Landings data from Atlantic surfclam logbooks are considered accurate in comparison to other fisheries because of the Individual Transferable Quota (ITQ) and cage tag systems. However, effort data are not reliable for 1981–1990 due to regulations that restricted the duration of fishing to 6 hours. Effort data are considered reliable for years before 1985 and after 1990.

Atlantic surfclam landings were mostly from the US Exclusive Economic Zone (EEZ) during 1965 to 2011 (Table 4 and Figure 8). EEZ landings peaked during 1973–1974 at about 33 thousand mt, and fell dramatically during the late 1970s and early 1980s before stabilizing beginning in about 1985. The ITQ system was implemented in 1990. EEZ landings were relatively stable and varied between 18 and 25 thousand mt during 1985 to 2015. Landings have not reached the quota of 26,218 mt since it was set in 2004 because of limited markets. The quotas are set at levels much lower than might be permitted under the FMP. Approximate state landings are shown in Table 4, and more accurate state landings are available in Appendices (7). Both New Jersey and New York have seen a sharp decline in Atlantic surfclam biomass within their state territorial waters over the past 15 years, and an accompanying drop in landings (7).

The bulk of EEZ landings were from the DMV region (Figure 7) during 1979-1980. After 1980, the bulk of landings were from the NJ region (Table 5 and Figure 9). Landings from LI were modest but began increasing in 2001. Landings from SNE were modest but increased starting in 2004. The high proportion of landings on GBK reflects the high catch rates there (see below).

Total fishing effort increased after 1990 and has been relatively high, but stable since 2007, particularly in the DMV and NJ regions (Table 6 and Figure 10). The bulk of the fishing effort was in areas where the majority of landings come from.

Real ex-vessel prices for the inshore and EEZ fisheries have been stable, since the mid-1990s (Table 7 and Figure 11). Nominal revenues for Atlantic surfclam during 2013 were about $33 million.

Landings per unit effort (LPUE)

Nominal landings per unit effort (LPUE) based on logbook data was computed as total landings divided by total fishing effort for all vessels and all trips (Table 8 and Figure 12). Standardized LPUE was not estimated for this assessment because the data are not used analytically and because Northeast Fisheries Science Center (2007) showed that nominal and standardized trends were almost identical, when standardized trends were estimated in separate general linear models for each region with vessel and year effects.

Nominal LPUE has been declining steadily in SVA, DMV and NJ, which have recently been at or near record lows. LPUE in GBK and SNE have generally been high.

LPUE is not an ideal measure of fishable biomass trends for sessile and patchy stocks like Atlantic surfclam because fishermen target high density beds and change their operations to maintain relatively high catch rates as stock biomass declines (Hilborn et al. 1992).

Spatial patterns in fishery data

Mean landings, fishing effort, and LPUE were calculated by ten-minute square (TNMS) from 1979-2015 in 5 year blocks (Figures 13 – 18). Only TNMS where more than ten bu of Atlantic surfclam were caught over the time period were included in maps. TNMS with reported landings less than 10 bu were probably in error, or from just a few exploratory tows. Inclusion of TNMS, with less than 10 bu distorted the graphical presentations because the area fished appeared unrealistically large.

Figures 13 – 18 show the spatial patterns of the Atlantic surfclam fishery over most of its history. In most blocks, the greatest concentration of fishing effort and landings occurred in the same thirty or so TNMS in the NJ region, with intermittent fishing activity in other regions and recent emphasis on SNE and GBK.

TNMS with the highest LPUE levels over time have been mostly in the NJ and DMV regions with irregular contributions from GBK and the Nantucket Shoals region of SNE.

Important TNMS

TNMS important to the fishery were identified by choosing the 10 TNMS from with the highest mean landings during each 5 year time block. For example, a TNMS important during 1991-1995 could be selected regardless of its importance during earlier or later time periods. The list contains a subset of the total TNMS, because of overlap between the time periods and because the same TNMS tend to remain important. These plots are complicated by the "rule of three", which states that fine scale fishing location data cannot be shown for areas fished by three or fewer vessels due to confidentiality concerns. Trends in landings, effort, and LPUE were plotted (Figures 19 – 21) for each TNMS to show changes in conditions over time within individual TNMS.

With the exception of GBK, there are very few important ten-minute squares in which the LPUE has trended upwards in recent years, if they are still being fished. Most are currently at or below about 100 bushels per hour.

Fishery length composition

Since 1982, port samplers have routinely collected shell length measurements from approximately 30 random landed Atlantic surfclam from selected fishing trips each year (Table 9).

Port sample length frequency data from the four regions show modest variation in size of landed Atlantic surfclam over time with declines in modal size in DMV and NJ since 2008 (Figures 22 – 28). Care should be taken in interpreting these due to small sample sizes in some cases (especially LI, SNE and GBK), but in general the data indicate that most landed Atlantic surfclam have been larger than 120mm SL. Commercial size distributions are discussed in detail in section (1.7).

Fishery management

The Atlantic surfclam is managed by the Mid-Atlantic Fishery Management Council (Council). The Council is one of eight regional fishery management councils created when the United States (U.S.) Congress passed Public Law 94-265, the Magnuson Fishery Conservation And Management Act of 1976 (also known as Magnuson-Stevens Act or MSA). The law created a system of regional fisheries management designed to allow for regional, participatory governance. The Council develops fishery management plans and recommend management measures to the Secretary of Commerce through the National Marine Fisheries Service (NMFS) for its fisheries in the Exclusive Economic Zone of the U.S. (EEZ; 3-200 miles off the east coast). There are also fisheries for Atlantic surfclam in New Jersey, New York, and Massachusetts within state waters (within 3 miles of shore); the state authorities are responsible for managing these fisheries, although fishing and survey data for state fisheries were presented in this document (see 7).

Atlantic surfclam is managed with another species (Ocean quahog, *Arctica islandica*) under a single fishery management plan, that was first developed by the Council in 1977. The Atlantic surfclam fishery was initially managed through limited-entry restrictions, quarterly quotas, and fishing time restrictions. By the mid-1980s, effort limitation combined with overcapacity in the fishery meant that capacity utilization was very low, with vessels operating only 6 hours every other week in 1990. An individual transferrable quota (ITQ) system was established in 1990 which initially allocated shares to vessel owners based on a formula including historical catch and vessel size. Economic efficiency improved and management monitoring decreased as a result of initial ITQ implementation, but it also led to consolidation and displacement of labor (particularly non-vessel owning captains and crew). ITQ shares can be traded or leased to any non-foreign person or entity, with no pre-conditions of vessel ownership. Market consolidation and existing vertical integration have increased over time. From 1990 to 2005, the Atlantic surfclam fleet size decreased by about 70%.

Under the current management system, managers set an annual catch limit for Atlantic surfclam and allocate landings to the ITQ shares. The Council's annual catch limit recommendations for the upcoming fishing year(s) cannot exceed the acceptable biological catch (ABC) recommendation of its Scientific and Statistical Committee (SSC). The SSC serves as the Councils primary scientific/technical advisory body, and provides ongoing scientific advice for fishery management decisions, including recommendations for ABC, preventing overfishing, maximum sustainable yield, and achieving rebuilding targets.

In order to participate in the Atlantic surfclam fishery, fishermen must have a permit to commercially harvest and sell Atlantic surfclam (using valid ITQ shares), and there are mandatory reporting and vessel-monitoring requirements, as well as clam cage-tagging requirements. There is a minimum size for Atlantic surfclam, which can be suspended by managers if it is demonstrated the harvest of small Atlantic surfclam is below a certain threshold. Fishing areas can be closed due to environmental degradation or due to the toxins that cause paralytic shellfish poisoning (PSP). PSP is a public health concern for Atlantic surfclam. It is caused by saxitoxins, produced by the alga *Alexandrium fundyense* (red tide), that accumulate in shellfish, and has resulted in fishery closures in the Georges Bank Area of the EEZ. NMFS recently (2013) reopened portions of the closed areas to harvest of Atlantic surfclam for those vessels using a protocol for onboard screening and dockside testing to verify that clams harvested from these areas are safe. Areas can also be closed to Atlantic surfclam fishing if the abundance of small clams in an area meets certain threshold criteria. This small Atlantic surfclam closure provision was applied during the 1980's with three area closures (off Atlantic City, NJ, Ocean City, MD, and Chincoteague, VA), with the last of the three areas reopening in 1991.

1.4 TOR 2: Survey

NEFSC clam surveys

Survey data used in this assessment were from 2 different sampling platforms. The first was the NEFSC clam surveys conducted during 1982–2011 by the *RV Delaware II* during summer (June–July), using a standard NEFSC survey hydraulic dredge with a submersible pump. The survey dredge had a 152 cm (60 in) blade and 5.08 cm (2 in) mesh liner to retain small individuals of the two target species (Atlantic surfclam and ocean quahogs). The survey dredge differed from commercial dredges because it was smaller (5 ft instead of 8-12.5 ft blade), had the small mesh liner, and because the pump was mounted on the dredge instead of the deck of the vessel. The survey dredge was useful for Atlantic surfclam as small as 50 mm SL (size selectivity described below). Changes in ship construction, winch design, winch speed and pump voltage that may have affected survey dredge efficiency were summarized in Table A7 of Northeast Fisheries Science Center (2003). The second survey platform was the *ESS Pursuit*, a commercial vessel that was contracted to conduct the NEFSC clam survey since 2012, when the *RV Delaware II* was retired. The *ESS Pursuit* used a modified commercial dredge described in detail in Hennen et al. (2016). Surveys conducted from the *ESS Pursuit* have taken place in August each year since 2012.

Surveys prior to 1982 were not used in this assessment because they were carried out during different seasons, used other sampling equipment or, in the case of 1981, have not been integrated into the clam survey database (Table A7 in (Northeast Fisheries Science Center 2003)).

NEFSC clam surveys were organized around NEFSC shellfish strata and stock assessment regions (Figure 7). Most Atlantic surfclam landings originate from areas covered by the survey. The survey did not cover GBK during 2005 and provided marginal coverage there in 1982, 1983, and 1984. Individual strata in other areas were sometimes missed. Strata and regions not sampled during a particular survey were "filled" for assessment purposes by borrowing data from the same stratum in the previous and/or next survey if these data were available (Table 10). Survey data were never borrowed from surveys before the previous, or beyond the next survey. A model–based imputation was investigated for the last assessment (Northeast Fisheries Science Center 2013), but the imputation tended to over–emphasize unsampled years and areas. Alternative approaches to imputing missing strata were not further pursued in this assessment.

Surveys followed a stratified random sampling design, allocating a pre-determined number of tows to each stratum. A standard tow was nominally 0.125 nm (232 m) in length (i.e. 5 minutes long at a speed of 1.5 knots) although sensor data used on surveys since 1997 show that tow distance increases with depth, varies between surveys and was typically longer than 0.125 nm (Weinberg et al. 2002). These problems were eliminated in 2012 when the survey was switched to the *ESS Pursuit*. For trend analysis, when using data from before 2012, changes in tow distance with depth were ignored and survey catches were adjusted to a standard tow distance of 1.5 nm based on ship's speed and start and stop times recorded on the bridge. Stations used to measure trends in Atlantic surfclam abundance were either random or "nearly" random. The few, nearly random tows were added in some previous surveys in a quasi–random fashion to ensure that important areas were sampled. Other non-random stations were occupied for a variety of purposes (e.g. selectivity experiments) but not used to estimate trends in abundance. Locations and catches of all stations in the survey have been mapped (Figures 29–34).

Occasionally, randomly selected stations were found to be too rocky or rough to tow, particularly on GBK. The proportion of random stations that could not be fished was an estimate of the proportion of habitat in an area that was not suitable habitat for Atlantic surfclam (1.5). These estimates were used in the calculation of Atlantic surfclam swept-area biomass (see below).

Following most survey tows, all Atlantic surfclam in the survey dredge are counted and shell length is measured to the nearest mm. Large catches were subsampled. Mean meat weight (kg) per tow was computed with shell length-meat weight (SLMW) equations (updated in this assessment) based on fresh meat weight samples obtained during the 1997–2015 surveys (see below).

Survey tow distance and gear performance based on sensor data

Beginning with the 1997 survey, sensors were used to monitor depth (ambient pressure), differential pressure (the difference in pressure between the interior of the pump manifold and the ambient environment at fishing depth), x-tilt (port- starboard angle, or roll), y-tilt (fore-aft angle, or pitch) and ambient temperature during survey fishing operations. At the same time, sensors on board the ship monitor GPS position, vessel bearing and vessel speed. Most of the sensor data are averaged and recorded at 1 second intervals. These metrics of tow performance can be used to accurately gauge the true distance fished by the dredge.

Determination of time fishing

The determination of time fishing, the “fishing seconds” for each tow (after 1997), was based on a measurement of the pitch of the dredge during each second of the tow. Pitch data were smoothed using a 7 second moving average and then compared to a “critical angle” to determine when the dredge was fishing effectively. When the dredge was above the critical angle it was assumed to be pitched too steeply for the blade to penetrate the sediment. When the dredge was pitched below the critical angle, it was assumed to be near enough to horizontal that the blade should penetrate and thus be actively fishing.

It is important to find a critical angle for tow distance that is neither too small, nor too large. When the dredge is bouncing over rough terrain it is unlikely to be fishing effectively and those seconds should be excluded. There is however, a certain amount of pitch that is within fishing tolerance and a certain amount of noise in the data. If the critical angle is too small, many seconds when the dredge was actually fishing would be excluded, which would tend to bias estimates of tow distance down. Further discussion of the determination of critical angle as well as summaries of dredge performance by year are in appendices (16–18).

NEFSC clam survey trends and composition data

NEFSC clam survey data for Atlantic surfclam, including the number and weight caught per tow were tabulated by year, region and for the entire stock (Table 11). Mean numbers per tow were used in the plots of trends because trends in mean kg per tow were similar. Approximate asymmetric

95% confidence intervals were based on the CV for stratified means and assume that the means were log normally distributed.

Survey trends for small Atlantic surfclam (Figure 35) provide some evidence for recruitment trends over time. Recruitment appears to be increasing in DMV, NJ, LI, and SNE since the last assessment. Survey trends for fishable (120+mm) Atlantic surfclam (Figures 36) show evidence of decreasing abundance in the SVA, and possibly LI regions, but there are increasing trends in abundance in DMV, NJ and SNE. We cannot make inference on trends in abundance or recruitment on GBK because there is only one data point available from the new survey. Based on survey data for the entire southern area, recruitment and fishable abundance have been increasing since the last assessment in 2011 (Figures 37 – 39).

Survey age–length keys and stratified mean length composition data were used to estimate the age composition of Atlantic surfclam in NEFSC clam survey catches and the stock as a whole by year and region. Age composition was estimated for the years between 1982 and 2015 when surveys occurred. Ages ranged from 1-37 (Figures 40 – 46). Specific year classes and trends in length and age composition are discussed in the context of the assessment model (see 1.6).

Shell length composition data (Figures 47 – 52) can be helpful in visually identifying shifts in population demography. For example, there is evidence of recent recruitment in the southern area regions.

Dredge efficiency

Changes to the NEFSC survey involved changes to the survey gear. In particular, shifting the survey dredge from the research dredge (RD) used on the *RV Delaware II* to the modified commercial dredge (MCD) used on the *ESS Pursuit* was an important modification in that it necessitated a re-evaluation of capture efficiency. Fortunately the MCD was the same dredge that was used in previous depletion experiments (Northeast Fisheries Science Center 2013) so estimates of capture efficiency already exist. These are discussed in detail in Appendix 4 and Northeast Fisheries Science Center (2013).

Estimates of survey dredge efficiency were used to generate prior distributions for capture efficiency for each survey in the assessment model (see 1.7). A comparison of the prior distribution for the RD to the prior distribution for the MCD shows that the MCD has higher and more precisely estimated efficiency (Figure 53).

Size selectivity

Selectivity data were collected on the *ESS Pursuit* during selectivity experiments in 2008 – 2015. Data from the experiments were used to estimate size-selectivity for the MCD. The MCD was configured for survey operations, rather than commercial fishing operations. Thus, the size selectivity estimates for the commercial dredge used by the *ESS Pursuit* during cooperative survey work are not directly applicable to commercial catch data. Selectivity experiments are described in Hennen et al. (2016).

The data available for each selectivity study site included shell length data from: one MCD tow, and one F/V selectivity tow using either a commercial dredge lined with wire mesh or a specially designed selectivity dredge (SD). Gear testing work done in 2014 showed that the SD and the lined commercial dredge should be interchangeable in selectivity studies (Hennen et al. (2016)).

Shell length data from selectivity experiments conducted since the last assessment were tabulated using 1 mm shell length size groups (Tables 12 – 13). Survey size selectivity was estimated using data from 47 total sites.

Selectivity was modelled as a generalized additive mixed model (GAMM), where the shell length bin was a factor, predicting the binomial proportion of the survey catch over the total catch (SD + MCD). The fully saturated model was

$$P_L = e^{(\alpha + s(L) + s[YrSta, L] + offset)} \quad (1)$$

Where P_L is the binomial proportion (logit link) estimated for shell length L with intercept α and vector of model terms evaluated over L. The $s()$ terms indicate a spline over variables, in this case shell length (L) and a random effect (indicated with braces) due to station and year. The final term is an offset (Pinheiro and Bates (2006)) based on the tow distance at each station. Tow distance is a potential source of bias because clams can be unevenly distributed on the sea floor. The nominal time fished for the lined dredge is 45 s compared to 5 min. for a nominal survey tow, while the SD was towed for 2 min.

Using the GAMM methodology allowed greater flexibility in the model, when compared to assuming any particular shape. The basis dimension (k) in a spline determines the amount of "wiggle" allowed in the spline. Wood (2009)[2] suggests an objective method for choosing a basis dimension in splines. This method allows the data to determine the shape required to adequately fit them rather than the modeller.

The inclusion of random effects based on station is important because there is a great deal of variation in selectivity between stations. Variation across stations is essentially a nuisance parameter in our assessment because we are interested in the general selectivity over all possible stations, rather than the differences between them (Figure 54). Because we believe that clams taken from a particular place and time would tend to experience similar selectivity when compared to clams taken from a different place and time, it is appropriate to model selectivity using random effects.

Approximate confidence intervals were estimated using

$$CI_L = elogit^{(\rho_L \pm 1.96\sigma_L)} \quad (2)$$

Where CI_L is the approximate confidence interval for selectivity at length L, ρ_L is the corresponding logit scale model estimate, σ_L is the standard error and elogit is the inverse of the logit function.

Selectivity estimates (Tables 14 – 15; Figure 55) were used to generate swept area and survey index plots (Figures 35 – 39) and are useful for comparison to assessment model results.

[2]See R package mgcv documentation

Shell length, meat weight relationships

The shell length-meat weight (SLMW) relationships are important because they are used to convert numbers of Atlantic surfclam in survey catches to meat weight equivalents. The survey meat weight equivalents are inputs in the stock assessment models used to estimate stock biomass, which is reported in units of meat weight. Meat weights for Atlantic surfclam include all of the soft tissues within the shell. All meat weights greater than 0.5 kg were assumed to be data entry error, and were removed from the analysis.

Generalized linear mixed models (GLMM; Venables and Dichmont (2004)) were used to predict clam meat weight, using equations of the form:

$$MW = e^{(\alpha+\beta_0 ln(L)+\beta_1 c_1+\beta_2 c_2+\cdots+\beta_n c_n)} \tag{3}$$

where MW was meat weight, L was shell length, $c_1, \cdots, c_n$ were covariate predictors (*e.g.*, region or depth), and α and β_i were the estimated parameters. Examination of the variance of the weights as a function of shell length indicated that weight increased approximately linearly with shell height, implying that the Poisson family was reasonable for the distributions of meat weights (McCullagh and Nelder 1989). The GLMM in all analyses used the quasi-Poisson family with a log link. Quasi-Poisson is a Poisson distribution with a variance inflation parameter that relaxes the Poisson requirement that the mean must equal the variance. Because shell length to meat weight relationships for Atlantic surfclam at the same station are likely to be more similar than those at other stations, we considered the sampling station as a grouping factor ("random effect") in the analysis.

We fit models with fixed effects for year and region (Table 16). The best model by AIC and BIC was a model with fixed effects for shell length, depth, and region and random effects for shell length slope and the intercept, using both the year and the station as the grouping variables.

Regional differences in meat weight are meaningful, particularly for the largest animals (Figure 56), though some of the differences between regions can be explained by the different depths found there (Figure 57).

Age and growth

Atlantic surfclam were measured at sea and the shells were retained for ageing in the laboratory. Shells for ageing were collected based on a length stratified sampling plan. A recent study confirmed that rings on shells collected during the summer clam survey are annuli that can be used to estimate age (Northeast Fisheries Science Center 2010). Age and length samples are available for most regions, but not from every survey (Table 17).

Plots of age vs. shell length by year and region (Figures 58 – 64) indicate that growth patterns have been relatively constant in most regions over time with DMV and NJ, where growth has slowed and maximum size has decreased over the last two decades.

Von Bertalanffy parameters for growth in shell length were estimated for each region and each survey year for which sufficient data existed (Table 18). The Von Bertalanffy growth curve used in the calculations was:

$$L_a = L_\infty(1 - e^{(-k(a-t_0))}) \tag{4}$$

Where L_a was length (mm) at age a, and L_∞, k and t_0 are Von Bertalanffy parameters.

Atlantic surfclam are thought to mature very early. Data are limited but Atlantic surfclam off New Jersey may reach maturity as early as 3 months after settlement and at lengths of less than 5 mm (Chintala and Grassle 1995; Chintala 1997).

Survey trends and LPUE for important ten-minute squares

We analyzed commercial LPUE and survey data for 1982 - 2011 for important ten-minute squares (TNMS see section 1.3) in the southern New Jersey and Delmarva regions where fishing is traditionally concentrated to better understand potential fishing effects on key southern fishing grounds. Modes in size composition data from the commercial catch declined steadily in these areas over the last decade (Figures 22 – 28) but the declines are not clear in survey size composition data through 2011 when survey gear changed (Figures 47 – 52), probably due to size selective removals of large clams on fishing grounds. Survey and LPUE data suggest that abundance trends in areas where fishing occurs were similar to trends for the New Jersey and Delmarva regions as a whole. Thus, fishing seems to have had modest effects on abundance in TNMS where fishing was highest.

TNMS were much smaller than survey strata and not all squares were sampled during each year. We therefore analyzed the data "as is" (ignoring the unsampled squares) and after filling the holes with imputed survey "data" from a GAM model. The GAM model (mgcv library in the R programming language) was $gam(N_{tow} \sim s(Y, tnms) + tnms)$. In this model, N_{tow} is the number of Atlantic surfclam caught in the tow, Y is the survey year (continuous) and $tnms$ is the ten-minute square (a categorical factor). About 5% of survey tows had zero catch so we fit the model using the default log link function assuming errors from a Tweedie distribution, which is a combination of a logistic distribution (for zero observations) and a Gamma distribution (for positive catches). Given these specifications, the model handles zero and non-zero catches directly while estimating a different intercept (average catch rate) and different interannual trends for each TNMS. In effect, there was a separate model for each TNMS.

The imputed data from the fitted GAM model ($R^2 = 0.48$, deviance explained=75%, N=299) amount to interpolations between years with observed data and extrapolations for missing years at the beginning and end of the time series (Figure 65). Extrapolation is possible in the mgcv GAM software as long as the years involved are within the range of years in the dataset as a whole, even though the models for different TNMS are nearly independent. The surveys were usually triennial so that interpolations and extrapolations were over relatively long periods of time (1-11 years). Extrapolation is not valid from a statistical point of view and should (along with interpolations over many years) be viewed with caution but the analysis was exploratory and results did not depend strongly on using imputed data (see below).

Interannual time series for the New Jersey and Delmarva regions were calculated by averaging all values (observed and/or predicted values) for each region and year. TNMS were the same size so the annual averages amounted to stratified random mean numbers per survey tow. Results with and without imputed data were similar (Figure 66). All results indicate that abundance declined rapidly during 1995-2005 (on fishing grounds) to current relatively low levels (Figure 67).

LPUE and survey data for important TNMS show that LPUE remained high as abundance declined off New Jersey (correlation coefficient $\rho = 0.2$, Figure 67). Survey trends in important TNMS and for New Jersey as a whole were strongly correlated ($\rho = 0.79$). In contrast to New Jersey, trends in survey and LPUE in important TNMS off Delmarva had a linear relationship and were strongly correlated ($\rho = 0.59$). Survey trends in important TNMS and for Delmarva as a whole were also strongly correlated ($\rho = 0.52$).

Evaluation of new survey

Spatial coverage

The assessment working group reviewed information showing fishing activity and survey catches in an area south of Nantucket that is not routinely surveyed, they also evaluated several approaches for identifying Atlantic surfclam habitat based on data from multiple surveys, multi-beam acoustic data, published studies, environmental measurements and habitat suitability models (Appendix 13). Such data would be useful for expanding the survey to cover new grounds, restratification and in improving the NEFSC clam survey design. The approaches presented appeared potentially useful and should be further developed for consideration by a future working group tasked specifically with evaluating survey design. NEFSC Survey Branch personnel and program managers would need to be heavily involved in the discussions.

Changes in the spatial distribution of biomass

We calculated relative swept-area survey biomass of Atlantic surfclam (all sizes) by region and area during 2012-2015. No adjustments were made for capture efficiency, size selectivity or changes when the new survey began in 2012 to keep the analysis simple and because these parameters may be the same for all regions in the same year and should tend to “cancel out”. The proportion of biomass in year y and region r was calculated $p_{y,r} = \frac{p_{y,r}}{\sum_s p_{y,s} A_s}$ where A_s is the area (nm^2) of one of the regions. The northern and southern areas were sampled in different years after 2011, so data from the survey in the northern area during 2013 was used in these calculations for both 2012 and 2015.

Results show the increase in the proportion of total biomass in GBK and declines off DMV during 1982-2011 measured using the old survey dredge (Figure 68). These patterns were attributed to rising water temperatures in the last assessment. Unexpectedly, proportions of total biomass on GBK dropped during 2012-2015 while fractions in NJ and DMV increased based on survey data from the new dredge. Biomass indices increased after 2011 in all regions because the new dredge is more efficient and sweeps more ground. However, increases during 2012-2015 in the south were larger than increases in the north. It is possible that these patterns reflect changes in spatial distribution but they may also be due to reduced capture efficiency in the new survey using the MCD in the relatively rough and rocky GBK region. The latter possibility could be investigated by conducting depletion studies on GBK to estimate capture efficiency directly.

Precision

The MCD survey was expected to be more precise than the original survey because the new dredge is more efficient (see 4), tow distance is more consistent (see below) and because the area swept by a tow in the new survey is larger (RD mean about 580 m^2 with CV=25% and MCD mean=1764 m^2 with CV=11%). However, there was no clear reduction in CVs for survey abundance indices (stratified mean catch per tow) with the MCD (Table 11 and Figures 35–38). Lower numbers of tows beginning in 2012 reduced the precision of abundance indices for the southern area. There is no evidence that the variance among individual tows in the same stratum was reduced after 2012 (Table 10 and Figure 35–38). However, swept-area stock size estimates were probably more precise (Figure 38) when using the MCD despite little or no improvement in abundance indices because capture efficiency estimates for the MCD are more precise than estimates for the RD (Figure 53; Table 10) and 4).

Borrowing should be less common in the future because NEFSC expects to survey the northern and southern areas completely during sequential years rather than in parts (see 2 for a discussion of the borrowing required for this assessment). This plan and the goal of reducing the frequency of unsampled strata are important because of the difficulties in borrowing lengths and ages from other years now that length and age data are used in the assessment model. Borrowing from adjacent surveys is a type of imputation, but further work on imputation techniques is warranted. NEFSC (2007) used negative binomial GAM models to impute catches for strata with no data that could not be filled by borrowing but with modest effect on results. Model based approaches might have larger effect if all strata with missing data were imputed.

The total number of stations in the NEFSC clam survey is limited by the time devoted to the survey with deductions for transit time, bad weather, etc. The proportion of the total number of random survey stations in each stratum for each region (northern or southern) in the new survey was based on stratum area and on the mean catch and variance in catch for Atlantic surfclam plus ocean quahogs in previous surveys (Cochran 1977). This standard approach minimizes the variance of the total stratified mean catch per tow but does not minimize the variance for either individual species.

It might be possible to improve overall precision of the clam survey by changing the relative amounts of time used to sample the northern and the southern areas in subsequent years without changing the total time or cost for the survey as a whole.

The precision of stratified random mean estimates like clam survey abundance estimates depends on the number of tows and variance in catches within each stratum (Table 10). The reduction in the number of tows in the southern area after 2011 increased the standard deviation and CVs of the stratified means.

Tow distance with the RD varied strongly with depth and among years when tow procedures changed unintentionally (Figure 69). Tow distances since 2012 have been less variable in general and relatively constant across depth and years. These changes should improve precision of survey data for recent years.

Analysis of precision was complicated by limited number or zero samples in some strata and years, a high proportion of tows with no catch (about 60%), different temporal trends among strata, and the tendency for variance to increase with the mean catch per tow. We dealt with these problems by considering variance in the proportion of positive tows and variance in log catch for positive tows separately, and by calculating the variance of randomized quantile residuals from models with likelihoods that were calculated using the compound Tweedie distribution which accommodates both zeroes and positive values. These analyses used data from random tows with sensor data collected since 1997, from strata that were sampled consistently (in all surveys) in each region (Table 19). In particular, we used survey data from northern strata 55, 57, 59, 61, 70-71 and 73-74 sampled during 1997, 1999, 2002, 2008, 2011 (RD), and 2014 (MCD) and data for southern strata 9, 10, 13, 17, 18, 21-22, 25-26, 29-30, 33-34 and 84-93 sampled during 1997, 1999, 2002, 2005, 2008, 2011 (RD), 2012 and 2015 (MCD) in the south.

To begin, we calculated the mean and standard deviations for a dummy variable that identified positive tows (=1 if Atlantic surfclam were caught and 0 otherwise) and for log of Atlantic surfclam catch in positive tows (Figure 70). There were no obvious changes in the proportion of positive tows in the new survey or in the variance of the dummy variable or log positive catch. Higher proportions and lower variance in the dummy variable for positive tows might be expected using a dredge that affords higher precision although positive tows are likely at even low Atlantic surfclam densities using either survey dredge (10).

Next, we fit a series of GLM and GAM models to catches (tows with and without catch combined) and used AIC to determine the "best" (by AIC) model (Table 20). The best model (gamB) explained 45% of the total deviance, 23% of the total variance and the residuals were close to normally distributed. The distributions and standard deviation of residuals from the best model do not indicate increases in precision of individual tows beginning in 2012 (Figure 71).

1.5 TOR 3: Habitat

This TOR was driven by concern that relatively high densities of clams measured by survey tows in easy to sample areas on Georges Bank might be applied to rocky low density habitats that are difficult to sample so that model and swept-area biomass estimates are biased high. In stock assessment calculations, stock biomass $B = \frac{bA}{ae} = bQ$ where b is mean catch per tow, A is the area surveyed (the parameter of concern), a is area swept and e is capture efficiency. In recent assessments, the area surveyed on Georges Bank (A) was reduced by 12% assuming that the proportion of untowable stations represents grounds that were poor habitat with no Atlantic surfclam. For this assessment, the working group reviewed survey procedures and recalculated the proportion of untowable ground.

A list of random survey stations is prepared prior to the first leg of each clam survey and the captain determines towability when the ship reaches each random station. In the past, during the 1999, 2002, and 2005 surveys (Georges Bank was not surveyed in 2005), untowable stations were noted in station logs using a special "SHG=151" code. In the more recent survey during 2013-2014, text in comment fields and other SHG codes can be used to determine if a station was untowable, if the dredge was filled with rocks and no Atlantic surfclam, or the dredge was damaged by rocks. Based on "151" codes, 12/83=14% of random stations on GBK were not trawlable. In later years, 13/74=18% of random stations were not trawlable. The combined average (14%) is somewhat higher than the 12% figure used in this assessment. New habitat databases and models under development will soon be available for refining estimates of poor Atlantic surfclam habitat for GBK (Appendix 13). In addition, procedures for dealing with untrawlable stations in the survey may need to be modified so that this information is collected routinely and is clear in the survey database.

1.6 TOR 4: Depth and changes in biological parameters

As ocean temperatures increase, the distribution and biology of Atlantic surfclam are potentially changing with potential effects on fishery productivity. For example, increasing water temperature may result in changes to the biological parameters that describe growth (Munroe et al. 2016). Increasing water temperature may also be driving a shift in Atlantic surfclam distribution, to deeper water in the southern area (Weinberg et al. 2002). It is reasonable to assume that any responses to temperature would be strongest in the southern-most regions (SVA, DMV and NJ), where ocean temperatures are warmest and probably nearest the warm water tolerance for Atlantic surfclam.

Depth and temperature

Survey stations are distributed randomly relative to depth within a stratum and the same strata tend to be sampled over time within a region (Table 10). Therefore, if the depth distribution of Atlantic surfclam were trending over time, the depth at which most of the animals were caught within a region might be expected to increase. Plots of the depth at which the median cumulative catch within each region occurs over time show this relationship in two regions, DMV and NJ (Figures 72 – 77).

Warming coastal waters might change the spatial overlap between Atlantic surfclam in relatively shallow water and ocean quahogs that are found in adjacent deeper water. Overlap is important because the fishery operates most efficiently where only one species is caught. The depth at which 95% of the cumulative catch of Atlantic surfclam was taken during 1982-2011 clam surveys was used as the offshore habitat boundary for Atlantic surfclam and the depth at which 5% of the cumulative quahog catch was used as the inshore boundary for ocean quahogs (Figure 78). In the 1980s and with the exception of the LI region, the two habitat boundaries were similar indicating that the habitat was partitioned across depth as expected. There was no evidence that the inshore boundary of ocean quahog habitat changed in later years but there was clear evidence that the offshore boundary of Atlantic surfclam habitat shifted to deeper water in the southern NJ and DMV regions and, surprisingly, in the northern most GBK region. By the mid- to late 1990s, the overlap in Atlantic surfclam and ocean quahog habitat was pronounced in the south. The shift on GBK may have been due to increases in Atlantic surfclam abundance (Figure 36). In contrast, abundance generally decreased after 1982 in the south and the change in habitat boundaries was more likely. Results for LI were anomalous given that the offshore boundary for Atlantic surfclam was consistently deeper than the inshore boundary for ocean quahogs, probably due to high density beds of ocean quahogs in cold shallow water (Figure 78) and the increased presence of clay as substrate, which tends to contain more ocean quahog than Atlantic surfclam.

The sampling properties of presence-absence data from NEFSC survey tows were characterized analytically (Appendix 11). Results show that survey tows are almost certain to detect clams at relatively low densities (roughly 0.013 per m^2, corresponding to about 15 encounters per tow in the RD). Thus, presence absence data are useful for detecting clams at relatively low densities but not for tracking trends in abundance when density is higher. Based on these results, presence-absence data were used in this assessment to quantify extent but neither quality of habitat nor density of clams.

Presence-absence GAM models showed that the probability of co-occurrence (both species in the same tow) decreased almost linearly during 1982-2011 in the SNE region while increasing almost linearly in the LI and NJ regions (Figure 79 and Appendix 10). Trends were not statistically significant in the DMV and GBK regions where strong changes in abundance may complicate interpretation.

The amount of habitat for Atlantic surfclam was quantified by dividing the area surveyed consistently in each region into relatively small areas based on latitude and longitude as well as two other coordinate systems (Appendix 12). Presence-absence GAM models with time and position as predictor variables were selected from a set of candidates based on AIC. Habitat was quantified by summing the predicted probability of a positive tow from the best model over all of the small areas in each region and year. Results suggest that habitat area declined in the south in the DMV area due to losses in shallow water, increased along the central Mid-Atlantic Bight (NJ and LI areas) due to increases in deep water and varied without trend in the north (SNE and GBK areas). Temperature data were not available but these changes were likely due to water temperatures increasing above the preferred range for Atlantic surfclam in nearshore coastal areas off DMV (Weinberg 2005) and above the lower bound of the preferred range in deep waters off NJ and LI.

Temperature was recorded as part of the survey station data (beginning in 2002), and may be a useful indicator of habitat preference for Atlantic surfclam. Plots of the temperature and depth recorded at each survey station over time, against the total number of Atlantic surfclam caught are provided here (Figures 80 – 85). The results indicate that temperature and depth preferences vary by region, but appear to be relatively consistent over (recent) time. This may be indicative of local adaptation, or there may be other local factors, potentially correlated with temperature and depth, that influence habitat preference in each region.

Changes in biological parameters

If increasing ocean temperature negatively affects the fitness of Atlantic surfclam, one might expect to see decreases in the biological parameters that describe growth, particularly in the southernmost regions where water temperatures are highest. Analysis indicates that DMV and NJ have experienced declines in average maximum length (L_∞) through time (Figure 86). NJ and SNE have shown decreases in the rate at which an animal approaches its theoretical maximum size (K; Figure 87).

1.7 TOR 5: Model

The Atlantic surfclam assessment model was implemented in SS3[3] (Methot and Wetzel 2013). Separate SS3 models were developed for Atlantic surfclam in the southern and northern areas. Divergent population dynamics (*i.e.*, different biomass and mortality trends, changes in proportion of total biomass in the two areas over time, very limited fishing in the north, and differences in occurrence of strong year classes) made it too difficult to estimate "average" population dynamics for the areas combined. Also, data would be lost if the areas were combined because surveys were not available for the entire combined assessment region in some years. In this assessment, biomass, fishing mortality, recruitment, and other quantities for the combined regions were estimated by combining elements for the southern and northern areas.

Configuration

Fishery and survey selectivity were functions of size rather than age in SS3 models. Conditional age at length data, rather than traditional age composition data, were used in fitting models. The conditional age vector with indices t, a, L for example, gives the proportion or number of observed ages (a) from samples of length L in year t of the NEFSC clam survey. The major advantage of the conditional approach is that more information about growth (including variance in size at age) and year-class strength is preserved. Size composition data are not used twice (once as size composition data and once in calculation of traditional catch at age). Finally, the sampling distribution of conditional age data is probably easier and more accurately characterized as a multinomial, conditional on the number of ages (at t and L) actually sampled.

The same types of data (Figures 88 and 89) were available for both areas, although more precise and numerous data were available for the southern area. The additional data for the south made it possible to estimate additional catchability, recruitment and selectivity parameters, as well as biomass and mortality over a longer time period (Tables 21 – 22). It was necessary to borrow some of these parameter estimates from the south in modelling Atlantic surfclam in the north because data were so limited and catches were nearly zero over much of the time series.

Dome shaped survey selectivity curves with parameters fixed at field study estimates were used in SS3 models for the MCD survey in the south and north and the RD survey in the south (Figure 90). Field estimates were used because they were relatively precise, based on a great deal of data, and were obtained from designed experiments carried out in association with the stratified random survey using actual survey sampling gear (Figure 55; Northeast Fisheries Science Center (2013)). Allowing the model for the north to estimate the ascending limb of the RD survey selectivity curve was helpful in reducing diagnostic problems.

The number of trips sampled by port agents was used as initial effective sample sizes for fishery length data in each year. The number of survey tows that caught Atlantic surfclam was used as initial effective sample size for survey size composition data in each year. The number of fish aged in each size group and year was used as the initial effective sample size for survey conditional catch at age data. Initial log scale standard deviations for survey abundance trend data were derived

[3] Stock Synthesis Model version SS-V3.24Y compiled for 64-bit linux.

from the CV for mean numbers per tow in each year (and assumed that errors were lognormal). These initial specifications for length and age data were "tuned" (adjusted up or down) based on preliminary model fits by multiplying the values for each type of data by a constant based on the recommendations of (Francis 2011). The initial standard deviations for survey trend data were tuned, if necessary, based on preliminary model fits by adding a constant to the standard deviation for each observation in the time series (Francis 2011).

Priors for survey dredge capture efficiency

The prior distributions for survey dredge capture efficiencies were important because the models are not otherwise strongly informed regarding scale. The last Atlantic surfclam assessment (Northeast Fisheries Science Center 2013) details the work that was done to estimate a prior for the distribution of capture efficiency for the research dredge (RD) last used in 2011. Appendix 4 details the work done to estimate a prior for the distribution of the modified commercial dredge (MCD) used since 2011.

Issues

South

The Atlantic surfclam assessment for the south is unable to estimate scale (absolute stock size) although trends in biomass were estimated more reliably. This is typical of a low F fishery. In general, there are several different scenarios involving combinations of selectivity, biological parameters and biomass scale that might explain the observed population dynamics when fishing mortality cannot account for it. Therefore the model is easily shifted from one scale to another based on small changes in the data or model.

Some of the issues with the assessment model for the south stem from the fact that there are only two years of data in the MCD survey. Because of this limitation, the prior distribution on the MCD survey catchability was very influential (see section 1.7).

The base model has some poorly determined parameters (Table 23). Most of these are recruitment deviations, which are generally difficult to estimate when the survey and commercial gear do not sample the youngest animals well. Both the survey and commercial gear have selectivity curves such that they are unlikely to capture very many animals less than about 3 years old. Therefore, poorly determined recruitment deviations are not unexpected. The model has particular trouble estimating the Q parameter associated with the catchability of the MCD survey. This is probably because the survey contributes only two data points to the model. This parameter is therefore strongly influenced by its prior distribution. Sensitivities in which the prior distribution was turned off were run and are discussed in section 1.7. The other poorly determined parameter is the one that describes the width of the plateau of the selectivity curve for the fishery (see Figure 90). This parameter was difficult to determine because the commercial length comps show conflicting tendencies over time. In the early years of the fishery the length composition was heavily weighted towards longer clams, and in later years the composition was broader and shows a higher proportion of smaller clams. This pattern was difficult to fit with one selectivity curve. Sensitivity runs designed to estimate this parameter better using time varying selectivity are described in section 1.7.

Other potential issues are the use of assumed parameter values for M, steepness and growth. The growth values estimated in the model were near the experimentally derived values presented in part 1.4 and the M value used was based on observed longevity. There was no experimental basis for the assumed steepness ($h = 0.95$) used in the assessment model as there were no observations of recruitment at low stock size available. The h used was high and resulted in no apparent relationship between spawning biomass and recruitment. Sensitivities testing each of these assumptions are described in section 1.7.

North

The Atlantic surfclam assessment model for the north is also uncertain relative to scale. As in the south, the model does not have enough information to estimate scale with precision because the population is lightly fished and there is little contrast in the survey indices. The model from the north also suffers from a shorter time series for catch, survey, age composition, and length composition data.

The estimated biomass trend in the early part of the time series does not fit the survey index well. The early part of the time series is uncertain relative to trend because the survey index increased rapidly in the absence of any prior fishery removals that would have accounted for the population being in a depleted state (where the increase would represent recovery). There is no support for a low biomass in the early part of the time series in the composition data either. With no mechanism to explain the increase from 1984 to 1995 (or more precisely the low biomass in 1984), the model does not believe the survey. Sensitivities to explore the affect of forcing the model to fit the survey index better are discussed in section 1.7.

The base model has some poorly determined parameters (Table 24). Most of these are recruitment deviations, which are generally difficult to estimate when the survey and commercial gear do not sample the youngest animals well. Model precision can be improved by increasing the weighting on the MCD survey. This approach was not taken because the MCD survey consists of only one data point and because increased model precision is not desirable when the information provided to the assessment is uncertain. In the case of the northern area, the model has little meaningful information and should not reflect an unrealistically precise estimate of biomass. Sensitivity runs in which the MCD index was heavily weighted and also removed from the calculation of the likelihood surface are described in section 1.7.

Fit and estimates from basecase models

South

The biological parameters used in the assessment model were based on experimentally derived values (Figures 91 – 93). Fishery selectivity was estimated and retained the domed shape seen in the last assessment (Figure 90). The fit to the surveys was acceptable and the residuals did not show trends or high variance (Figures 94 – 96). The fit to the composition data was generally tight, with the possible exception of the MCD survey which showed conflicting length composition over only two years and was difficult to fit well with one selectivity pattern (Figures 97 – 109). Data weighting decisions are shown in Figure 110. Model time series results are shown and in Figure 111 and parameter estimates are shown in Table 22.

North

The biological parameters used in the assessment model were based on experimentally derived values (Figures 112 – 114). Fishery selectivity was partially estimated and shared the domed shape seen in the model for the south (Figure 115). The fit to the surveys was reasonable given the constraints of the data and the residuals did not have high variance (Figures 116 – 117). The fit to the composition data was generally tight, with the possible exception of the MCD survey which had only a single year of data (Figures 118 – 128). Selectivity for the MCD survey was assumed because allowing the model to fit a single year of data would have resulted in overfitting. Data weighting decisions are shown in Figure 129. Model time series results are shown and in Figure 130 and parameter estimates are shown in Table 22.

Likelihood profile analysis

South

Likelihood profile analysis of the model for the southern area consisted of fixing the unfished recruitment parameter (R_0) at successive values that bracketed the R_0 solution (from the base case model) and estimating all of the other parameters in the model.

Likelihood profile results for the south indicate that goodness of fit for the priors on survey catchability were best near the basecase model run (Table 25 and Figure 131). Survey age data support higher R_0 (higher biomass) and length composition data lower R_0 (lower biomass). However, the differences in total likelihood were small (Table 25). The one area of data conflict that appears to make a substantial difference in total likelihood is between the parameter prior distributions (on survey catchability), which prefers the solution, and the age composition data, which prefer a lower values of R_0.

North

There is model tension between the RD survey index and its composition data (Table 26 and Figure 132) in the model for the north. The composition data support a higher R_0 (higher biomass), while the survey data support a smaller R_0 (lower biomass). The biomass scale at the solution is set by prior distributions on survey catchability, which affect the MCD survey and RDscale index (RDscale did not contribute to the likelihood in the north because the Q were not estimated and RDscale was not fit for trend. See Table 21).

Sensitivities

Experimental model runs testing the effects of model manipulations (for example with either extra parameters or fewer sources of data) were informative.

South

Natural mortality was fixed at $M = 0.15$, based on the observed longevity of Atlantic surfclam in the base model, and an experimental run was conducted to estimate it. M was estimable and decreased with age (Figure 133). Estimating M produced a slightly better fit to the commercial length composition data, but a slightly worse fit to the survey length composition data compared to the base run. The fits to other data were unchanged. There was virtually no change in either the trend or scale of biomass and the base model was preferred due to parsimony.

The growth parameter K was fixed at values derived in the last assessment (Northeast Fisheries Science Center 2013) in the base model run. An experimental run attempted to estimate it. The Von Bertalanffy K parameter and the coefficients of variation around the growth curve were estimable. The estimated K was slightly less than the K assumed in the base model, while the estimated parameters describing uncertainty around the growth curve were nearly identical to the values used in the base model. Estimating growth had virtually no effect on the model fit and the base model was preferred due to parsimony.

There is experimental evidence that growth has changed over time in at least part of the southern stock area (Figure 86). In one sensitivity run growth was allowed to vary over time. The closest SS3 equivalent to the Von Bertalanffy L_∞ parameter was estimated for two time blocks (<2000 and >1999). This run had a negligible effect on the biomass estimates in the model (Figure 134). An additional run in which the Von Bertalanffy K parameters were fit in each of the time blocks produced only slight changes as well. This run improved the fit to the length composition very slightly at a minor cost to the fit of the conditional age at length composition data. There was virtually no change in either the trend or scale of biomass and the base model was preferred due to parsimony.

Although commercial selectivity was estimated, it may have changed over time. The evidence for this is in the apparent lack of fit to commercial length composition data that occurs in the early years of the time series (Figure 97) and the fact that the the model has trouble estimating the parameter describing the width of the plateau of the commercial selectivity curve (Table 23). The gear used by the commercial fishery has not changed substantially over time so any changes in fishery selectivity were probably due to changes in behavior. That is, the fishery probably targeted the beds with the largest and oldest clams first, and then later moved to beds of smaller clams when those were fished down. Sensitivity runs where commercial length composition was allowed to vary in time blocks (<1986 and >1985) produced better fits to the commercial length composition data. The overall fit to the commercial length composition data was already fairly good, however, and there was virtually no change in either the trend or scale of biomass and the base model was preferred due to parsimony.

The base model somewhat underfits the RD survey (Figure 96). This base case solution is fairly stable. In order to force the model into a fit tight enough to reduce the standard deviation of the standardized residuals of the fit the RD survey, the lambda (likelihood weighting component) of the RD survey had to be increased by a factor of 10. Forcing the model to better fit the RD survey trend changed the overall biomass trend somewhat (Figure 135). It also caused a degradation in the fit to the composition data, and the conditional age at length composition data in particular. Biomass scale was unchanged and given the large weight being put on the survey data, the base model was preferred.

There is tension between the survey data and the composition data (Figure 131). The weights associated with each of these data sources determines the shape and scale of the model to some extent. A sensitivity run in which the variance associated with the composition data (both length, and age at length composition data) was increased relative to the base model, so that the harmonic mean of the effective sample size matched the mean of the input sample size (implicitly decreasing the information content of the RD survey). This was compared to the base model and the previous sensitivity run (Figure 135) in which the weight of the RD survey was increased (implicitly decreasing the information content of the composition data). The trade off between the composition data and the RD survey indices are clear in the comparison in that weighting the composition data more heavily tends to smooth out the biomass trajectory, while weighting the RD survey tends to introduce additional topography to the trend. All three runs show similar scales, while the base model is a compromise between the two in trend.

Profile analysis showed that the prior distribution associated with the MCD survey was influential in the base model solution. A sensitivity run in which the prior was not used confirmed this. The scale of estimated biomass shifted considerably, though the trend was very similar to the base run (Figure 136). The fits to the composition data were not affected by the removal of the prior distribution on catchability. When the prior distribution for the RD survey was removed, the effect on the model was almost undetectable, further indicating that the prior on the MCD survey is influential. When both prior distributions were removed, the model estimated a lower biomass (R_0 near the lower end of the range covered in the likelihood profile analysis), but the trend and fit to composition data were similar to the base model.

The MCD survey has only two data points in the base model, which is a small sample size to use for estimating trend. When the MCD survey index contribution to the likelihood was removed (multiplied by $\lambda = 0$), the scale of the estimated biomass shifted and trend was not strongly affected (Figure 137). This implies that the MCD survey and its prior are important for setting scale in the assessment model, but that they do not have a strong influence on the trend, even over the period that the MCD survey covers (>2011).

The steepness of the stock recruit relationship is assumed ($h = 0.95$) in the base model. There are no observations of the stock at low biomass in the time series (typical of a low F fishery) and so there is little information available with which to estimate steepness. A sensitivity run estimated steepness at 0.33 ($cv = 0.54$; Figure 138), but it is difficult to credit this estimate given the lack of information available to the model. The lower steepness value had little affect on the scale, trend or fit of the model, but would have an affect on biological reference points, if they were derived from the stock-recruit relationship. This aspect will be discussed further in 1.8.

The split survey in 2012 and 2013 caused some difficulty in compiling the data for the assessment model. In particular, the inclusion of 2013 data with the 2012 ages (Table 17) introduced additional observation error in the conditional age at length composition data. The error in the length composition data was expected to matter less because Atlantic surfclam grow relatively slowly, are fished lightly and the length composition from one year to the next should not change very much. A sensitivity run in which the conditional age at length information from 2013 was left out of the model was indistinguishable from the base run (Figure 139).

A comparison of the biomass time series estimated in several sensitivity runs demonstrated that the model varied in scale (Figure 140), but was relatively stable in trend (Figure 141). Allowing flexibility in the model by estimating more parameters, including time varying growth and natural mortality, produced runs that started and ended at similar biomass levels and had confidence intervals with a high degree of overlap. The run that used no prior information for estimating the catchability of the surveys had a different scale than the other runs, but showed a similar trend. In general, the model for the southern area was stable over many different configurations.

North

The assessment model for the north does not fit the survey well in the early part of the time series. One possible explanation for this is that the population was in a period of low recruitment and is currently in a period of high recruitment. A sensitivity run in which the parameter R_0 was estimated for each of two time periods (before 1995 and after) did estimate a lower R_0 for the early part of the time series, but did not substantively improve the fit to the survey index (Figure 142).

It was not possible to estimate recruitment variation (around the stock recruitment curve) in the model for the north in any of the runs tested. It is possible that the assumed value for recruitment variation was too low to provide the model enough flexibility to fit the early part of the RD survey well. A sensitivity run in which the recruitment variation was increased by 100% did not improve the fit to the survey (Figure 143).

Forcing the model to fit the RD survey better, by increasing its likelihood weight by a factor of ($\lambda = 10$), caused a degradation in the fit to the composition data (Figures 144 – 145). It was necessary to increase the weight on the survey by an order of magnitude before the model was able to fit the early RD index well (Figure 146).

The model was sensitive to the inclusion and relative weighting of the MCD survey. The MCD survey contributed only one year to the model. The MCD composition data were not particularly well fit by the model using an assumed selectivity, but it was not reasonable to allow the model to estimate selectivity given the single data point. When the variance associated with the MCD survey index was reduced (increasing its relative information content), the model produced a far more certain biomass estimate for the whole time series (Figure 147). While this result improved model diagnostics, it relied heavily on the information provided by a single data point and is therefore unstable. This is easily demonstrated by removing the MCD index from the likelihood calculation (making its contribution 0), which resulted in a model with a different biomass scale. The change in scale indicates that the entire model depends heavily on the catchability parameter for the MCD survey. The dependence on the prior for the MCD index in setting scale was clear from sensitivity runs in which the MCD index was included but the prior on catchability for it was not (Figure 148).

The inclusion of the 2014 conditional age at length composition with the 2013 data introduced additional observation error to the model. Removing the age data from 2014 would be expected to cause a bigger change in the model for the north, than the corresponding removal of 2013 data from the model for the south, because a higher proportion of the total data for the north came from the staggered year (Table 17). A sensitivity run in which the conditional age at length information from 2014 was left out of the model was similar to the base run (Figure 149), and the base run was preferred in order to make use of more of the available data and because the differences were minor relative to the uncertainty in the model.

A comparison of the biomass time series estimated in several sensitivity runs demonstrated that the model was relatively stable in trend (Figure 150), except when the trend was forced to fit the early part of the survey time series in the run called "WeightRD". Allowing flexibility in the model by including time varying recruitment, or increasing the variance around recruitment produced runs that started and ended at similar biomass levels and had confidence intervals with a high degree of overlap. Removing either the trend or the prior on catchability for the MCD survey tended to reduce the scale of the estimated biomass, though trends were still similar (Figure 151).

Internal retrospective

South

There is a shift in scale when the MCD survey drops out of the assessment (retrospective peels that do not include years after 2011; Figure 152). The Atlantic surfclam model for the southern area however, does not have a retrospective pattern in trend, which can be seen in a plot of the relative biomass from each retrospective run (Figure 153). Relative biomass was determined by dividing the biomass in each year and run by 25% of the virgin biomass estimated in that run.

North

The shift in scale in the model for the northern area is larger than in the southern area, and the trend is less stable over 10 peels of retrospective analysis (Figure 154 - 155).

Whole stock results

A simulation testing the relative merits of different approaches to combining F from multiple areas when absolute abundance was poorly determined, demonstrated that the abundance weighted average F was negatively biased when the correlation between abundance and F was close to -1 (See 9). The simulation also showed that the geometric mean of the F from each of two areas was close to the true combined F at all correlation levels. However, the geometric mean was strongly negatively biased when F is very low and in fact undefined when $F = 0$, which is true for a substantial proportion of the Northern area time series. The abundance weighted mean was therefore the preferred method of calculating combined F for the stock and determining the stock status relative to 2015.

Whole stock fishing mortality was $F_W = \frac{(C_S+C_N)}{(\widehat{N_S}+\widehat{N_N})}$ where C_S and C_N were the catch in numbers from each area and $\widehat{N_S}$ and $\widehat{N_N}$ were average fully selected abundances

$$\widehat{N_a} = \sum_L s_L \frac{N_L(1 - e^{Z_L})}{Z_L}$$

where the total mortality rate (Z) was based only on fully selected lengths and s_L was commercial fishery size selectivity. Whole stock results are discussed in part 1.9.

The F in projections was far enough from zero to allow the use of the geometric mean as a method for combining F from different areas. Therefore, the whole stock fishing mortality in projections was $F_W = e^{log(F_S)+log(F_N)}$. Whole stock projection results are discussed in 1.10. Fortunately, this choice had little effect on the whole stock results because F was so low. If F increases in the future it may be prudent to revisit the method for combining F from different areas in order to minimize the potential bias caused by correlation between F and abundance (9).

Whole stock spawning biomass estimates for clams was $SSB_W = e^{log(\frac{SSB_S}{SSB_{Threshold,S}})+log(\frac{SSB_N}{SSB_{Threshold,N}})}$, where $SSB_{Threshold,A} = \frac{SSB_{0,A}}{4}$ and A was area (either N or S). The variance around $\frac{SSB_A}{SSB_{Threshold,A}}$ was

$$\sigma^2_{SSB_A} = \left(\frac{\widehat{SSB}_A}{\widehat{SSB_{Threshold}}}\right)^2 \left(\frac{\sigma^2_{SSB_A}}{\widehat{SSB}_A{}^2} + \frac{\sigma^2_{Threshold,A}}{\widehat{SSB_{Threshold,A}}{}^2} - \left(\frac{2 * cov[SSB_A, SSB_{Threshold}]}{(\widehat{SSB}_A * \widehat{SSB_{Threshold}})}\right)\right)$$

Historical retrospective

The estimated whole stock biomass in this assessment is higher in scale than previous assessments (Figure 156). The scale shift over time reflects the difficulty in determining scale in the Atlantic surfclam assessment, progress as priors for catchability were developed, and is typical of a low F fishery.

1.8 TOR 6: Reference points

Current reference points

According to the harvest control rule in the FMP for Atlantic surfclam, overfishing occurred whenever the annual fishing mortality rate on the whole stock was larger than the overfishing limit (OFL), which was defined as a proxy for F_{MSY} ($F_{Threshold} = M = 0.15\, y^{-1}$). B_{Target} was defined as a proxy for B_{MSY} ($B_{Target} = \frac{1}{2} B_{1999}$ where B_{1999} was near the highest estimated biomass in previous assessments). The stock was overfished if total biomass fell below $B_{Threshold}$, which was $\frac{1}{2} B_{MSY}$ ($B_{Threshold} = \frac{1}{2} B_{MSY} = \frac{1}{4} B_{1999}$).

Current and recommended biological reference points (BRP) for Atlantic surfclam are proxies because spawner-recruit relationships required to determine F_{MSY} and B_{MSY} directly have not been estimated (low stock size has never been observed). Both current and recommended biomass reference points are based on trends/status ratios such as $\frac{B_{2015}}{B_{Threshold}}$ rather than absolute biomass estimates because the overall level of Atlantic surfclam biomass is uncertain. The current fishing mortality reference point is a fishing mortality rate but the recommended reference point is based on relative catch, again because of the uncertainty in biomass.

Reference points may be selected based on fishery performance and/or policy (risk aversion). Recommendations in this assessment are based on fishery performance criteria leaving MAFMC to consider policy to consider risk involved in setting catch targets, with the advice of its Scientific and Statistical Committee.

The $B_{MSY} = \frac{1}{2} B_{1999\, proxy}$ currently used for Atlantic surfclam has no theoretical justification beyond the notion that the biomass in 1999 was high at that time and might approximate carrying capacity. The major advantage was that both B_{1999} and biomass in the terminal year (e.g. B_{2015}) were estimated in the same model so that uncertainty in the overall scale of population size cancelled out in ratios used to determine stock status such as $\frac{B_{2015}}{\frac{1}{2} B_{1999}}$. In effect, the current approach is based on estimated trends in biomass but not on the absolute size of the estimates themselves. This property is important because sensitivity and historical retrospective analyses in this assessment show that estimated stock size trends are more robust for Atlantic surfclam than estimates of scale (Figures 147 - 156).

F_{MSY} and proxies depend on spawner-recruit, and yield/spawning biomass per-recruit relationships. Proxies for F_{MSY} are often set at some fraction of M ($F_{MSY} = cM$, $c < 1$ such that M is an upper bound for F_{MSY}) or at the fishing mortality rate corresponding to some fraction of maximum average reproductive output per recruit ($F_{SPR\%}$, Zhou et al. 2012). Existing $F_{SPR\%}$ proxies are not applicable to Atlantic surfclam because the analyses on which they are based generally assume that individuals mature and recruit to the fishery at about the same time. In addition, F_{MSY} cannot be computed directly because we have never observed a low stock size and thus have no way to characterize the stock recruit relationship. The current $F_{MSY\, proxy}$, $F = M = F_{Threshold}$ relies on biomass scale, and status determination relative to fishing mortality was therefore subject to the uncertainty associated with scale in the assessment.

Simulation analyses can be used to identify robust reference points that work well across a range of potential spawner-recruit curves and life-history patterns. This assessment includes management strategy evaluation (MSE) simulations which were tailored to Atlantic surfclam and the uncertainties about their life history and dynamics (8). The MSE analysis included two scenarios of particular interest. The primary scenario reflects current practice in managing two spatial areas (Northern and Southern) with different biological properties and independent recruitment patterns as a single unit. The secondary scenario uses separate harvest control rules for each unit and provides a means for assessing the potential costs and benefits of managing the two regions as a unit or separately.

MSE

MSE simulations were used to evaluate how MAFMC control rule parameters (a simplified version) affect average biomass relative to virgin biomass $\frac{SSB}{B_0}$[4], average relative yield measured as $\frac{Y}{B_0}$, interannual variation in yield cv(Y) and the proportion of years with no fishing ($t_{F=0}$). Simulations included a relatively wide and realistic range of random inputs for recruitment parameters, natural mortality, Beverton-Holt and Ricker spawner-recruit patterns, and other important, but uncertain parameters (8).

MSE results for combined region management and assuming both Beverton-Holt and Ricker recruitment patterns showed that $F_{Threshold}$ (F_{MSY} proxy) in the simulations, B_{Target} (B_{MSY} proxy) and $B_{Threshold}$ were all important for Atlantic surfclam in the MAFMC control rule (Figures 234 - 235). However, a wide range of different combinations of these parameters performed well based on MSE results. To simplify analysis we base recommendations on results for $F_{Threshold} < M = 0.15$ (an upper bound for F_{MSY}) and MAFMC control rule values of B_{MSY}=B_{Target}=$\frac{1}{2}B_0$, $B_{Threshold}$=$\frac{1}{4}B_0$.

For simulations at B_{Target}=$\frac{1}{2}B_0$, and considering combined area management, and with two spawner-recruit patterns, $F_{Threshold}$ values near 0.12 maximized yield while maintaining relatively high average spawning biomass with low interannual variation in yield and infrequent years with no fishing (Tables 41 - 44 and Figures 236 - 237).

Recommendations

$F_{MSY\,proxy} = 0.12$ is preferred over $F_{MSY proxy} = 0.15$ because higher levels of biomass, lower levels of variation in catch and less frequent years with no fishing would be expected according to the MSE (Appendix 8). $F_{MSY\,proxy} = 0.12$ is lower than the upper bound estimate $M = 0.15$, as should be expected. It is slightly larger than the range of $F_{MSY} = cM$ proxies for finfish with $0.63 < c < 0.74$ and $0.09 < F_{MSY} < 0.11$ (Zhou et al. (2012)). $F_{Threshold} = 0.12$, $B_{Threshold} = \frac{1}{4}B_0$ and $B_{Target} = \frac{1}{2}B_0$ provided high levels of catch and stock biomass at relatively low levels of variation in catch and years with no fishing. There is no reason to change the biomass reference points $B_{Target} = \frac{1}{2}B_0$ or $B_{Threshold} = \frac{1}{2}B_{Target}$ because they performed well in MSE simulations. These results were robust to assumptions about the underlying spawner recruit curve (Figures 236 - 237).

Based on the MSE analysis, mean stock biomass would increase by about one-third at $F_{Threshold} = 0.12$, with no change in mean yield if Atlantic surfclam in both areas were managed separately

[4]Because Atlantic surfclam mature before age 1, there is no practical difference between B_0 and SSB_0 and the terms may be used interchangeably

although variance in catch and the number of years with no catch would increase (Figure 235). The simulations assume that all available yield is taken. Changes in average biomass, average yield, variance in catch, and years with no fishing would be smaller in the current fishery where catches are low relative to the levels calculated using the MAFMC control rule.

The recommendation $F_{Threshold} = 0.12$ is superior to $F_{Threshold} = 0.15$ on theoretical grounds but it shares an important implementation problem given that estimated fishing mortality rates are uncertain due to uncertainty in the scale of the biomass estimates. Thus, it would be very difficult to reliably compare an estimated fishing mortality rate to $F_{Threshold}$ and determine if overfishing is occurring. The assessment working group concluded it would be better to employ an $F_{Threshold}$ reference point based on trends using the average fishing mortality rate between 1982 and 2015 (the period for which we have survey data) in the southern area.

$$E_{y=1982}^{2015}[F_y] = F^*$$

The catch during that time period did not appear to result in overfishing. There is no evidence of overfishing in the current age/size compositions and current biomass estimates are near B_0 (see 1.7 and 14). The highest average fishing mortality between 1982 and 2015 for the southern area in sensitivity analyses was $F^*_{Max} = 0.03$. There is a high probability that $\frac{F_{MSY}}{F^*} > 4$ because

$$\frac{F_{MSY}}{F^*_{Max}} = \frac{0.12}{0.03} = 4$$

and F^*_{Max} was taken from the sensitivity run with the lowest biomass and thus highest F of any model run for the southern area. In addition, catch curve total mortality $(F + M)$ estimates for the southern area during this time period averaged 0.14, compared to the assumed M of 0.15. Empirical exploitation rates < 0.05, provding further evidence that F was low (14). Thus any F^* calculated from another model run would likely be lower than F^*_{Max}.

The recommended fishing mortality reference point is

$$F_{OFL} = F_{Threshold} = F^* \frac{F_{MSY}}{F^*_{Max}}$$

rather than a specific rate such as 0.12. It is important that F^* be calculated using the period between 1982 and 2015 in this, and in future assessments, as that was a period during which overfishing was very unlikely. Allowing the years that compose the reference point to shift over time would allow the reference point to normalize to current behavior. That is, the reference point would decrease during a regime of less fishing pressure and increase during a regime of more fishing pressure, which is not a desirable characteristic for a reference point.

There are three primary advantages to this recommendation. First, the status ratio used to identify overfishing

$$\frac{F_y}{F_{Threshold}} = \frac{F_y}{F^* \frac{F_{MSY}}{F^*_{Max}}}$$

provides information about relative exploitation rates that is not available in the ratio $\frac{F_y}{0.12}$ given the high degree of certainty in estimated trends and high degree of uncertainty in the scale of biomass estimates. Second, the recommended reference point is robust because it will adjust to changes in the scale of Atlantic surfclam biomass estimates, which can be expected in future assessments, at least over the short term. Finally, the scaling factor $\frac{F_{MSY}}{F^*_{Max}}$ can be re-examined and/or replaced as biomass estimates improve.

Table 4: Biological reference points used in the last assessment and the revised values used in the current assessment.

Reference point	Previous assessment	Revised
$F_{MSY} = F_{Theshold}$	$M = 0.15$	$F^* \frac{F_{MSY}}{F^*_{Max}}$
K	B_{1999}	B_0
$B_{MSY} = B_{Target}$	$\frac{B_{1999}}{2}$	$\frac{B_0}{2}$
$\frac{B_{MSY}}{2} = B_{Threshold}$	$\frac{B_{1999}}{4}$	$\frac{B_0}{4}$

1.9 TOR 7: Stock status

The assessment model was configured some what differently from the base model in the last assessment (Northeast Fisheries Science Center 2013), with the most important change being the addition of the new survey MCD survey. No new data from the RD survey has been collected since the previous assessment. It was not possible to add the new survey data to the previous assessment model because it was not configured to accept data from a different survey. Therefore, the previous assessment model cannot be directly compared to the model used in the current assessment, though a reasonable effort has been made to do so in (6). It is, however, possible to compare the current assessment estimates of biomass and fishing mortality to the current and recommended biological reference points.

Current reference points

Comparing the terminal biomass (B_{2015}) and fishing mortality estimates (F_{2015}) to the current reference points (Table 4) shows a low probability of either overfishing or overfished status for the Atlantic surfclam stock in the US EEZ (Table 27; Figure 157). The current $F_{threshold}$ was a point estimate with no associated uncertainty. Therefore the probability of overfishing was equal to the probability of overlap between the distribution of F_{2015} and the point estimate of $F_{threshold}$.

Recommended reference points

There is a near zero probability that the Atlantic surfclam stock in the US EEZ is experiencing overfishing ($F_{2015} < F_{Threshold}$; Table 28; Figure 158–159), and there is a low probability that the Atlantic surfclam stock in the US EEZ is overfished ($B_{2015} < B_{Threshold}$; Table 29; Figure 158 and 160). According to the recommended reference point definitions, the Atlantic surfclam stock is not overfished and overfishing is not occurring.

1.10 TOR 8: Projections

Basecase models were used to project biomass of Atlantic surfclam, catch (mt), and fully recruited fishing mortality in both areas, and in the combined stock during 2016-2025 (Tables 30 - 31 and Figure 161). Three harvest policies were assumed: 1) $F = F_{Threshold} = F_{OFL}$ (F at the OFL), 2) status quo catch (20333 mt) and 3) the maximum allowed catch under the current FMP or "quota level" catch (29364 mt) in the combined areas. Results indicate that biomass will remain higher than the biomass threshold and projected fishing mortality levels will be lower than the fishing mortality threshold for the entire resource.

Projection calculations were carried out in SS3 for the two areas using basecase models. Results for the whole stock were derived by combining projections for the northern and southern areas. Thus, the distribution of catches, relative growth rates, etc., were the same as in the terminal years of the base case models. Catches were landings multiplied by 1.12 to account for assumed 12% incidental mortality. Catches during 2016 were assumed the same as during 2015. For lack of better information, catches in the northern area during 2016-2025 were assumed to be the same in the status quo catch and quota level catch scenarios. This assumption is likely reasonable for the first few years because of processor infrastructure and fleet range limitations.

Projections for each year assumed time series average recruitment with uncertainty in starting stock size equal to the uncertainty in the final (non-forecast) model year (Figure 162). Projected total catch for the combined area was obtained by adding catches estimates for the southern and northern areas. Fishing mortality for the combined area (whole stock) was computed as the geometric mean (see Appendix 9) of the F from each area (calculated separately for each catch scenario). Overfishing status determination in each year (y) for the combined area was computed as $\frac{F_y}{F_{Threshold}} = \frac{F_y}{F^* \frac{F_{MSY}}{F^*_{Max}}}$ (see 1.8), where F^* was the mean F for the whole stock between 1982 and 2015 (Table 31). Whole stock spawning stock biomass was the sum of the spawning stock biomass from each area. These were considered unreliable due to scale uncertainty and are only included to document the calculation of projected catch at the OFL. Whole stock status ratios were the geometric mean of the status ratios from each area. Overfished status ratios were computed as $\frac{SSB_y}{SSB_{Threshold}} = \frac{SSB_y}{0.25SSB_0}$.

It is unlikely that the stock will be overfished within the next five years. The maximum probability of overfished status coincides with the minimum biomass estimate over the five year time horizon. The distributions of SSB_y and $SSB_{Threshold}$ were assumed log normal with means equal to their respective point estimates and variances equal to their delta method variances. One million draws from possible threshold values were drawn from correlated distributions with means and variances as described above, where the correlation between them was equal to the correlation between SSB_y and $SSB_{Threshold}$ estimated in the model. Each pair of draws was compared. Overfished status occurred when the threshold draw was greater than the biomass draw. Probabilities were equal to the number of overfished occurrences divided by the number of comparisons made (Shertzer et al. 2008). The probability of the whole stock being overfished was low for all projection scenarios considered (Figure 163).

The most likely fishing scenario is probably status quo catch, because the fishery is market limited and has been catching less than the quota since 2004 (Table 4). The quota scenario with higher catches was therefore a reasonable upper bound on likely fishing pressure over the next ten years. Using the quota scenario, the maximum probability of being overfished in any one year in next five

(P^*) was low (Figure 163) and the cumulative probability of being overfished at any time during the next ten years $(1 - \prod_y \{1 - p_y^*\})$ (Table 32), where p_y^* is the P^* value for each year was also low (see Shertzer et al. (2008)).

Projected fishing mortality levels are lower than the fishing mortality threshold for the entire resource under all scenarios except $F = F_{OFL}$ for each of the stock areas (Figure 164; Table 31). The cumulative probability of experiencing overfishing using the status quo catch or quota scenarios in any of the projection years was also low (Table 32).

In order to test the sensitivity of the projections to uncertainty in biomass scale, as well as model specification, quota scenario projections were conducted using the sensitivity runs with the lowest and highest biomass scale from 1.7 ("NoQPriors" and "EstimateM" for the southern area; see Figure 140). For the northern area the sensitivity runs with the lowest scale were the runs that excluded the MCD survey and the scale was too low to be creditable. Projection sensitivities for the northern area were run with the two models with the highest and lowest creditable scales ("HighRecrVariance" and "WeightRD"; see Figure 150). Projecting forward using the status quo catch scenario with these sensitivity runs showed that probabilities of overfishing and overfished status for the southern, northern and whole stock areas were similar in projection over a wide range of initial biomass scales (Table 33). The projection sensitivity results indicate that the status of the stock over the projected time horizon is robust to uncertainty in biomass scale, when recruitment remains near time series average values.

Probability distributions of the catch at the OFL were generated by repeated draws from a lognormal distribution of catch in each year, with a mean equal to the point estimate of the catch and a cv equal to the model estimated cv for each catch value (Figures 165 - 167; Table 34).

1.11 TOR 9: Stock definitions

Atlantic surfclam are assumed in the fishery management plan to be one unit stock throughout their range in US waters. The stock assessment workgroup discussed stock definitions of Atlantic surfclam at length during the last assessment (SAW 56) without reaching consensus. After reviewing all of the information presented, the SARC 56 review panel, "could not and did not choose to draw any conclusions as to whether a one- or two-stock definition was appropriate (SARC 56, 2013)." Ideas and arguments about Atlantic surfclam stock structure were summarized in two tables for SAW 56 which are also presented in this report (Figures 168 and 169).

The validity of the current stock definition was discussed by the working group briefly again in this assessment without reaching consensus. Opinions on this issue are strongly divided between industry-supported academic scientists and other members. As a result, the working group was unable to develop consensus recommendations as to whether there is a need to modify the current stock definition. Most of the stock definition discussion to date has focused on whether Georges Bank should be treated as a separate stock, both because it tends to be reproductively isolated due to persistent oceanographic conditions, and because it is unique based on the biological and fishery factors listed in Figure 168.

Below, the workgroup chair has summarized opinions of the assessment workgroup for purposes of addressing this TOR. Working group members agree that Atlantic surfclam consists of two or more meta-populations with different population dynamics, degrees of connectivity, fishery, exploitation, recruitment, post-settlement survival, growth rates, and shell height-meat weight patterns. However, some working group members view these differences as clinal and suggest that stock distinctions could be drawn in other places or not at all. They suggest that flexibility and lack of potential constraints on fishing activity are the most important benefits from the one stock approach. The multi-stock approach could lead to management constraints on the fishery that might not be necessary.

Other workgroup members noted that reference points like F_{MSY} and B_{MSY} are not well defined for heterogeneous stocks with independent population dynamics. Proxy reference points might not protect either population unit or maximize yield when used by the Council's SSC to set catch and landings limits intended to prevent Atlantic surfclam from being overfished, or overfishing from occurring. Stock conditions may suffer overall because problems in one area will be masked by conditions in the other. As shown in MSE analyses for Atlantic surfclam in this assessment (see 8) and in other studies, yield is reduced at F_{MSY} because productive areas in good condition may be fished too lightly while unproductive areas in poor condition may be fished too hard. These disadvantages are pronounced and likely to be important if fishing mortality rates approach or exceed F_{MSY}.

All members of the workgroup agree that stock definitions are unlikely to affect management, yield, or biological risk in the near term as long as fishing mortality rates remain low and overall abundance and biomass are relatively high.

The single stock assumption complicates and adds uncertainty to stock status determinations based on current and recommended reference points because biomass trend estimates for the whole stock are sensitive to independent errors in estimating scale for each area. Stock status conclusions in this assessment were robust to this problem because stock size was relatively high in both areas such that overfished status and overfishing were unlikely in either.

1.12 TOR 10: Research recommendations

The following are research recommendations from the previous assessment, in no particular order:

1. Determine the best spatial and temporal distribution to use for Atlantic surfclam assessment models.

   There have been no changes in stock definition, but the consensus of the assessment working group is that two areas modeled independently (northern area and southern area) with the results combined is the best configuration for stock assessment.

2. Biomass reference points need to be reconsidered.

   The SS3 model used for the assessment estimates B_0 for both southern and northern areas upon which biomass reference points can be based. See discussion of reference points in 1.8.

3. Has Atlantic surfclam biomass shifted offshore into deeper water over time?

   Sections 11 and 12 address this question analytically.

4. Look into a better way to implement regime change into the SS3 model. Look into patterns which may match other species and climate indices.

   Model sensitivity runs for the southern area were done with two possible growth stanzas. The model did estimate decreased growth in the second stanza, but the differences in outcome were negligible. See 1.7 for details.

5. Look at habitat on Georges Bank

   Section 13 lists methods explored in order to better determine the Atlantic surfclam habitat in the northern area that can be sampled effectively with a hydraulic clam dredge. These approaches will become available when stratification of the survey is reconsidered in the coming year. The working group agreed that the current approach was adequate for now.

New research recommendations, in no priority order:

1. Include Nantucket Shoals in the surveyed area for Atlantic surfclam.
2. Re-stratify northern area to make the survey more efficient and effective.
3. Examine coefficients used to convert commercial catches in bushels to meat weights.

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2 Tables

Table 3: Surfclam discard estimates from 1982 through 1993. A minimum size regulation was in effect from 1982 through 1990. Within two years of dropping the minimum size regulation (1993) the discard rate had dropped to zero and has remained zero since then.

	Discards						
Year	NJ	DMV	Total	Landings (mt)	Discard proportion	Catch	Size limit (mm)
1982	3,899	2,295	6,194	16,688	37.1%	22,882	140
1983	2,507	2,127	4,634	18,592	24.9%	23,226	140
1984	2,724	2,015	4,739	22,889	20.7%	27,628	133
1985	2,186	1,725	3,911	22,480	17.4%	26,391	127
1986	2,561	239	2,800	24,521	11.4%	27,321	127
1987	1,475	415	1,890	21,744	8.7%	23,634	127
1988	1,330	106	1,436	23,378	6.1%	24,814	127
1989	1,054	258	1,312	21,888	6.0%	23,200	127
1990	1,146	123	1,269	24,018	5.3%	25,287	127
1991	561	5	566	20,615	2.7%	21,181	
1992	1,020	4	1,024	21,686	4.7%	22,710	
1993	0	0	0	21,859	0.0%	21,859	

Table 4: Atlantic surfclam landings and EEZ quotas. All figures are meat weights in mt. Total landings for 1965-1981 are from NEFSC (2003) and other years were from a dealer database (CFDBS). EEZ landings for 1965-1982 are from NEFSC (2003) while later years are from a logbook database (SFOQVR). Landings for state waters are approximated as total landings - EEZ landings and may not accurately reflect state landings. Summary statistics ignore years without fishing.

Year	Total	EEZ	State	$\frac{EEZ}{Total}$	Quota
1965	19998	14968	5030	0.75	
1966	20463	14696	5767	0.72	
1967	18168	11204	6964	0.62	
1968	18394	9072	9322	0.49	
1969	22487	7212	15275	0.32	
1970	30535	6396	24139	0.21	
1971	23829	22704	1125	0.95	
1972	28744	25071	3673	0.87	
1973	37362	32921	4441	0.88	
1974	43595	33761	9834	0.77	
1975	39442	20080	19362	0.51	
1976	22277	19304	2973	0.87	
1977	23149	19490	3659	0.84	
1978	17798	14240	3558	0.8	13880
1979	15836	13186	2650	0.83	13880
1980	17117	15748	1369	0.92	13882
1981	20910	16947	3963	0.81	13882
1982	23631	16688	6943	0.71	18506
1983	23631	18592	5039	0.79	18892
1984	30530	22889	7641	0.75	18892
1985	28316	22480	5836	0.79	21205
1986	35073	24521	10552	0.7	24290
1987	27231	21744	5487	0.8	24290
1988	28506	23378	5128	0.82	24290
1989	30081	21888	8193	0.73	25184
1990	32628	24018	8610	0.74	24282
1991	30794	20615	10179	0.67	21976
1992	33164	21686	11478	0.65	21976
1993	32878	21859	11019	0.66	21976
1994	32379	21943	10436	0.68	21976
1995	30061	19627	10434	0.65	19779
1996	28834	19827	9007	0.69	19779
1997	26311	18612	7699	0.71	19779
1998	24506	18234	6272	0.74	19779
1999	26677	19577	7100	0.73	19779
2000	31093	19778	11315	0.64	19779
2001	31237	22017	9220	0.7	21976
2002	32645	24006	8639	0.74	24174

Table 4 cont.

2003	31526	24994	6532	0.79	25061
2004	26463	24197	2266	0.91	26218
2005	22734	21163	1571	0.93	26218
2006	25779	23573	2206	0.91	26218
2007	27091	24915	2176	0.92	26218
2008	25038	22510	2528	0.9	26218
2009	22283	20065	2218	0.9	26218
2010	19941	17984	1957	0.9	26218
2011	19776	18839	937	0.95	26218
2012	18378	18054	324	0.98	26218
2013	18459	18551	0	1	26218
2014	18707	18227	480	0.97	26218
2015	18284	18154	130	0.99	26218
min	15836	6396	0	0.21	13880
max	43595	33761	24139	1	26218
mean	26172	19847	6327	0.77	22309

Table 5: EEZ surfclam landings (mt meats) by stock assessment area and year. Summary statistics ignore years without fishing.

Year	SVA	DMV	NJ	LI	SNE	GBK	Other	Total
1979		12087	1099					13186
1980	64	12789	2878	17				15748
1981	568	7472	8820	87				16947
1982	1705	6679	8086	94	124			16688
1983	2226	7173	8095	263	835			18592
1984	1797	5978	11905	7	382	2765	54	22889
1985	741	7856	11245		452	2185		22480
1986	529	2853	17731	18	1223	1991	176	24521
1987	378	1303	18017		1140	907		21744
1988	558	1149	19420		1512	739		23378
1989	439	3123	16532		1361	434		21888
1990	1502	3546	17886		998	7	79	24018
1991		1634	18912	15	33		21	20615
1992		1221	20399	61	5			21686
1993		3416	18378	62	3			21859
1994		3454	18418	71				21943
1995		2752	16497		378			19627
1996		2239	17480	26	82			19827
1997		1540	16999	73				18612
1998		484	17511	117	121			18234
1999		649	18755	157	16			19577
2000		2041	17513	121	103			19778
2001		3282	17719	935	81			22017
2002	64	4489	18271	1130	52			24006
2003		1432	21669	1626	267			24994
2004		1482	19197	906	2612			24197
2005		1668	16851	759	1885			21163
2006		2773	19660	245	895			23573
2007		3073	20267	1117	458			24915
2008		3261	17517	1309	423			22510
2009		1977	14834	1798	1444	11		20065
2010		1556	11065	1181	2870	1311		17984
2011		1446	12042	409	2553	2388		18839
2012		3785	6206	307	4143	3580	33	18054
2013		3599	5359	231	4959	4403		18551
2014		3544	6063	306	5079	3236		18227
2015		2816	6179	1013	4085	4061		18154
min	64	484	1099	7	3	7	21	13186
max	2226	12789	21669	1798	5079	4403	176	24994
mean	249	2959	14118	387	1084	734	9	20570

Table 6: EEZ fishing effort (hours fished by all vessels) for surfclam, by stock assessment area and year based on logbook data. Summary statistics ignore years without fishing.

Year	SVA	DMV	NJ	LI	SNE	GBK	Other	Total
1981	1337	15839	16770	204				34150
1982	2790	18050	24635	225	136			45837
1983	4190	18805	23584	536	1130			48244
1984	2603	8972	20819	27	1264	1732	42	35459
1985	397	4687	10518		1702	2608		19912
1986	236	1630	10764	38	2516	1610	675	17469
1987	262	722	11910		3781	1006		17681
1988	322	593	13175		5274	587		19950
1989	228	1616	11794		4741	389		18768
1990	1150	2065	12437		3032		898	19582
1991		1254	17243	20	107		292	18916
1992		797	21379	67				22243
1993		2423	18232	56	15			20726
1994		1930	21495	70				23495
1995		1560	18625		1058			21243
1996		1577	20994	40	287			22899
1997		1098	20383	77				21558
1998		289	19608	134	519			20550
1999		734	18146	150	148			19179
2000		1859	16787	114	368			19128
2001		2537	18461	962	148			22107
2002	112	5505	19826	1240	62			26746
2003		2366	25017	1830	177			29390
2004		3161	26429	1252	1098			31940
2005		2660	24383	1208	1321			29572
2006		5883	27254	343	1032			34512
2007		7065	34691	1580	960			44296
2008		8154	34066	2318	541			45079
2009		5667	33521	4137	2520	12		45857
2010		4125	31847	3297	5571	492		45333
2011		3099	35335	1326	7752	975		48487
2012		7398	21751	948	11467	2044	13	43621
2013		6139	19931	869	15903	3811		46653
2014		6680	18172	1031	17165	2950		45998
2015		6623	18976	3496	15257	4387		48739
min	112	289	10518	20	15	12	13	17469
max	4190	18805	35335	4137	17165	4387	898	48739
mean	345	5297	19878	743	2871	593	51	30723

Table 7: Real and nominal exvessel prices and revenues for surfclam based on dealer data. Average price was computed as total revenues divided by total landed meat weight during each year, rather than as annual averages of prices for individual trips, to reduce effects of small deliveries at relatively high prices. The consumer price index (CPI) used to convert nominal dollars to 2009 equivalent dollars is for unprocessed and packaged fish, which includes shellfish and finfish (Eric Thunberg, NEFSC, pers. comm.).

Year	CPI	Nominal_Prices	Real_Prices	Nominal_Revenue	Real_Revenue
1982	0.45	8.94	19.87	25.19	55.98
1983	0.46	7.57	16.31	23.21	49.98
1984	0.48	8.37	17.29	33.16	68.45
1985	0.50	9.34	18.62	34.30	68.38
1986	0.51	9.20	18.00	41.84	81.89
1987	0.53	7.83	14.78	27.64	52.20
1988	0.55	7.80	14.14	28.83	52.27
1989	0.58	7.78	13.45	30.33	52.47
1990	0.61	7.66	12.56	32.39	53.16
1991	0.63	7.51	11.82	29.98	47.21
1992	0.65	7.40	11.32	31.83	48.67
1993	0.67	7.83	11.62	33.37	49.53
1994	0.69	9.82	14.22	41.24	59.69
1995	0.71	10.58	14.89	41.25	58.05
1996	0.73	10.24	13.99	38.27	52.33
1997	0.75	10.31	13.78	35.19	47.03
1998	0.76	9.19	12.09	29.20	38.43
1999	0.78	8.79	11.32	30.42	39.17
2000	0.80	9.43	11.75	38.02	47.37
2001	0.83	9.76	11.83	39.55	47.91
2002	0.84	9.45	11.26	39.99	47.68
2003	0.86	9.64	11.24	39.43	45.96
2004	0.88	9.40	10.67	32.24	36.61
2005	0.91	9.41	10.33	27.73	30.45
2006	0.94	10.08	10.72	33.69	35.85
2007	0.97	10.48	10.85	36.84	38.12
2008	1.00	10.95	10.91	35.56	35.43
2009	1.00	11.46	11.46	33.13	33.13
2010	1.02	11.70	11.50	30.25	29.75
2011	1.05	11.59	11.06	29.73	28.35
2012	1.07	12.34	11.53	29.41	27.48
2013	1.09	12.14	11.17	29.05	26.75
2014	1.10	12.20	11.06	29.61	26.83
2015	1.10	12.66	11.48	30.02	27.22

Table 8: Nominal landings per unit effort (LPUE, bushels h^{-1}) for surfclam fishing (all vessels) in the US EEZ from logbooks. LPUE is total landings in bushels divided by total hours fished. Summary statistics ignore years without fishing.

Year	SVA	DMV	NJ	LI	SNE	GBK	Other	Total
1981	55.1	61.2	68.2	55.3				64.4
1982	79.3	48	42.6	54.2	118.2			47.2
1983	68.9	49.5	44.5	63.6	95.8			50
1984	89.5	86.4	74.2	33.6	39.2	207	166.7	83.7
1985	242.1	217.4	138.6		34.4	108.7		146.4
1986	290.7	227	213.6	61.4	63	160.4	33.8	182
1987	187.1	234	196.2		39.1	116.9		159.5
1988	224.7	251.3	191.2		37.2	163.3		152
1989	249.7	250.6	181.8		37.2	144.7		151.2
1990	169.4	222.7	186.5		42.7		11.4	159.1
1991		169	142.2	97.3	40		9.3	141.3
1992		198.7	123.7	118.1				126.4
1993		182.8	130.7	143.6	25.9			136.8
1994		232.1	111.1	131.5				121.1
1995		228.8	114.9		46.3			119.8
1996		184.1	108	84.3	37.1			112.3
1997		181.9	108.2	122.9				112
1998		217.2	115.8	113.2	30.2			115.1
1999		114.7	134	135.7	14			132.4
2000		142.4	135.3	137.6	36.3			134.1
2001		167.8	124.5	126	71			129.2
2002	74.1	105.8	119.5	118.2	108.8			116.4
2003		78.5	112.3	115.2	195.6			110.3
2004		60.8	94.2	93.8	308.5			98.2
2005		81.3	89.6	81.5	185.1			92.8
2006		61.1	93.5	92.6	112.5			88.6
2007		56.4	75.8	91.7	61.9			72.9
2008		51.9	66.7	73.2	101.4			64.8
2009		45.2	57.4	56.4	74.3	118.9		56.7
2010		48.9	45.1	46.5	66.8	345.6		51.4
2011		60.5	44.2	40	42.7	317.6		50.4
2012		66.3	37	42	46.9	227.1	329.2	53.7
2013		76	34.9	34.5	40.4	149.8		51.6
2014		68.8	43.3	38.5	38.4	142.3		51.4
2015		55.1	42.2	37.6	34.7	120		48.3
min	55.1	45.2	34.9	33.6	14	108.7	9.3	47.2
max	290.7	251.3	213.6	143.6	308.5	345.6	329.2	182
mean	345	5297	19878	743	2871	593	51	102.4

Table 9: Numbers of commercial trips sampled and numbers of surfclams measured in port samples from landings during 1982-2015, by region. Numbers of trips during 1982-1999 were estimated assuming 30 individuals sampled per trip, as specified in port sample instructions.

	SVA		DMV		NJ		LI		SNE		GBK	
Year	Lengths	Trips	Lengths	Trips	Lengths	Trips	Lengths	Trips	Lengths	Trips	Lengths	Trips
1982	30	1	7756	259	7477	249			30	1		
1983	30	1	5923	197	11253	375			30	1		
1984	90	3	3066	102	12751	425			90	3	30	1
1985			1832	61	7674	256			150	5	275	15
1986	23	1	1260	42	5130	171			330	11	143	7
1987			730	24	900	30			569	19		
1988			420	14	900	30			810	27		
1989			866	29	919	31			449	15		
1990			892	30	901	30			209	7		
1991			1080	36	2272	76						
1992			1170	39	1710	57						
1993			1392	46	928	31	1127	56				
1994			119	4	900	30						
1995			720	24	510	17						
1996			1154	38	1117	37						
1997			1622	54	957	32						
1998			1560	52	690	23						
1999			1720	57	856	29						
2000			600	20	3315	111	30	1				
2001			970	33	1260	42						
2002			210	7	1111	37						
2003			60	2	2455	80	198	11				
2004			18	1	425	21	441	24				
2005			410	18	1250	62	349	18				
2006			1074	50	940	47	374	20				
2007			1582	67	1568	80	994	47				
2008			1195	55	1317	67	774	38				
2009			697	31	1148	57	1127	56				
2010			450	20	1064	49	614	30	941	43	30	1
2011			578	26	2558	119	210	10	145	7	30	1
2012	30	1	919	40	1213	58	170	8	30	1	275	15
2013			604	27	1621	75	156	8	30	1	143	7
2014			325	16	1118	51			90	3	220	11
2015			521	24	819	39			150	5	482	25
min	23	1	18	1	425	17	30	1	30	1	30	1
max	90	3	7756	259	12751	425	1127	56	941	43	482	25
mean	41	1	1279	45	2383	86	505	25	270	10	181	9

Table 10: Number of successful random tows in NEFSC clam surveys used for survey trends and efficiency corrected swept area biomass. 'Holes' (unsampled survey strata in some years) were filled by borrowing from adjacent surveys were possible (borrowed totals are negative numbers in gray shaded boxes). Holes that could not be filled have zeros in black boxes. Survey strata are grouped by region. In 2012 and later the NEFSC survey was conducted from a commercial platform using different gear, and tows were not borrowed across gear types. Starting in 2012, not all regions were sampled in each survey year. Instead the survey was conducted in either the northern or southern area. Areas intentionally not sampled are left blank in those years. 2014 was not intended to be a survey year, but some strata were sampled in order to fill holes left over from 2013. SNE was surveyed in 2013 (except stratum 96, which was surveyed in 2014), but the survey results were borowed to 2012 and not used in 2013. Survey strata not used for surfclams are not shown.

Strata	1982	1983	1984	1986	1989	1992	1994	1997	1999	2002	2005	2008	2011	2012	2013	2014	2015
SVA																	
1	-10	10	14	7	10	10	11	10	-10	0	0	0	0	0			0
2	0	0	0	-1	1	2	1	1	-1	0	0	0	0	0			0
5	4	9	13	8	8	8	7	8	-16	8	8	-17	9	8			6
6	1	1	1	1	1	1	1	1	-3	2	1	-1	0	0			0
80	-6	6	9	3	7	7	8	7	-7	0	0	0	0	0			0
81	-4	4	7	3	5	5	5	5	-10	5	-5	0	0	0			0
DMV																	
9	30	26	35	29	37	37	39	39	38	39	36	31	15	9			9
10	2	2	3	3	3	3	3	3	3	3	3	2	4	3			4
13	19	18	25	20	20	20	21	22	19	20	18	15	7	5			4
14	2	2	3	3	3	3	5	3	3	3	3	-26	23	6			8
82	1	1	1	1	1	1	1	1	2	2	-3	1	-1	0			0
83	2	2	2	2	2	2	2	2	2	2	2	2	-2	-3			3
84	4	3	3	4	4	4	4	4	3	4	4	4	4	3			3
85	6	5	4	5	5	5	5	5	5	5	3	5	5	13			16
86	2	2	3	3	3	2	3	3	3	3	3	3	5	3			3
NJ																	
17	11	11	17	12	12	12	12	14	12	12	12	12	5	5			4
18	3	3	-6	3	3	3	3	3	3	3	3	3	5	4			3
21	18	18	21	19	20	20	23	26	39	29	20	28	15	9			9
22	3	3	-6	3	3	3	5	3	3	3	3	3	5	4			3
25	9	9	13	8	9	9	9	12	8	9	9	13	8	4			24
26	2	2	-5	3	3	3	3	3	3	3	3	3	3	3			3
87	8	7	10	9	9	9	9	9	9	16	8	9	6	10			3
88	15	15	24	17	20	20	20	21	23	20	17	19	6	7			4

Table 10 cont.

89	14	15	21	15	18	17	17	19	18	18	15	18	4	5			11
90	2	2	3	2	2	2	2	2	2	2	2	1	4	3			13
LI																	
29	11	10	-20	10	10	10	10	10	11	10	10	16	10	5			2
30	7	8	-14	6	6	6	6	6	7	6	7	12	4	5			3
33	4	4	-8	4	4	4	5	4	4	4	4	10	4	4			3
34	2	2	-4	2	2	2	5	2	2	2	2	8	6	6			3
91	2	2	4	4	3	3	3	3	3	3	3	5	11	4			13
92	2	2	3	2	2	2	2	2	2	2	2	5	11	7			5
93	1	1	2	1	1	1	1	1	1	2	1	4	6	4			7
SNE																	
37	7	4	-7	3	-6	3	5	4	4	3	-3	-2	2	-2	2		2
38	3	2	-5	3	3	3	5	3	3	3	2	3	7	-6	6		2
41	6	5	7	5	6	6	6	6	5	6	6	6	4	-4	4		3
45	3	7	9	4	4	4	4	4	4	3	3	4	7	-4	4		3
46	2	5	5	3	2	3	5	3	3	2	3	3	6	-4	4		-3
47	4	3	4	2	2	4	5	4	3	1	7	4	8	-10	10		-3
94	1	2	-2	0	-1	1	2	2	-4	2	-2	-5	5	0	0		0
95	4	14	11	4	4	4	4	4	4	4	-8	4	5	-6	6		2
96	-12	12	-13	1	1	3	2	4	-4	0	-1	1	-1	-2	0	2	-5
GBK																	
54	0	-3	3	3	-6	3	3	3	-3	0	-2	2	2		-5	5	
55	3	-3	-3	3	1	3	3	3	2	2	-4	2	3		7		
57	0	0	-2	2	1	2	5	2	2	2	-4	2	11		11		
59	1	4	-5	1	2	6	5	5	4	5	-9	4	16		10		
61	8	1	-6	5	-12	7	6	6	6	6	-11	5	5		5		
65	0	0	-2	2	-4	2	4	3	-4	1	-1	-3	3		4		
67	0	-5	5	5	7	7	7	7	-7	0	-2	2	1		-9	9	
68	1	-8	7	3	6	6	5	5	-5	0	-6	6	-6		-5	5	
69	2	5	-11	6	6	6	7	6	8	-8	-4	4	1		3		
70	1	2	-6	4	-8	4	4	4	3	2	-6	4	19		9		
71	0	-2	2	3	1	2	3	3	1	2	-3	1	3		5		
72	2	-10	8	1	8	8	8	8	6	-6	-4	4	5		3		
73	1	1	-4	3	6	6	6	6	5	6	-9	3	5		7		

Table 10 cont.

74	3	-4	1	3	-7	4	4	4	3	3	-6	3	11	4

Table 11: Trends in abundance and biomass for surfclam > 50 mm shell length during 1982-2015 based on NEFSC clam survey data. Survey values are the clams caught in the survey dredge. Stock values are the survey values adjusted to account for the selectivity of the survey dredge. Fishable values are the stock values adjusted to account for the selectivity of a commercial dredge. Figures include original plus borrowed tows. The column "N strata" includes strata sampled by tows borrowed from the previous and subsequent surveys if needed.

	Survey				**Stock**				**Fishable**						
Year	$\frac{N}{tow}$	CV	$\frac{kg}{tow}$	CV	$\frac{N}{tow}$	CV	$\frac{kg}{tow}$	CV	$\frac{N}{tow}$	CV	$\frac{kg}{tow}$	CV	N tows	Pos. tows	N strata
								SVA							
1982	7.26	0.90	0.60	0.87	8.25	0.88	0.64	0.87	7.26	0.90	0.60	0.87	25	6	5
1983	12.31	0.58	0.99	0.57	15.76	0.55	1.10	0.55	12.31	0.58	0.99	0.57	30	12	5
1984	29.66	0.30	2.96	0.29	35.22	0.28	3.15	0.28	29.66	0.30	2.96	0.29	44	17	5
1986	23.69	0.72	2.50	0.72	25.07	0.70	2.58	0.71	23.69	0.72	2.50	0.72	23	13	6
1989	12.89	0.81	1.31	0.81	18.41	0.77	1.44	0.80	12.89	0.81	1.31	0.81	32	13	6
1992	30.25	0.65	2.50	0.65	35.64	0.60	2.69	0.64	30.25	0.65	2.50	0.65	33	18	6
1994	49.76	0.40	1.69	0.28	391.41	0.68	5.32	0.49	49.76	0.40	1.69	0.28	33	19	6
1997	10.80	0.43	0.47	0.45	58.99	0.77	0.93	0.48	10.80	0.43	0.47	0.45	32	14	6
1999	10.54	0.38	0.46	0.33	58.65	0.77	0.93	0.45	10.54	0.38	0.46	0.33	47	21	6
2002	19.35	0.58	1.13	0.57	32.87	0.52	1.48	0.56	19.35	0.58	1.13	0.57	15	7	3
2005	3.65	0.66	0.07	0.57	39.31	0.80	0.43	0.73	3.65	0.66	0.07	0.57	14	4	3
2008	10.30	0.29	0.24	0.29	59.70	0.39	0.89	0.31	10.30	0.29	0.24	0.29	18	11	2
2011	15.54	0.29	0.40	0.27	63.54	0.26	1.18	0.27	15.54	0.29	0.40	0.27	9	8	1
2012	80.75	0.46	3.71	0.43	119.80	0.50	4.97	0.46	80.75	0.46	3.71	0.43	8	8	1
2015	65.33	0.50	2.72	0.51	116.67	0.51	4.19	0.51	65.33	0.50	2.72	0.51	6	6	1
								DMV							
1982	178.49	0.42	13.11	0.41	223.73	0.41	15.09	0.41	178.49	0.42	13.11	0.41	68	47	9
1983	61.88	0.49	5.83	0.44	75.08	0.43	6.27	0.43	61.88	0.49	5.83	0.44	61	41	9
1984	219.01	0.63	11.27	0.40	406.22	0.76	16.40	0.53	219.01	0.63	11.27	0.40	79	58	9
1986	133.56	0.39	12.28	0.36	150.01	0.37	13.00	0.36	133.56	0.39	12.28	0.36	70	53	9
1989	47.94	0.26	4.81	0.23	54.03	0.25	5.08	0.23	47.94	0.26	4.81	0.23	78	53	9
1992	42.35	0.28	4.34	0.26	54.42	0.24	4.70	0.25	42.35	0.28	4.34	0.26	77	58	9

Table 11 cont.

1994	129.67	0.23	10.93	0.22	232.77	0.21	12.77	0.20	129.67	0.23	10.93	0.22	83	66	9
1997	131.71	0.17	10.42	0.19	170.75	0.15	11.67	0.18	131.71	0.17	10.42	0.19	82	64	9
1999	55.98	0.23	4.94	0.21	62.78	0.22	5.26	0.21	55.98	0.23	4.94	0.21	78	47	9
2002	37.17	0.22	3.51	0.19	53.35	0.24	3.96	0.19	37.17	0.22	3.51	0.19	81	58	9
2005	11.19	0.27	0.92	0.24	16.62	0.24	1.06	0.23	11.19	0.27	0.92	0.24	75	45	9
2008	12.34	0.23	0.73	0.27	29.41	0.21	1.06	0.24	12.34	0.23	0.73	0.27	89	50	9
2011	51.92	0.26	2.69	0.31	123.43	0.26	3.98	0.26	51.92	0.26	2.69	0.31	66	37	9
2012	91.04	0.46	6.77	0.51	113.74	0.42	7.55	0.49	91.04	0.46	6.77	0.51	45	31	8
2015	254.95	0.23	15.75	0.21	329.20	0.25	18.36	0.22	254.95	0.23	15.75	0.21	50	32	8
NJ															
1982	65.88	0.19	6.87	0.18	80.15	0.18	7.45	0.17	65.88	0.19	6.87	0.18	85	60	10
1983	53.16	0.30	5.32	0.25	63.69	0.27	5.72	0.25	53.16	0.30	5.32	0.25	85	63	10
1984	45.90	0.18	4.84	0.18	73.87	0.22	5.41	0.18	45.90	0.18	4.84	0.18	126	86	10
1986	40.01	0.17	5.00	0.17	51.24	0.17	5.36	0.17	40.01	0.17	5.00	0.17	91	70	10
1989	41.40	0.15	4.96	0.14	51.26	0.16	5.29	0.14	41.40	0.15	4.96	0.14	99	75	10
1992	39.68	0.20	4.30	0.17	52.73	0.19	4.68	0.16	39.68	0.20	4.30	0.17	98	73	10
1994	150.16	0.16	14.50	0.17	338.76	0.37	17.67	0.17	150.16	0.16	14.50	0.17	103	85	10
1997	101.63	0.13	12.86	0.12	110.99	0.12	13.42	0.12	101.63	0.13	12.86	0.12	112	91	10
1999	58.60	0.21	7.69	0.19	70.44	0.20	8.10	0.19	58.60	0.21	7.69	0.19	120	93	10
2002	45.71	0.14	6.19	0.15	56.13	0.12	6.59	0.15	45.71	0.14	6.19	0.15	115	99	10
2005	26.90	0.16	3.28	0.16	31.83	0.15	3.49	0.16	26.90	0.16	3.28	0.16	92	73	10
2008	27.11	0.13	2.97	0.16	42.82	0.12	3.35	0.15	27.11	0.13	2.97	0.16	109	93	10
2011	25.82	0.16	2.59	0.17	37.86	0.16	2.91	0.16	25.82	0.16	2.59	0.17	61	44	10
2012	189.85	0.16	22.86	0.17	206.73	0.16	24.00	0.17	189.85	0.16	22.86	0.17	54	47	10
2015	390.53	0.35	35.31	0.30	433.68	0.35	37.63	0.30	390.53	0.35	35.31	0.30	77	63	10
LI															
1982	4.03	0.61	0.75	0.60	4.16	0.61	0.77	0.60	4.03	0.61	0.75	0.60	29	5	7
1983	0.58	0.60	0.06	0.69	0.89	0.56	0.07	0.65	0.58	0.60	0.06	0.69	29	4	7
1984	2.20	0.22	0.30	0.32	3.06	0.14	0.33	0.29	2.20	0.22	0.30	0.32	55	14	7
1986	2.30	0.45	0.33	0.57	3.05	0.38	0.35	0.54	2.30	0.45	0.33	0.57	29	8	7
1989	5.72	0.78	0.59	0.75	9.28	0.79	0.68	0.76	5.72	0.78	0.59	0.75	28	5	7
1992	8.28	0.39	0.62	0.37	12.46	0.37	0.71	0.37	8.28	0.39	0.62	0.37	28	10	7
1994	11.48	0.17	1.15	0.20	15.73	0.16	1.26	0.19	11.48	0.17	1.15	0.20	32	12	7
1997	5.62	0.59	0.69	0.62	6.21	0.57	0.72	0.62	5.62	0.59	0.69	0.62	28	6	7

Table 11 cont.

1999	12.32	0.65	1.64	0.60	17.34	0.66	1.77	0.61	12.32	0.65	1.64	0.60	30	9	7
2002	2.80	0.59	0.37	0.64	4.10	0.61	0.40	0.63	2.80	0.59	0.37	0.64	29	8	7
2005	14.04	0.47	1.91	0.47	15.73	0.44	2.00	0.46	14.04	0.47	1.91	0.47	29	9	7
2008	5.00	0.21	0.60	0.23	7.18	0.20	0.65	0.23	5.00	0.21	0.60	0.23	60	22	7
2011	14.77	0.21	1.70	0.24	24.09	0.24	1.90	0.23	14.77	0.21	1.70	0.24	52	33	7
2012	58.69	0.28	8.33	0.30	61.94	0.28	8.65	0.30	58.69	0.28	8.33	0.30	35	18	7
2015	88.61	0.26	9.06	0.17	103.03	0.27	9.70	0.17	88.61	0.26	9.06	0.17	36	29	7
SNE															
1982	14.99	0.33	2.43	0.39	18.44	0.29	2.57	0.38	14.99	0.33	2.43	0.39	42	19	9
1983	8.72	0.38	1.76	0.39	9.76	0.37	1.84	0.38	8.72	0.38	1.76	0.39	54	24	9
1984	11.65	0.34	2.33	0.34	14.12	0.31	2.44	0.33	11.65	0.34	2.33	0.34	63	26	9
1986	5.24	0.54	0.90	0.68	10.85	0.27	1.02	0.62	5.24	0.54	0.90	0.68	25	11	8
1989	5.75	0.31	0.98	0.33	7.35	0.32	1.05	0.32	5.75	0.31	0.98	0.33	29	12	9
1992	3.64	0.44	0.59	0.55	6.79	0.44	0.67	0.51	3.64	0.44	0.59	0.55	31	9	9
1994	2.96	0.45	0.44	0.50	3.92	0.41	0.48	0.49	2.96	0.45	0.44	0.50	38	11	9
1997	15.23	0.25	2.71	0.30	21.52	0.19	2.89	0.29	15.23	0.25	2.71	0.30	34	15	9
1999	6.90	0.45	1.11	0.60	12.05	0.33	1.25	0.56	6.90	0.45	1.11	0.60	34	16	9
2002	4.86	0.31	0.89	0.23	5.55	0.27	0.93	0.23	4.86	0.31	0.89	0.23	24	9	8
2005	2.95	0.14	0.46	0.21	5.54	0.18	0.52	0.19	2.95	0.14	0.46	0.21	35	14	9
2008	5.37	0.47	0.87	0.54	7.35	0.34	0.94	0.52	5.37	0.47	0.87	0.54	32	11	9
2011	3.07	0.18	0.43	0.25	5.31	0.15	0.50	0.23	3.07	0.18	0.43	0.25	45	13	9
2012	5.44	0.30	1.14	0.27	6.45	0.32	1.20	0.26	5.44	0.30	1.14	0.27	38	10	8
2015	19.11	0.71	3.16	0.68	20.54	0.71	3.30	0.68	19.11	0.71	3.16	0.68	11	6	5
GBK															
1982	3.27	0.14	0.20	0.11	10.14	0.16	0.34	0.12	3.27	0.14	0.20	0.11	22	10	9
1983	6.09	0.39	0.75	0.59	10.14	0.27	0.86	0.53	6.09	0.39	0.75	0.59	48	26	12
1984	8.56	0.34	1.13	0.46	14.48	0.23	1.28	0.43	8.56	0.34	1.13	0.46	65	31	14
1986	24.97	0.68	1.61	0.53	86.32	0.78	2.61	0.60	24.97	0.68	1.61	0.53	44	20	14
1989	30.07	0.66	3.85	0.70	35.99	0.57	4.07	0.69	30.07	0.66	3.85	0.70	75	37	14
1992	23.43	0.33	1.93	0.32	44.00	0.27	2.40	0.30	23.43	0.33	1.93	0.32	66	43	14
1994	75.85	0.33	8.57	0.38	97.98	0.29	9.33	0.36	75.85	0.33	8.57	0.38	70	47	14
1997	82.07	0.28	6.55	0.26	119.17	0.26	7.75	0.26	82.07	0.28	6.55	0.26	65	45	14
1999	53.60	0.35	5.50	0.34	69.53	0.34	6.05	0.34	53.60	0.35	5.50	0.34	59	34	14
2002	49.15	0.46	5.17	0.44	67.41	0.42	5.74	0.43	49.15	0.46	5.17	0.44	43	23	11

Table 11 cont.

2005	39.70	0.21	4.95	0.23	48.54	0.18	5.26	0.23	39.70	0.21	4.95	0.23	71	38	14
2008	39.23	0.21	4.94	0.22	44.69	0.20	5.20	0.22	39.23	0.21	4.94	0.22	45	29	14
2011	43.79	0.24	6.12	0.24	48.38	0.23	6.40	0.24	43.79	0.24	6.12	0.24	91	52	14
2013	94.62	0.53	11.24	0.51	100.10	0.53	11.69	0.51	94.62	0.53	11.24	0.51	87	33	14
SVAtoSNE															
1982	64.30	0.28	5.41	0.24	79.64	0.28	6.05	0.25	64.30	0.28	5.41	0.24	249	137	40
1983	32.23	0.26	3.20	0.22	38.87	0.23	3.44	0.22	32.23	0.26	3.20	0.22	259	144	40
1984	71.19	0.46	4.82	0.23	124.46	0.59	6.22	0.33	71.19	0.46	4.82	0.23	367	201	40
1986	47.40	0.27	4.82	0.23	55.65	0.25	5.12	0.23	47.40	0.27	4.82	0.23	238	155	40
1989	26.00	0.15	2.87	0.13	31.69	0.15	3.06	0.13	26.00	0.15	2.87	0.13	266	158	41
1992	26.93	0.17	2.72	0.15	35.23	0.15	2.96	0.15	26.93	0.17	2.72	0.15	267	168	41
1994	79.35	0.13	6.79	0.12	206.95	0.26	8.64	0.12	79.35	0.13	6.79	0.12	289	193	41
1997	62.81	0.10	6.37	0.10	83.39	0.12	6.91	0.10	62.81	0.10	6.37	0.10	288	190	41
1999	33.15	0.14	3.64	0.13	47.17	0.19	3.93	0.13	33.15	0.14	3.64	0.13	309	186	41
2002	26.21	0.11	3.05	0.11	34.87	0.12	3.32	0.11	26.21	0.11	3.05	0.11	264	181	37
2005	13.86	0.13	1.60	0.14	19.72	0.14	1.75	0.14	13.86	0.13	1.60	0.14	245	145	38
2008	13.75	0.11	1.34	0.13	25.78	0.10	1.59	0.12	13.75	0.11	1.34	0.13	308	187	37
2011	25.35	0.15	1.88	0.14	52.11	0.17	2.40	0.13	25.35	0.15	1.88	0.14	233	135	36
2012	95.65	0.15	10.46	0.15	109.13	0.15	11.13	0.14	95.65	0.15	10.46	0.15	180	114	34
2015	226.10	0.22	18.60	0.19	267.39	0.21	20.34	0.19	226.10	0.22	18.60	0.19	180	136	31

Table 12: Shell length composition data used to estimate dredge selectivity for surfclams between 2012 and 2015. Number of surfclams caught (no.) and positive stations (pos.) for the modified commercial dredge used for the NEFSC survey and a lined dredge presumed to catch all animals available. Some of the stations were targeting ocean quahog and few surfclams were captured at these sites.

SL group	Lined no.	Survey no.	Lined pos.	Survey pos.
0-10	0	0	0	0
10-20	1	0	1	0
20-30	5	0	2	0
30-40	16	0	6	0
40-50	35	0	10	0
50-60	57	0	9	0
60-70	54	2	6	1
70-80	55	11	6	4
80-90	64	44	9	4
90-100	89	142	6	5
100-110	115	212	7	5
110-120	86	193	6	4
120-130	68	221	5	4
130-140	90	277	5	4
140-150	91	308	4	4
150-160	75	289	3	3
160-170	40	164	3	2
170-180	5	18	2	2
180-190	0	4	0	1
190-200	1	0	1	0

Table 13: Numbers of surfclams in survey dredge selectivity experiments by length bin and station between 2012 and 2015. For example, 3:8 in the row corresponding to shell length (SL) bin 40−50 indicates that 3 surfclams between 40 and 50 mm were caught in the survey dredge and 8 surfclams were caught in the selectivity dredge at that station. Stations with very few total surfclams caught were ocean quahog stations, but are included for completeness.

SL bin	Sta 33	Sta 53	Sta 59	Sta 67	Sta 113	Sta 117	Sta 150	Sta 162	Sta 170
0-10	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0
10-20	0:0	0:0	0:0	0:0	0:0	0:0	1:0	0:0	0:0
20-30	0:0	0:0	0:0	0:0	0:0	0:0	2:0	0:0	0:0
30-40	3:0	4:0	0:0	1:0	1:0	0:0	4:0	0:0	0:0
40-50	7:0	6:0	1:0	1:0	5:0	0:0	8:0	1:0	1:0
50-60	10:0	8:0	4:0	1:0	26:0	1:0	3:0	0:0	0:0
60-70	2:0	2:0	12:2	0:0	30:0	0:0	7:0	0:0	0:0
70-80	1:4	1:0	12:2	0:0	38:4	0:0	2:1	0:0	0:0
80-90	5:12	3:0	1:2	0:0	39:10	0:0	11:20	1:0	0:0
90-100	5:15	2:8	0:0	0:0	51:42	0:0	26:76	2:0	3:0
100-110	4:27	7:24	0:0	0:0	62:68	0:0	35:92	2:0	4:0
110-120	3:41	5:44	0:0	0:0	47:66	0:0	24:42	6:0	1:0
120-130	6:67	5:38	0:0	0:0	49:100	0:0	7:16	0:0	1:0
130-140	8:100	21:94	0:0	0:0	55:78	0:0	5:5	0:0	1:0
140-150	16:125	51:116	0:0	0:0	22:66	0:0	2:1	0:0	0:0
150-160	27:189	44:80	0:0	0:0	4:20	0:0	0:0	0:0	0:0
160-170	16:140	23:24	0:0	0:0	1:0	0:0	0:0	0:0	0:0
170-180	4:16	1:2	0:0	0:0	0:0	0:0	0:0	0:0	0:0
180-190	0:4	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0
190-200	1:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0
0-10	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0
10-20	0:0	0:0	0:0	0:0	0:0	0:0	1:0	0:0	0:0
20-30	0:0	0:0	0:0	0:0	0:0	0:0	2:0	0:0	0:0
30-40	3:0	4:0	0:0	1:0	1:0	0:0	4:0	0:0	0:0
40-50	7:0	6:0	1:0	1:0	5:0	0:0	8:0	1:0	1:0
50-60	10:0	8:0	0:0	1:0	26:0	1:0	3:0	0:0	0:0
60-70	2:0	2:0	0:0	0:0	30:0	0:0	7:0	0:0	0:0
70-80	1:4	1:0	0:0	0:0	38:4	0:0	2:1	0:0	0:0
80-90	5:12	3:0	0:0	0:0	39:10	0:0	11:20	1:0	0:0
90-100	5:15	2:8	0:0	0:0	51:42	0:0	26:76	2:0	3:0
100-110	4:27	7:24	0:0	0:0	62:68	0:0	35:92	2:0	4:0
110-120	3:41	5:44	0:0	0:0	47:66	0:0	24:42	6:0	1:0
120-130	6:67	5:38	0:0	0:0	49:100	0:0	7:16	0:0	1:0
130-140	8:100	21:94	0:0	0:0	55:78	0:0	5:5	0:0	1:0
140-150	16:125	51:116	0:0	0:0	22:66	0:0	2:1	0:0	0:0
150-160	27:189	44:80	0:0	0:0	4:20	0:0	0:0	0:0	0:0
160-170	16:140	23:24	0:0	0:0	1:0	0:0	0:0	0:0	0:0
170-180	4:16	1:2	0:0	0:0	0:0	0:0	0:0	0:0	0:0
180-190	0:4	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0

Table 13 cont.

190-200	1:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0

SL bin	Sta 178	Sta 182	Sta 184
0-10	0:0	0:0	0:0
10-20	0:0	0:0	0:0
20-30	0:0	3:0	0:0
30-40	0:0	3:0	0:0
40-50	0:0	4:0	0:0
50-60	0:0	3:0	1:0
60-70	0:0	0:0	1:0
70-80	0:0	1:0	0:0
80-90	1:0	2:0	1:0
90-100	0:0	0:1	0:0
100-110	1:1	0:0	0:0
110-120	0:0	0:0	0:0
120-130	0:0	0:0	0:0
130-140	0:0	0:0	0:0
140-150	0:0	0:0	0:0
150-160	0:0	0:0	0:0
160-170	0:0	0:0	0:0
170-180	0:0	0:0	0:0
180-190	0:0	0:0	0:0
190-200	0:0	0:0	0:0
0-10	0:0	0:0	0:0
10-20	0:0	0:0	0:0
20-30	0:0	3:0	0:0
30-40	0:0	3:0	0:0
40-50	0:0	4:0	0:0
50-60	0:0	3:0	1:0
60-70	0:0	0:0	1:0
70-80	0:0	1:0	0:0
80-90	1:0	2:0	1:0
90-100	0:0	0:1	0:0
100-110	1:1	0:0	0:0
110-120	0:0	0:0	0:0
120-130	0:0	0:0	0:0
130-140	0:0	0:0	0:0
140-150	0:0	0:0	0:0
150-160	0:0	0:0	0:0
160-170	0:0	0:0	0:0
170-180	0:0	0:0	0:0
180-190	0:0	0:0	0:0
190-200	0:0	0:0	0:0

Table 14: Results from generalized additive model fits to selectivity data for the MCD survey. The response variable is number of surfclams caught in the survey dredge (a modified commercial dredge) compared to the number of surfclams caught in a lined dredge. The predictors are length bin (L), and a year−station (YrSta) effect. Some models included an offset based on the tow distance at each station. The s indicates a spline function and RE indicates random effects. The best model by AIC included random effects for each year−station combination in both intercept and length.

Model	AIC	BIC
s(L)+s(YrSta,RE)+s(YrSta,L,RE)	3223	3633
s(L)+s(YrSta,RE)	3594	3831
s(L)	6838	6879

Table 15: The MCD survey dredge (post 2011) selectivity coefficients estimated using the best (by AIC) selectivity model, by size bin.

Length	Selx	uci	lci	Length	Selx	uci	lci
5	0.054	0.683	0.002	101	0.787	0.807	0.765
7	0.046	0.571	0.002	103	0.804	0.823	0.785
9	0.039	0.454	0.002	105	0.818	0.835	0.800
11	0.033	0.346	0.002	107	0.829	0.845	0.811
13	0.029	0.257	0.003	109	0.837	0.852	0.820
15	0.025	0.189	0.003	111	0.843	0.858	0.826
17	0.022	0.140	0.003	112	0.847	0.863	0.830
18	0.020	0.105	0.003	114	0.850	0.866	0.833
20	0.018	0.081	0.004	116	0.853	0.869	0.835
22	0.016	0.065	0.004	118	0.855	0.872	0.836
24	0.015	0.053	0.004	120	0.857	0.874	0.837
26	0.014	0.045	0.005	122	0.858	0.877	0.838
28	0.014	0.040	0.005	124	0.860	0.879	0.839
30	0.014	0.036	0.005	126	0.862	0.882	0.840
32	0.014	0.033	0.006	128	0.865	0.886	0.842
34	0.014	0.031	0.006	130	0.868	0.889	0.844
36	0.014	0.030	0.007	132	0.871	0.893	0.846
38	0.015	0.029	0.008	134	0.875	0.897	0.848
40	0.016	0.029	0.008	136	0.878	0.901	0.851
41	0.017	0.030	0.009	137	0.882	0.905	0.854
43	0.018	0.030	0.010	139	0.885	0.908	0.857
45	0.019	0.032	0.011	141	0.888	0.912	0.859
47	0.020	0.033	0.012	143	0.891	0.915	0.861
49	0.022	0.035	0.014	145	0.893	0.917	0.862
51	0.024	0.038	0.015	147	0.894	0.919	0.862
53	0.027	0.041	0.017	149	0.895	0.921	0.862
55	0.030	0.045	0.020	151	0.895	0.922	0.861
57	0.033	0.049	0.022	153	0.895	0.923	0.859
59	0.038	0.055	0.026	155	0.894	0.923	0.857
61	0.043	0.061	0.030	157	0.893	0.922	0.853
63	0.050	0.070	0.035	159	0.891	0.922	0.849
64	0.058	0.080	0.042	160	0.888	0.921	0.844
66	0.069	0.094	0.051	162	0.885	0.920	0.839
68	0.083	0.110	0.062	164	0.882	0.919	0.833
70	0.101	0.131	0.077	166	0.880	0.918	0.827
72	0.123	0.156	0.096	168	0.877	0.917	0.822
74	0.150	0.188	0.119	170	0.875	0.916	0.817
76	0.184	0.225	0.149	172	0.873	0.916	0.813
78	0.225	0.269	0.186	174	0.873	0.917	0.809
80	0.273	0.320	0.231	176	0.873	0.918	0.808
82	0.327	0.375	0.282	178	0.874	0.920	0.807
84	0.385	0.434	0.340	180	0.877	0.923	0.808
86	0.446	0.493	0.401	182	0.880	0.927	0.809
88	0.507	0.551	0.463	183	0.884	0.931	0.811
89	0.564	0.605	0.523	185	0.889	0.937	0.814
91	0.617	0.654	0.579	187	0.895	0.942	0.817

Table 15 cont.

93	0.664	0.697	0.630	189	0.901	0.948	0.819
95	0.704	0.733	0.673	191	0.907	0.954	0.822
97	0.738	0.763	0.710	193	0.913	0.959	0.824
99	0.765	0.788	0.740	195	0.919	0.964	0.825

Table 16: Results from model fits to predict meat weight. Predictors are ln(shell length) (L), ln(depth) (D), density (ρ), and region (R). Random effects are enclosed in parentheses and are limited to station (St), year (both affecting the estimate of the intercept), and length (affecting the estimate of the length coefficient). Regional coefficients are shown. SVA is assumed to have coefficient equal to 0.

Formula	int	L	D	ρ	R	AIC	BIC
L+D+R+(L+St)+(L+Year)	-8.03 (0.05)	2.7 (0.044)	-0.16 (0.021)		X	26780	26864
L+D+Density+R+(L+St)+(L+Year)	-8.03 (0.05)	2.7 (0.044)	-0.16 (0.021)	-0.003 (0.004)	X	26781	26871
L+R+(L+St)+(L+Year)	-8.56 (0.049)	2.7 (0.044)			X	26833	26911
L+D+R+(L+St)	-8.25 (0.045)	2.73 (0.021)	-0.13 (0.022)		X	26855	26921
L+R+(L+St)	-8.68 (0.045)	2.73 (0.021)			X	26886	26946
L+D+(L+St)+(L+Year)	-8.12 (0.034)	2.69 (0.056)	-0.1 (0.019)			27237	27292
L+(L+St)+(L+Year)	-8.49 (0.03)	2.7 (0.057)				27264	27312
L+Density+(L+St)	-8.67 (0.008)	2.75 (0.021)		-0.02 (0.004)		27315	27351
L+D+(L+St)	-8.67 (0.008)	2.73 (0.021)	-0.06 (0.02)			27317	27353
L+(L+St)	-8.69 (0.008)	2.74 (0.021)				27325	27355
L+D+(St)	-8.45 (0.007)	2.73 (0.011)	-0.06 (0.019)			27744	27768
L+(St)	-8.67 (0.007)	2.73 (0.011)				27752	27770

Formula	DMV	NJ	LI	SNE	GBK
L+D+R+(L+St)+(L+Year)	0.02 (0.044)	0.03 (0.043)	-0.01 (0.045)	0.21 (0.054)	0.22 (0.049)
L+D+Density+R+(L+St)+(L+Year)	0.02 (0.044)	0.04 (0.043)	-0.01 (0.045)	0.21 (0.054)	0.22 (0.05)
L+R+(L+St)+(L+Year)	-0.03 (0.045)	0 (0.044)	-0.009 (0.046)	0.19 (0.056)	0.1 (0.049)
L+D+R+(L+St)	0.02 (0.047)	0.02 (0.046)	-0.03 (0.048)	0.18 (0.056)	0.18 (0.051)
L+R+(L+St)	-0.02 (0.047)	-0.002 (0.046)	-0.03 (0.049)	0.17 (0.057)	0.09 (0.049)
L+D+(L+St)+(L+Year)					
L+(L+St)+(L+Year)					
L+Density+(L+St)					
L+D+(L+St)					
L+(L+St)					
L+D+(St)					
L+(St)					

Table 17: Number of age samples in NEFSC clam surveys by survey year and region.

Year	SVA	DMV	NJ	LI	SNE	GBK
1978	0	199	289	0	0	0
1980	2	389	452	29	61	0
1981	45	401	641	27	38	0
1982	5	796	927	40	123	4
1983	142	422	934	6	369	0
1984	0	0	0	0	0	643
1986	64	748	1216	45	71	413
1989	60	102	566	53	42	86
1992	11	134	257	47	54	311
1994	0	299	476	0	0	0
1997	0	626	227	0	0	50
1999	0	510	496	22	50	178
2002	29	327	779	31	20	54
2005	17	322	523	21	6	0
2008	0	138	459	99	39	105
2011	26	114	133	71	15	75
2012	13	43	148	86	0	0
2013	0	0	0	0	35	58
2014	0	0	0	0	4	38
2015	32	139	362	141	12	0

Table 18: Growth curve (Von Bertalanffy) parameter estimates and standard errors for each region by year. Year and region combinations that did not provide sufficient data for model convergence are not shown. SVAtoSNE is the southern area and GBK is the northern area.

Region	Year	n	L_∞	$L_\infty se$	K	K se	t_0	$t_0 se$
SVA	1983	142	183.8	13.75	0.205	0.045	-0.266	0.451
SVA	1986	64	142.2	5.01	0.535	0.192	1.688	0.720
SVA	1989	60	136.9	3.58	0.417	0.098	0.471	0.428
SVA	1992	11	156.1	9.36	0.258	0.077	-0.565	0.608
SVA	2002	29	142.4	19.68	0.230	0.161	-1.426	1.836
SVA	2005	17	122.6	18.35	0.366	0.195	-0.191	0.443
SVA	2011	26	113.0	7.47	0.624	0.159	0.231	0.226
SVA	2012	16	112.9	5.66	0.854	0.236	0.333	0.254
SVA	2015	32	108.9	5.21	0.514	0.145	-0.096	0.463
DMV	1982	796	175.2	1.67	0.206	0.008	-0.380	0.129
DMV	1983	422	176.5	2.49	0.209	0.014	-0.494	0.220
DMV	1986	748	184.2	3.05	0.134	0.010	-1.706	0.374
DMV	1989	102	144.1	3.40	0.302	0.052	0.005	0.462
DMV	1992	134	172.7	7.27	0.159	0.027	-1.320	0.523
DMV	1994	299	149.5	1.66	0.343	0.022	0.937	0.134
DMV	1997	626	151.4	3.25	0.148	0.014	-1.972	0.395
DMV	1999	510	136.4	1.92	0.238	0.027	-0.814	0.482
DMV	2002	327	156.5	4.36	0.172	0.022	-1.567	0.445
DMV	2005	322	151.1	2.99	0.157	0.013	-1.326	0.298
DMV	2008	138	159.0	3.52	0.200	0.018	-1.012	0.221
DMV	2011	115	121.9	3.23	0.361	0.049	-0.261	0.275
DMV	2012	43	149.2	11.23	0.152	0.065	-2.528	2.166
DMV	2015	140	144.3	8.18	0.115	0.029	-4.022	1.329
NJ	1982	927	173.4	1.43	0.264	0.009	-0.244	0.087
NJ	1983	934	176.3	1.73	0.244	0.010	-0.233	0.109
NJ	1986	1216	175.6	1.87	0.177	0.008	-0.965	0.174
NJ	1989	566	162.9	2.01	0.238	0.015	0.085	0.183
NJ	1992	257	167.0	4.11	0.187	0.023	-0.922	0.432
NJ	1994	476	159.6	2.18	0.197	0.017	-1.080	0.356
NJ	1997	227	165.6	2.05	0.212	0.018	-0.546	0.291
NJ	1999	496	160.9	1.38	0.264	0.015	-0.265	0.172
NJ	2002	779	163.9	1.73	0.209	0.015	-1.338	0.279
NJ	2005	523	164.1	2.42	0.150	0.013	-1.711	0.455
NJ	2008	459	157.1	2.27	0.185	0.015	-1.317	0.306
NJ	2011	140	155.1	4.09	0.179	0.029	-1.525	0.714
NJ	2012	175	165.1	4.33	0.144	0.023	-2.964	0.882
NJ	2015	366	156.3	3.00	0.136	0.016	-3.091	0.702
LI	1982	40	156.7	1.86	0.800	0.213	2.315	0.198
LI	1986	45	165.9	3.40	0.222	0.039	-0.477	0.695
LI	1989	53	163.1	3.56	0.259	0.034	0.029	0.394
LI	1992	47	155.8	3.03	0.307	0.036	-0.492	0.314

Table 18 cont.

LI	1999	22	167.9	4.72	0.302	0.044	0.050	0.283
LI	2002	31	174.9	8.13	0.250	0.059	-0.187	0.594
LI	2005	21	160.1	7.63	0.210	0.070	-1.098	1.226
LI	2008	99	150.4	3.62	0.424	0.060	0.400	0.262
LI	2011	72	163.7	4.64	0.226	0.052	-0.534	1.015
LI	2012	86	153.4	6.15	0.269	0.066	-0.458	0.737
LI	2015	141	170.6	7.26	0.123	0.030	-4.188	1.517
SNE	1982	123	160.4	2.40	0.222	0.025	0.142	0.378
SNE	1983	369	167.9	1.66	0.265	0.023	-0.709	0.350
SNE	1986	71	163.6	2.62	0.316	0.038	1.071	0.258
SNE	1989	42	172.0	5.18	0.422	0.079	1.509	0.350
SNE	1992	54	162.4	2.30	0.203	0.024	0.086	0.317
SNE	1999	50	174.8	6.34	0.210	0.041	-0.584	0.560
SNE	2002	20	162.3	5.31	0.452	0.118	1.039	0.525
SNE	2008	39	172.9	5.14	0.161	0.033	-1.592	0.952
SNE	2013	35	169.6	4.42	0.499	0.192	2.081	0.852
SNE	2015	12	171.6	28.62	0.099	0.093	-5.357	7.271
GBK	1984	643	146.7	3.22	0.266	0.022	0.371	0.153
GBK	1986	413	149.0	3.24	0.225	0.019	-0.233	0.175
GBK	1989	86	152.8	5.20	0.197	0.040	-0.750	0.765
GBK	1992	311	148.7	2.82	0.270	0.020	0.585	0.155
GBK	1997	50	138.8	7.37	0.194	0.045	-0.507	0.683
GBK	1999	178	145.6	3.13	0.355	0.033	0.081	0.160
GBK	2002	54	143.2	4.76	0.427	0.095	1.636	0.416
GBK	2008	105	146.4	3.70	0.212	0.036	-1.018	0.550
GBK	2011	75	144.9	2.10	0.545	0.206	2.084	0.931
GBK	2013	59	136.4	3.78	0.421	0.106	0.929	0.596
GBK	2014	40	144.7	3.61	0.223	0.061	-0.645	1.299
south	1982	1891	169.9	1.00	0.239	0.007	-0.399	0.083
south	1983	1873	172.6	1.08	0.249	0.008	-0.246	0.092
south	1986	2144	176.6	1.42	0.165	0.006	-1.130	0.153
south	1989	823	159.7	1.67	0.245	0.014	-0.057	0.165
south	1992	503	164.8	2.18	0.201	0.013	-0.712	0.212
south	1994	775	152.4	1.14	0.292	0.014	0.399	0.139
south	1997	853	162.8	3.28	0.130	0.011	-2.364	0.379
south	1999	1078	150.5	1.38	0.233	0.014	-0.754	0.225
south	2002	1186	162.8	1.74	0.186	0.012	-1.646	0.247
south	2005	889	160.1	1.78	0.155	0.008	-1.337	0.213
south	2008	735	156.5	1.62	0.214	0.012	-0.899	0.179
south	2011	368	155.4	2.51	0.189	0.015	-1.176	0.280
south	2012	320	160.5	3.35	0.165	0.020	-2.275	0.578
south	2013	35	169.6	4.42	0.499	0.192	2.081	0.852
south	2015	691	159.1	3.12	0.120	0.012	-3.789	0.612
All	1982	1895	169.9	1.00	0.239	0.007	-0.394	0.083
All	1983	1873	172.6	1.08	0.249	0.008	-0.246	0.092

Table 18 cont.

All	1984	643	146.7	3.22	0.266	0.022	0.371	0.153
All	1986	2557	172.0	1.24	0.186	0.006	-0.543	0.098
All	1989	909	158.2	1.55	0.247	0.014	-0.050	0.161
All	1992	814	161.4	1.93	0.208	0.011	-0.359	0.155
All	1994	775	152.4	1.14	0.292	0.014	0.399	0.139
All	1997	903	162.0	3.14	0.132	0.011	-2.241	0.355
All	1999	1256	149.4	1.21	0.254	0.013	-0.547	0.166
All	2002	1240	162.7	1.74	0.185	0.011	-1.646	0.244
All	2005	889	160.1	1.78	0.155	0.008	-1.337	0.213
All	2008	840	154.8	1.49	0.216	0.012	-0.899	0.172
All	2011	443	152.8	1.98	0.204	0.015	-1.006	0.254
All	2012	320	160.5	3.35	0.165	0.020	-2.275	0.578
All	2013	94	151.6	3.74	0.369	0.081	0.987	0.581
All	2014	44	149.1	7.14	0.144	0.054	-2.690	2.346
All	2015	691	159.1	3.12	0.120	0.012	-3.789	0.612

Table 19: Numbers of successful random survey tows with sensor data used to evaluate the precision of the MCD survey. Tows are shown in the year they were made (with no borrowing).

Year	South	North
1997	266	57
1999	216	30
2002	251	28
2005	208	
2008	241	12
2011	221	84
2012	131	
2013	35	64
2014	1	19
2015	164	

Table 20: Models relating the proportion of positive tows in the survey to year and stratum used to evaluate the precision of the MCD survey, where C_t is catch in tow t, yr is year as a factor, and str is the stratum.

Model	Formula	Family	Link	df	AIC
glmA	$C_t = yr$	Tweedie(p=1.7)	log	9	14,060
glmB	$C_t = str$	Tweedie(p=1.7))	log	31	13,923
gamA	$C_t = s(yr, by = str)$	Tweedie(p=1.7)	log	67	14,160
gamB	$C_t = s(yr, by = str) + str$	Tweedie(p=1.7)	log	118	13,495

Table 21: Structure of SS3 models used for surfclams in the southern and northern areas.

Model aspect	South	North	Note
M	0.15	0.15	Constant for all ages and years
Age bins	0–30	0–30	
Length bins	1–20 cm	1–20 cm	
Time	1965–2015	1984–2015	
Seasons/morphs/subareas	0	0	
Commercial fleets	1	1	
Fishery selectivity	Double normal	Double normal	
Surveys (trend)	2	2	RD (trend) RD-SWAN (scale) MCD (scale and trend)
Survey selectivity RD	Double normal	Double normal	Based on field estimates
Survey selectivity MCD	Double normal	Double normal	Based on field estimates
Survey catchability (RD-SWAN)	Estimated	Estimated	Uses informative prior distribution
Survey catchability (MCD)	Estimated	Estimated	Uses informative prior distribution
Recruitment Model	Beverton-Holt	Beverton-Holt	Fixed steepness, estimated R_0 and variance (south)
Recruit dev years	1965–2015	1969–2015	
Bias Adjustment parameters	1955,1976,2008,2015,0.79	1961,1974,2006,2015,0.87	
F method	Hybrid	Hybrid	6 iterations (exact F)

Table 22: Parameters estimated internally and externally in SS3 base models for Atlantic surfclam in the southern and northern areas. Parameters listed as fixed or estimated apply to both areas. Parameters listed as estimated in one area are fixed in the other. Numbers of parameters are summarized in the last rows.

Parameter	South	North	Note
M	0.15	0.15	Fixed
Length at age 4	9.613	9.184	Estimated
Length at age 30	16.255	14.912	Estimated
Von Bertalanffy K	0.224	0.253	Fixed
CV of size at ages 5 y	0.172	0.17	Estimated in South
CV of size at age 30 y	0.088	0.077	Estimated in South
Shell length to meat weight multiplier	9e-05	0.00011	Fixed
Shell length to meat weight exponent	2.733	2.733	Fixed
Spawner recruit R_0	16.018	14.251	Estimated
Spawner recruit steepness	0.95	0.95	Fixed
Spawner recruit sd	0.861	1	Estimated
Catchability RD	0.103	0.098	Estimated (with prior)
Catchability MCD	0.738	0.661	Estimated (with prior)
Fishery selectivity peak	15.107	15.075	Estimated
Fishery selectivity top	-8.65802	-2.12929	Estimated in South
Fishery selectivity asc. width	1.638	2.199	Estimated
Fishery selectivity dec. width	1.375	0.553	Estimated in South
Fishery selectivity init	-999	-999	Fixed
Fishery selectivity final	-999	-999	Fixed
Survey (RD) selectivity Peak	8.819	9.534	Estimated in North
Survey (RD) selectivity top	-0.64891	-0.64891	Fixed
Survey (RD) selectivity asc. width	2.239	1.909	Estimated in North
Survey (RD) selectivity dec. width	2.356	2.356	Fixed
Survey (RD) selectivity init	-999	-999	Fixed
Survey (RD) selectivity final	-0.81743	-0.81743	Fixed
Survey (MCD) selectivity Peak	11	11	Fixed
Survey (MCD) selectivity top	1.1	1.1	Fixed
Survey (MCD) selectivity asc. width	2.239	2.239	Fixed
Survey (MCD) selectivity dec. width	8	8	Fixed
Survey (MCD) selectivity init	-999	-999	Fixed
Survey (MCD) selectivity final	-0.81743	-0.81743	Fixed
Initial F	0.005	0	Estimated in South
Total estimated (-recruit deviations)	13	9	
Recruit deviations	51	32	
Total estimated	64	41	

Table 23: Parameter estimates and estimated precision in a basecase model run for Atlantic surfclam in the southern area . This table shows the thirty parameters that are the least precisely determined, ranked by coefficient of variation.

name	value	std.dev	cv
Q_parm[2]	-0.30	11120.00	36566.92
recdev2015	-0.01	0.85	78.57
recdev1975	-0.02	0.53	23.84
recdev1994	-0.04	0.43	11.87
recdev1966	-0.06	0.68	11.76
recdev1965	-0.07	0.69	9.99
recdev1974	-0.06	0.51	9.10
recdev1987	0.06	0.53	8.78
recdev1984	-0.06	0.50	8.48
recdev2007	0.07	0.53	7.13
recdev1982	0.09	0.50	5.57
recdev1986	0.10	0.44	4.57
recdev2014	-0.19	0.83	4.33
recdev1968	-0.15	0.63	4.27
recdev1967	-0.16	0.67	4.19
recdev2012	0.15	0.60	3.95
selparm[2]	-8.66	28.69	3.31
recdev1973	-0.18	0.54	2.98
recdev1998	-0.13	0.34	2.67
recdev2013	-0.31	0.73	2.32
recdev1993	0.25	0.59	2.32
recdev1969	-0.29	0.62	2.14
recdev2011	-0.45	0.75	1.66
recdev1985	-0.38	0.59	1.56
recdev1972	-0.41	0.58	1.40
recdev2006	-0.30	0.41	1.35
recdev1970	-0.48	0.61	1.27
recdev1971	-0.53	0.59	1.13
recdev1983	0.35	0.38	1.09
recdev2008	0.45	0.49	1.09

Table 24: Parameter estimates and estimated precision in a basecase model run for Atlantic surfclam in the northern area. This table shows the thirty parameters that are the least precisely determined, ranked by coefficient of variation.

name	value	std.dev	cv
recdev1973	-0.06	0.42	7.09
recdev1990	-0.06	0.45	6.93
recdev2005	-0.08	0.44	5.47
recdev1989	0.12	0.37	3.19
recdev2004	-0.17	0.50	2.85
recdev1977	-0.12	0.33	2.65
recdev2006	0.18	0.43	2.40
selparm[2]	-2.13	4.89	2.30
recdev2014	-0.54	0.99	1.81
recdev2015	-0.54	0.99	1.81
recdev2013	-0.55	0.99	1.80
recdev1985	0.19	0.34	1.79
recdev1999	0.32	0.52	1.66
recdev1971	-0.35	0.52	1.46
recdev1980	0.16	0.23	1.38
recdev1991	0.42	0.51	1.21
recdev1983	0.23	0.27	1.16
recr_std2015	884760.00	1013800.00	1.15
recr_std2014	842830.00	965640.00	1.15
recr_std2013	802040.00	918190.00	1.14
recdev1978	0.23	0.25	1.10
recdev1992	0.49	0.53	1.08
recdev2002	-0.68	0.72	1.05
recr_std2012	448290.00	467970.00	1.04
recdev1982	0.23	0.23	1.00
recdev2007	-0.57	0.57	0.99
recdev1986	0.35	0.34	0.96
recr_std2001	237510.00	225330.00	0.95
recdev2003	-0.69	0.65	0.94
recdev1970	-0.64	0.60	0.93

Table 25: Likelihood profile over unfished recruitment parameter (R0). The values in the table are the differences, in likelihood units, between each profile run and the minimum likelihood for that row (likelihood component). Conflicts within the data are apparent when the minimum likelihood values (gray cells) occur in different columns for each row. That is, different likelihood components within the model were minimized at different values of R0. Because R0 is important for setting the scale of estimated biomass in the model (Relative B; last row), data conflicts around R0 tend to increase uncertainty in scale. The coloumn corresponding to the minimum total likelihood is shown in italics.

ln(R0)	14.5	15	15.5	*16.02*	16.5	17
Total	24.1	9.75	2.3	*0*	1.93	7
Parm priors	22.8	10.7	3.2	*0*	0.8	4.5
RDtrend	0	2.4	3.9	*5.1*	5.8	6
RDscale	0	0	0.1	*0.3*	0.4	0.6
ComLen	0	0.2	0.3	*0.4*	0.4	0.3
LenRD	1	0.1	0	*0.1*	0.4	0.7
LenMCD	0	0	0.2	*0.4*	0.5	0.7
AgeRD	4.9	2.2	1	*0.3*	0	0
AgeMCD	2.9	1.8	1.1	*0.6*	0.3	0
Relative B	1	1.6	2.6	*4.2*	6.4	9.5

Table 26: Likelihood profile over unfished recruitment parameter (R0). The values in the table are the differences, in likelihood units, between each profile run and the minimum likelihood for that row (likelihood component). Conflicts within the data are apparent when the minimum likelihood values (gray cells) occur in different columns for each row. That is, different likelihood components within the model were minimized at different values of R0. Because R0 is important for setting the scale of estimated biomass in the model (Relative B; last row), data conflicts around R0 tend to increase uncertainty in scale. The coloumn corresponding to the minimum total likelihood is shown in italics.

ln(R0)	12	13.00	*14*	*14.24*	15	16
Total	7.7	2.1	*0*	*0*	1.2	5.8
Parm priors	1.6	0.5	*0*	*0*	0.2	0.9
RDtrend	0	0.5	*1*	*1.1*	1.5	1.9
RDscale	141.3	52.5	*5.5*	*0.4*	0	35.7
MCD	7.7	2.3	*0.1*	*0*	0.7	4.1
ComLen	0	0.2	*0.2*	*0.3*	0.3	0.3
AgeRD	0.3	0.4	*0.3*	*0.3*	0.2	0
AgeMCD	0	0.1	*0.2*	*0.2*	0.3	0.5
Relative B	1	3.1	*8.5*	*10.9*	23	61.4

Table 27: Whole stock biomass (mt) and fishing mortality status estimates with cv and approximate 95% confidence intervals, using the current reference points from the previous assessment. The table shows the overlap between the distributions of the threshold and the terminal B (P[overlap]) and the probability of overfished status (P[overfishing]), which accounts for the correlation between the threshold and the terminal B. The current F reference point was a point estimate with no uncertainty and therefore the probability of overfishing was equal to the overlap.

	Estimate	CV	LCI	UCI	P[overlap]	P[overfishing]
SSB_{2015}	46355730	0.635	14822331	144974076	0.434	0.000
SSB Threshold	19076275	0.149	6455642	56369955		
F_{2015}	0.009	0.637	0.003	0.029	0.000	0.000
F Threshold	0.15					

Table 28: Whole stock Atlantic surfclam fishing mortality status estimates (based on recommended reference points) with cv and approximate 95% confidence intervals.

	F	CV	LCI	UCI
$\frac{F_{2015}}{F_{Threshold}}$	0.295	0.225	0.191	0.456

Table 29: Whole stock Atlantic surfclam biomass status estimates (based on recommended reference points) with cv and approximate 95% confidence intervals.

	Ratio	CV	LCI	UCI
$\frac{SSB_{2015}}{SSB_{Threshold}}$	2.54	0.696	0.74	8.71

Table 30: Projected spawning stock biomass (1000 mt) and biomass status ($\frac{SSB}{SSB_{Threshold}}$, where $SSB_{Threshold} = 0.25SSB_0$) during 2016-2025 for Atlantic surfclam in the southern, northern and combined areas. The biomass estimates from basecase models in the top panel are very uncertain and shown only to document calculation of the more reliable status ratios in the lower panel.

	Southern area			**Northern area**			**Whole stock**		
Year	Status Quo	Quota	F=FOFL	Status Quo	Quota	F=FOFL	Status Quo	Quota	F=FOFL
				SSB (1000 mt)					
2016	2937	2937	2937	396	396	396	3333	3333	3333
2017	2900	2894	2855	358	356	356	3258	3251	3212
2018	3002	2991	2914	329	325	326	3331	3316	3240
2019	2979	2963	2853	316	311	313	3295	3274	3166
2020	2983	2962	2823	309	302	305	3291	3264	3128
2021	3044	3020	2854	305	298	302	3349	3318	3156
2022	3113	3085	2897	327	319	324	3440	3404	3220
2023	3180	3149	2940	351	342	347	3531	3491	3287
2024	3243	3210	2982	375	365	371	3618	3575	3353
2025	3302	3267	3021	398	388	393	3701	3654	3414
				$\frac{SSB}{SSB_{Threshold}}$					
2016	3.24	3.24	3.24	2.04	2.04	2.04	2.57	2.57	2.57
2017	3.33	3.32	3.30	2.30	2.29	2.29	2.76	2.76	2.75
2018	3.41	3.41	3.37	2.52	2.51	2.51	2.93	2.92	2.91
2019	3.48	3.48	3.42	2.71	2.70	2.70	3.07	3.06	3.04
2020	3.55	3.54	3.47	2.87	2.86	2.86	3.19	3.18	3.15
2021	3.60	3.59	3.51	3.02	3.00	3.01	3.30	3.28	3.25
2022	3.65	3.64	3.55	3.14	3.12	3.13	3.39	3.37	3.33
2023	3.69	3.68	3.58	3.25	3.22	3.23	3.46	3.44	3.40
2024	3.73	3.71	3.60	3.34	3.31	3.32	3.53	3.50	3.46
2025	3.76	3.74	3.63	3.42	3.39	3.40	3.58	3.56	3.51

Table 31: Projected catch (landings + incidental mortality; mt) and fishing mortality status ratio $\frac{F}{F_{Threshold}}$ during 2016-2025 for Atlantic surfclam in the southern, northern and combined areas. $\frac{F}{F_{Threshold}}$ for the northern area was not possible due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.

	Southern area			**Northern area**			**Whole stock**		
Year	Status Quo	Quota	F=FOFL	Status Quo	Quota	F=FOFL	Status Quo	Quota	F=FOFL
				Catch (mt)					
2016	15771	22610	68725	4562	6753	6444	20333	29363	75169
2017	15771	22610	69447	4562	6753	5917	20333	29363	75364
2018	15771	22610	69332	4562	6753	5527	20333	29363	74859
2019	15771	22610	68981	4562	6753	5279	20333	29363	74260
2020	15771	22610	68930	4562	6753	5201	20333	29363	74131
2021	15771	22610	69328	4562	6753	5288	20333	29363	74615
2022	15771	22610	70044	4562	6753	5503	20333	29363	75547
2023	15771	22610	70914	4562	6753	5793	20333	29363	76707
2024	15771	22610	71818	4562	6753	6113	20333	29363	77931
2025	15771	22610	72684	4562	6753	6431	20333	29363	79115
				$\frac{F}{F_{Threshold}}$					
2016	0.227	0.326	0.999				0.362	0.529	0.903
2017	0.222	0.319	0.999				0.372	0.546	0.903
2018	0.219	0.315	0.999				0.383	0.562	0.903
2019	0.217	0.314	0.999				0.390	0.575	0.903
2020	0.215	0.311	0.999				0.390	0.578	0.903
2021	0.212	0.307	0.999				0.384	0.570	0.903
2022	0.208	0.302	0.999				0.373	0.554	0.903
2023	0.205	0.296	0.999				0.360	0.535	0.903
2024	0.201	0.291	0.999				0.348	0.517	0.903
2025	0.198	0.286	0.999				0.336	0.499	0.903

Table 32: Cumulative probability of being in overfished status in any of the years from 2016-2025 under a variety of catch scenarios for Atlantic surfclam in the southern, northern and combined areas. Overfishing determination for the northern area was not possible due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.

Catch scenario	$P[Overfished]$	$P[Overfishing]$
Southern area		
Status Quo	0.007	0.000
Quota	0.007	0.008
F=FOFL	0.009	0.529
Northern area		
Status Quo	0.107	
Quota	0.116	
F=FOFL	0.111	
Whole stock		
Status Quo	0.091	0.095
Quota	0.093	0.240
F=FOFL	0.098	0.498

Table 33: Projected stock status ($\frac{SSB}{SSB_{Threshold}}$ and $\frac{F}{F_{Threshold}}$) during 2016-2025 for Atlantic surfclam in the southern, northern and combined areas from projections based on the highest and lowest (in biomass scale) of credible sensitivity runs for each area. Overfishing determination for the northern area was not possible due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.The results indicate that projected stock status is reasonably robust to biomass scale uncertainty.

	Southern area		**Northern area**		**Whole stock**	
Year	High Biomass	Low Biomass	High Biomass	Low Biomass	High Biomass	Low Biomass
			$\frac{SSB}{SSB_{Threshold}}$			
2016	3.072	2.954	1.611	2.532	2.225	2.735
2017	3.226	3.073	1.924	2.716	2.491	2.889
2018	3.350	3.169	2.196	2.875	2.712	3.018
2019	3.450	3.252	2.432	3.012	2.897	3.130
2020	3.531	3.323	2.636	3.130	3.051	3.225
2021	3.596	3.385	2.812	3.233	3.180	3.308
2022	3.650	3.438	2.964	3.321	3.289	3.379
2023	3.694	3.484	3.095	3.396	3.381	3.440
2024	3.730	3.524	3.209	3.461	3.460	3.492
2025	3.761	3.558	3.307	3.517	3.526	3.537
			$\frac{F}{F_{Threshold}}$			
2016	0.360	0.358			0.385	0.673
2017	0.358	0.353			0.402	0.702
2018	0.358	0.351			0.419	0.735
2019	0.357	0.348			0.431	0.766
2020	0.353	0.343			0.432	0.789
2021	0.346	0.336			0.422	0.798
2022	0.337	0.327			0.405	0.792
2023	0.329	0.319			0.385	0.779
2024	0.321	0.311			0.366	0.761
2025	0.314	0.304			0.349	0.744

Table 34: Estimated catch (landings + incidental mortality; mt) at the Over Fishing Limit (OFL) from 2016-2025 for Atlantic surfclam in the southern, northern and combined areas. OFL for the northern area was an approximation due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.

Year	Mean	Median	CV	LCI	UCI
Southern area					
2016	70607	68733	0.23	44822	111225
2017	71299	69404	0.23	45347	112104
2018	71234	69338	0.24	45135	112424
2019	70984	68983	0.24	44472	113300
2020	71062	68909	0.25	43776	115355
2021	71633	69310	0.26	43392	118255
2022	72435	70043	0.26	43551	120475
2023	73309	70912	0.26	44159	121701
2024	74201	71836	0.26	45031	122266
2025	75029	72713	0.25	45961	122481
Northern area					
2016	7394	6447	0.56	2644	20679
2017	6789	5917	0.56	2435	18926
2018	6352	5534	0.56	2268	17793
2019	6070	5277	0.57	2150	17139
2020	6004	5205	0.57	2106	17115
2021	6111	5288	0.58	2127	17559
2022	6368	5507	0.58	2209	18355
2023	6699	5793	0.58	2331	19248
2024	7061	6114	0.58	2461	20256
2025	7425	6432	0.58	2592	21267
Whole stock					
2016	87892	75126	0.61	29278	263854
2017	88243	75432	0.61	29394	264908
2018	87709	74832	0.61	29081	264532
2019	87316	74281	0.62	28639	266210
2020	87511	74110	0.63	28309	270519
2021	88370	74625	0.64	28240	276534
2022	89700	75509	0.64	28404	283269
2023	90904	76631	0.64	28917	285766
2024	92344	77954	0.64	29510	288970
2025	93501	79083	0.63	30016	291255

3 Figures

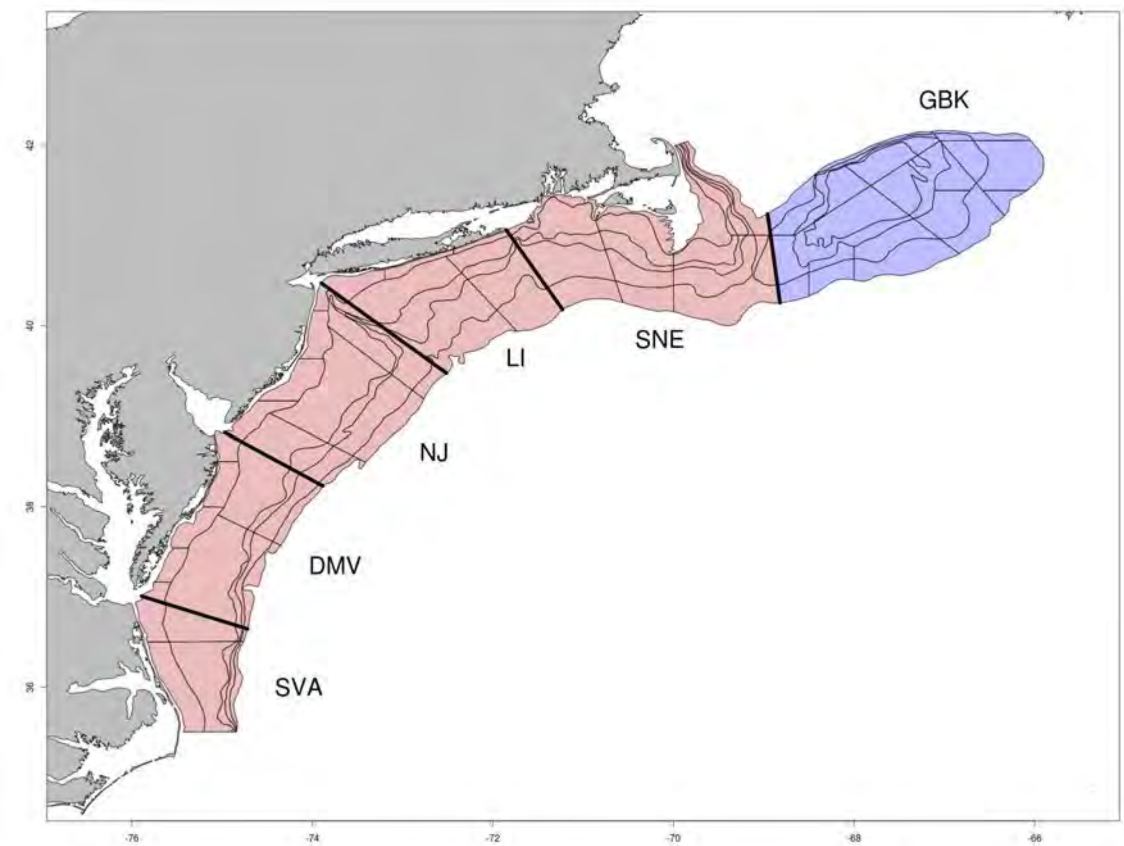


Figure 6: The Atlantic surfclam regions divided, for assessment modeling, into two areas. The northern area is blue and the southern area is pink.

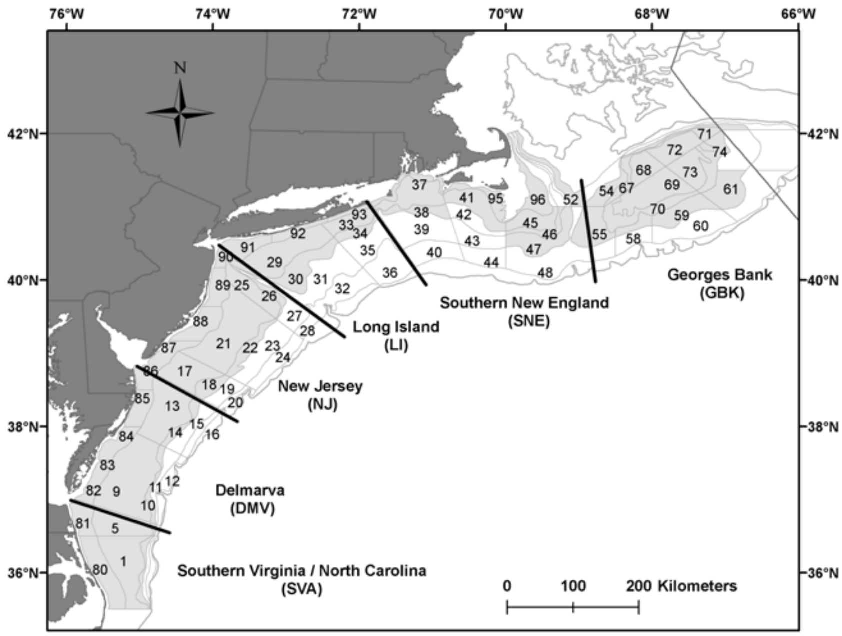


Figure 7: Surfclam stock assessment regions and NEFSC shellfish survey strata. The shaded strata are the surfclam strata that have been used in past assessments.

Figure 8: Atlantic surfclam landings (total and EEZ) during 1965-2015.

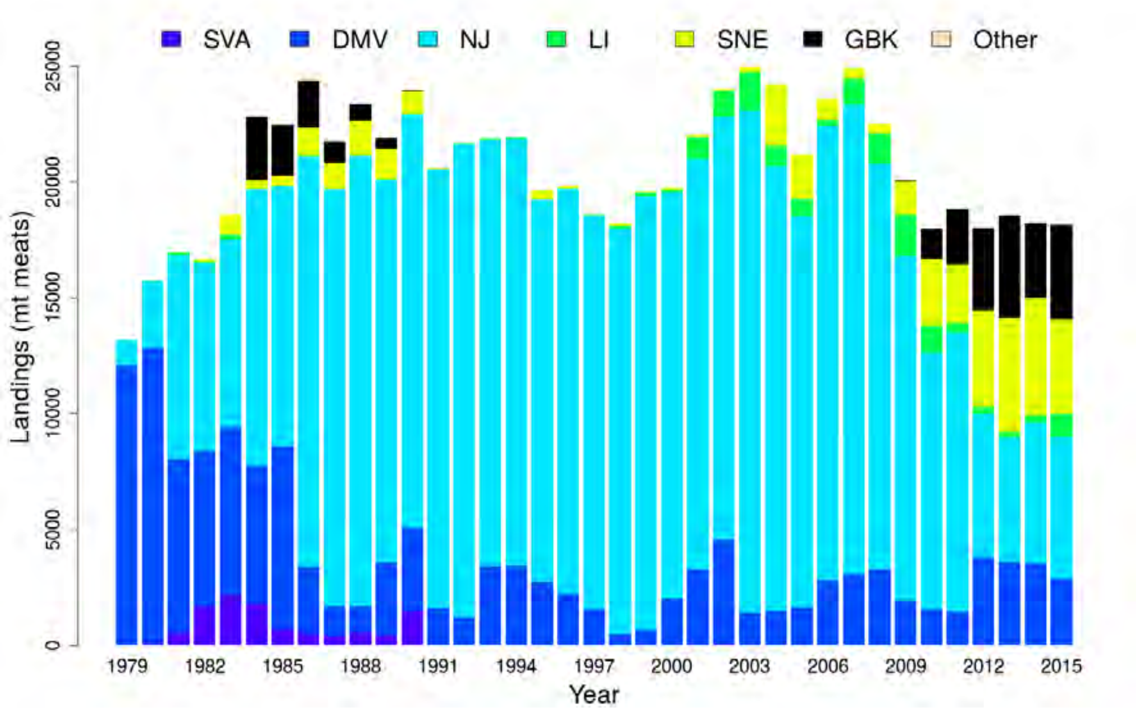


Figure 9: Surfclam landings from the US EEZ during 1979-2015, by stock assessment region.

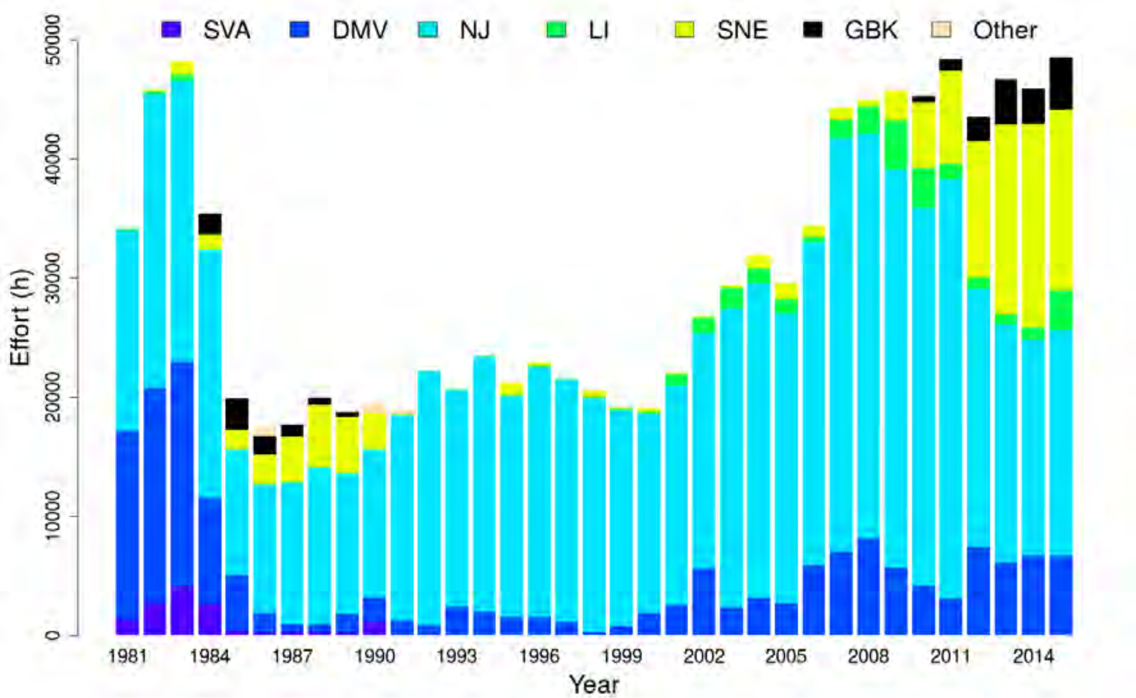


Figure 10: Surfclam hours fished from the US EEZ during 1981-2015, by stock assessment region.

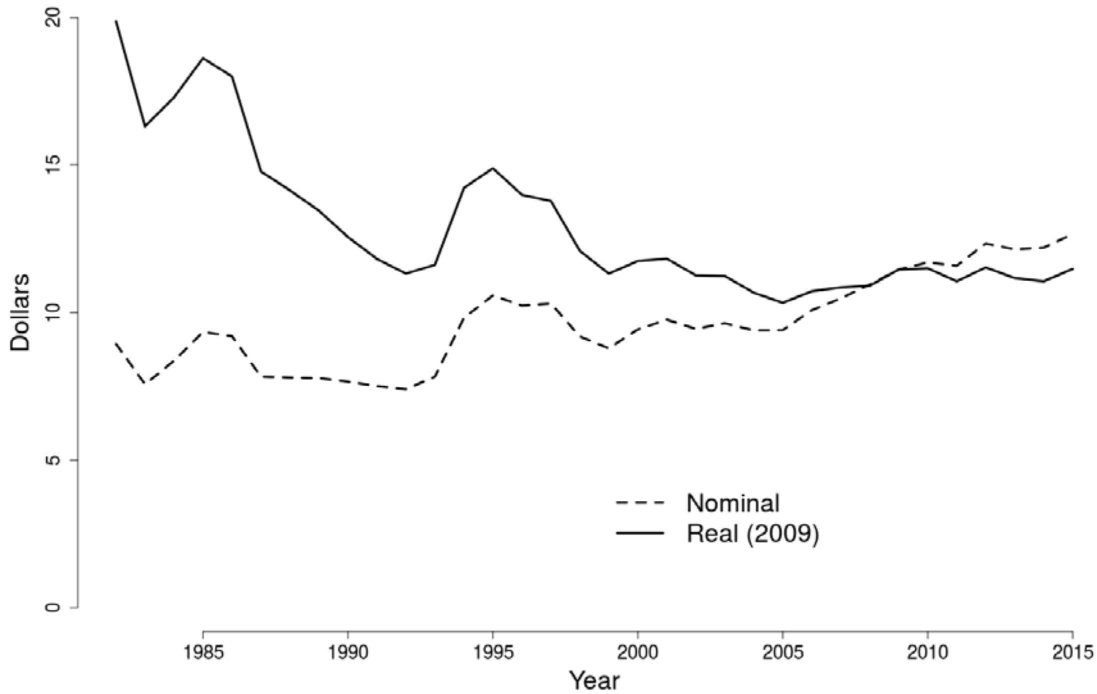


Figure 11: Nominal and 2009 dollar equivalent prices for surfclam 1981-2015.

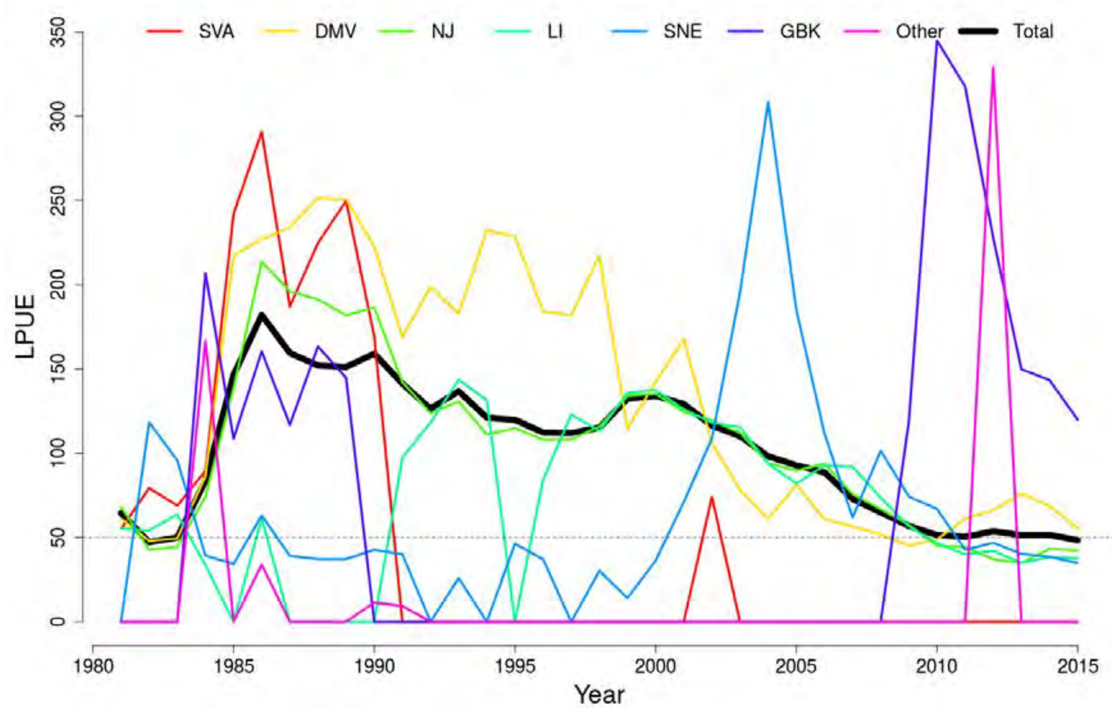


Figure 12: Nominal landings per unit effort (LPUE in bushels landed per hour fished) for surfclam, by region and overall. LPUE is total landings in bushels divided by total fishing effort. A dashed line has been added at LPUE=50 for reference.

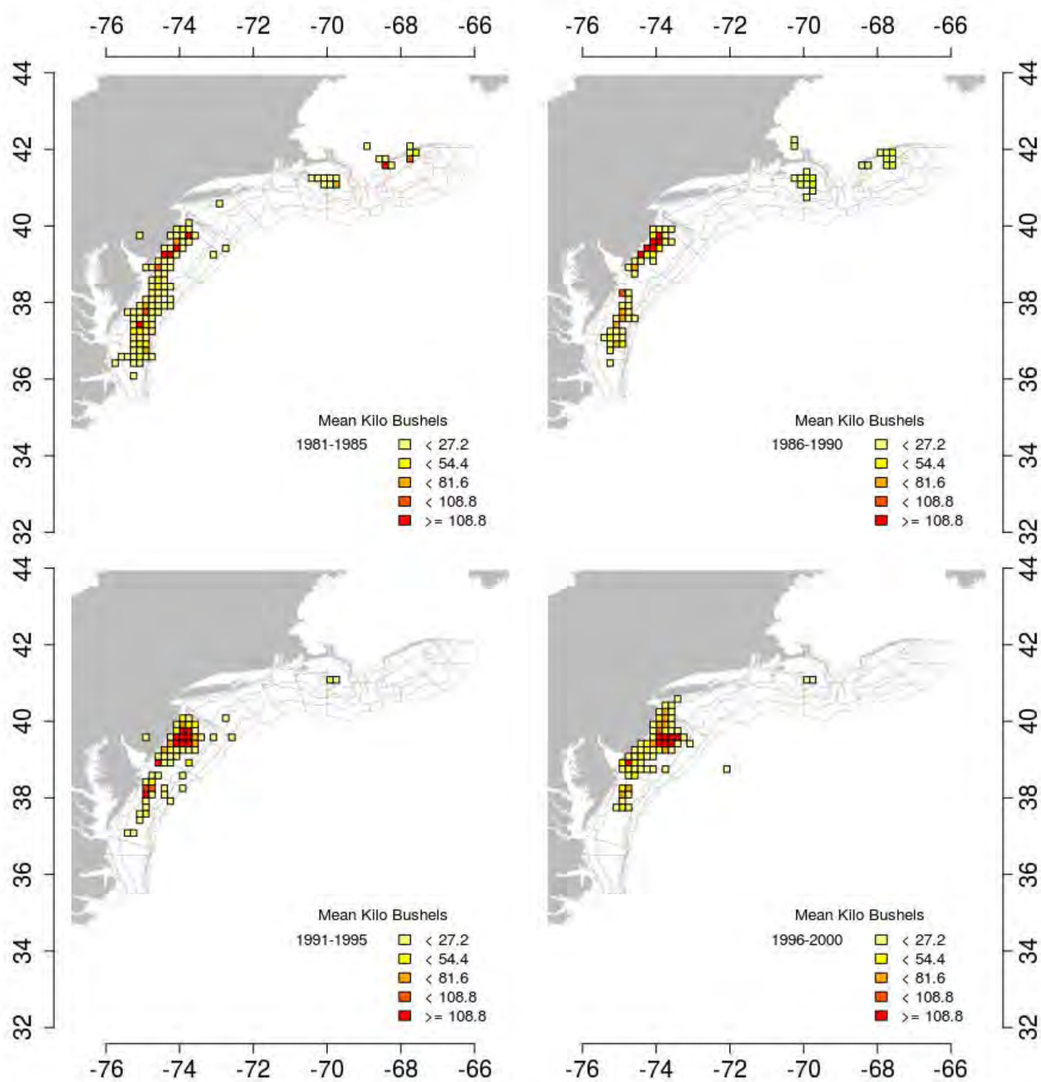


Figure 13: Average surfclam landings by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

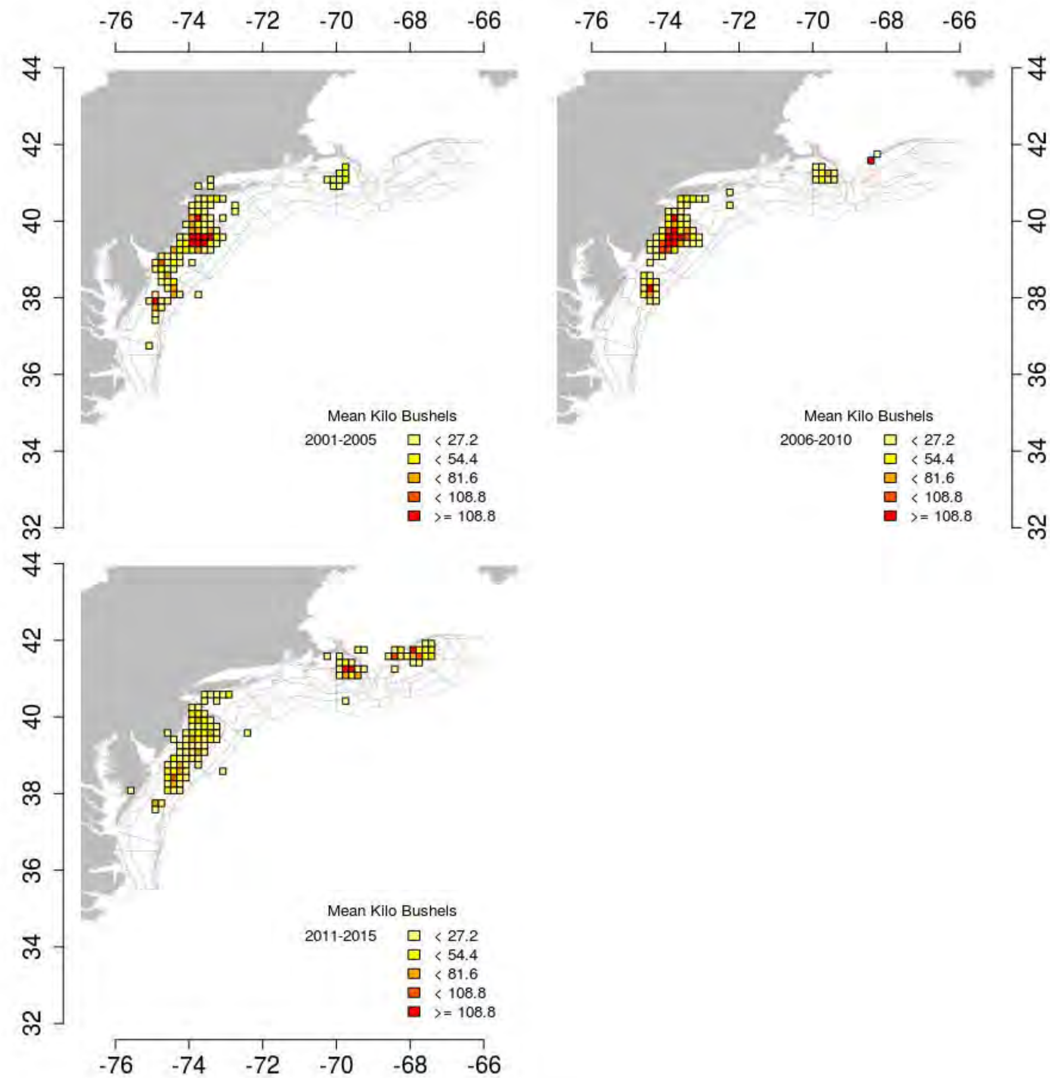


Figure 14: Average surfclam landings by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

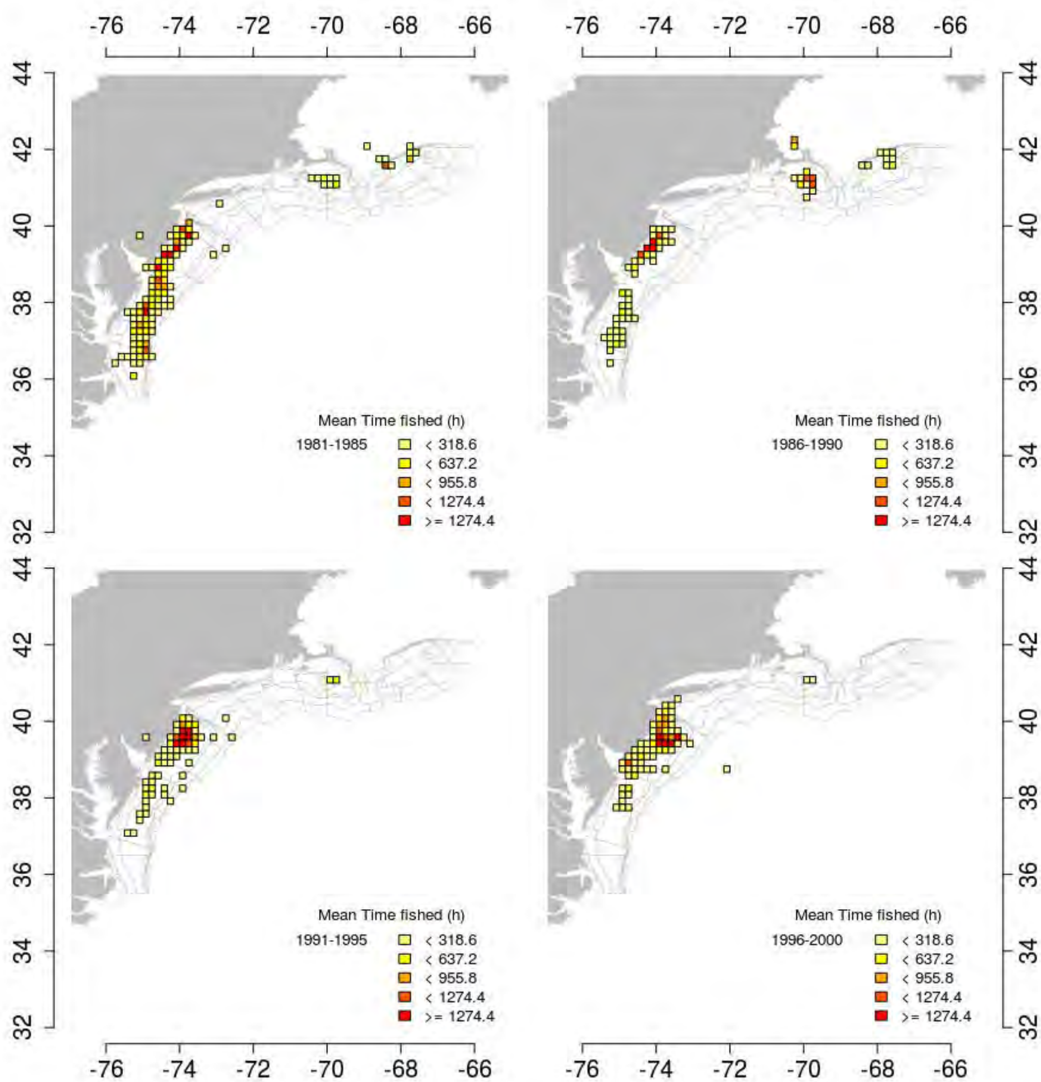


Figure 15: Average surfclam effort by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

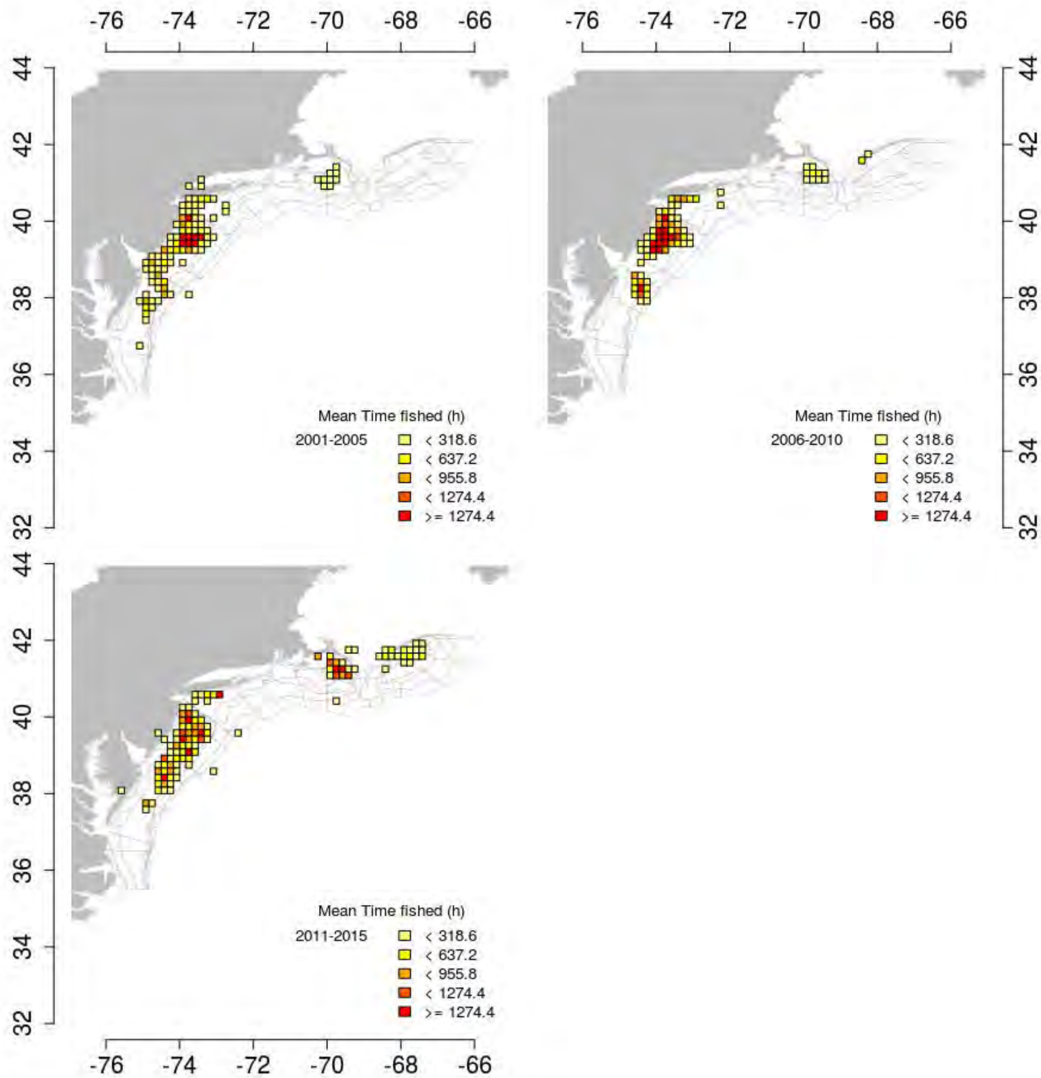


Figure 16: Average surfclam effort by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

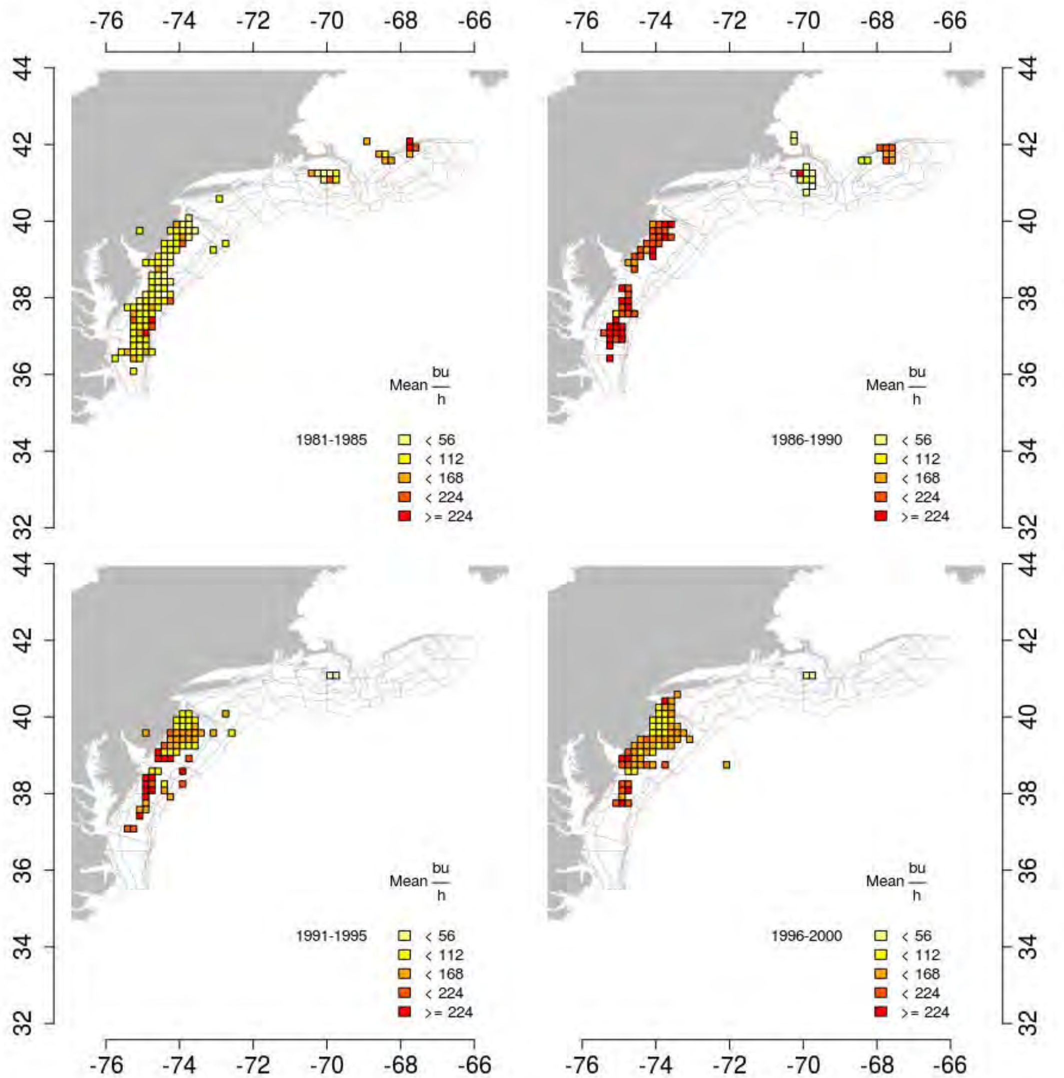


Figure 17: Average surfclam LPUE (bu. h^{-1}) by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

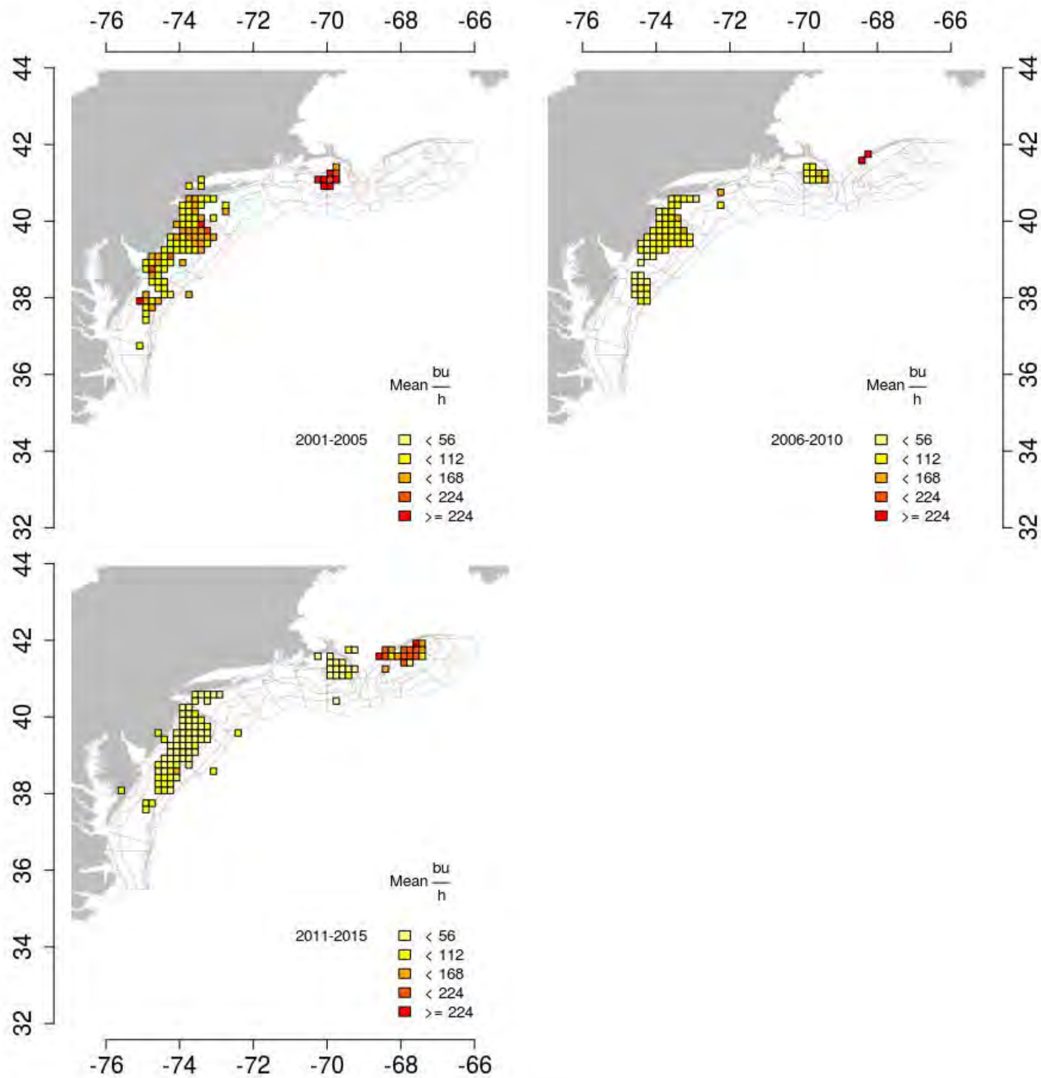


Figure 18: Average surfclam LPUE (bu. h^{-1}) by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

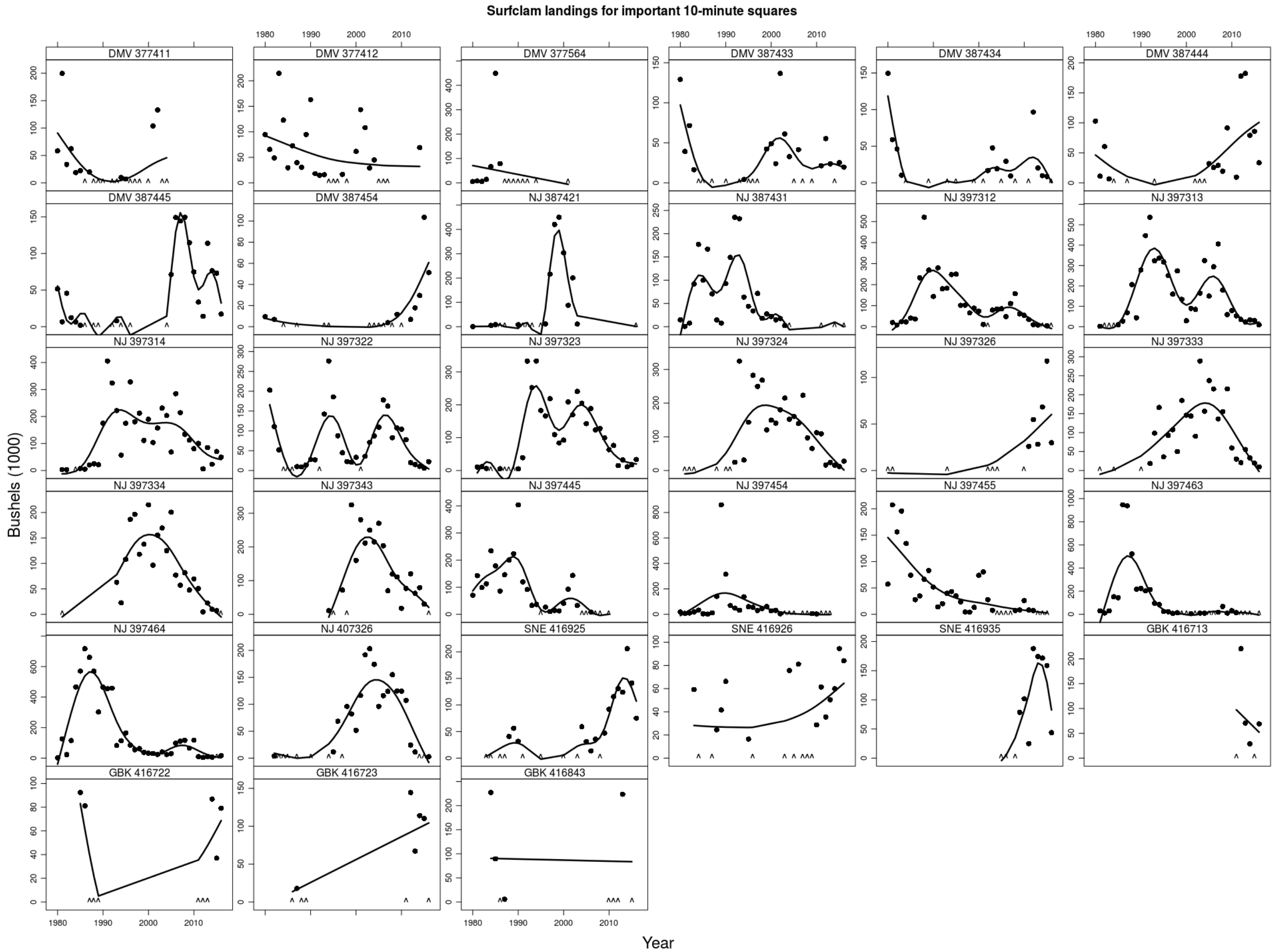


Figure 19: Annual surfclam landings in "important" ten minute squares (TNMS) during 1980-2015 based on logbook data. Important means that a square ranked in the top 10 TNMS for total landings during any five-year period (1980-1984, 1985-1989, ..., 2000-2004, 2005-2009, 2010-2015). To protect the privacy of individual firms, data are not plotted if the number of vessels is less than 3. Instead, a "$\wedge$" is shown on the x-axis to indicate where data are missing. The solid dark line is a spline intended to show trends. The spline was fit too all available data, including data not plotted.

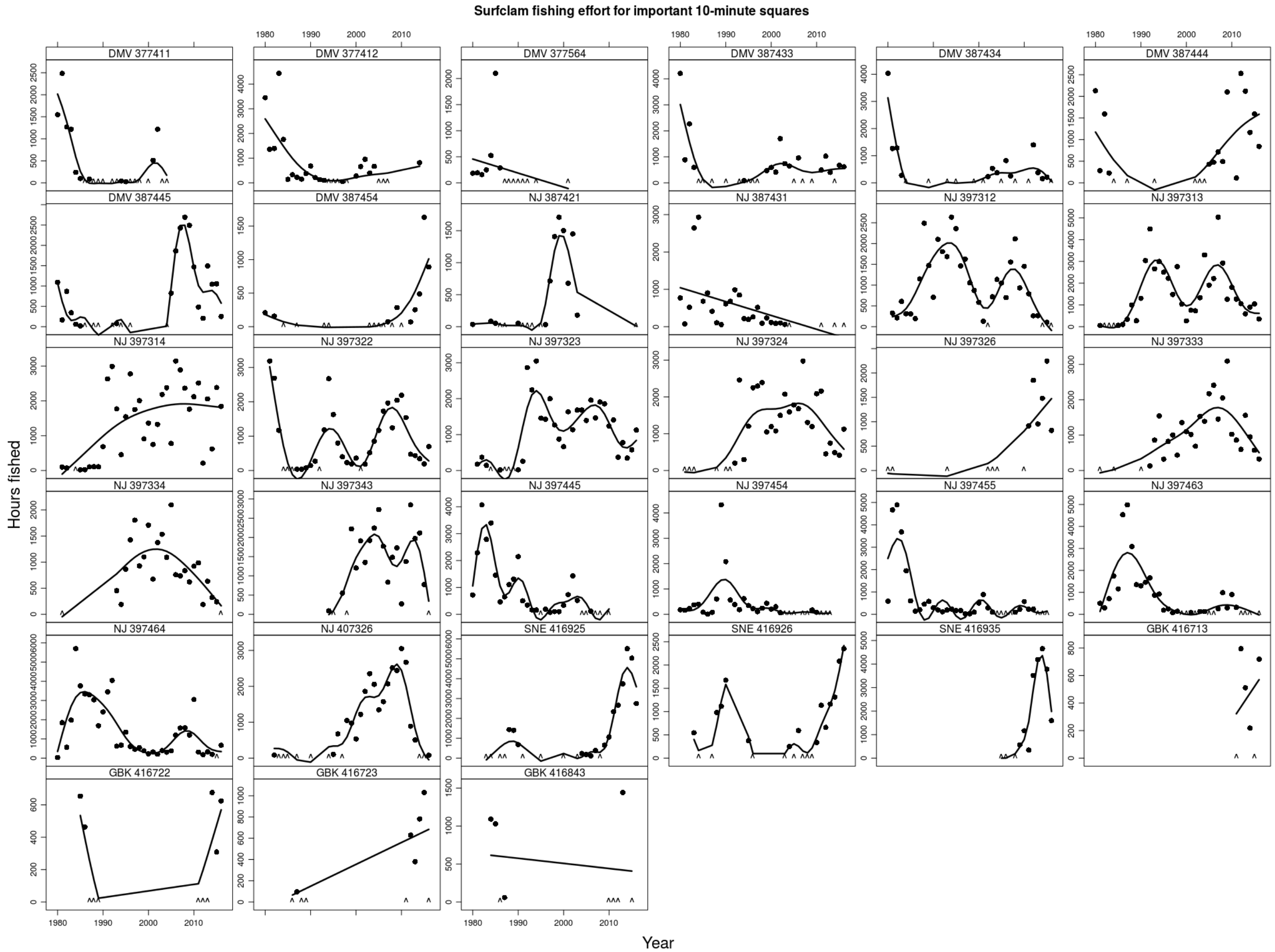


Figure 20: Annual surfclam effort (hours y^{-1}) in "important" ten minute squares (TNMS) during 1980-2015 based on logbook data. Important means that a square ranked in the top 10 TNMS for total landings during any five-year period (1980-1984, 1985-1989, ..., 2000-2004, 2005-2009, 2010-2015). To protect the privacy of individual firms, data are not plotted if the number of vessels is less than 3. Instead, a "$\wedge$" is shown on the x-axis to indicate where data are missing. The solid dark line is a spline intended to show trends. The spline was fit too all available data, including data not plotted.

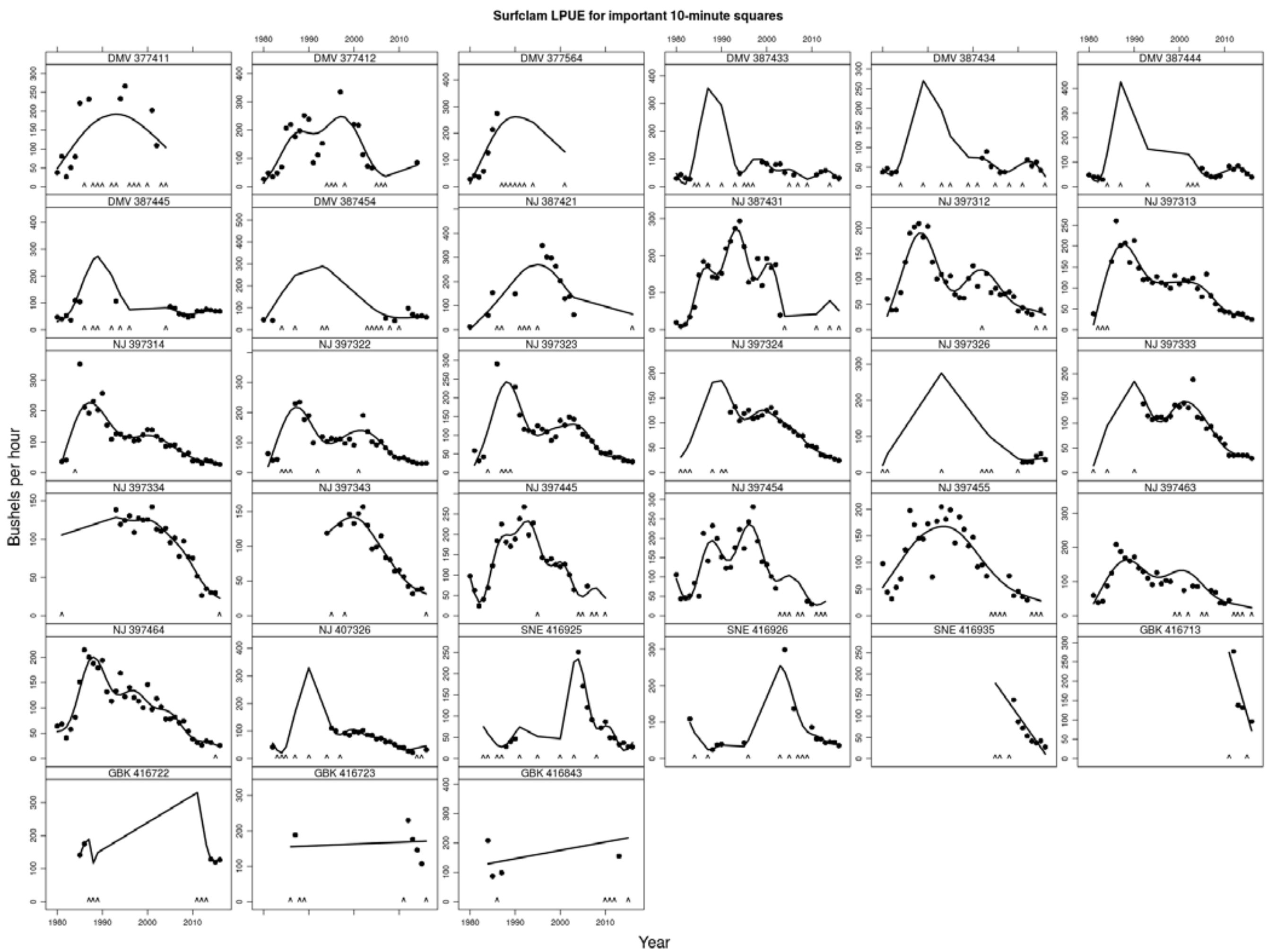


Figure 21: Annual surfclam LPUE (bu h^{-1}) in "important" ten minute squares (TNMS) during 1980-2015 based on logbook data. Important means that a square ranked in the top 10 TNMS for total landings during any five-year period (1980-1984, 1985-1989, ..., 2000-2004, 2005-2009, 2010-2015). To protect the privacy of individual firms, data are not plotted if the number of vessels is less than 3. Instead, a "$\wedge$" is shown on the x-axis to indicate where data are missing. The solid dark line is a spline intended to show trends. The spline was fit too all available data, including data not plotted.

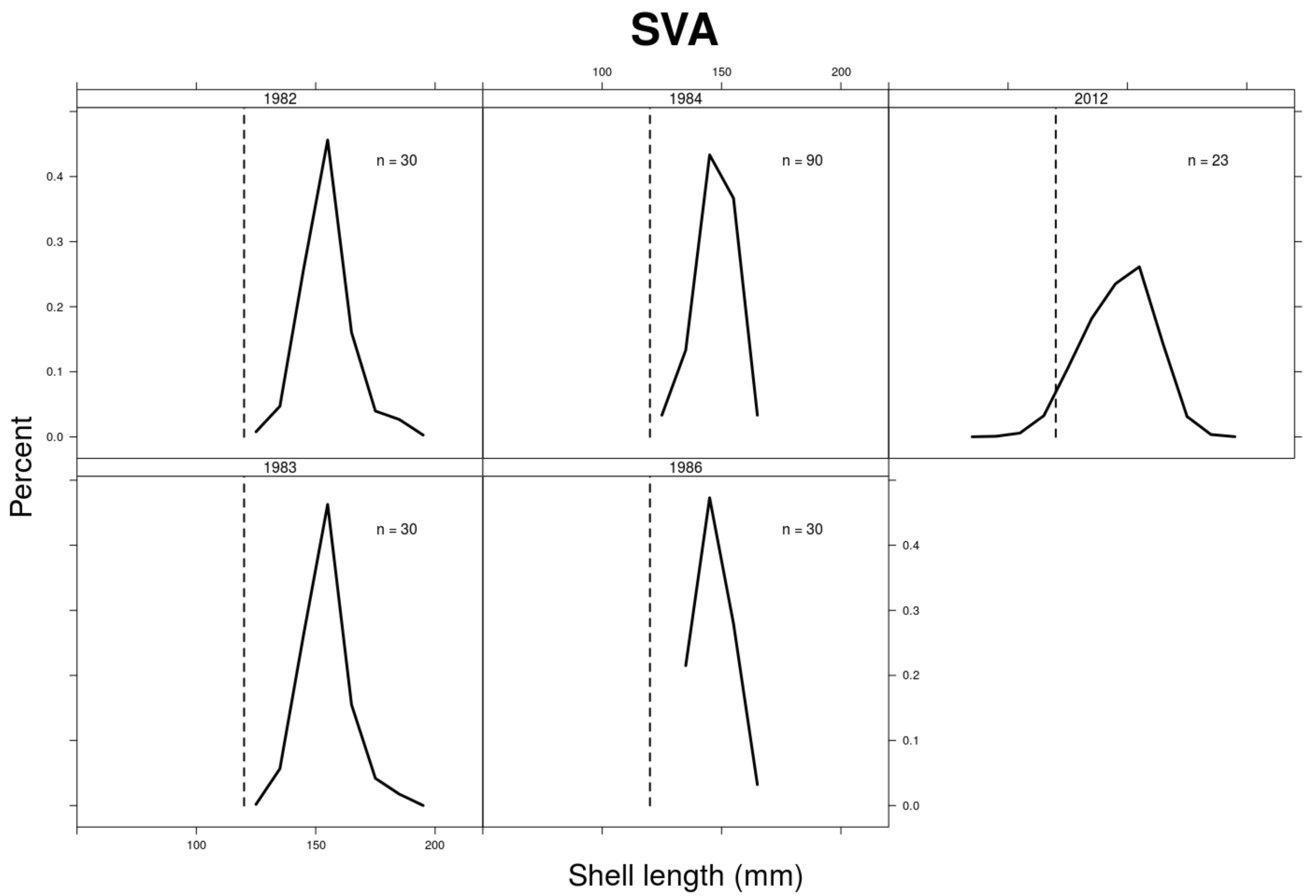


Figure 22: Length compositions for Atlantic surfclam from port samples of landings from the SVA region. Sample sizes are the number of clams measured in each year.

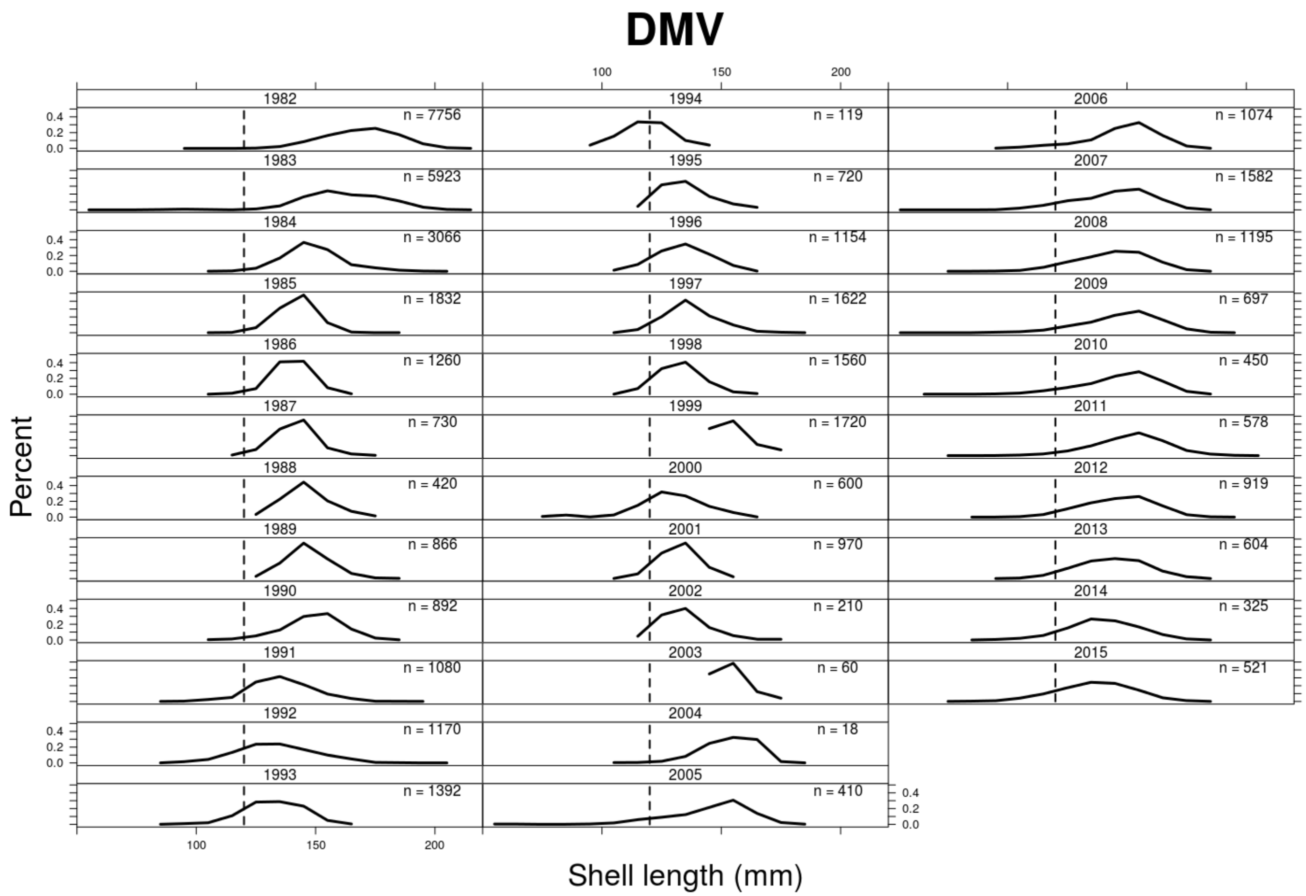


Figure 23: Length compositions for Atlantic surfclam from port samples of landings from the DMV region. Sample sizes are the number of clams measured in each year.

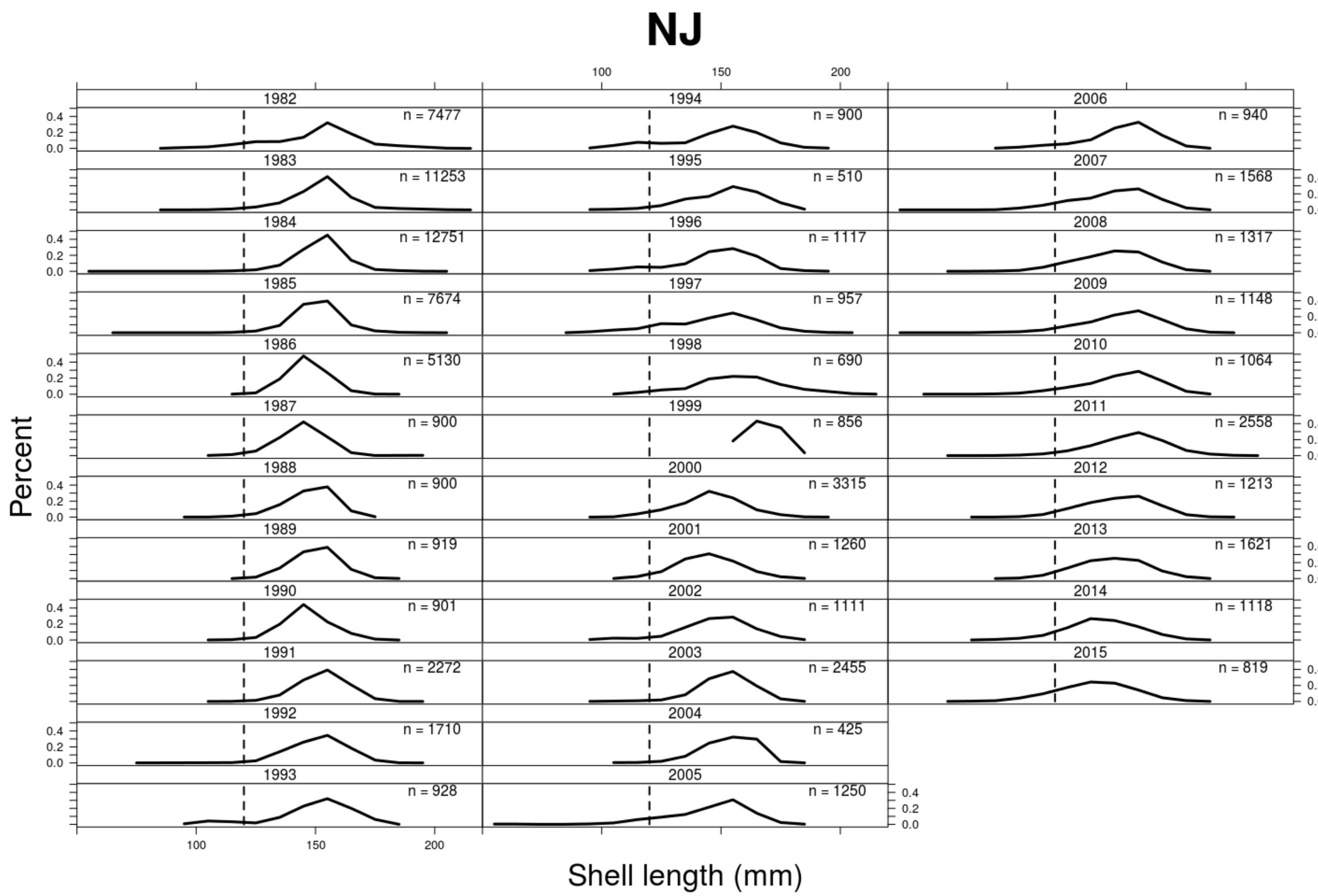


Figure 24: Length compositions for Atlantic surfclam from port samples of landings from the NJ region. Sample sizes are the number of clams measured in each year.

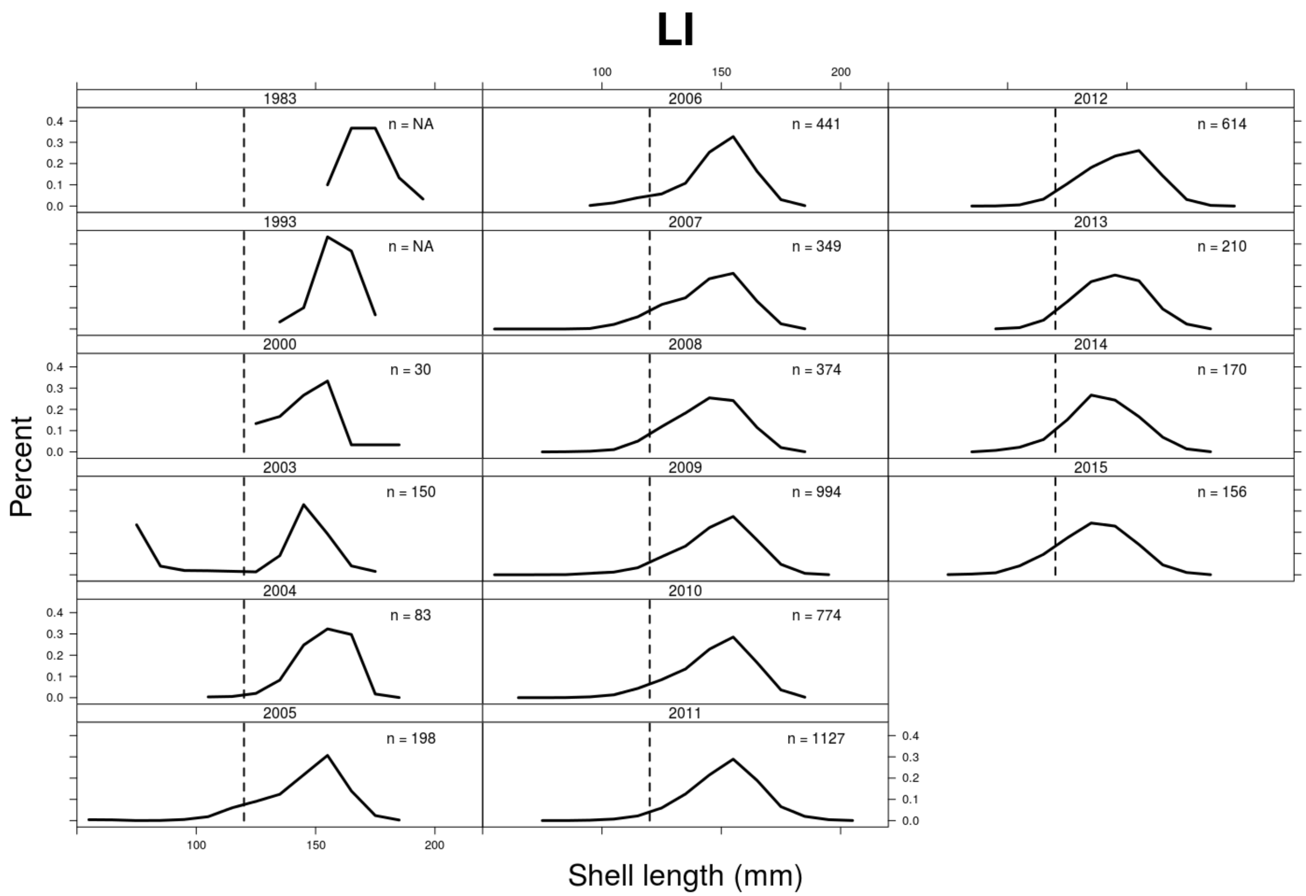


Figure 25: Length compositions for Atlantic surfclam from port samples of landings from the LI region. Sample sizes are the number of clams measured in each year.

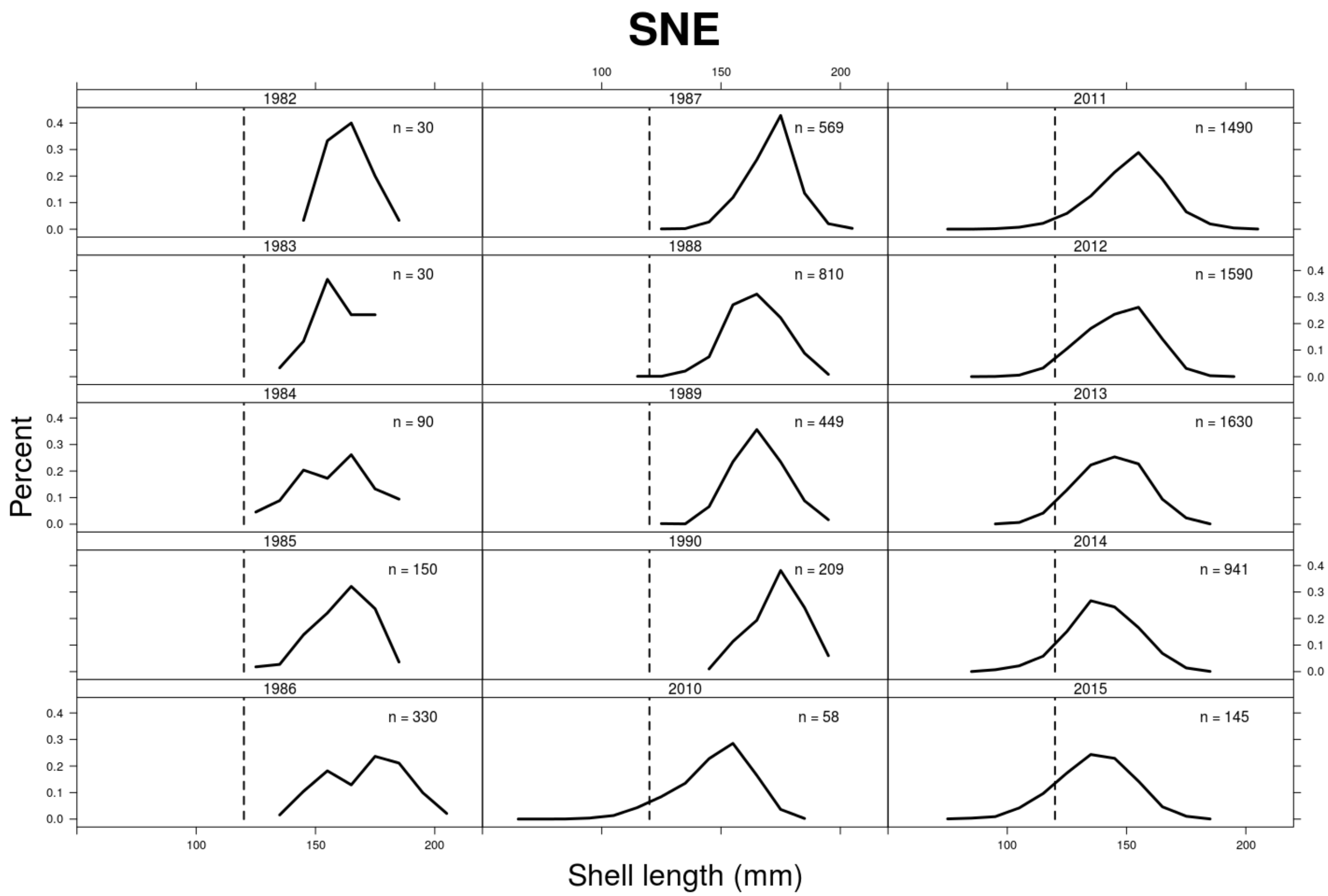


Figure 26: Length compositions for Atlantic surfclam from port samples of landings from the SNE region. Sample sizes are the number of clams measured in each year.

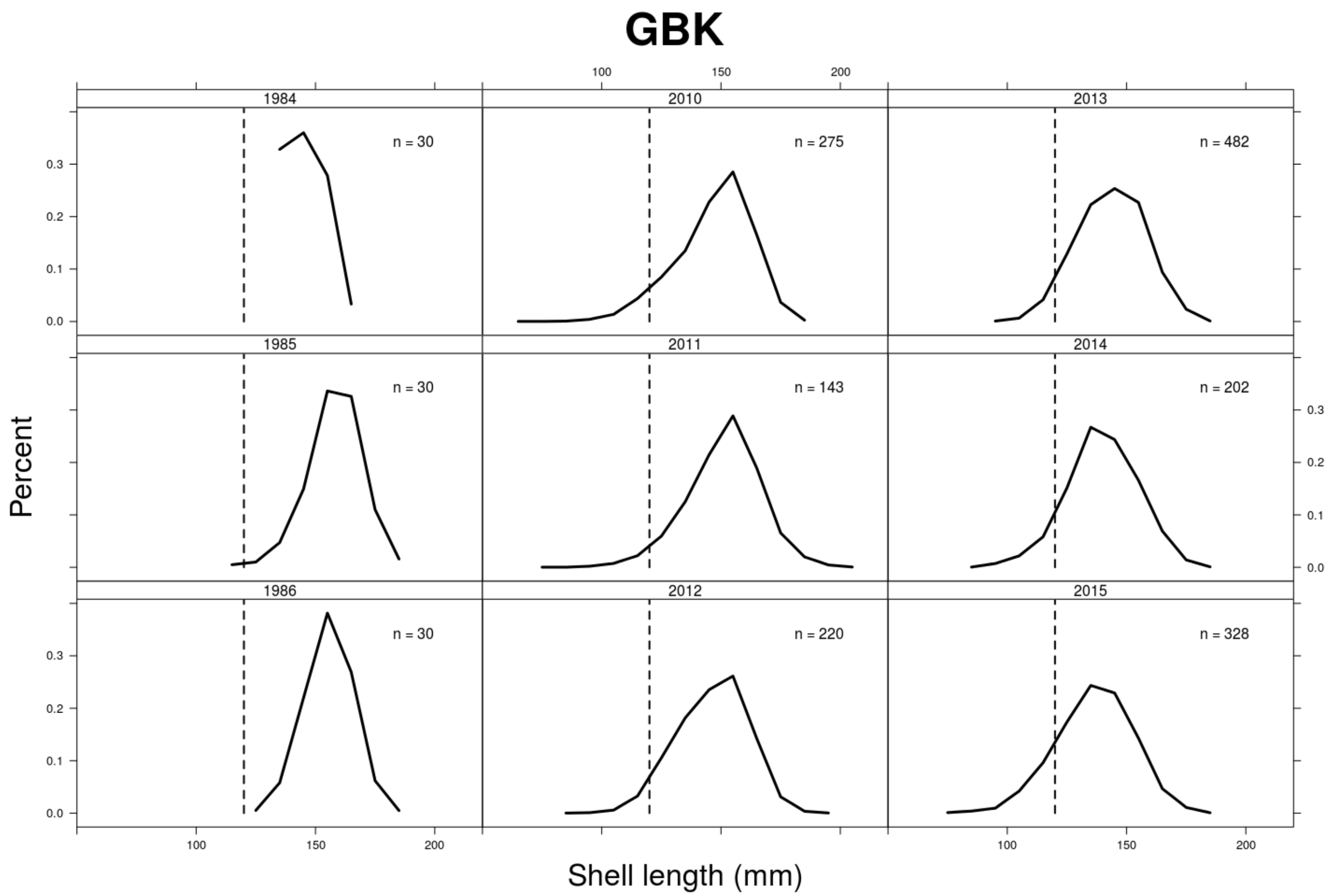


Figure 27: Length compositions for Atlantic surfclam from port samples of landings from the GBK region. Sample sizes are the number of clams measured in each year.

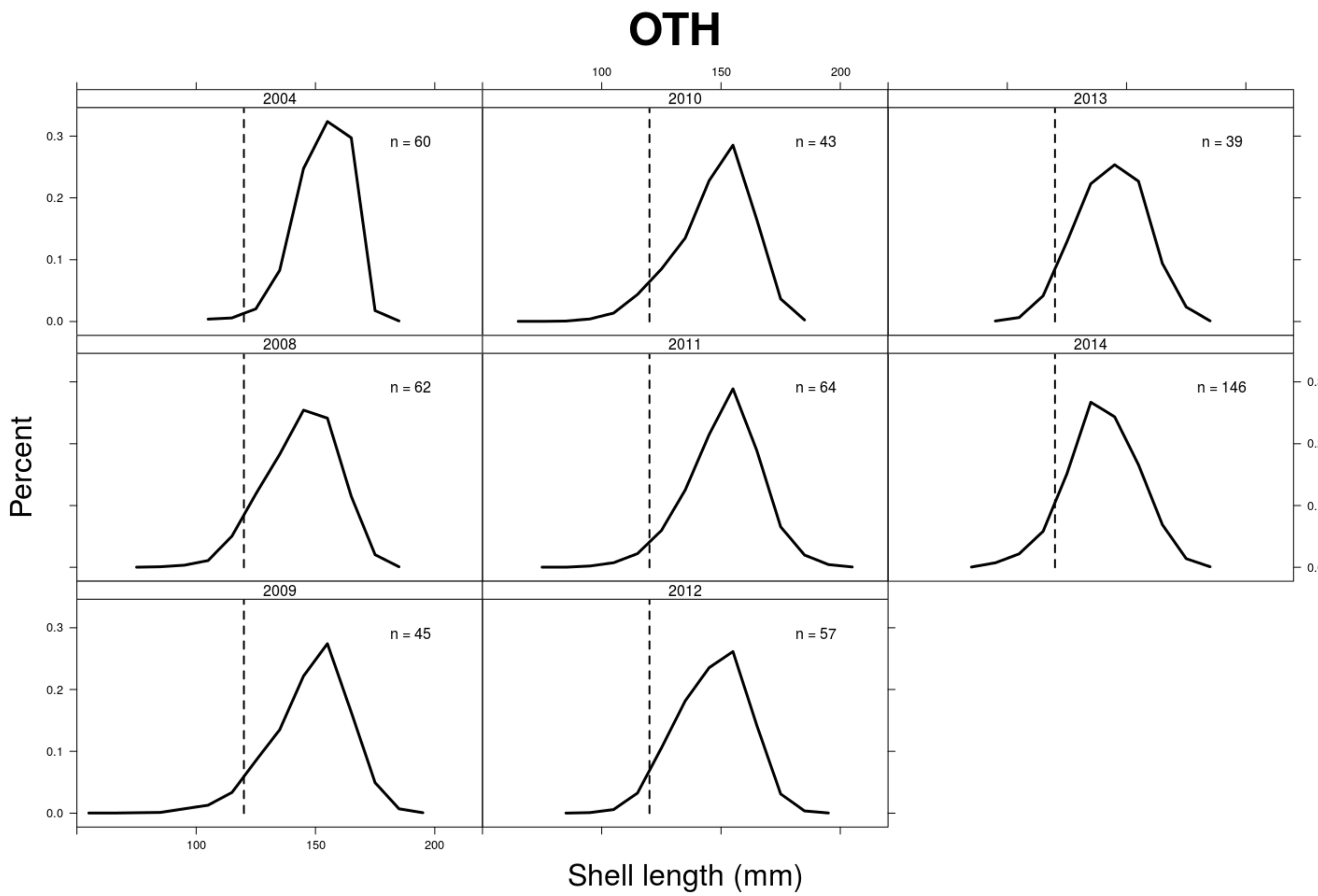


Figure 28: Length compositions for Atlantic surfclam for which no area was recorded (OTH). Sample sizes are the number of clams measured in each year.

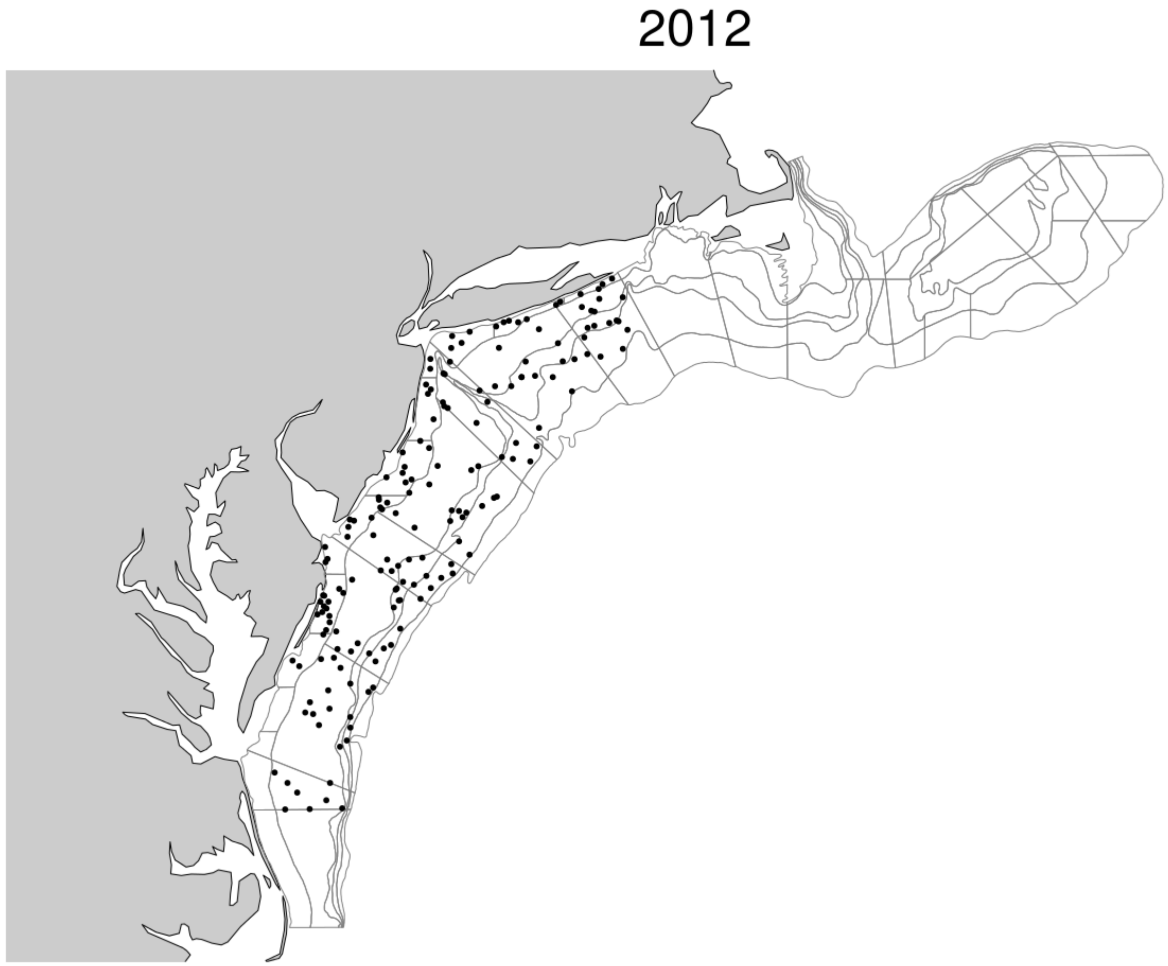


Figure 29: Station locations from the 2012 survey

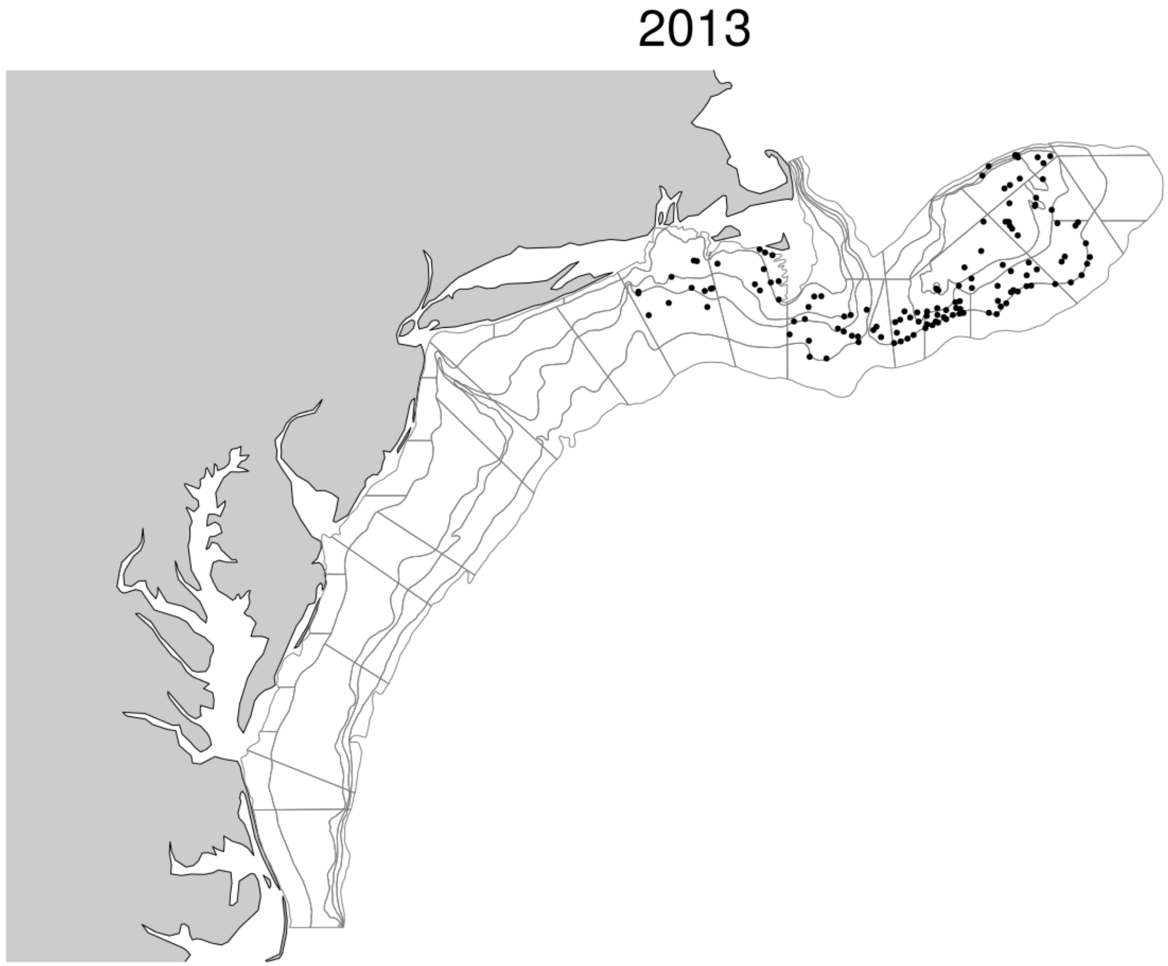


Figure 30: Station locations from the 2013 survey

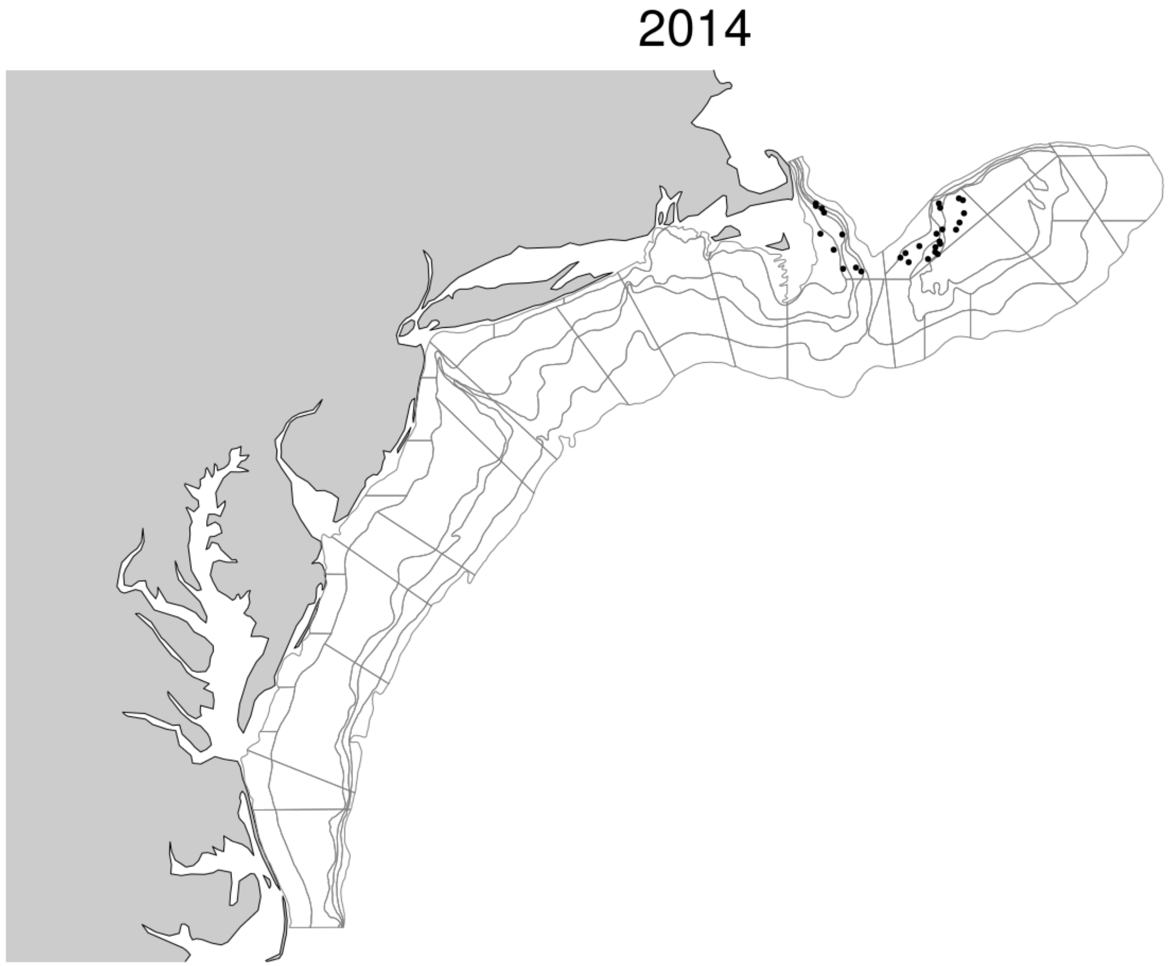


Figure 31: Station locations from the 2014 survey

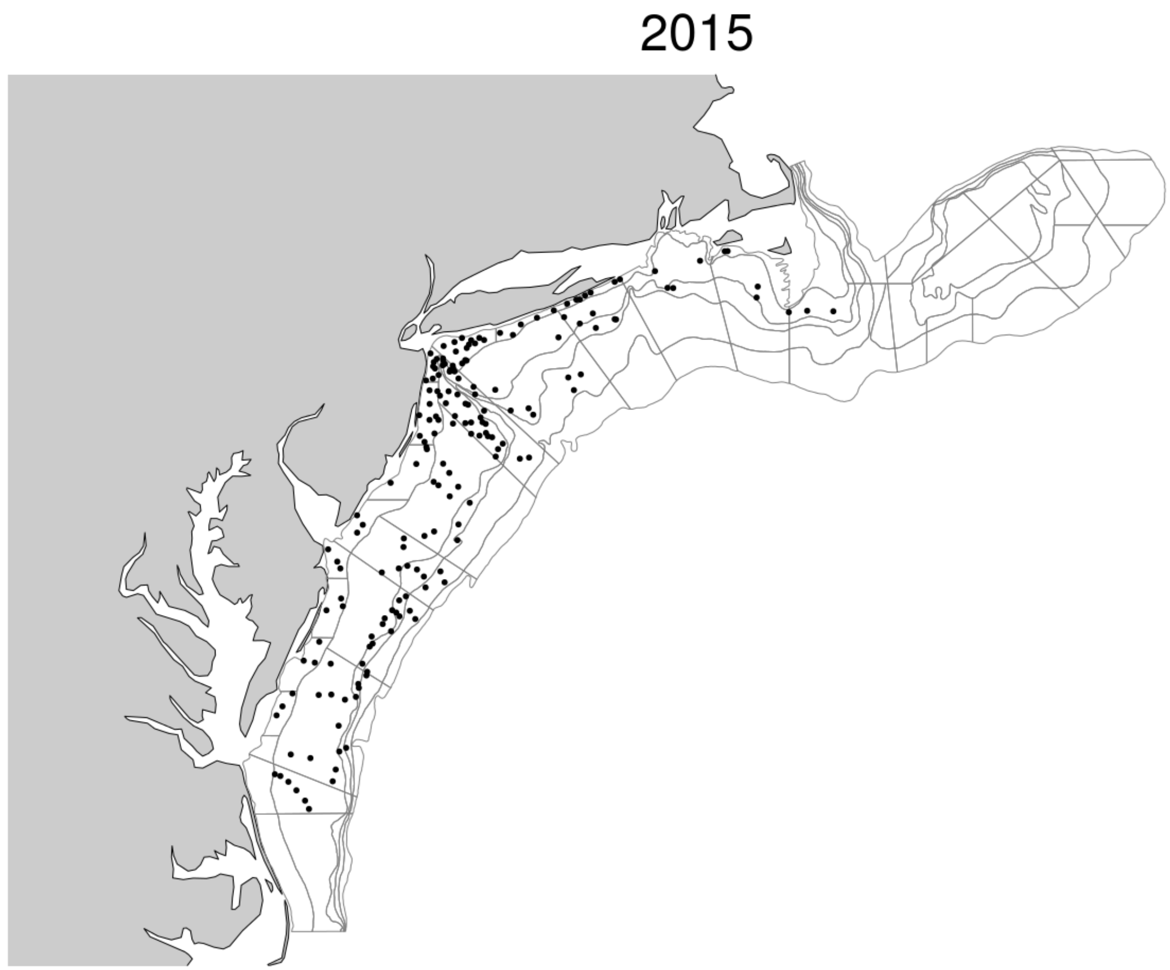


Figure 32: Station locations from the 2015 survey

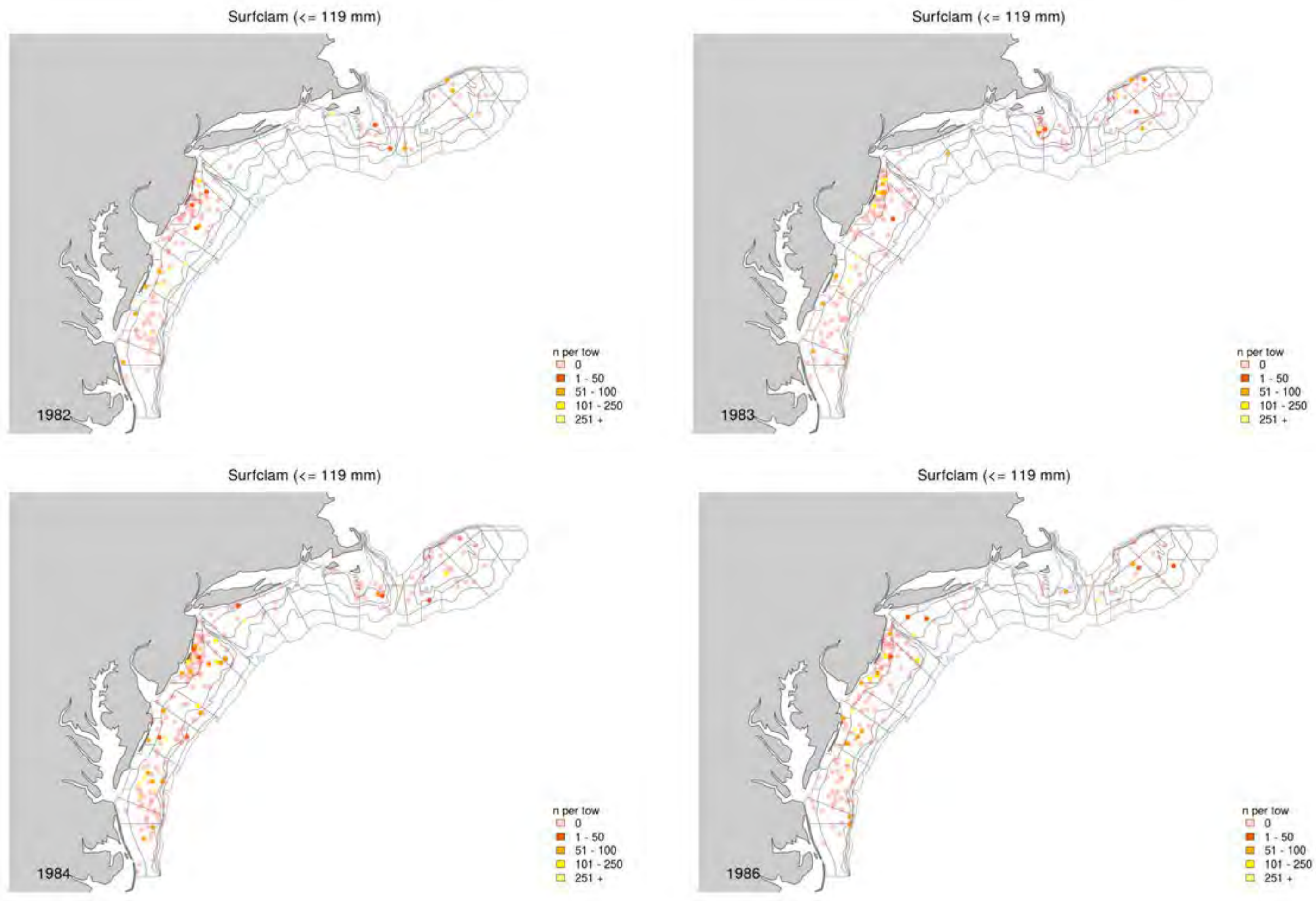


Figure 33: Survey stations where small ($<= 119\ mm$) surfclam were caught, by year.

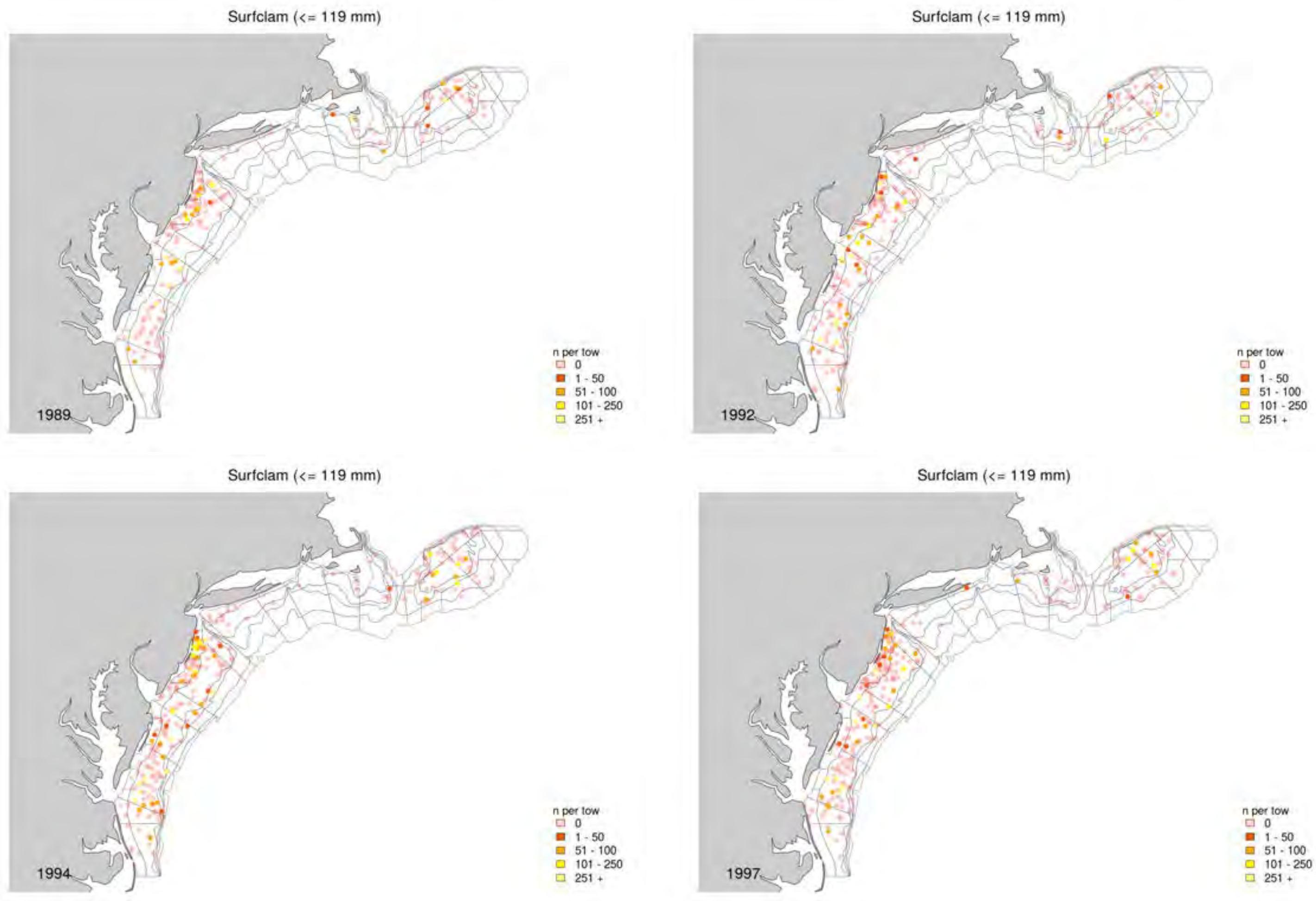
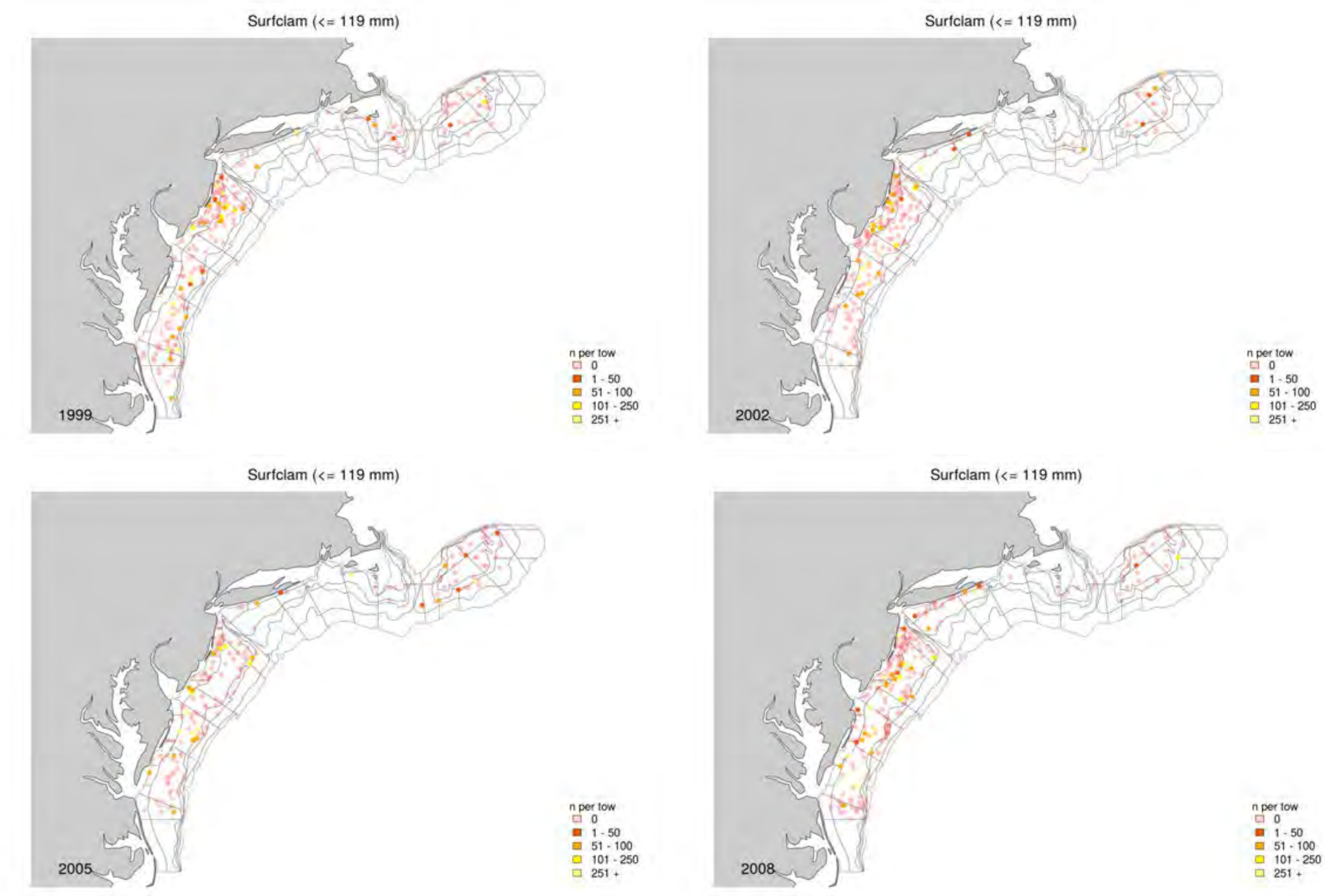


Figure 33 cont.



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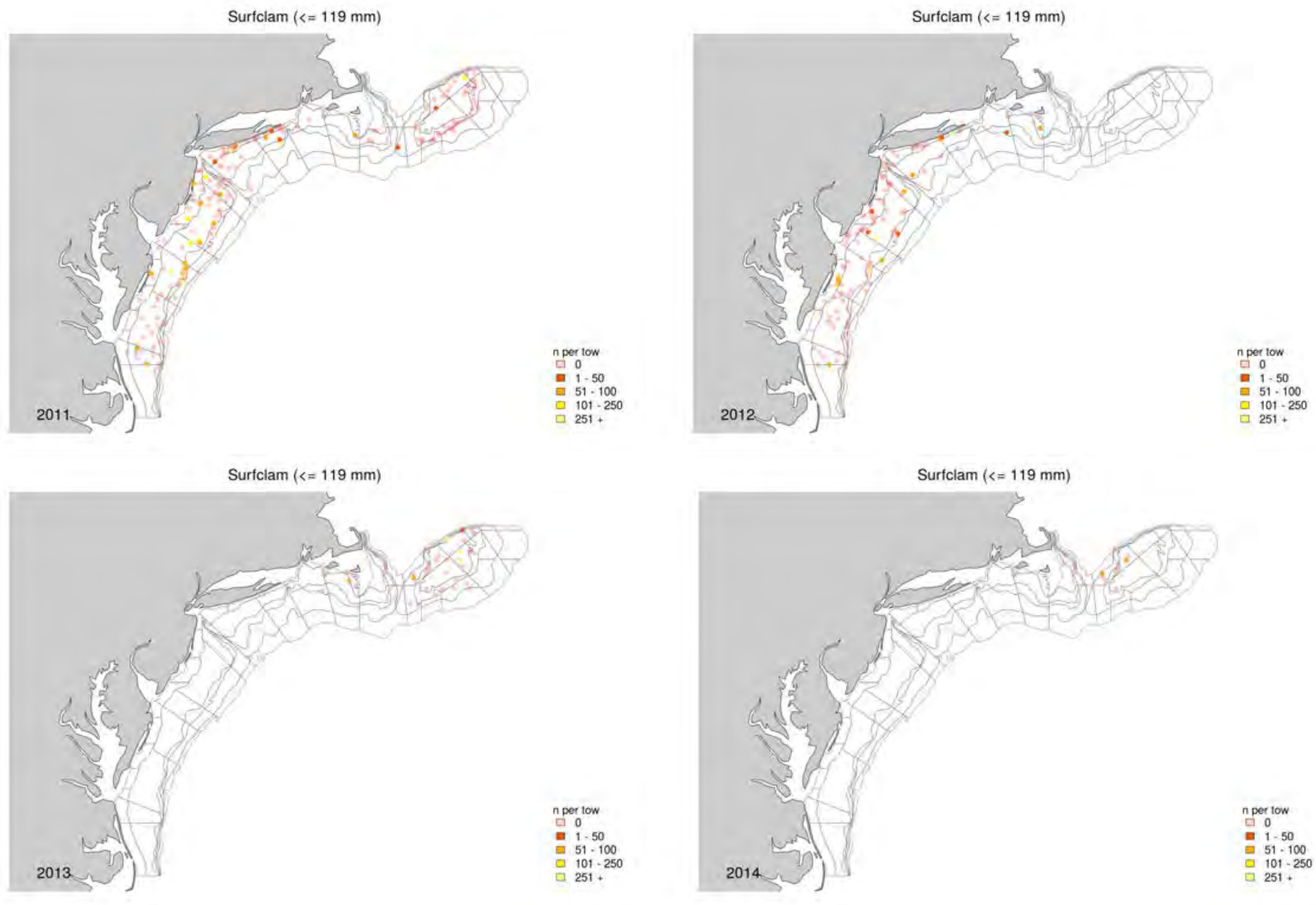

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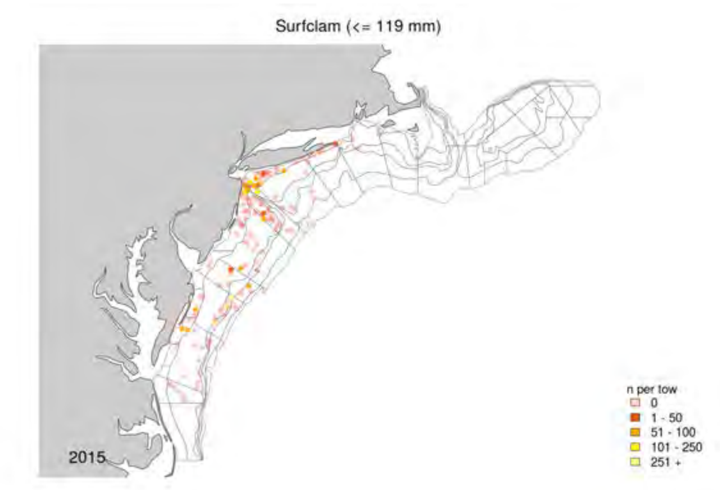

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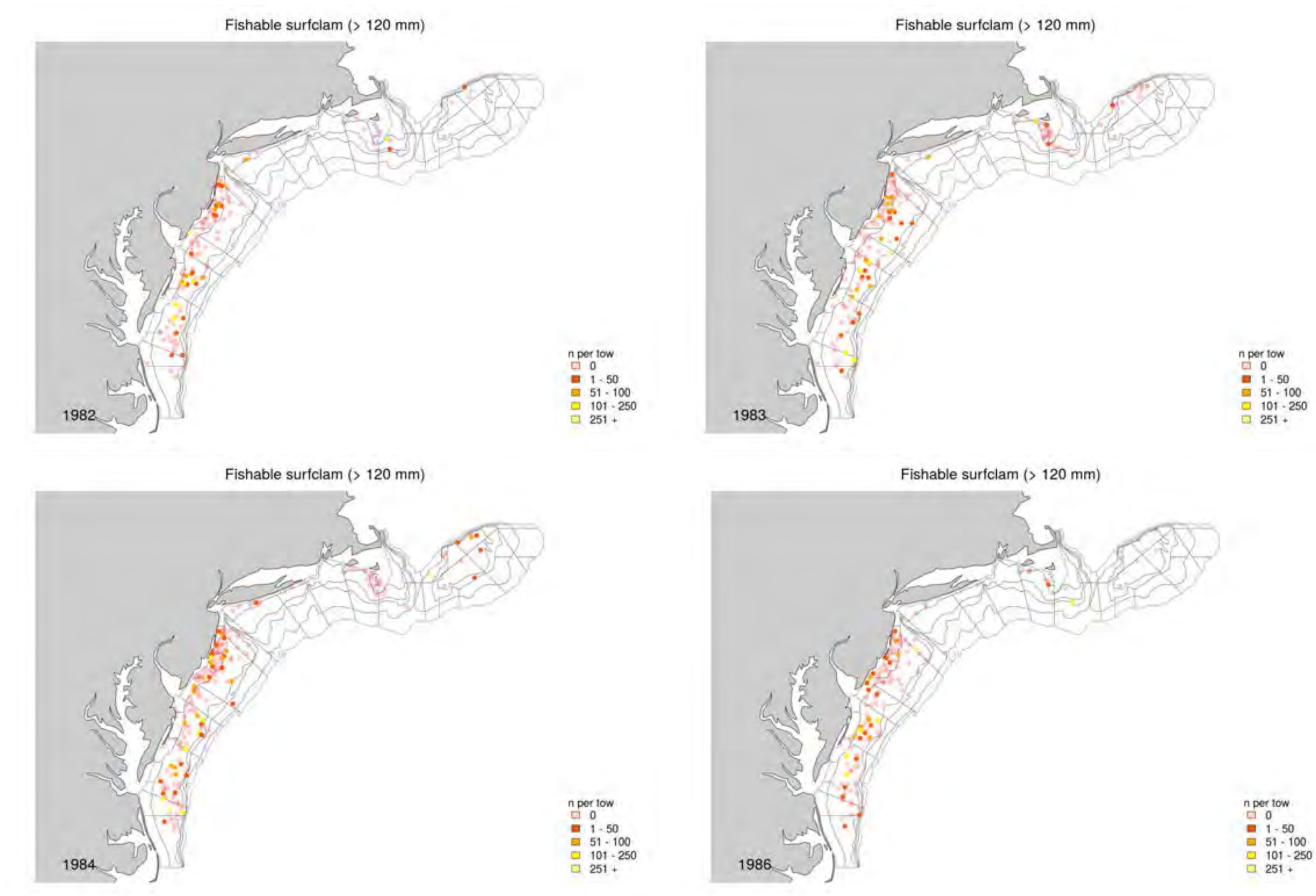


Figure 34: Survey stations where large ($> 120\ mm$) surfclam were caught, by year.

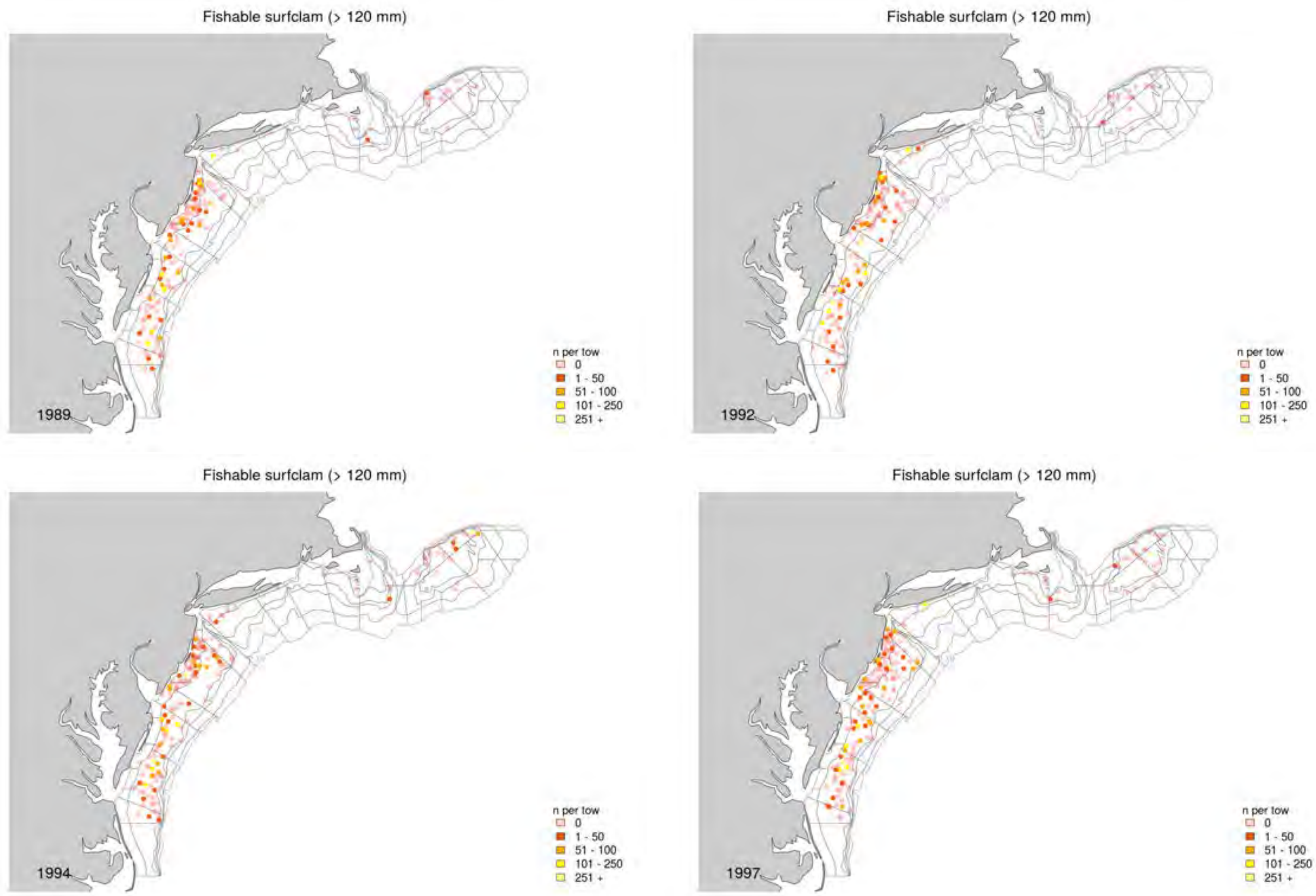
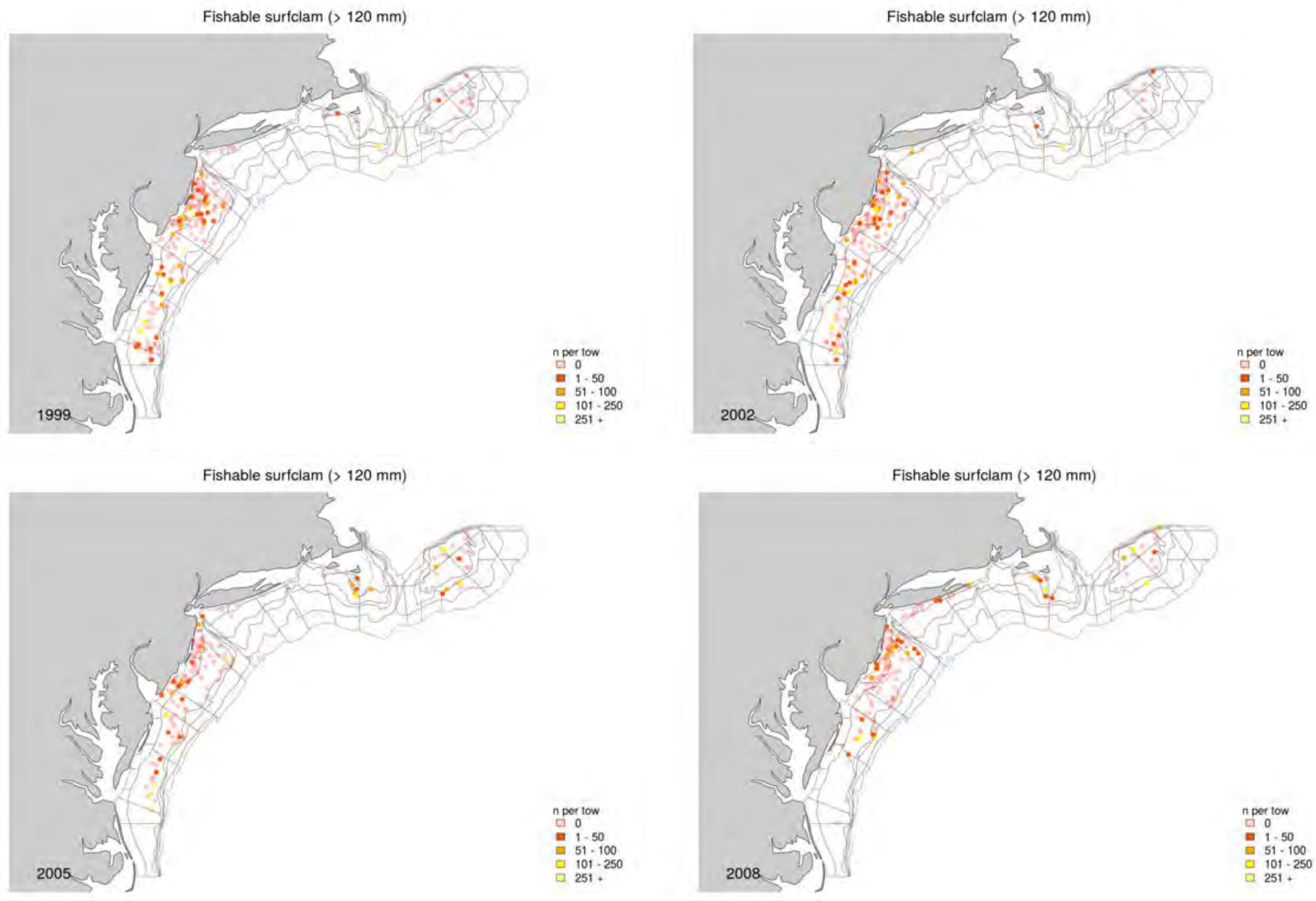


Figure 34 cont.



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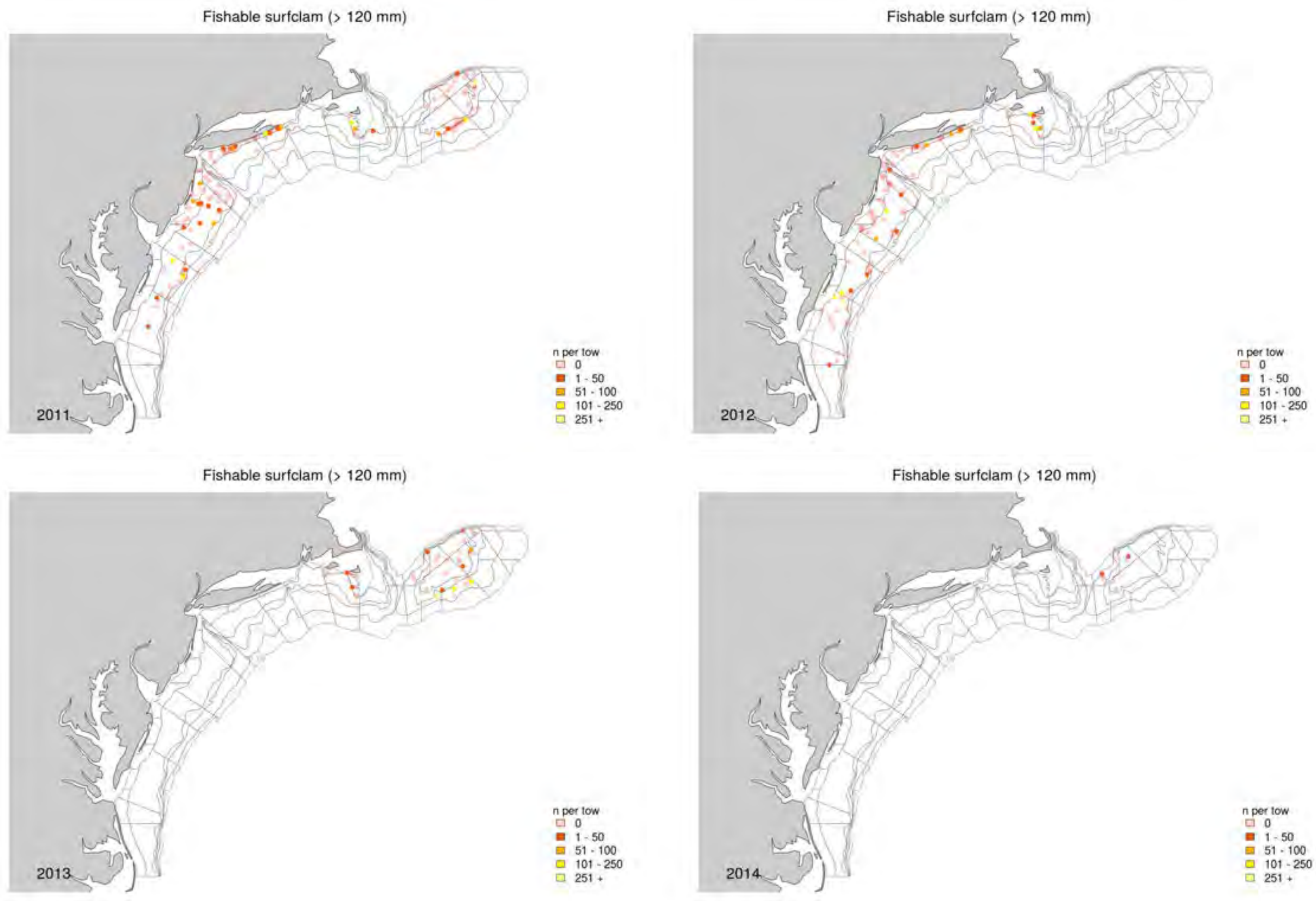


Figure 34 cont.

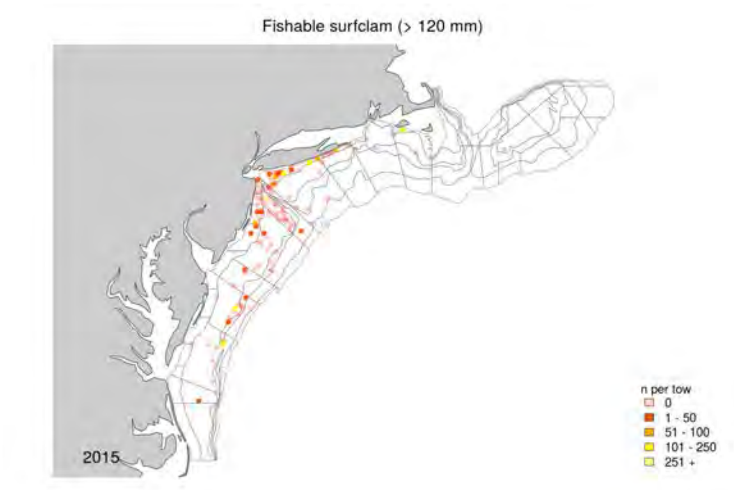


Figure 34 cont.

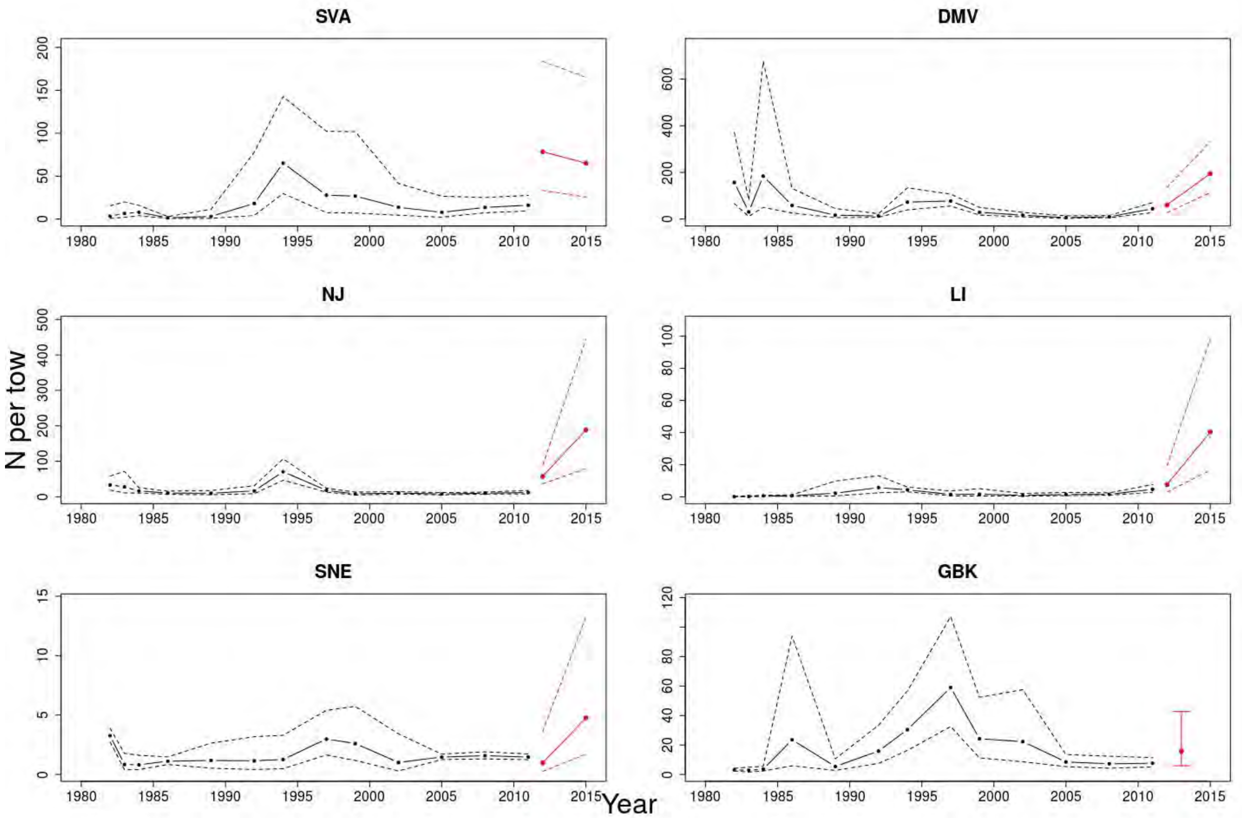


Figure 35: Surfclam 50 – 119 mm from NEFSC surveys adjusted for selectivity, but not efficiency, with approximate 95% asymmetric confidence intervals, by region. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

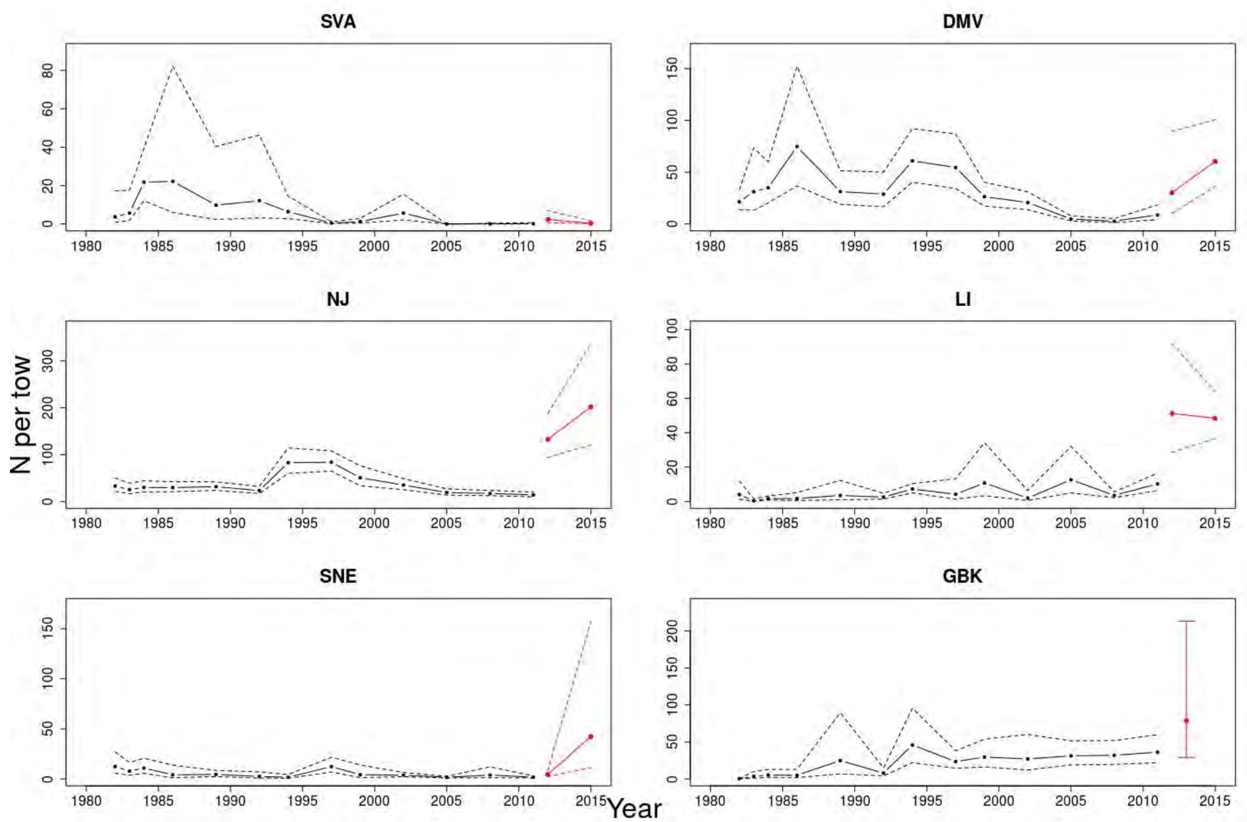


Figure 36: Surfclam > 119 mm from NEFSC surveys adjusted for selectivity, but not efficiency, with approximate 95% asymmetric confidence intervals, by region. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

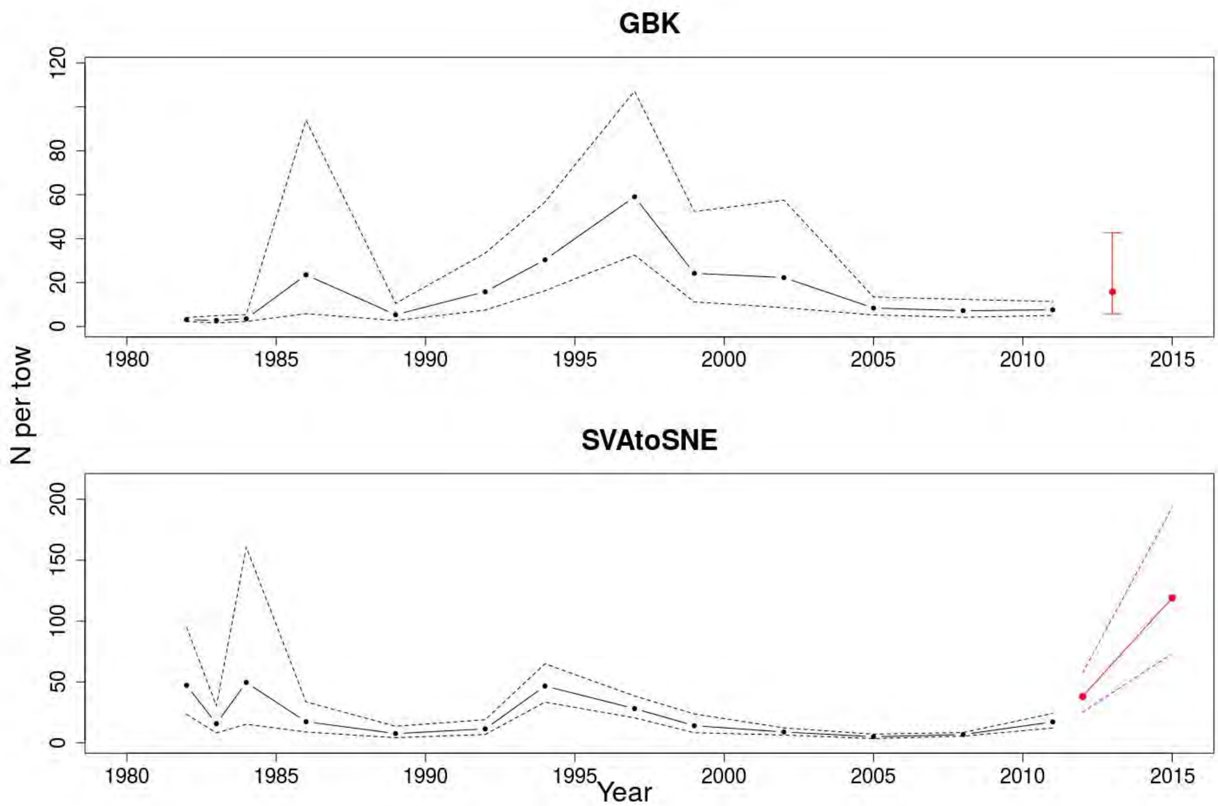


Figure 37: Surfclam 50 – 119 mm from NEFSC surveys adjusted for selectivity, but not efficiency, with approximate 95% asymmetric confidence intervals, by area. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

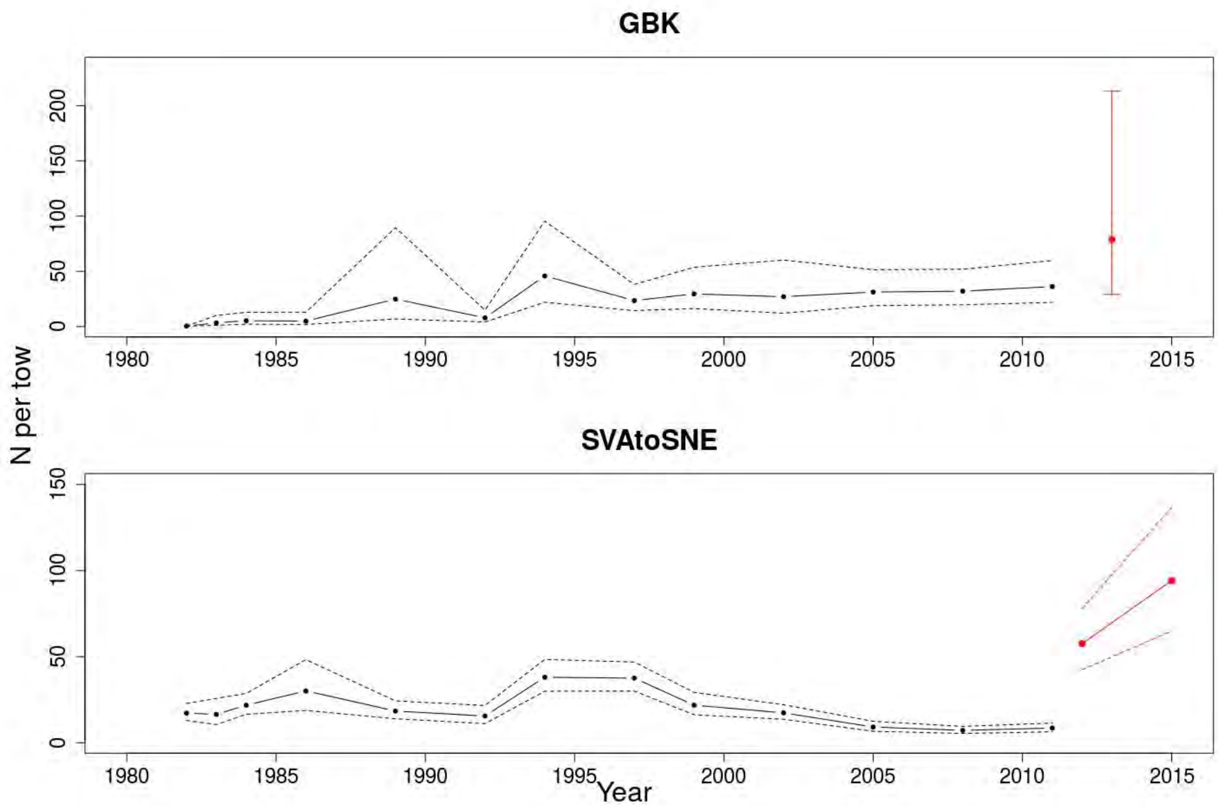


Figure 38: Surfclam > 119 mm from NEFSC surveys adjusted for selectivity, but not efficiency, with approximate 95% asymmetric confidence intervals, by area. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

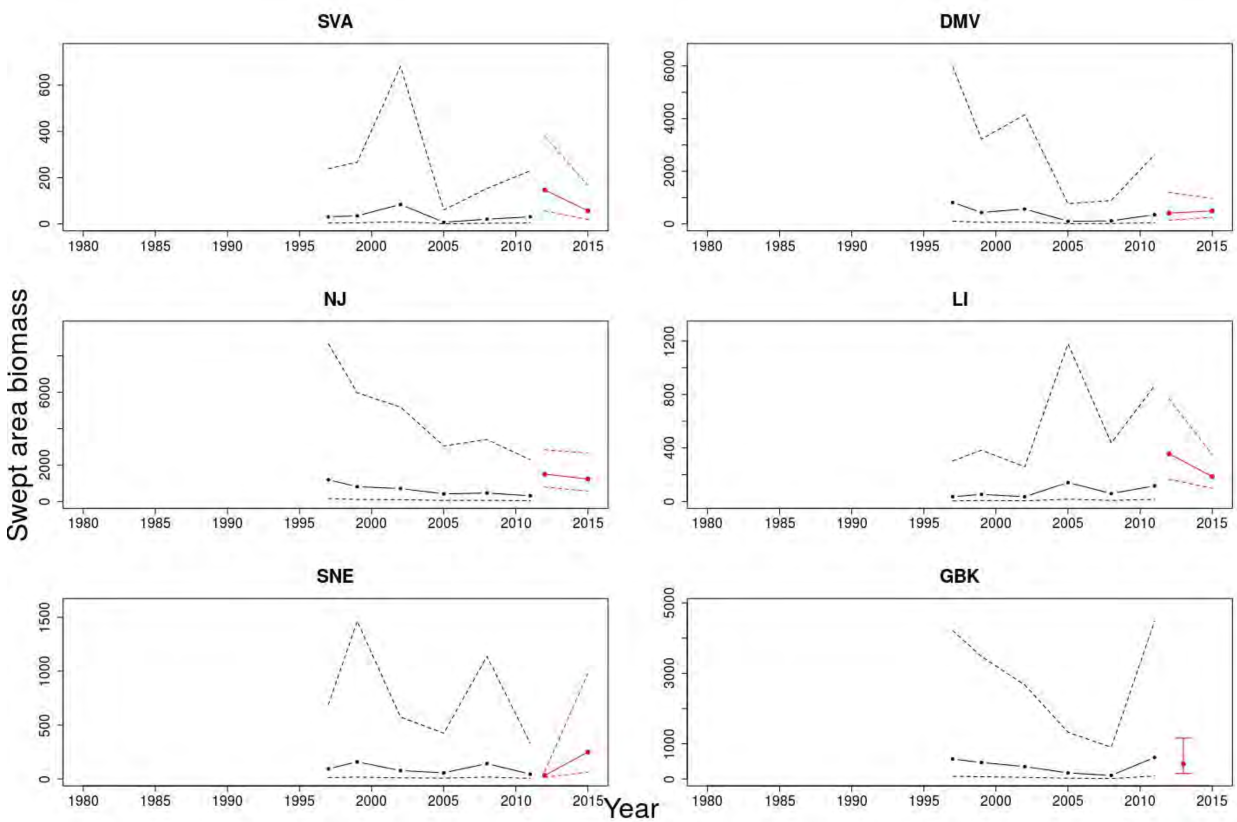


Figure 39: Surfclam swept area biomass from NEFSC surveys adjusted for selectivity and efficiency, with approximate 95% asymmetric confidence intervals, by area. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

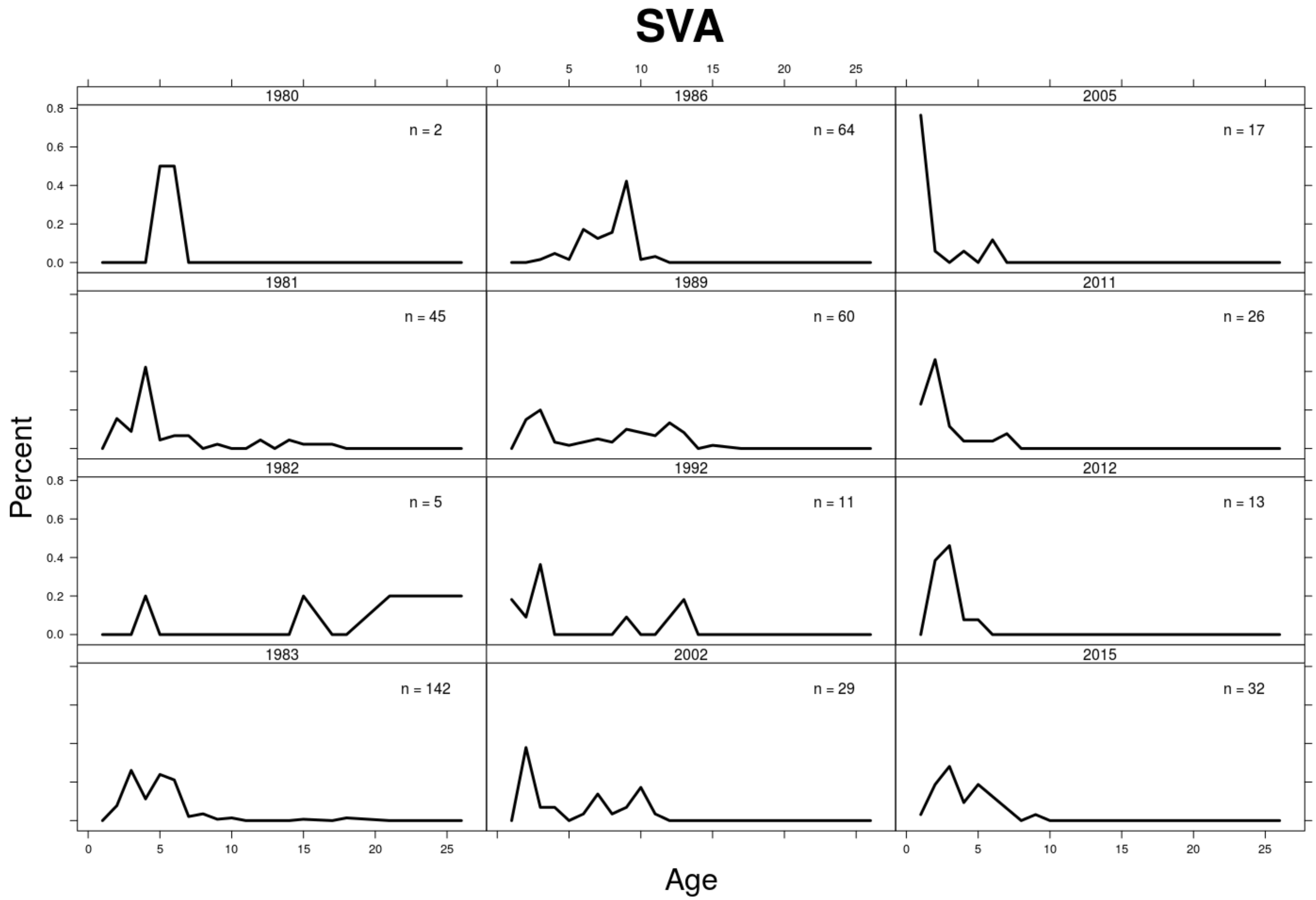


Figure 40: Age composition of Atlantic surfclam in NEFSC surveys in SVA, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

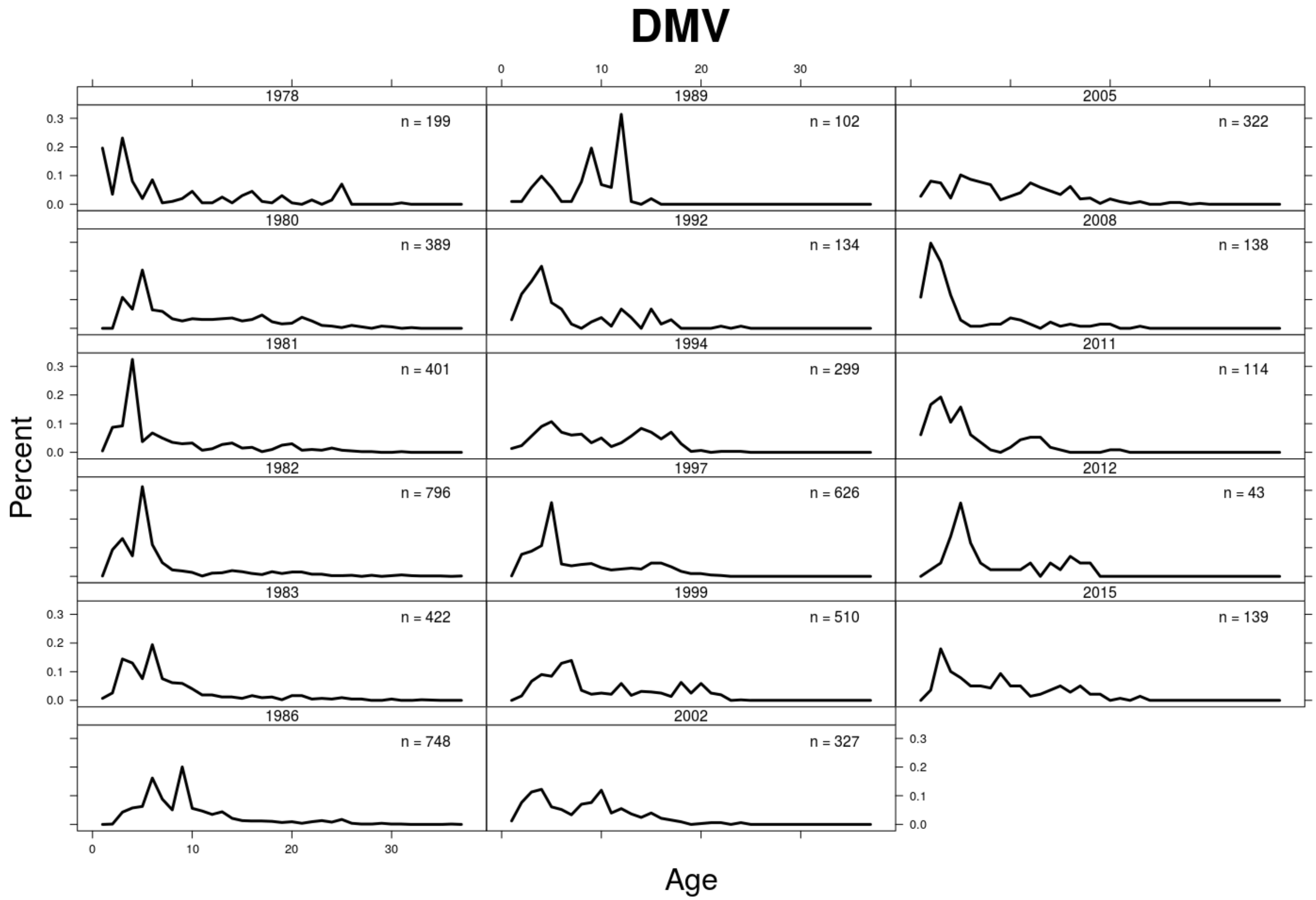


Figure 41: Age composition of Atlantic surfclam in NEFSC surveys in DMV, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

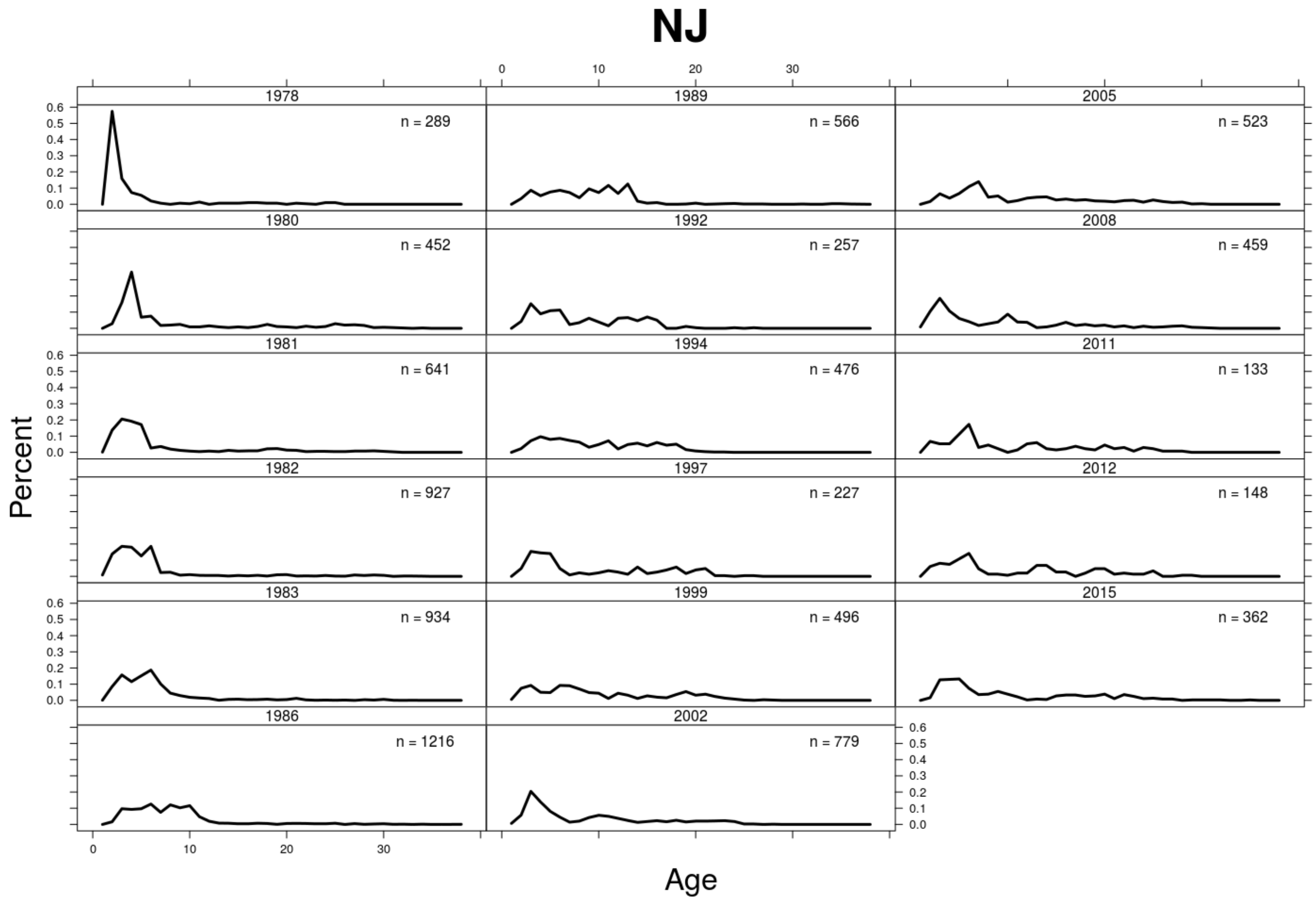


Figure 42: Age composition of Atlantic surfclam in NEFSC surveys in NJ, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

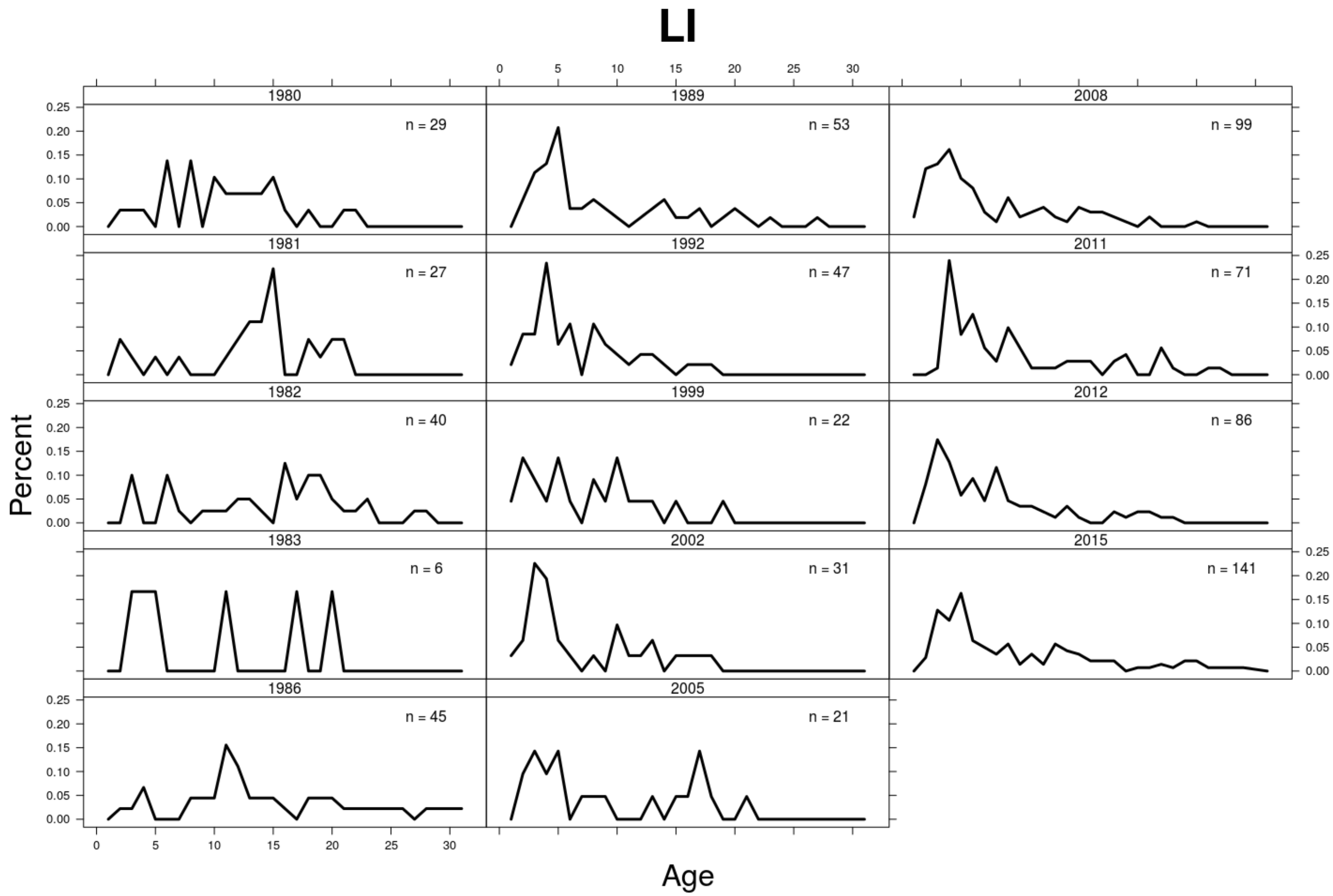


Figure 43: Age composition of Atlantic surfclam in NEFSC surveys in LI, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

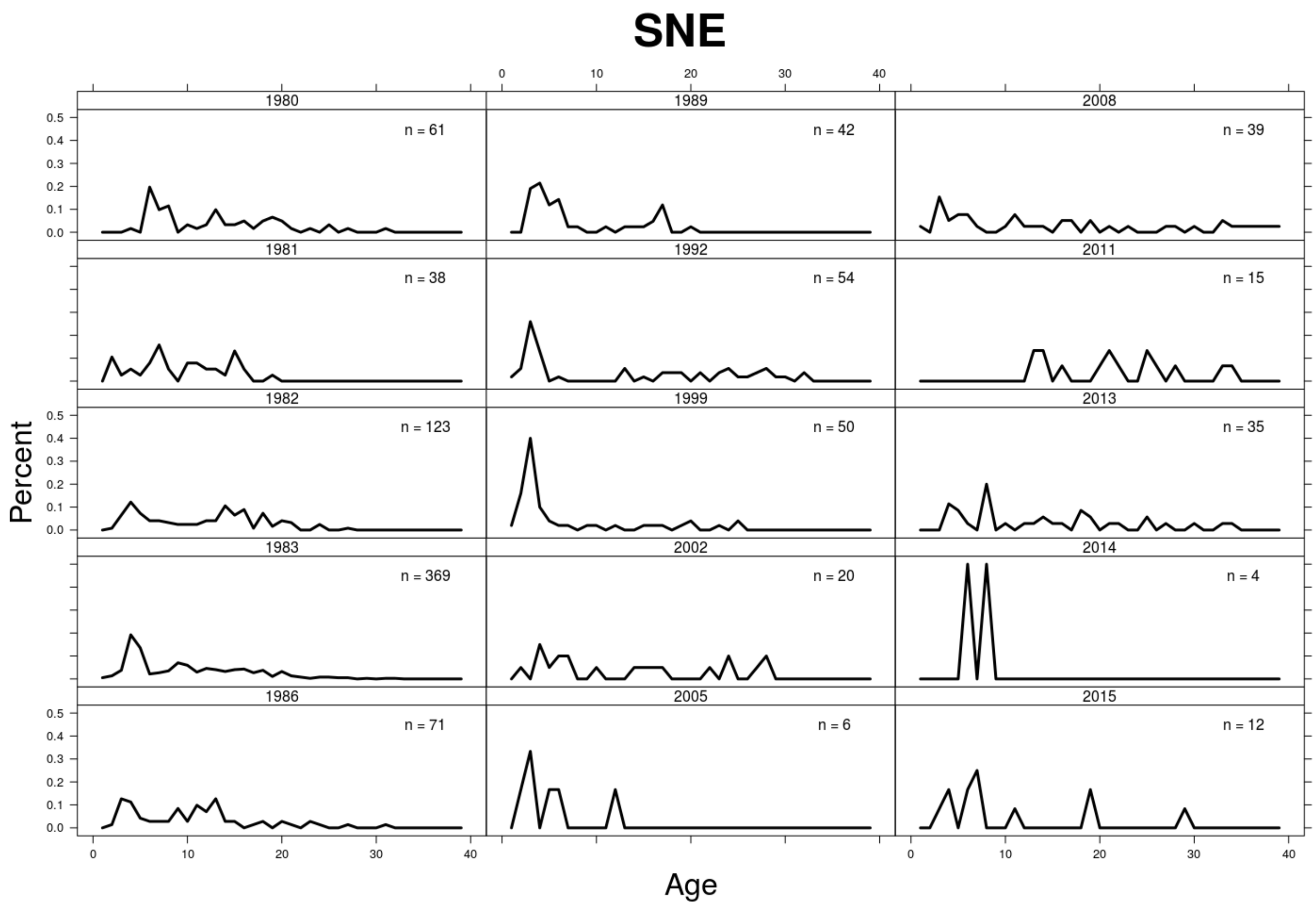


Figure 44: Age composition of Atlantic surfclam in NEFSC surveys in SNE, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

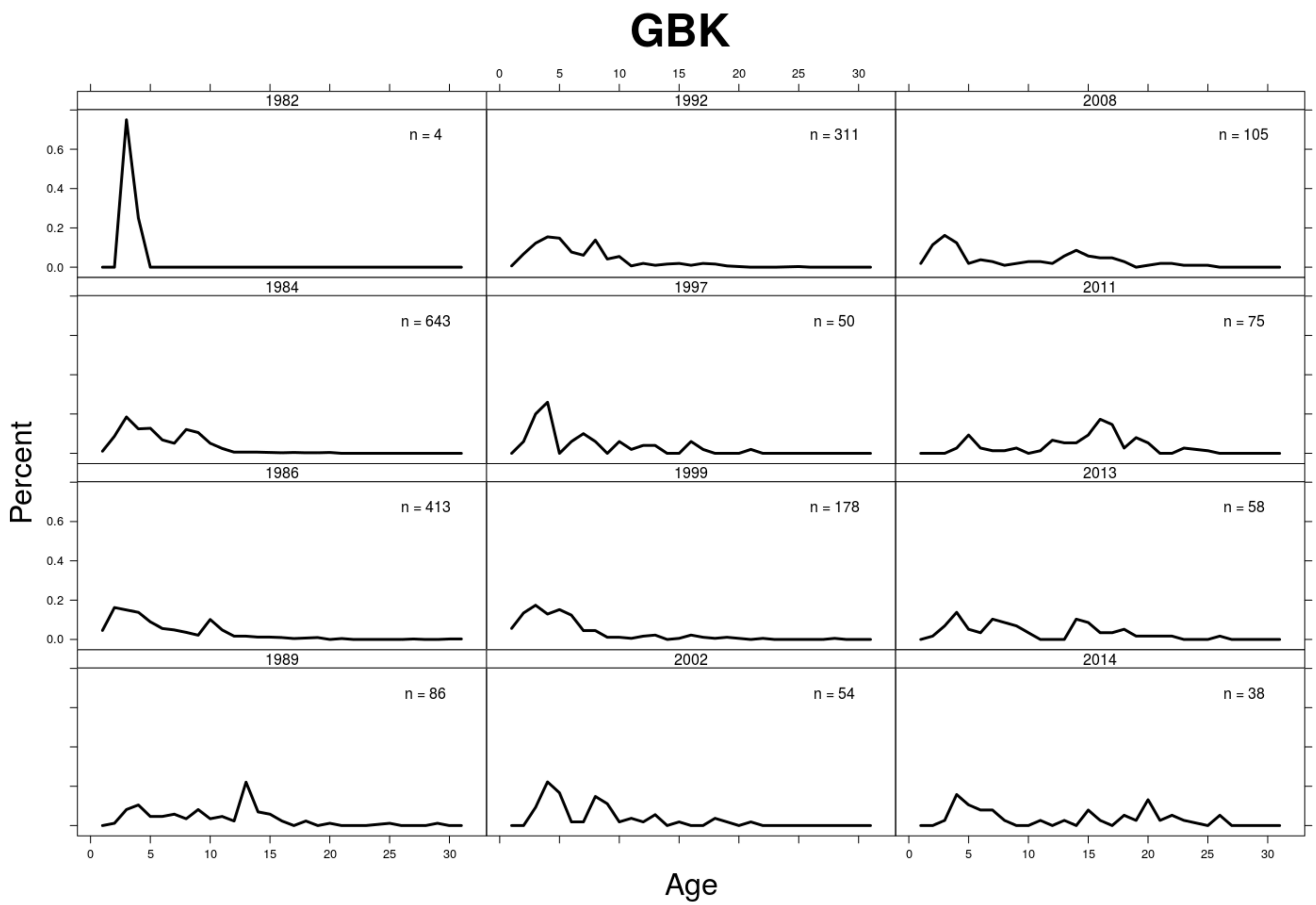


Figure 45: Age composition of Atlantic surfclam in NEFSC surveys in the northern area (GBK), including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

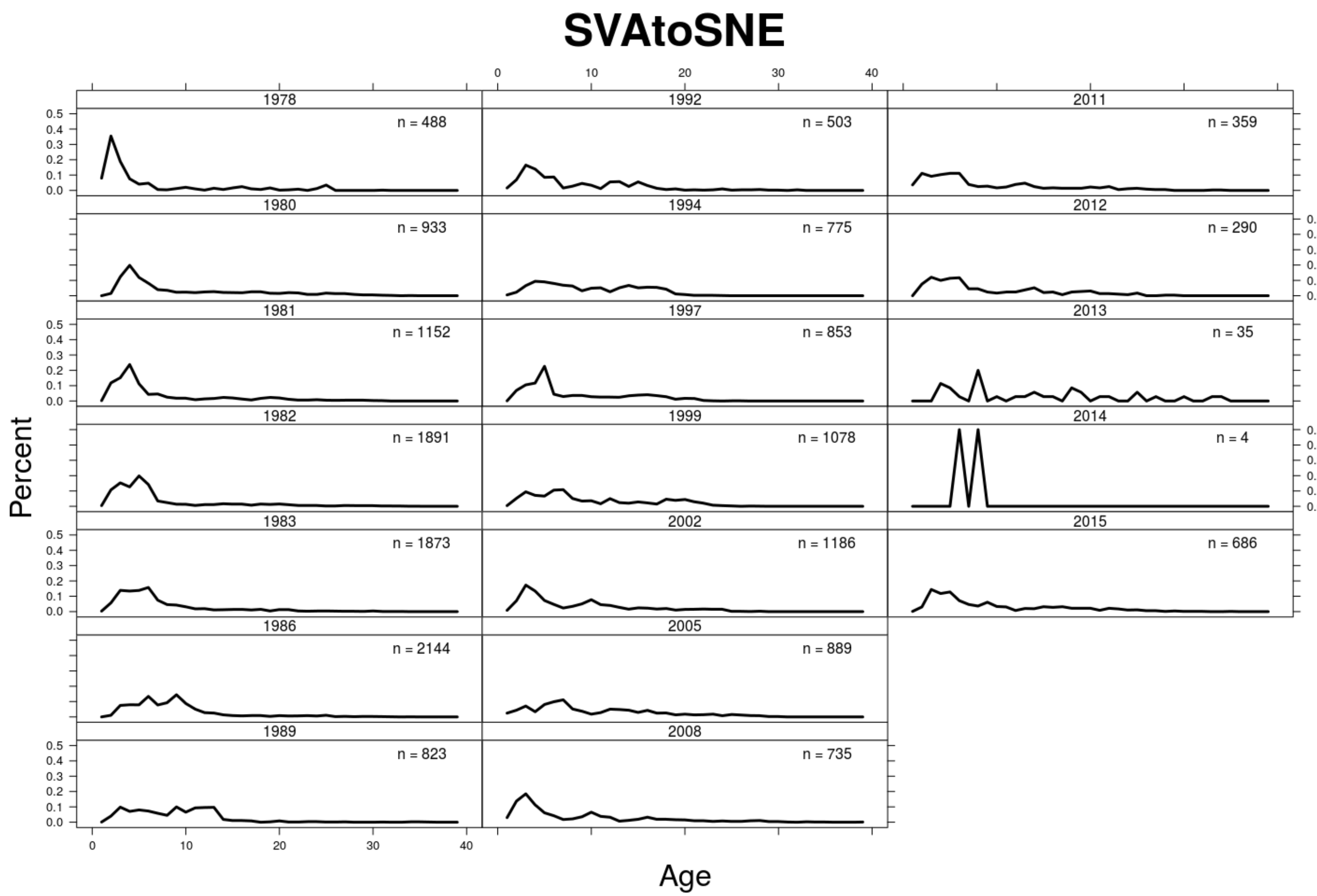


Figure 46: Age composition of Atlantic surfclam in NEFSC surveys in the southern area (SVAtoSNE), including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

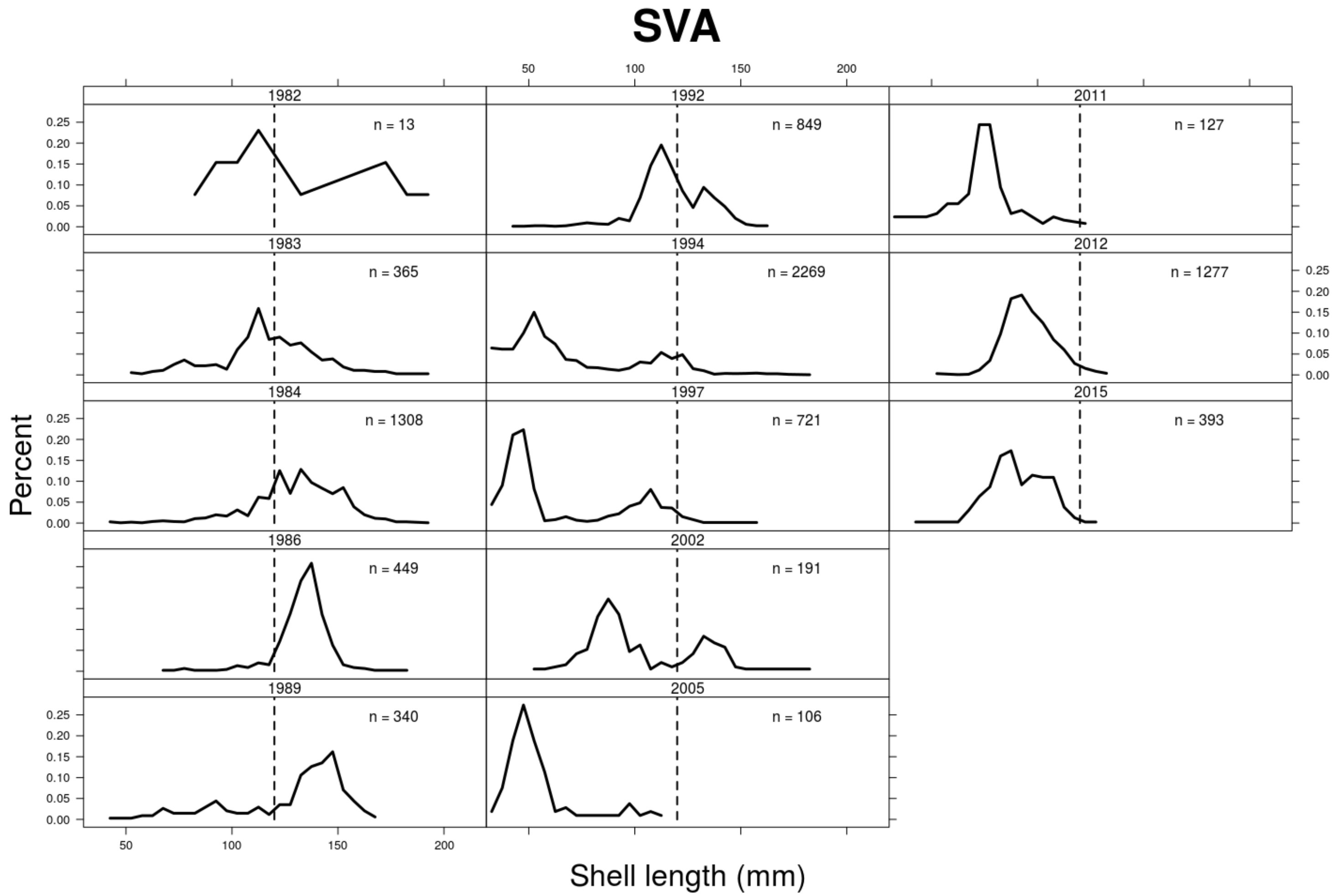


Figure 47: Length composition of Atlantic surfclam in NEFSC surveys in SVA, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

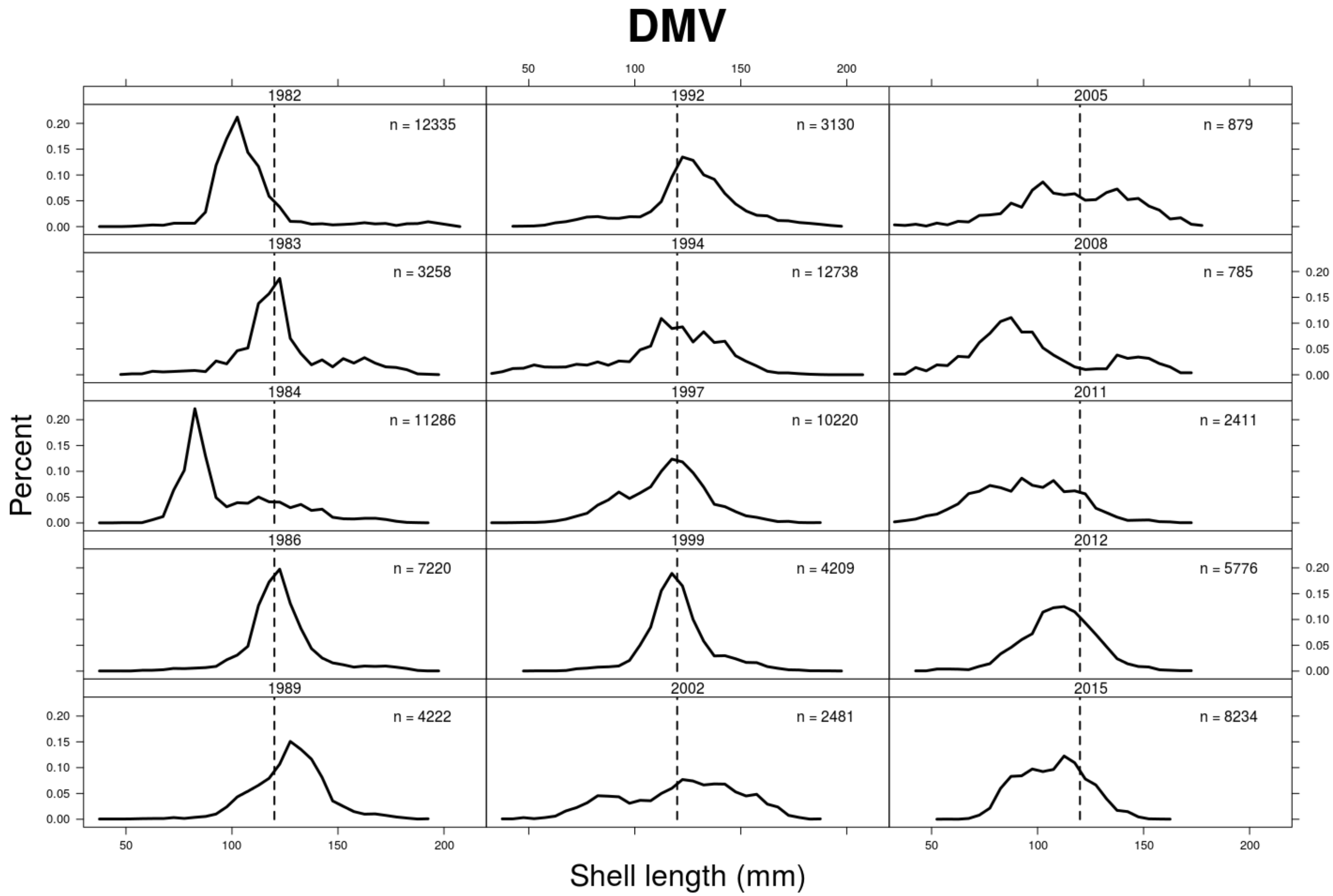


Figure 48: Length composition of Atlantic surfclam in NEFSC surveys in DMV, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

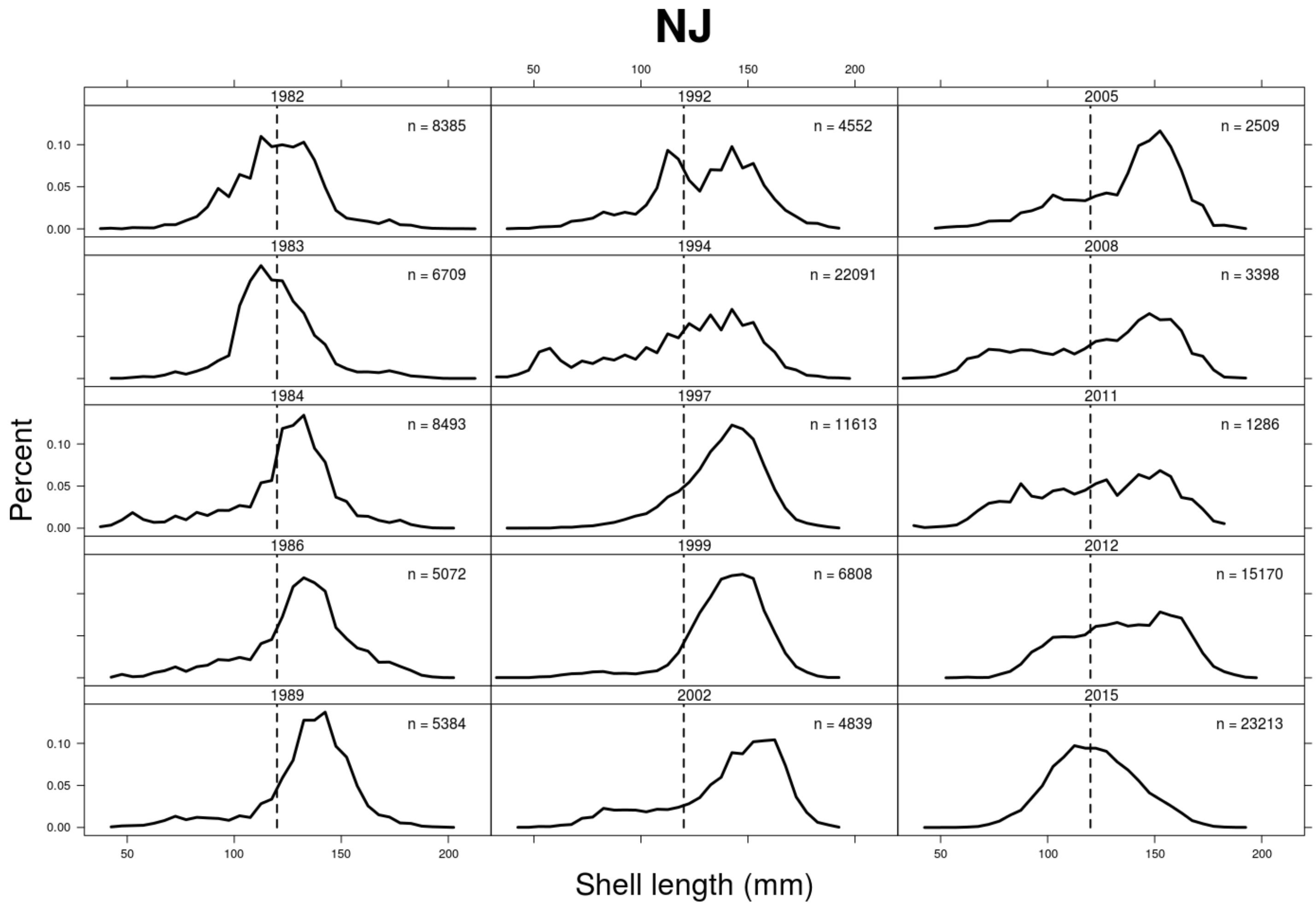


Figure 49: Length composition of Atlantic surfclam in NEFSC surveys in NJ, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

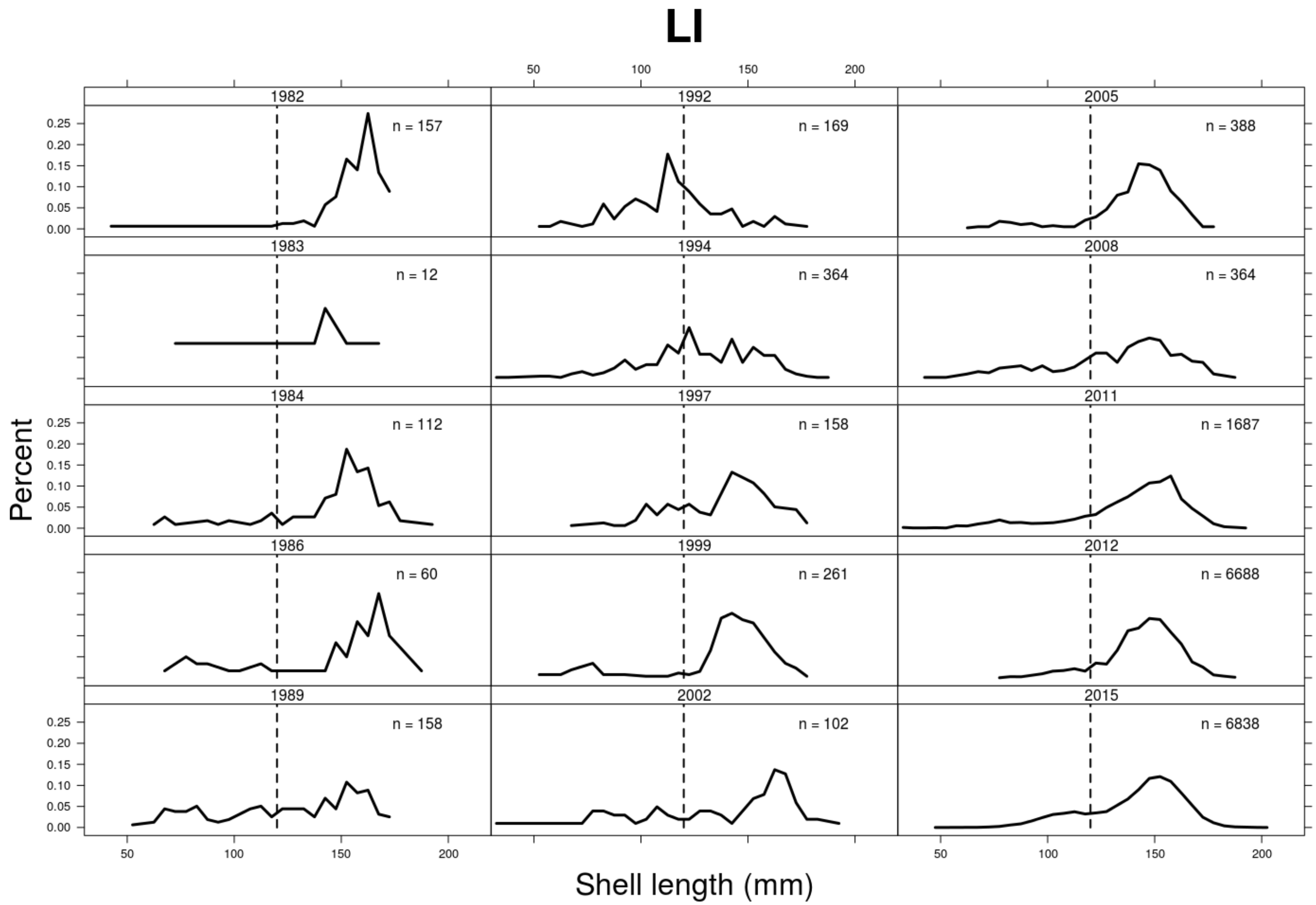


Figure 50: Length composition of Atlantic surfclam in NEFSC surveys in LI, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

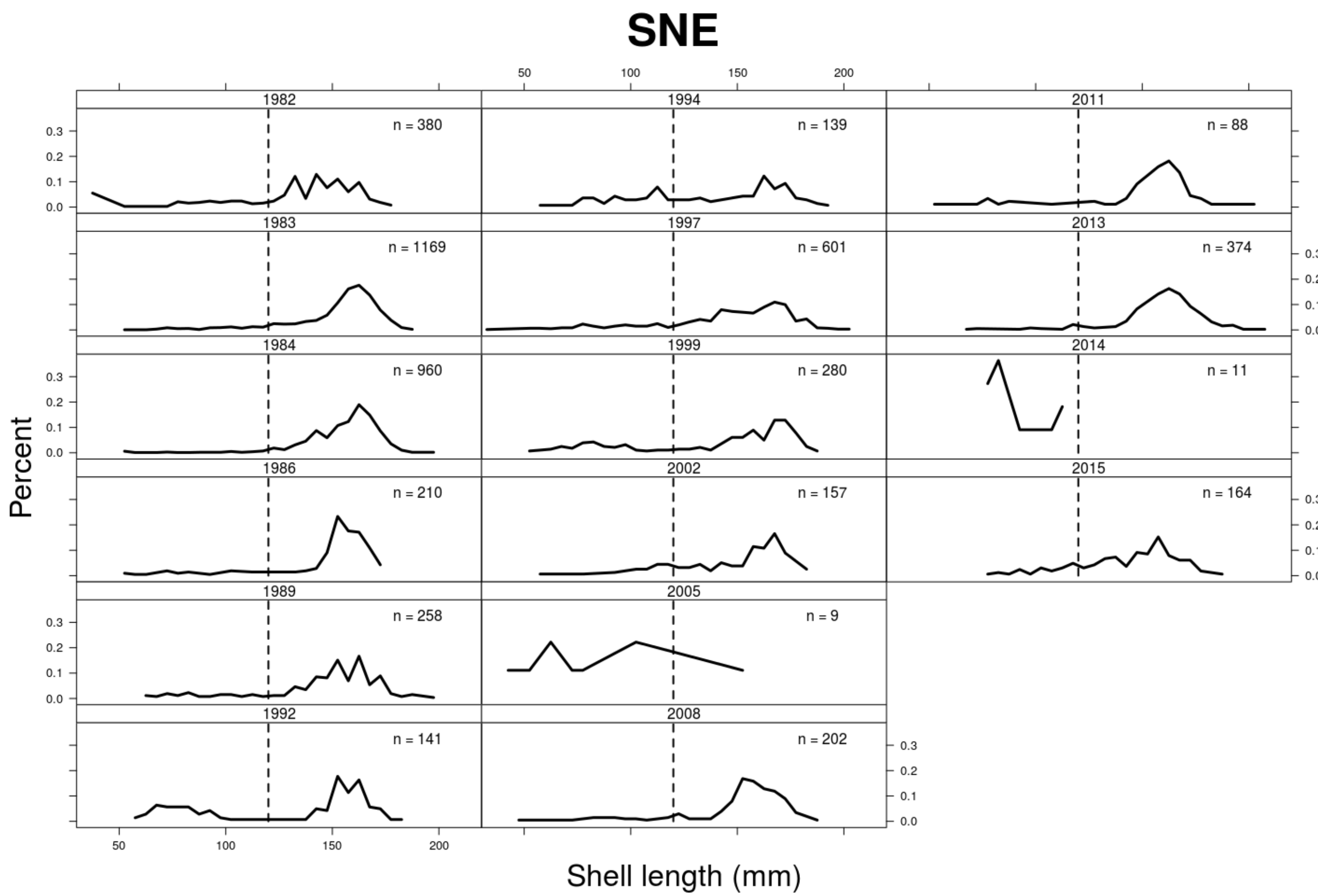


Figure 51: Length composition of Atlantic surfclam in NEFSC surveys in SNE, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

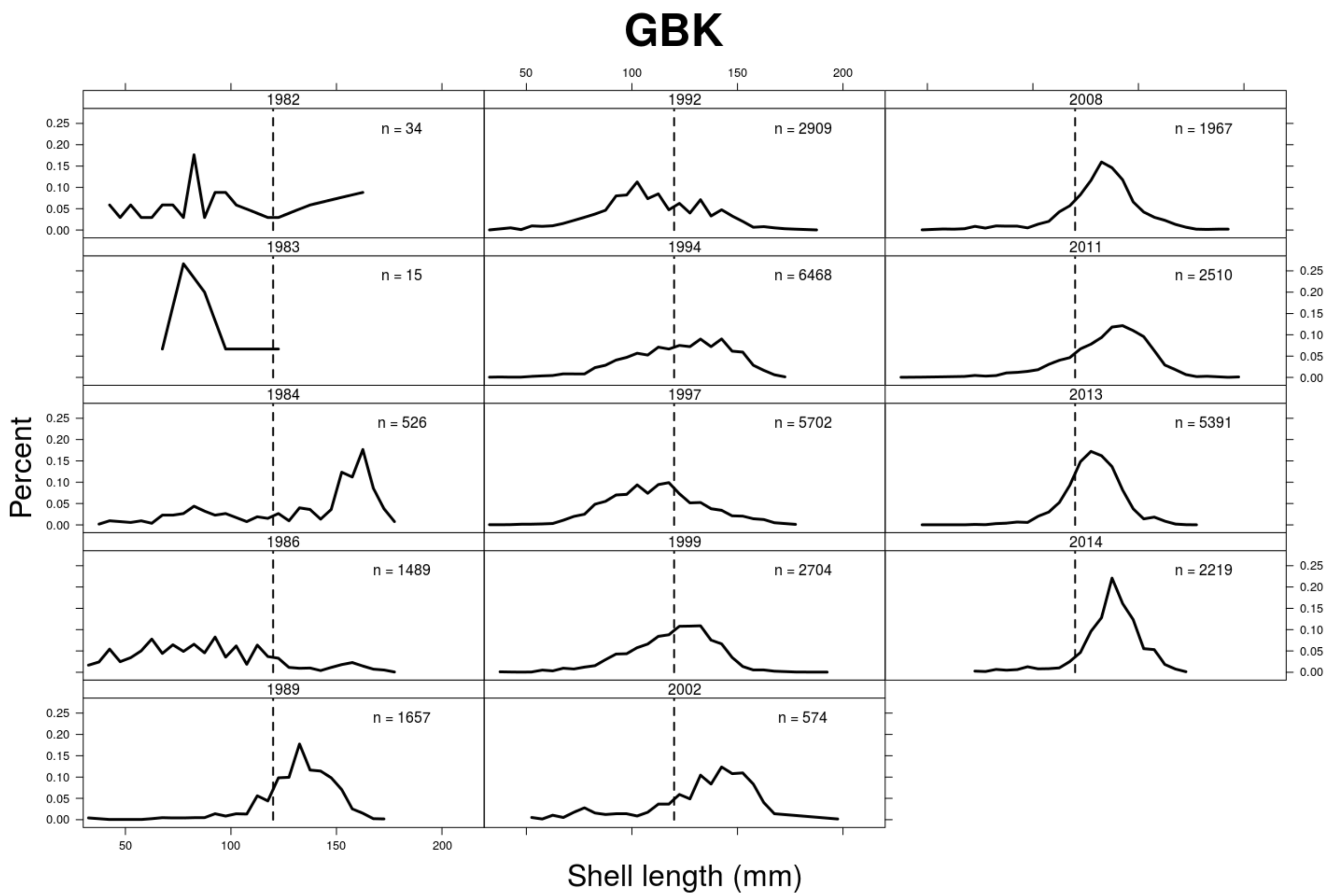


Figure 52: Length composition of Atlantic surfclam in NEFSC surveys in GBK, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

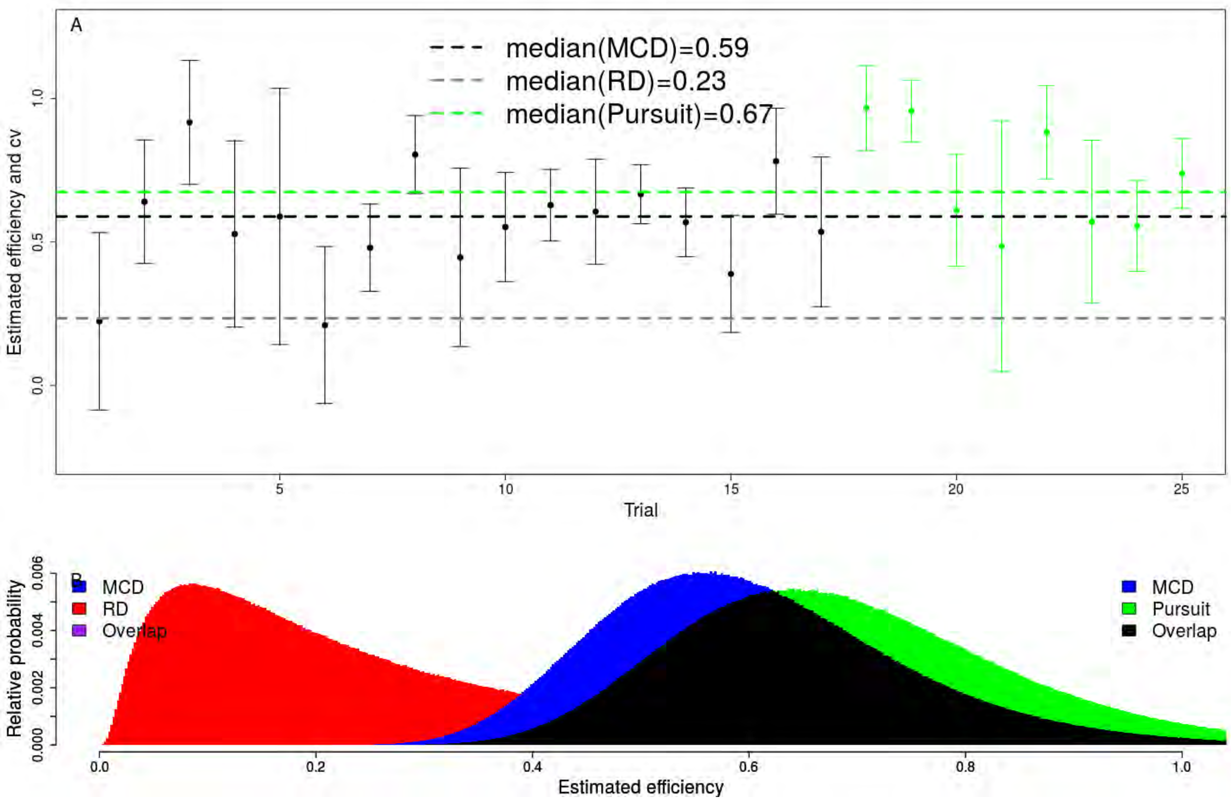


Figure 53: Panel A) Individual modified commercial dredge (MCD) capture efficiency estimates with coefficients of variation compared to median values for the MCD and the survey dredge used from the research vessel (RD) as well as the specific dredge used on the current survey (Pursuit). Panel B) A comparison of median values values incoprorating the pooled cv for each dredge where each is shown as a truncated lognormal distribution. The MCD and Pursuit dredge had higher and more precisely estimated capture efficiency than the RD.

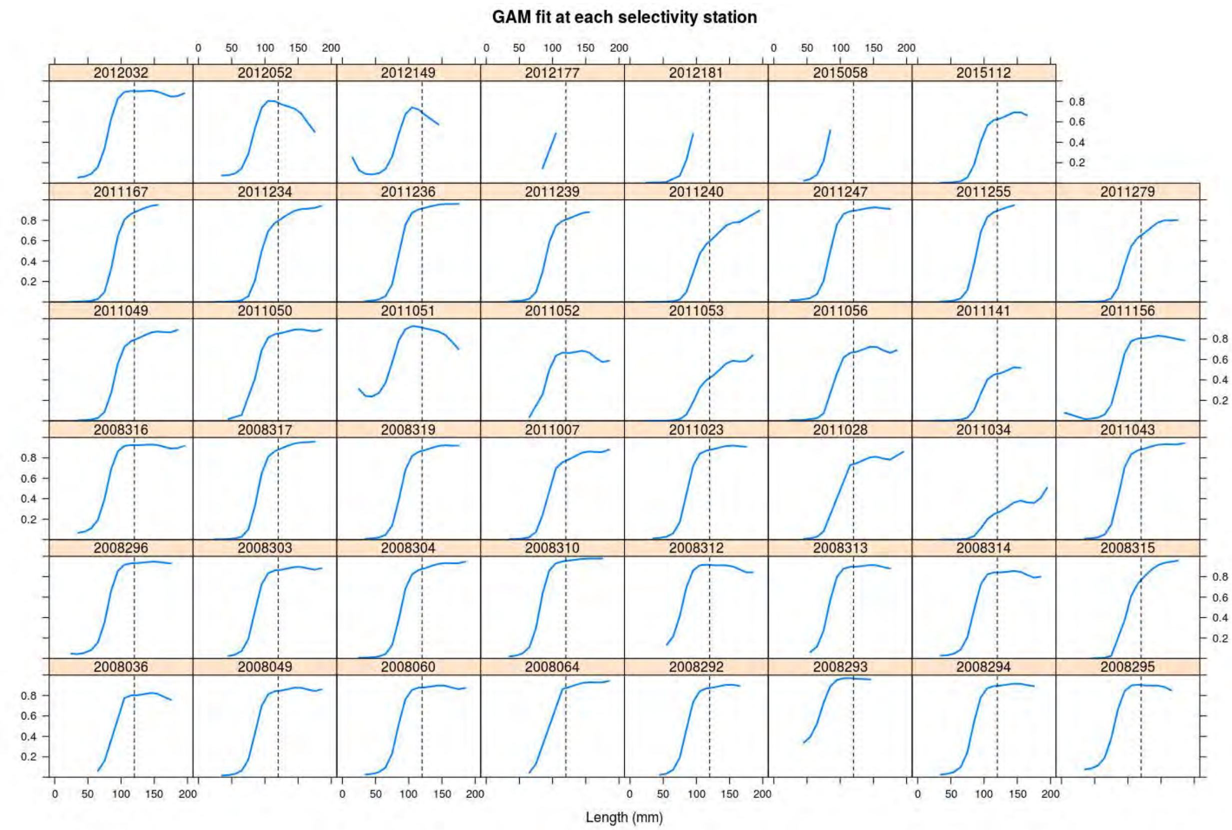


Figure 54: GAM fits to the selectivity data for Atlantic surfclam from field experiments (MCD compared to lined dredge) by year and station. The plots generally indicate flat topped selectivity curves.

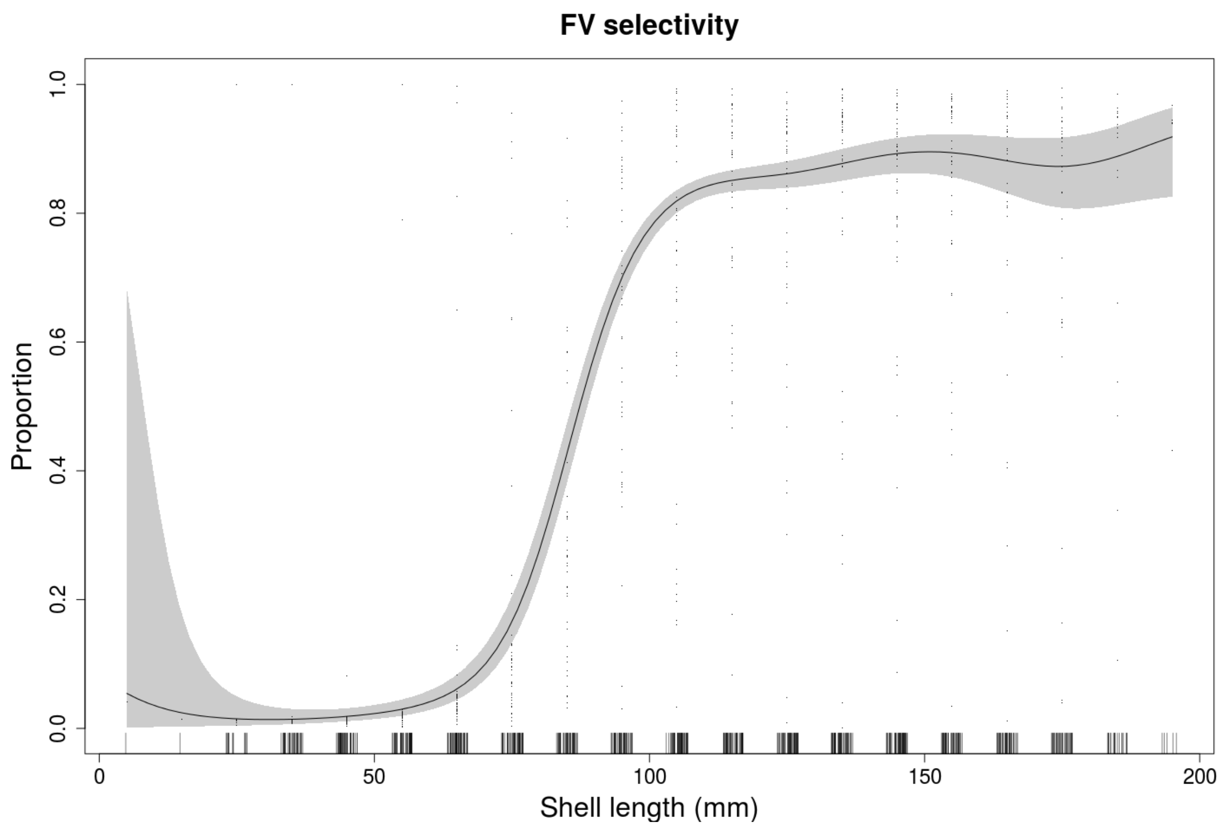


Figure 55: The GAM fit to all the selectivity data for Atlantic surfclam in the MCD in all years. The best (by AIC) model included random effects in both the intercept and spline over length. The data density is shown in the rug plot along the horizontal axis and relative confidence is represented by the shaded region.

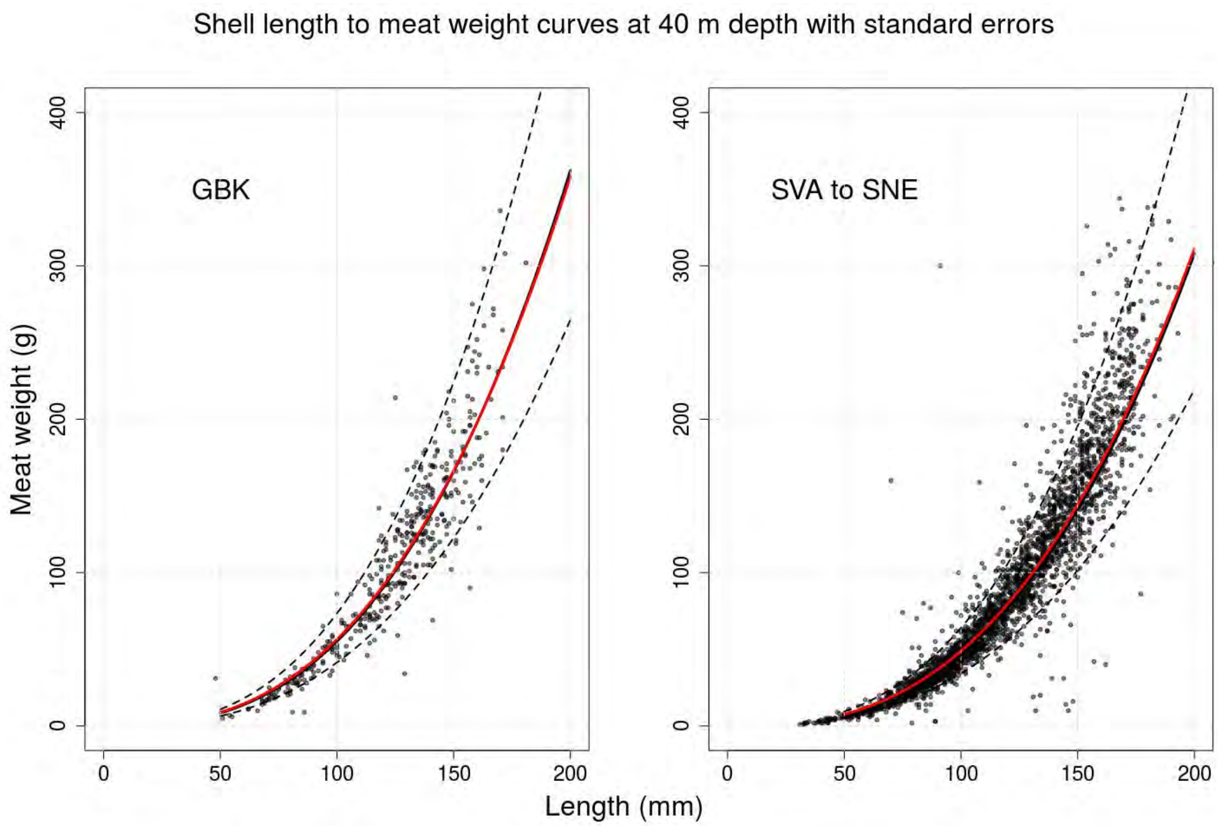


Figure 56: Broad scale area differences in allometric relationships for Atlantic surfclam based on survey data. The same depth (40 m) was used to generate the curves for each area. The 95% confidence regions are represented by the dotted line.

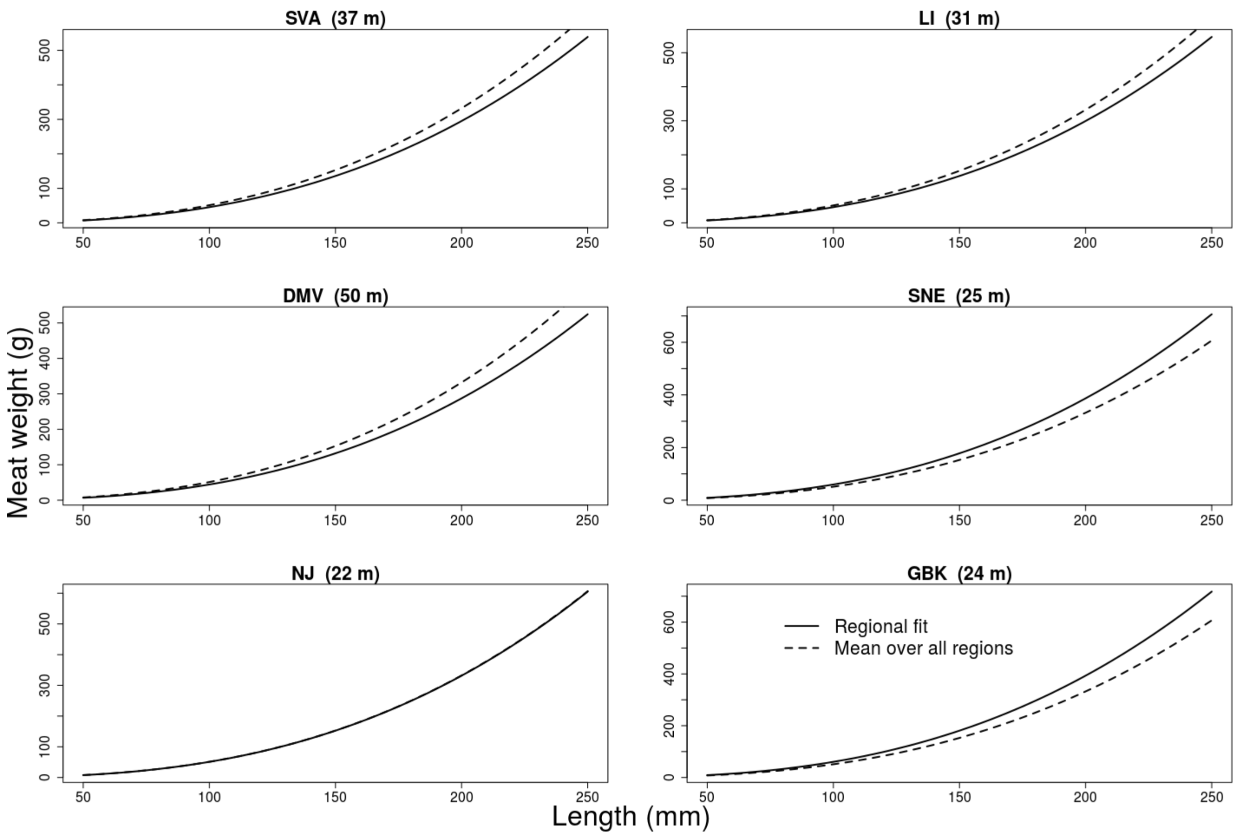


Figure 57: Regional differences in allometric relationships for Atlantic surfclam based on survey data. The median depth in each region was used to generate the curves. The global mean is represented by the dotted line.

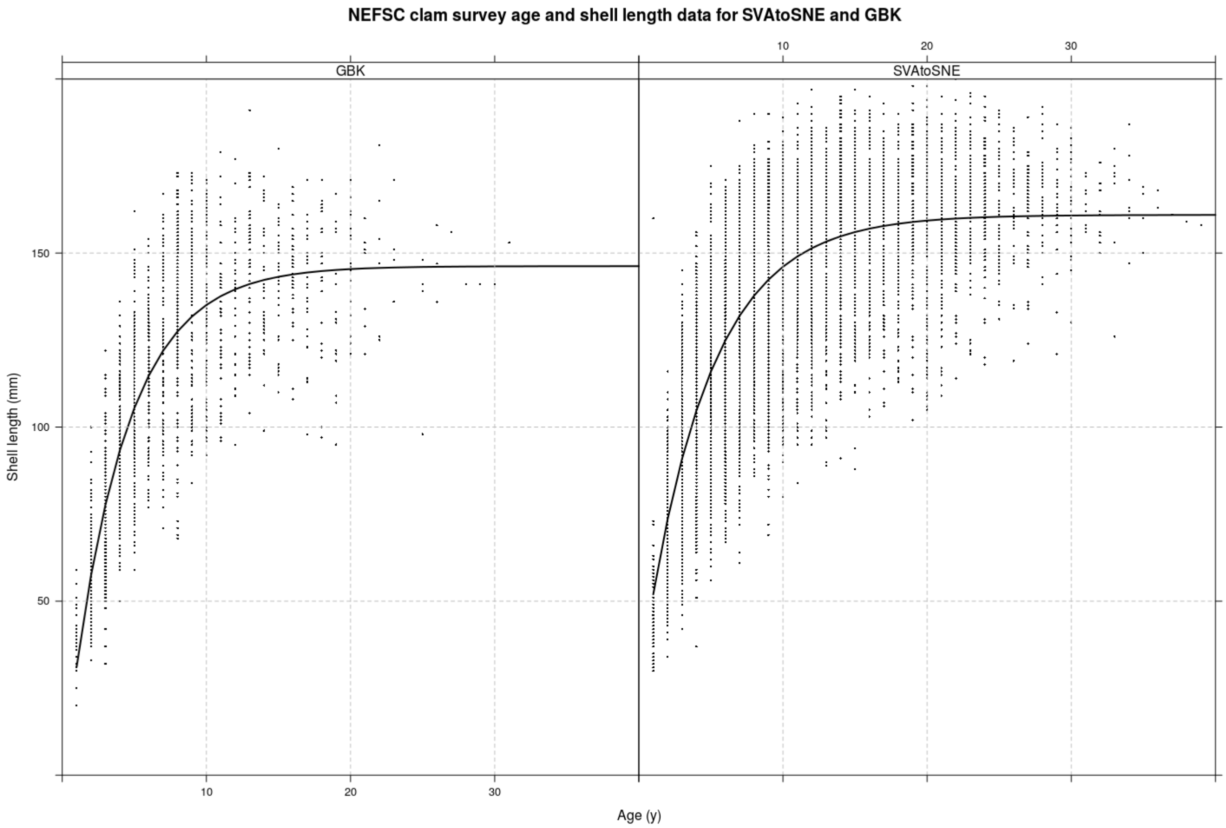


Figure 58: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve in different areas.

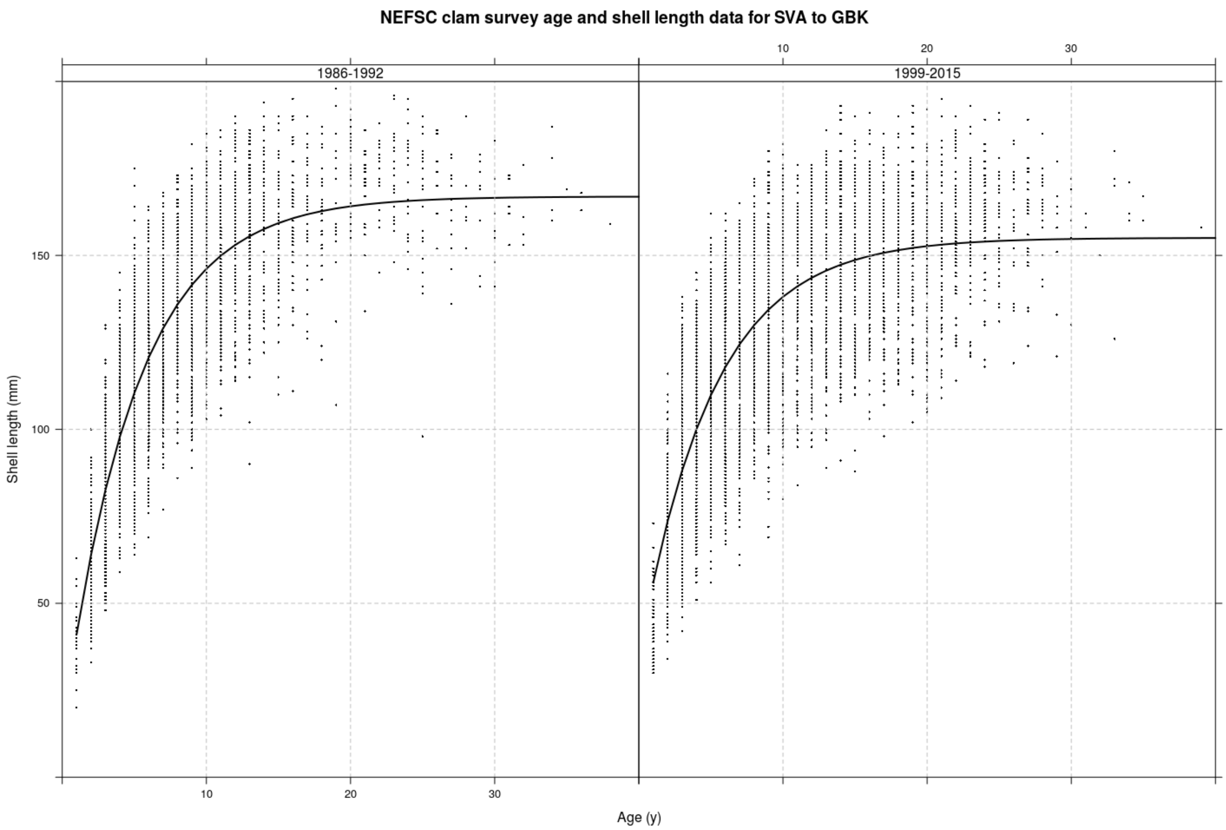


Figure 59: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve in different eras for the whole stock.

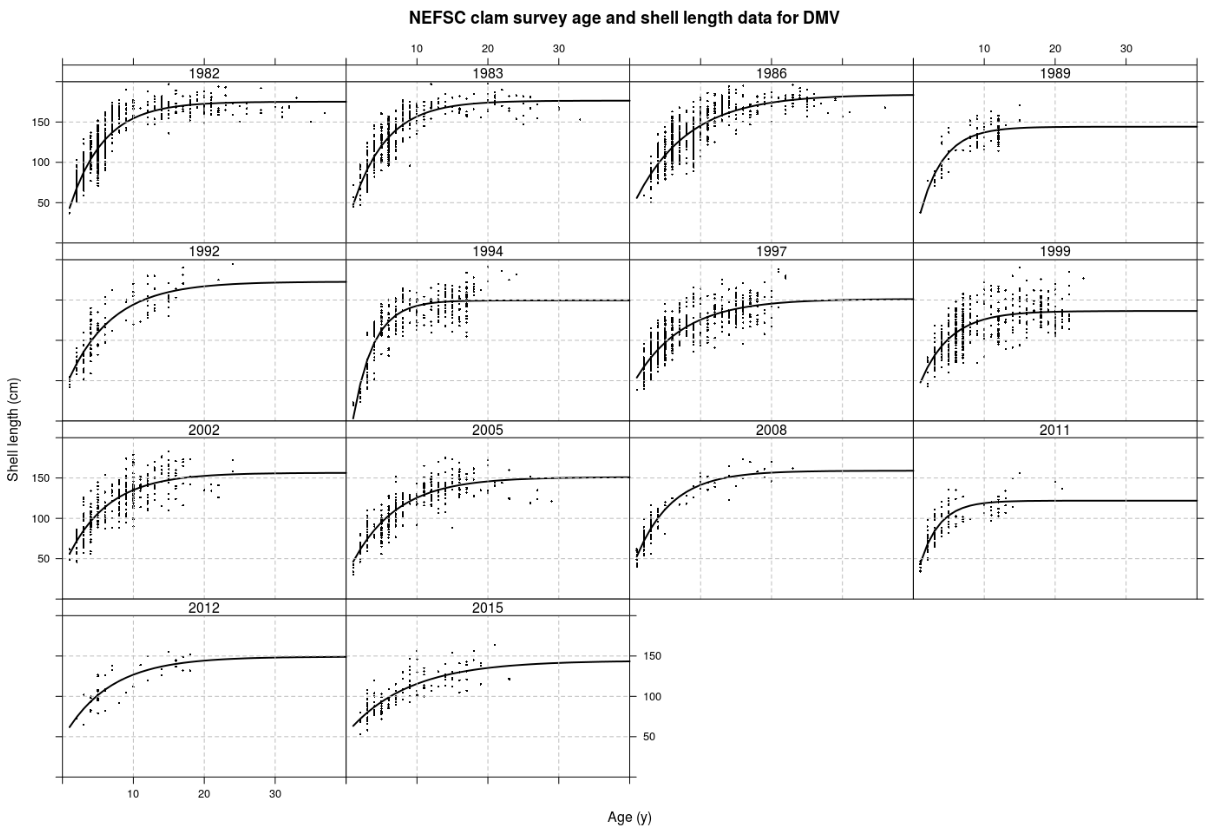


Figure 60: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the DMV region in each survey year.

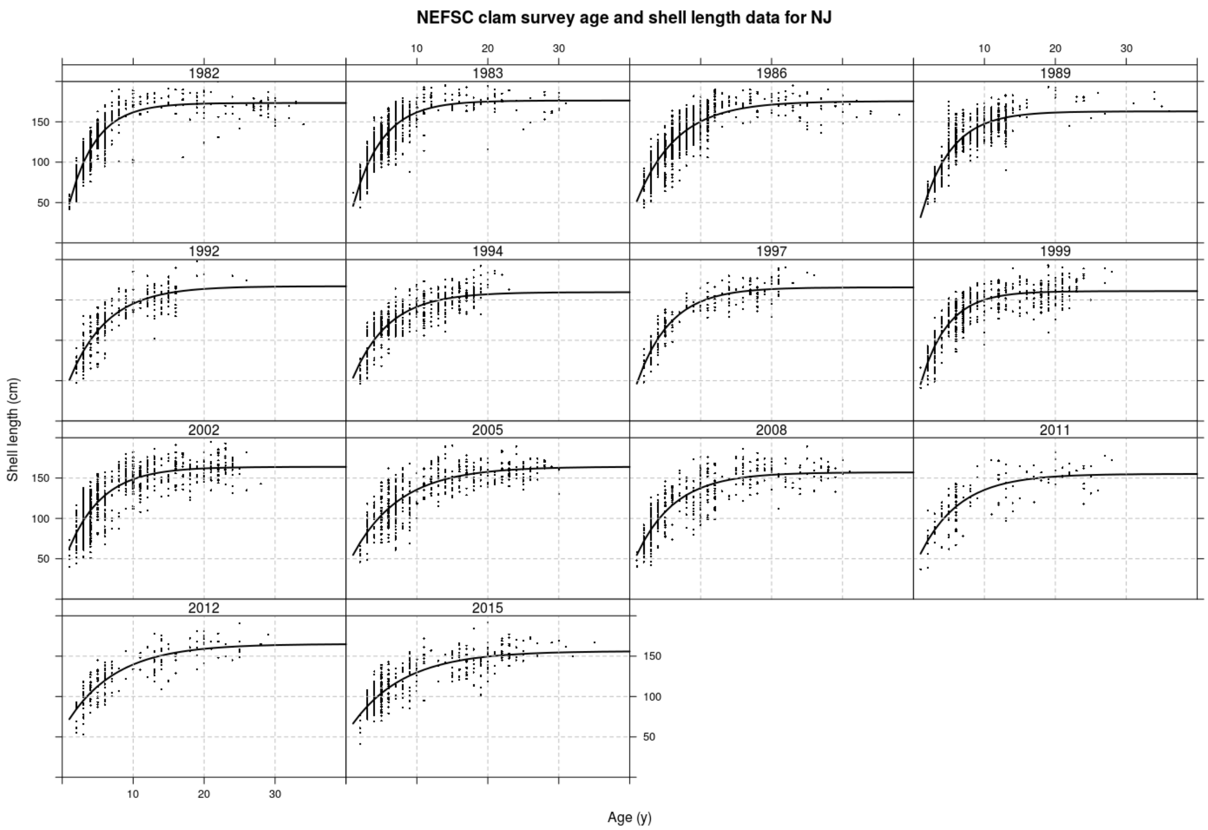


Figure 61: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the NJ region in each survey year.

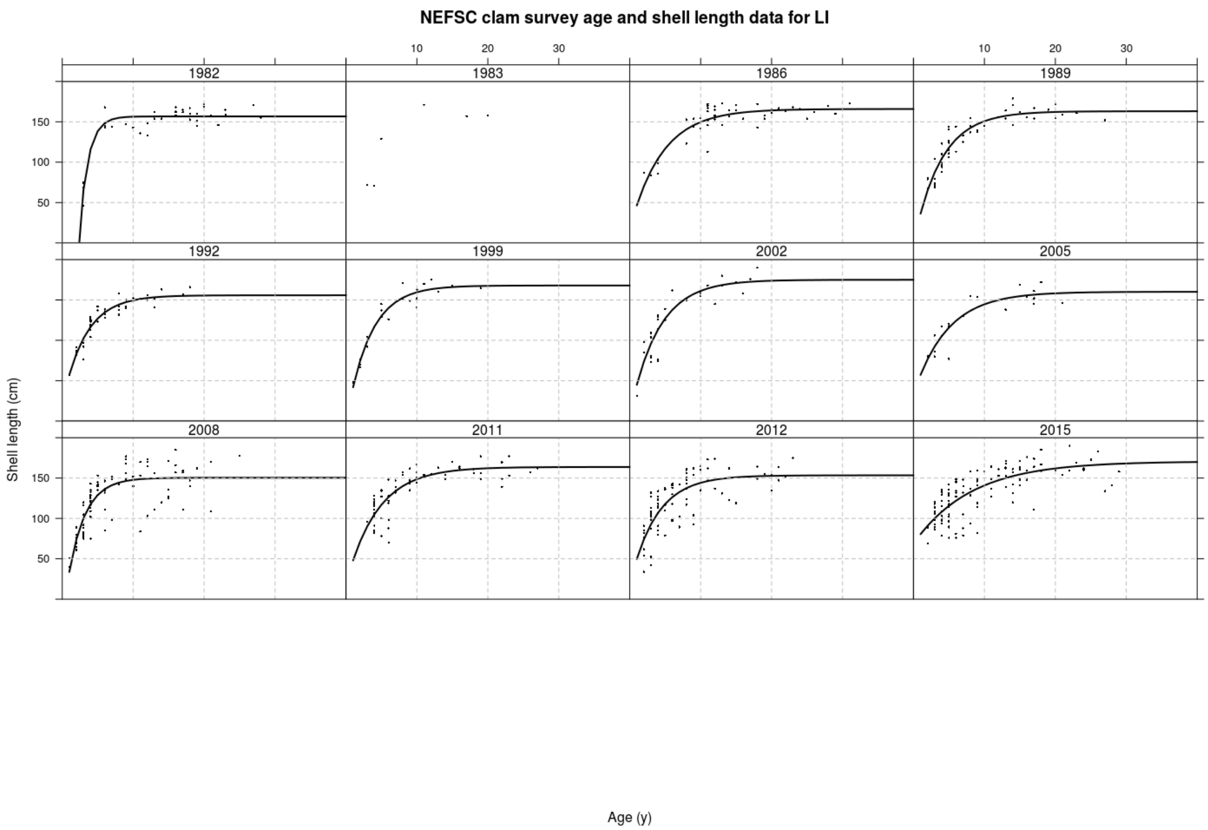


Figure 62: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the LI region in each survey year.

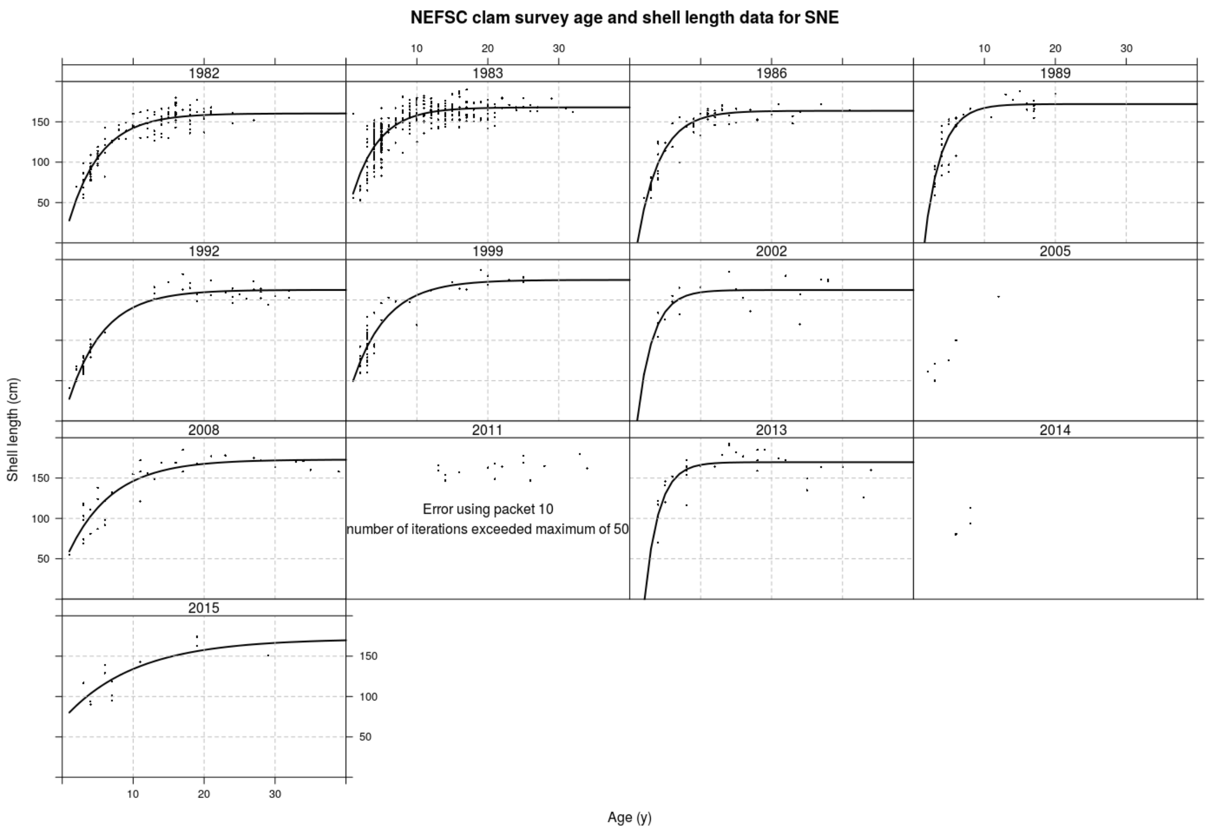


Figure 63: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the SNE region in each survey year.

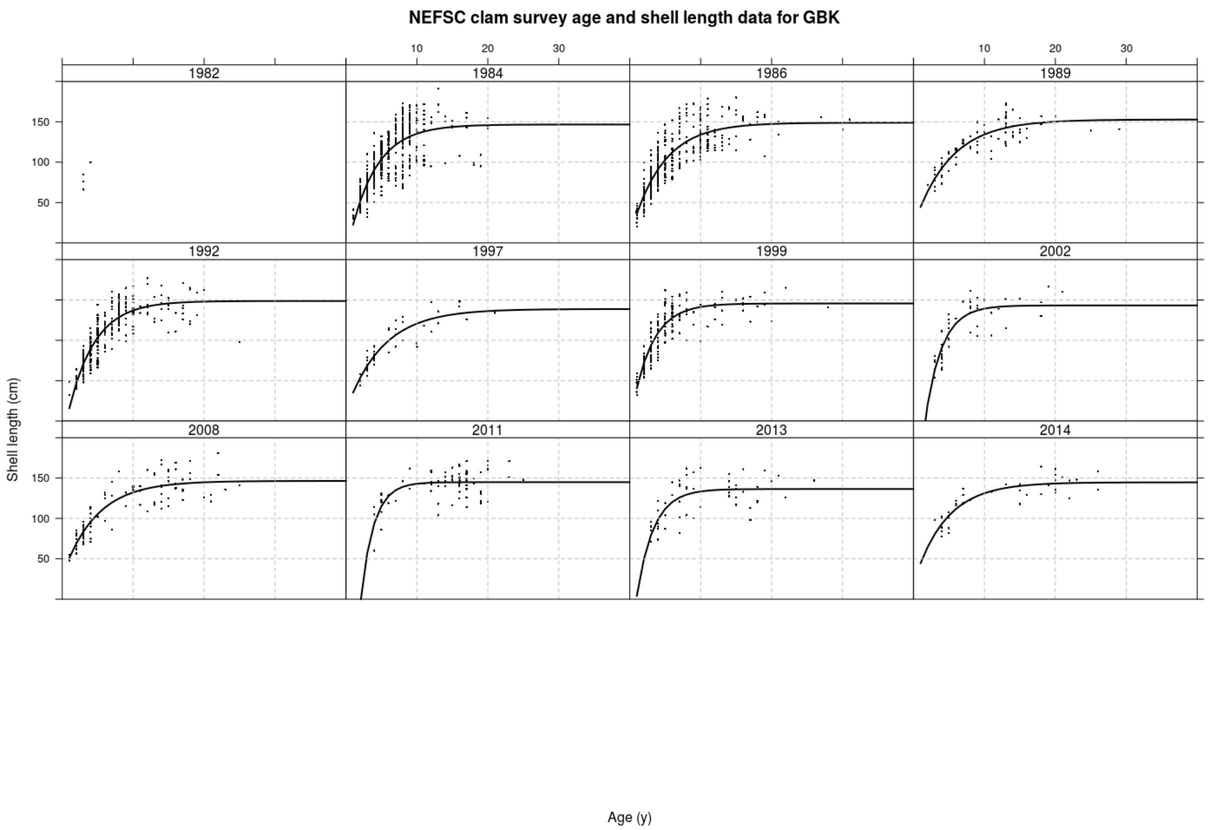


Figure 64: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the GBK region in each survey year.

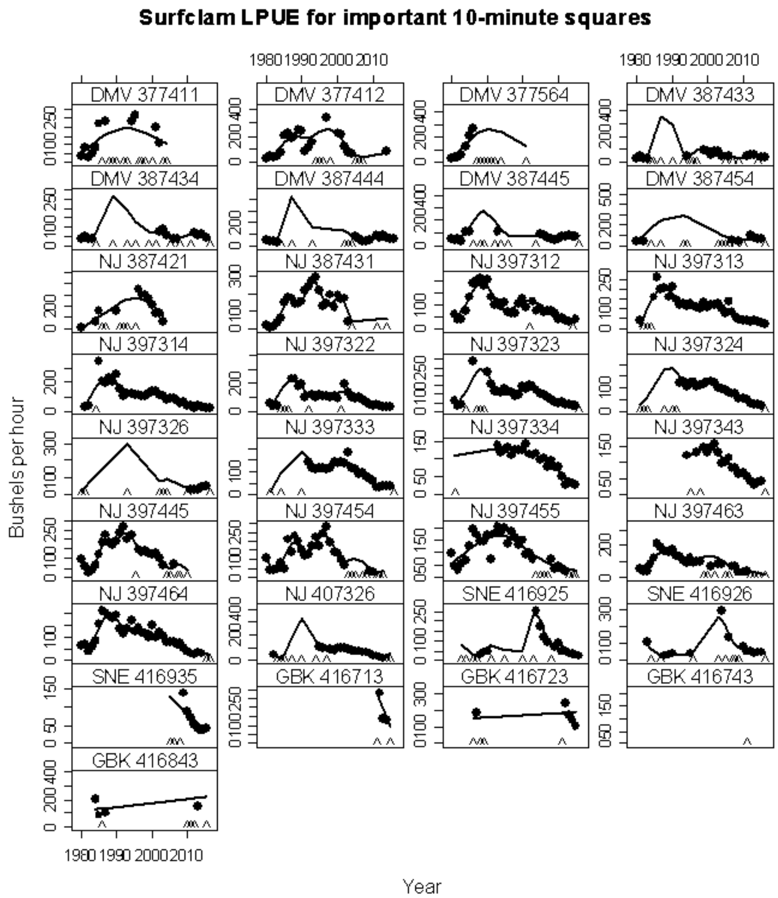


Figure 65: Observed and predicted survey catch rates in ten-minute squares that are important to the fishery.

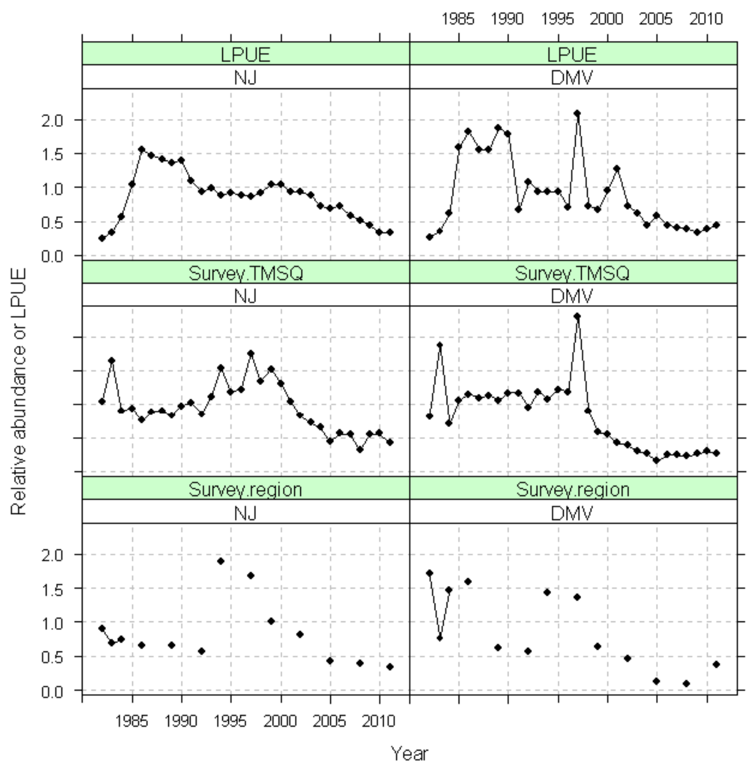


Figure 66: LPUE and survey abundance trends for Atlantic surfclam during 1982-2011 in the New Jersey (left) and Delmarva (right) regions (rescaled for convenience in plotting). LPUE and "Survey.TMSQ" are commercial catch rate and survey trends for important ten-minute squares. "Survey.region" is the survey trend for the entire region (all ten-minute squares).

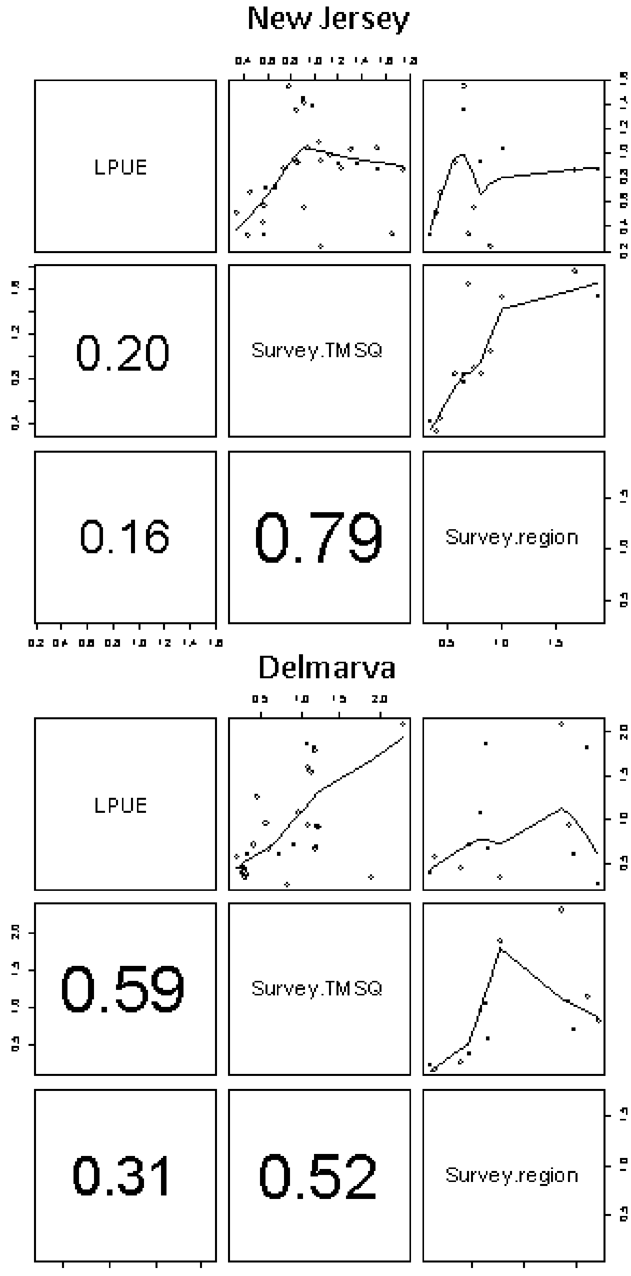


Figure 67: Relationships between LPUE and survey abundance trends for Atlantic surfclam during 1982-2011 in the New Jersey (top) and Delmarva (bottom) areas (rescaled for convenience in plotting). LPUE is commercial catch rates in important TNMS. Survey.TNMS is the survey trend in important TNMS. "Survey.region" is the survey trend for the entire region (all ten-minute squares). Scatter plots with smooth lines to show trends are above the diagonal in each panel and correlation statistics are below the diagonal.

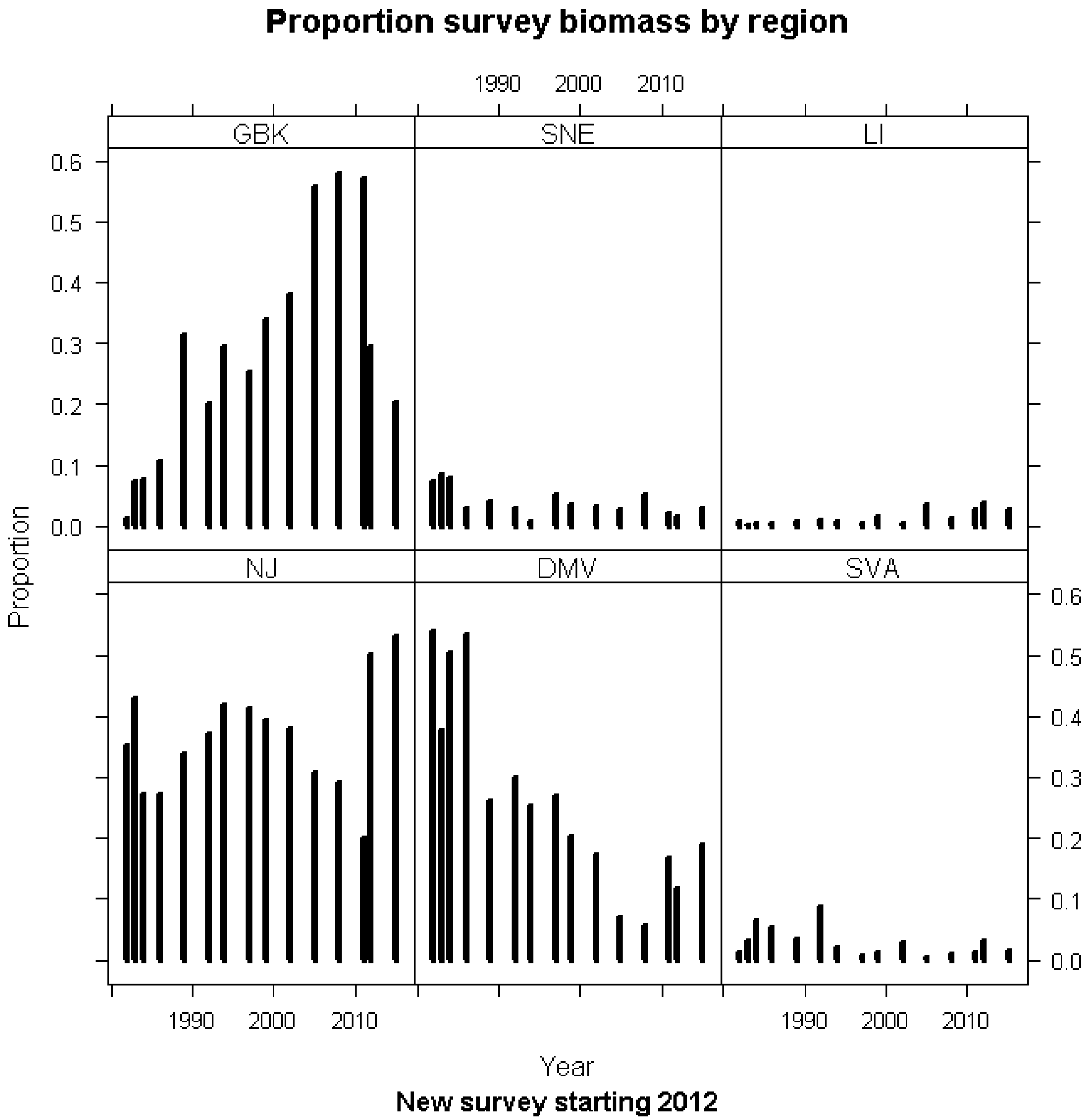


Figure 68: Proportions of relative survey biomass for surfclams by region during 1982-2015. For example, the proportion of total biomass on GBK during 2015 is about 20% and the sum of values plotted for 2015 in all regions is 100%. Estimates for 1982-2011 may not be comparable to estimates for 2012-2015 because a new survey using a different vessel, gear, etc. started in 2012.

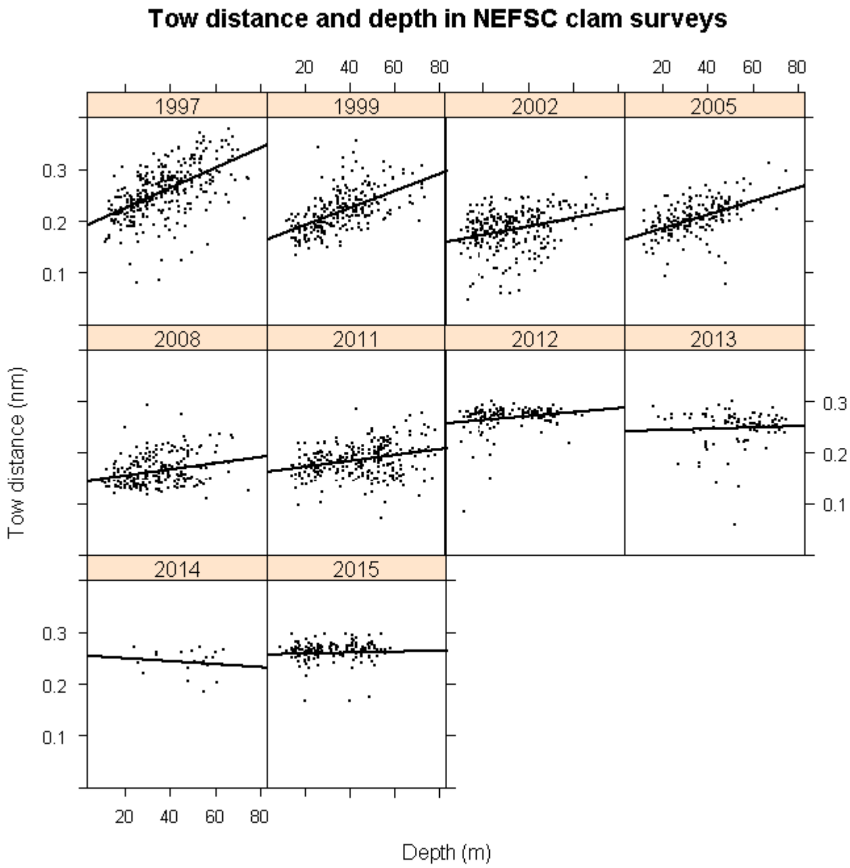


Figure 69: Relationships between tow depth and tow distance from inclinometer measurements in NEFSC clam surveys during 2007-2011 (RD) and 2012-2015 (MCD).

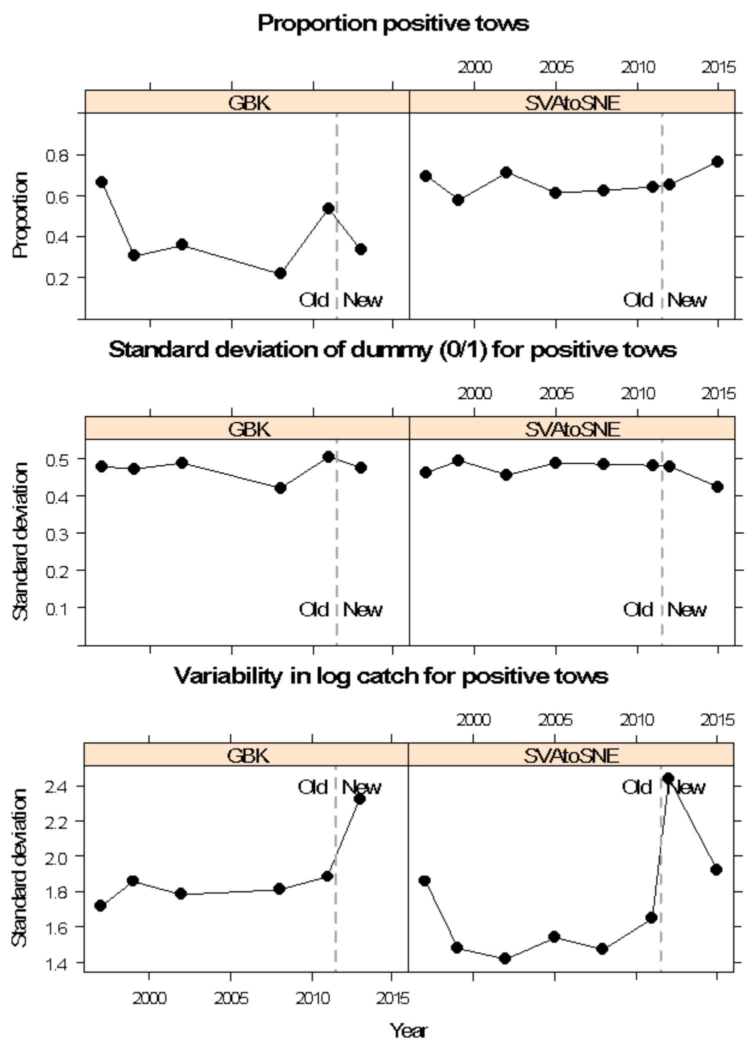


Figure 70: Trends in proportion positive tows (top), the standard deviation of a dummy variable that identifies positive tows (=0 if Atlantic surfclam catch was zero and 1 otherwise), and the standard deviation of log transformed catches (positive tows only) for Atlantic surfclam in NEFSC clam surveys during 1997-2015.

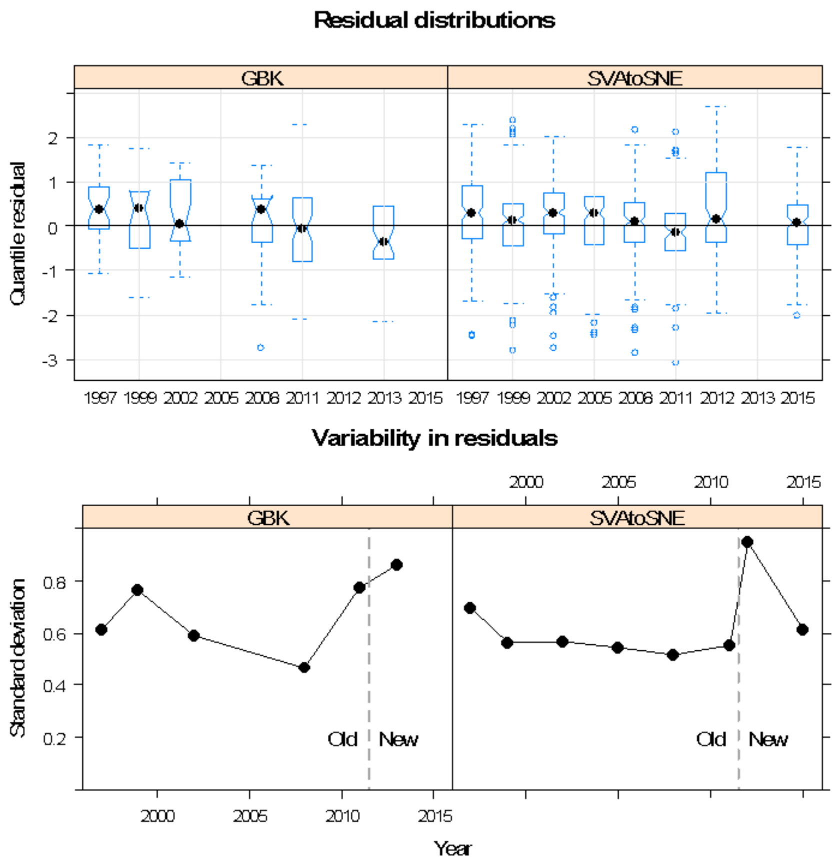


Figure 71: Top, distributions of randomized quantile residuals from the best GAM model (Tweedie family) fit to consistently sampled NEFSC clam survey strata. Bottom: standard deviations for residual distributions in top panel.

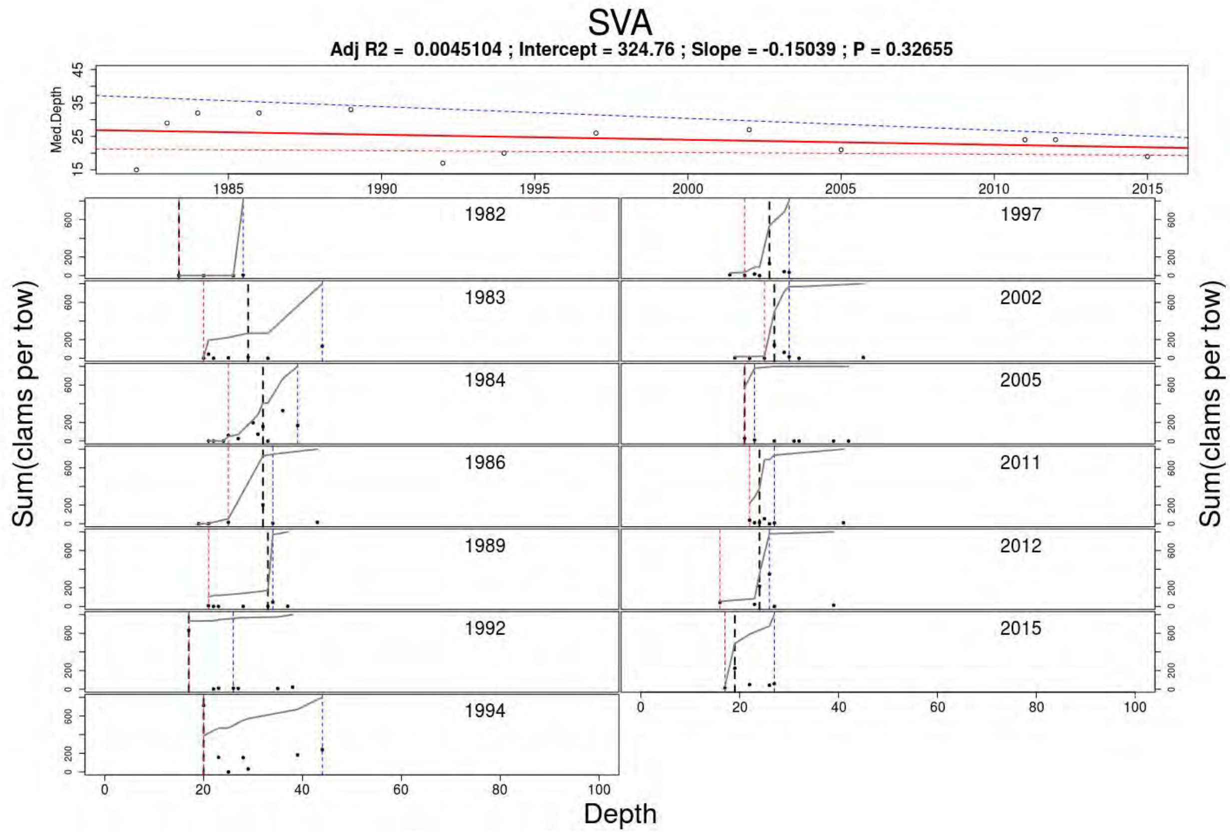


Figure 72: Total surfclams caught at depth by year in SVA. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years. Inshore (shallow) strata were not well sampled in recent years and were excluded from this analysis

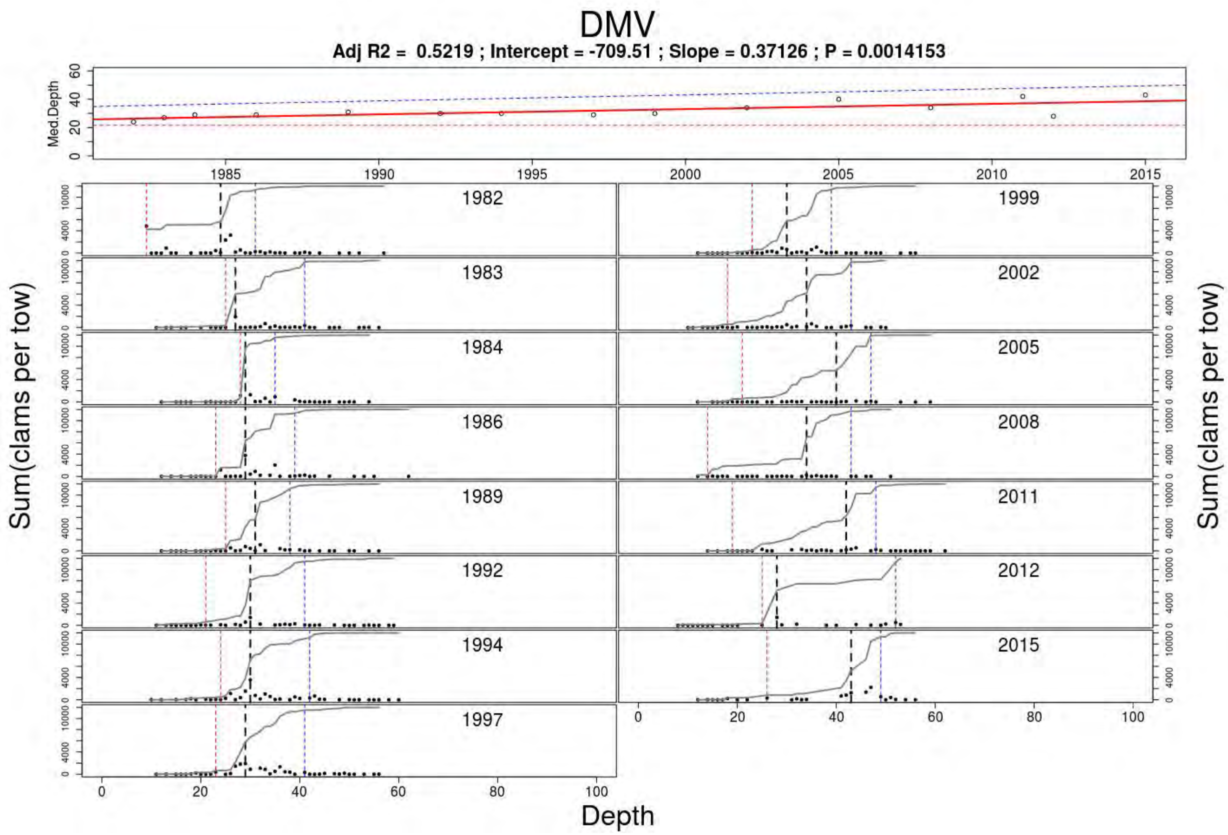


Figure 73: Total surfclams caught at depth by year in DMV. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years. Inshore (shallow) strata were not well sampled in recent years and were excluded from this analysis

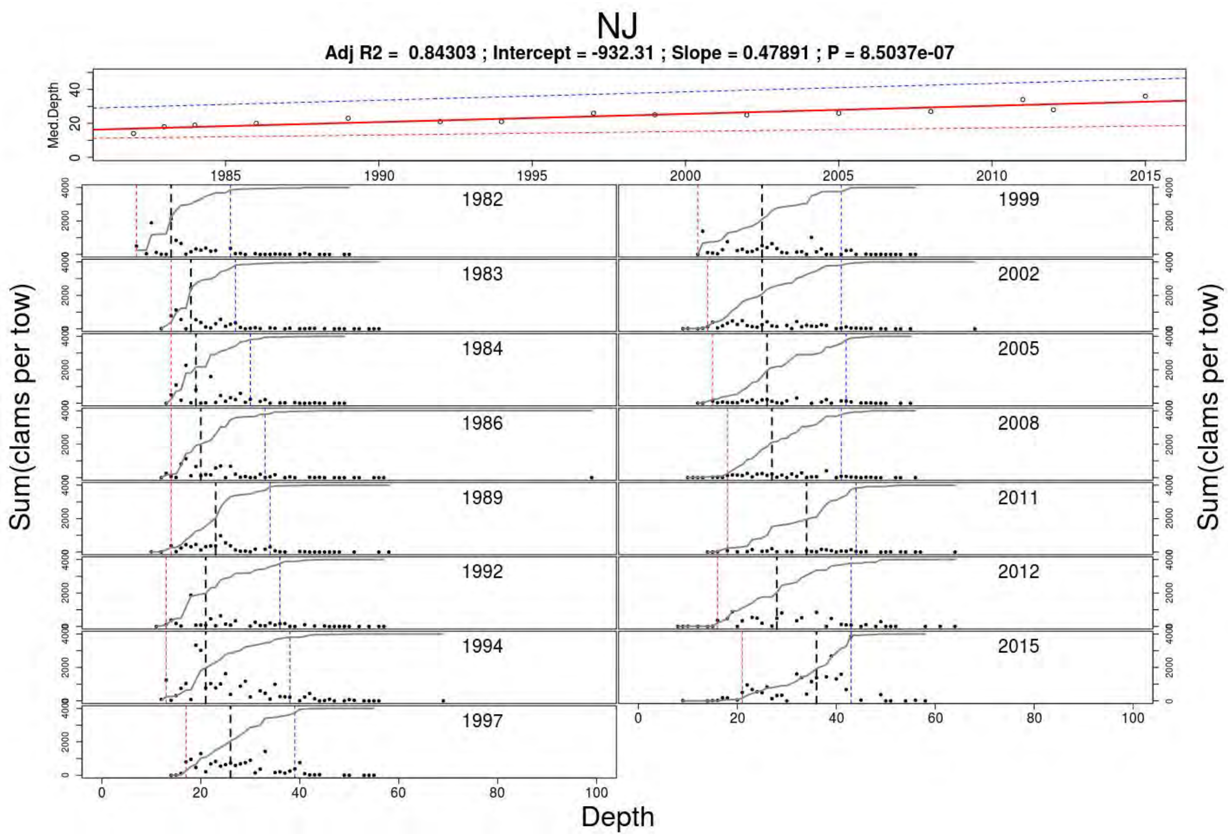


Figure 74: Total surfclams caught at depth by year in NJ. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

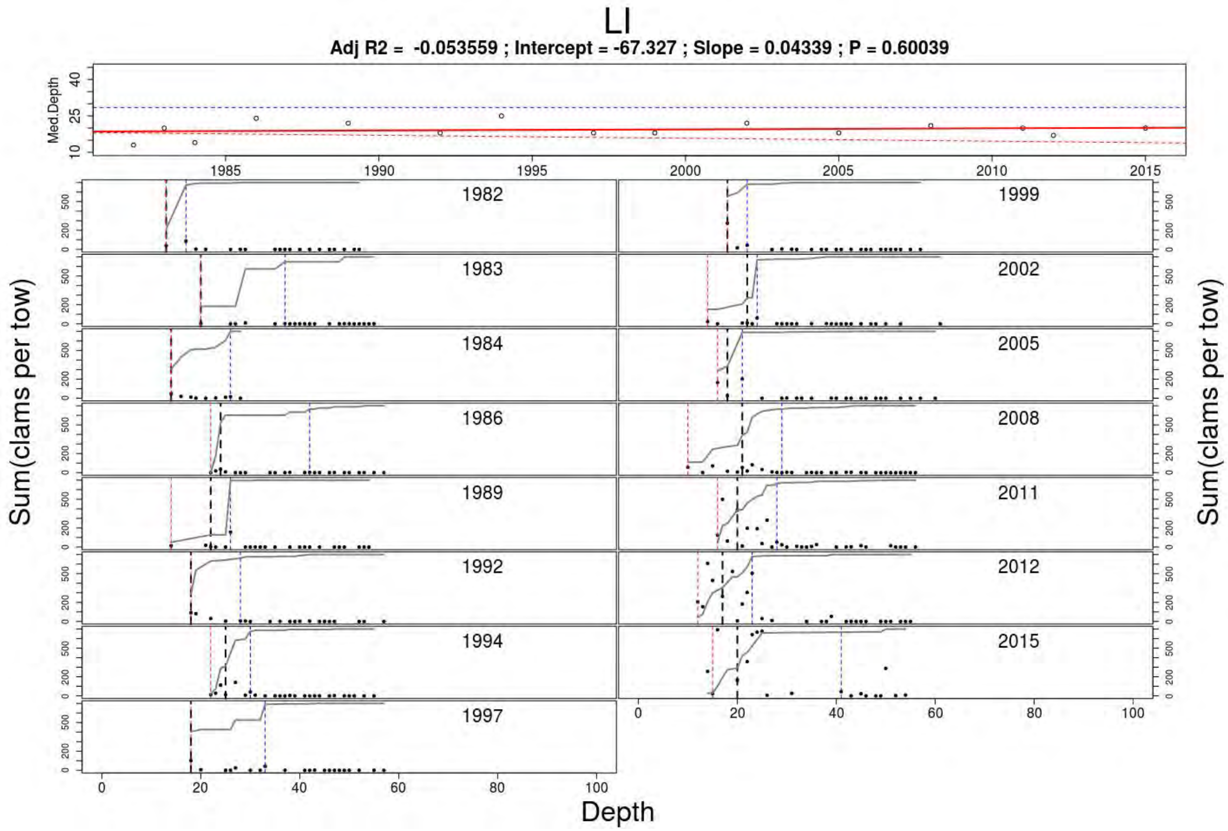


Figure 75: Total surfclams caught at depth by year in LI. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

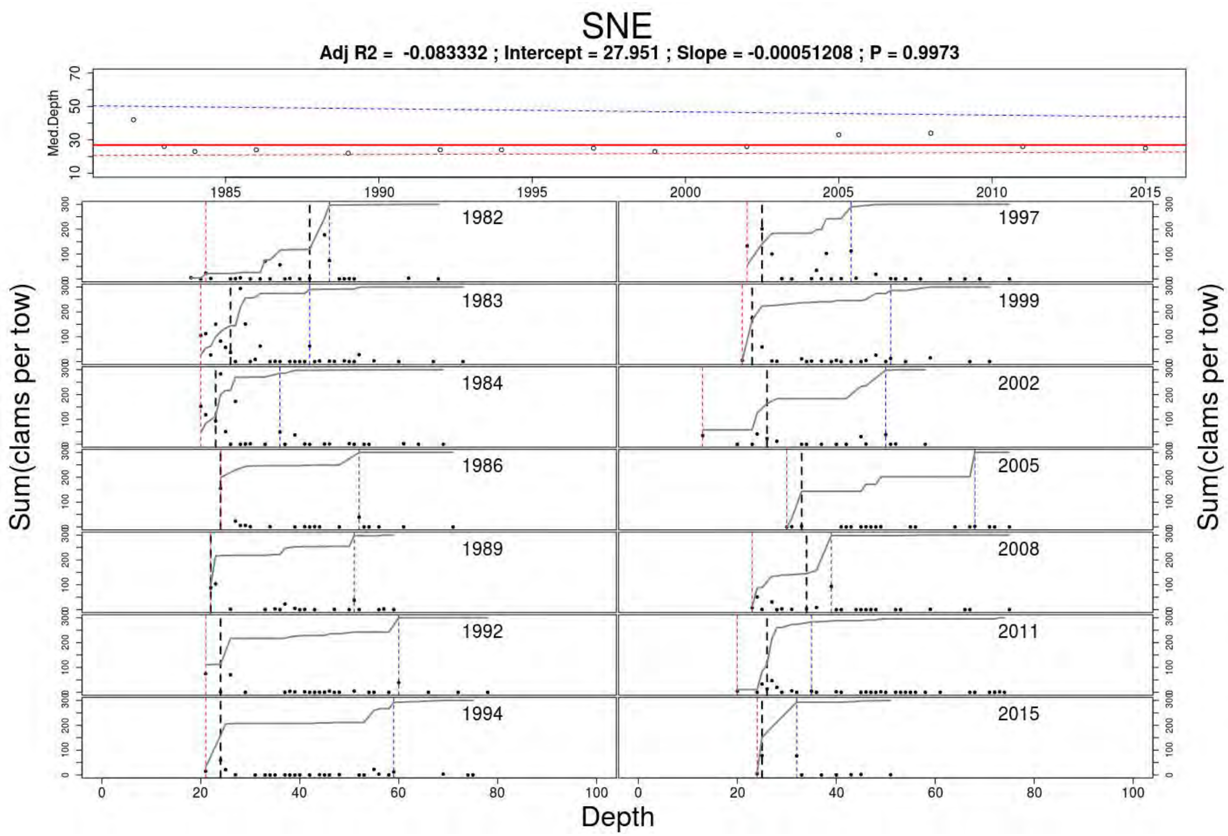


Figure 76: Total surfclams caught at depth by year in SNE. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

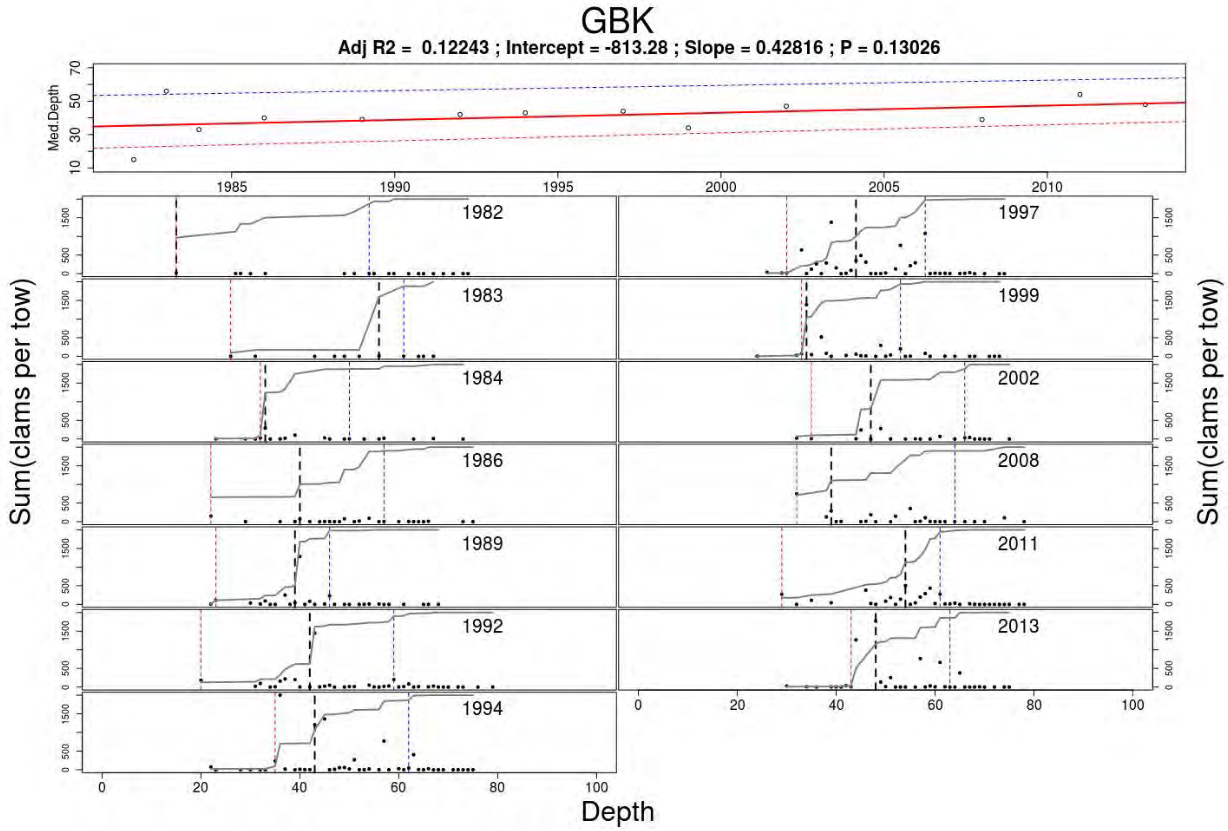


Figure 77: Total surfclams caught at depth by year in GBK. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

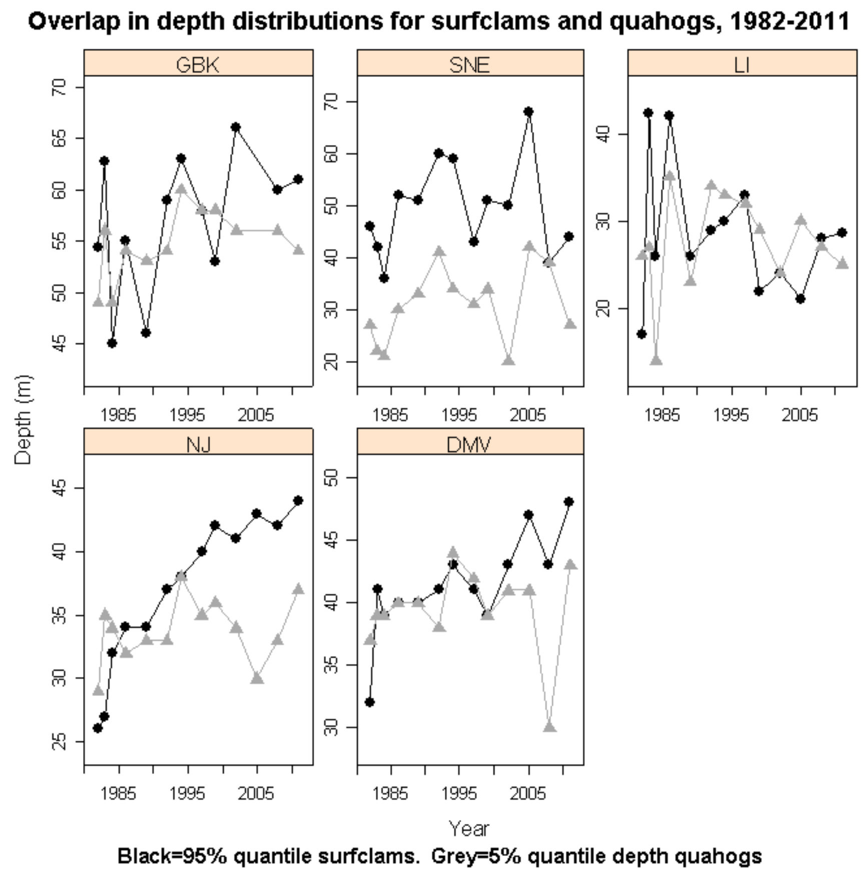


Figure 78: Trends in the offshore habitat boundary for Atlantic surfclam and the inshore habitat boundary for ocean quahog over time. The offshore boundary in each region is the 95% percentile for cumulative catch with depth in NEFSC clam surveys. The inshore habitat boundary for ocean quahogs is the 5% percentile for cumulative catch.

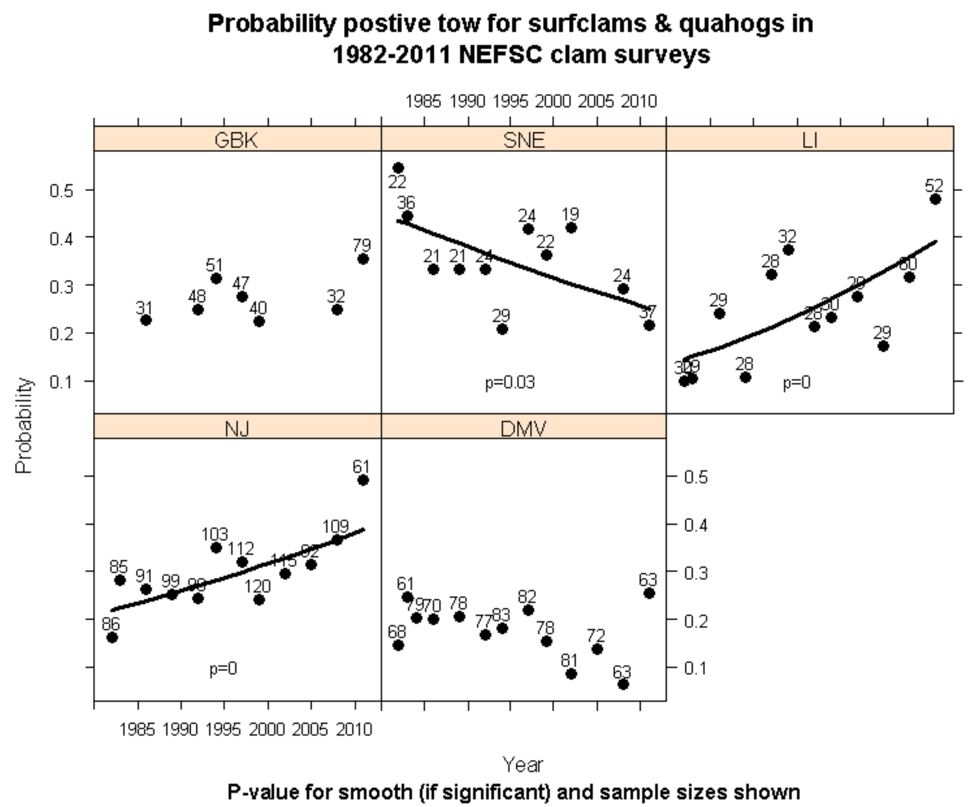


Figure 79: Probability that both Atlantic surfclam and ocean quahogs were taken in the same tow during 1982-2011 clam surveys in consistently sampled strata. Logistic regression lines and p-values are shown if the trend was statistically significant ($p < 0.1$).

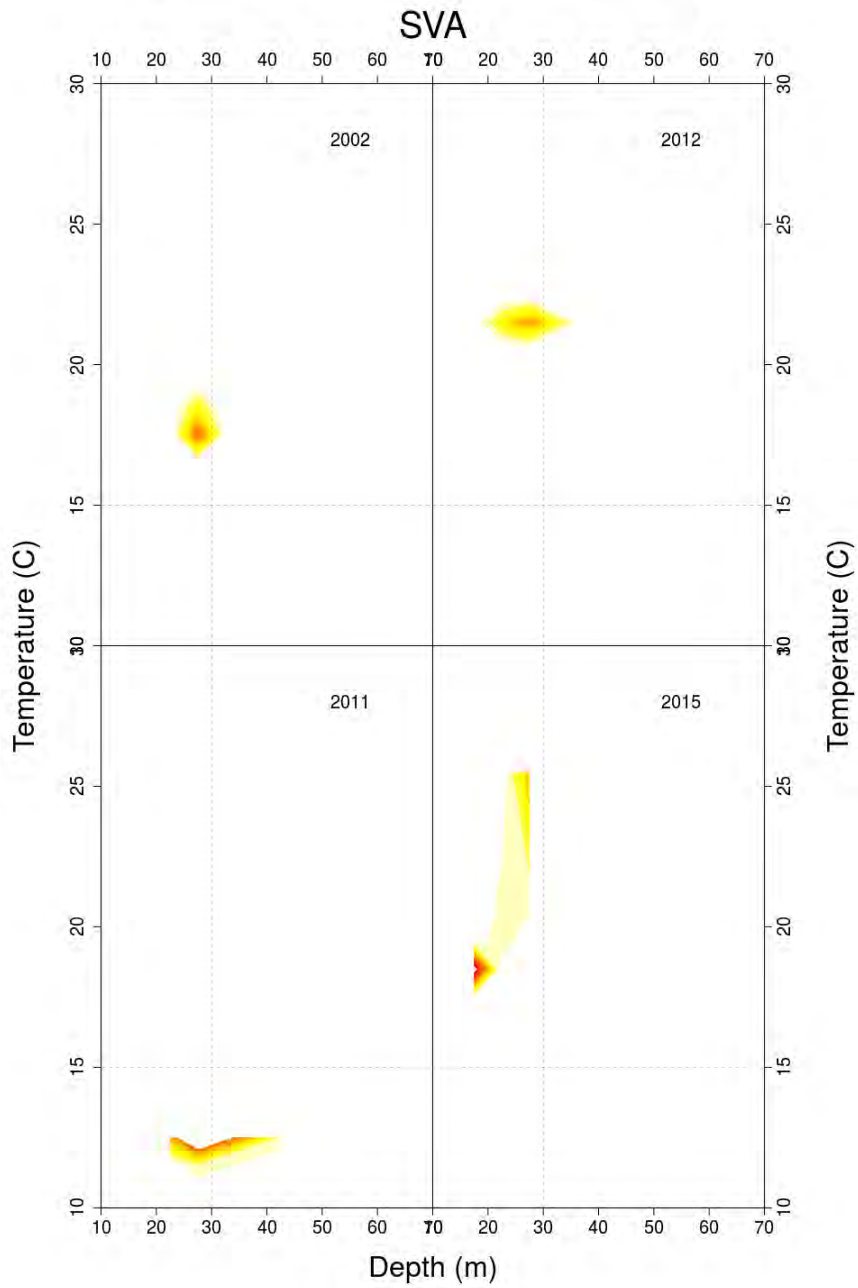


Figure 80: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in SVA. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

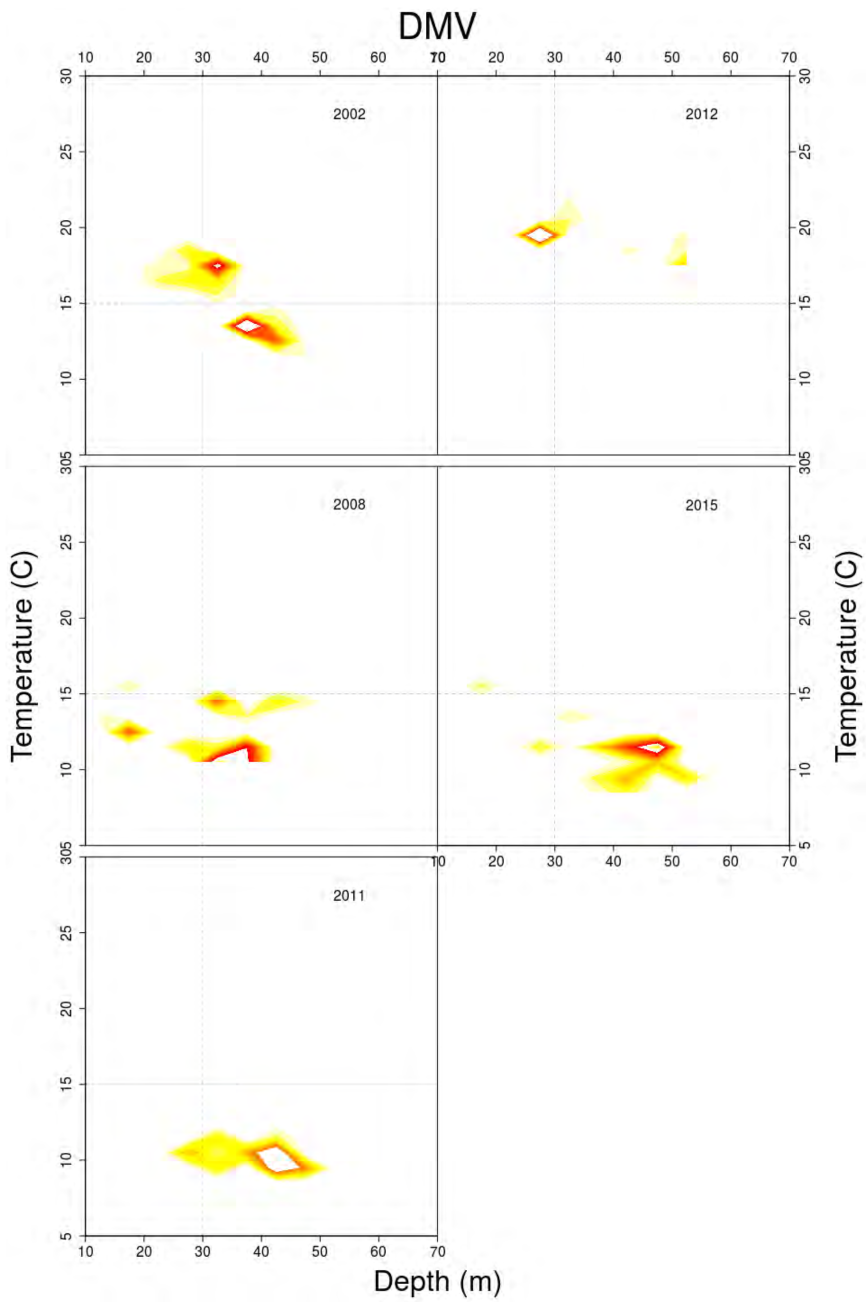


Figure 81: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in DMV. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at $15°$ C and 30 m depth are for reference only.

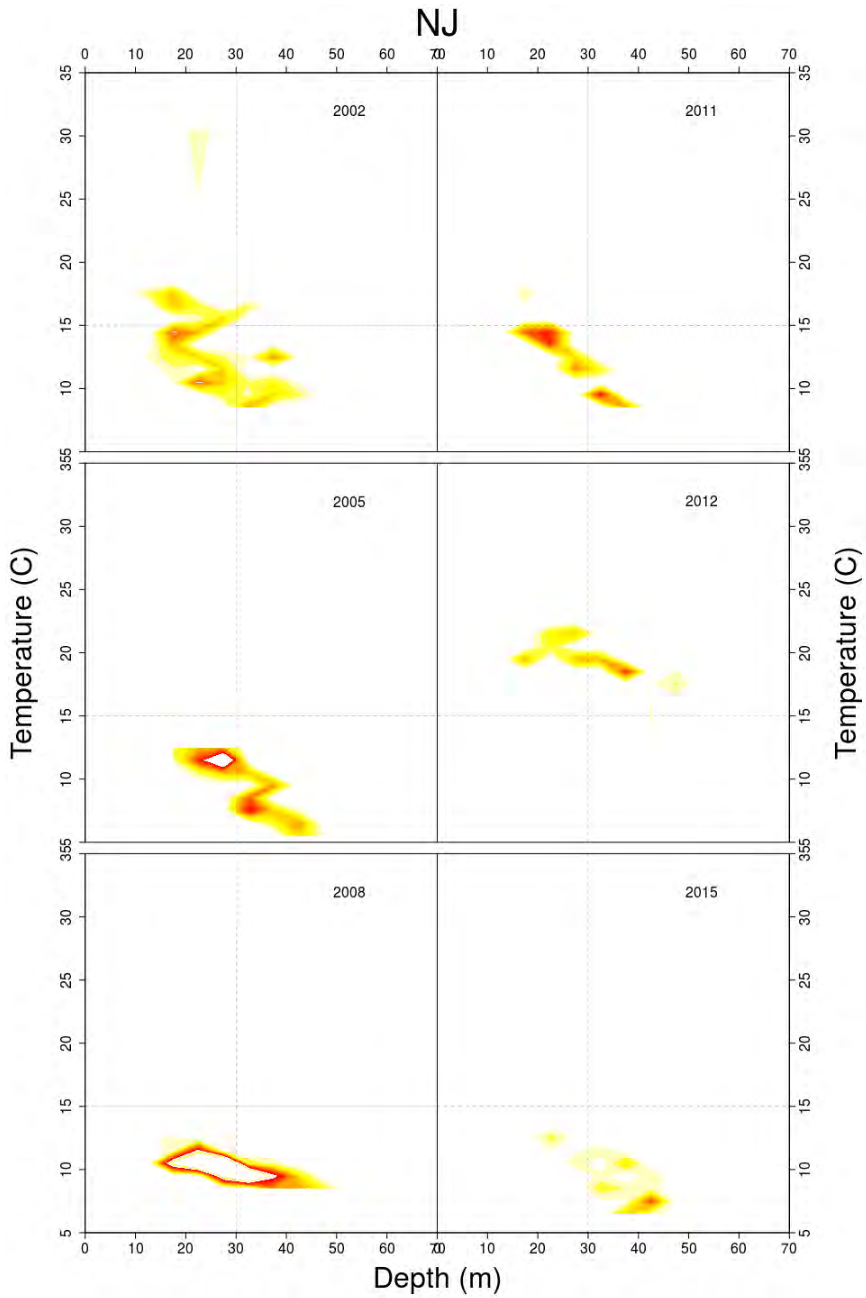


Figure 82: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in NJ. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

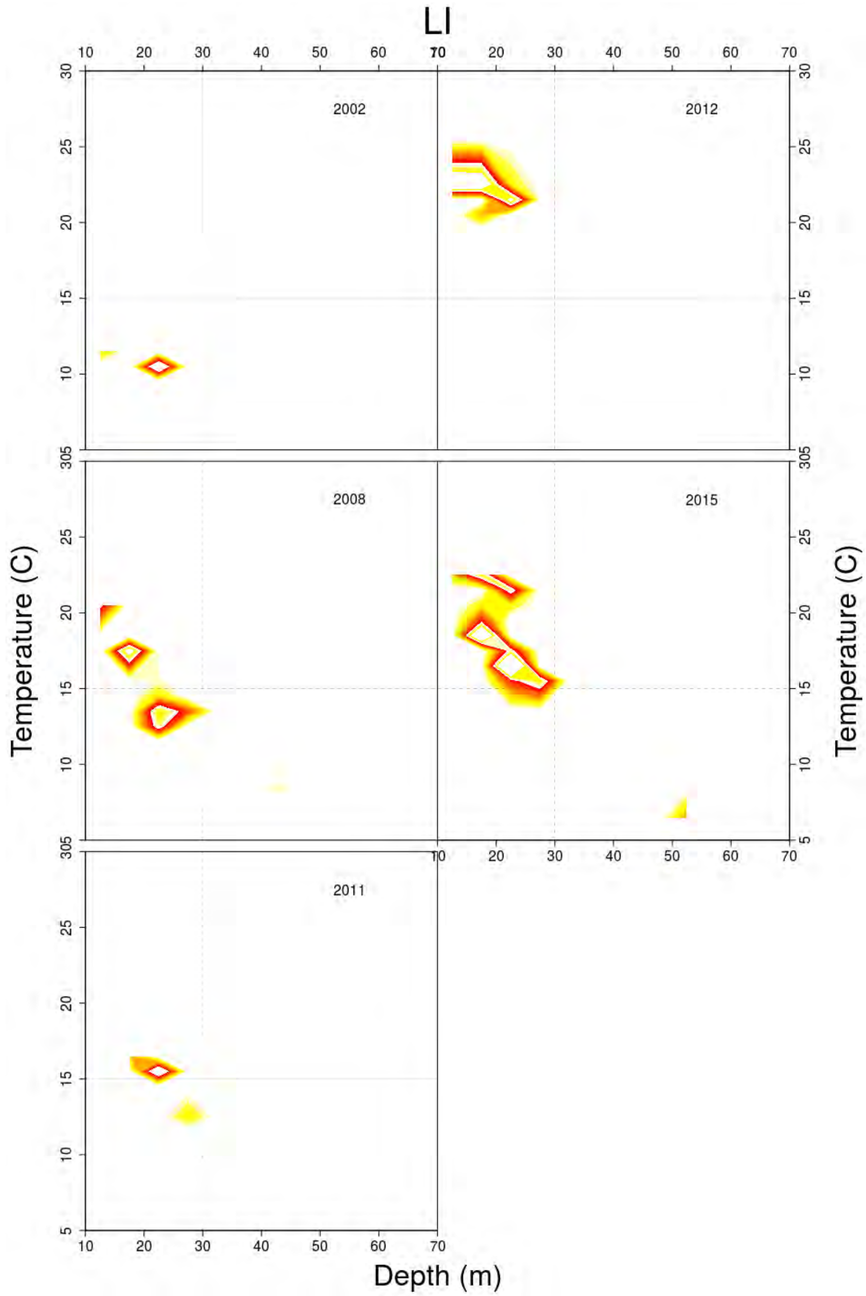


Figure 83: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in LI. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at $15°$ C and 30 m depth are for reference only.

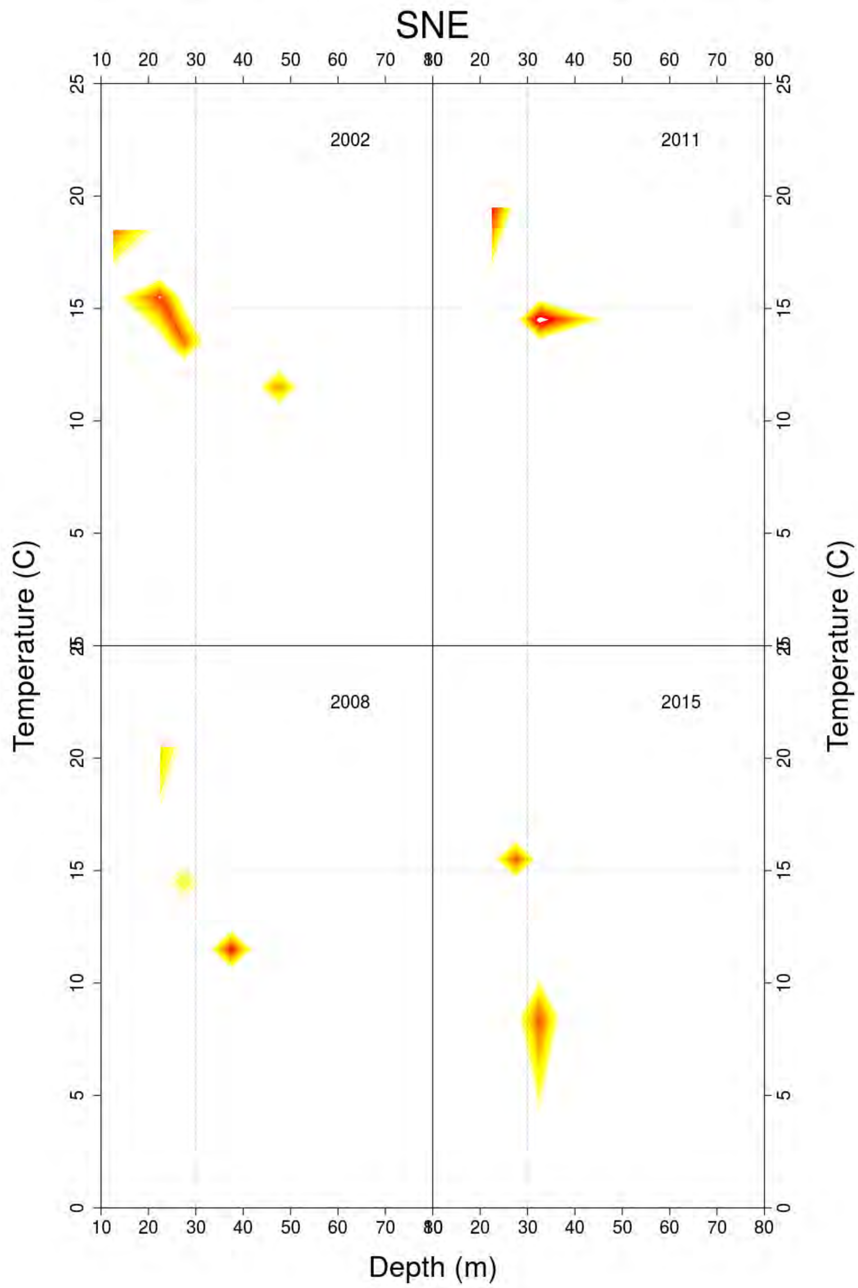


Figure 84: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in SNE. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

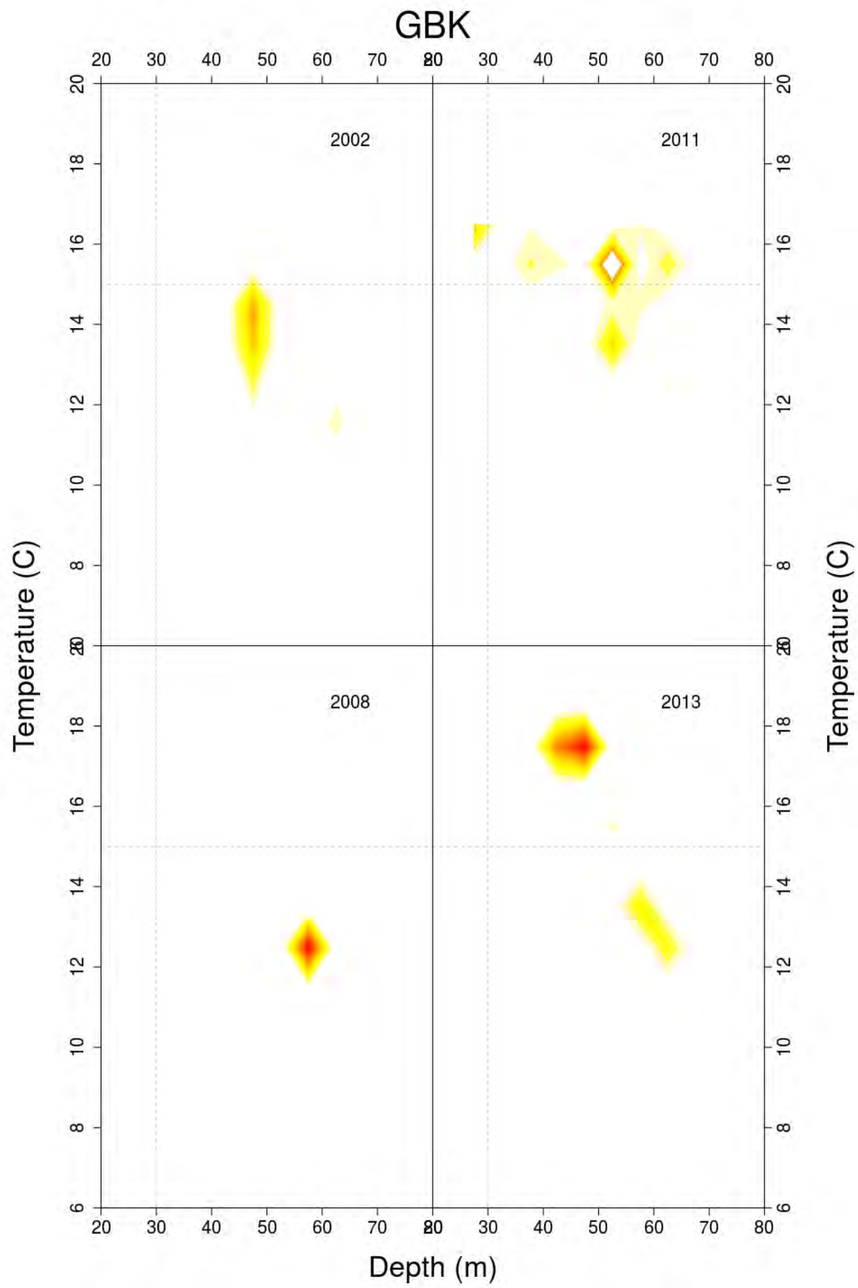


Figure 85: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in GBK. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at 15° C and 30 m depth are for reference only.

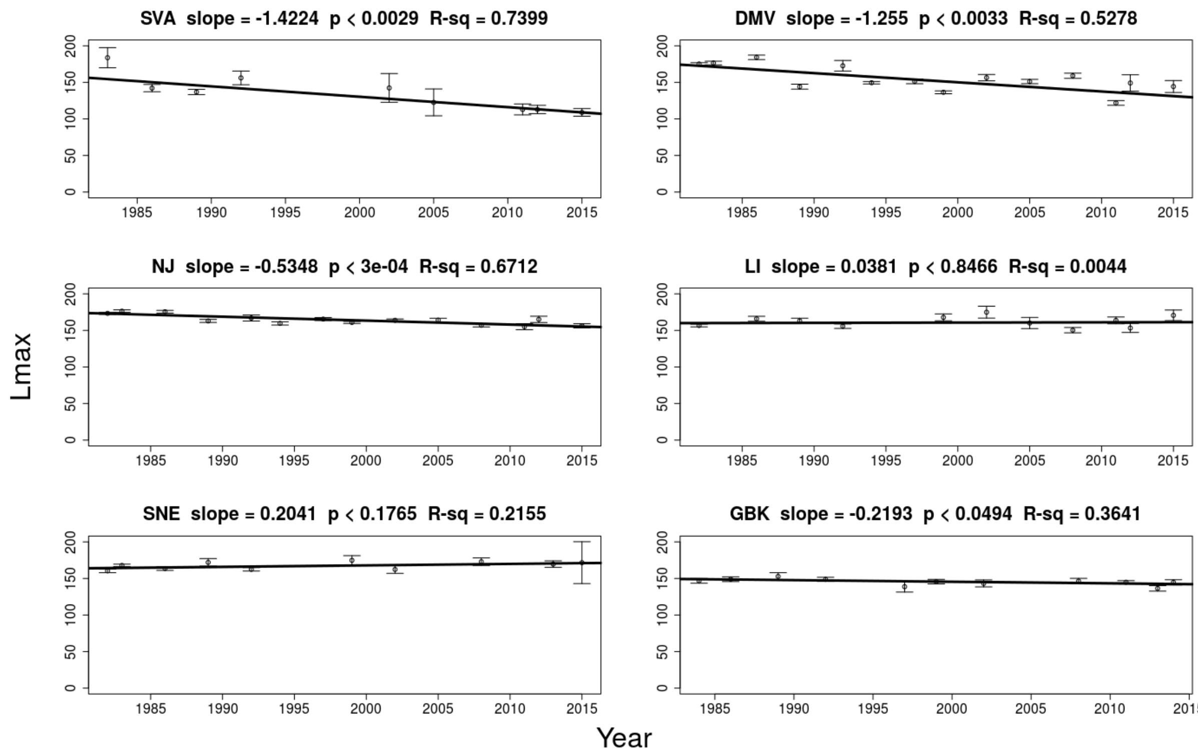


Figure 86: Estimated values of the parameter L_∞ for Atlantic surfclam in NEFSC clam surveys, over time in each region. The L_∞ values for each region were fit with an inverse variance weighted regression, and the slope, p-value and R^2 that result are shown above each plot.

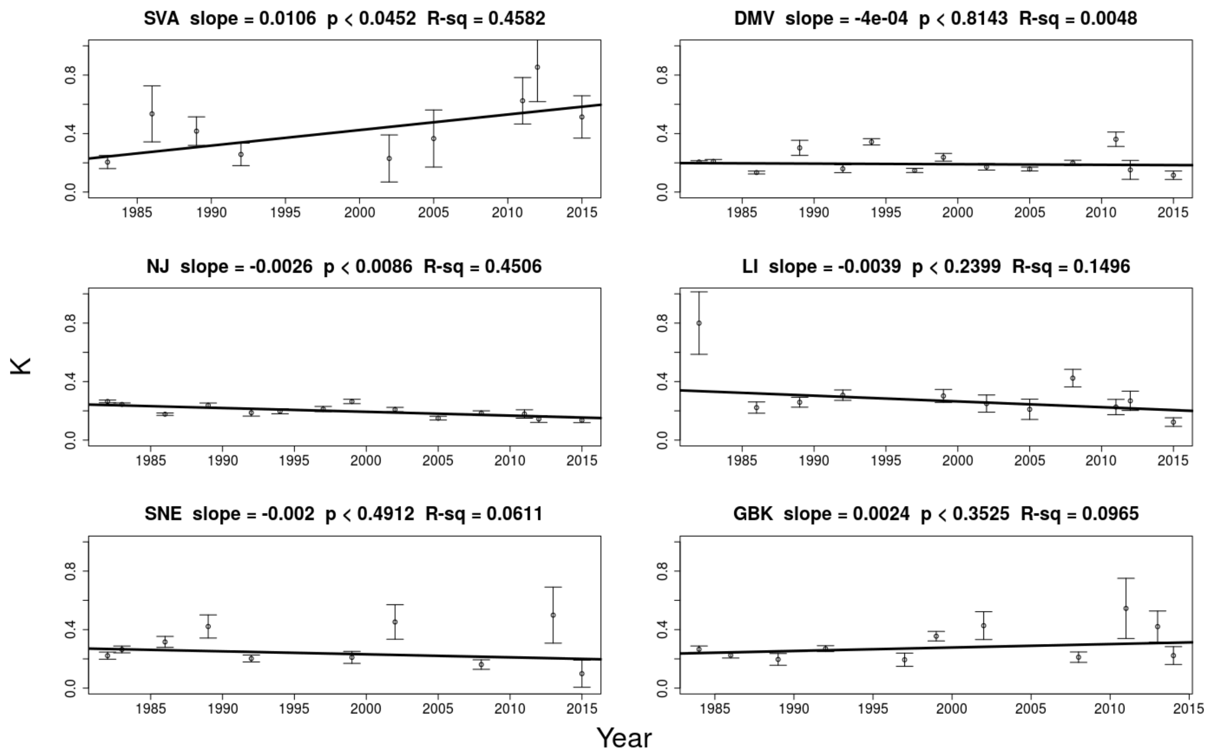


Figure 87: Estimated values of the parameter K for Atlantic surfclam in NEFSC clam surveys, over time in each region. The K values for each region were fit with an inverse variance weighted regression, and the slope, p-value and R^2 that result are shown above each plot.

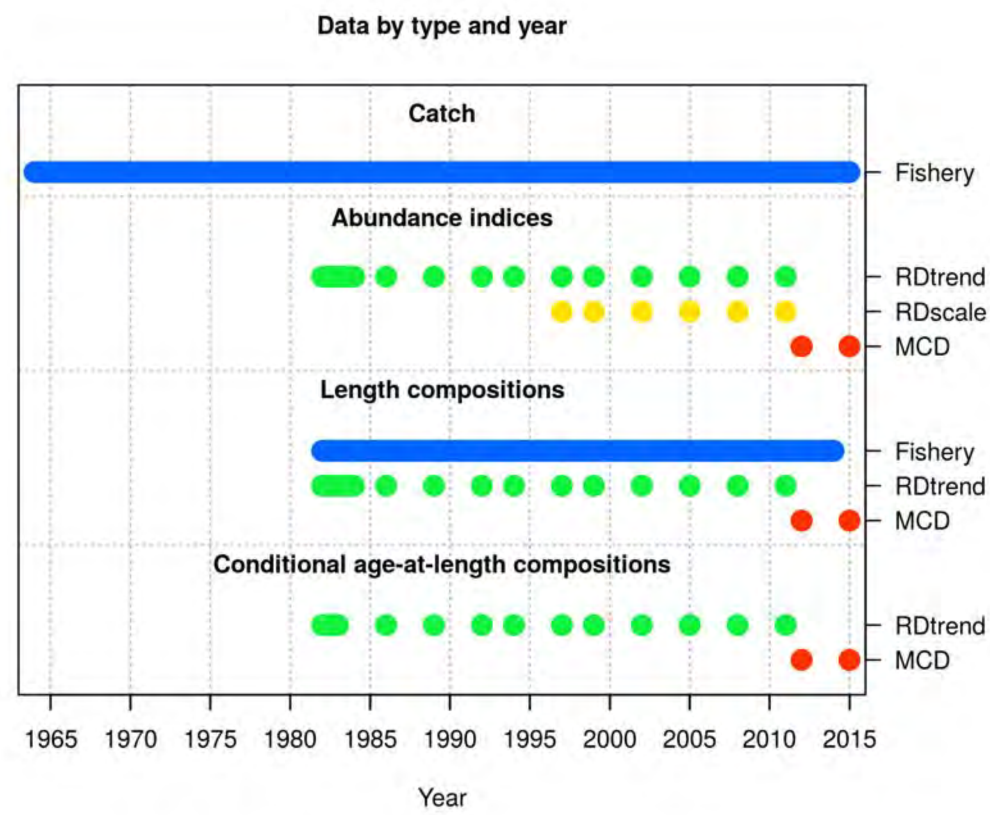


Figure 88: Data included in the Atlantic surfclam assessment model for the southern area. RD scale was not included in the likelihood.

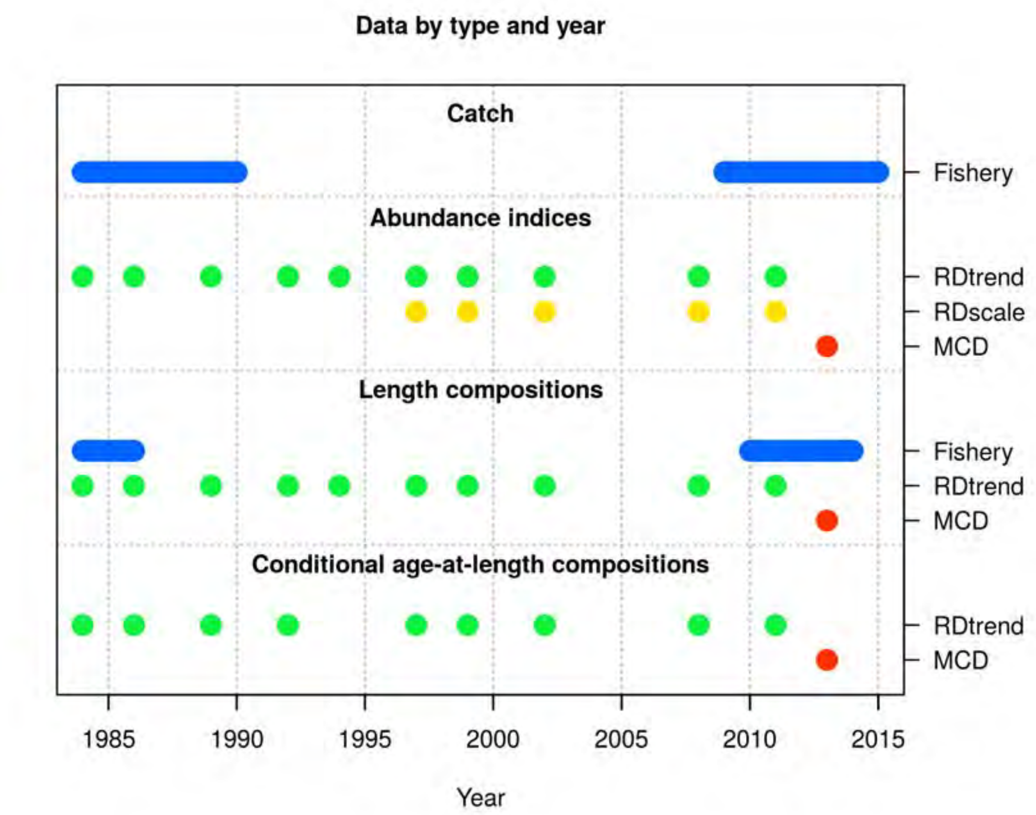


Figure 89: Data included in the Atlantic surfclam assessment model for the northern area. RD scale was not included in the likelihood.

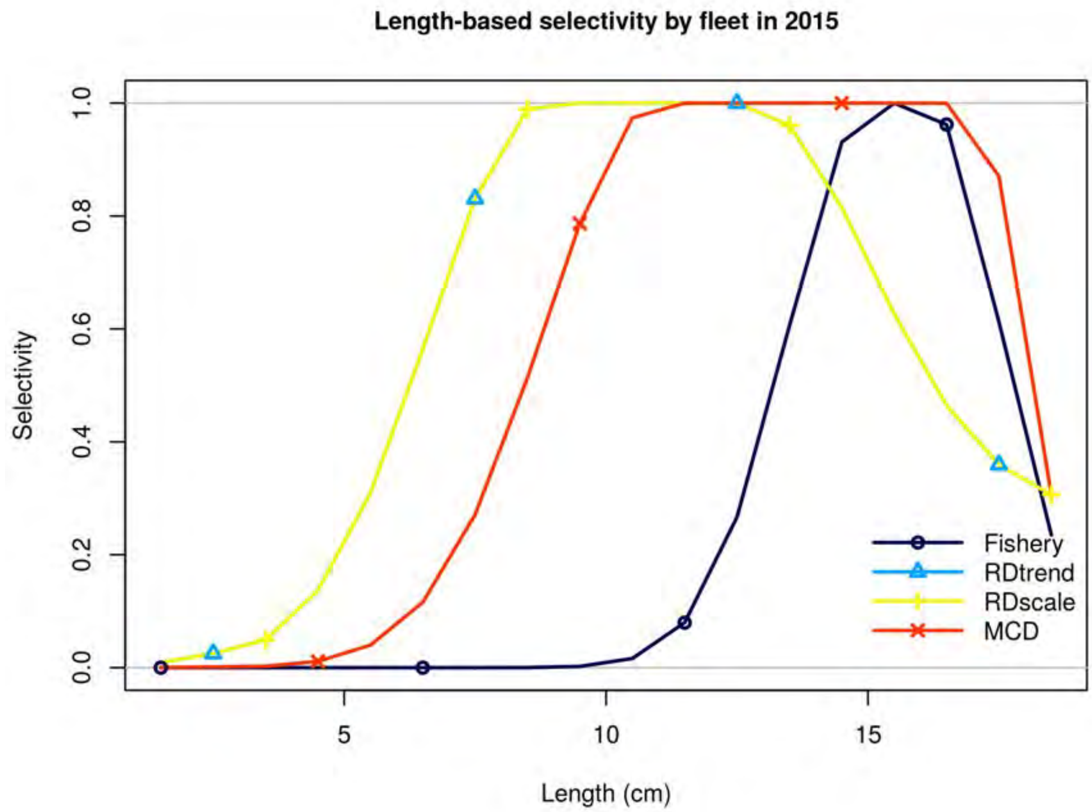


Figure 90: Comparison of selectivity curves for each fleet included in the assessment model for Atlantic surfclam in the southern area. RD trend and RD scale have identical selectivities because they are from the same survey (RD scale was not included in the likelihood).

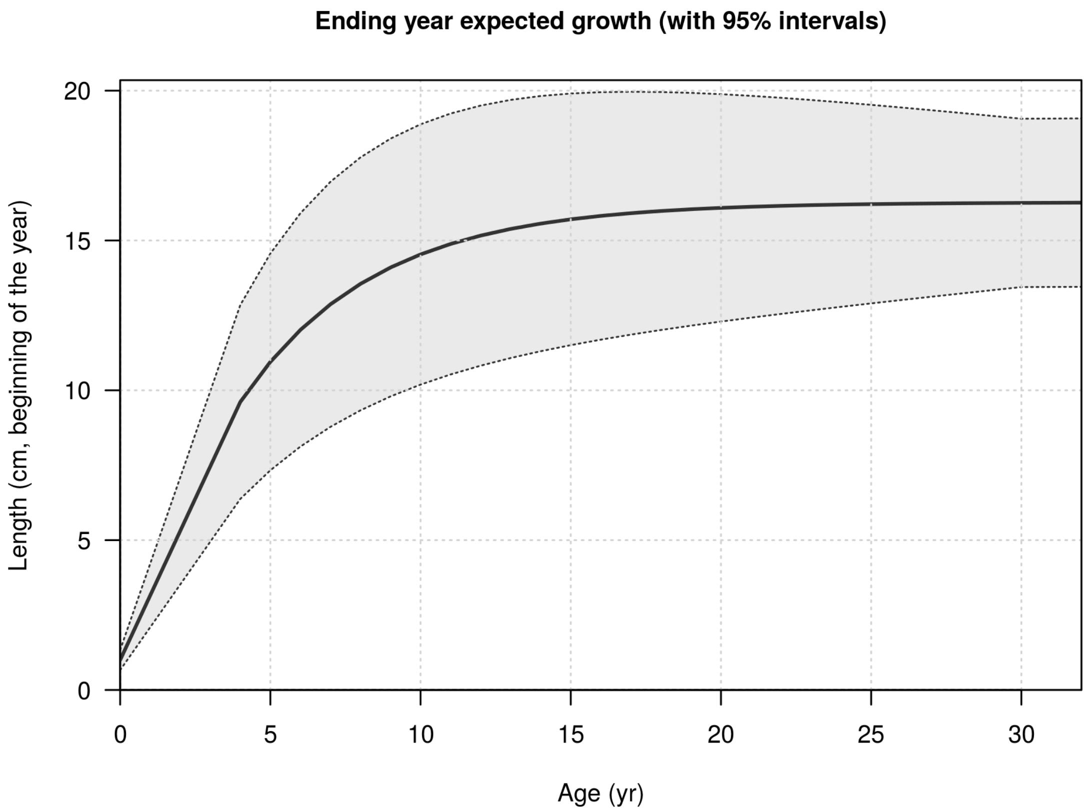


Figure 91: Length at age relationship from the assessment model for Atlantic surfclam in the southern area.

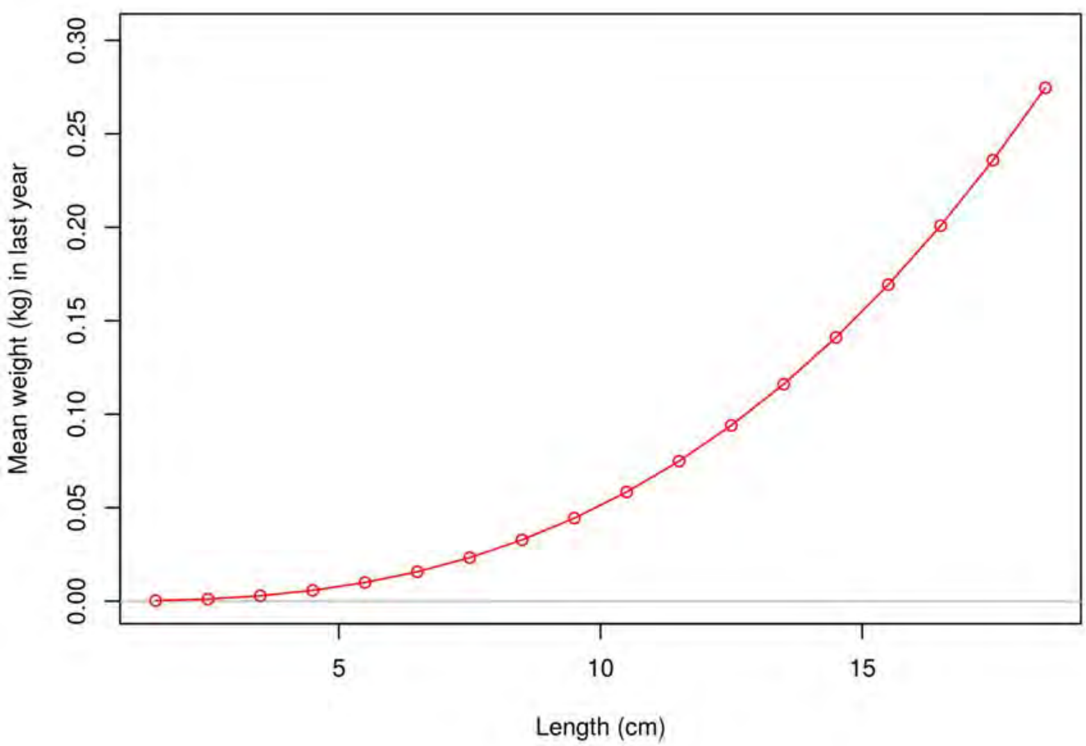


Figure 92: Weight at length relationship used in the assessment model for Atlantic surfclam in the southern area.

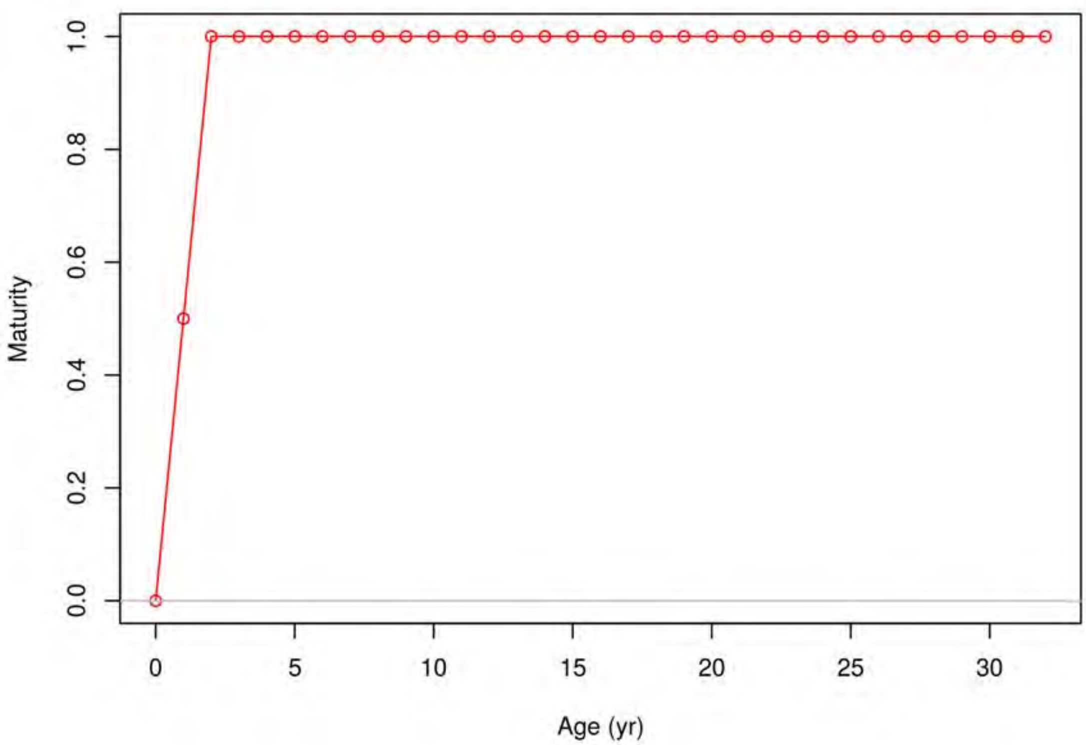


Figure 93: Maturity at age relationship used in the assessment model for Atlantic surfclam in the southern area.

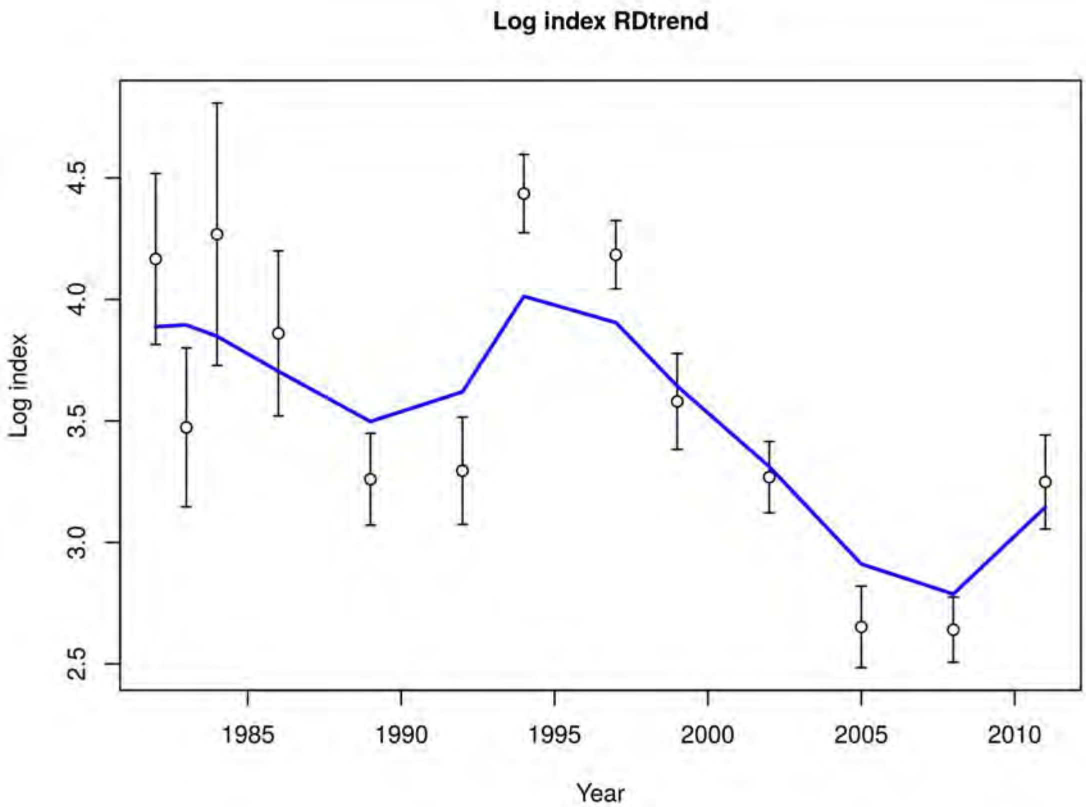


Figure 94: Fit to log index data on log scale for RDtrend survey for Atlantic surfclam in the southern area. Vertical lines are 95% confidence intervals.

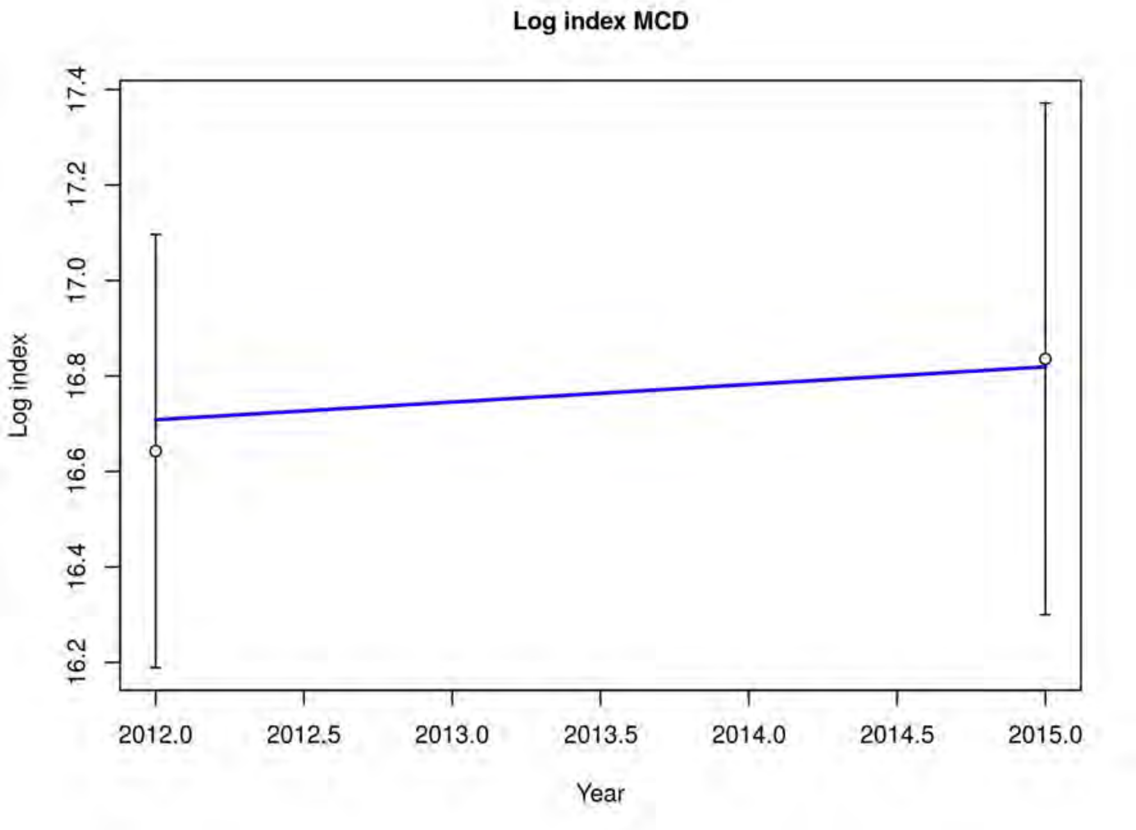


Figure 95: Fit to log index data on log scale for MCD survey for Atlantic surfclam in the southern area. Vertical lines are 95% confidence intervals.

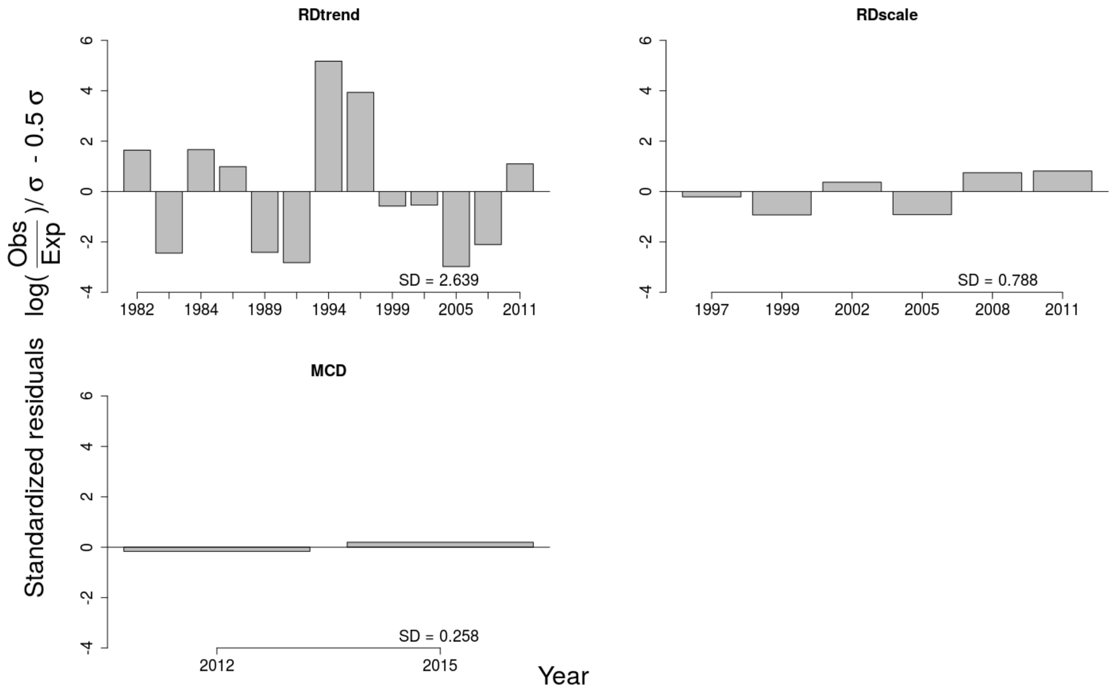


Figure 96: Residuals from the model fits to each survey index used in the assessment model for Atlantic surfclam in the southern area by year. The standard deviation of the residuals over the time series is indicated above the horizontal axis.

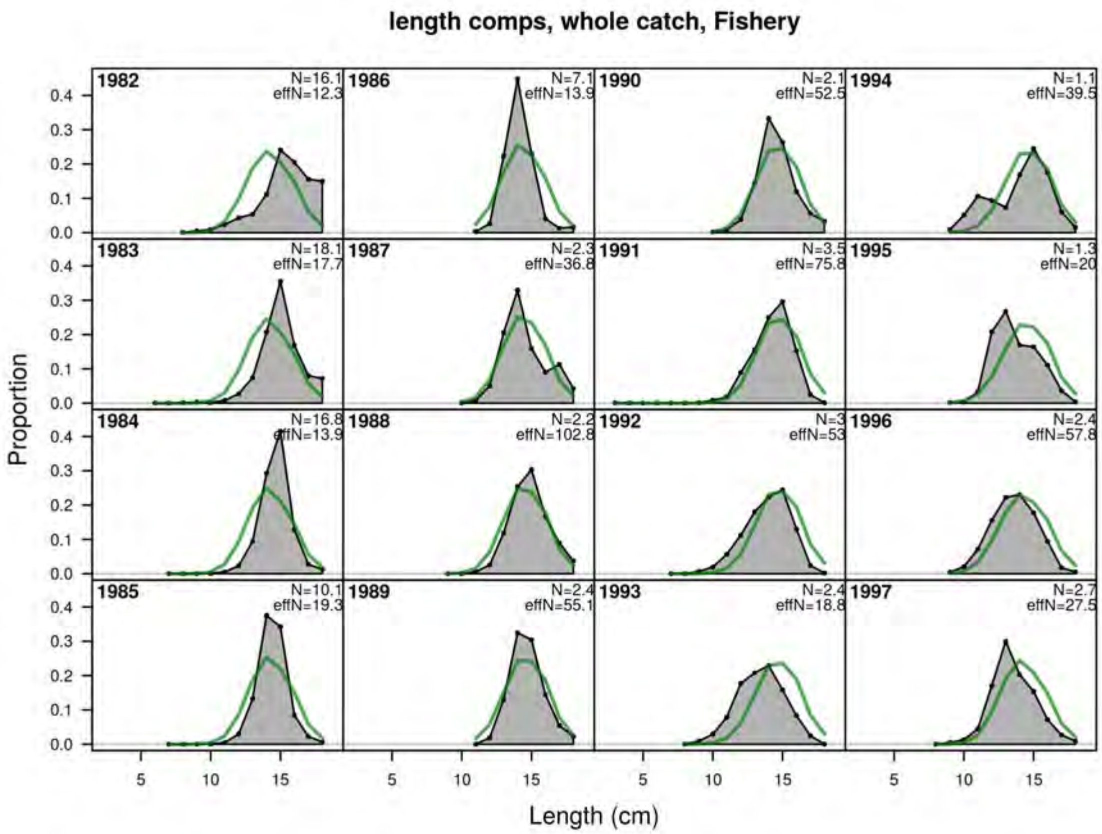


Figure 97: Model fit to length composition data from the commercial fishery used in the assessment model for Atlantic surfclam in the southern area.

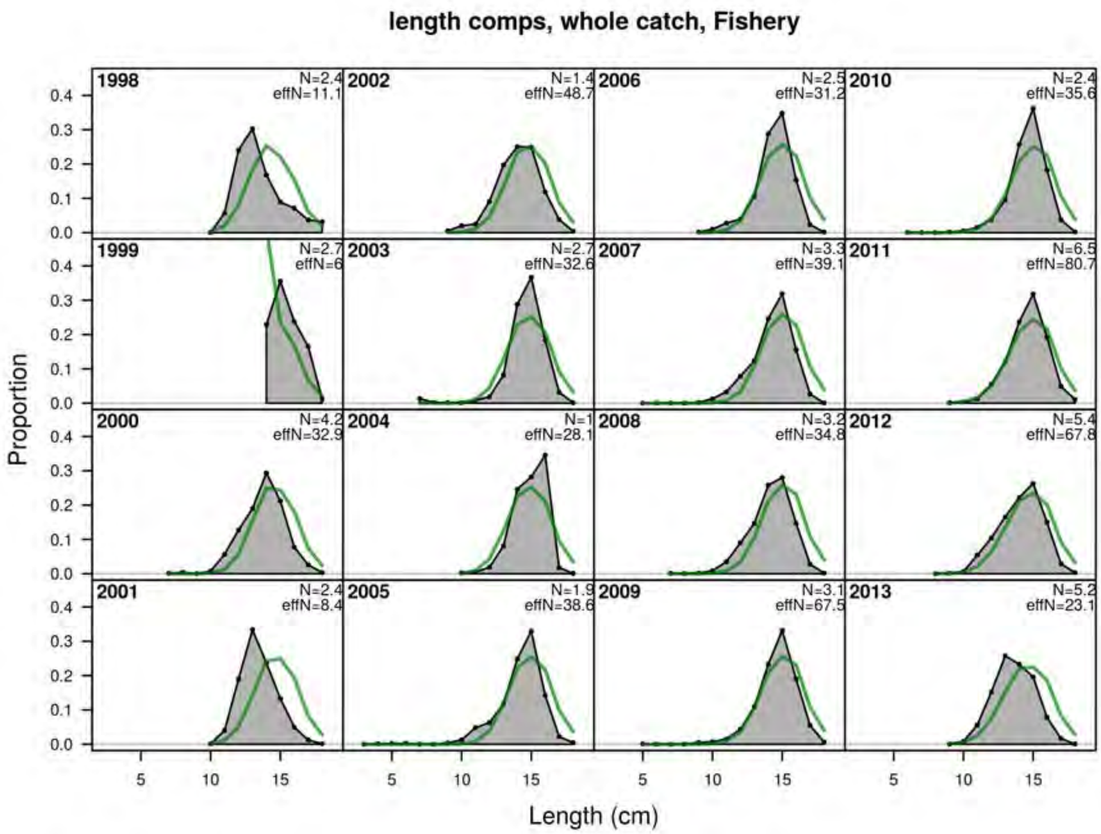


Figure 97 cont.

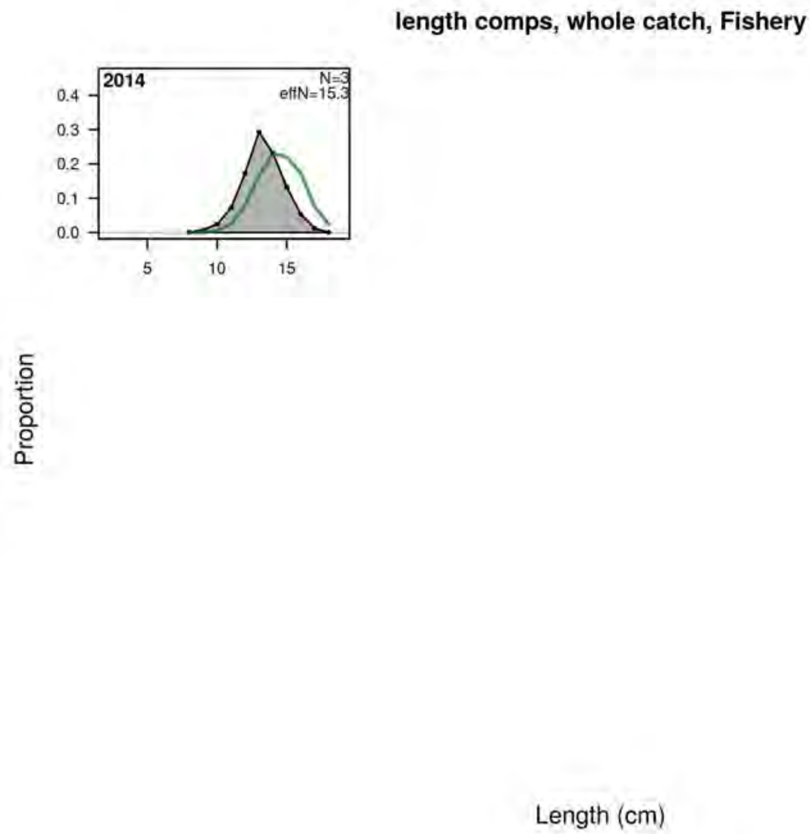


Figure 97 cont.

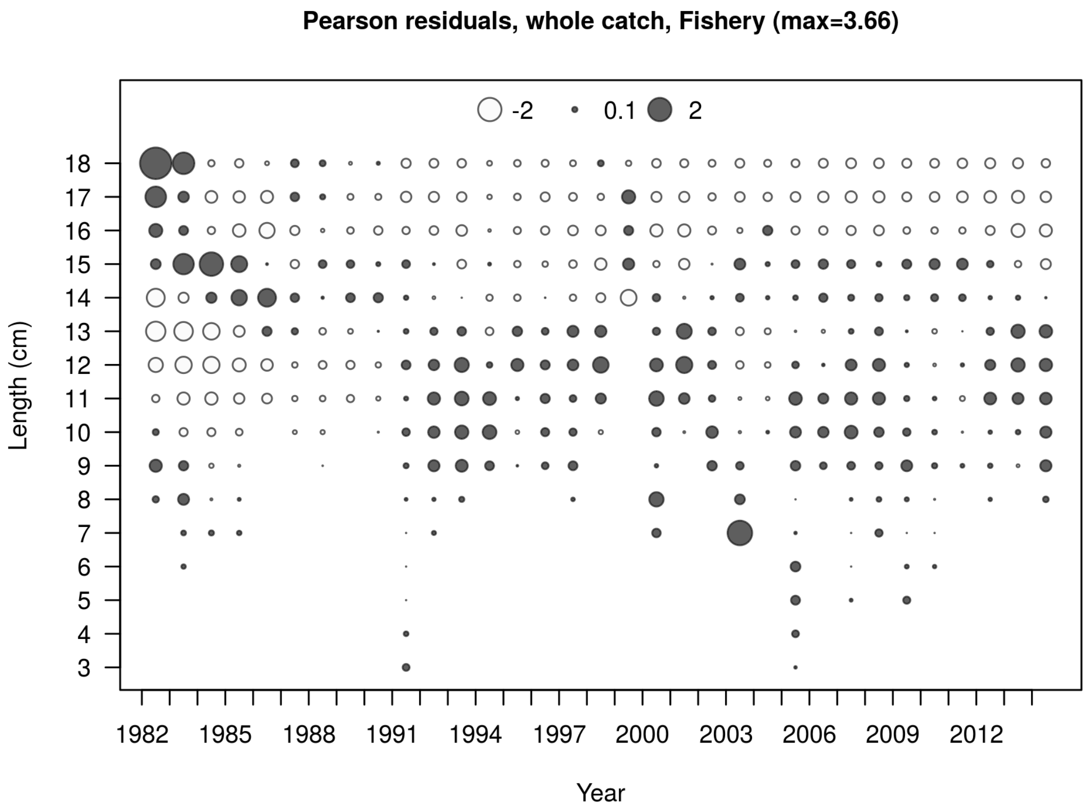


Figure 98: Pearson residuals from the fit to commercial length composition data used in the assessment model for Atlantic surfclam in the southern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

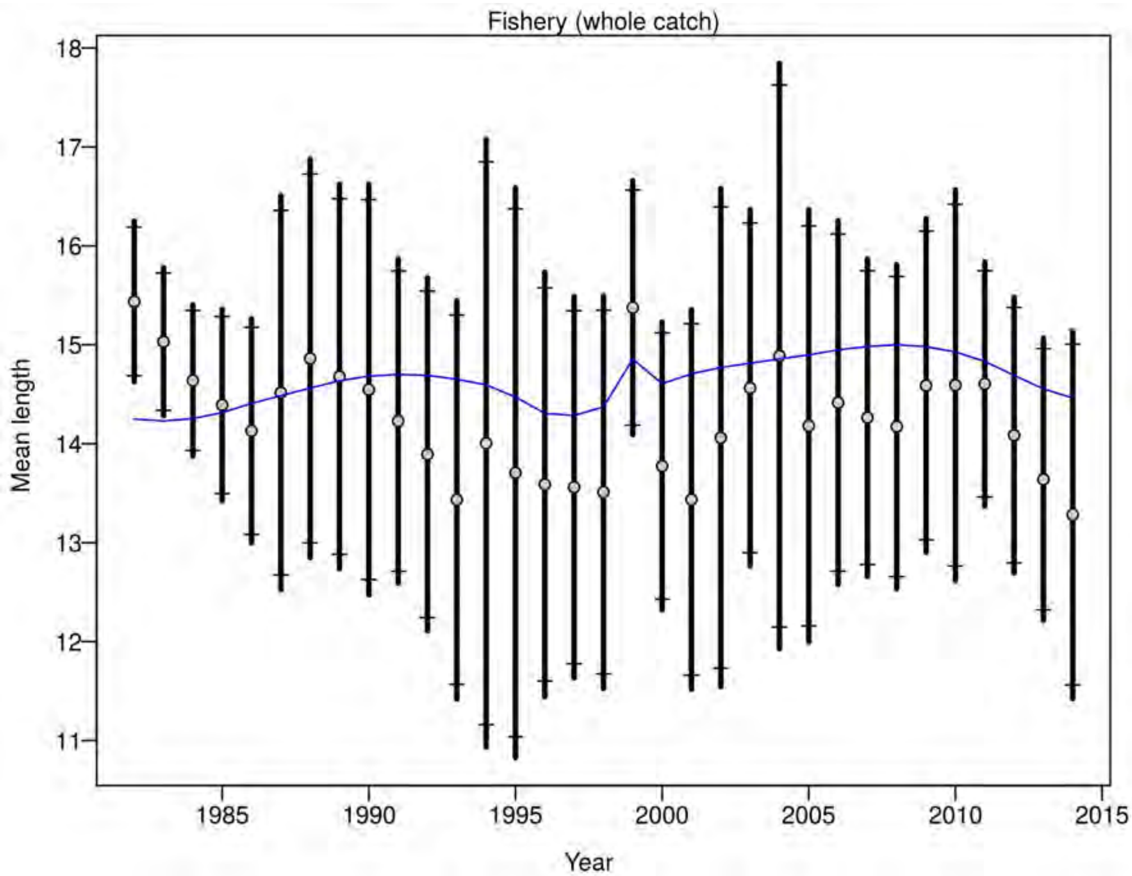


Figure 99: Observed mean length vs. the mean length predicted by the model based on fits to commercial length composition data used in the assessment model for Atlantic surfclam in the southern area.

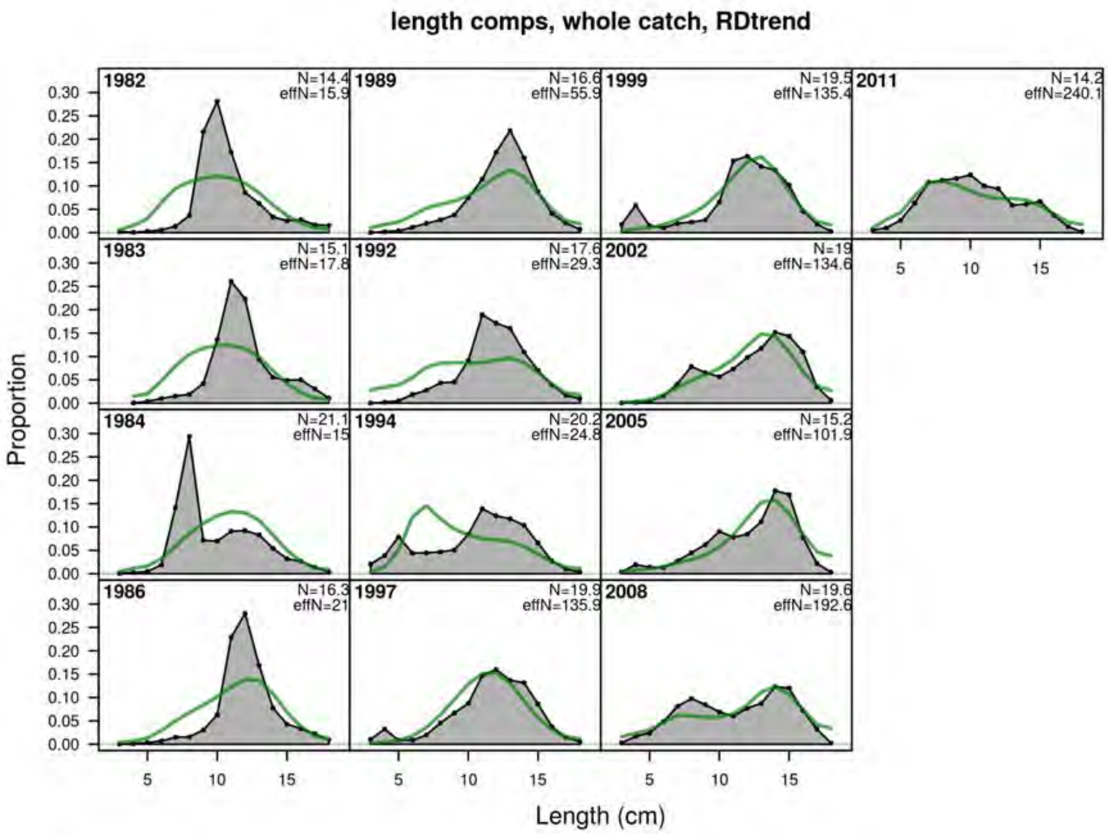


Figure 100: Model fit to length composition data from the NEFSC survey (RD) used in the assessment model for Atlantic surfclam in the southern area.

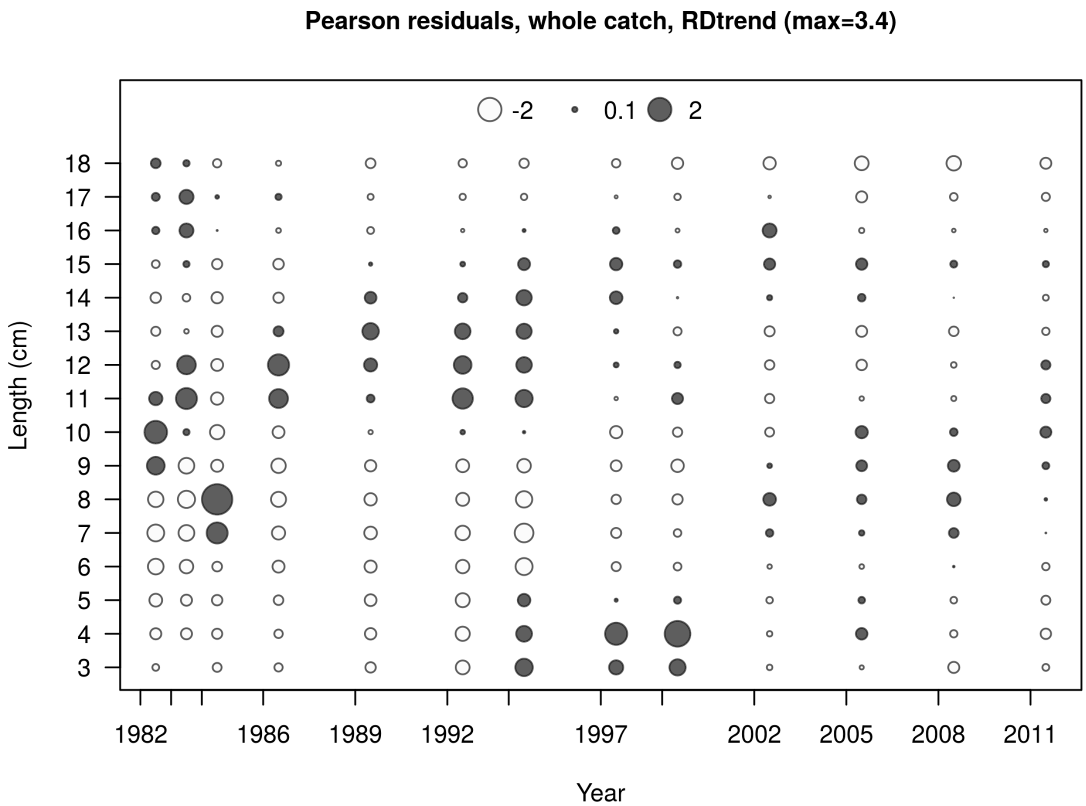


Figure 101: Pearson residuals from the fit to NEFSC survey (RD) length composition data used in the assessment model for Atlantic surfclam in the southern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

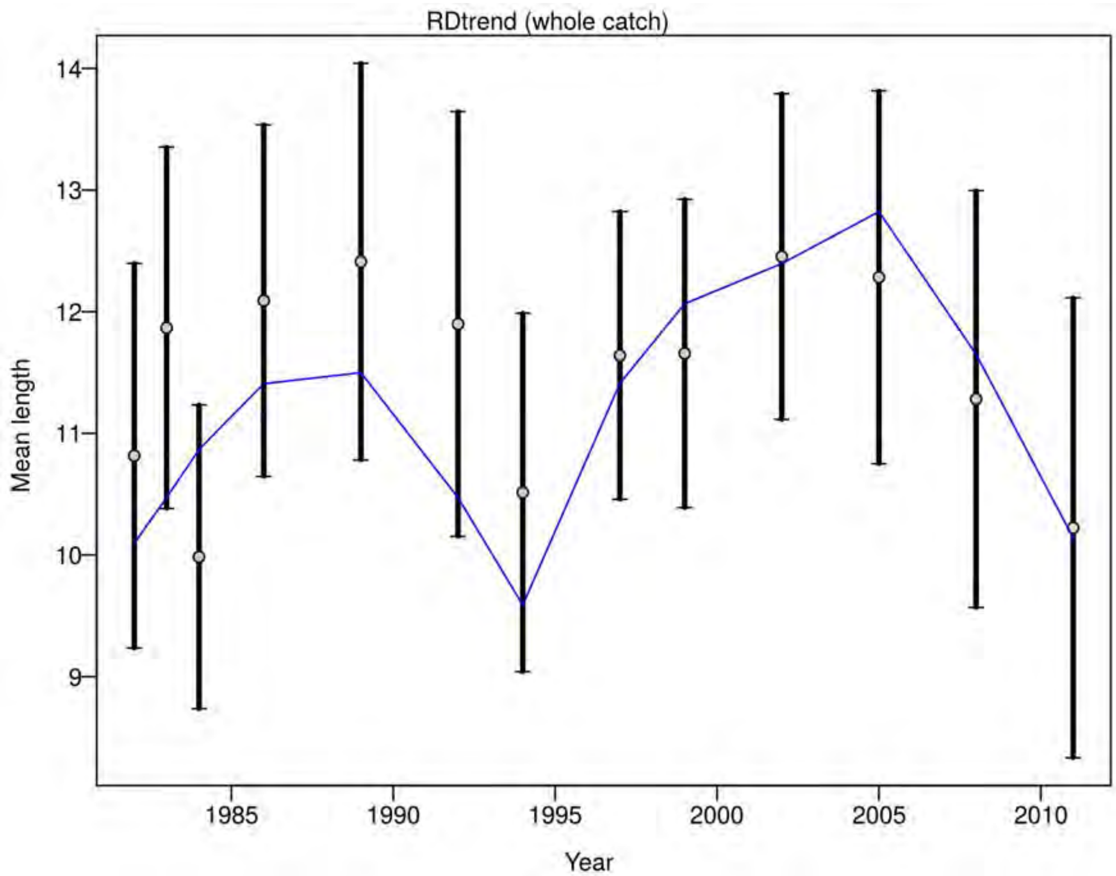


Figure 102: Observed mean length vs. the mean length predicted by the model based on fits to NEFSC survey (RD) length composition data used in the assessment model for Atlantic surfclam in the southern area.

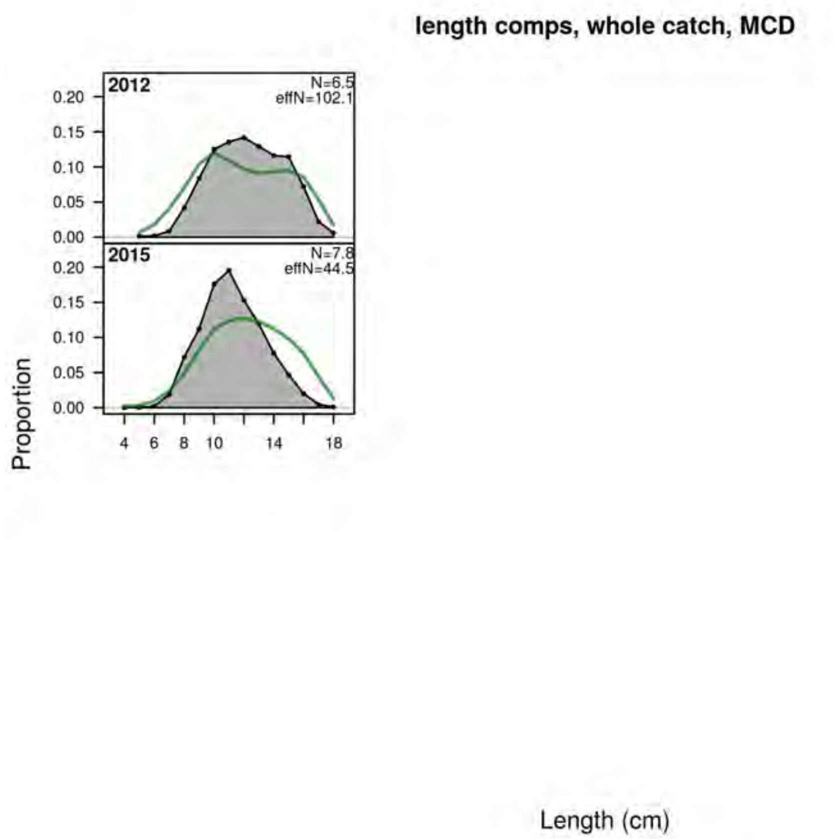


Figure 103: Model fit to length composition data from the NEFSC survey (MCD) used in the assessment model for Atlantic surfclam in the southern area.

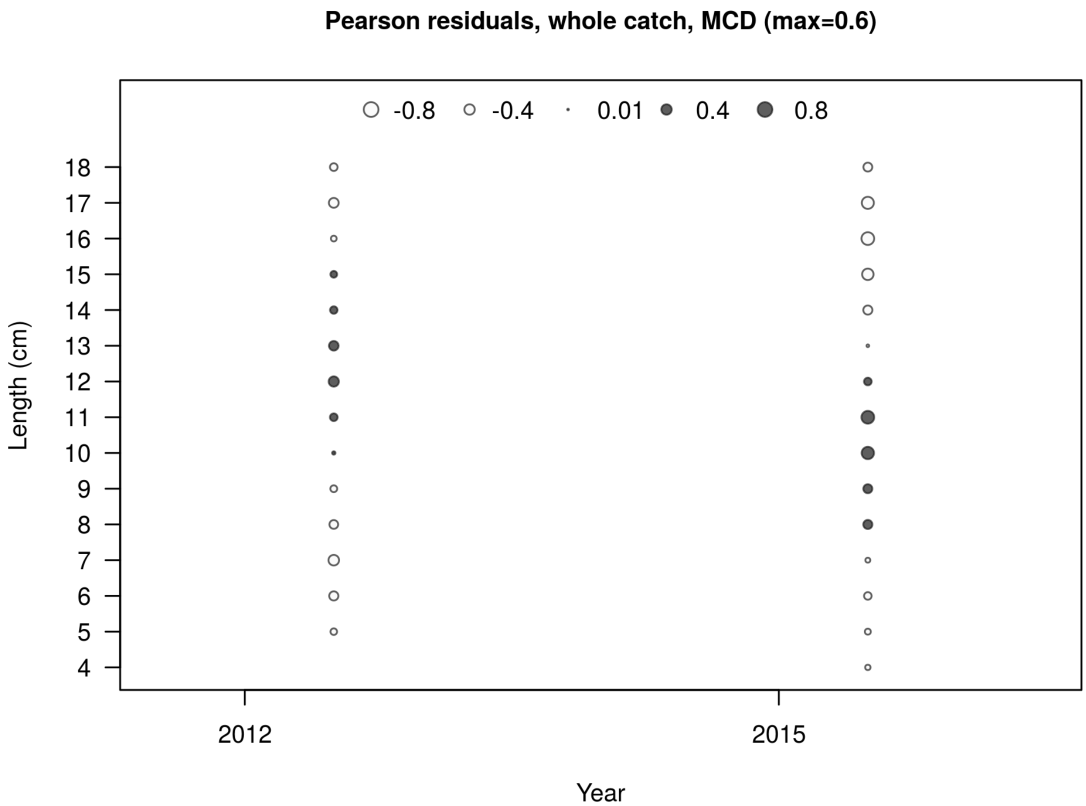


Figure 104: Pearson residuals from the fit to NEFSC survey (MCD) length composition data used in the assessment model for Atlantic surfclam in the southern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

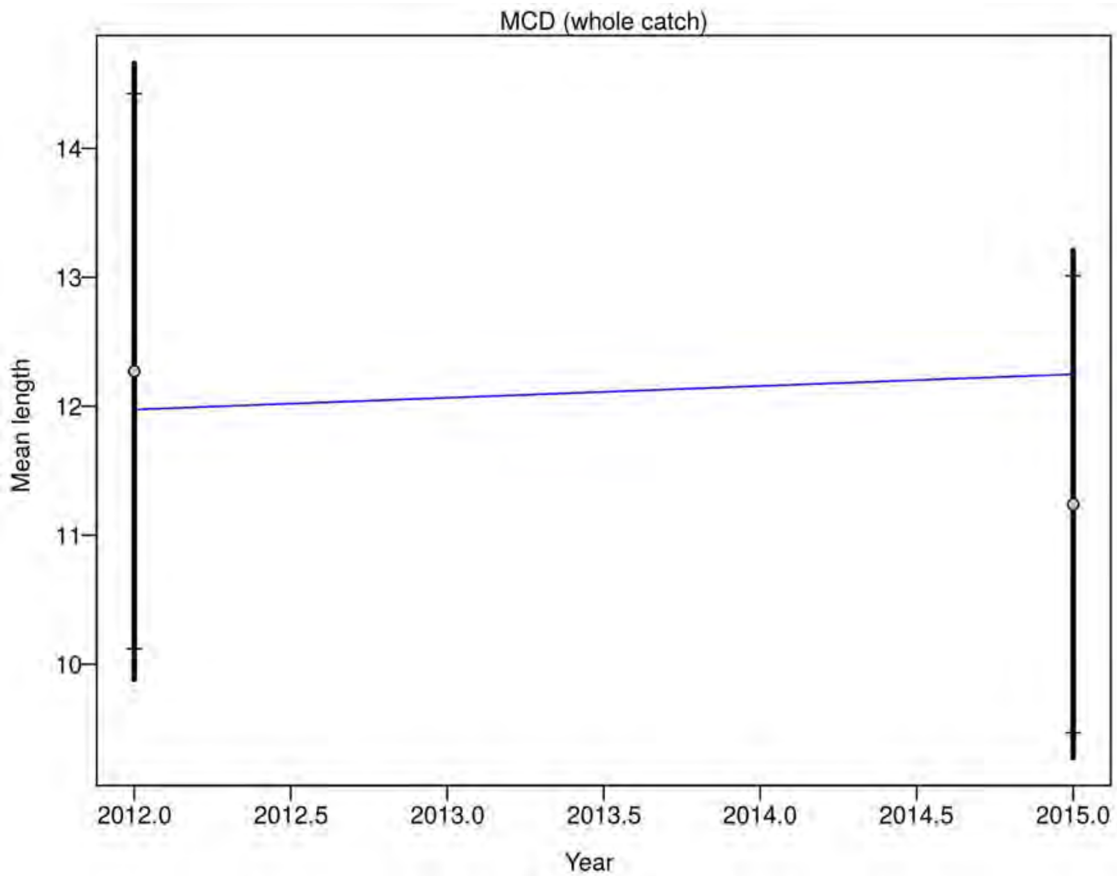


Figure 105: Observed mean length vs. the mean length predicted by the model based on fits to NEFSC survey (MCD) length composition data used in the assessment model for Atlantic surfclam in the southern area.

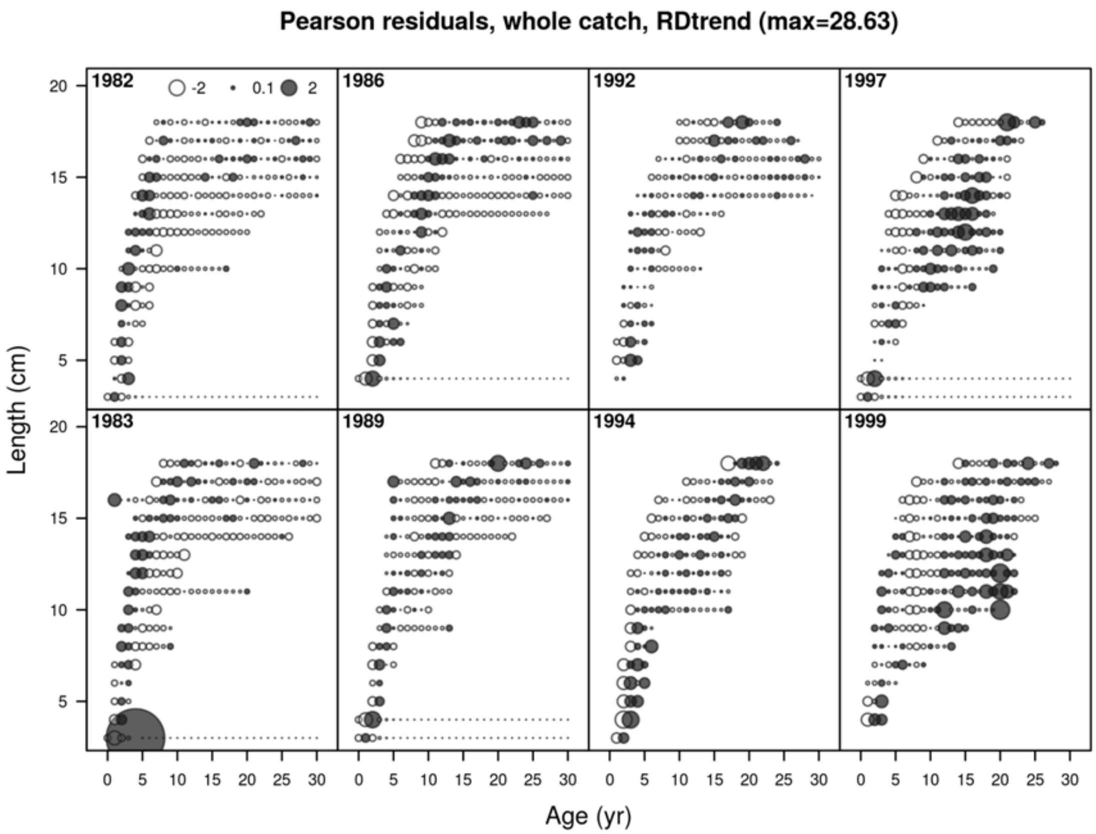


Figure 106: Pearson residuals from the fit to NEFSC survey (RD) conditional age at length composition data used in the assessment model for Atlantic surfclam in the southern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

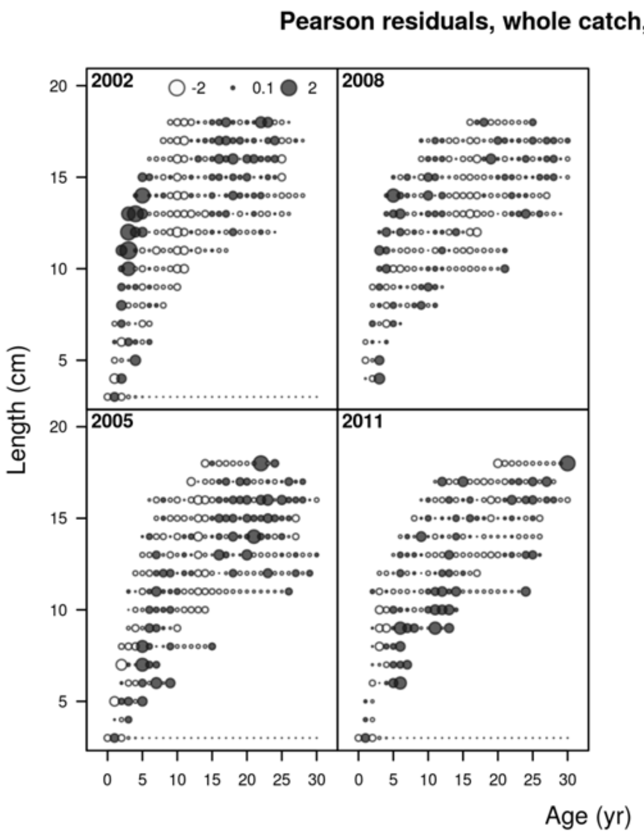


Figure 106 cont.

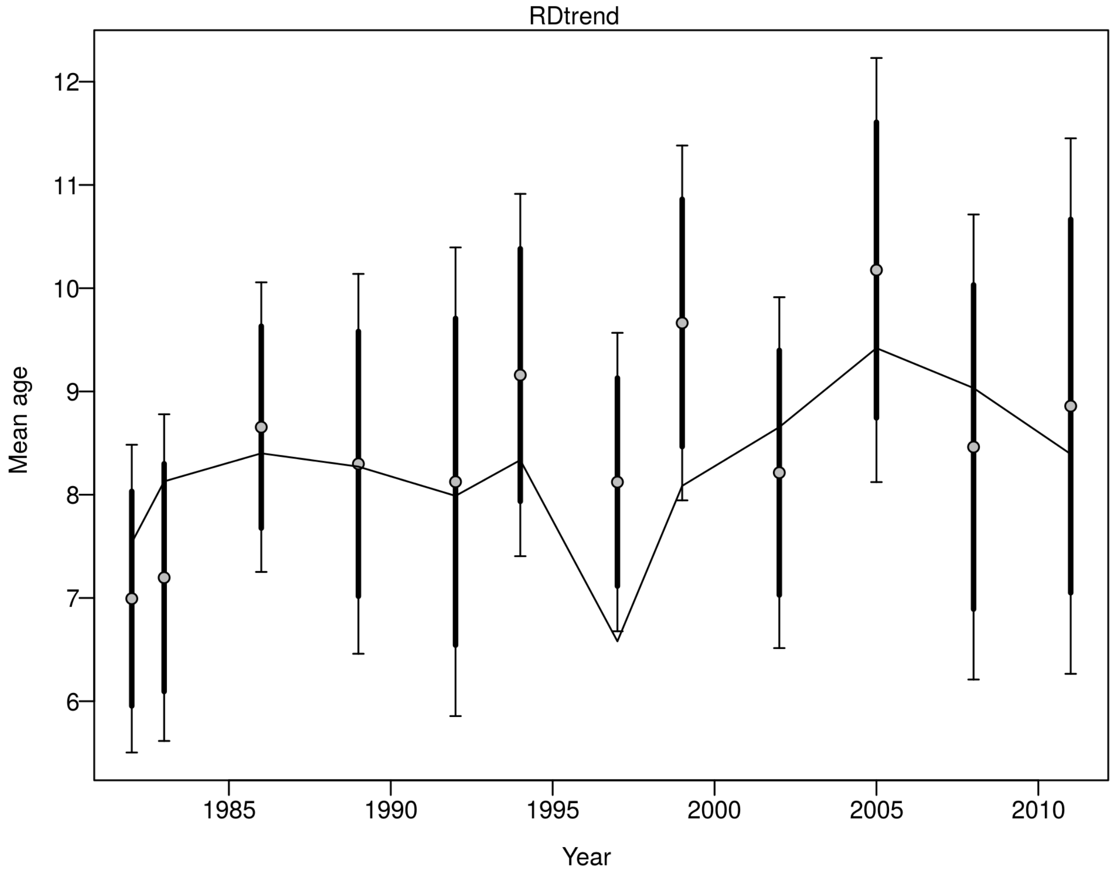


Figure 107: Observed mean age vs. the mean age predicted by the model based on fits to NEFSC survey (RD) age at length conditional composition data used in the assessment model for Atlantic surfclam in the southern area. The thicker vertical lines show the standard deviation of the observed data and the thinner lines show the standard deviation after accounting for the data weighting adjustments used in the model.

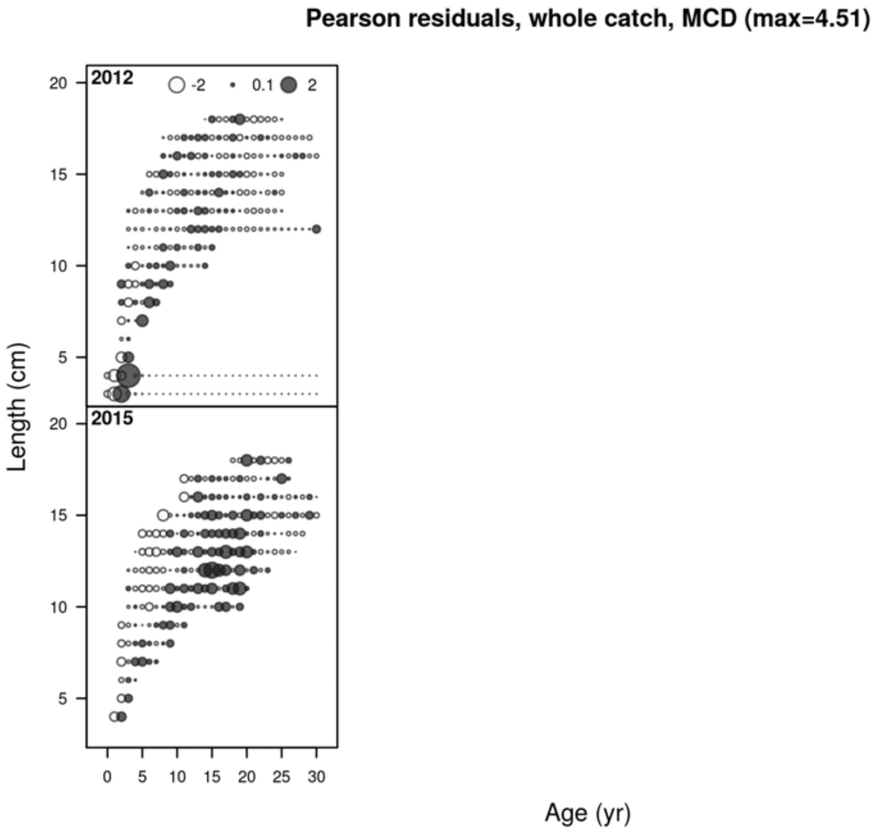


Figure 108: Pearson residuals from the fit to NEFSC survey (MCD) conditional age at length composition data used in the assessment model for Atlantic surfclam in the southern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

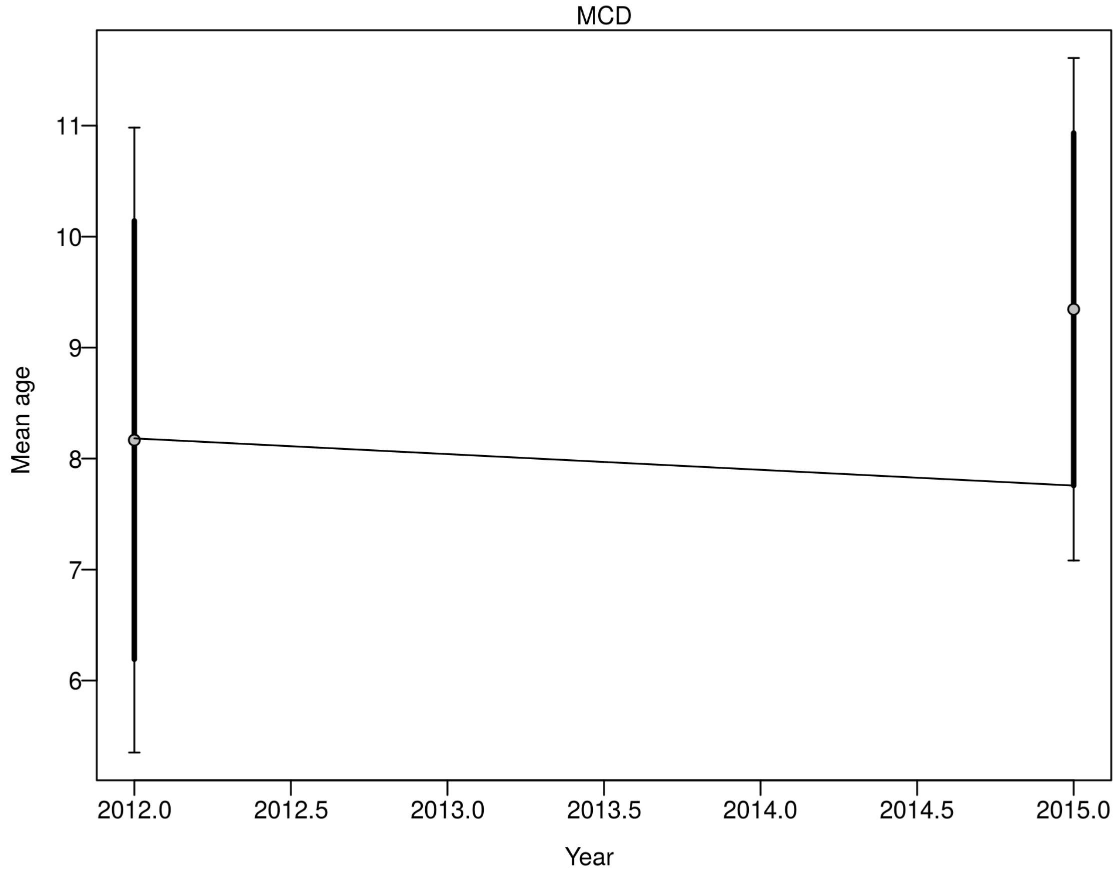


Figure 109: Observed mean age vs. the mean age predicted by the model based on fits to NEFSC survey (MCD) age at length conditional composition data used in the assessment model for Atlantic surfclam in the southern area. The thicker vertical lines show the standard deviation of the observed data and the thinner lines show the standard deviation after accounting for the data weighting adjustments used in the model.

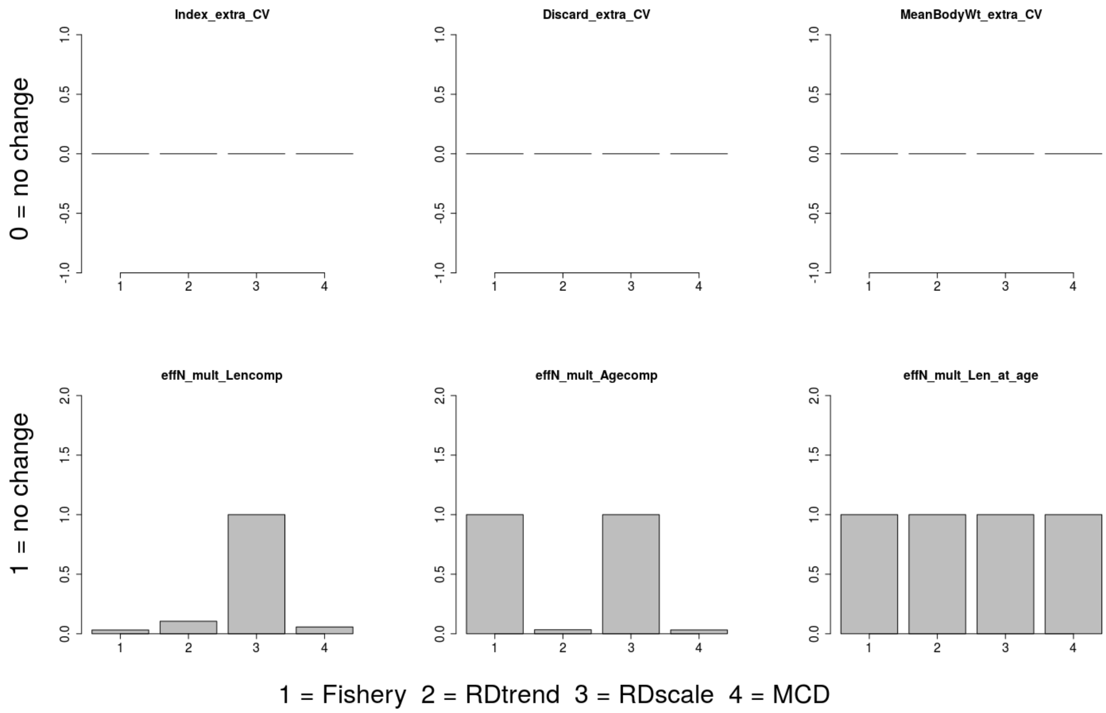


Figure 110: Adjustments made to variance components of model parameters used in the assessment model for Atlantic surfclam in the southern area. The bar plots reflect data weighting decisions. In the top row deviations from 0 are the amount added to the standard deviation around input parameters. In the bottom row, the value shown in the bar plot is multiplied by the input effective sample size associated with each composition component. Thus, for example a value of less than 1 represents a reduction in the relative weight of a component.

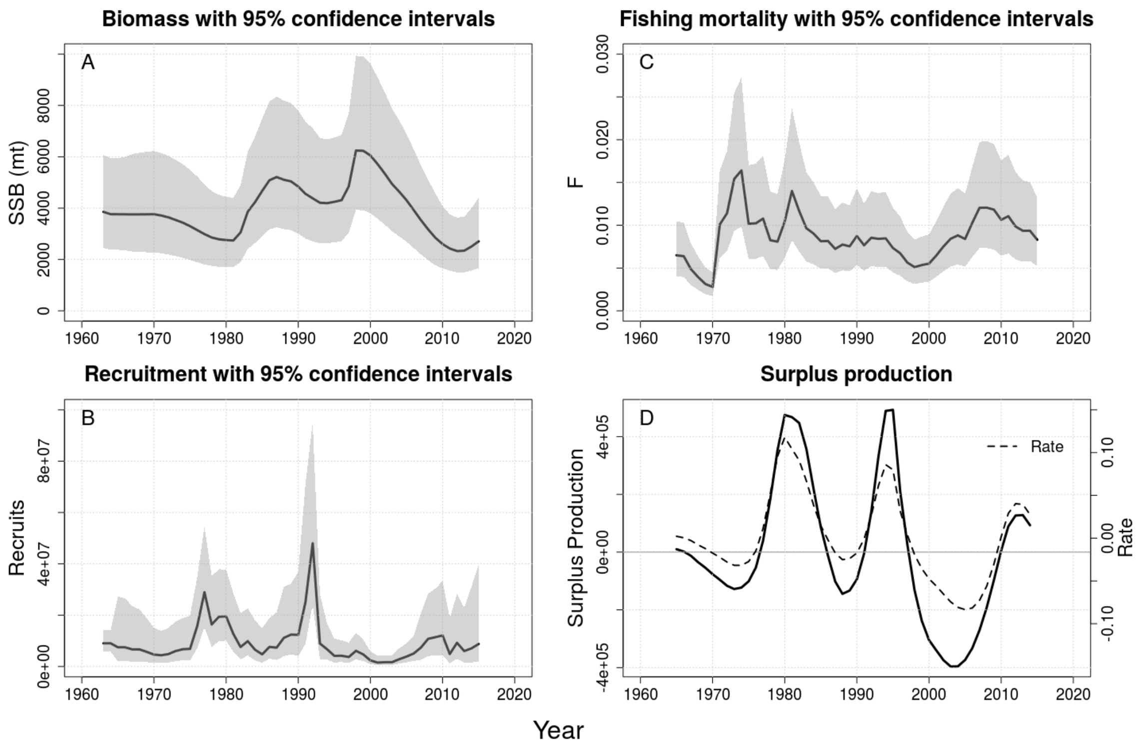


Figure 111: Estimated SSB and approximate 95% asymmetric confidence interval (A), estimated recruitment and approximate 95% asymmetric confidence interval (B), estimated fully selected fishing mortality and approximate 95% asymmetric confidence interval (C), and surplus production with surplus production rate (D), for the southern area.

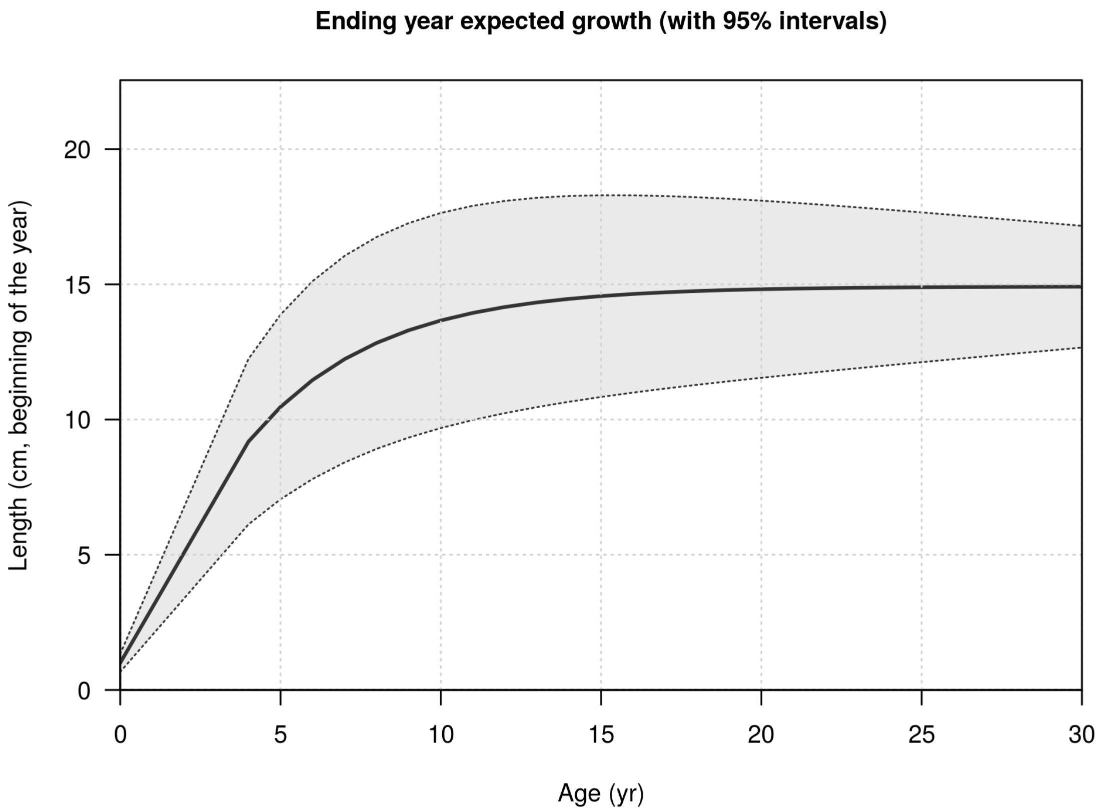


Figure 112: Length at age relationship used in the assessment model for Atlantic surfclam in the northern area.

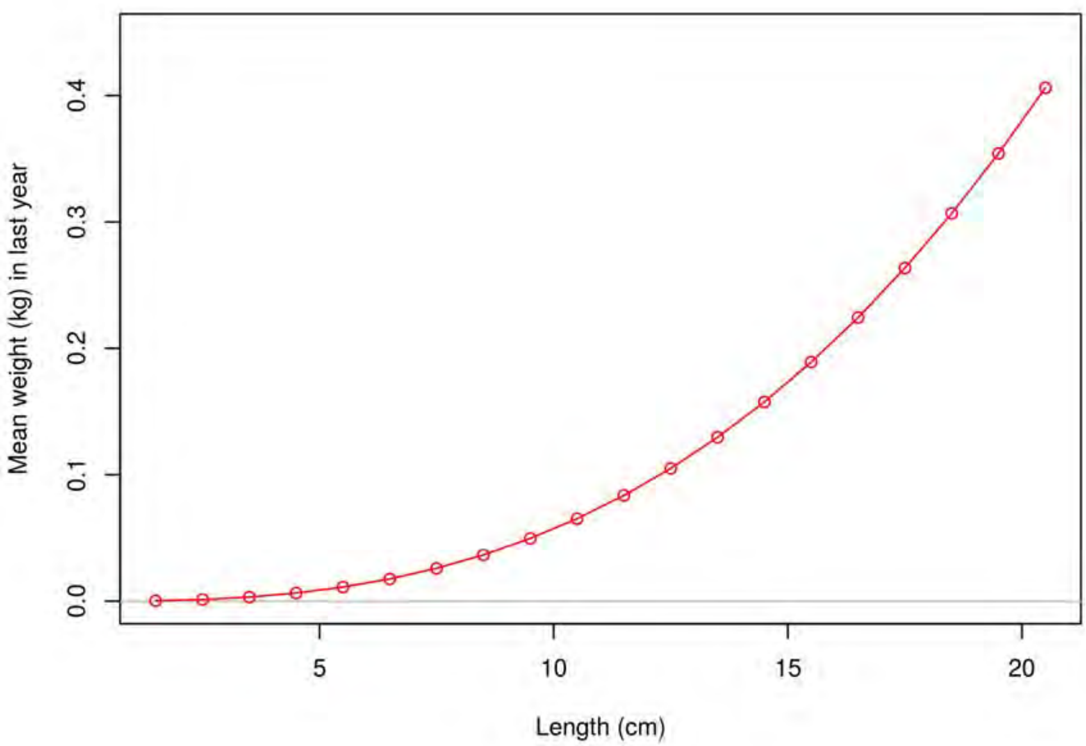


Figure 113: Weight at length relationship used in the assessment model for Atlantic surfclam in the northern area.

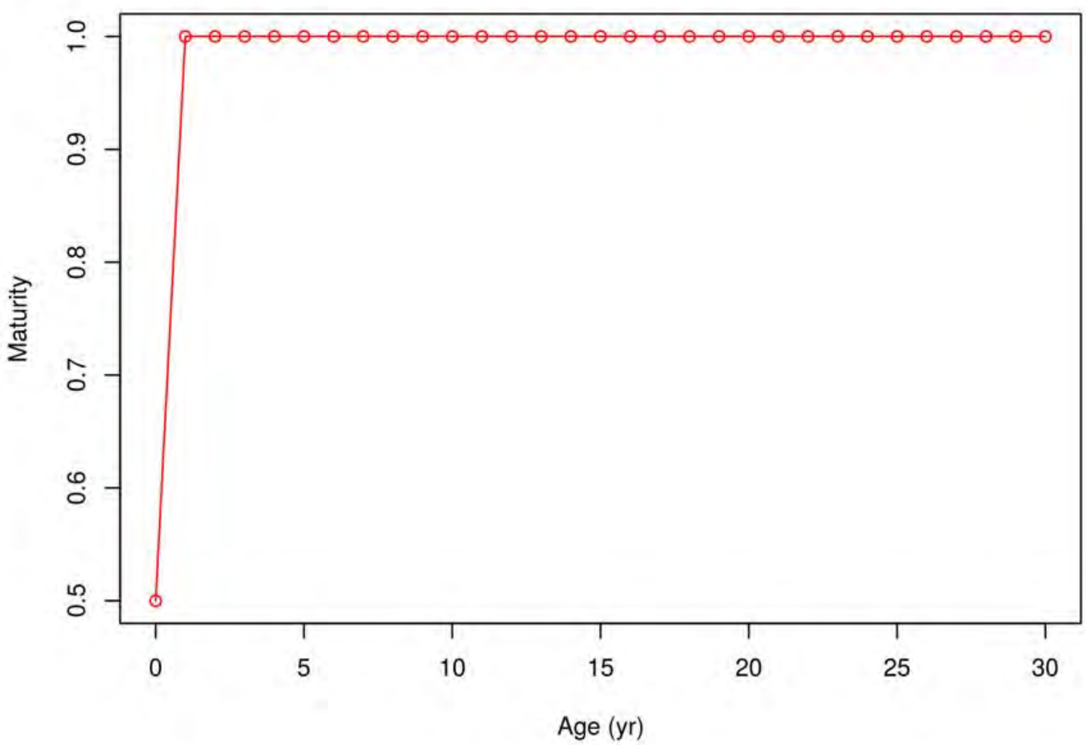


Figure 114: Maturity at age relationship used in the assessment model for Atlantic surfclam in the northern area.

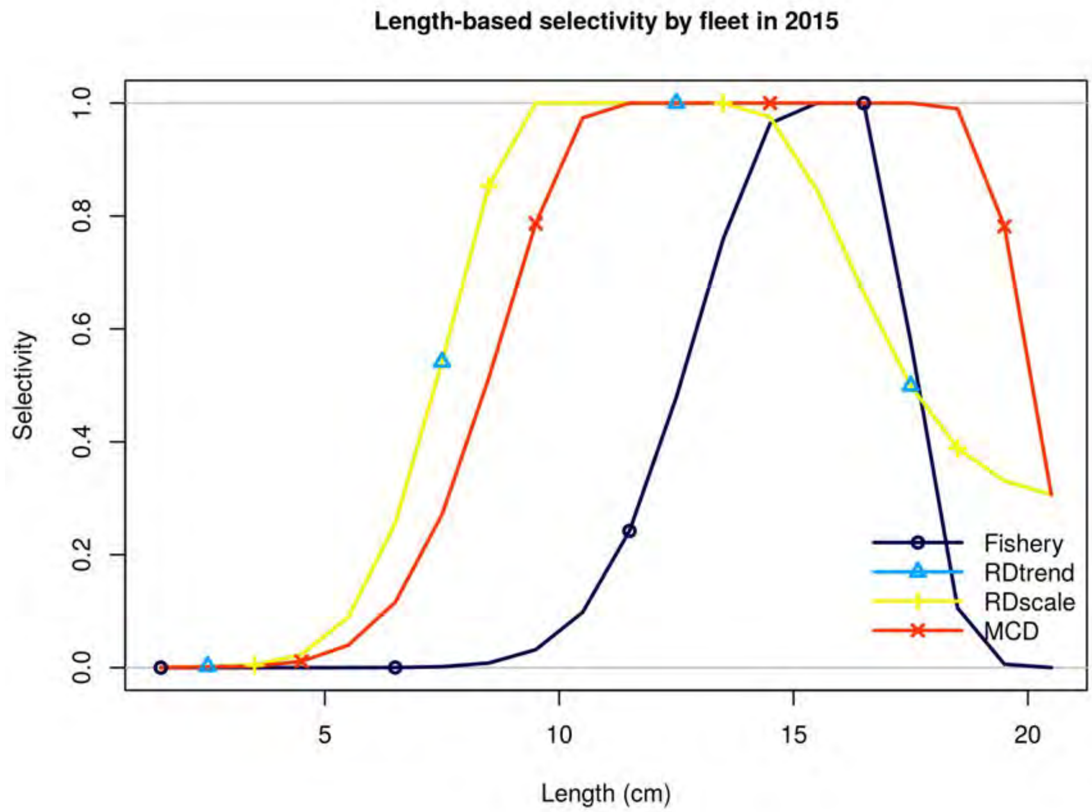


Figure 115: Comparison of selectivity curves for each fleet included in the assessment model for Atlantic surfclam in the northern area. RD trend and RD scale have identical selectivities because they are from the same survey (RD scale was not included in the likelihood).

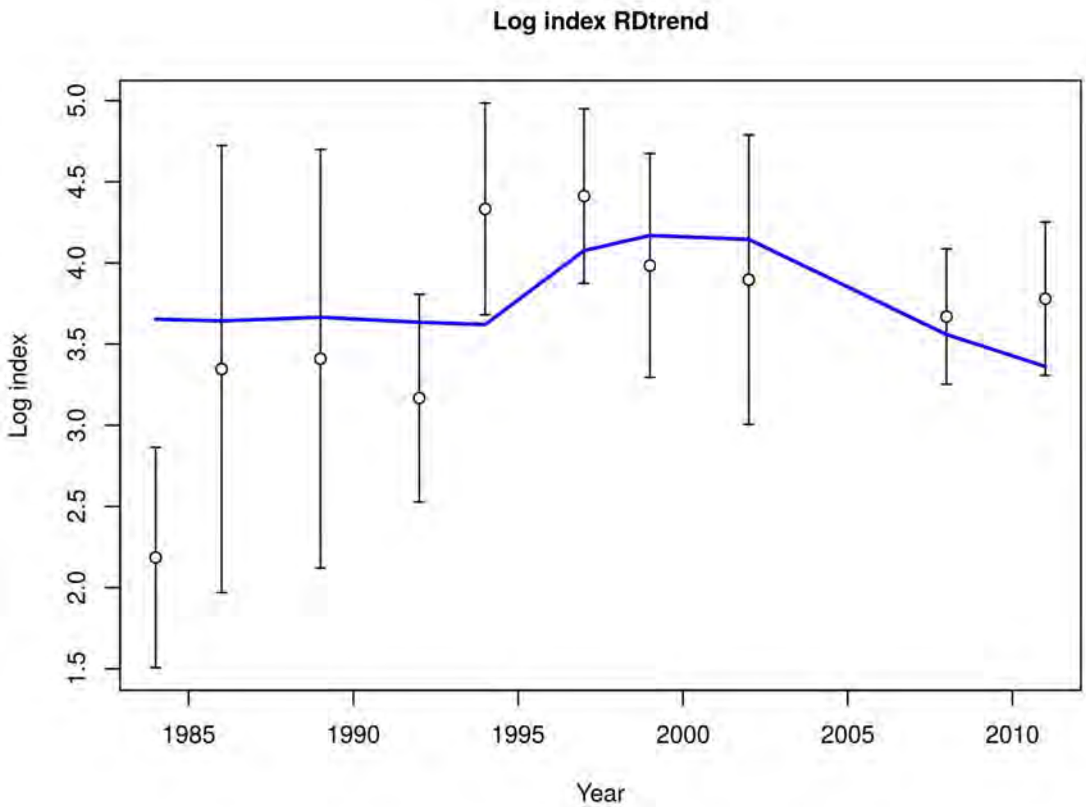


Figure 116: Fit to log index data on log scale for RDtrend survey for Atlantic surfclam in the northern area. Vertical lines are 95% confidence intervals.

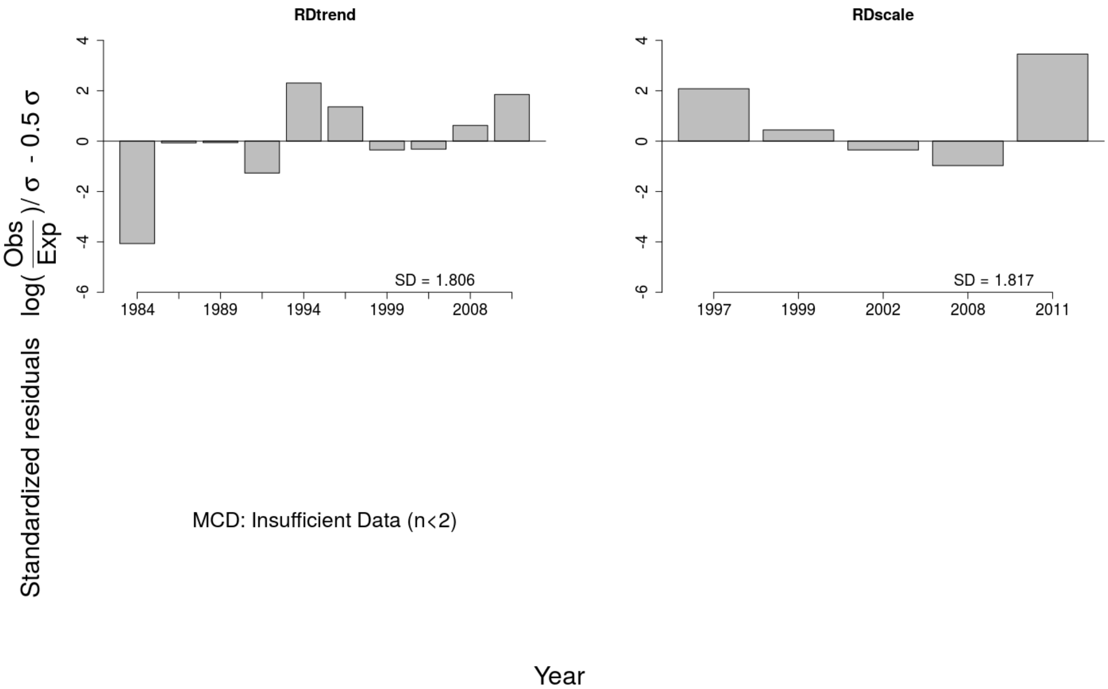


Figure 117: Residuals from the model fits to each survey index used in the assessment model for Atlantic surfclam in the northern area by year. The standard deviation of the residuals over the time series is shown over the horizontal axis.

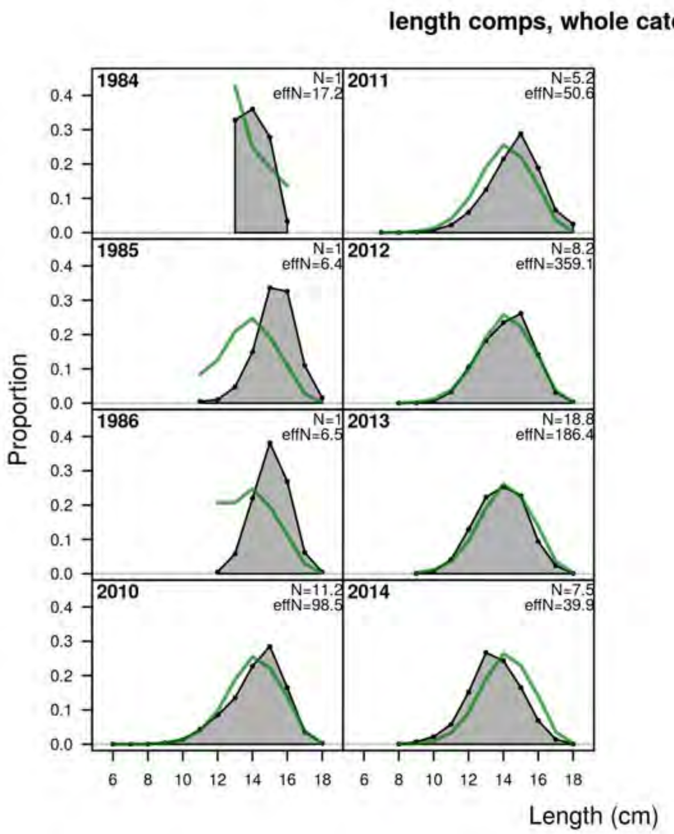


Figure 118: Model fit to length composition data from the commercial fishery used in the assessment model for Atlantic surfclam in the northern area.

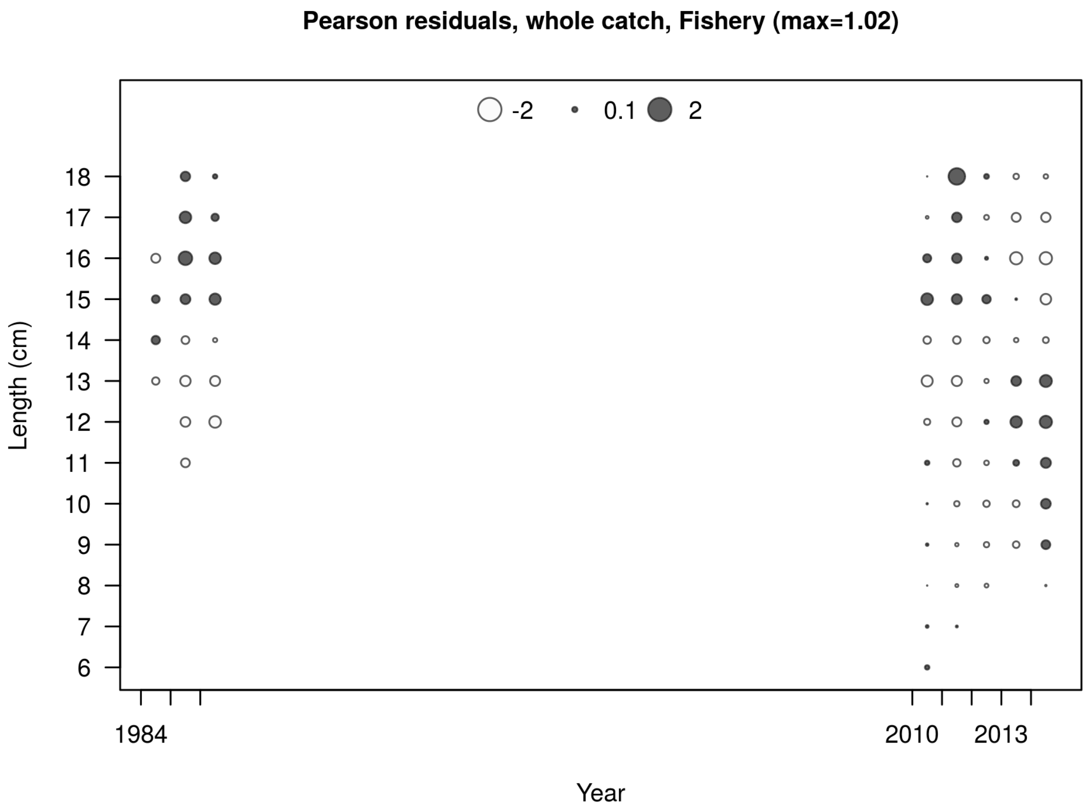


Figure 119: Pearson residuals from the fit to commercial length composition data used in the assessment model for Atlantic surfclam in the northern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

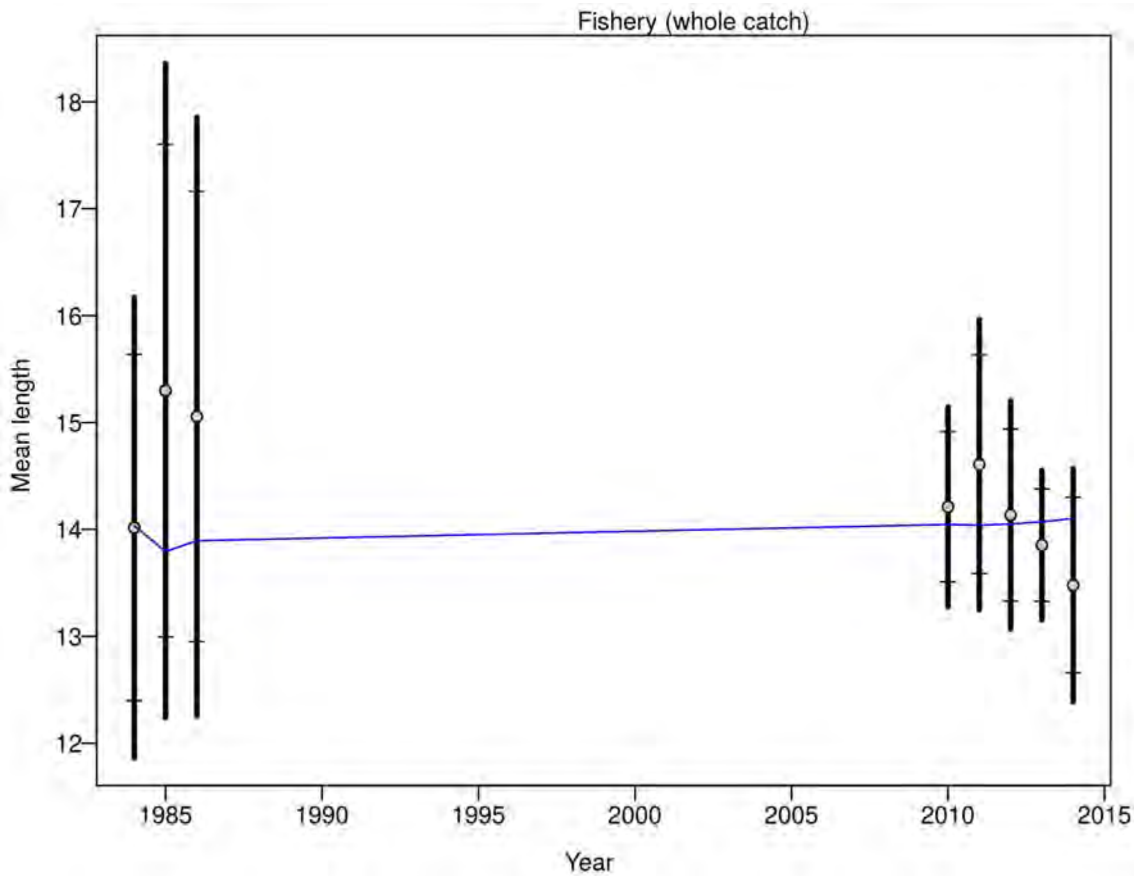


Figure 120: Observed mean length vs. the mean length predicted by the model based on fits to commercial length composition data.

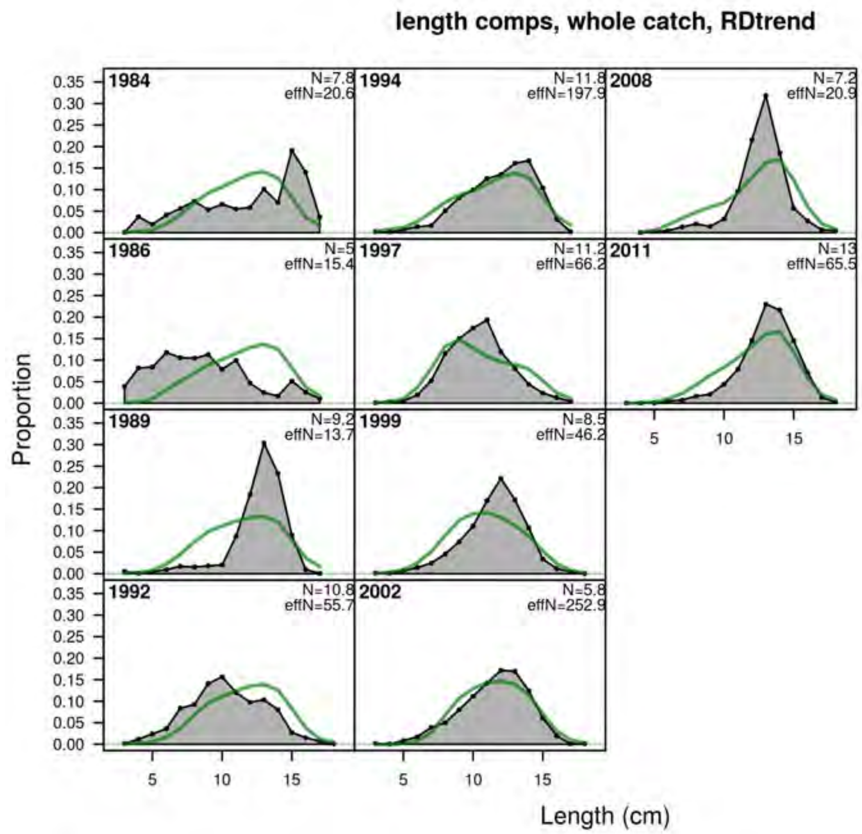


Figure 121: Model fit to length composition data from the NEFSC survey (RD) used in the assessment model for Atlantic surfclam in the northern area.

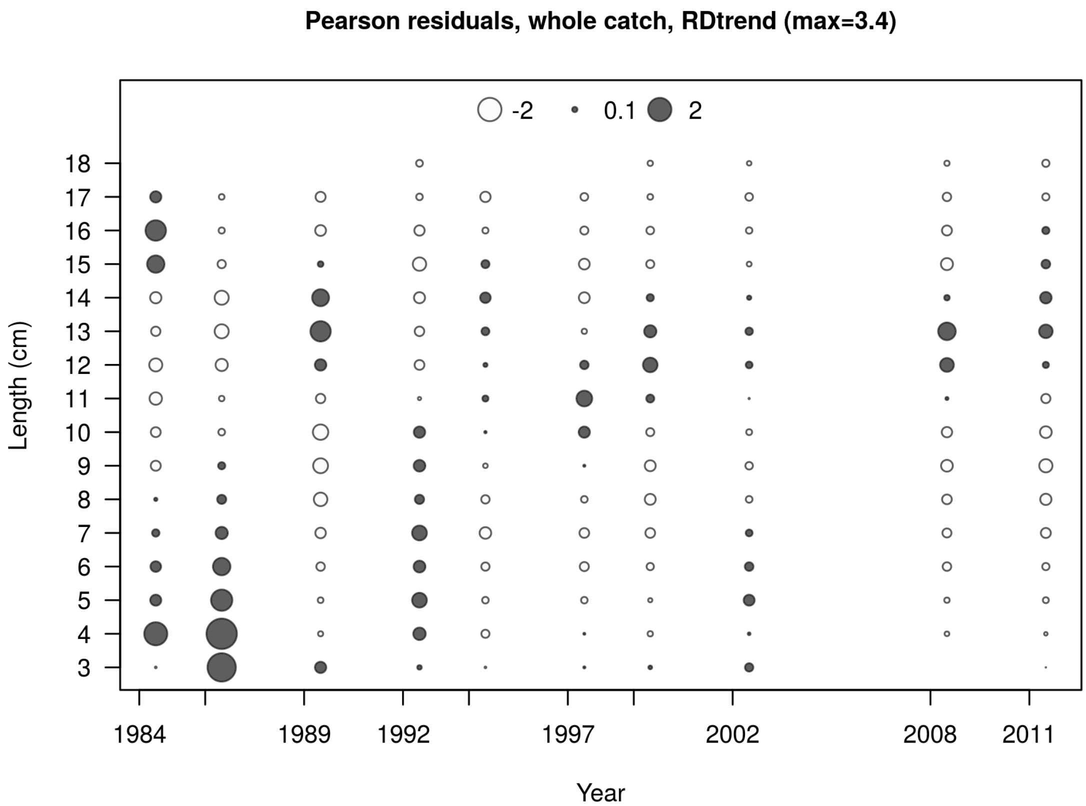


Figure 122: Pearson residuals from the fit to NEFSC survey (RD) length composition data used in the assessment model for Atlantic surfclam in the northern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

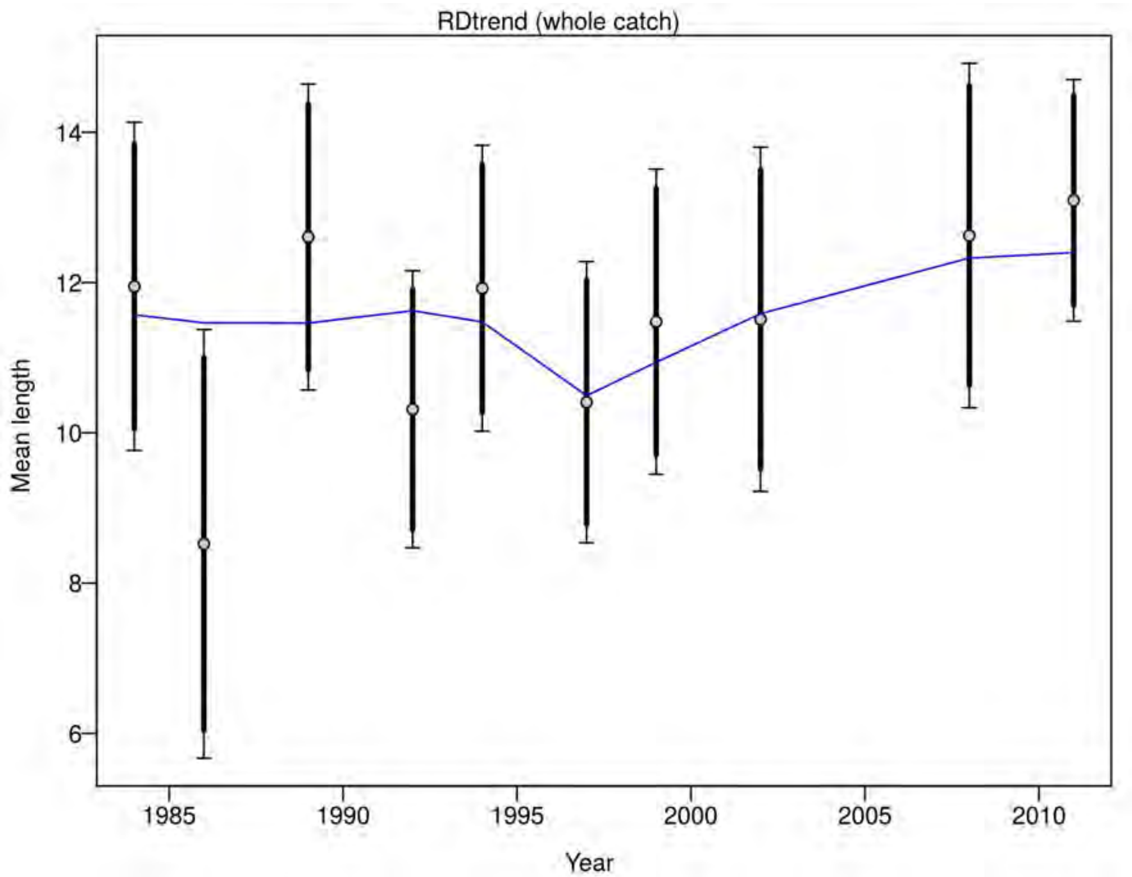


Figure 123: Observed mean length vs. the mean length predicted by the model based on fits to NEFSC survey (RD) length composition data used in the assessment model for Atlantic surfclam in the northern area. The thicker vertical lines show the standard deviation of the observed data and the thinner lines show the standard deviation after accounting for the data weighting adjustments used in the model.

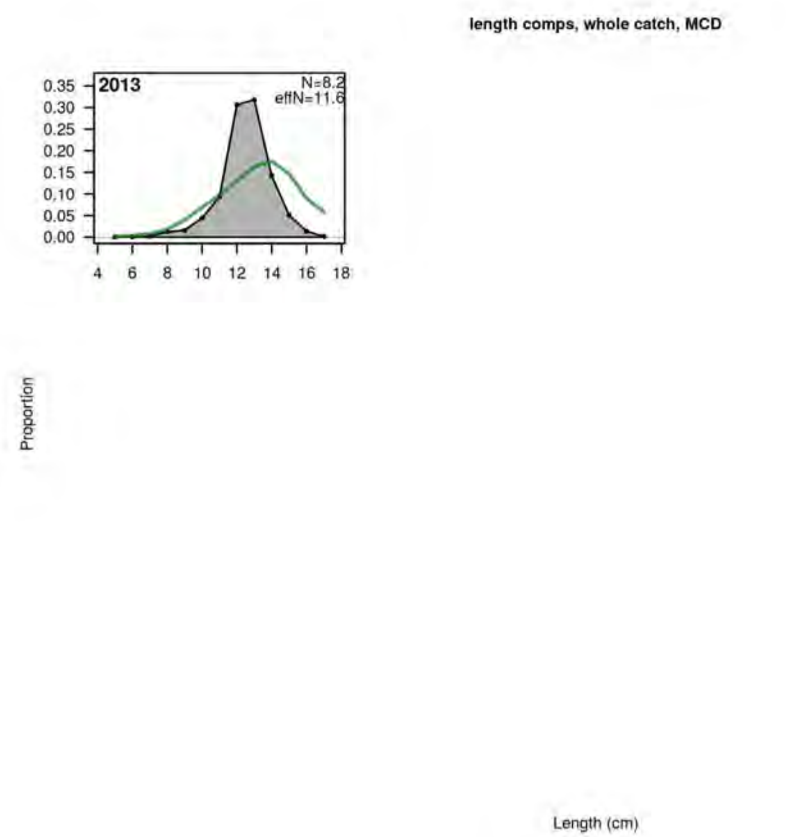


Figure 124: Model fit to length composition data from the NEFSC survey (MCD) used in the assessment model for Atlantic surfclam in the northern area.

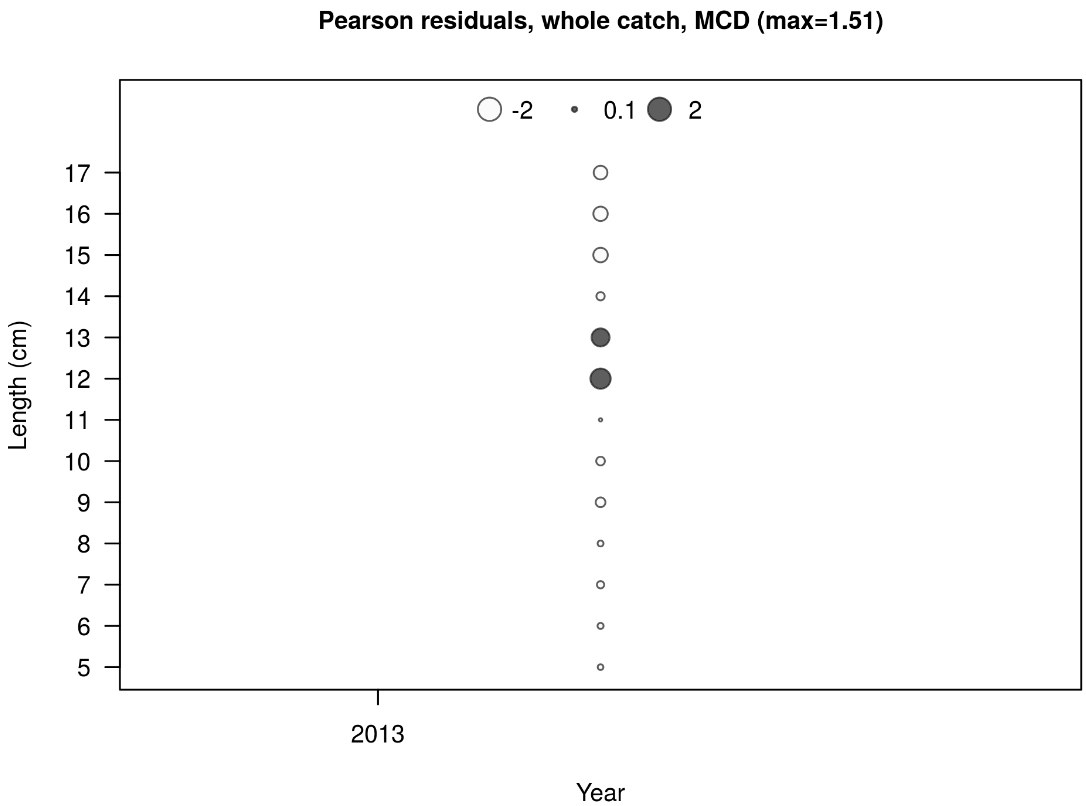


Figure 125: Pearson residuals from the fit to NEFSC survey (MCD) length composition data used in the assessment model for Atlantic surfclam in the northern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

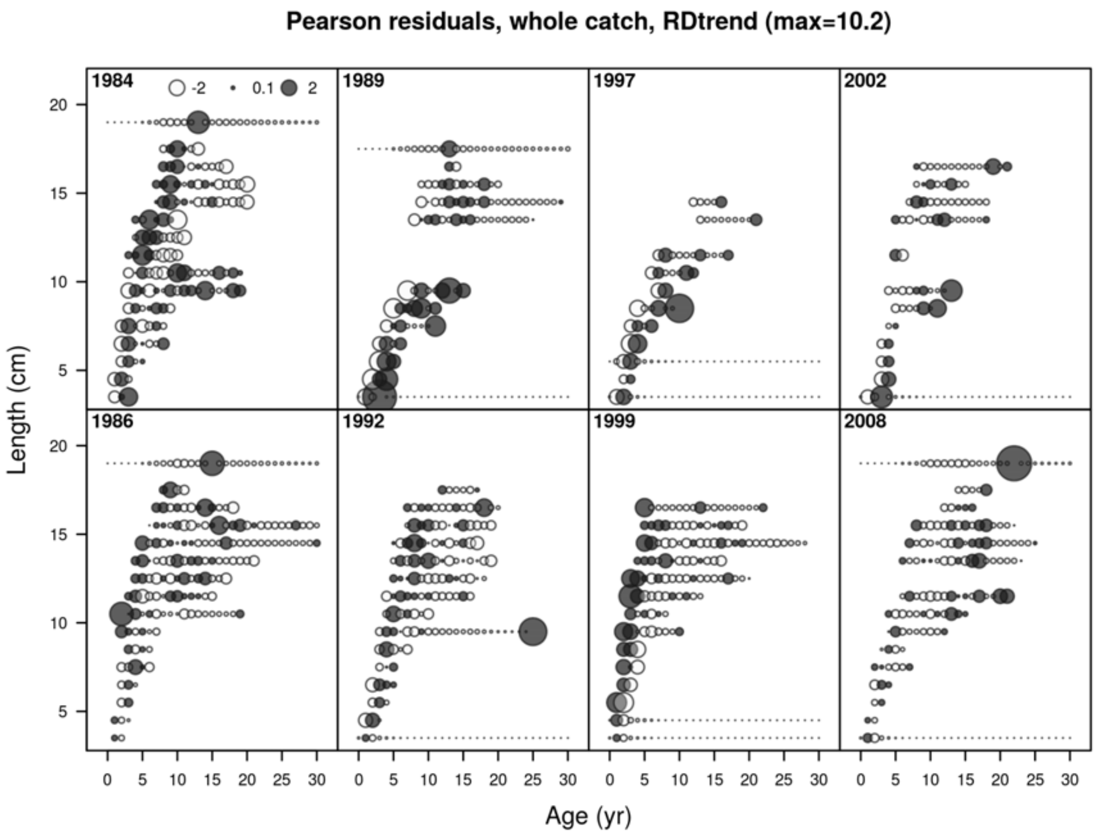
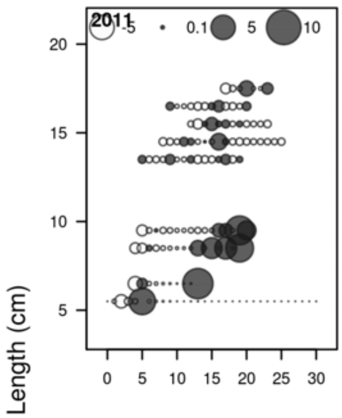


Figure 126: Pearson residuals from the fit to NEFSC survey (RD) conditional age at length composition data used in the assessment model for Atlantic surfclam in the northern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

Pearson residuals, whole catch, RDtrend (max=10.2)



Age (yr)

Figure 126 cont.

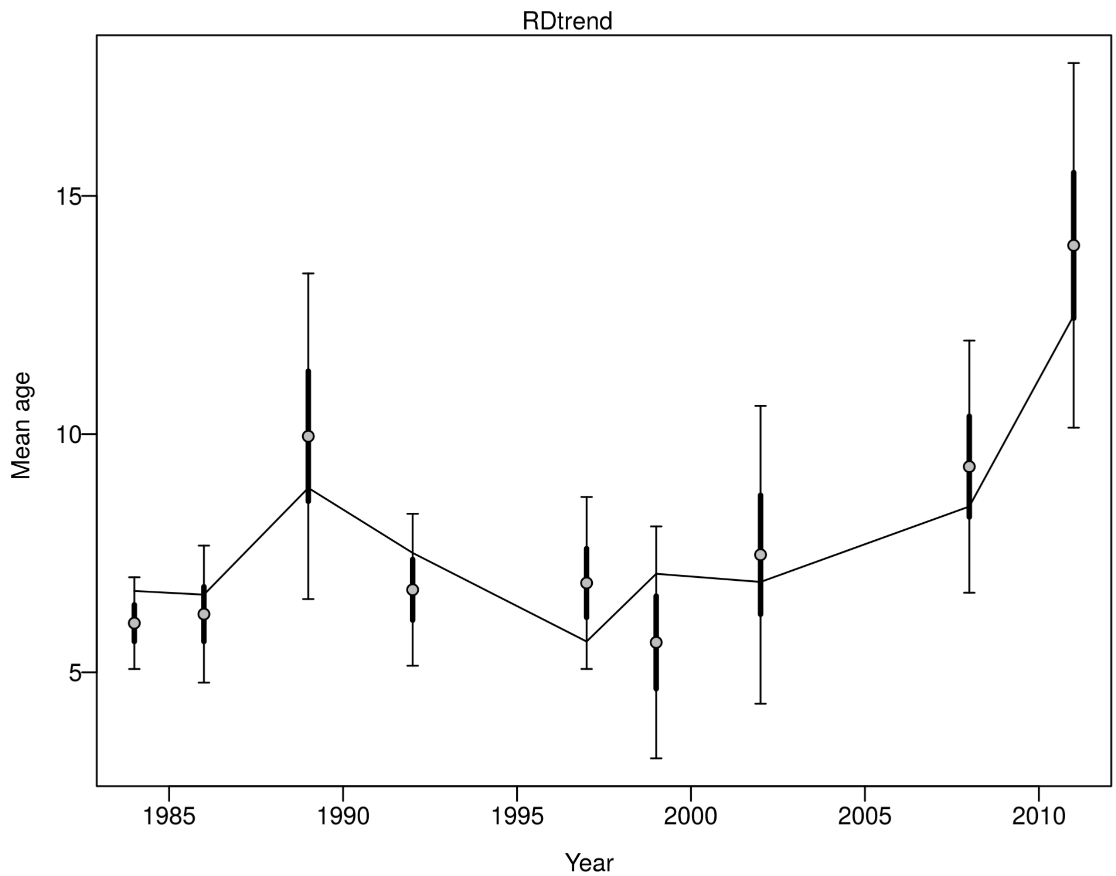


Figure 127: Observed mean age vs. the mean age predicted by the model based on fits to NEFSC survey (RD) age at length conditional composition data used in the assessment model for Atlantic surfclam in the northern area. The thicker vertical lines show the standard deviation of the observed data and the thinner lines show the standard deviation after accounting for the data weighting adjustments used in the model.

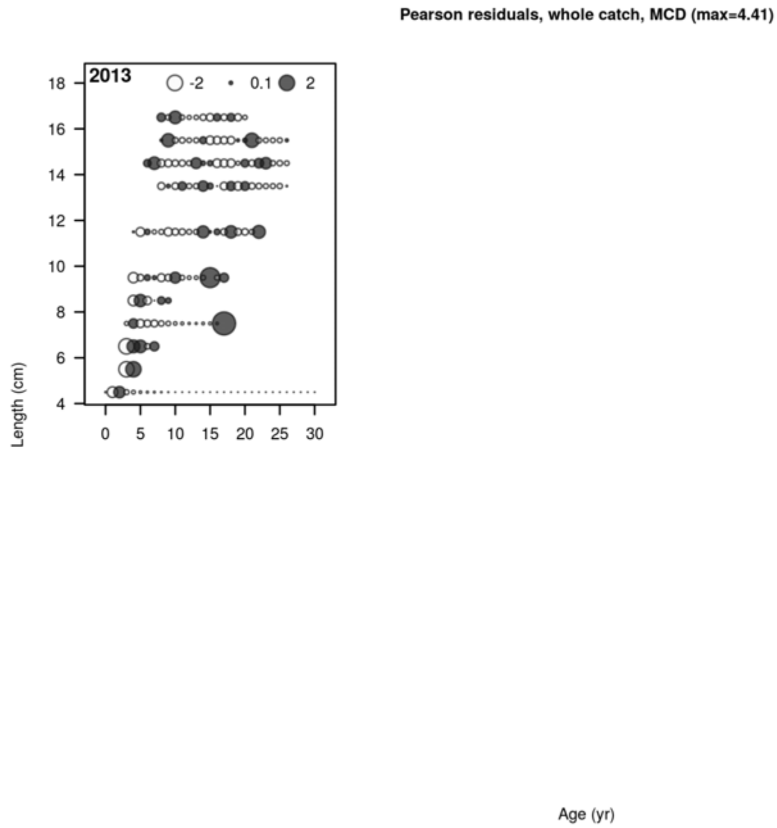


Figure 128: Pearson residuals from the fit to NEFSC survey (MCD) conditional age at length composition data used in the assessment model for Atlantic surfclam in the northern area. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

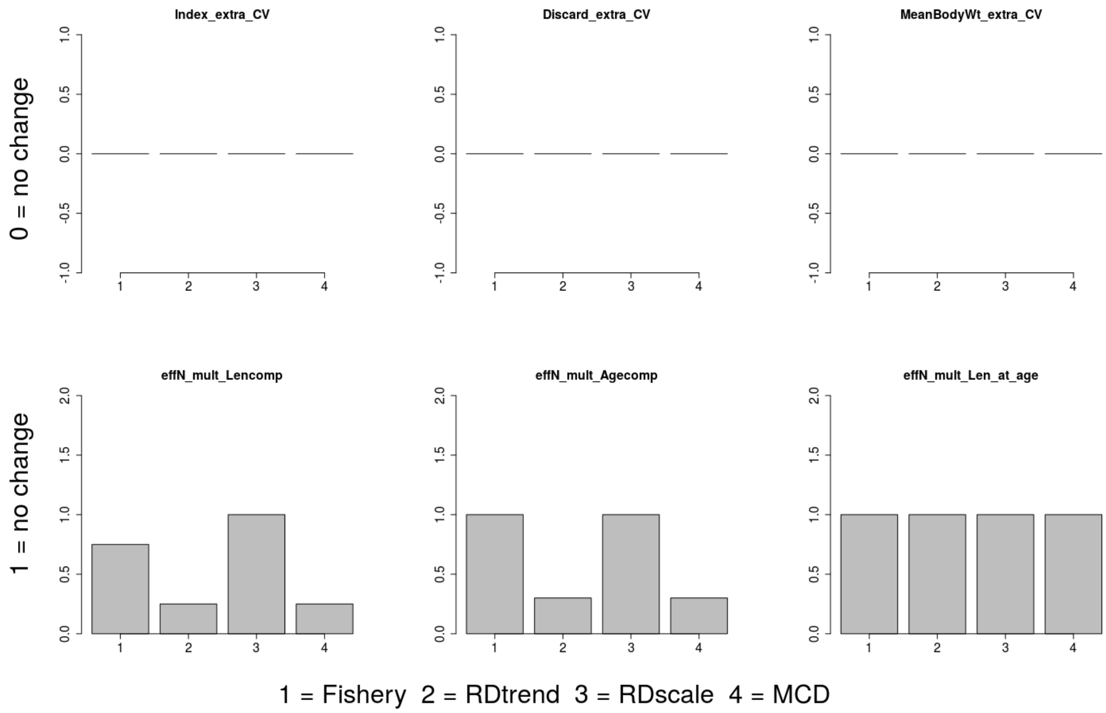


Figure 129: Adjustments made to variance components of model parameters used in the assessment model for Atlantic surfclam in the northern area. The bar plots reflect data weighting decisions. In the top row deviations from 0 are the amount added to the standard deviation around input parameters. In the bottom row, the value shown in the bar plot is multiplied by the input effective sample size associated with each composition component. Thus, for example a value of less than 1 represents a reduction in the relative weight of a component.

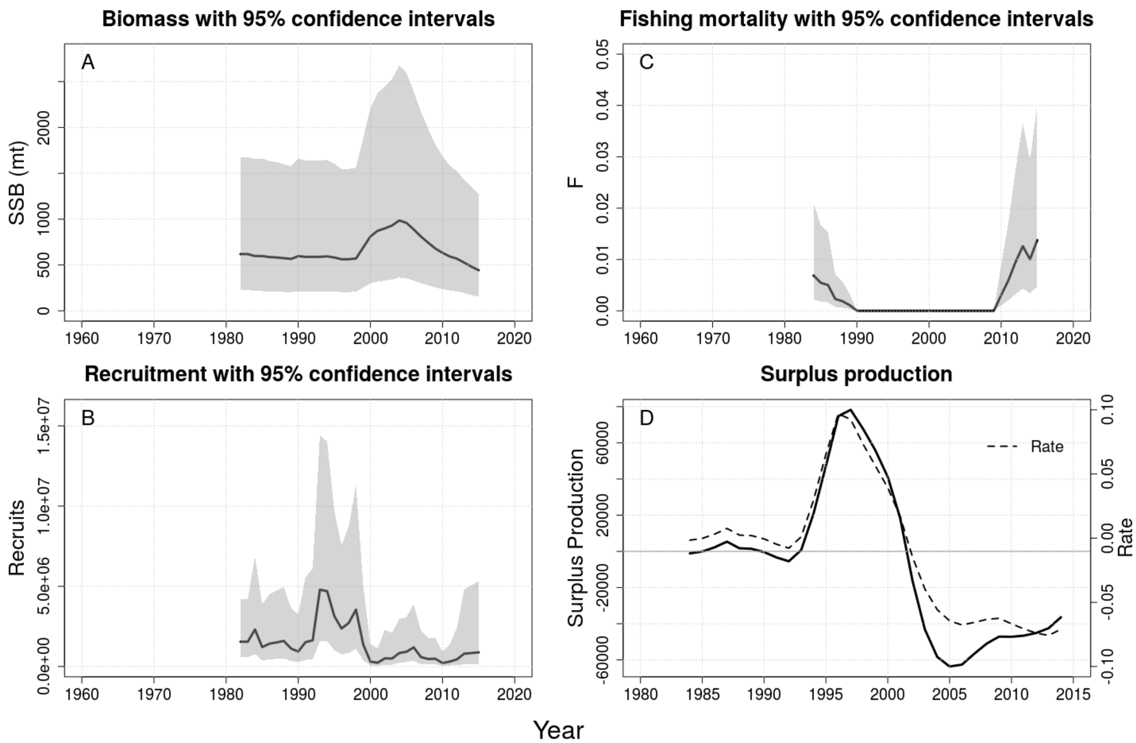


Figure 130: Estimated summary biomass and approximate 95% asymmetric confidence interval (A), estimated recruitment and approximate 95% asymmetric confidence interval (B), estimated fully selected fishing mortality and approximate 95% asymmetric confidence interval (C), and surplus production with surplus production rate (D), for Atlantic surfclam in the northern area.

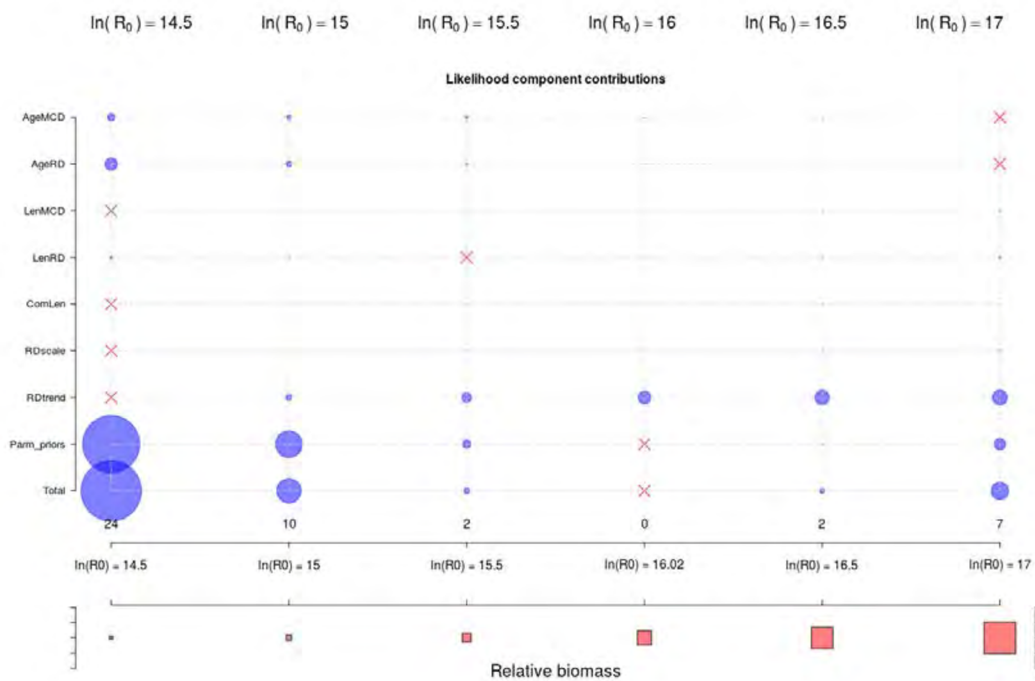


Figure 131: Likelihood profile over the virgin recruitment parameter (R0). A total of 5 model runs are depicted here. In each case, the R0 parameter was fixed at a different value. The columns of the large plot show how the component and total likelihoods change as the R0 parameter is varied. Each column of the large bubble plot represents one model run and the non-zero likelihood components in each run are shown in rows. For each row, the minimum likelihood component value was subtracted from each individual value, such that the minimum value in each row is represented by a red x. Bubbles are proportional to the values of each likelihood component in each run. The base value for R0 is the value at the model solution (middle column). The difference (in likelihood units) between each column and the minimum total likelihood is shown just above the x axis. Conflicts within the data are apparent when the minimum likelihood values (red x's) occur in different columns for each row. The red boxes show the relative difference in estimated terminal year biomass between runs.

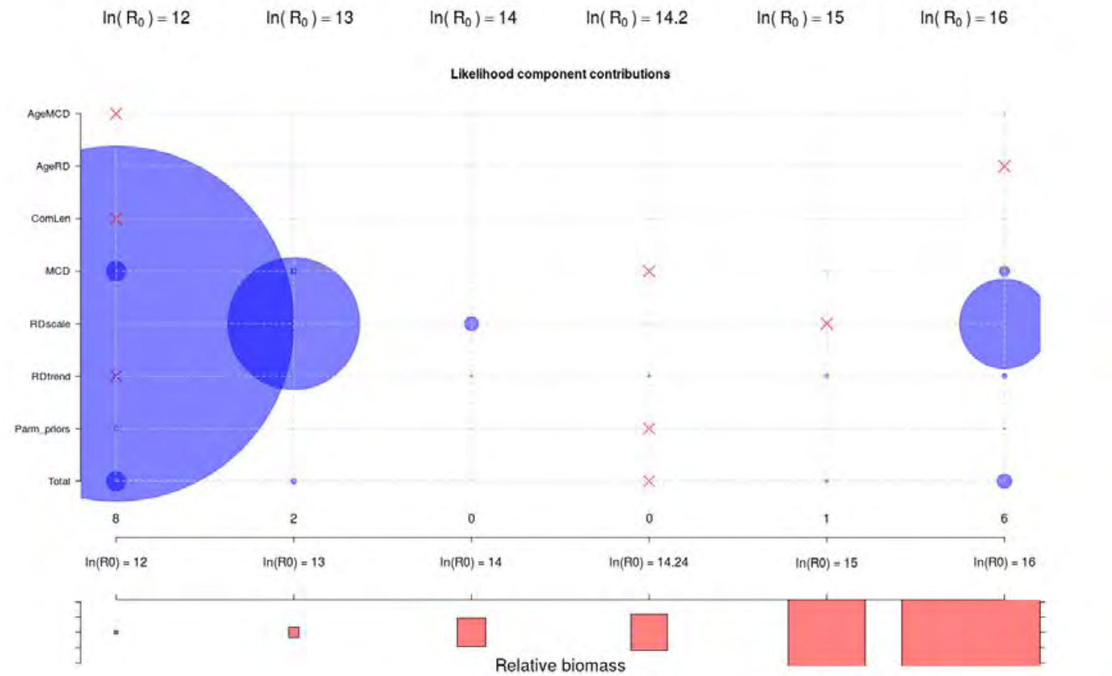


Figure 132: Likelihood profile over the virgin recruitment parameter (R0). A total of 5 model runs are depicted here. In each case, the R0 parameter was fixed at a different value. The columns of the large plot show how the component and total likelihoods change as the R0 parameter is varied. Each column of the large bubble plot represents one model run and the non-zero likelihood components in each run are shown in rows. For each row, the minimum likelihood component value was subtracted from each individual value, such that the minimum value in each row is represented by a red x. Bubbles are proportional to the values of each likelihood component in each run. The base value for R0 is the value at the model solution (middle column). The difference (in likelihood units) between each column and the minimum total likelihood is shown just above the x axis. Conflicts within the data are apparent when the minimum likelihood values (red x's) occur in different columns for each row. The red boxes show the relative difference in estimated terminal year biomass between runs.

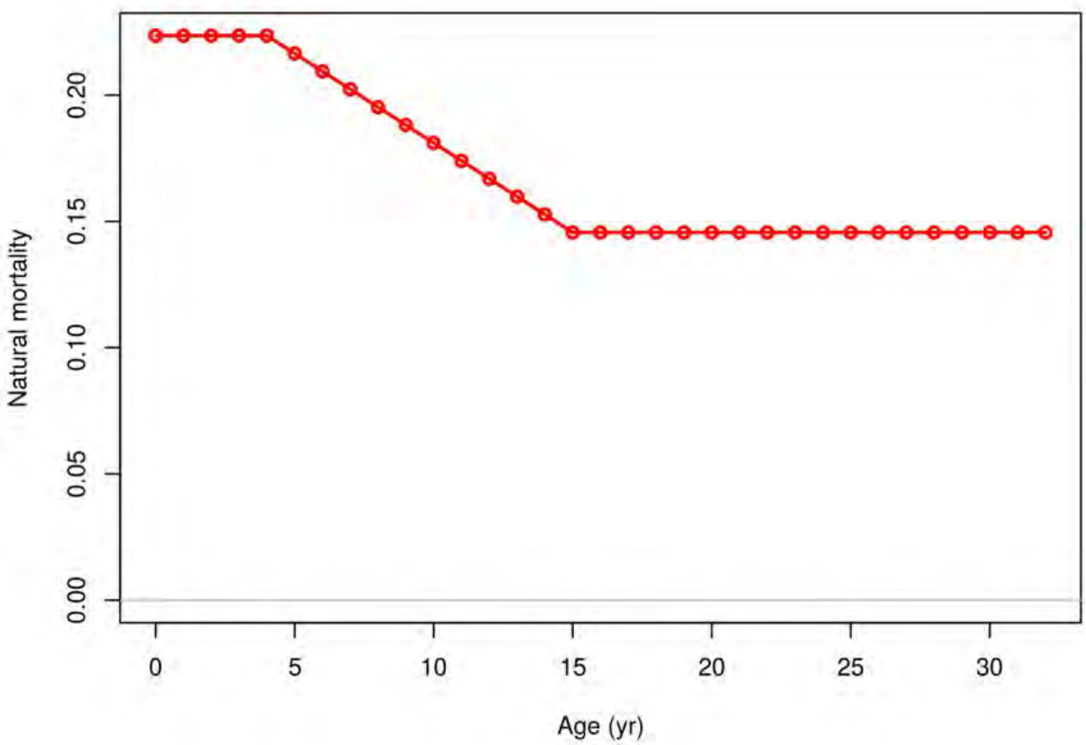


Figure 133: Natural mortality at age estimated in a model sensitivity run for Atlantic surfclam in the southern area.

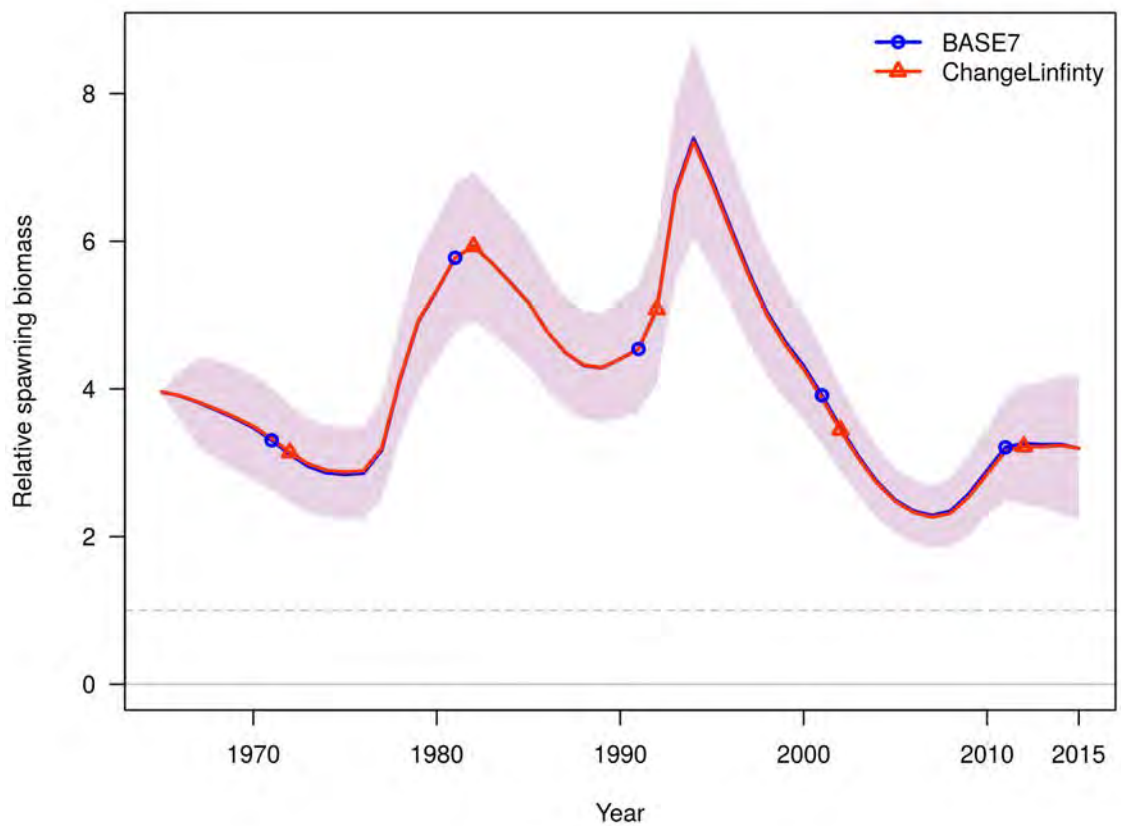


Figure 134: A comparison of the biomass trends of the base model (BASE7) for Atlantic surfclam in the southern area and a sensitivity run in which the length at A_{max} was estimated for each of two time blocks (<2000 and >1999). There was very little difference between the two runs. The trends depict the ratio of the biomass in each year to B_0 and include a dashed line at $\frac{B}{B_0} = 0.25$.

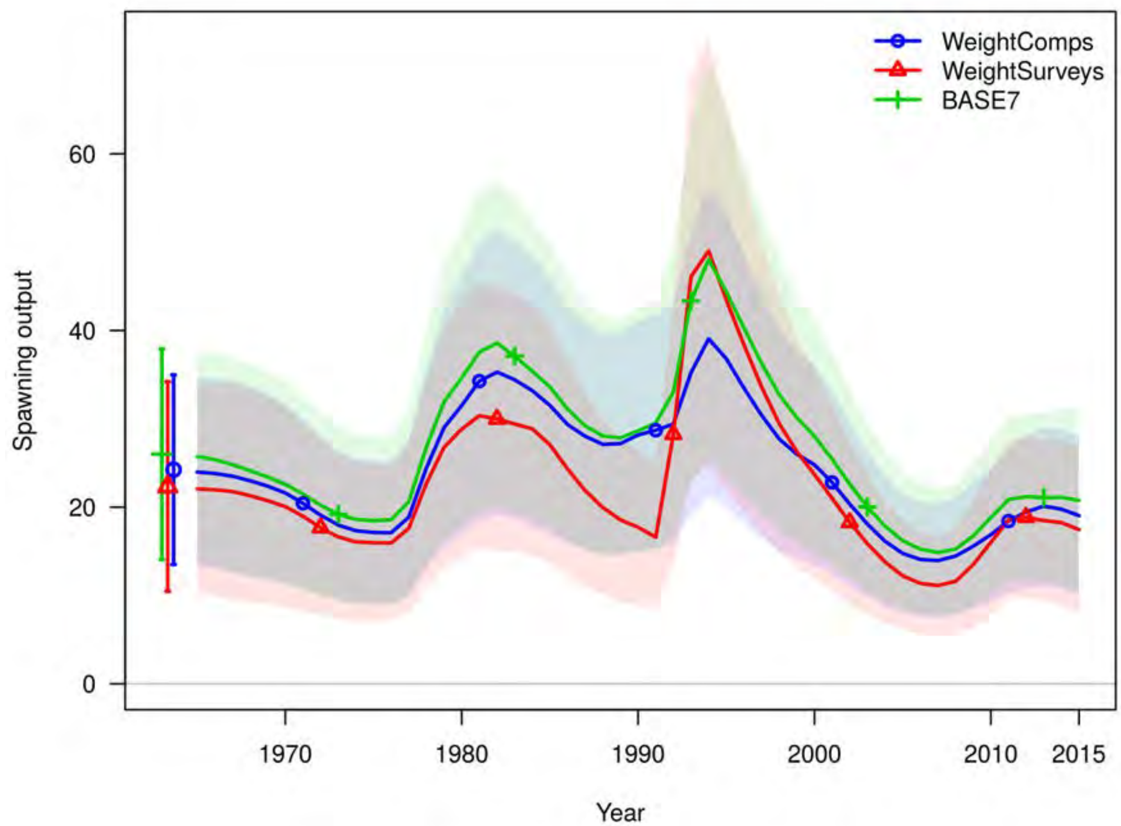


Figure 135: A comparison of the estimated biomass scales between the base run for Atlantic surfclam in the southern area (BASE7) and sensitivity runs in which the likelihood component associated with the fit the RD survey was increased by an order of magnitude (WeightSurveys), and where the variance associated with the composition data (both length and age at length) was adjusted so that the harmonic mean of the effective sample size matched the mean of the input sample size.

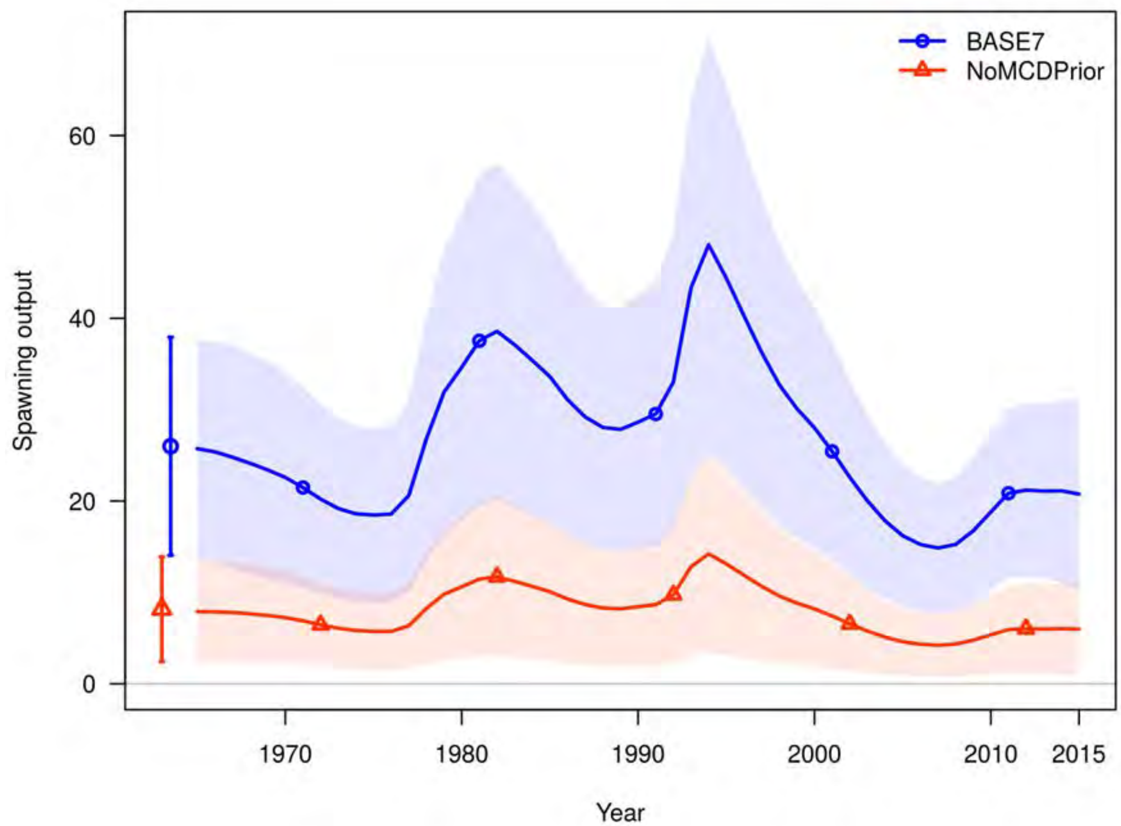


Figure 136: Biomass scale in a model sensitivity run for Atlantic surfclam in the southern area in which the prior for the MCD survey was not used compared to the base model (BASE7). The scale differs between the two but the trend is similar.

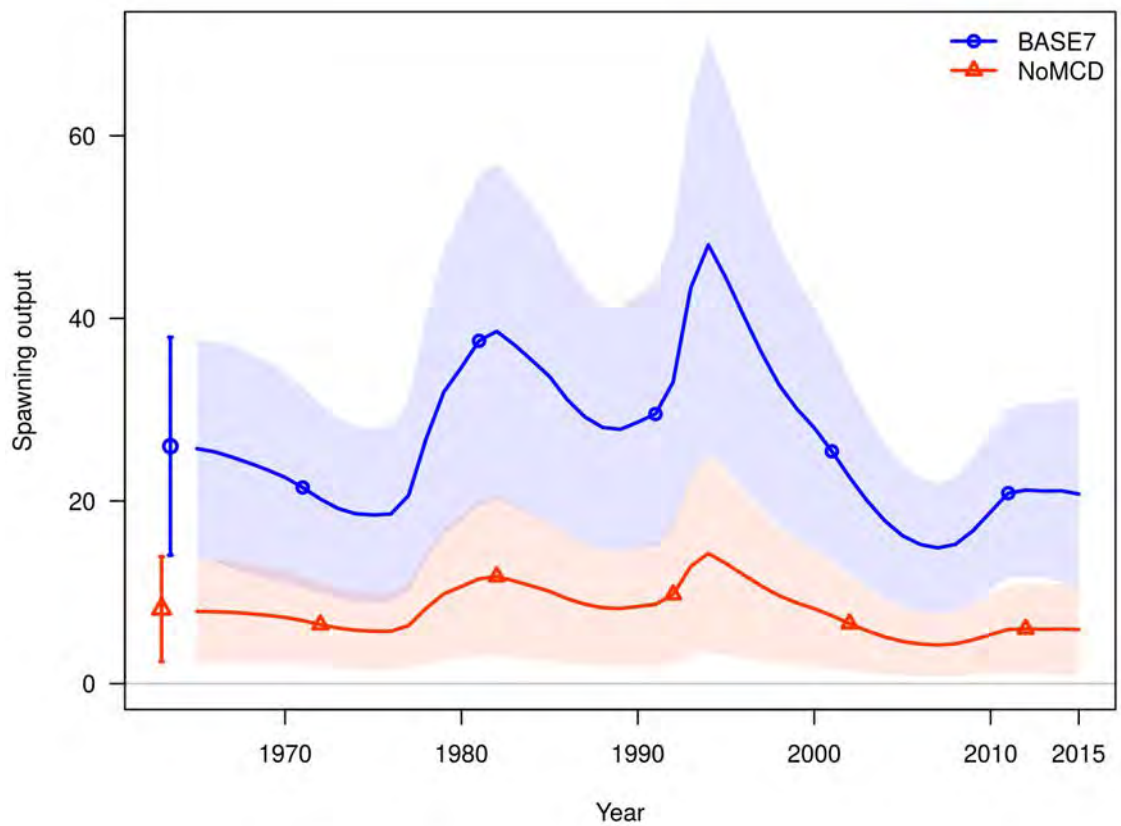


Figure 137: Biomass trend in a model sensitivity run for Atlantic surfclam in the southern area in which the likelihood component associated with the fit the MCD survey was reduced to 0, compared to the base model (BASE7). The scale differs between the two but the trend is similar.

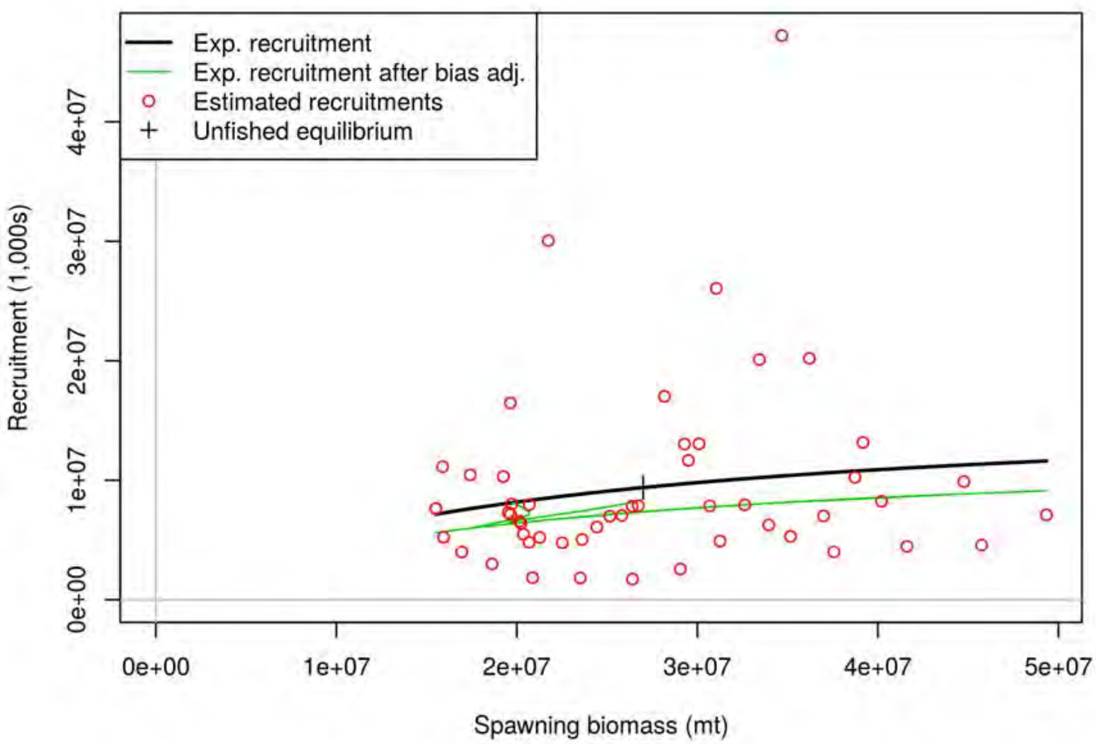


Figure 138: Stock recruit relationship with steepness estimated in a model sensitivity run for Atlantic surfclam in the southern area. There is no information to inform the left side of the stock recruit curve because no low stock sizes have been observed.

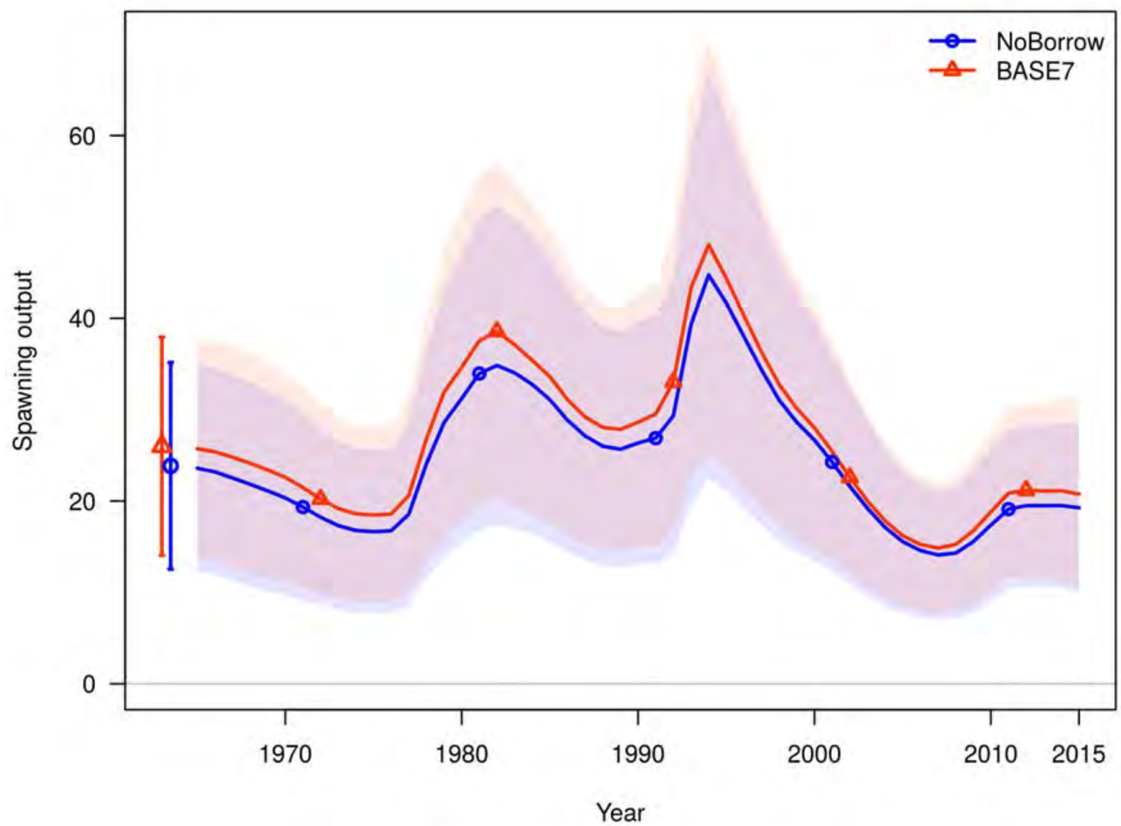


Figure 139: Biomass scale and uncertainty from 2 model runs, one in which the conditional age at length data was not borrowed from 2013 to 2012 (NoBorrow) and the other being the base model run for Atlantic surfclam in the southern area (BASE7). The biomass trajectories from each run were nearly identical.

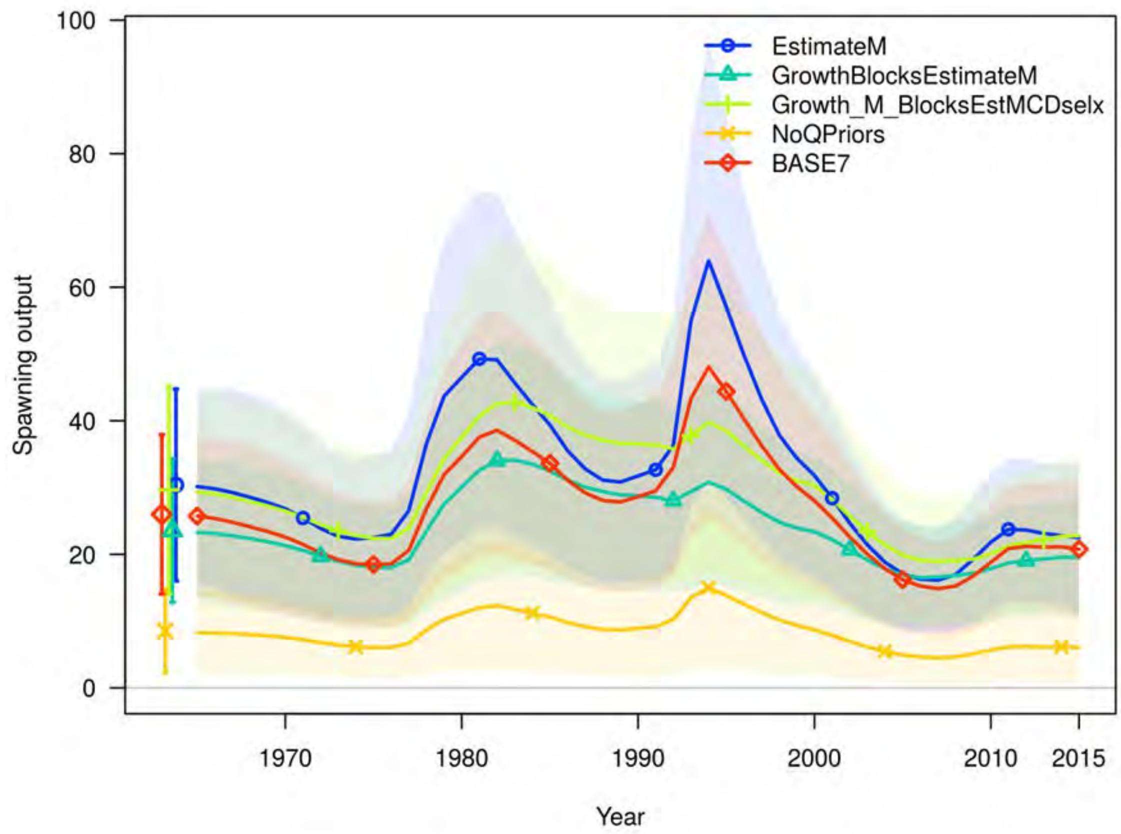


Figure 140: Biomass scale and uncertainty from several sensitivity model runs compared to the base run (BASE7) for Atlantic surfclam in the southern area. Each of the runs produced similar trends and only the run in which no prior distributions for catchability were used produced large differences in scale.

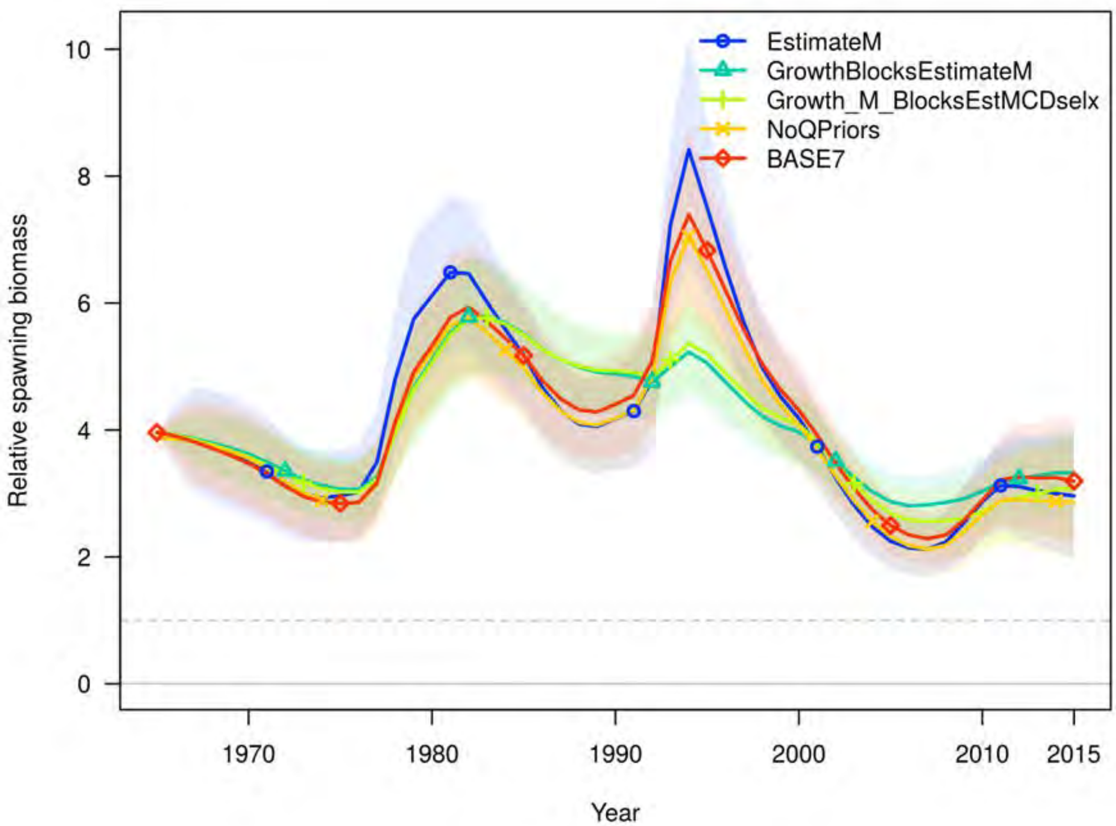


Figure 141: Relative spawning biomass and uncertainty from several sensitivity model runs compared to the base run (BASE7) for Atlantic surfclam in the southern area. Each of the runs produced similar trends. There was very little difference between the two runs. The trends depict the ratio of the biomass in each year to B_0 and include a dashed line at $\frac{B}{B_0} = 0.25$.

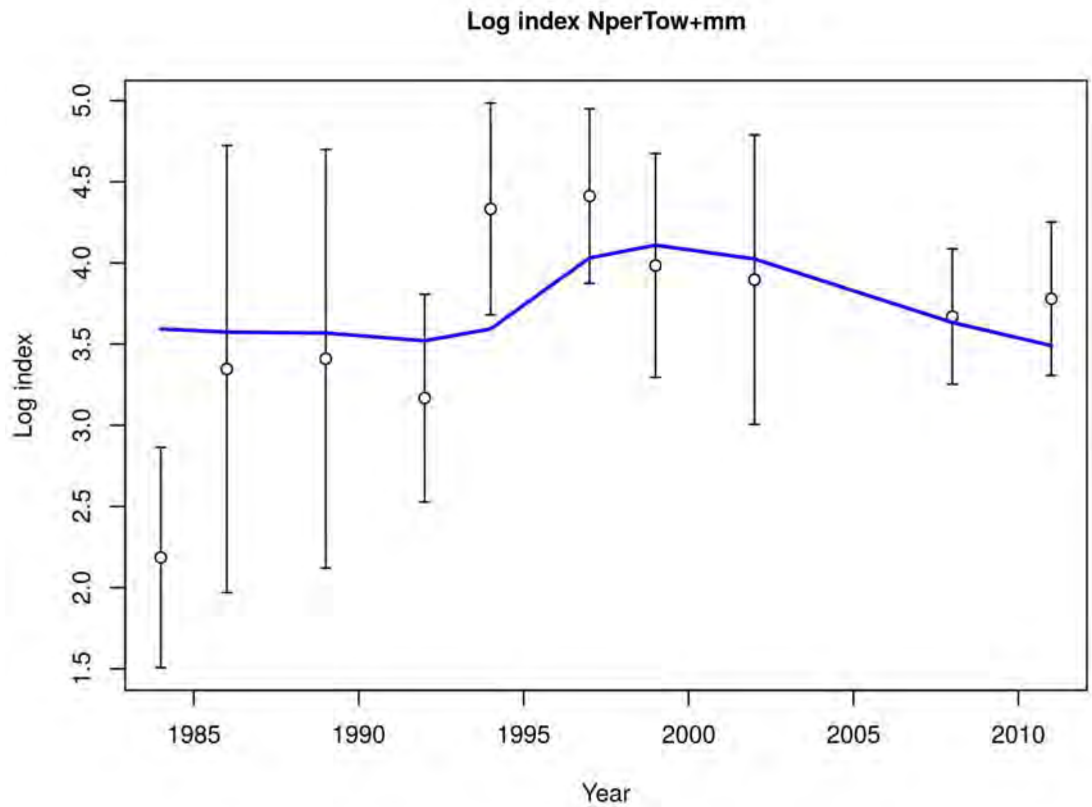


Figure 142: Model fit to the log of the RD survey index estimated in a model sensitivity run for Atlantic surfclam in the northern area in which the R_0 parameter was allowed to vary over time in two blocks (before and after 1995).

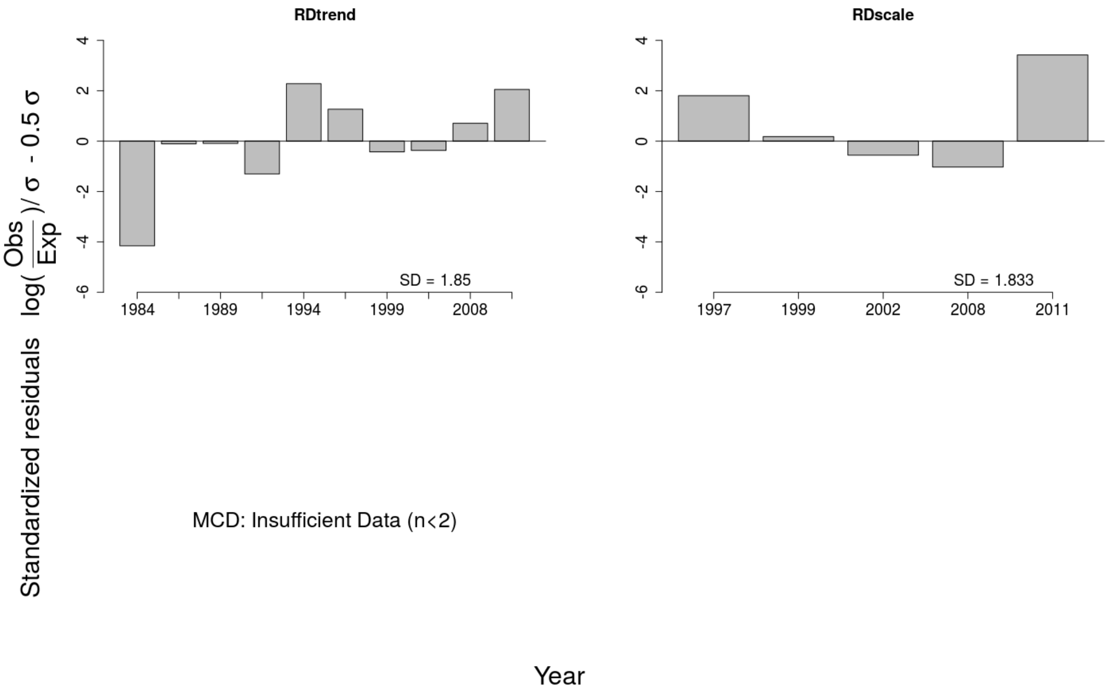


Figure 143: Standardized residuals from the model fit to the RD survey index estimated in a model sensitivity run for Atlantic surfclam in the northern area in which recruitment variance was increased by 100%.

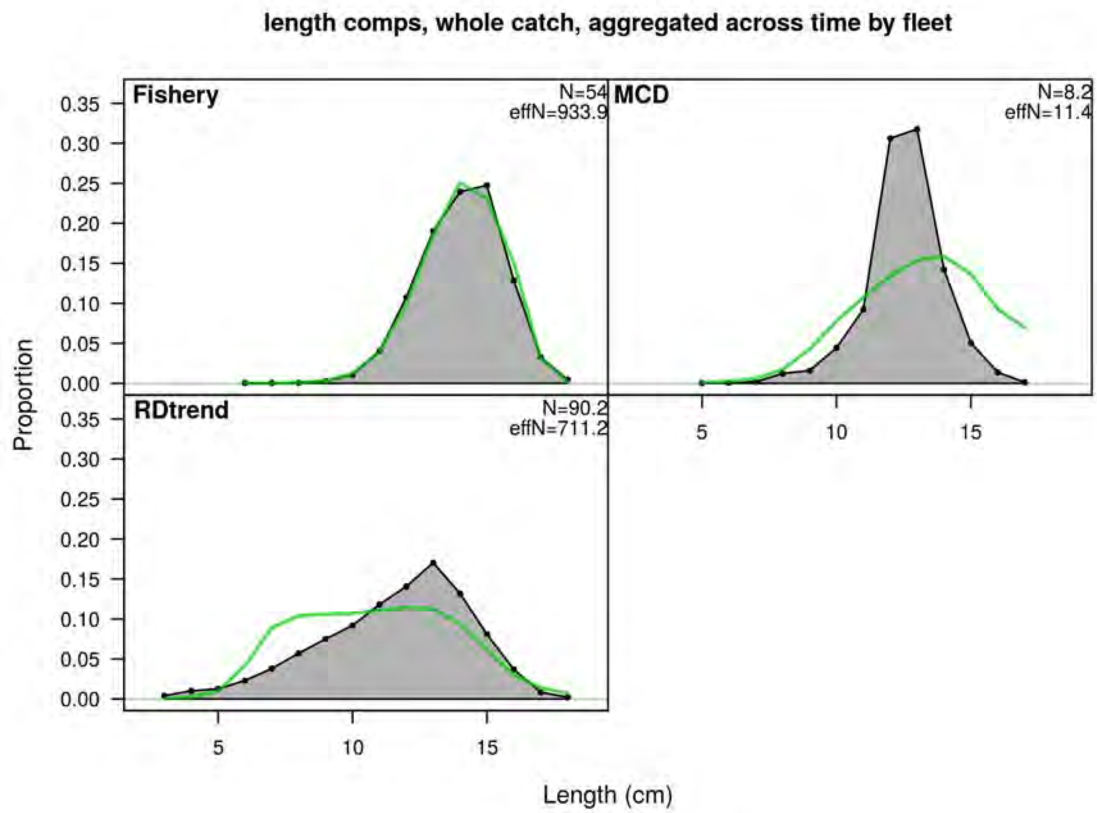


Figure 144: Length composition fits in a model sensitivity run for Atlantic surfclam in the northern area in which the weight of the likelihood component associated with the RD survey was increased by 1000%.

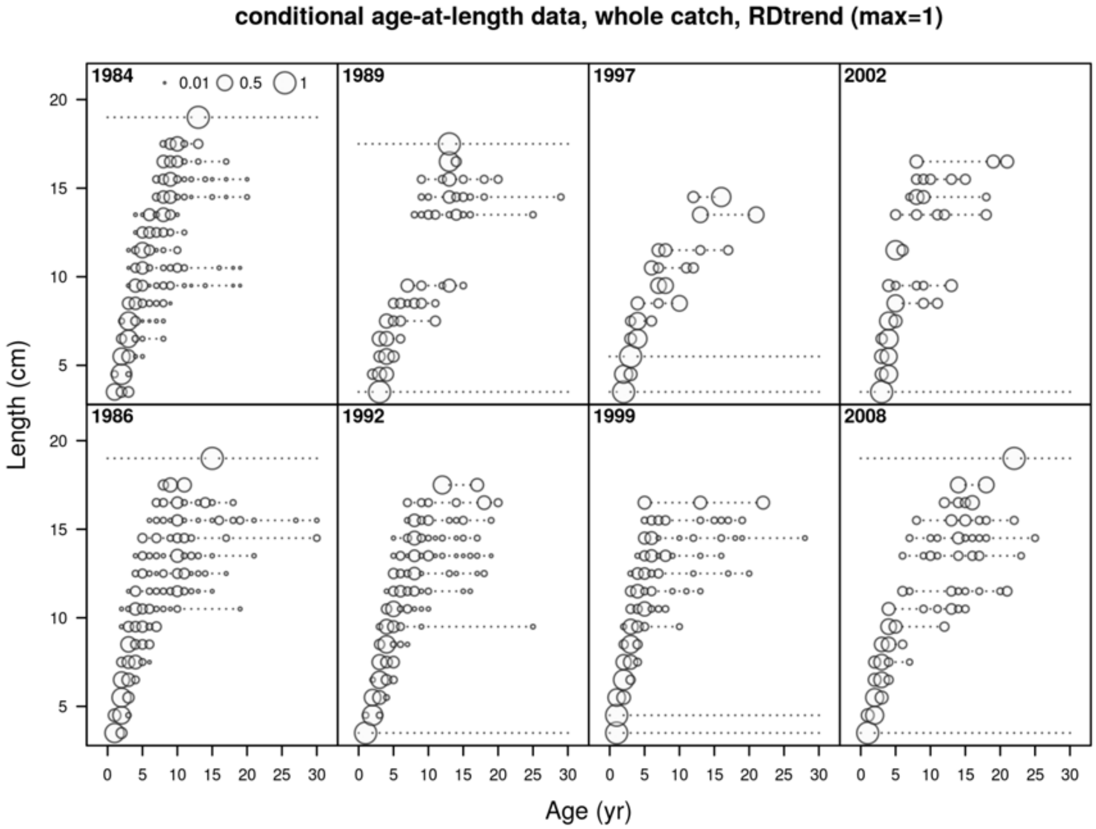


Figure 145: Standardized residuals from conditional age at length composition fits in a model sensitivity run for Atlantic surfclam in the northern area in which the weight of the likelihood component associated with the RD survey was increased by 1000%.

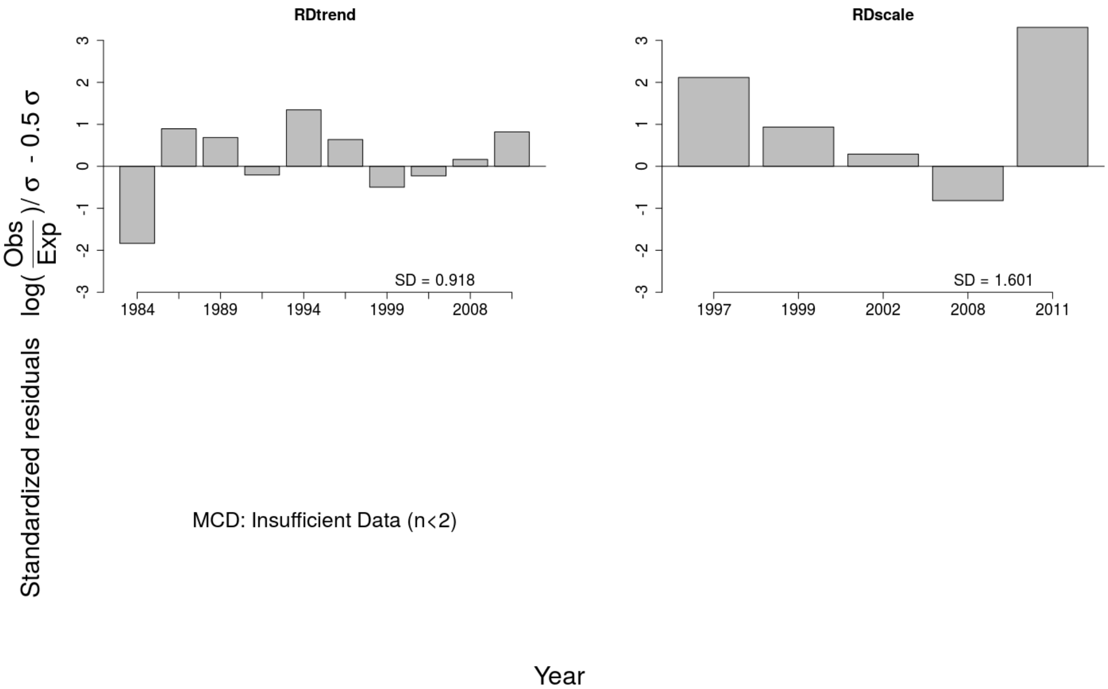


Figure 146: Standardized residuals from the model fit to the RD survey index estimated in a model sensitivity run for Atlantic surfclam in the northern area in which recruitment variance was increased by 100%.

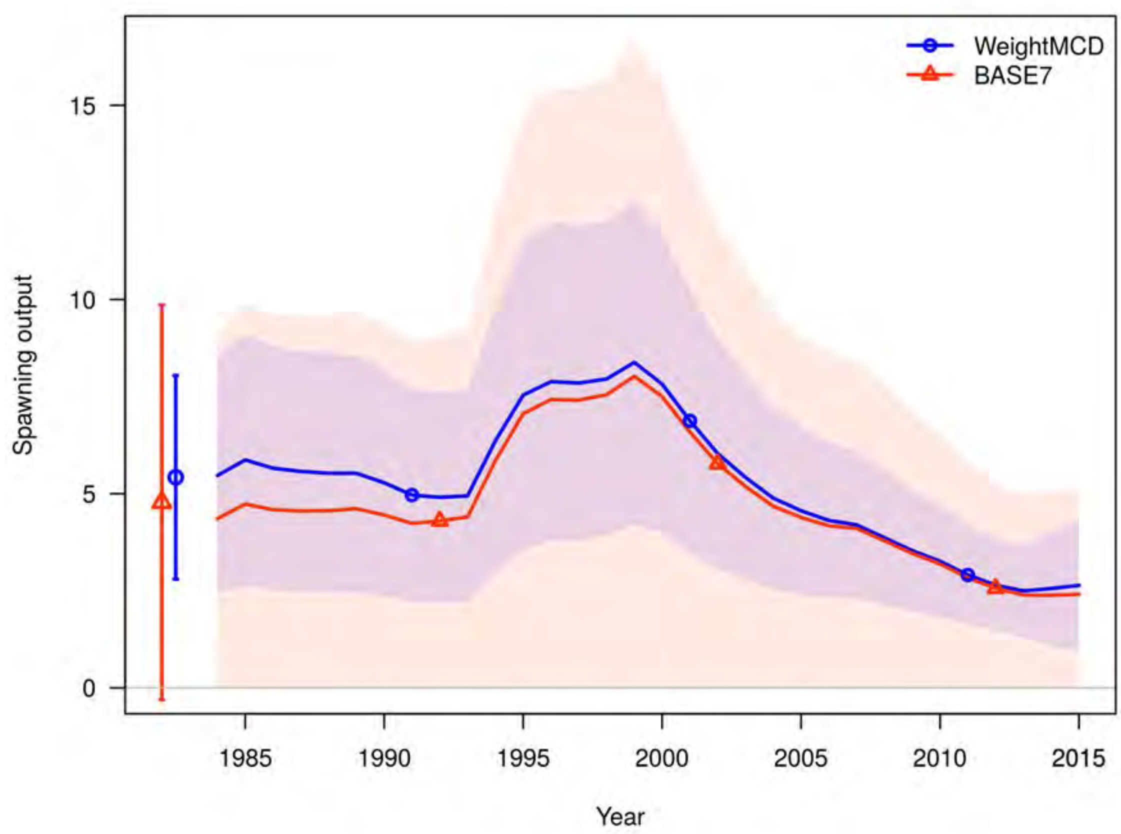


Figure 147: Estimated biomass from a model sensitivity run for Atlantic surfclam in the northern area in which the relative variance associated with the MCD survey index was reduced by about 50%, compared to estimated biomass from the base model run (BASE6).

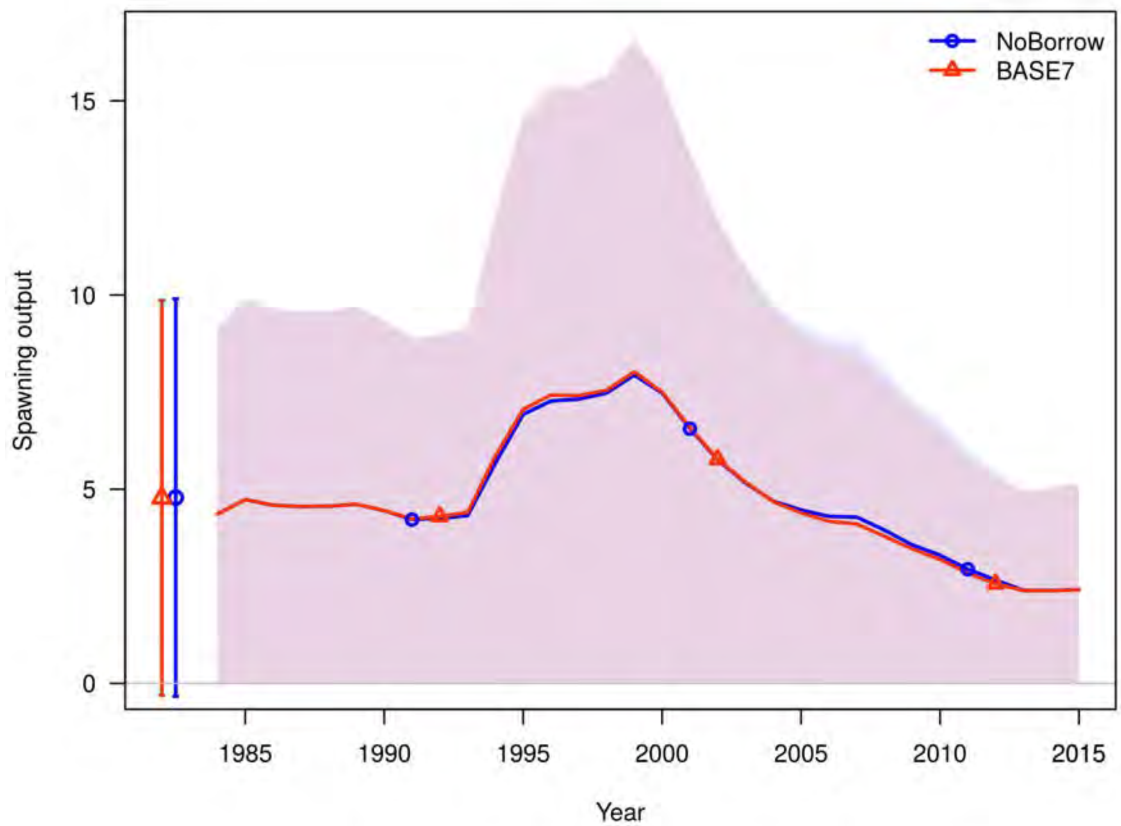


Figure 148: Biomass scale and uncertainty from 2 model runs, one in which the likelihood weight on the MCD survey trend information was set to 0 (RemoveMCD) and the other being the base model run for Atlantic surfclam in the northern area (BASE6). The biomass trajectories from each run were similar but the scale was not.

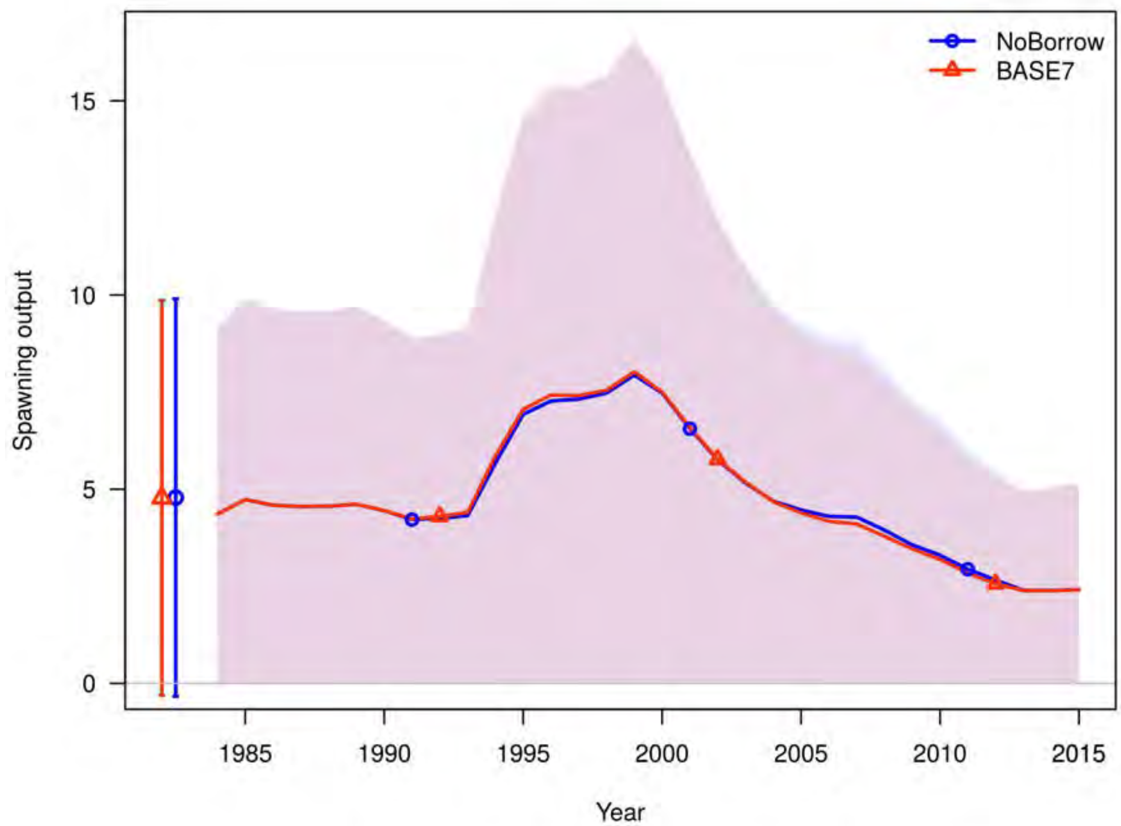


Figure 149: Biomass scale and uncertainty from 2 model runs, one in which the conditional age at length data was not borrowed from 2014 to 2013 (NoBorrow) and the other being the base model run for Atlantic surfclam in the northern area (BASE6). The biomass trajectories from each run were similar and the confidence regions overlapped.

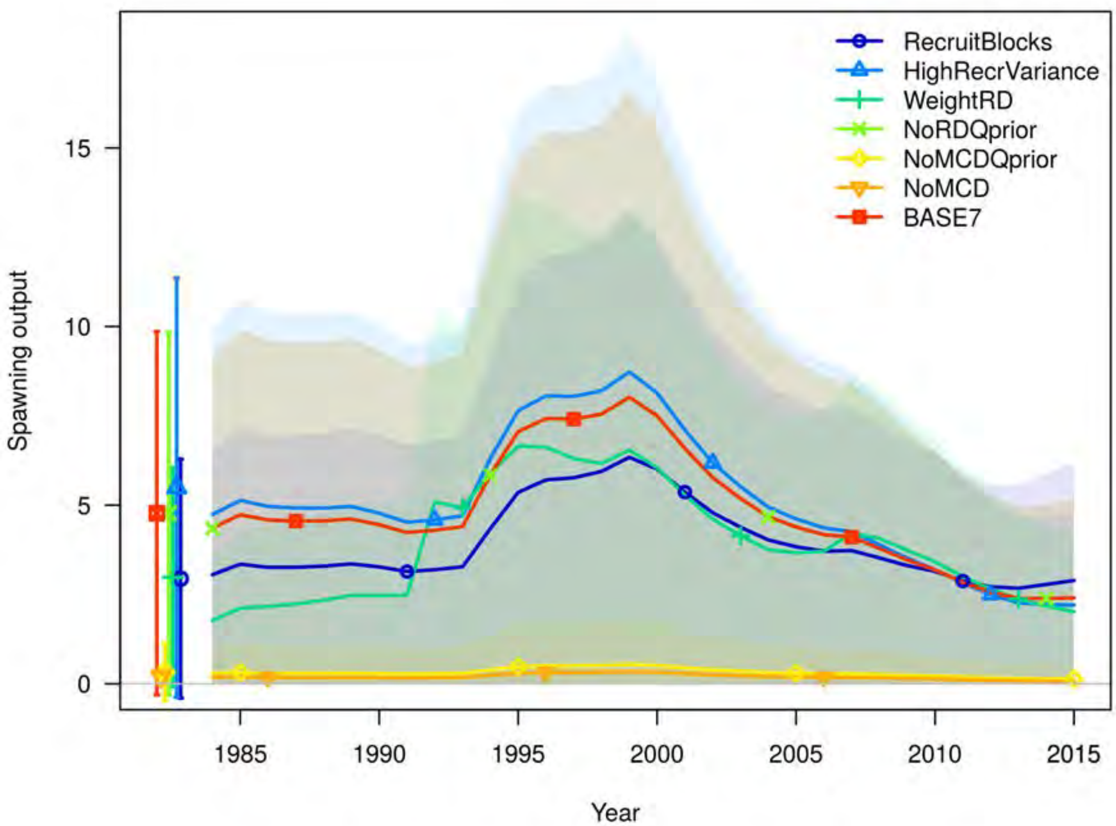


Figure 150: Biomass scale and uncertainty from several sensitivity model runs compared to the base run (BASE6) for Atlantic surfclam in the northern area. Each of the runs produced similar trends except when the model was forced to fit the early survey time series (WeightRD), but different scales when the information from the MCD survey was removed (NoMCD) or when the prior distribution for the catchability of the MCD was turned off (NoMCDprior).

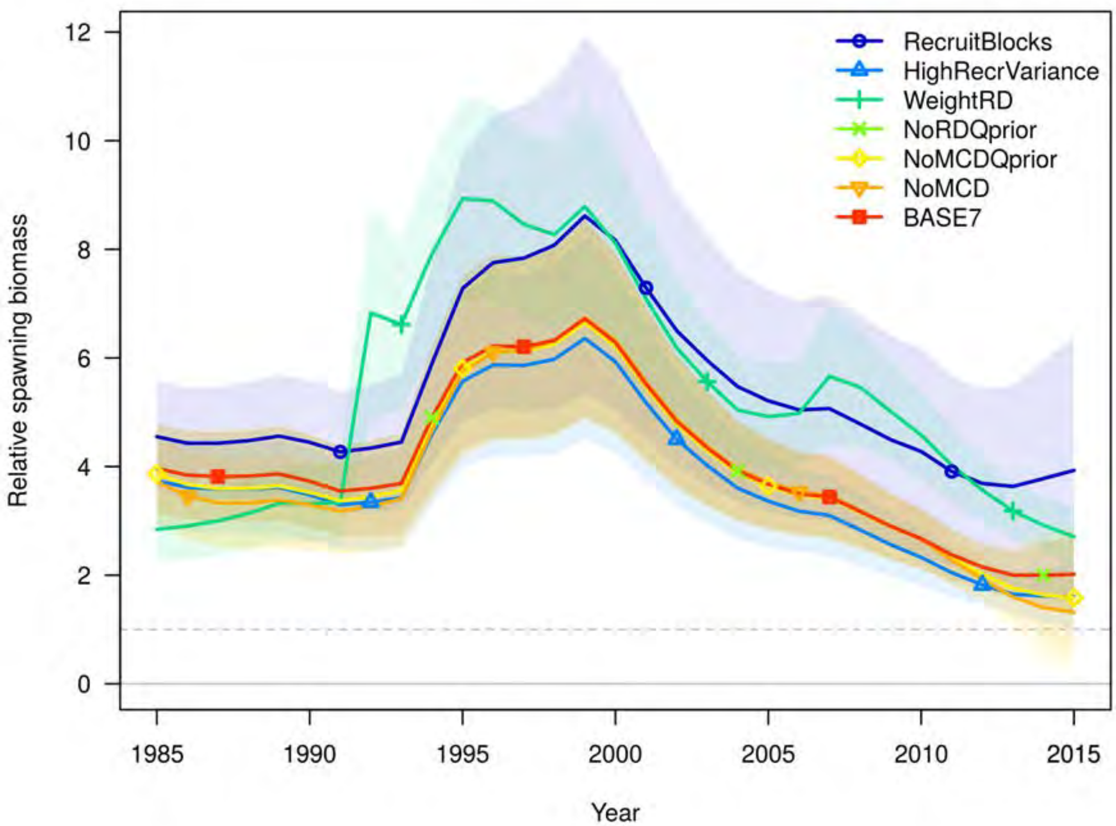


Figure 151: Relative spawning biomass and uncertainty from several sensitivity model runs compared to the base run (BASE6) for Atlantic surfclam in the northern area. Each of the runs produced similar trends except when the model was forced to fit the early survey time series (WeightRD). The trends depict the ratio of the biomass in each year to B_0 and include a dashed line at $\frac{B}{B_0} = 0.25$.

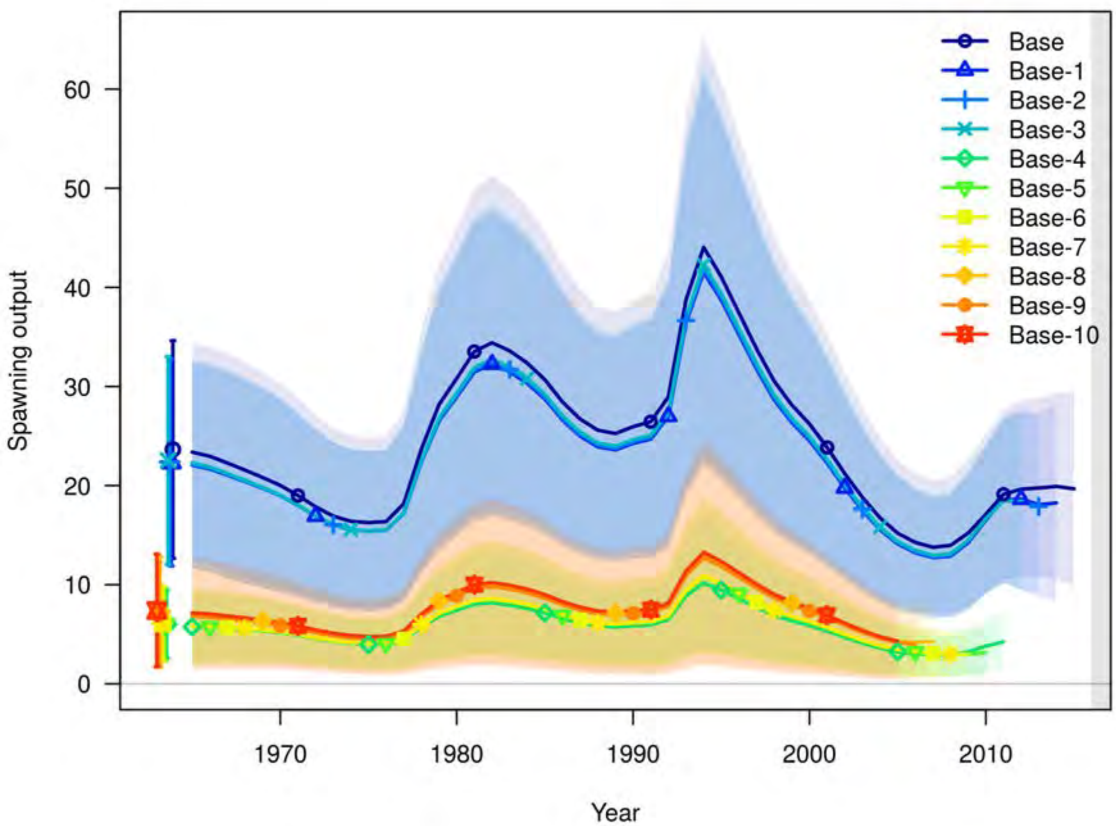


Figure 152: Biomass scale and uncertainty from 10 retrospective runs of the model for the southern area. The biomass scale shifts when the MCD survey is removed from the model. The dashed line represents a theoretical threshold value where the biomass is equal to 25% of the virgin biomass estimated in each retrospective run.

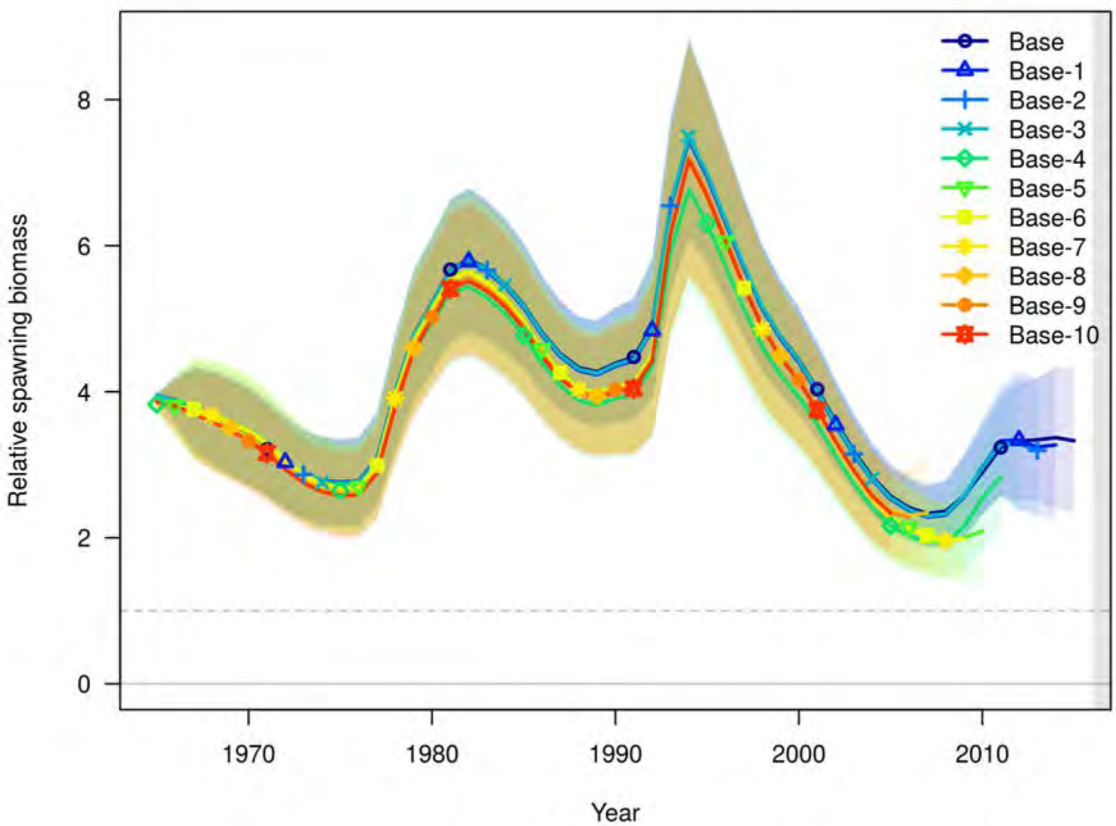


Figure 153: Relative spawning biomass and uncertainty from 10 retrospective runs of the model for the southern area. The trend in biomass is robust to the removal of data from recent years.

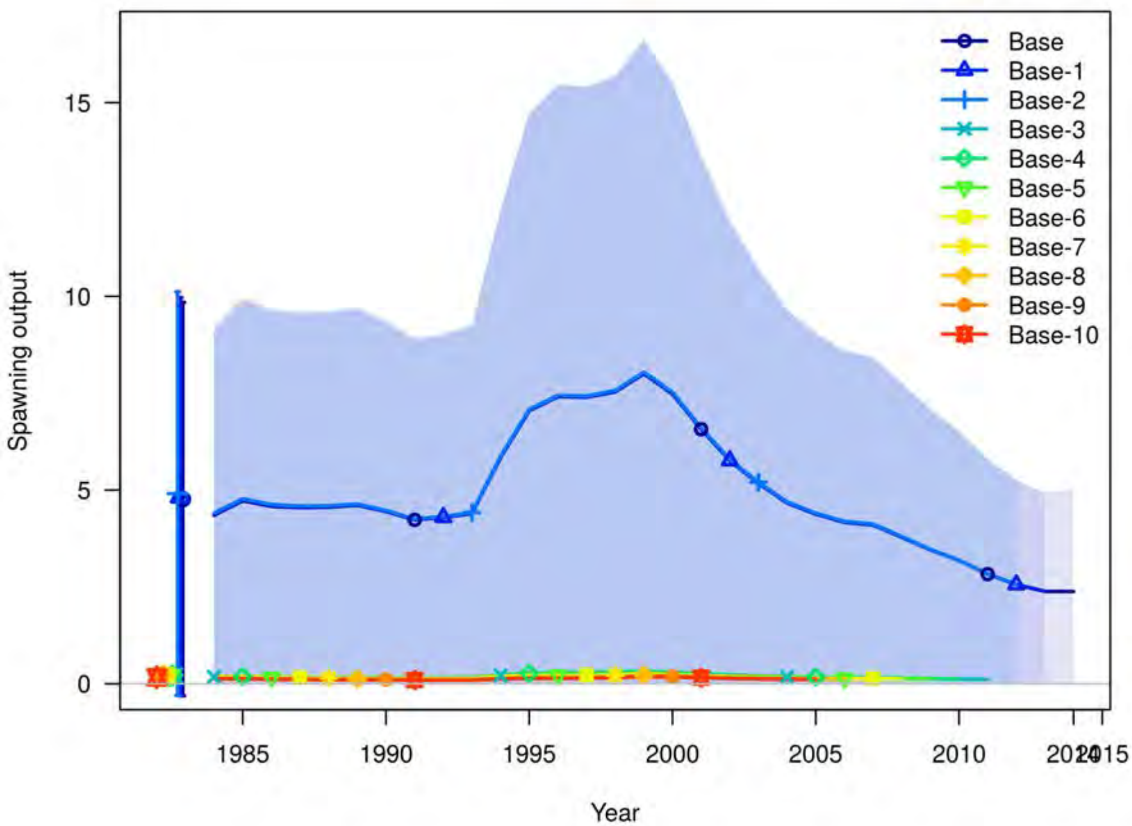


Figure 154: Biomass scale and uncertainty from 10 retrospective runs of the model for the northern area. The biomass scale shifts when the MCD survey is removed from the model.

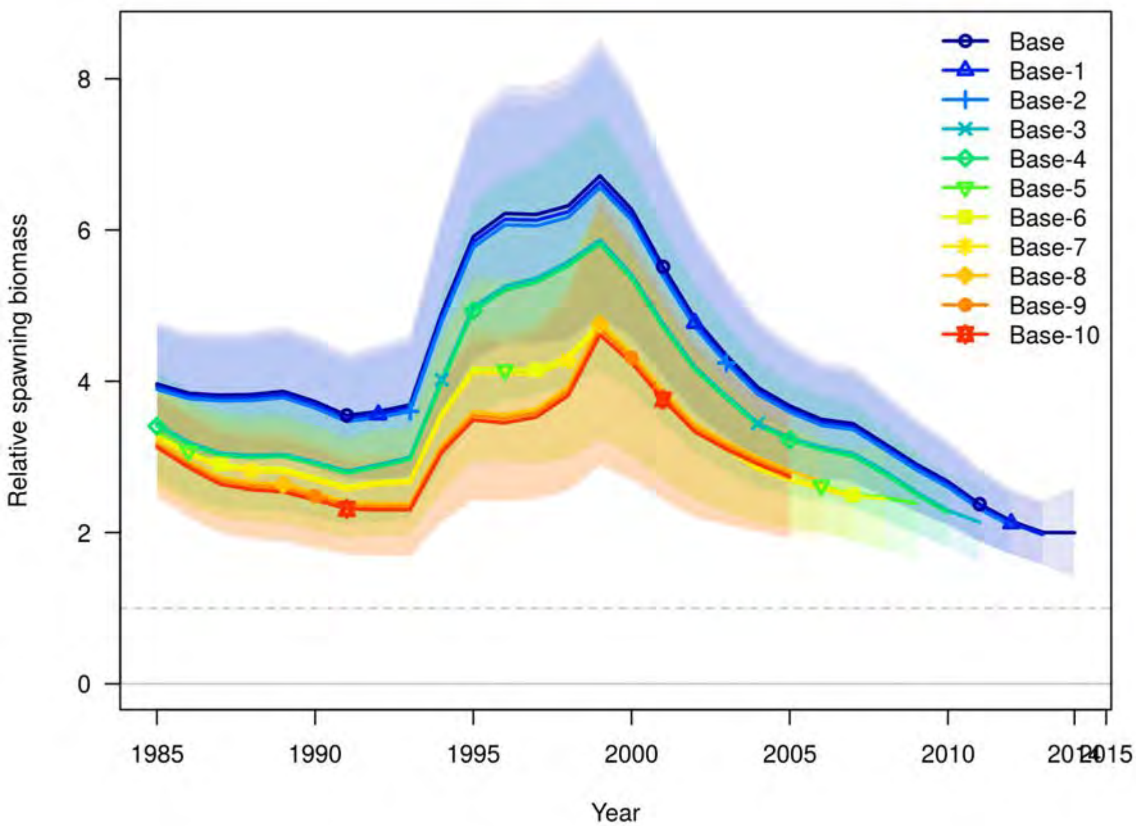


Figure 155: Relative spawning biomass and uncertainty from 10 retrospective runs of the model for the northern area. The dashed line represents a theoretical threshold value where the biomass is equal to 25% of the virgin biomass estimated in each retrospective run.

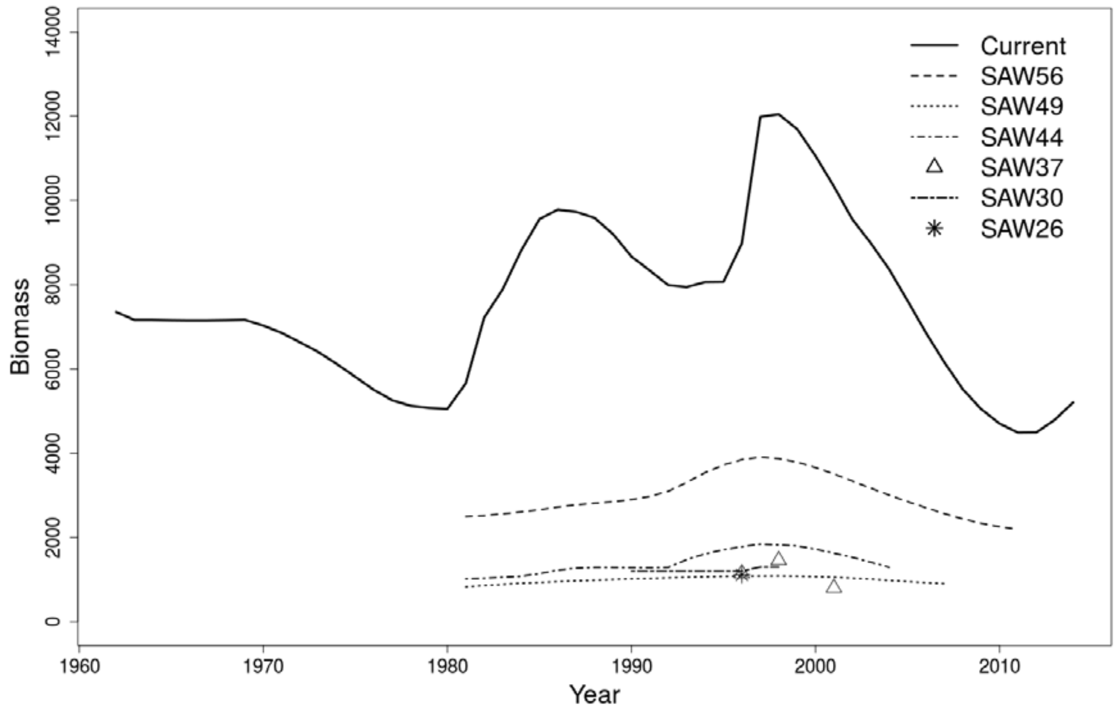


Figure 156: Historical retrospective plot showing the biomass trajectory from each of the previous Atlantic surfclam assessments.

Figures

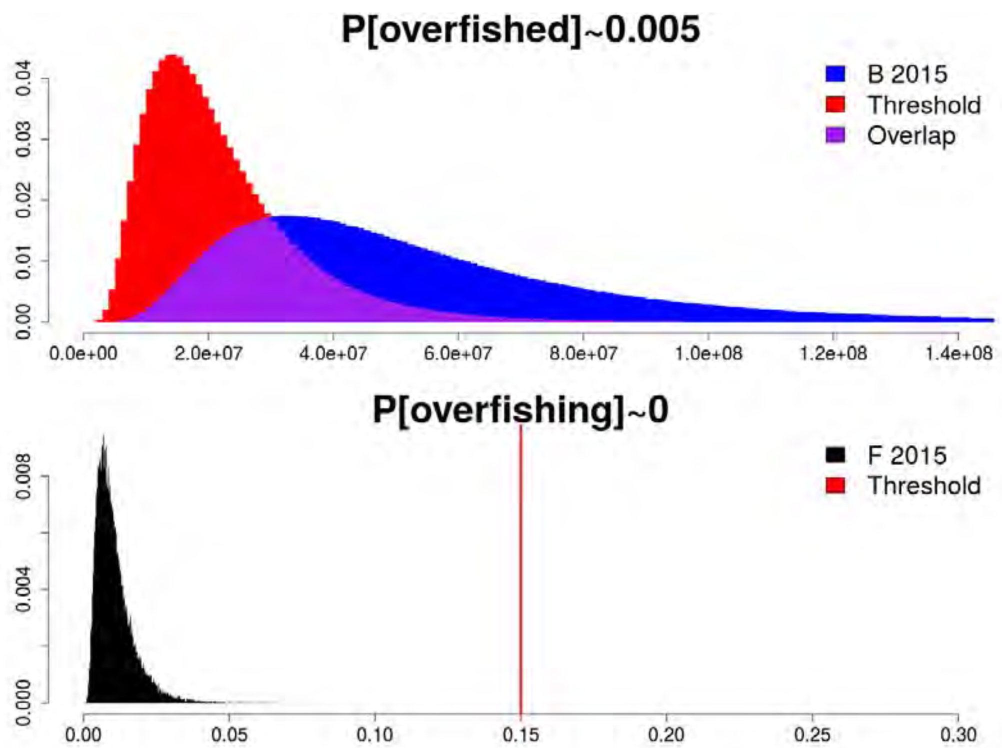


Figure 157: Probability of overfished and overfishing status during 2015 using the current reference points from the previous assessment. The overfished probability (upper panel) presented in this figure accounts for the positive correlation between the reference point ($\frac{B_{1999}}{4}$) and the biomass in 2015, which results in a probability of overfished status that is less than the apparent overlap between the two distributions. The current $F_{Threshold}$ is a point estimate and uncorrelated to F_{2015}. Therefore, the probability of overfishing was equal to the probability of overlap between the distribution of F_{2015} and the point estimate of $F_{Threshold}$.

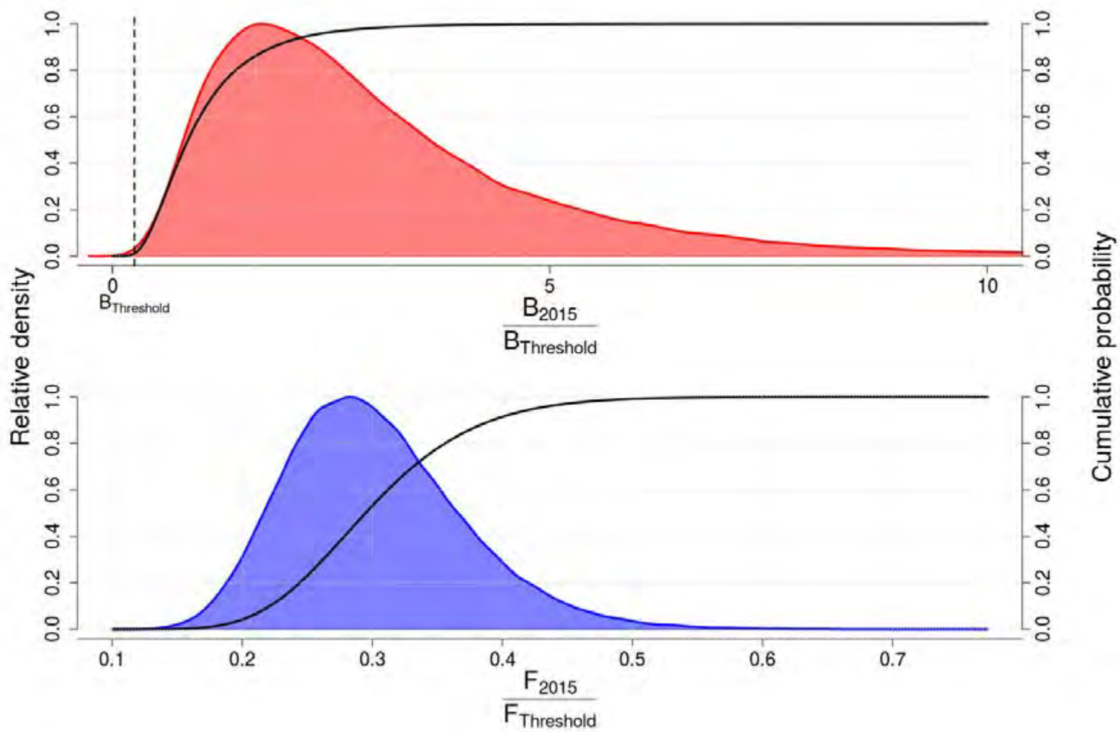


Figure 158: Probability distributions of $\frac{B_{2015}}{B_{Threshold}}$ and $\frac{F_{2015}}{F_{Threshold}}$, using the recommended reference points. The probability of overfished status during 2015 is equal to the area of the red, upper curve that is less than $B_{Threshold}$. The probability of overfishing status during 2015 is equal to the area of the blue, lower curve that is greater than $F_{Threshold}$. The probability of overfished and overfishing status can be approximated by the elevation (y axis scale) at which the solid line representing the cumulative probability distribution crosses the dashed vertical line representing the reference point in each plot. The probability distributions presented in this figure account for the positive correlation between the reference points ($B_{Threshold} = \frac{B_0}{4}$ and $F_{OFL} = F_{Threshold} = F^* \frac{F_{MSY}}{F^*_{Max}}$) and the fishing mortality and biomass estimates in 2015, as well as the uncertainty in the estimation of both the point estimates and their respective reference points.

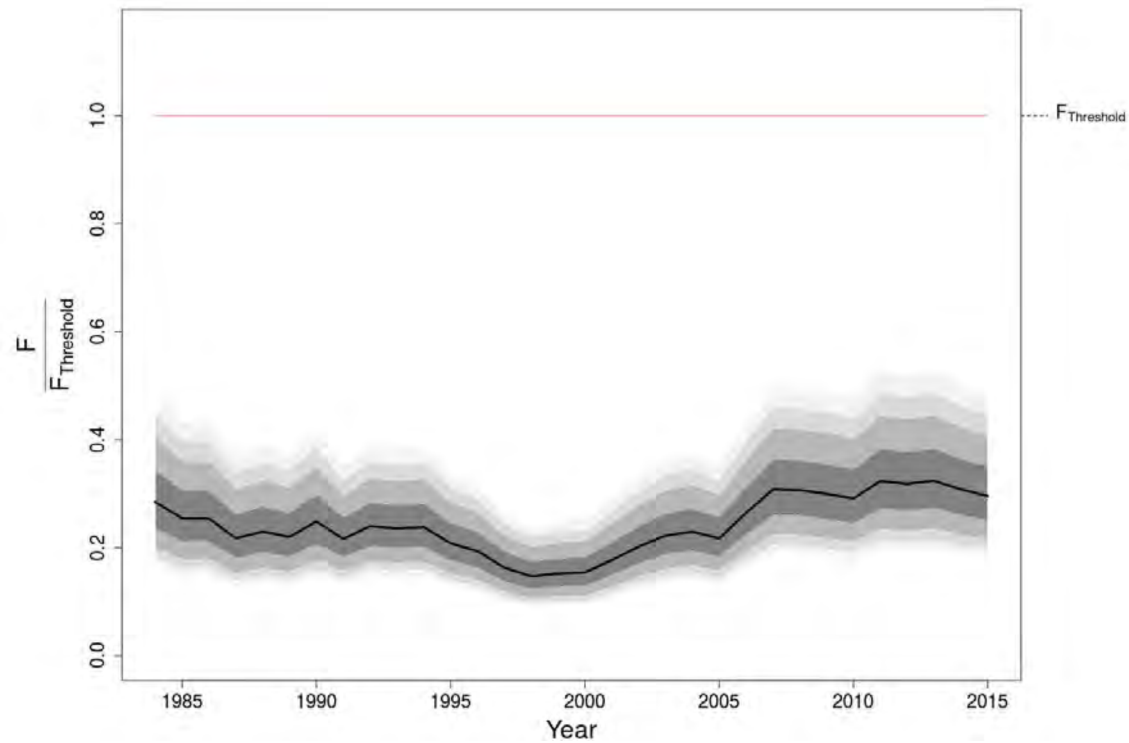


Figure 159: The time series of the ratio of fishing mortality estimates to the recommended F threshold, with the 50, 80, 90, and 95 % lognormal confidence intervals in shades of gray. The confidence intervals account for the correlation between F and $F_{Threshold}$. Over fishing would occur if the ratio exceed 1.0.

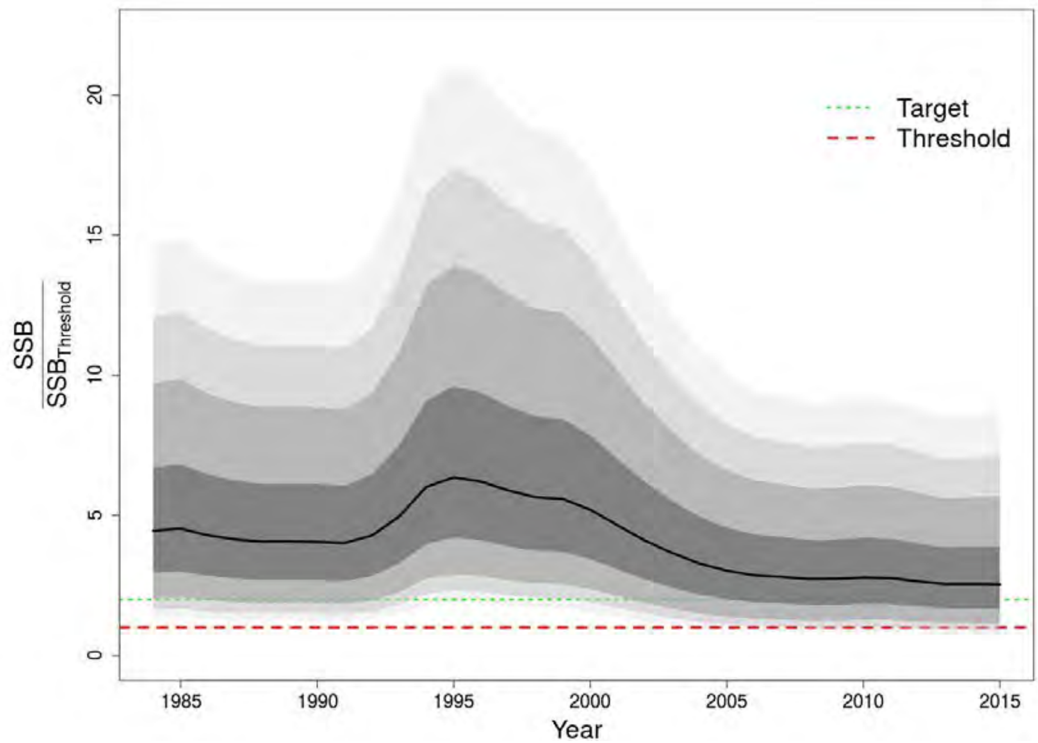


Figure 160: The time series of the ratio of biomass estimates to the unfished biomass (B_0), with the 50, 80, 90, and 95 % lognormal confidence intervals in shades of gray. The confidence intervals account for the correlation between B and B_0. Overfished status would occur if the ratio went below 0.25.

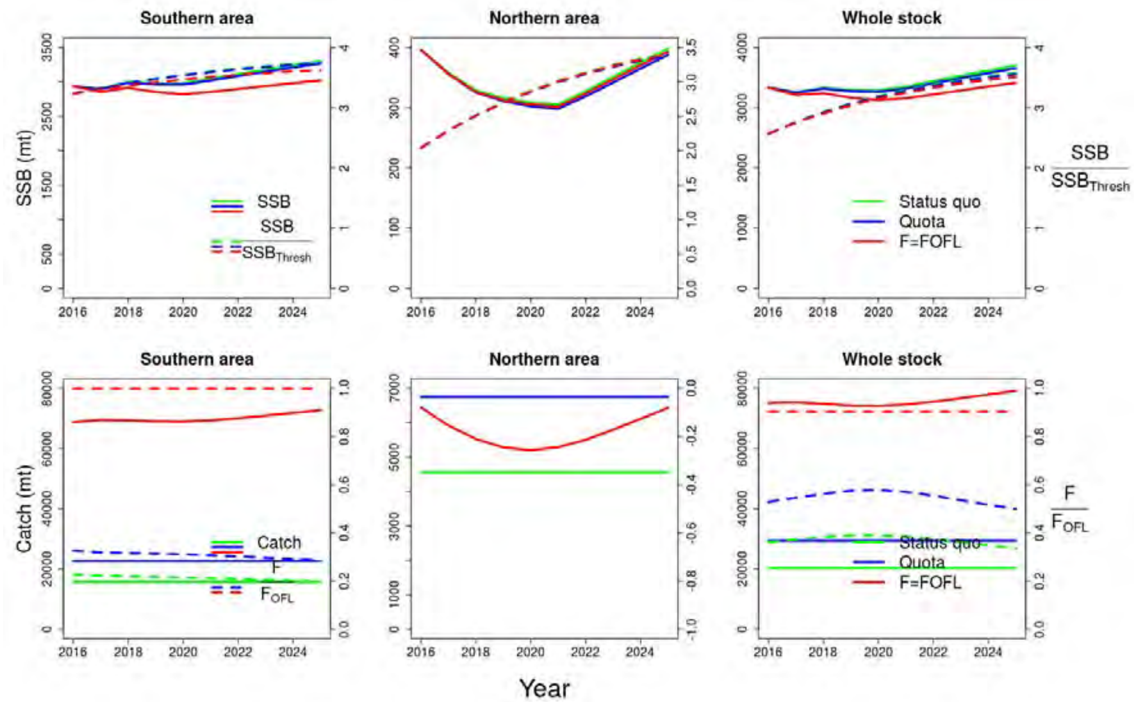


Figure 161: Projections using three different catch scenarios in the southern, northern and whole stock areas. The upper row of plots show the biomass trends over time (solid lines) and the ratio of biomass to biomass threshold (dashed lines). The lower plots show the landings (solid lines) and the ratio of F to F_{OFL}. In all plots the status quo catch scenario is green, the quota catch scenario is blue and the $F = F_{OFL}$ scenario is red. Determination of $\frac{F}{F_{OFL}}$ for the northern area was not possible due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.

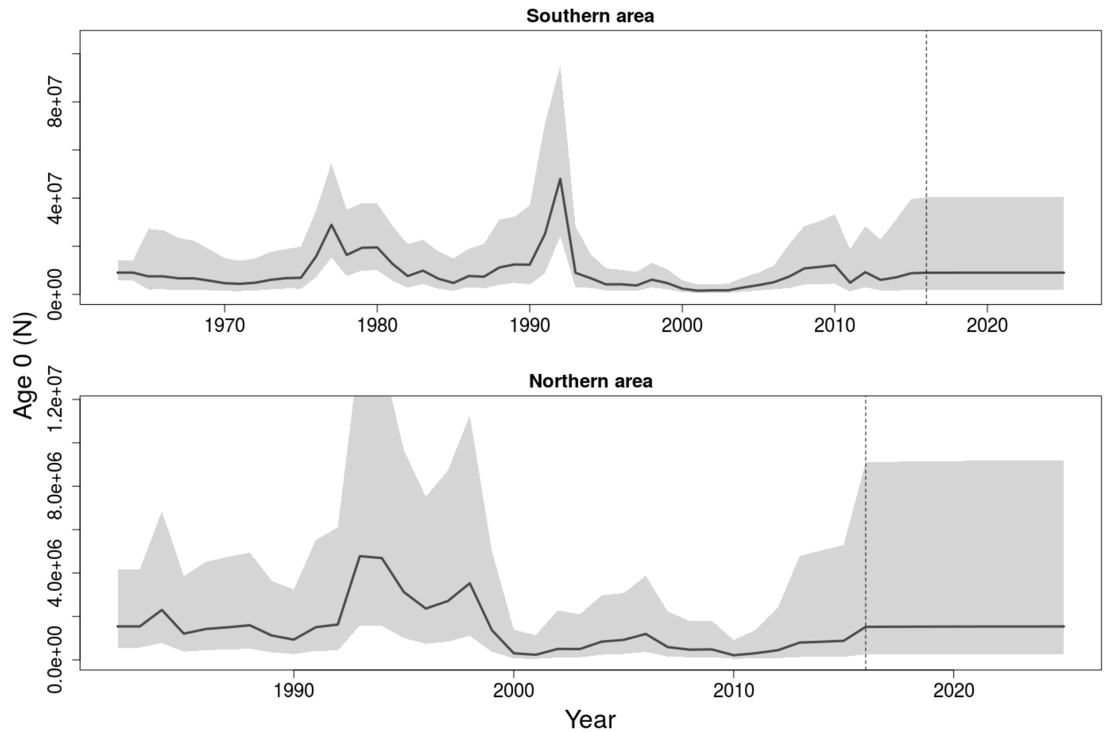


Figure 162: Forecast and time series recruitment estimates for the southern, and northern areas. Projections begin at the vertical dashed line. Note the different ranges of the vertical axes.

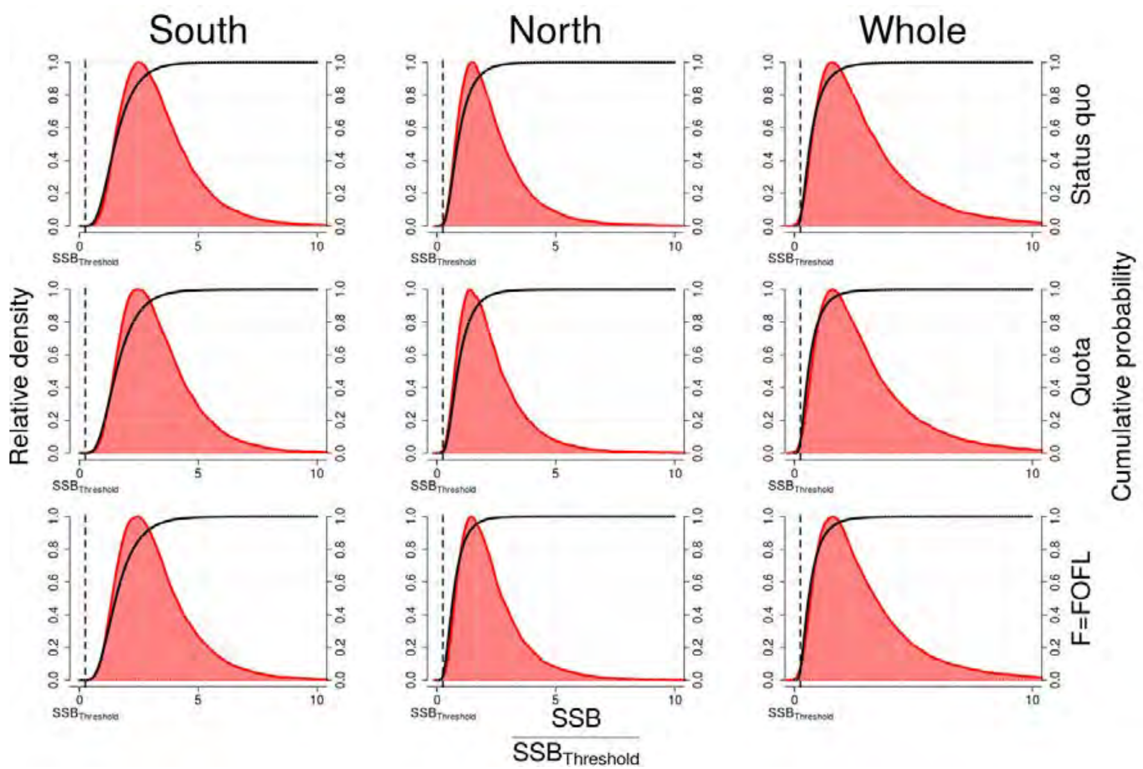


Figure 163: Probability of overfished status for Atlantic surfclam during the projection year with the lowest biomass from 2016-2025. The different catch scenarios are in rows and the different areas are in columns.

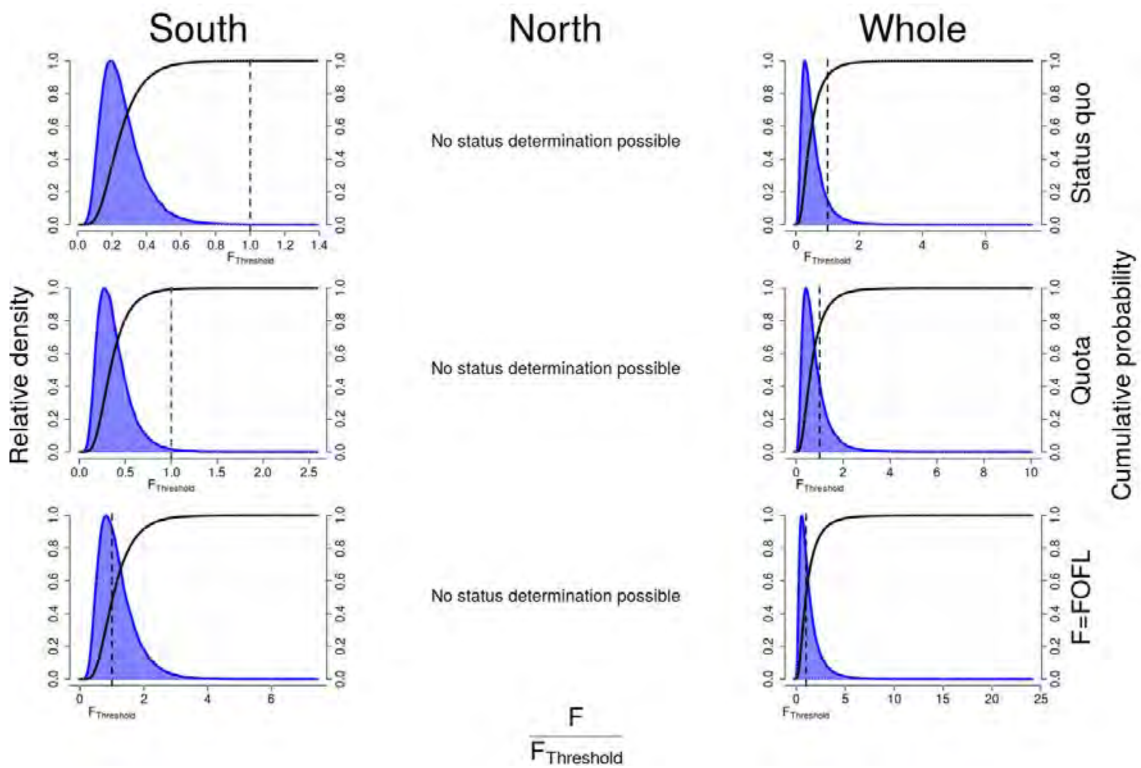


Figure 164: Probability of overfishing status for Atlantic surfclam during the projection year with the highest F from 2016-2025. The different catch scenarios are in rows and the different areas are in columns. Determination of F_{OFL} for the northern area was not possible due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.

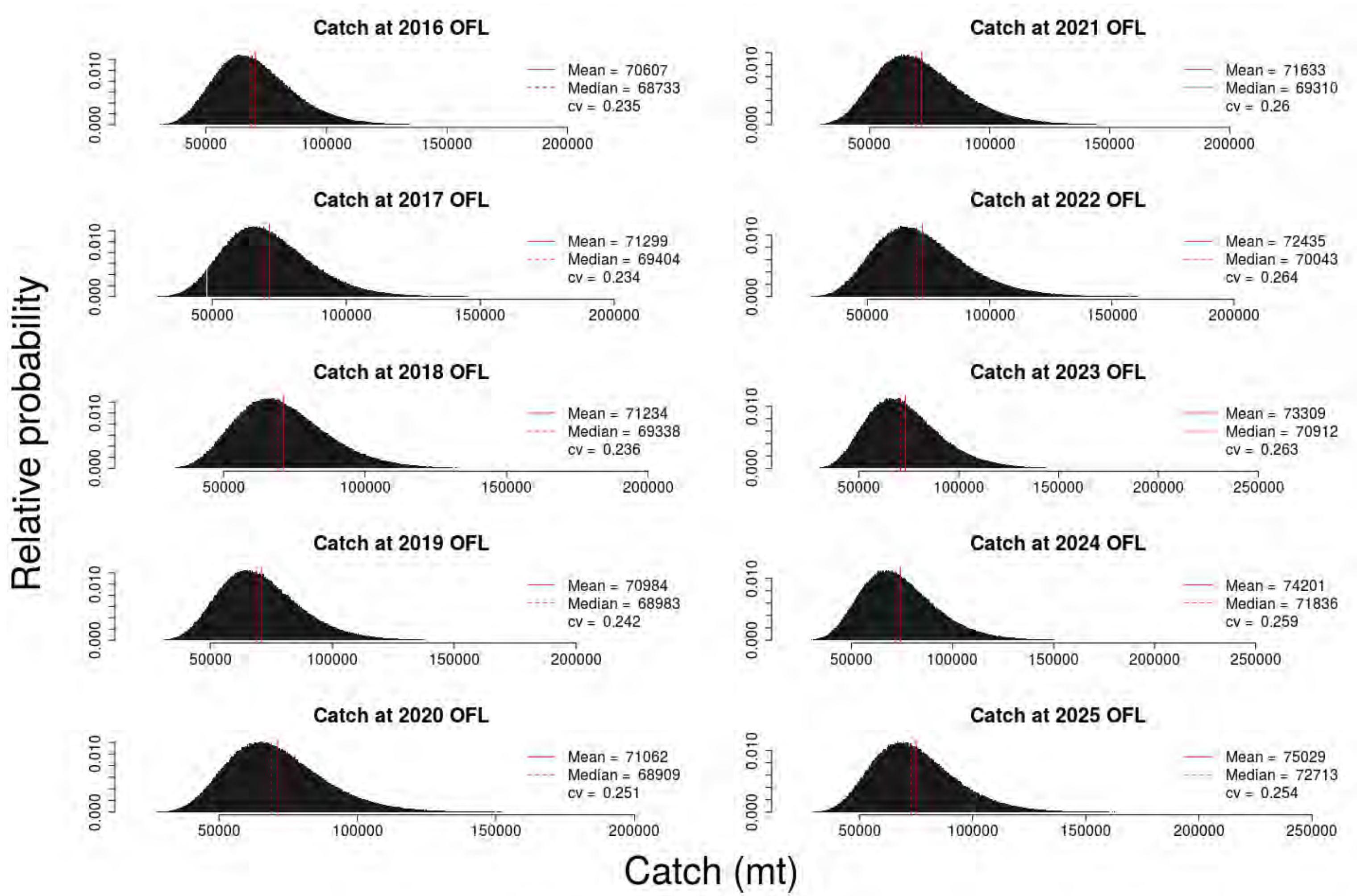


Figure 165: Distribution of catch (landings + incidental mortality) at the Over Fishing Limit (OFL) from 2016-2025 for Atlantic surfclam in the southern area.

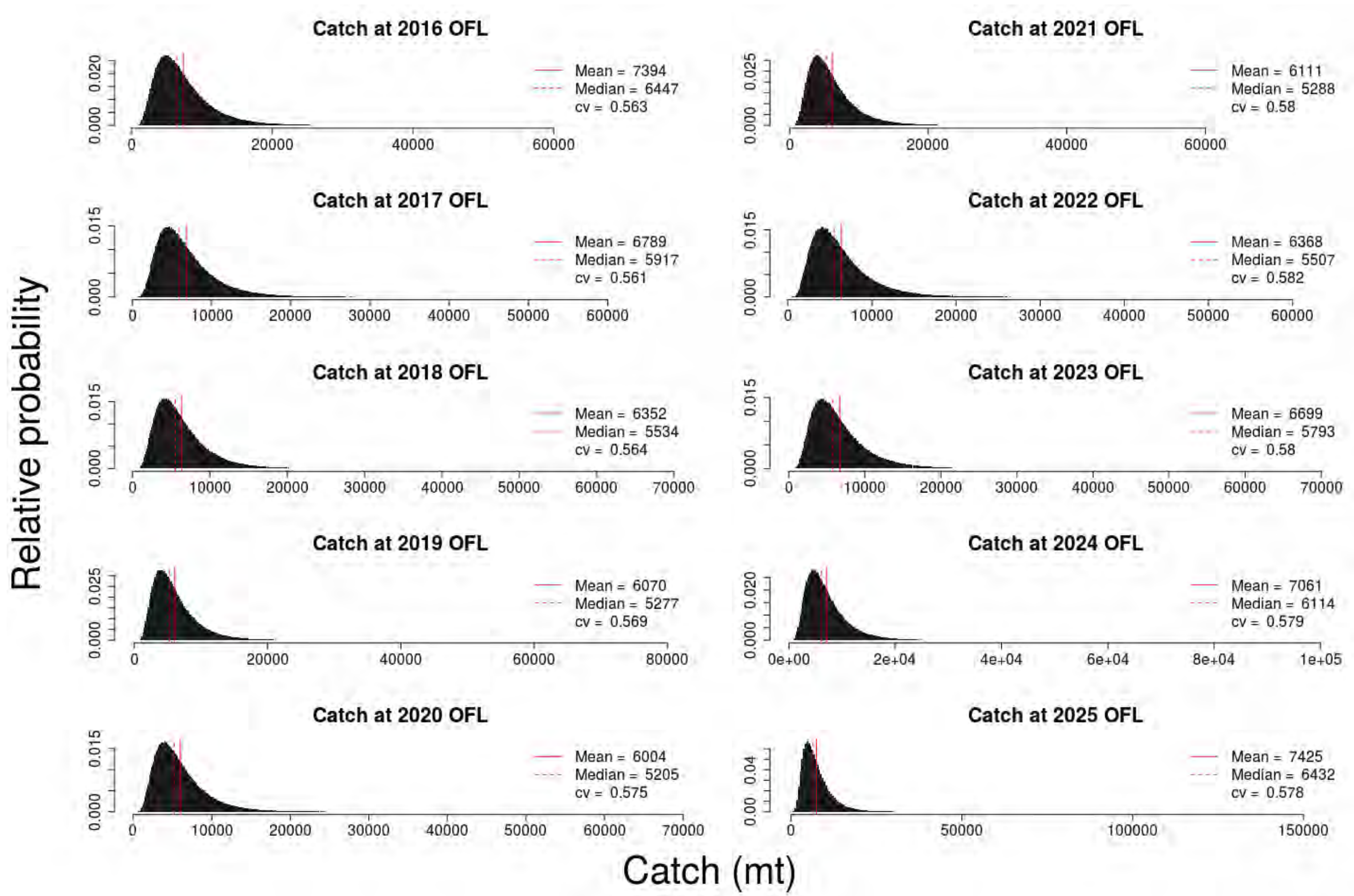


Figure 166: Distribution of catch (landings + incidental mortality) at an approximation of the Over Fishing Limit (OFL) from 2016-2025 for Atlantic surfclam in the northern area. There was not sufficient catch history to generate an OFL for the northern area, so one was approximated based on the average F during years in which fishing occurred.

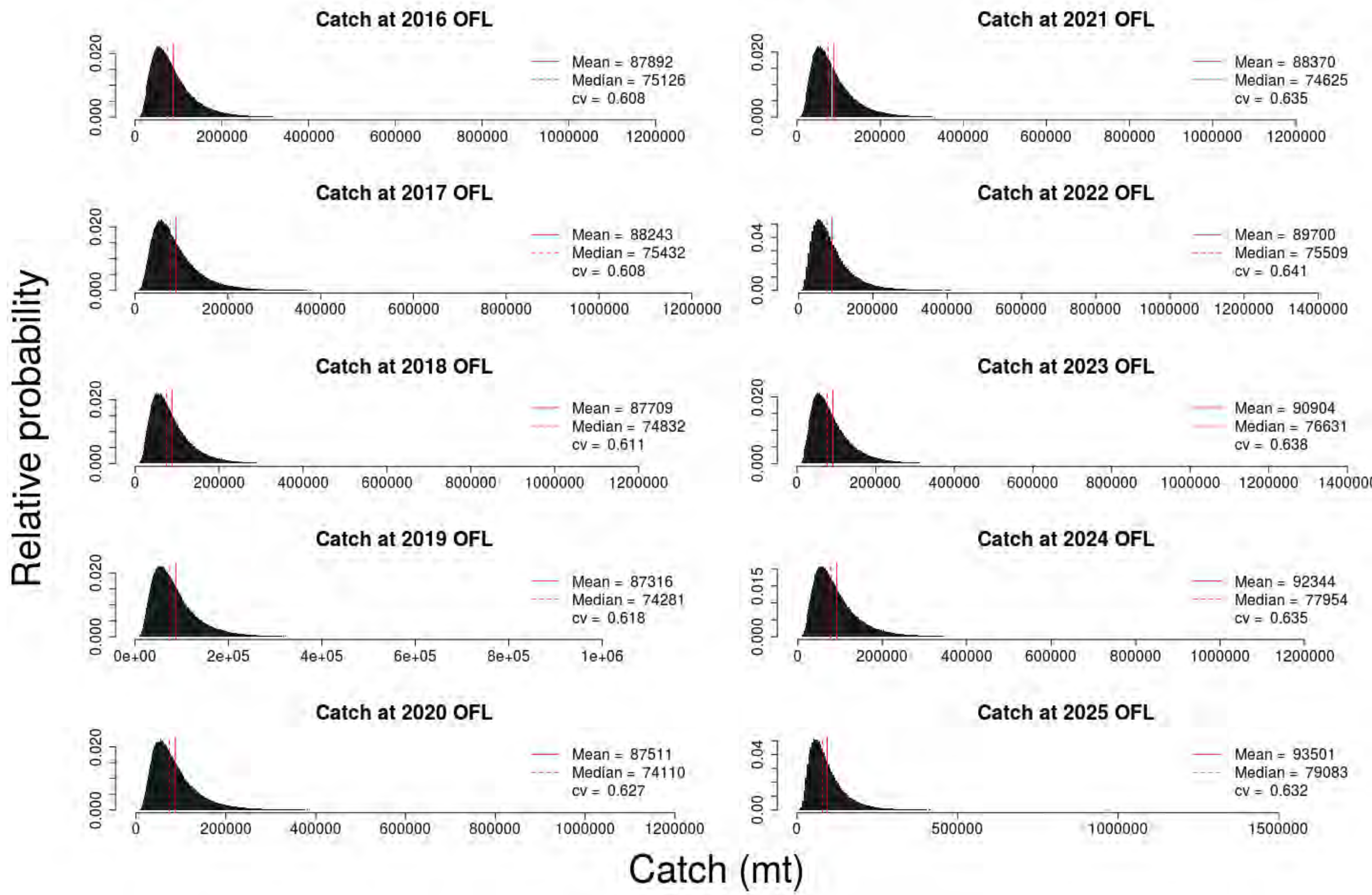


Figure 167: Distribution of catch (landings + incidental mortality) at the Over Fishing Limit (OFL) from 2016-2025 for Atlantic surfclam in the whole stock.

Pro	Con	References
Spatial Patterns in Biological and Other Characteristics		
Growth curves and shell length-meat weight differ markedly between GBK and the southern region.	The differences are clinal or continuous and the split could be made elsewhere or not at all.	Table Table A14, Table A16, Figure A57, A58-62; Kim and Powell (2004); Marzec, et al. (2006); Weinberg (2005)
Post-settlement survival has decreased in the south but not on GBK.	Southern and northern portions of a large stock should respond differently to environmental change. The differences are clinal or concentrated in shallow water south of New Jersey and the split could be made elsewhere or not at all.	NEFSC 2010
Georges Bank tends to retain larvae spawned there due to a persistent gyre current. Published larval drift models for scallops show substantial movement of larvae from GBK to the south, but none from the south to GBK. A detailed unpublished surfclam larval drift presented to the Working Group indicates no movement of larvae from GBK to Southern New England and other southern areas occurs or *vice-versa* assuming no daily mortality during the assumed 35 day larval lifetime observed in culture (X. Zhang and D. Haidvogel, IMCS, Rutgers).	Larval drift models are not definitive and do not cover the whole time period of interest or all possible oceanographic conditions when substantial interchange may occur, particularly between GBK and Southern New England which is directly to the south. In certain circumstances, up to 10% of GBK larvae would reach Southern New England and these larvae would be 'unsuccessful' in the model, but near a reasonable size for metamorphosis in a biological sense.	Miller et al 1998; Werner et al 1993; Gilbert et al 2010; Tian et al 2009; Table A19
Georges Bank and MAB surfclam habitats are entirely within different and well recognized eco-regions.		Fogarty et al. (2011)

Figure 168: Points made to support splitting the Atlantic surfclam into two stocks with counterpoints (Copied directly from Table A17 in (Northeast Fisheries Science Center 2013)). The status quo is a single stock and the alternative is two stocks with the break southwest of Georges Bank. Under this option, the Georges Bank stock in the north would be separated from the rest of the resource in the south. Points made to support the status quo and counterpoints are listed in Figure 169. The tables presented here have not been updated with any new information since the last assessment.

The split south of GBK crosses an area that separates the two major concentrations of the resource in the south (off New Jersey) and on GBK.	The split could be made elsewhere or not at all.	Appendix A7
	Population Dynamics	
Surfclams in GBK and south resemble two independent populations based on abundance, recruitment and life history trends.	The northern and southern portions of SVASNE differ as well, why not identify three stocks?	POPULATION DYNAMICS (Figures A26, A27, A74, A75, A77 and A78)
Strong year classes occur independently and more often in the south and often over wide areas within the region.	Recruitment patterns are regional and the split could be made elsewhere or not at all.	Fig A67
	Fishery Patterns	
The split south of GBK crosses an area of relatively low fishing activity and catch.		See Table A3, Figures A3,A4, and A8
	Practical	
The new cooperative survey cannot sample the whole resource in one year but can be extended to include all of the SVASNE area.	Does not mean the split has to be made at GBK. Spatially explicit assessment models could be developed to handle areas incompletely sampled in annual surveys.	
Including GBK in a whole stock assessment model means that certain survey years cannot be included because GBK was not sampled in all years.	Areas can modeled separately but managed together, with results combined.	
Previous reviews of the surfclam assessment have been critical of the current stock definition.	Restoration of fishing on GBK invalidates some of these previous criticisms.	
The proposed boundary is along lines historically used to assess the stock and to collect survey data.	Historical use and best practice are not necessarily the same.	
	Utility of Biological Reference Points	
"Average" biological reference points for two quasi-populations with different population dynamics do not result in MSY for either population unit, particularly when differences are as large as for GBK and the southern region.	The same argument can be made with respect to different portions of the southern area.	Hart, D. R. 2001. Can. J. Fish. Aquat. Sci. 58:2351–2358.

Figure 168 cont.

The surfclam stock could be removed entirely in the south or on GBK without triggering an overfishing or overfished status determination because biomass would remain > Bmsy/2 for the combined areas.	This scenario is unlikely to occur in either GBK or the southern area now that GBK is open to fishing	
Combining two quasi-populations with different population dynamics obscures the condition of both.	Assessments should contain information about both stock components and other important regions, regardless of stock definitions.	

Figure 168 cont.

Pro	Con	References
Split is a needless departure from historical precedent.	Historical precedent is not necessarily best practice particularly given biological and ecological changes.	
Scallops and ocean quahogs (other sessile bivalves) are managed as one stock	Many species (lobsters and relatively sessile fish such as goosefish and flounders) with interconnected meta-populations are managed as separate stocks. Precedent does not define best practice.	
Split made at the proposed point is not optimal - this aspect should be studied further before management action occurs	GBK is the most distinct region based on biological characteristics, oceanography, geography, larval dispersal and general ecological classifications. Additional divisions in the south can be made later if warranted.	
No genetic differences were found among samples of surfclams from Georges Bank to Virginia.	Lack of significant differences in genetic studies does not prove population homogeneity.	Weinberg, J.W. 2005. Mar. Biol. 146(4): 707-716
Recruitment in SNE may come from GBK at periods that have not been observed in models	There is insufficient age data for SNE to evaluate this hypothesis. However, the limited available data indicate that recruitment patterns differ between the major population centers (GBK in the north and New Jersey and Delmarva in the south).	TABLE A19

Figure 169: . Points made to support maintaining the status-quo (single) stock definition for Atlantic surfclam, with counterpoints (copied from Table A18 in (Northeast Fisheries Science Center 2013)). The status quo is a single stock and the alternative is two stocks with the break just southwest of Georges Bank.

Appendix 1 Atlantic surfclam assessment working group members

The working group met February 1-3, March 28-30 and May 31-June 2 at the NEFSC in Woods Hole, MA to work on the Atlantic surfclam stock assessment. Members, contributors and attendees are listed alphabetically below.

Working group:

Jessica Coakley (MAFMC)
Bob Glenn (Mass. DMR)
Dan Hennen (NEFSC, Assessment Lead)
Tom Hoff (Wallace and Associates)
Larry Jacobson (NEFSC, Subcommittee Chair)
Roger Mann (VIMS)
Daphne Munroe (Rutgers)
Eric Powell (University of Southern Mississippi)

Contributors/attendees:

Tom Alspach (SeaWatch International)
Nicole Charriere (NEFSC)
Toni Chute (NEFSC)
Wendy Gabriel (MAFMC SSC, NEFSC)
Scott Gallagher (WHOI)
Jon Hare (NEFSC)
Deborah Hart (NEFSC)
Robert Johnston (NEFSC)
Chris Legault (NEFSC)
Michael Martin (NEFSC)
Vic Nordahl (NEFSC)
Jeff Normant (NJ DFW)
Loretta O'Brien (NEFSC)
Jennifer O'Dwyer (NY DEC)
Doug Potts (GARFO)
Mark Terceiro (NEFSC)
Dave Wallace (Wallace and Associates)
Jim Weinberg (NEFSC)

Appendix 2 Changes to assessment inputs

Commercial

The commercial length compositions were altered from the last assessment. The length compositions come from samples taken from landed catch (port samples). Each port samples consists of approximately 25 lengths (selected randomly) per landed catch from a single boat (trip). Boats are randomly selected from the vessels available on the day of sampling. Port samples are designed to be roughly proportional to the landings from each region. Port samples are systematic relative to time (evenly distributed over each quarter). The port sampler also collects information from the vessel landings sampled, including the approximate location of the area fished and the weight of the total landings.

In the 2013 assessment (Northeast Fisheries Science Center 2013), each port sample was attributed to a region (using the location data) and then the pooled proportion at length (averaging over all samples) from each region were expanded by the total landings from that region in that year.

$$\hat{P}_{r,y,l} = P_{r,y,l}C_{r,y}$$

where $\hat{P}_{r,y,l}$ was the expanded proportion at length (l), in region (r) and year (y), $P_{r,y,l}$ was the unexpanded proportion and $C_{r,y}$ was the catch by region and year. In order to get the length composition for the southern area, the $\hat{P}_{r,y,l}$ were summed over the regions that compose the southern area (SVA to SNE). The length compositions did not sum to one but that is not important for the assessment model which requires relative, but not true proportions.

The implied assumption of expanding the length composition by total landings in a region is that the port samples are randomly distributed in time and space relative to the landings from a region (random stratified sampling where the strata are the regions). Because the vessels selected for port sampling are randomly selected, random selection relative to space within a region is probably a reasonable assumption. Port samples are systematic relative to time however (they are stratified by quarter year), which is a violation of random selection relative to time. Therefore, it may be better to use cluster sampling techniques (see Cochran (1977)). Port samples are subsamples of samples (a single trip of many trips taken that quarter and landed at that port). They can be considered as 2 stage cluster samples (Cochran 1977). The estimate of the population mean is unbiased when the second stage sampling units are chosen with equal probability. The estimate of the population mean consists of a simple ratio based expansion, where the subsample is expanded to reflect the size of total sample from which it was drawn.

In the new assessment, the $P_{r,y,l}$ were expanded by the weight of the haul from which they came and then summed over each region and year (similar to the process for calculating a weighted average).

$$\hat{P}_{r,y,l} = \sum_{y} \sum_{r} P_{v,l}C_{v}$$

where $P_{v,l}$ and C_v are the vessel specific proportions and landings, respectively. Weight was the unit of measure chosen because the total number of animals landed was not recorded.

The change had the strongest effect on commercial catch at length during 1995 - 1999 and very little effect in most other years (Figure 170). 1995 - 1999 were years with relatively few port samples taken from relatively few regions.

Survey

The change to a cooperative survey using the *FV Pursuit* beginning in 2012 affected the way random tows from adjacent years were borrowed to fill holes (strata with no random tows) during 2011 and 2013 for calculation of abundance indices. In particular, it was not possible to use 2011 tows to fill 2012 holes or vice-versa because different vessels, gear and protocols were used starting in 2012. In addition, the new survey in 2012 and 2015 was meant to exclude the northern area while the survey in 2013 was meant to be on the northern area only. The 2014 survey was used primarily for gear testing and only a few strata were sampled in random survey mode. Survey data for 2012 and 2015 were therefore used to calculate abundance indices only for the southern area while survey data for 2013 was used to calculate abundance indices for the northern area only. No 2014 abundance indices were calculated. Therefore, northern area tows during 2013 were not borrowed to fill the intentional northern area 2012 holes although 2013 tows in other areas were used to fill 2012 holes. Northern area tows in 2014 tows were used to fill 2013 the northern area holes where necessary. The plan to survey areas south of the northern area in year one, survey the northern area in year two and take year three off was not followed perfectly during 2012-2014. It was followed in 2015 and is expected to be followed in future to the extent possible so that borrowing imputation and other approaches to filling holes are not necessary.

The ageing error vector in the assessment model was updated. The previous values could not be reproduced and the method used to generate them was unclear. The new values were based on the same data (with additional years added). The new ageing error vector was generated as a linear model fit to

$$\epsilon_a = sd(a_{prod,i,a} - a_{check,i,a})$$

where ϵ_a is the standard deviation of the ageing error for age a, $a_{prod,i}$ is the production age for individual i at age a and $a_{check,i,a}$ is the re-age of the same individual.

The standard deviation of ageing error increased with production age (Figure 171). The ageing error vector used in the assessment model was the linear fit to all of the non-zero ϵ_a. Because all zero values of ϵ_a had low sample sizes (Figure 172).

Figures

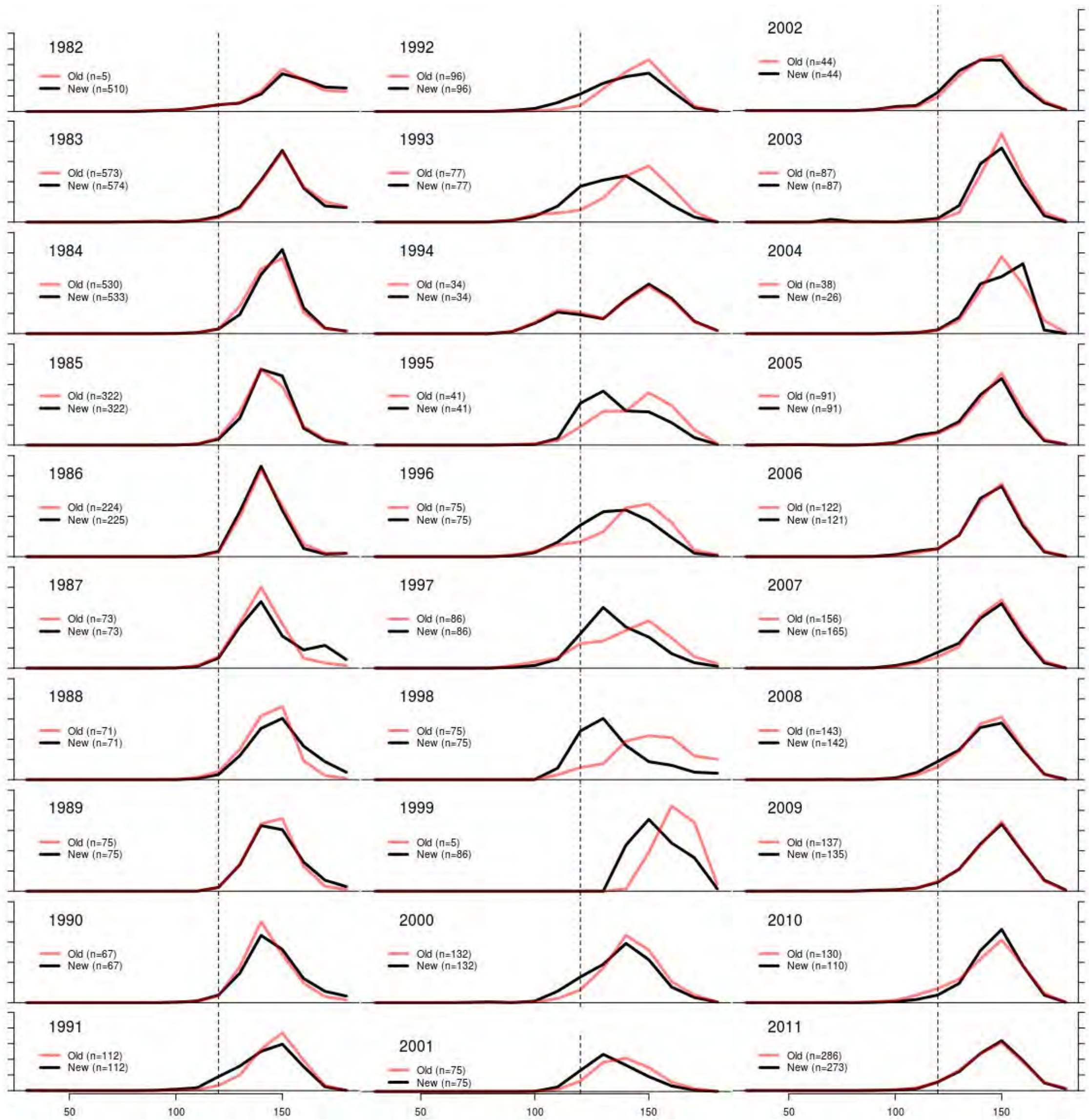


Figure 170: A comparison of the length compositions used on the surfclam assessment model in the last assessment (Old) vs. the current assessment (New). The x axis shows the shell length in mm and the y axis shows the relative frequency at each shell length. The sample sizes (n=) in the previous assessment are not the number of trips sampled (as in the current assessment). The sample sizes in the old assessment are the values used for data weighting of each component in the assessment. The vertical line at 120 mm is for reference only.

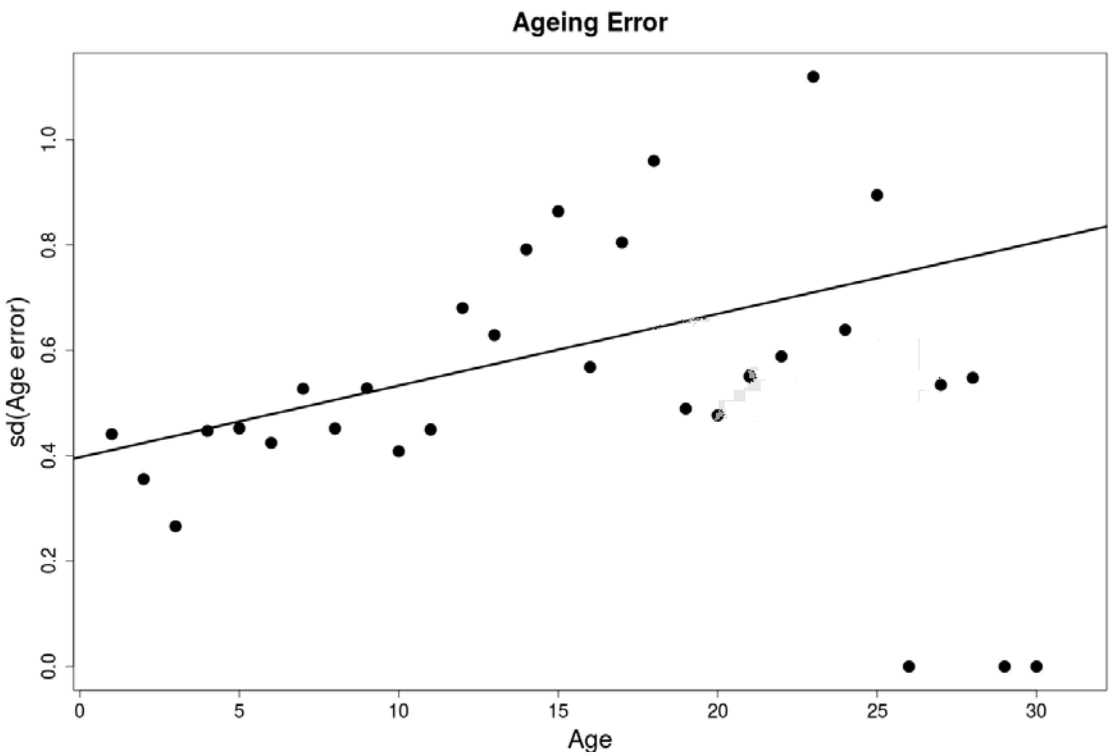


Figure 171: The standard deviation of the difference between production age and the re-age done to test ageing error against a linear fit.

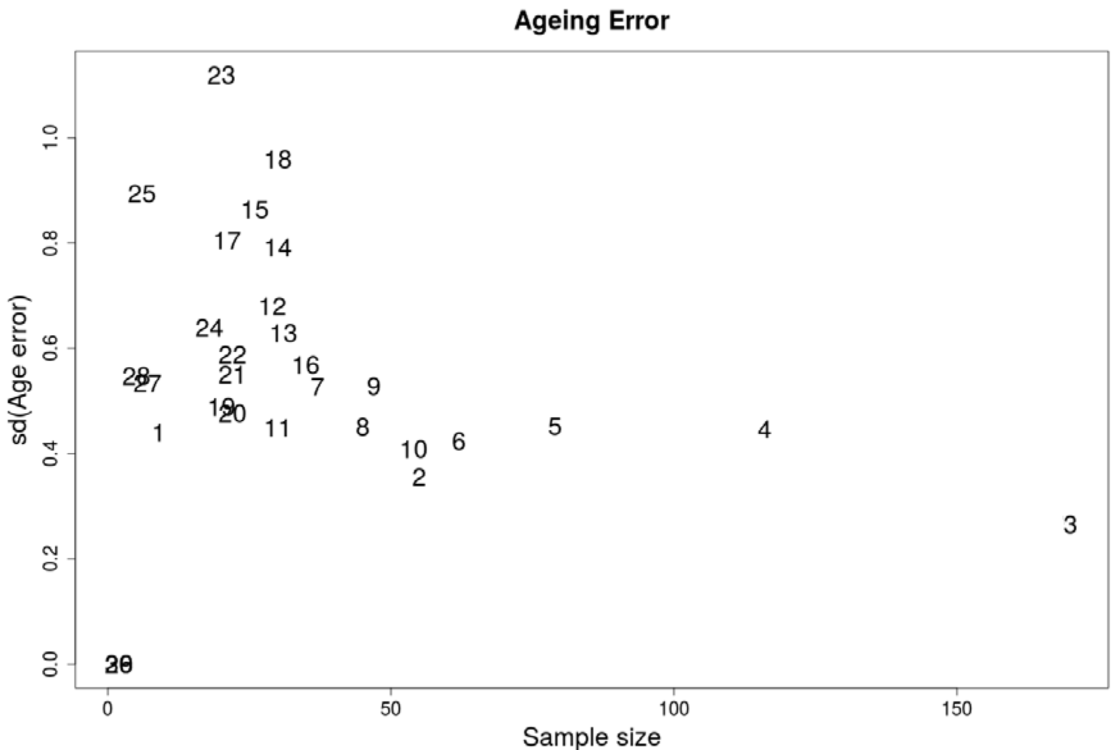


Figure 172: The sample size at age for standard deviation of the difference between production age and the re-age done to check ageing error. Each age is plotted as a numeral.

Appendix 3 Selectivity and assessment model performance

Introduction

In 2012 NMFS moved the clam survey from a research platform to a commercial one. All surveys previous to 2012 used a specially designed research dredge (RD). In 2012 the survey was conducted with a commercial dredge modified to retain smaller animals (MCD). The two dredges differ in selectivity (Figure 173) and efficiency (Figure 174). The MCD retains small animals at a reduced relative rate (lower selectivity at small sizes), and there was concern about loss of important information in future assessments.

Preliminary investigations of the data from the partial survey (4 of 6 regions were sampled) conducted with the MCD in 2012 show length composition similar to what would be expected based on selectivity. Comparing the length composition of the animals sampled by the MCD and RD reveal some differences between them (Figure 175).

The age composition of the animals surveyed with the MCD should not be as different from the age composition of those sampled with the RD (compared to length composition). The animals used for aging are stratified by length, which will mask selectivity differences because each length has representation in both dredges. Animals from the 2012 survey have not been aged so comparisons must be made based on the length of the animals that will be aged. So far, there appears to be some undersampling of small animals in the aging subsample (Figure 176). This issue bears watching as the survey continues in 2013.

There is no *apriori* reason to believe that the MCD will be less useful than the RD in providing informative data to the assessment. A reduced sample of a particular length should not theoretically pose a problem for the assessment model as long as the sample is representative of the general population and can be scaled up to population level values through selectivity. In fact, we expect that the increase in survey catchability should make the MCD a much more reliable tool for surveys.

Here, we examine the probable effects of changing dredges by comparing the results of the 2013 Atlantic surfclam assessment model (NEFSC 2013) with a mock model run using simulated MCD survey data. This exercise is intended to show how much the results of the current assessment would have differed had we conducted the survey from a commercial platform and used the MCD throughout the time series.

Methods

A SS3 model for the southern area (all regions south of GBK) was run using data from the 2013 Atlantic surfclam assessment, which was modified to simulate the MCD sampling properties as follows: 1) the selectivity of the survey index was altered, 2) the length composition data was altered and 3) the prior distribution on survey catchability was altered. All three of these changes represent likely differences in both data and model configuration corresponding to the shift in survey platform.

Selectivity

The assessment model used in the 2013 Atlantic surfclam assessment fixed (RD) selectivity at values estimated in a series of field experiments. Because we conducted selectivity experiments on the MCD simultaneously, we were able to substitute the field values estimated using the MCD for the values estimated using the RD (Figure 173).

Length composition data

Length composition data were altered as

$$L_{i,new} = L_{i,old} + (D_{s,i} * L_{i,old}) * c \tag{5}$$

where $L_{i,new}$ is the altered proportion at length for length bin i, $L_{i,old}$ is the proportion at length for length bin i used in the assessment, $D_{s,i}$ is the difference between the MCD selectivity, and RD selectivity for length bin i and c is a constant scaler used to increase the effect of the alterations (Table 35). The value of $c = 2$ was chosen to maximize the simulated effect of switching dredges. It would not be possible to increase the effect much further without losing some length classes entirely. It should be noted that (5) allows for both increases and decreases in the number of clams caught within a length bin. That is, for length bins in which the MCD catches clams at a higher rate than the RD, the number of animals in that length bin was increased. The opposite was true for length bins in which the MCD was less efficient than the RD (Table 35).

Prior on survey catchability

The prior on survey catchability was based on a log normal fit to variance weighted bootstrapped estimates of MCD efficiency (Figure 177). The estimates came from patch model analysis of depletion experiments. The methods used in patch model analysis are explained in Rago et al. (2006) and Hennen et al. (2012). The methods used in generating the prior distribution are explained in detail in Northeast Fisheries Science Center (2013).

Projections

The projection run examined here assumes that total catch will be equal to the average catch over the last 5 years. It also assumes that approximately 0.3 of the total catch will be fished in GBK and not the southern area. This scenario is identical to the ”status quo” fishing scenario in the 2013 Atlantic surfclam assessment (Northeast Fisheries Science Center (2013)).

Results

The SS3 model using altered inputs converged and diagnostics did not indicate any problems. Differences between the model used in the 2013 Atlantic surfclam assessment and the current exercise in selectivity (Figure 173), and fits to length composition data (Figures 175 and 180) were relatively minor. The scale, trend and terminal year status of estimated biomass was preserved with the altered inputs (Figures 181 and 182). Precision of the estimates improved with the altered data (Table 36). Conclusions about stock status with regard to fishing mortality were unchanged (Figures 181 and 182). Projections were somewhat more precise, but generally similar in trend, scale and probable stock status, to the projections from the 2013 Atlantic surfclam assessment (Table 36).

Discussion

The results of this exercise show that using data similar to what would have been observed had the survey always been conducted with the MCD produced assessment results that were similar to what was seen in the 2013 Atlantic surfclam assessment.

The expected effect of switching to the MCD on length composition was exaggerated in this study to make it a stringent test. In some cases, the length bin relative proportions were reduced by as much as 95% (Table 35). If the scaler c from 5 was increased much further we would have lost length classes all together, which would have made modeling difficult and reduced the comparability of the results. Setting $c = 2$ was considered to be a reasonable upper bound on the likely effects of switching dredges.

The increase in precision of this model over the 2013 assessment model is potentially spurious and may result from the somewhat artificial agreement between the selectivity and the length composition data (because length composition was adjusted using selectivity). It is likely however that the increase in precision is largely due to the reduction in the variance of the prior distribution on survey catchability and therefore a real result and an endorsement of the new dredge.

The results of this study indicate that switching to the MCD is not likely to diminish the performance of the assessment model, and may in fact increase the precision of model estimates.

Tables

Table 35: Size composition (cm) comparison between 2013 surfclam assessment and a size composition similar to what would have come from the survey using the MCD.

N	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
								RD								
138	0.15	0.04	0.18	0.38	0.88	2.35	13.92	18.19	11.15	5.52	4.05	2.17	1.64	1.80	1.07	1.01
144	0.00	0.02	0.12	0.32	0.49	0.61	1.36	4.37	8.42	7.21	3.00	1.78	1.59	1.61	0.99	0.35
10	0.02	0.17	0.37	1.34	10.09	21.00	5.11	4.98	6.50	6.59	5.94	3.88	2.28	1.90	0.98	0.24
156	0.01	0.06	0.16	0.33	0.71	0.75	1.45	2.97	10.88	13.31	8.02	3.68	2.04	1.58	1.06	0.45
158	0.01	0.05	0.10	0.30	0.52	0.71	0.99	1.94	2.98	4.49	5.70	4.18	2.30	1.06	0.53	0.19
168	0.00	0.05	0.14	0.50	0.75	1.18	1.22	2.46	5.11	4.63	4.33	2.95	1.90	1.05	0.45	0.26
193	1.75	3.28	6.67	3.73	3.78	3.93	4.31	7.11	11.74	10.45	9.92	8.75	5.55	2.28	0.83	0.30
190	0.68	2.14	0.56	0.56	1.32	3.00	4.40	5.73	9.68	10.50	8.99	8.63	5.65	2.47	0.96	0.35
186	0.64	2.10	0.53	0.37	0.71	0.81	0.98	2.36	5.52	5.88	5.10	4.81	3.67	1.65	0.66	0.10
182	0.02	0.05	0.11	0.41	1.10	2.06	1.72	1.49	1.93	2.57	3.09	3.99	3.78	2.89	0.92	0.17
150	0.06	0.28	0.20	0.18	0.39	0.64	0.88	1.28	1.11	1.20	1.58	2.52	2.41	1.10	0.31	0.04
189	0.04	0.24	0.34	0.68	1.14	1.37	1.19	0.97	0.84	1.09	1.23	1.73	1.69	1.00	0.45	0.04
135	0.14	0.27	0.69	1.64	2.77	2.89	2.99	3.19	2.59	2.43	1.52	1.58	1.72	0.96	0.33	0.05
								Conversion Factor (2.0)								
selx change	-0.03	-0.16	-0.46	-0.81	-0.95	-0.76	-0.45	-0.21	-0.07	-0.03	-0.05	-0.05	0.03	0.23	0.53	0.88
								MCD								
138	0.15	0.03	0.10	0.07	0.05	0.57	7.69	14.45	10.32	5.33	3.86	2.07	1.69	2.20	1.64	1.90
144	0.00	0.02	0.06	0.06	0.03	0.15	0.75	3.47	7.79	6.96	2.86	1.70	1.64	1.98	1.51	0.66
10	0.02	0.14	0.20	0.25	0.54	5.10	2.82	3.95	6.01	6.36	5.67	3.70	2.35	2.33	1.50	0.45
156	0.01	0.05	0.09	0.06	0.04	0.18	0.80	2.36	10.07	12.84	7.66	3.51	2.10	1.94	1.63	0.85
158	0.01	0.04	0.05	0.06	0.03	0.17	0.55	1.54	2.76	4.33	5.44	3.99	2.37	1.31	0.82	0.36
168	0.00	0.04	0.08	0.09	0.04	0.29	0.68	1.96	4.73	4.47	4.14	2.82	1.96	1.28	0.69	0.48
193	1.69	2.74	3.60	0.69	0.20	0.96	2.38	5.65	10.87	10.09	9.47	8.35	5.72	2.80	1.28	0.56
190	0.65	1.79	0.30	0.10	0.07	0.73	2.43	4.55	8.96	10.14	8.58	8.24	5.83	3.03	1.47	0.66
186	0.62	1.75	0.29	0.07	0.04	0.20	0.54	1.87	5.11	5.68	4.86	4.59	3.78	2.03	1.01	0.19
182	0.01	0.04	0.06	0.08	0.06	0.50	0.95	1.18	1.78	2.48	2.95	3.81	3.89	3.55	1.41	0.31
150	0.05	0.23	0.11	0.03	0.02	0.15	0.49	1.02	1.03	1.16	1.51	2.41	2.48	1.35	0.48	0.08
189	0.04	0.20	0.18	0.13	0.06	0.33	0.66	0.77	0.78	1.05	1.17	1.65	1.74	1.23	0.69	0.07
135	0.13	0.23	0.37	0.31	0.15	0.70	1.65	2.53	2.39	2.34	1.45	1.50	1.77	1.18	0.50	0.10

Table 36: Biomass precision comparison between the 2013 surfclam assessment and the modified assessment presented here.

Year	Biomass	cv	lci	uci	Biomass	cv	lci	uci
1963	1250	0.14	955	1636	1200	0.08	1030	1398
1964	1160	0.14	879	1531	1112	0.08	950	1302
1965	1160	0.14	879	1531	1112	0.08	950	1302
1966	1157	0.14	878	1523	1109	0.08	947	1298
1967	1154	0.14	879	1515	1106	0.08	945	1295
1968	1155	0.14	881	1513	1107	0.08	945	1297
1969	1157	0.14	884	1515	1110	0.08	947	1300
1970	1162	0.14	887	1521	1114	0.08	950	1306
1971	1135	0.14	866	1487	1083	0.08	923	1270
1972	1101	0.14	837	1448	1045	0.08	888	1229
1973	1044	0.14	790	1379	986	0.08	836	1163
1974	990	0.15	745	1317	931	0.09	786	1102
1975	922	0.15	689	1233	863	0.09	726	1025
1976	856	0.15	638	1148	798	0.09	670	950
1977	794	0.15	591	1068	739	0.09	620	880
1978	746	0.15	555	1003	692	0.09	581	823
1979	733	0.15	545	985	677	0.09	570	806
1980	738	0.15	549	992	682	0.09	574	810
1981	768	0.15	572	1031	708	0.09	596	840
1982	950	0.15	707	1277	877	0.09	740	1040
1983	1277	0.15	950	1717	1182	0.09	997	1402
1984	1484	0.15	1103	1996	1375	0.09	1160	1630
1985	1684	0.15	1251	2266	1564	0.09	1320	1854
1986	1929	0.15	1432	2598	1802	0.09	1521	2135
1987	1974	0.15	1464	2662	1849	0.09	1561	2191
1988	1967	0.15	1457	2656	1848	0.09	1561	2188
1989	1956	0.15	1446	2645	1844	0.09	1557	2183
1990	1880	0.16	1388	2547	1777	0.09	1501	2104
1991	1789	0.16	1318	2430	1696	0.09	1432	2009
1992	1756	0.16	1290	2390	1674	0.09	1413	1983
1993	1696	0.16	1243	2314	1624	0.09	1371	1925
1994	1634	0.16	1194	2236	1573	0.09	1327	1865
1995	1608	0.16	1172	2206	1557	0.09	1312	1847
1996	1539	0.16	1119	2116	1496	0.09	1260	1776
1997	1490	0.17	1081	2053	1455	0.09	1224	1728
1998	1511	0.17	1093	2088	1484	0.09	1248	1765
1999	1488	0.17	1073	2063	1469	0.09	1234	1748
2000	1399	0.17	1006	1947	1386	0.09	1163	1651
2001	1294	0.17	926	1807	1285	0.09	1076	1534
2002	1207	0.17	861	1692	1205	0.09	1007	1441
2003	1128	0.18	801	1589	1132	0.09	945	1358
2004	1104	0.18	779	1564	1119	0.09	931	1345
2005	1079	0.18	758	1537	1102	0.10	915	1329

2006	1013	0.18	707	1450	1040	0.10	860	1257
2007	912	0.19	633	1314	940	0.10	773	1142
2008	827	0.19	571	1197	856	0.10	700	1046
2009	750	0.19	516	1091	781	0.10	635	959
2010	706	0.20	483	1032	740	0.11	597	916
2011	703	0.20	481	1028	740	0.12	589	929
2012	699	0.20	476	1027	735	0.13	572	945
2013	691	0.20	464	1029	728	0.14	551	962
2014	678	0.22	441	1042	709	0.16	515	976
2015	687	0.23	439	1073	698	0.18	495	983
2016	731	0.23	464	1152	732	0.18	514	1044
2017	726	0.24	459	1147	729	0.18	508	1045
2018	761	0.24	481	1204	759	0.19	528	1092
2019	800	0.24	506	1265	793	0.19	551	1142
2020	838	0.24	531	1322	826	0.19	574	1189
2021	873	0.23	555	1375	857	0.19	596	1232

Figures

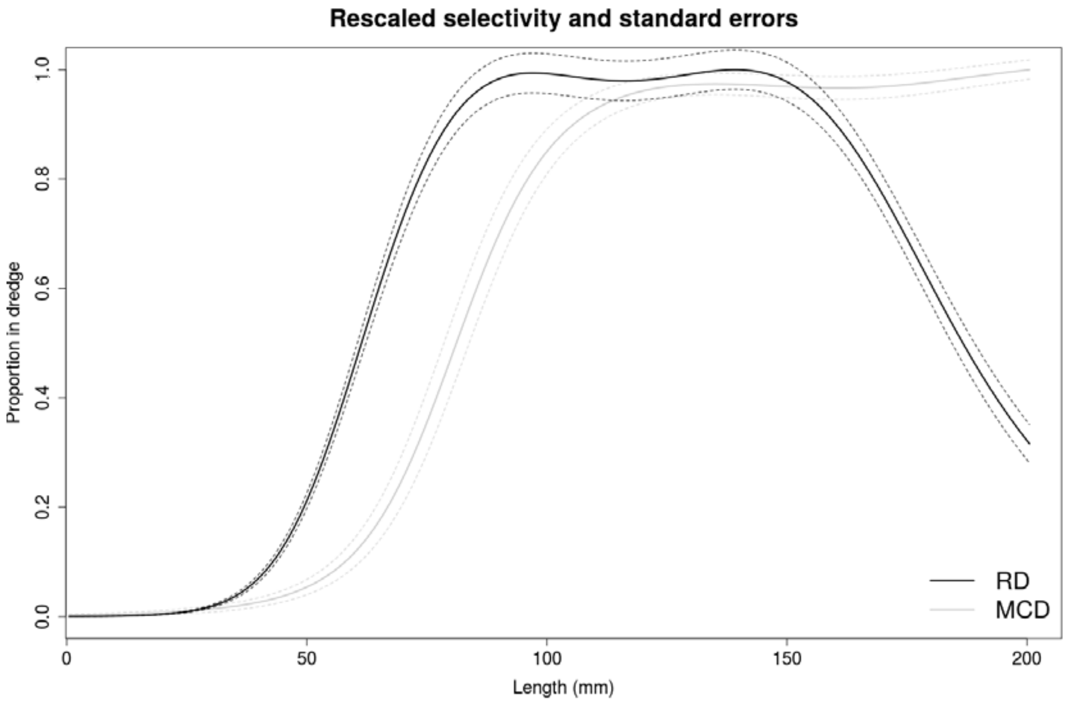


Figure 173: Selectivity differences between the MCD and RD. Curves have been rescaled so that the maximum selectivity for each curve is 1.

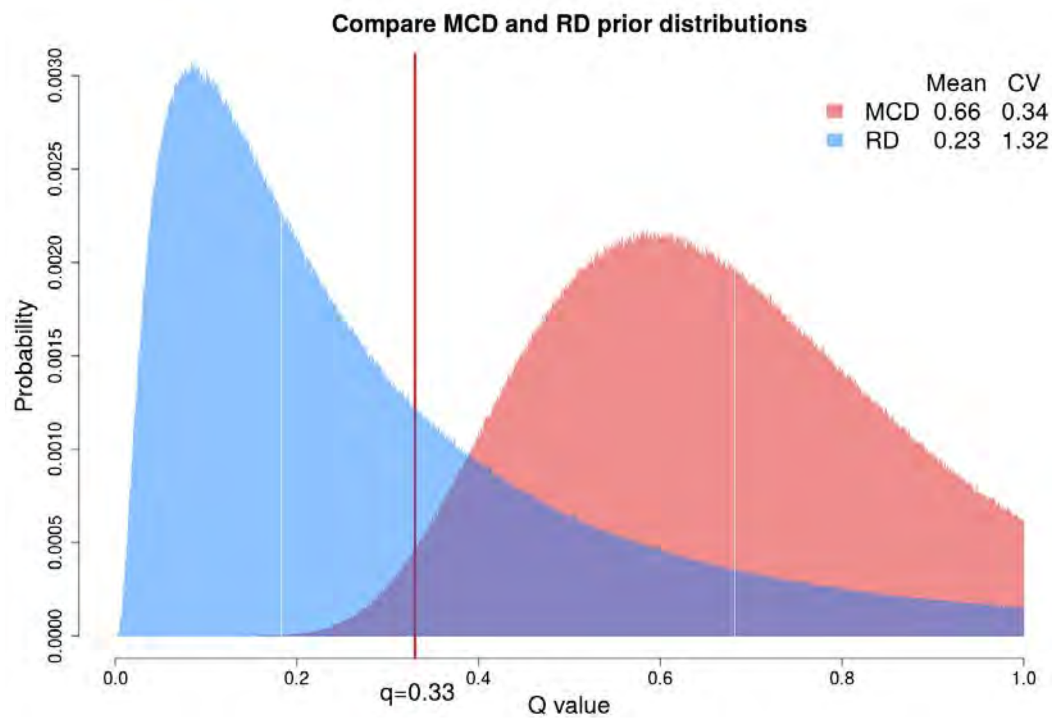


Figure 174: Differences in dredge efficiency between the MCD and RD, with the current dredge efficiency estimated in the assessment ($q = 0.33$) shown.

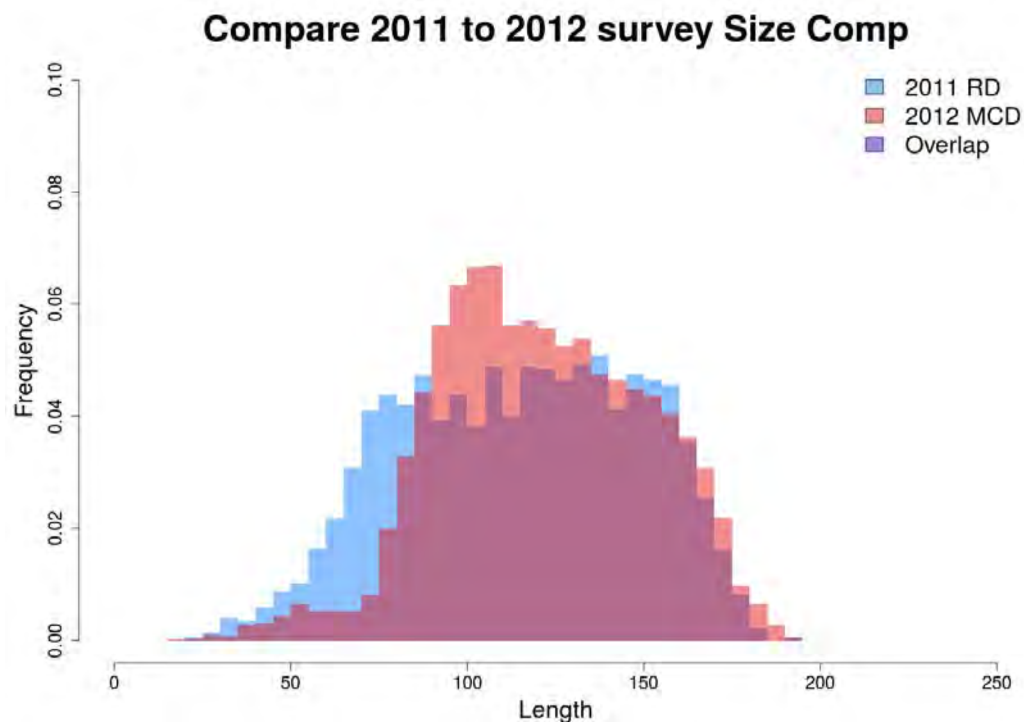


Figure 175: Length composition of survey samples from MCD and RD. Because the 2012 survey did not cover SNE or GBK, only samples from regions that were covered in both surveys are shown here.

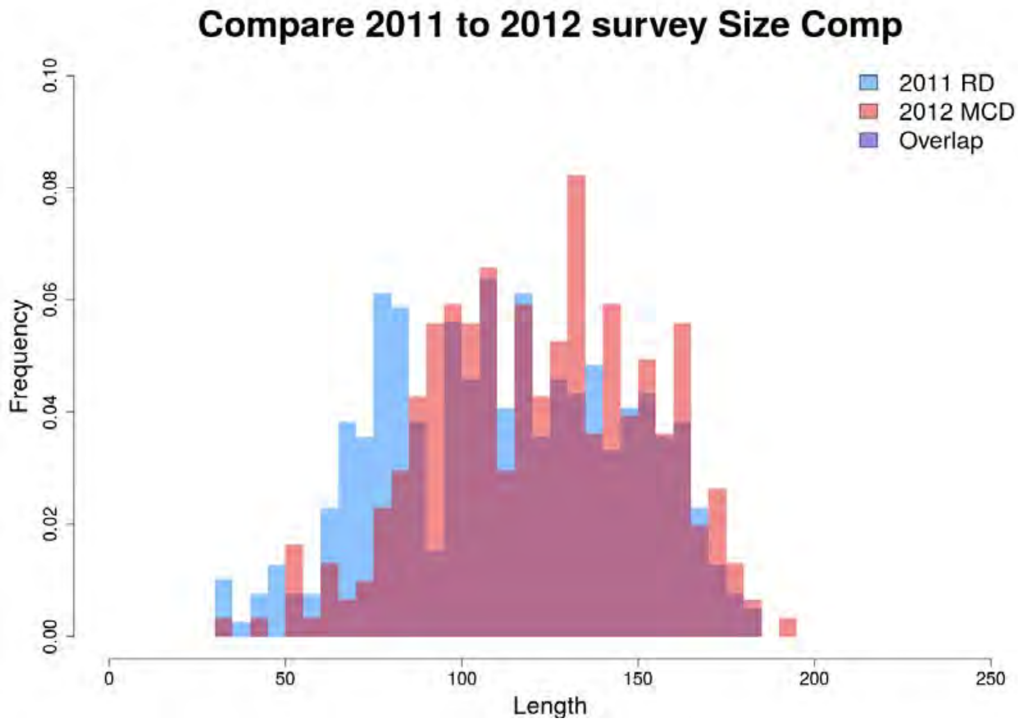


Figure 176: Length composition of survey samples that will eventually be aged from MCD and RD. Because the 2012 survey did not cover SNE or GBK, only samples from regions that were covered in both surveys are shown here.

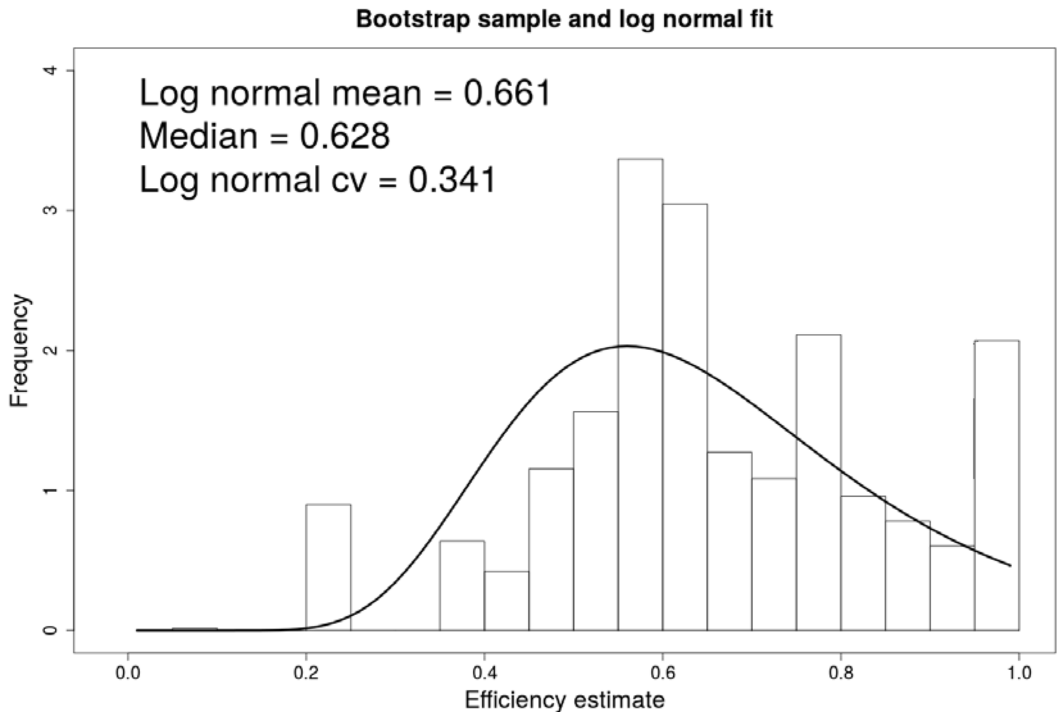
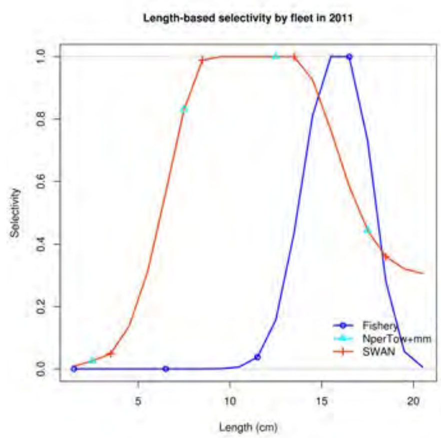
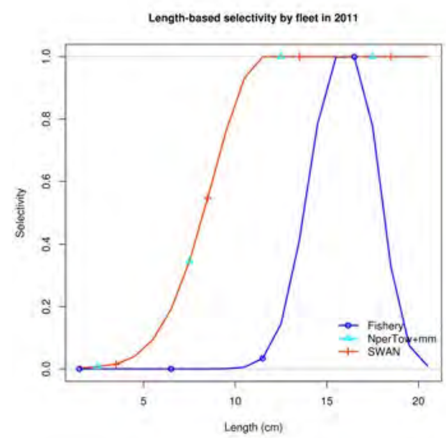


Figure 177: Log normal fit to a variance weighted bootstrap of MCD efficiency from field depletion studies.



(a) RD selectivity



(b) MCD selectivity

Figure 178: SS3 output plots showing the different selectivities used in the 2013 Atlantic surfclam assessment (a) and in this exercise (b). The red line shows the comparison between the RD and MCD.

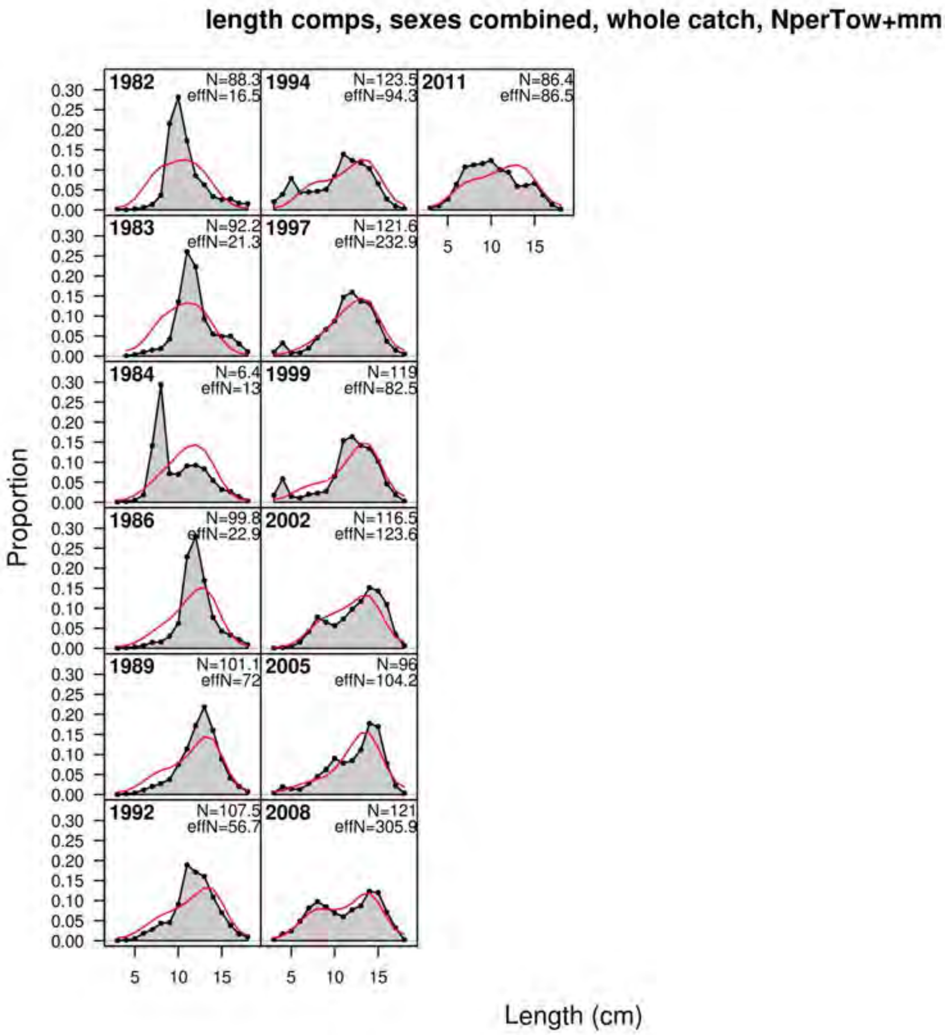


Figure 179: 2013 Atlantic surfclam assessment model fits to length composition data.

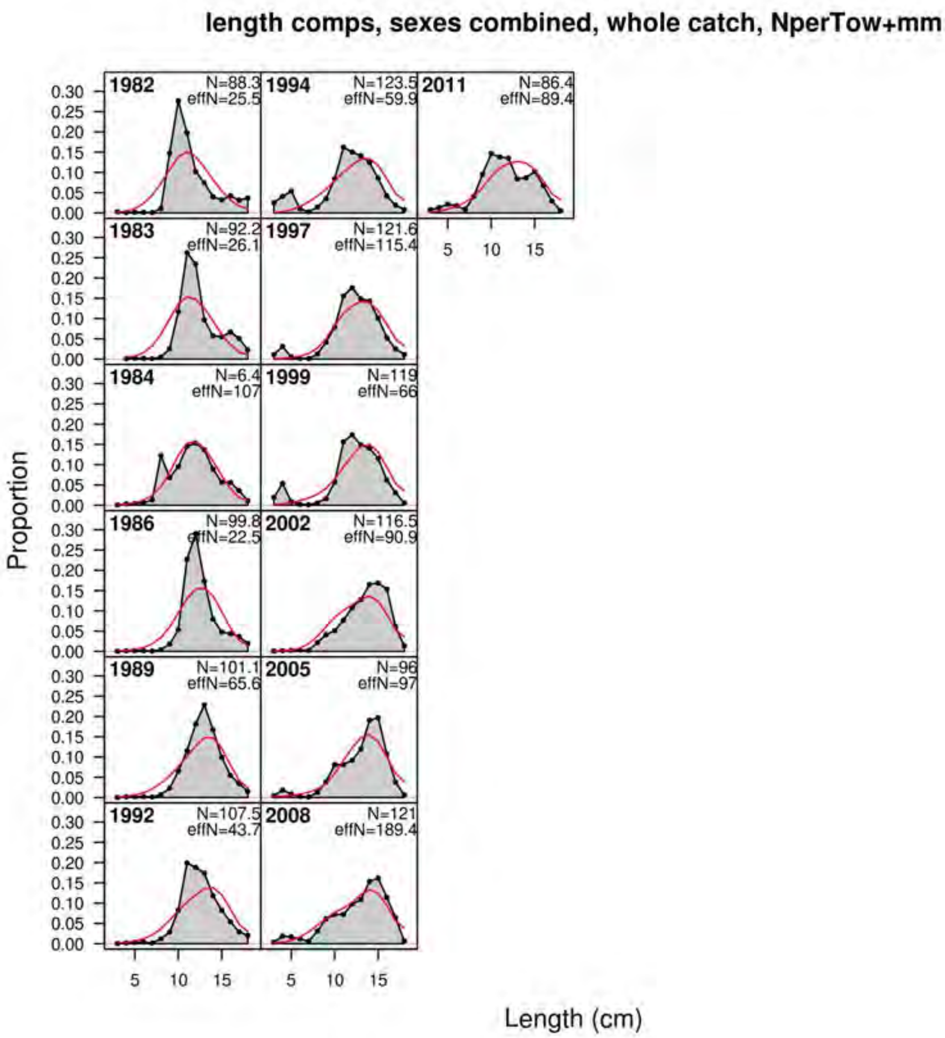


Figure 180: Fits to length composition data using modified selectivity, length composition and survey catchability prior.

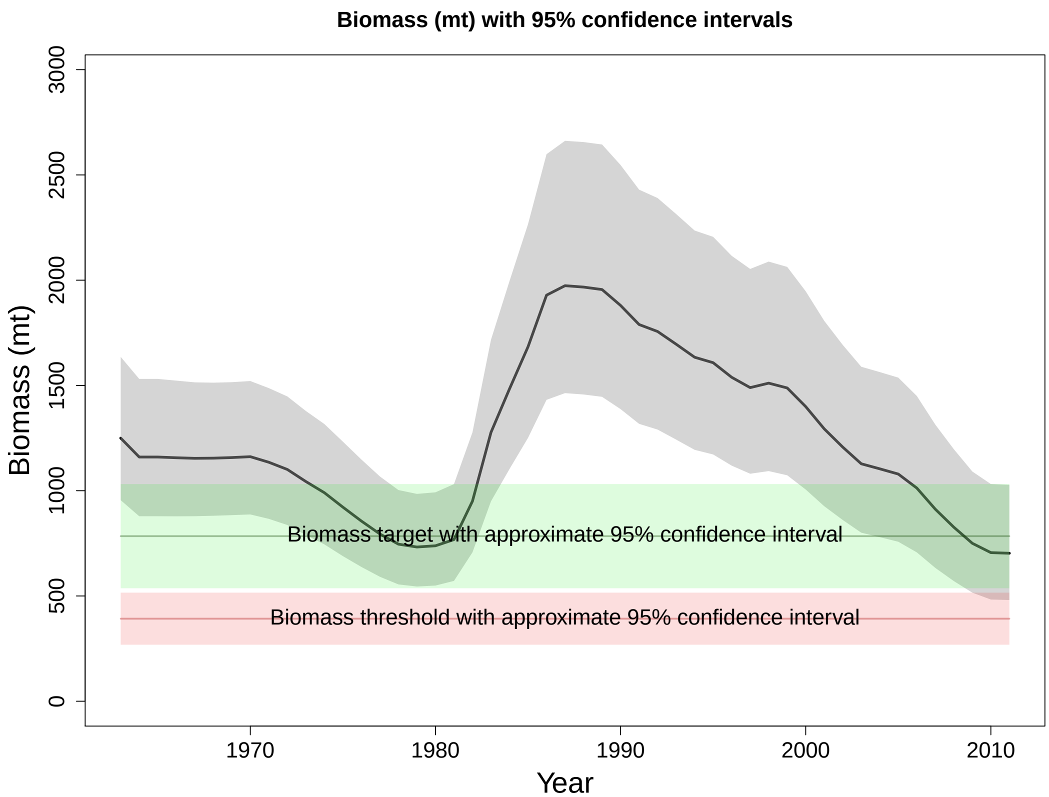


Figure 181: Biomass (1000 mt) trajectory and status estimated in the 2013 Atlantic surfclam assessment.

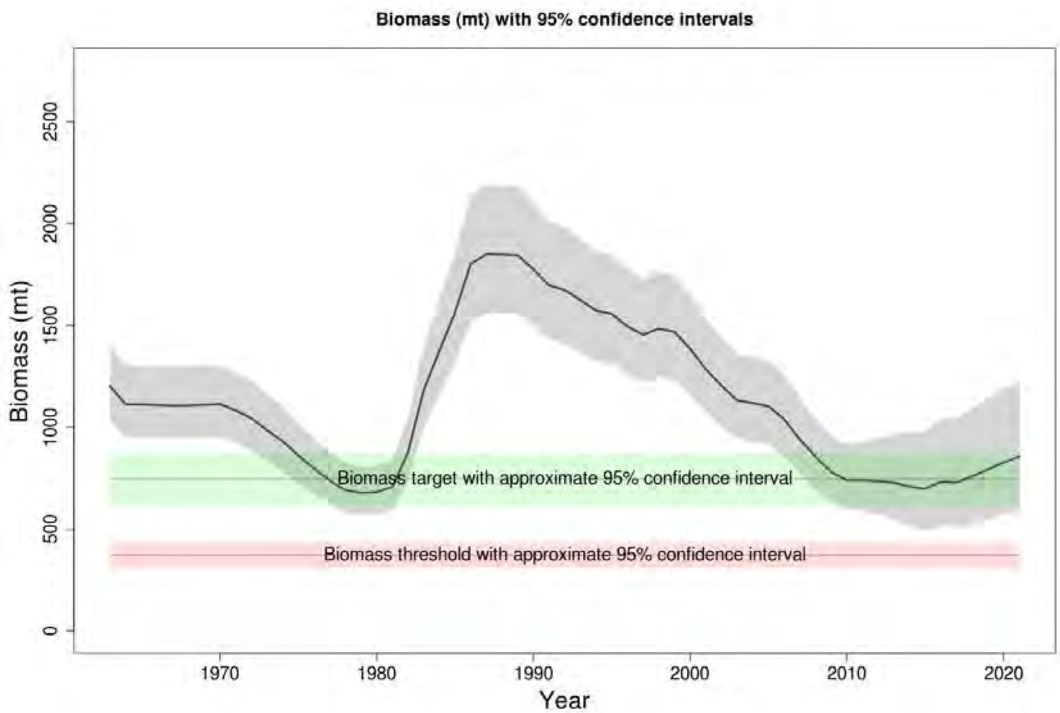


Figure 182: Biomass (1000 mt) trajectory using modified selectivity, length composition and survey catchability prior. The projection results assume status quo fishing.

Appendix 4 Survey dredge efficiency

Increasing survey dredge efficiency, defined as the probability of capturing an animal if the dredge is towed over the bottom where that animal is buried, was an important consideration in switching to a commercial vessel as a platform for the NEFSC clam survey. The relatively small survey dredge deployed by the *RV Delaware II* had an estimated mean efficiency of approximately 0.23 and high variability in performance, with an estimated cv for efficiency of 1.32. A low mean dredge efficiency coupled with high variability resulted in high variance catches, which in turn increased the variability in estimates of mean abundance for survey strata, and ultimately for estimated biomass in the assessment.

The complex process for estimating survey dredge efficiency (described in detail in Northeast Fisheries Science Center (2013)) included 27 direct estimates of the efficiency of modified commercial dredges (MCD) similar to those that have been used in the NEFSC clam survey since 2012, including 8 estimates using the actual MCD used for the post-2012 surveys (Table 37). The efficiency of the MCD and the Pursuit dredge are substantially higher and more precisely estimated than the RD (Figure 53).

The depletion experiments have thus far been conducted in the southern area, with the most effort concentrated in the NJ region (Figure 183)

Tables

Table 37: Estimated dredge capture efficiency from depletion experiments. All experiments were conducted using a modified commercial dredge similar to, though somewhat smaller than the dredge that has been used for the NEFSC clam survey since 2012. Experiments after 2007 were conducted using the same dredge used in the survey.

Experiment	Efficiency	St. dev.
1997.2	0.224	0.069
1997.3	0.641	0.138
1997.4	0.917	0.198
1997.6	0.528	0.171
1999.2	0.589	0.263
1999.5	0.211	0.058
1999.7	0.480	0.073
2002.2	0.805	0.109
2002.3	0.446	0.139
2004.1	0.552	0.105
2004.2	0.628	0.078
2004.3	0.606	0.111
2005.2	0.666	0.068
2005.3	0.569	0.068
2005.4	0.389	0.079
2005.5	0.781	0.145
2005.6	0.535	0.140
2008.1	0.966	0.142
2008.2	0.957	0.103
2008.3	0.610	0.119
2008.4	0.485	0.212
2008.6	0.882	0.143
2011.3	0.571	0.162
2011.2	0.556	0.088
2011.1	0.738	0.090

Figures

Figures

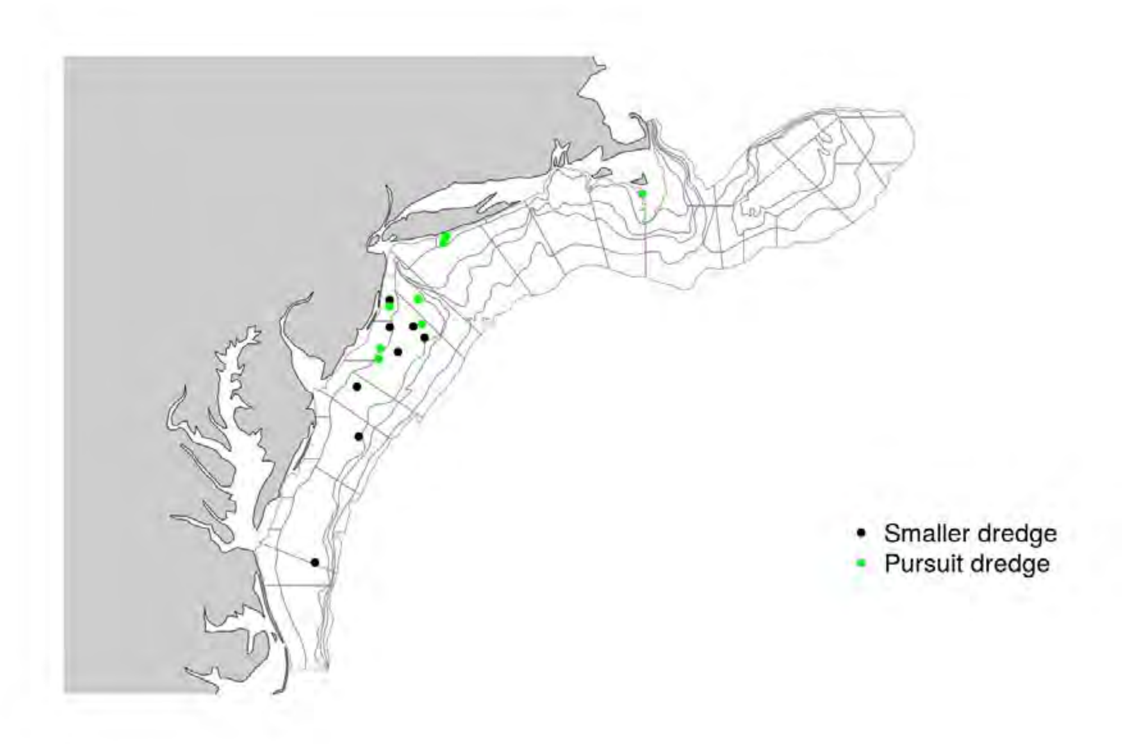


Figure 183: Position of each depletion experiment. The different colors represent the depletion experiments done with different dredges. The green dots are the experiments done with the dredge being used currently on the NEFSC clam survey.

Appendix 5 Appendix: Are broken clams a problem?

The mechanical sorting equipment employed on the ESS Pursuit results in higher sampling efficiency in terms of the number of animals processed per unit time, but also tends to increase breakage. The volume, mass and approximate length of broken clams is routinely recorded, but there has been concern that a size bias in the tendency to break could skew the size composition of the survey catch. A simple size composition comparison indicates that if there is size bias in the broken clams, it is unlikely to bias the size composition. Plots of length compositions (Figures 184 - 185) demonstrate that there is very little difference between compositions composed of whole animals and those composed of whole and broken animals. All survey analyses currently include both whole and broken clams.

There is also the possibility that clams are broken more often in smaller catches, as there would be less detritus to cushion the clams as they dropped from the dredge into the hopper for sorting. This could potentially bias the survey if the length composition of clams in "clean" habitat with less detritus were skewed by a high proportion of broken animals. Bias produced by this affect would probably not be very important to the assessment unless there was some reason to suspect that clean bottom resulted in some inherent difference in the length composition of clams caught there (e.g. clams grow more slowly on clean bottom). Nonetheless it may be worth evaluating, to determine if more clams are broken in smaller catches.

Although "trash" volume is no longer recorded on the NEFSC clam survey, we can compare the proportion of broken clams to the total number of clams caught in each tow. The relationship was weakly negative (Figure 186) implying that smaller catches do indeed produce a slightly higher proportion of broken clams. The effect was small enough however, to be unlikely to warrant much concern.

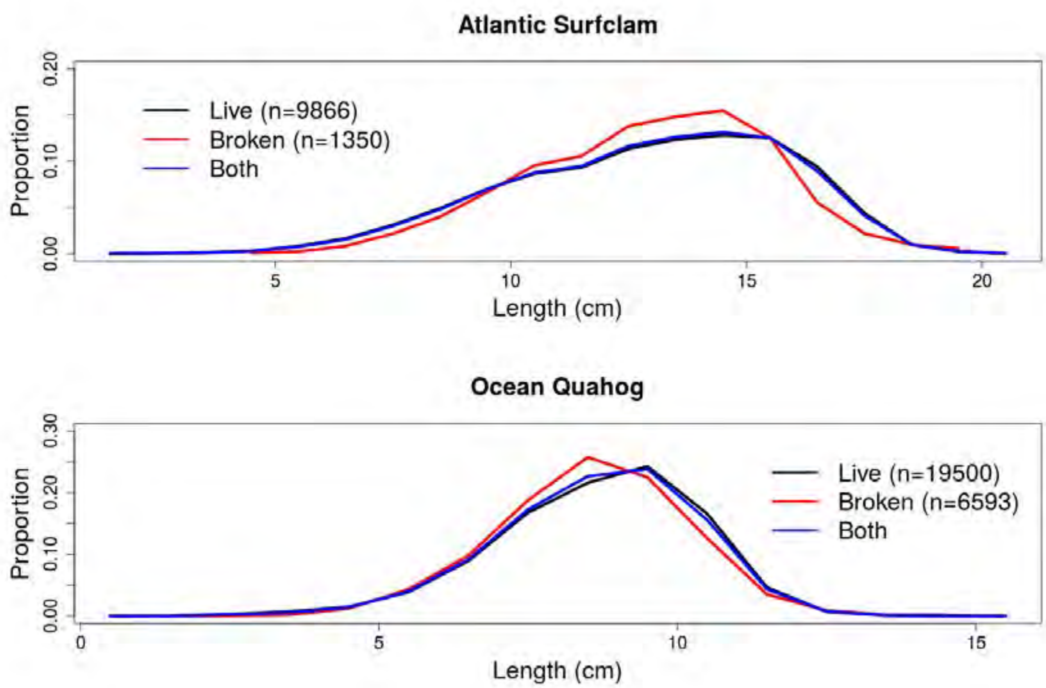


Figure 184: Length compositions from clam surveys on the ESS Pursuit through 2014. Proportion at length using only live (whole) clams, only broken clams, and live and broken clams together. There is very little difference between the length composition based only on live animals and the length composition using both whole and broken animals for both Atlantic surfclam and ocean quahog.

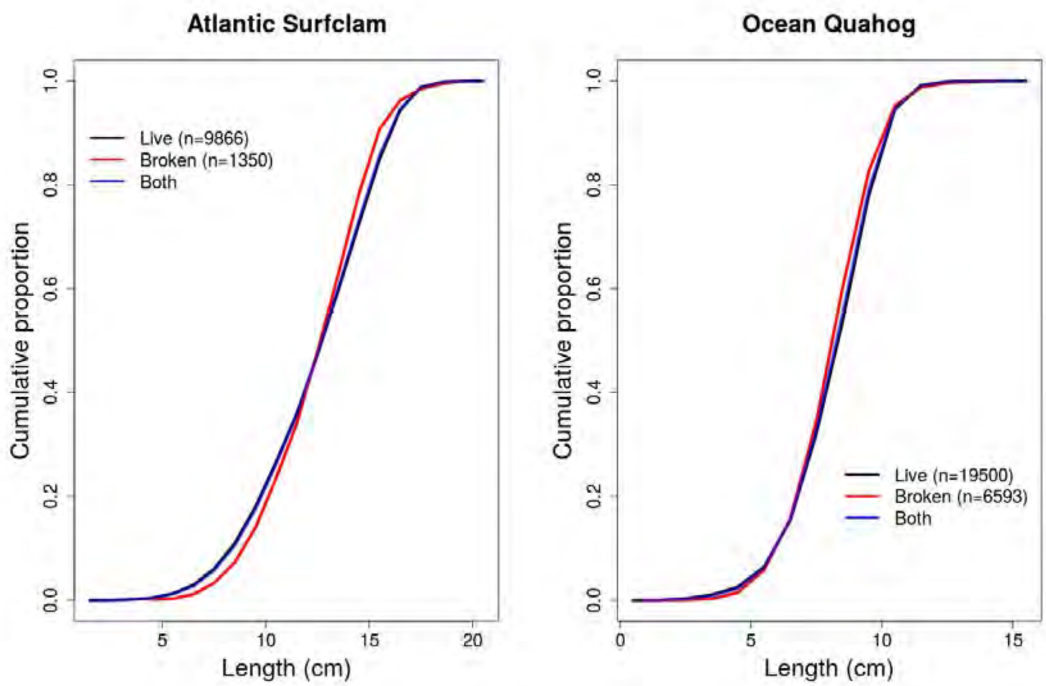


Figure 185: Cumulative length compositions from clam surveys on the ESS Pursuit through 2014. Cumulative proportion at length using only live (whole) clams, only broken clams, and live and broken clams together. There is very little difference between the cumulative length composition based only on live animals and the length composition using both whole and broken animals for both Atlantic surfclam and ocean quahog.

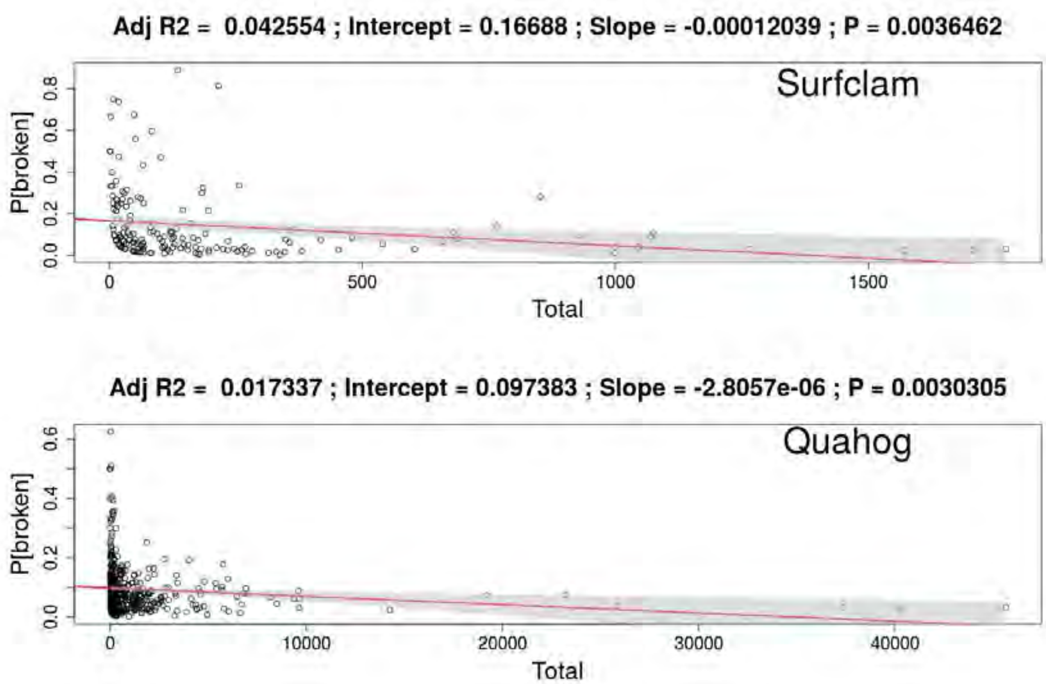


Figure 186: Correlation between the proportion of broken clams to the total clams caught in each tow from clam survey on the ESS Pursuit through 2014. The relationship was weak for both Atlantic surfclam and ocean quahog.

Appendix 6 Build a bridge

Southern area

The current assessment model for the southern area was based on the configuration of the assessment model for the southern area from the previous assessment (Northeast Fisheries Science Center (2013)). The alterations listed below illustrate step wise changes to the previous assessment model that result in the current assessment model. The sequence of these steps is not important, nor is it the actual sequence in which the changes occurred.

The first change was to incorporate new data (Figure 187). This required the addition of several new parameters (not estimated here, and left for illustrative purposes at previous values) because the new data came from a new survey (MCD). The MCD survey used a different dredge and required different selectivity parameters (Figure 188). The MCD also required a different prior probability distribution on catchability (Figure 189). The error around the growth curve was adjusted to follow a constant cv rather than a constant standard deviation (Figure 190). The relative weighting, in terms of assumed variance, of the composition data was decremented. This implicitly increased the weighting associated with the survey data and caused a shift in the trend in biomass (Figure 191) as the model began to fit the survey more closely. The ageing error was estimated, incorporating precision data from recent surveys (Figure 192). The cv of growth for young and old animals was estimated, rather than assumed (Figure 193). The number of recruitment deviations being estimated was increased to account for the additional years of data in the model, and the recruitment bias adjustment curve was altered to better fit the current data (Figure 194). The selectivity parameters for the MCD were adjusted in order to make the curve more flat topped and thus have higher selectivity for larger animals (Figure 195). Finally, the prior distribution for catchability on the RD was adjusted slightly to bring it more in line with the values estimated in the previous assessment ((Northeast Fisheries Science Center 2013); Figure 196). All of these adjustments together describe the sum of the changes made to the previous assessment model and build a bridge to the current model (Figure 197).

Northern area

The current assessment model for the northern area was based on the configuration of the assessment model for the northern area from the previous assessment (Northeast Fisheries Science Center (2013)). The alterations listed below illustrate step wise changes to the previous assessment model that result in the current assessment model. The sequence of these steps is not important, nor is it the actual sequence in which the changes occurred.

The first change was to incorporate new data (Figure 198). This required the addition of several new parameters (not estimated here, and left for illustrative purposes at previous values) because the new data came from a new survey (MCD). The previous assessment mistakenly allowed the swept area number per tow survey (SWAN) to contribute to the likelihood for estimating trend, that was corrected in this assessment (Figure 199). The MCD required a different prior probability distribution on catchability (Figure 200). The number of recruitment deviations being estimated was increased to account for the additional years of data in the model, the recruitment bias adjustment curve was altered to better fit the current data, and the variance around the recruitment deviations was fixed rather than estimated (Figure 201). The relative weighting, in terms of assumed variance, of the composition data was decremented. This implicitly increased the weighting associated with the survey data and caused a shift in the trend in biomass (Figure 202) as the model began to fit the survey more closely. The error around the growth curve was adjusted to follow a constant cv rather than a constant standard deviation (Figure 203). The MCD survey used a different dredge and required different selectivity parameters (Figure 204). The cv of growth for young and old animals was reduced to field estimated values (Figure 205). All of these adjustments together describe the sum of the changes made to the previous assessment model and build a bridge to the current model (Figure 206).

Figures

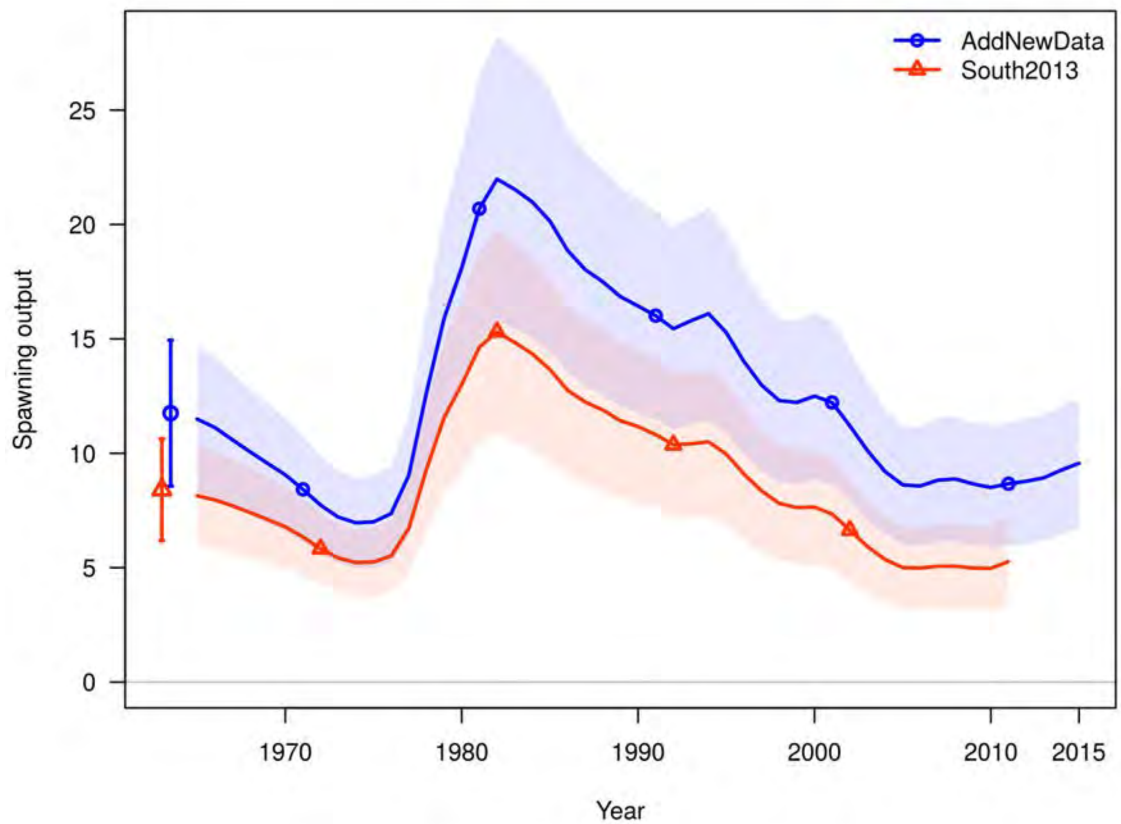


Figure 187: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model with identical configuration, but incorporating data from additional years (AddNewData).

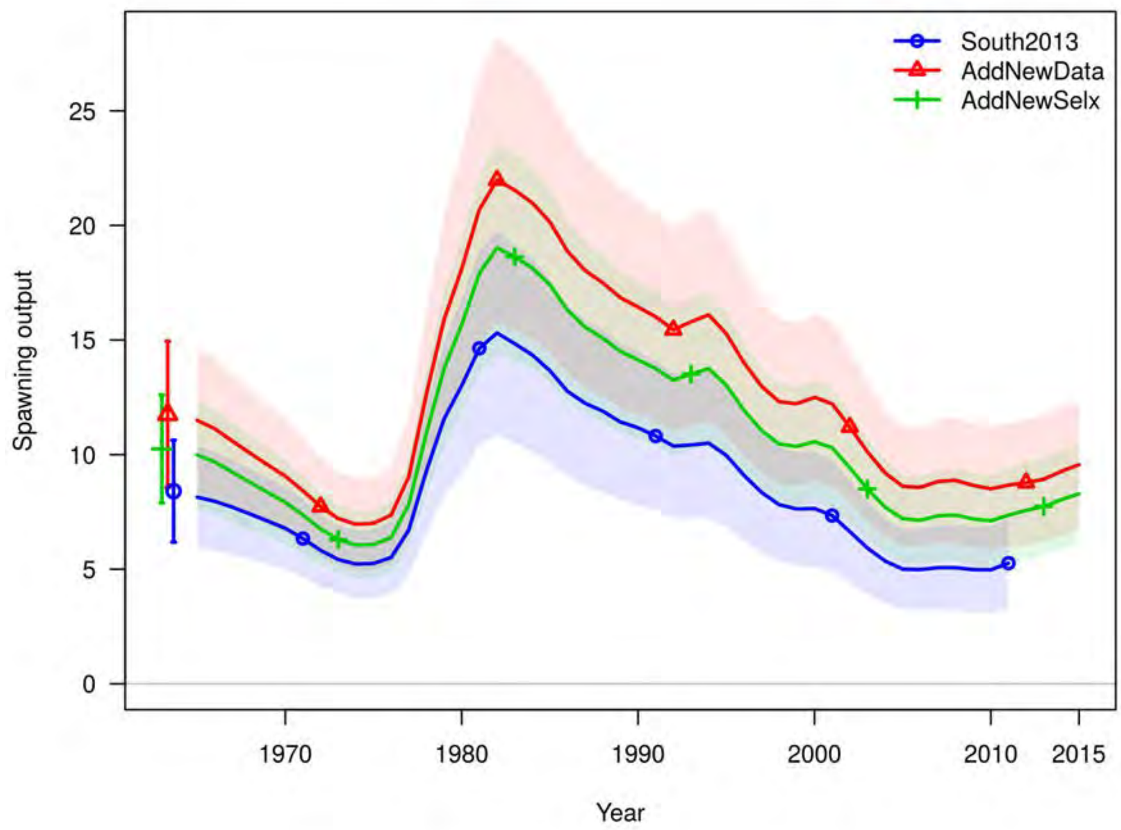


Figure 188: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model incorporating the selectivity of the new survey (AddNewSelx), as well as the previous model iteration (AddNewData).

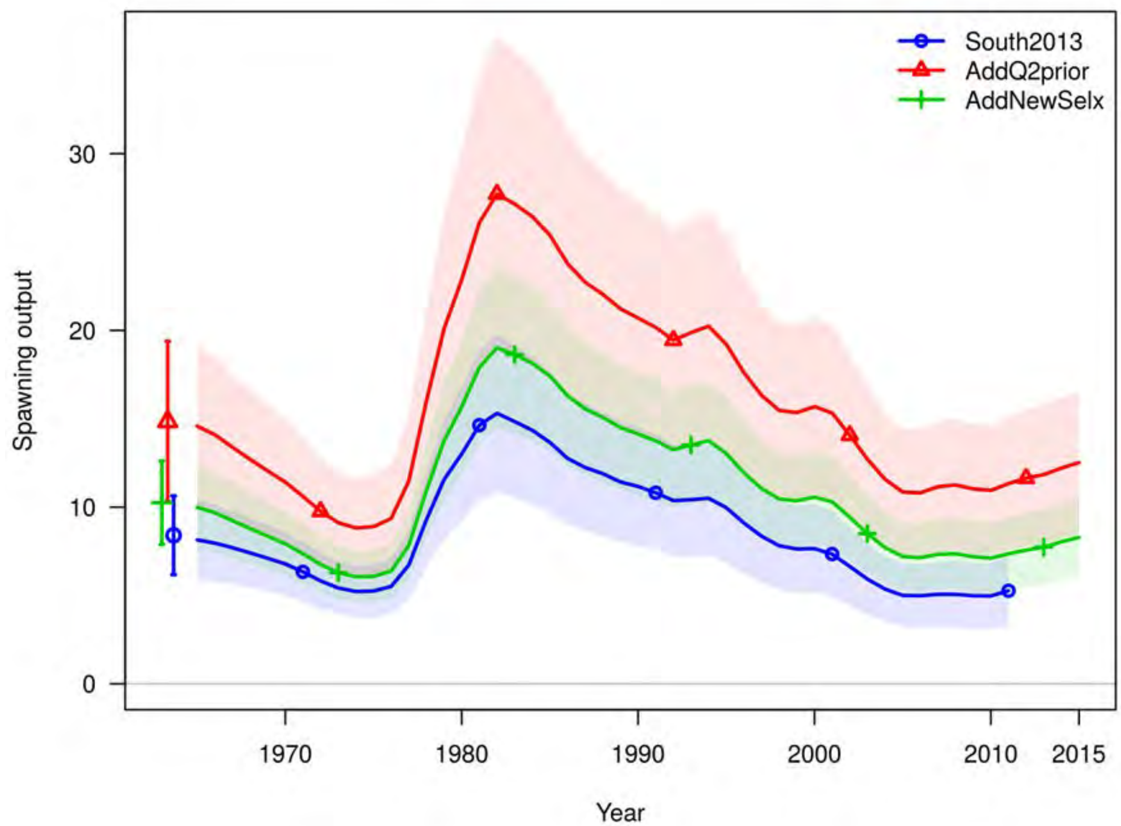


Figure 189: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model incorporating the prior on catchability for the MCD (AddQ2prior), as well as the previous model iteration (AddNewSelx).

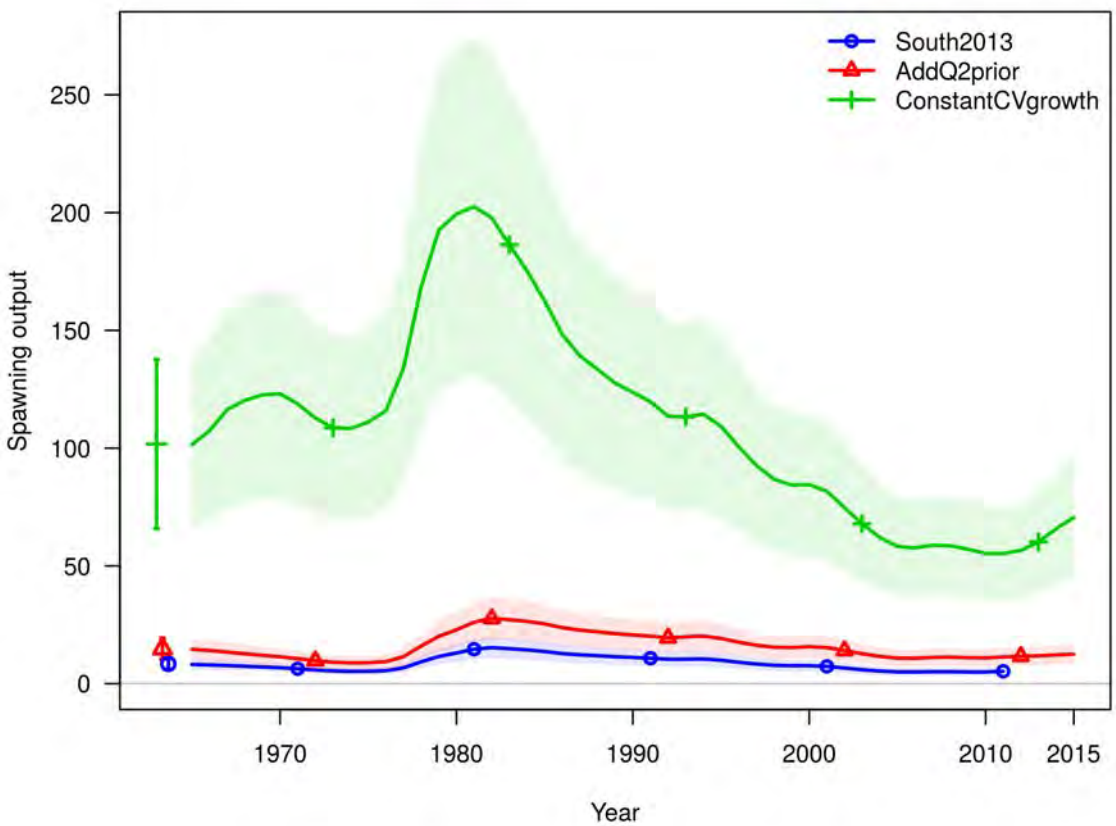


Figure 190: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model where the error around the growth curve has a constant cv rather a constant standard deviation (ConstantCVgrowth), as well as the previous model iteration (AddQ2prior).

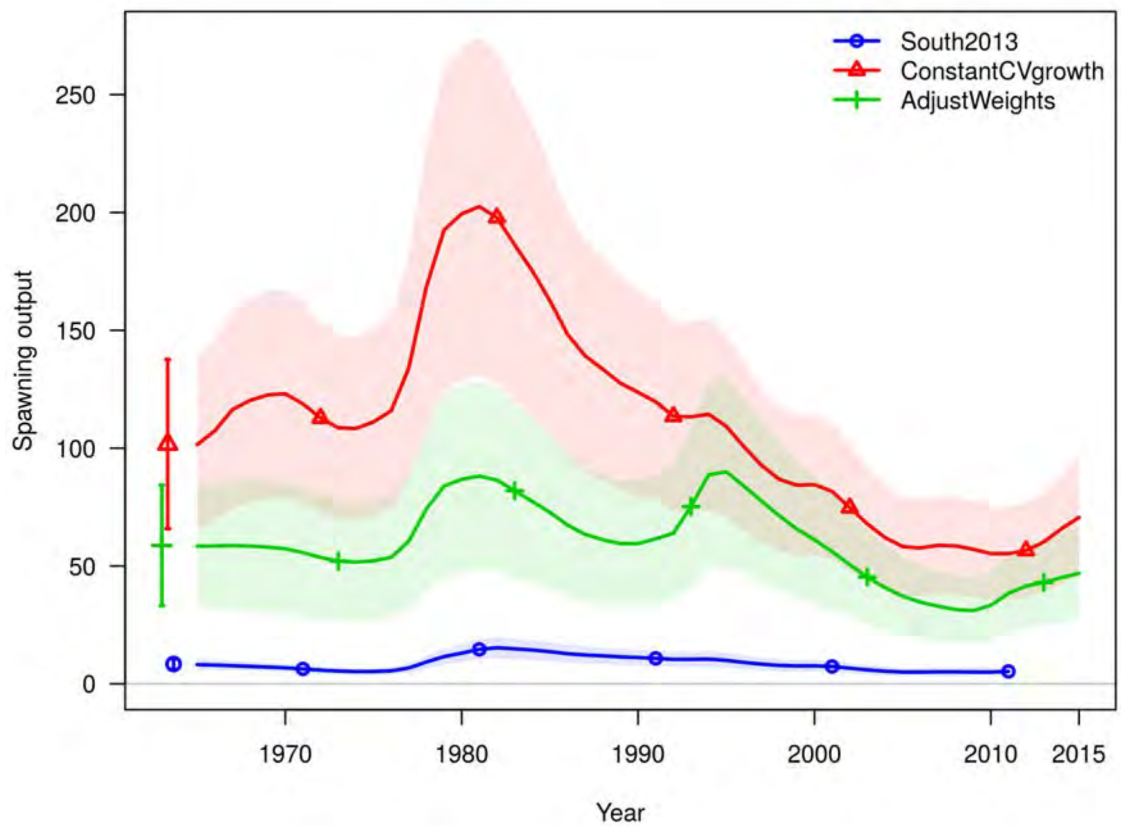


Figure 191: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model where relative weightings of the data sources has been adjusted so that the information content of the composition data is decremented (AdjustWeights), as well as the previous model iteration (ConstantCVgrowth).

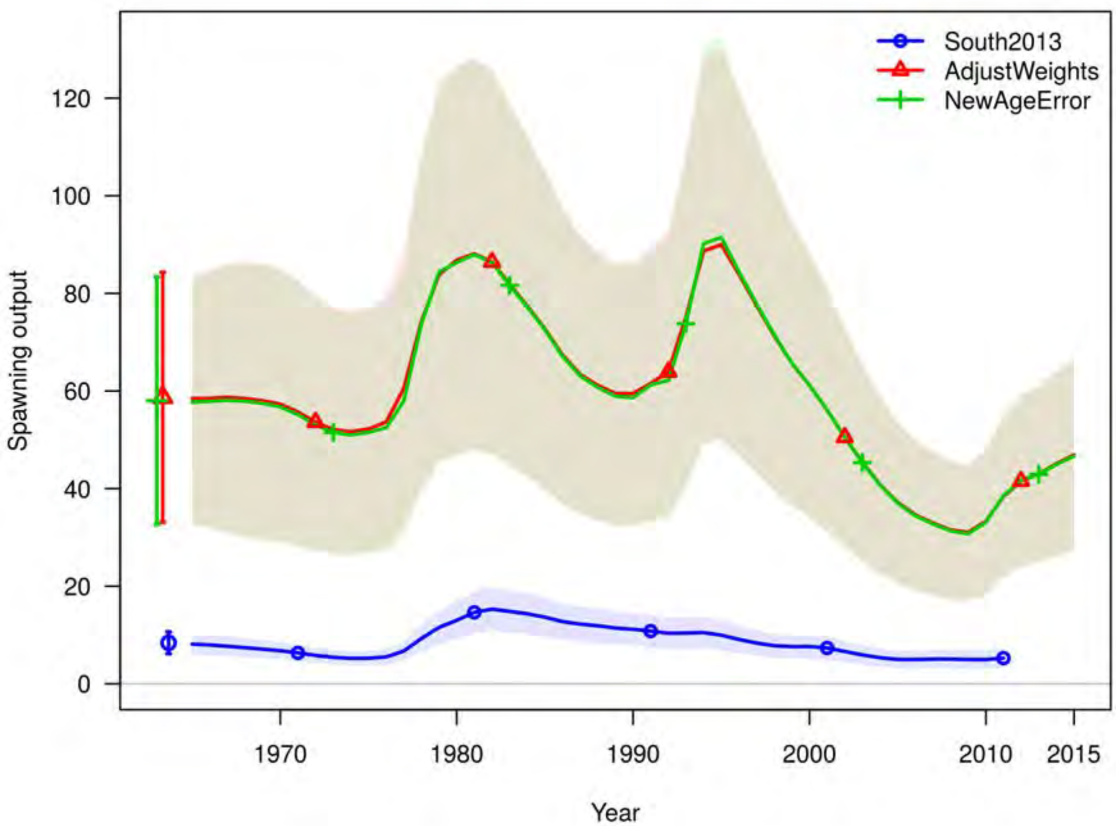


Figure 192: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model incorporating the new ageing error vector (NewAgeError), as well as the previous model iteration (AdjustWeights).

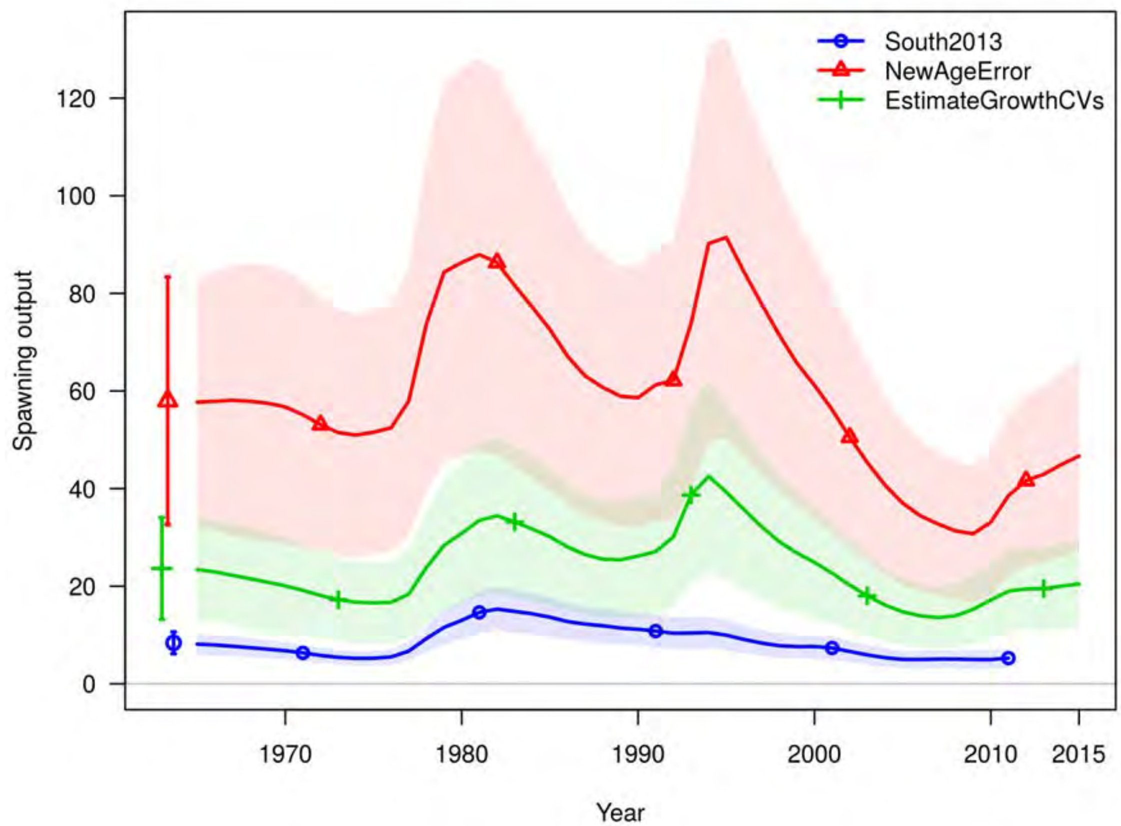


Figure 193: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model that estimates the cv of growth at the oldest and youngest ages (EstimateGrowthCVs), as well as the previous model iteration (NewAgeError).

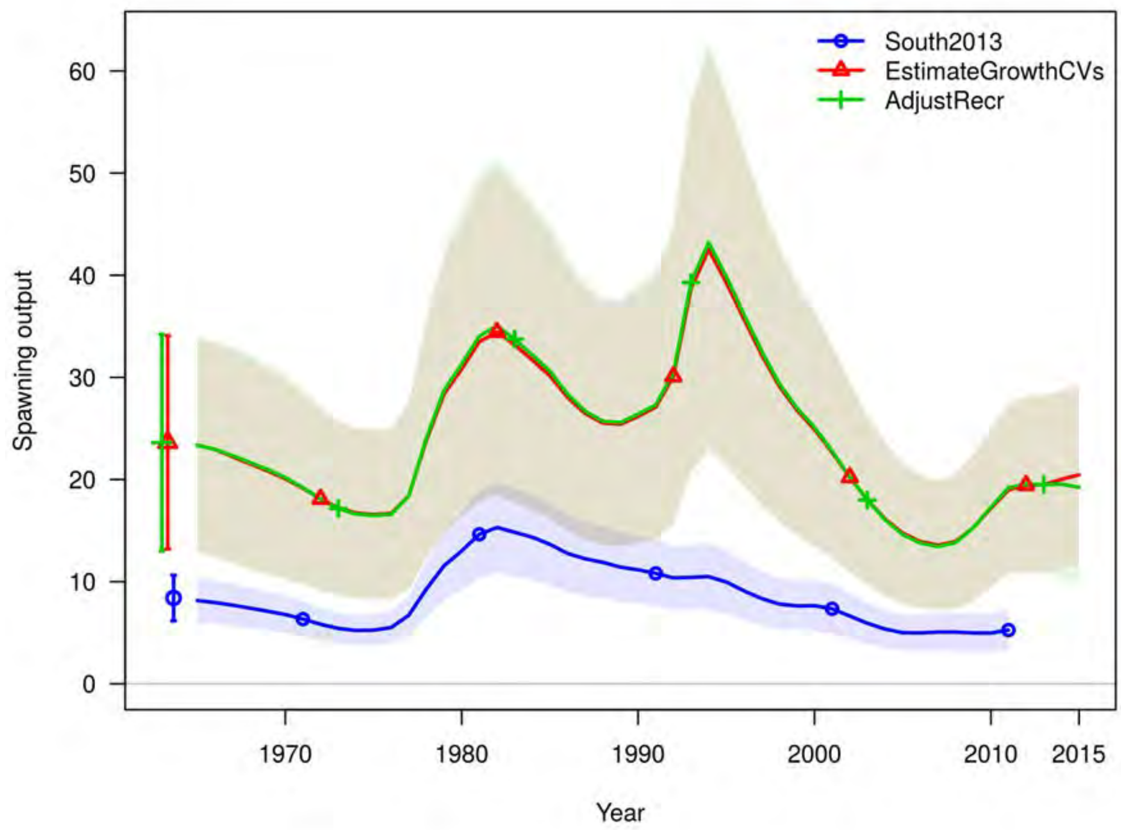


Figure 194: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model that estimates additional recruitment deviations and adjusts the parameters of the recruitment bias curve (AdjustRecr), as well as the previous model iteration (EstimateGrowthCVs).

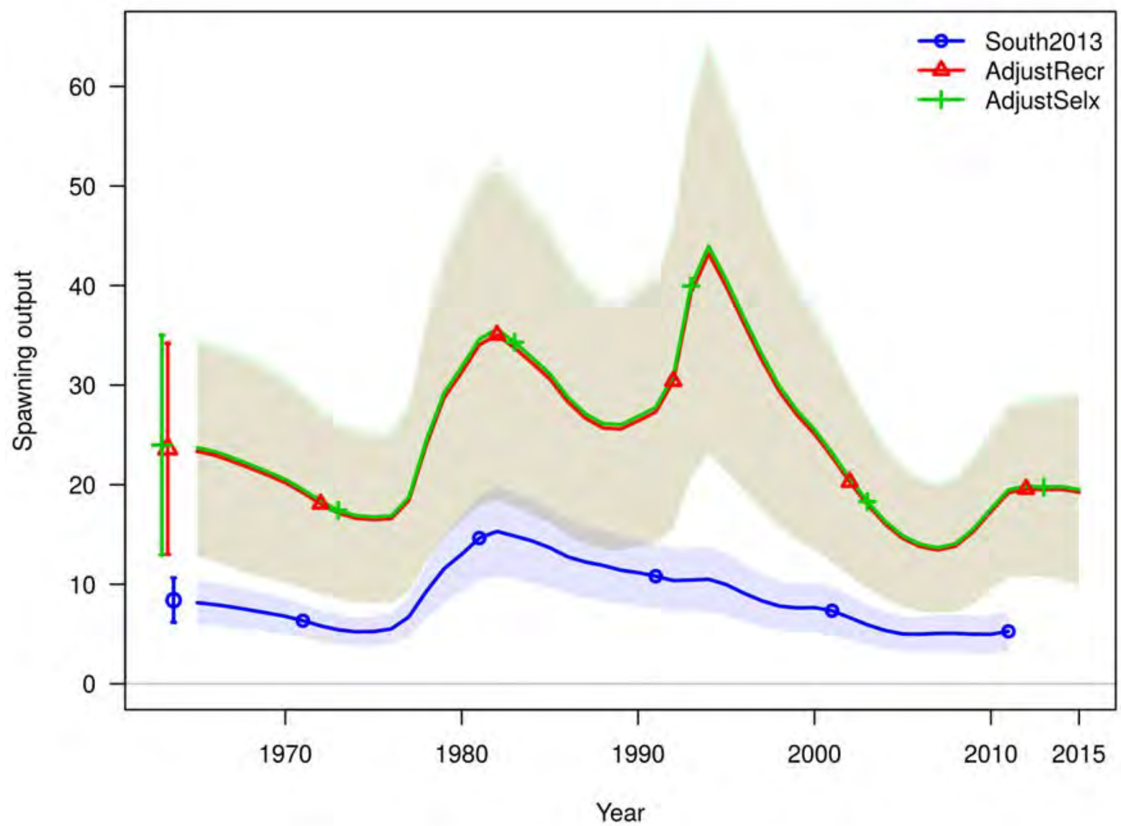


Figure 195: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model that estimates additional selectivity parameters and adjusts the right side of the MCD selectivity curve (AdjustSelx), as well as the previous model iteration (AdjustRecr).

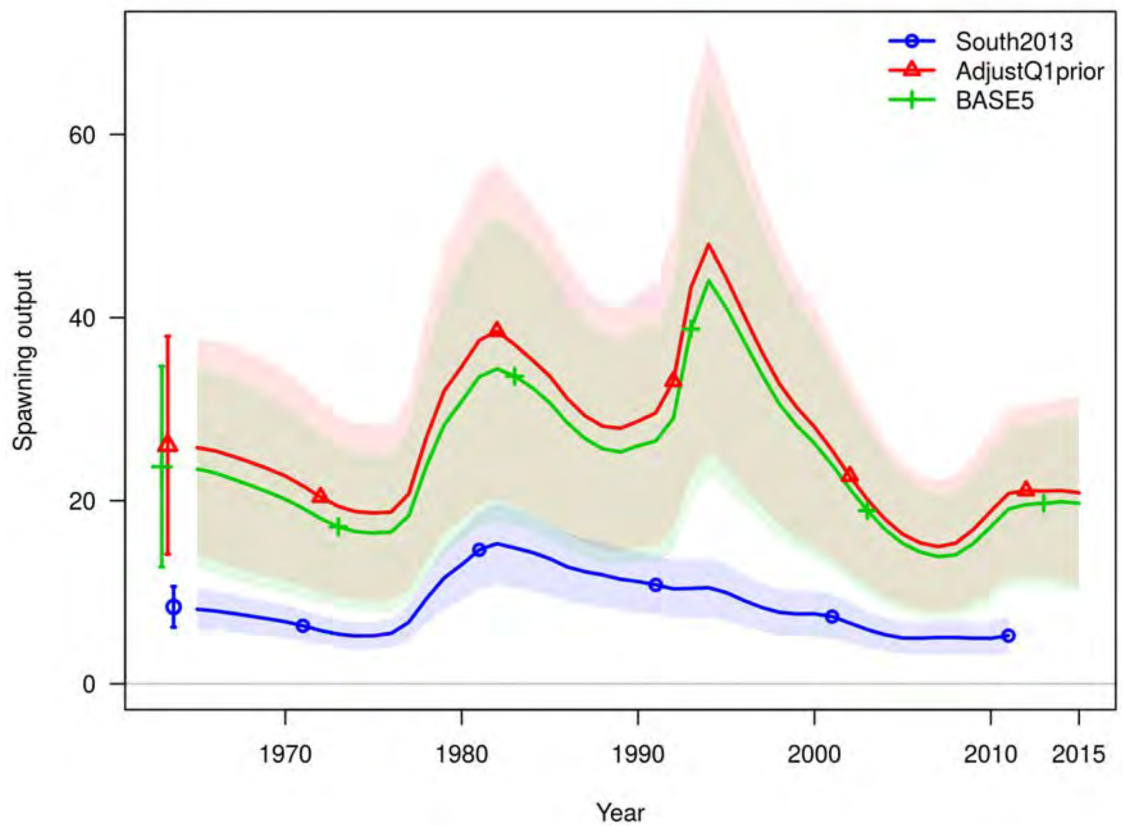


Figure 196: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to a model that includes a small adjustment to the prior distribution for the RD that brings it in line with the field prior distribution described in the last assessment (AdjustQ1prior), as well as the base model from the current assessment (BASE5).

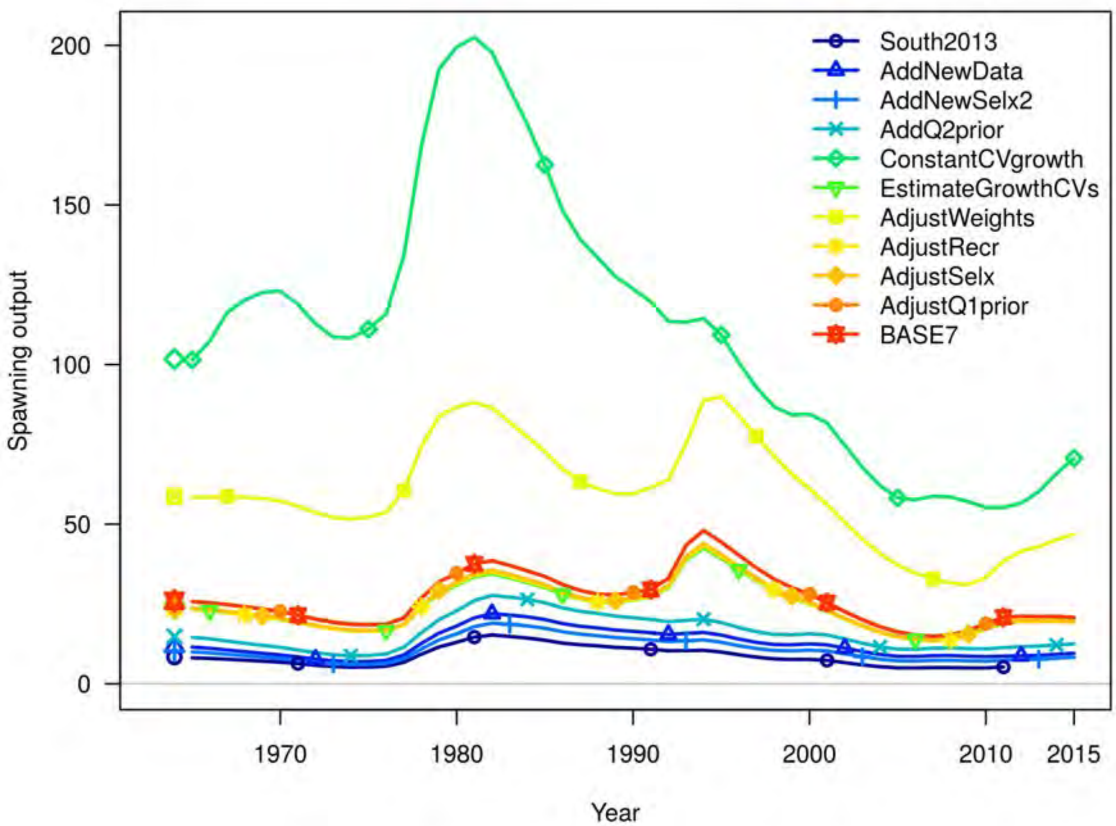


Figure 197: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (South2013) to each iteration in the sequence of model changes, as well as the base model from the current assessment (BASE7).

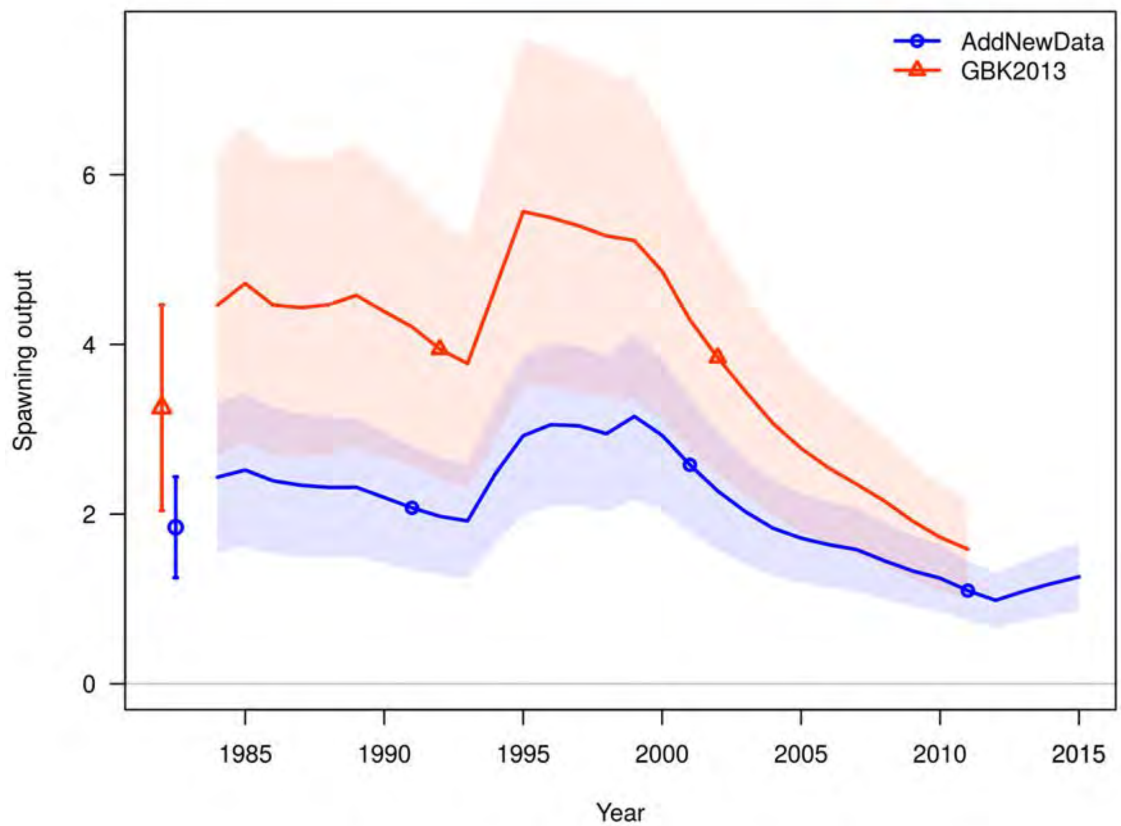


Figure 198: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model with identical configuration, but incorporating data from additional years (AddNewData).

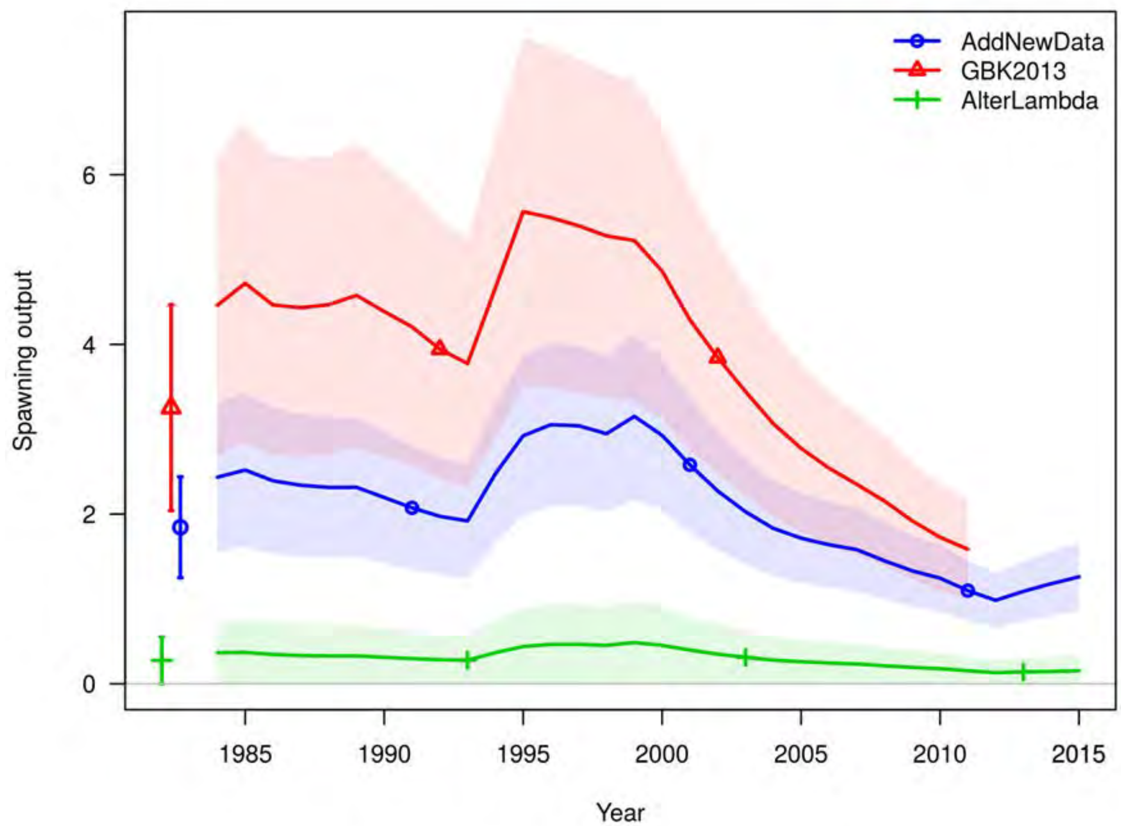


Figure 199: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model run where the likelihood component corresponding to the swept area number per tow in the survey was removed from the model solution (AlterLambda), as well as the previous model iteration (AddNewData).

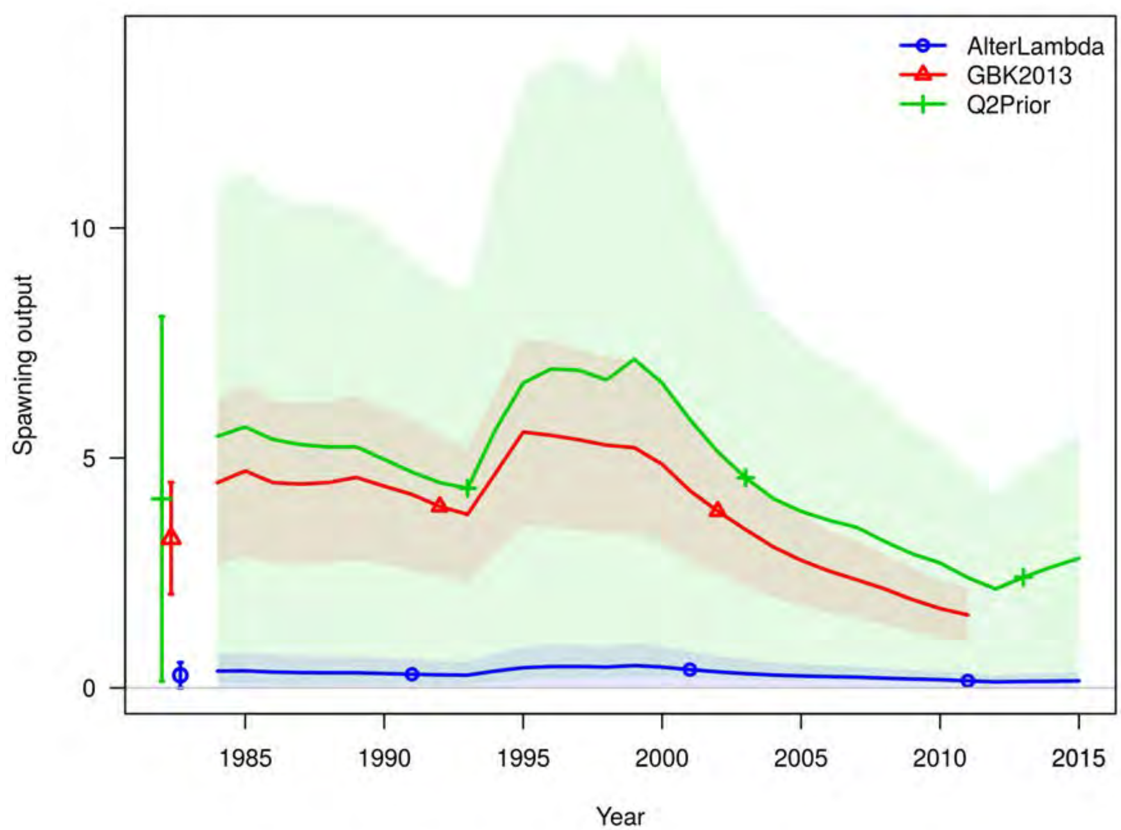


Figure 200: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model incorporating the prior on catchability for the MCD (Q2Prior), as well as the previous model iteration (AlterLambda). A comparison model run did not converge so the uncertainty associated with each spawning output trajectory could not be estimated.

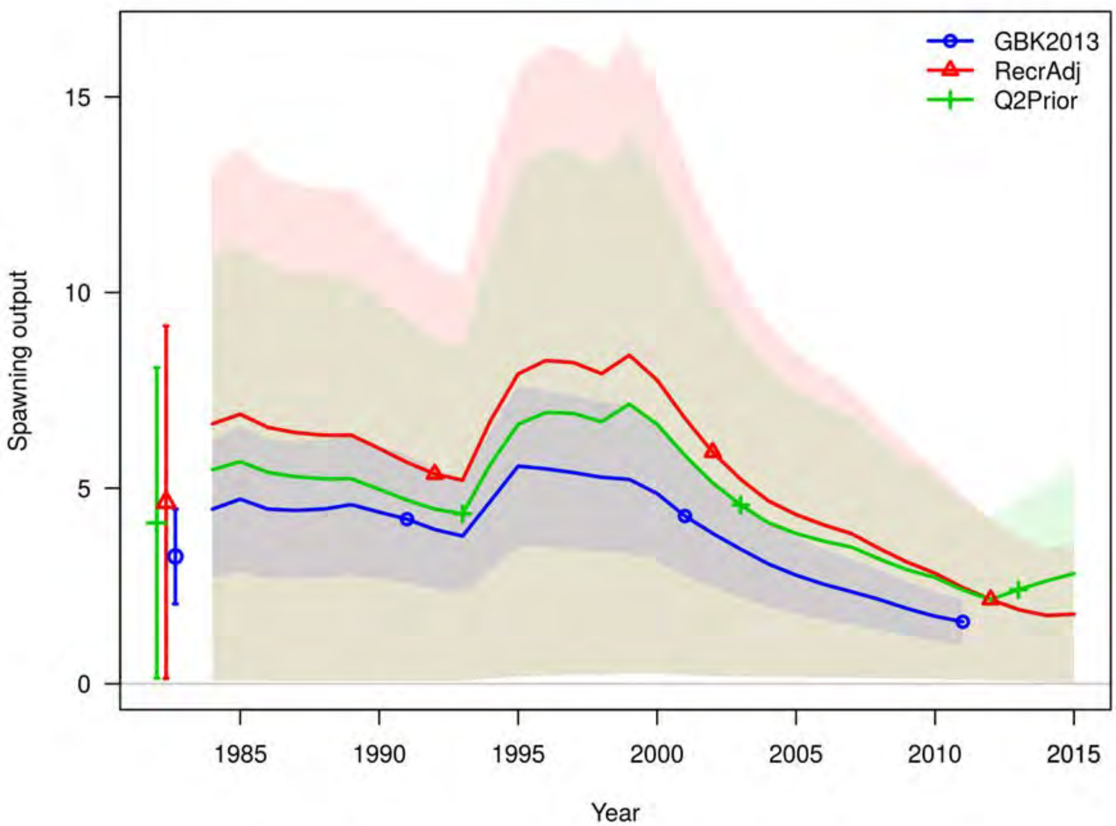


Figure 201: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where several recruitment parameters were adjusted (RecrAdj), including the number of recruitment deviations being estimated, the recruitment bias adjustment curve parameters, and the variance in recruitment was fixed rather than estimated. These runs were also compared with the previous model iteration (Q2Prior).

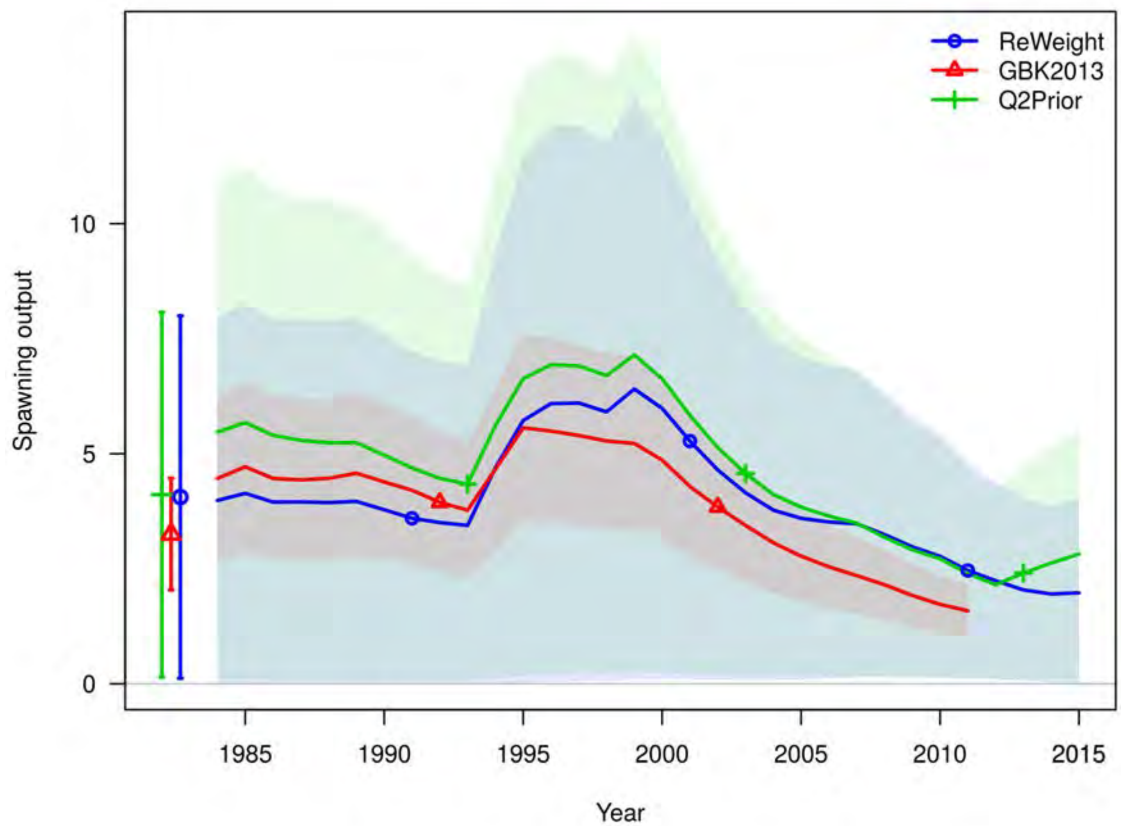


Figure 202: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where relative weightings of the data sources has been adjusted so that the information content of the composition data is decremented (ReWeight), as well as the previous model iteration (RecrAdj).

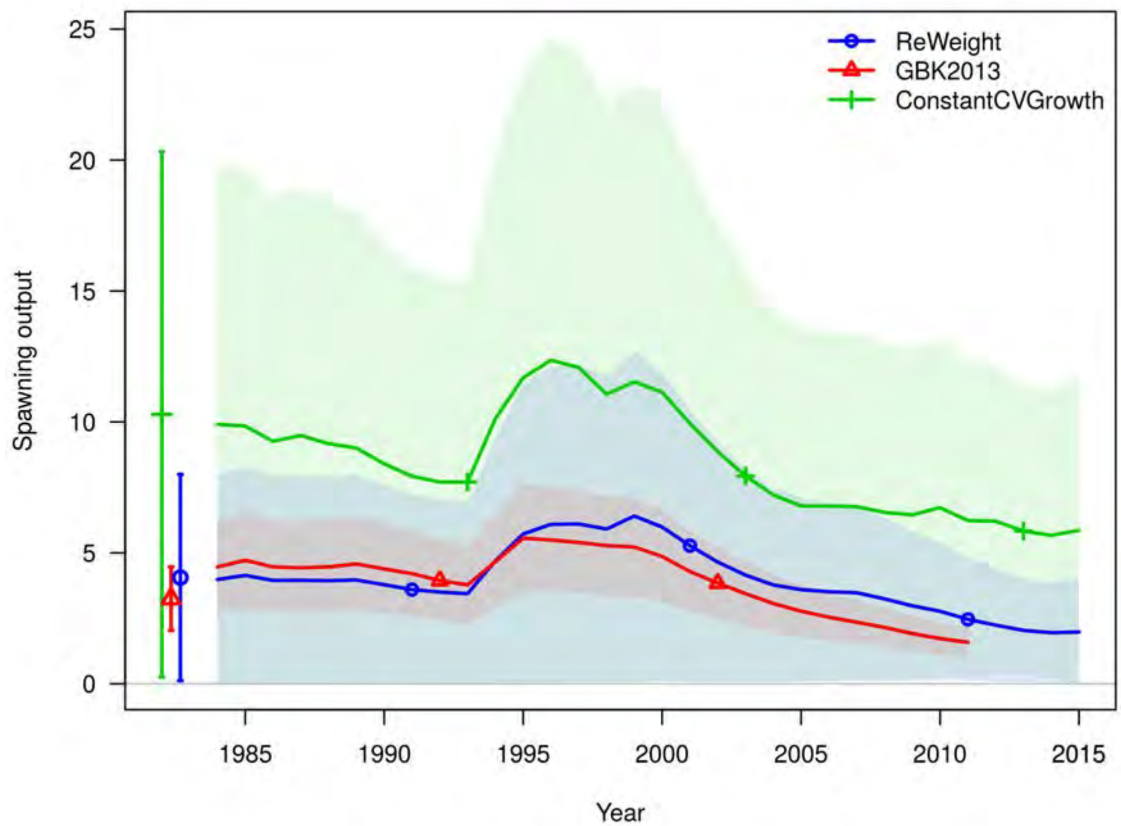


Figure 203: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where the error around the growth curve has a constant cv rather a constant standard deviation (ConstantCVGrowth), as well as the previous model iteration (ReWeight).

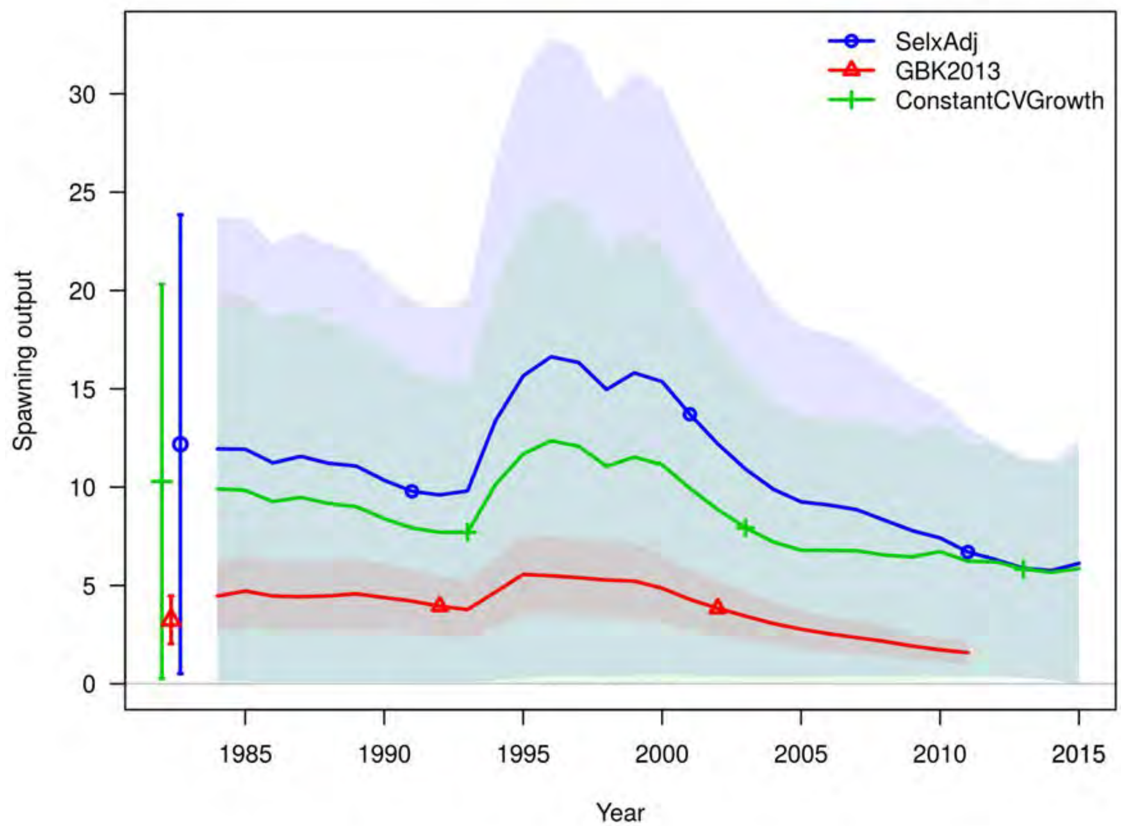


Figure 204: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where several selectivity parameters were estimated rather than fixed (SelxAdj), as well as the previous model iteration (ConstantCVGrowth).

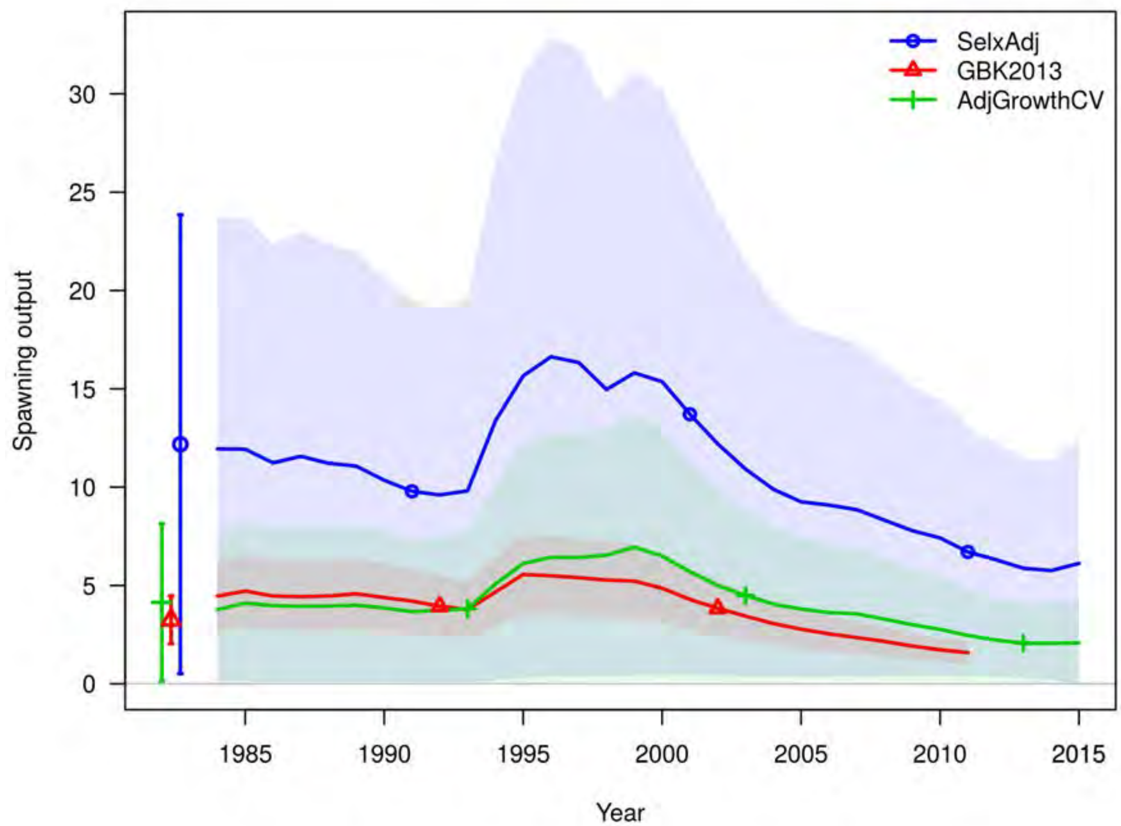


Figure 205: A comparison of the spawning output trajectories from the final model for the northern area from the last assessment (GBK2013) to a model where the cv around growth was adjusted to field estimated values (AdjGrowthCV), as well as the previous model iteration (SelxAdj).

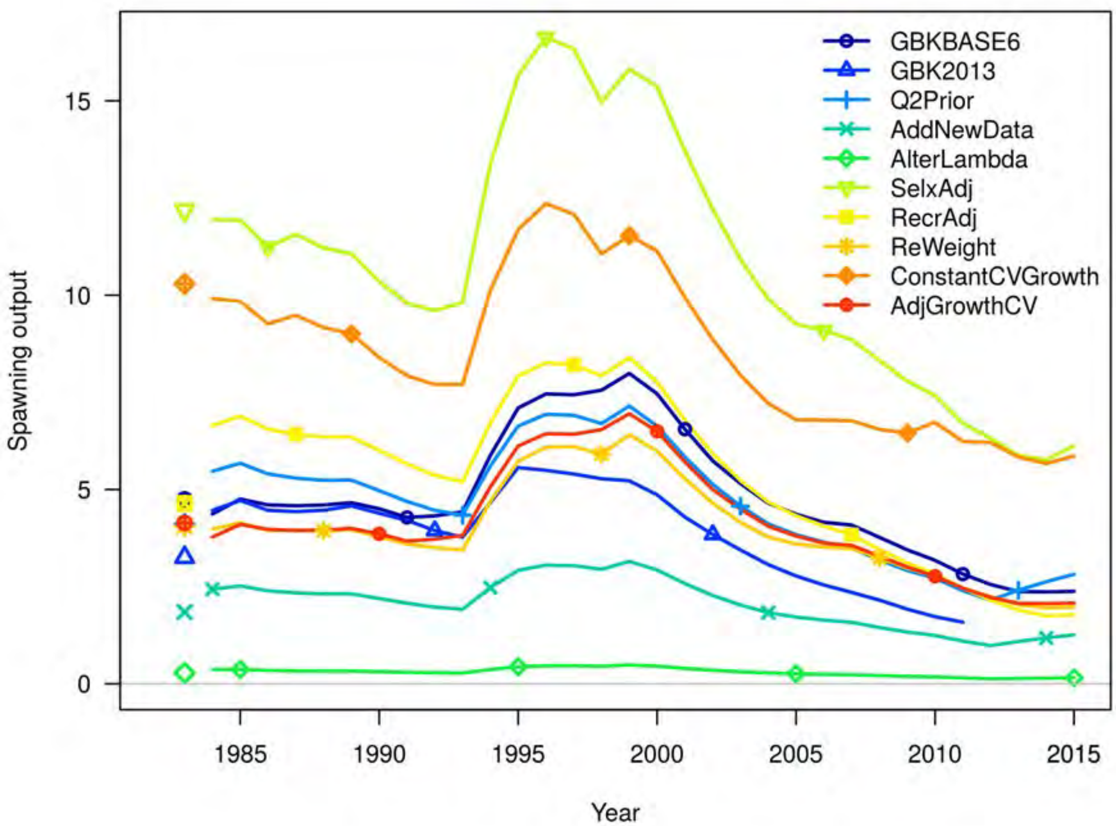


Figure 206: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (GBK2013) to each iteration in the sequence of model changes, as well as the base model from the current assessment (GBKBASE6).

Appendix 7 Atlantic surfclam in Massachusetts, New York and New Jersey state waters

Thanks to Robert Glenn of the Massachusetts Division of Marine Fisheries, Jeff Normant of the New Jersey Division of Fish and Wildlife Bureau of Shellfisheries, and Jennifer O'Dwyer of the New York State Department of Environmental Conservation for data and assistance with this report.

The states of Massachusetts, New York, and New Jersey support and manage commercial Atlantic surfclam fisheries in their territorial waters (defined as from the shoreline to three nautical miles offshore) not covered by the NEFSC clam survey or assessment process. Commercial and survey data from state waters complement the assessment of the Federally managed EEZ stock given the biological linkage between state waters and the EEZ, and the possibility that environmental effects in inshore Atlantic surfclam habitat will be mirrored in the offshore population or vice versa.

Massachusetts, New Jersey and New York state waters have historically been excellent habitat for Atlantic surfclam and supported robust fisheries. In recent years, however, there is evidence of declining recruitment to the fishable population and mortality of large clams in New Jersey and New York based on size frequencies and total biomass estimates. This could be happening for any number of reasons including not enough successful spawning leading to reduced larval supply, or because newly settled Atlantic surfclam are not surviving due to predation, environmental conditions, or disease.

The percentage of total Atlantic surfclam landings (EEZ plus state waters) harvested from within state waters has been falling since the late 1980s (Figure 207). Commercial landings have also fallen dramatically in each of the three states. As recently as the 1990s, landings from state waters were around 500,000 bushels per year from New Jersey (all along the coast), 400,000 bushels per year from New York (off the south side of Long Island) and 260,000 bushels from Massachusetts (mostly from around Cape Cod Bay, Martha's Vineyard, and Nantucket). Since then, landings have been down about 90% in New Jersey, 70% in New York, and 75% in Massachusetts.

Each state has a shellfish management plan in place involving various methods of assessing the population. New Jersey and New York conduct annual or semi-annual surveys of the Atlantic surfclam resource in their territorial waters and track landings by subarea. Massachusetts has tracked Atlantic surfclam landings from subareas within its state waters since 1994. For details and results from each state see below.

New Jersey

The New Jersey State Atlantic surfclam survey has been conducted each summer by the New Jersey Bureau of Shellfisheries since 1988. The survey platform is a commercial clam vessel using a hydraulic dredge lined with 2x2 inch steel mesh; since 2010 either the F/V Ocean Bird or the FV Jersey Girl (Figures 208 - 209). The survey has followed a stratified random sampling protocol since 1994. The survey area includes the New Jersey territorial waters off the whole east coast of the state facing the Atlantic Ocean. The survey area is divided into 5 regions, and each region is divided into three one-mile-wide strata running parallel to the coast, covering Atlantic surfclam habitat out to the 3-mile limit of state waters (Figure 210). Surveys have generally completed between 250 and 330 five minute tows each year.

In preparation for the 2013 field season, a new survey station allocation plan was established to deliver the information needed for less money and time by emphasizing key strata. Unfortunately, hurricane Sandy struck in the fall of 2012, disrupting the coast to such a degree that there were virtually no Atlantic surfclam left in the reduced strata set, and the newly streamlined survey could not be considered a viable part of the time series. During the summer of 2014 the survey resumed sampling almost the whole strata set with a reduced number of stations.

After each survey tow, the volume of the total Atlantic surfclam catch is measured in bushels, and all the clams from one bushel are counted and measured for calculation of population estimates and length frequencies. For swept-area biomass estimates, the dredge efficiency is assumed to be 1.0, which yields a conservative population estimate. Abundance estimates are made using the mean number of clams per bushel from any given stratum multiplied by the biomass estimate in bushels. Grab samples of the sediment are also taken and juvenile Atlantic surfclam too small to be retained by the dredge are sorted out and counted.

Data from the state of New Jersey available for this appendix include survey biomass estimates, survey length frequencies, an index of juveniles from sediment grab samples through 2015, and landings from 1988 through the 2014-2015 fishing year (October 1 through May 31). The survey data from 2015 are considered preliminary.

Estimates of Atlantic surfclam biomass for all the survey strata combined since the first survey year rose to a peak in 1997, then fell to the lowest estimate of the time series in 2014. Rough estimates of exploitation rate (landings over biomass estimate for the year) in New Jersey state waters have been between about 2 and 12 percent (Figure 211). Whether overexploitation contributed to the biomass decline is unclear, but the population did recover from a time of high exploitation in the 1980s. The impact of Hurricane Sandy can be seen in the estimates following 2012.

In the 2000s, the length composition of Atlantic surfclam in New Jersey was narrow and composed of only larger Atlantic surfclam, indicating a lack of new recruitment. However, recent survey data shows some smaller clams recruiting to the population (Figure 212). Grab sample data collected regularly since 1994 from the area of the survey show that juvenile Atlantic surfclam are consistently setting successfully (Figure 213). Some years have been better than others with occasional larger sets such as the ones seen in 2005 and 2009, a typical pattern for bivalve recruitment. These data do not show any downward trend in production of juvenile Atlantic surfclam that might occur as the result of unsuccessful spawning due to a decline in spawning stock.

Atlantic surfclam landings for human consumption from New Jersey state waters have fallen from a high of about 700,000 bushels in 2003 to less than 100,000 in 2005 and to zero or near-zero levels since 2006. Since the early 2000s, a small fraction of landings came from “prohibited waters” - fishing areas where landings can only be sold as bait due to contamination (Figure 214). Since 2008 the percentage of estimated Atlantic surfclam standing stock in prohibited waters has varied from 5 to 26 percent (Figure 215). As of 2005 the landings of bait Atlantic surfclam surpassed edible Atlantic surfclam, and during the 2014-2015 season the only Atlantic surfclam harvested were less than 300 bushels for bait. As the standing stock of edible Atlantic surfclam has declined, the quota has been cut to levels prohibitive to fishing. There is no quota for bait Atlantic surfclam harvested from prohibited waters.

Temperature change may be at least partly to blame for the rapid decline in adult Atlantic surfclam off New Jersey, whether directly or indirectly (such as changes in the timing, location or type of phytoplankton blooms). Increased predation on juvenile clams may also be occurring as the result of temperature-driven changes in predator species or densities.

New York

The New York state Atlantic surfclam surveys are conducted by the New York Department of Environmental Conservation. Surveys took place in 1992, 1993, 1996, 1999, 2002, 2005, 2006, 2008 and 2012. Plans for running the survey in 2014, and then plans for 2015, were set aside due to problems with contracting the survey vessel. The surveys from 1992-1996 were conducted and analyzed using different methods than the later surveys, so the results may not be directly comparable to more recent surveys and thus are usually not included in plots and summaries in this report.

The survey area comprises four regions spanning the southern shore of Long Island. The three westernmost regions are subdivided into three mile-wide strata running parallel to the coast, reaching the limit of state waters. The remaining easternmost region consists of a single stratum from the shore to one mile out (Figure 216). The area further offshore in this region is not surveyed as the bottom is extremely rocky and incompatible with hydraulic clam dredges.

The survey is conducted using a commercial clam vessel, most recently the FV Ocean Girl (Figure 217), using a hydraulic dredge lined with 1 in. inch plastic mesh to retain smaller clams. The 1999-2012 surveys were conducted in the summer or fall, had an average of 236 stations, and used a random stratified sampling technique. Survey tows are three minutes long, the total volume of Atlantic surfclam from each tow is measured in bushels, and half a bushel of Atlantic surfclam from each tow is measured and counted for population estimates and length frequencies.

Data from the New York State surveys include total numbers, densities and length frequencies for all surveys and ages from all surveys except 2012. Atlantic surfclam landings from New York state waters are available through 2015 (although not all 2015 reports were in when we received these data so they are considered preliminary).

Population estimates from the survey years show that the Atlantic surfclam abundance increased through the 1990s and peaked in the early 2000s. After that begins a decline that is just as fast as the increase, and in 2012 the population was estimated to be about what is was in 1994 (Figure 218). The decline has been especially pronounced in the inshore and western strata. The simple catch/biomass exploitation rate has been less than 6% since the population increase so it does not seem like overfishing is responsible for the decrease (Figure 219). Just like New Jersey but to a lesser degree, it seems that New York Atlantic surfclam are declining mostly as the result of environmental stress.

Recruitment to the population has declined, but the 2008 and 2012 survey age frequencies both suggest there were more young clams than the two previous surveys (Figure 220), but many fewer than in 2002. There has also been an increase in very old Atlantic surfclam over the time series, so even though there are fewer clams overall the old ones do not seem to be dying disproportionally. The three main cohorts seen in the age frequency plots can all be followed from 2002 through 2012 but no new cohorts of any size seem to be making it past the age of five or six. The percentage of the Atlantic surfclam less than 100mm shell length caught (considered seed) caught on the survey is also a measure of recruitment. Many seed Atlantic surfclam were caught in the 2002 survey, especially in the western strata where up to 54% of clams caught were seed (Figure 221). The percentage of seed taken in the survey in years since has been falling. Survey length frequencies also indicate poor recruitment (Figure 222). Length at age plots do not seem to suggest New York Atlantic surfclam are growing more slowly in recent years (Figure 223), although all regions and strata were lumped together so spatial changes may be masked.

Despite the decline, Atlantic surfclam continue to be harvested in New York state waters at about 33 percent of the 1994-2014 mean (Figure 224). There was a very large harvest limit set in 2004 (930,000 bushels) and it was almost reached, making the landings from New York from that year almost double what they had been the year before, and since then there has been a downward trend. The harvest limit based on the results of the 2012 state survey is the lowest since 1994.

The Atlantic surfclam fishery in New York state waters has been limited entry since 1993 when 25 boats qualified, and as of 2015 there were 17 vessels still fishing. In 2003 an FMP was implemented, requiring the harvest limit not to exceed 5% of the biomass estimated by the most recent survey, and dividing it into equal quotas for each permitted vessel.

Massachusetts

The Massachusetts Department of Marine Fisheries has been logging total Atlantic surfclam landings from state waters since 1994, and since 2008, the location harvested. Landings are recorded as having been harvested in one of over 75 contiguous Designated Shellfish Growing Areas (DSGAs) surrounding the Massachusetts coast including Boston Harbor, Cape Cod, Buzzards Bay and the islands of Marthas Vineyard and Nantucket (Figure 225). Because there are so many small areas, these data give the DMF an overview of how both the resource and the fishing are distributed and where the particularly productive areas are (Figure 226). The data are also used to calculate landings per unit effort and track fishing effort and its impact in specific areas. The numeric data per DSGA are often confidential due to a small number of harvesters using the area and not available for publication, so they are reported by the larger statistical reporting areas SRAs (Figure 227). Even then much data remain confidential (Figure 228).

There is a cap on the number of commercial permits issued, a daily harvest limit of 200 bushels and a minimum size of 5.0 in. shell length. Catches must be reported using daily trip reports. Some of the Atlantic surfclam harvested are from contaminated areas and are only used for bait. A special permit must be issued for this and only 50 bushels can be landed per day. Landings of all Atlantic surfclam from Massachusetts have declined since the early 1990s and have varied without trend since 1997 (Figure 229).

Figures

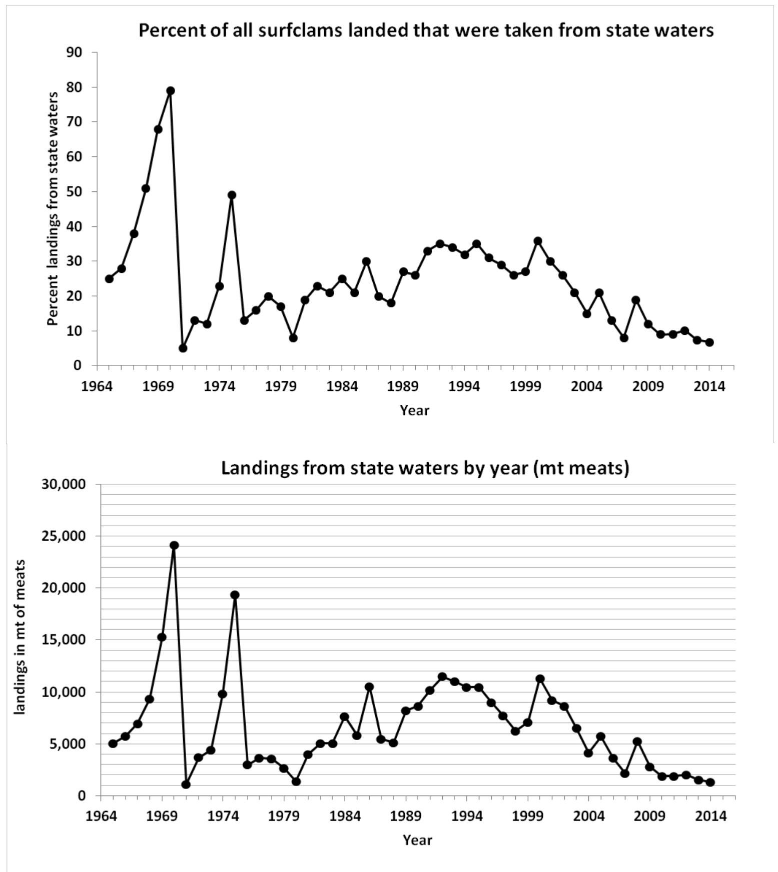


Figure 207: Percentage of total Atlantic surfclam landings harvested from state waters, almost entirely from New York, New Jersey and Massachusetts (top), and landings from state waters in metric tons of meats by year (bottom). There may be differences between the landings shown above and landings attributed to state waters in the main assessment report. The report has historically used dealer-reported landings minus logbook-reported landings (from EEZ - permitted vessels) to estimate state landings, which is not as accurate as the landings reported directly from the states. However, the assessment time series begins well before the states were keeping track of their landings and the subtraction method is still used for consistency.

Figure 208: The New Jersey state survey under way aboard the FV Jersey Girl.

Figure 209: Results of a tow from the New Jersey state survey.

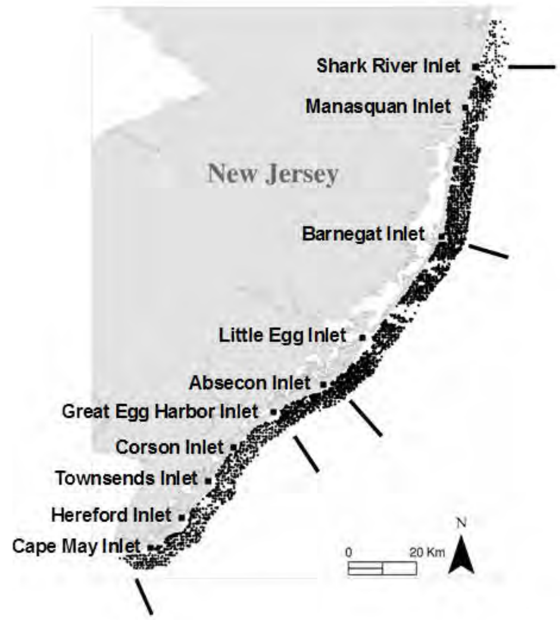


Figure 210: Map showing the sampling regions for the NJ state survey, and station locations 1988-2008. Within each region there are three along-shore depth strata one mile wide. Map courtesy of Jeff Normant.

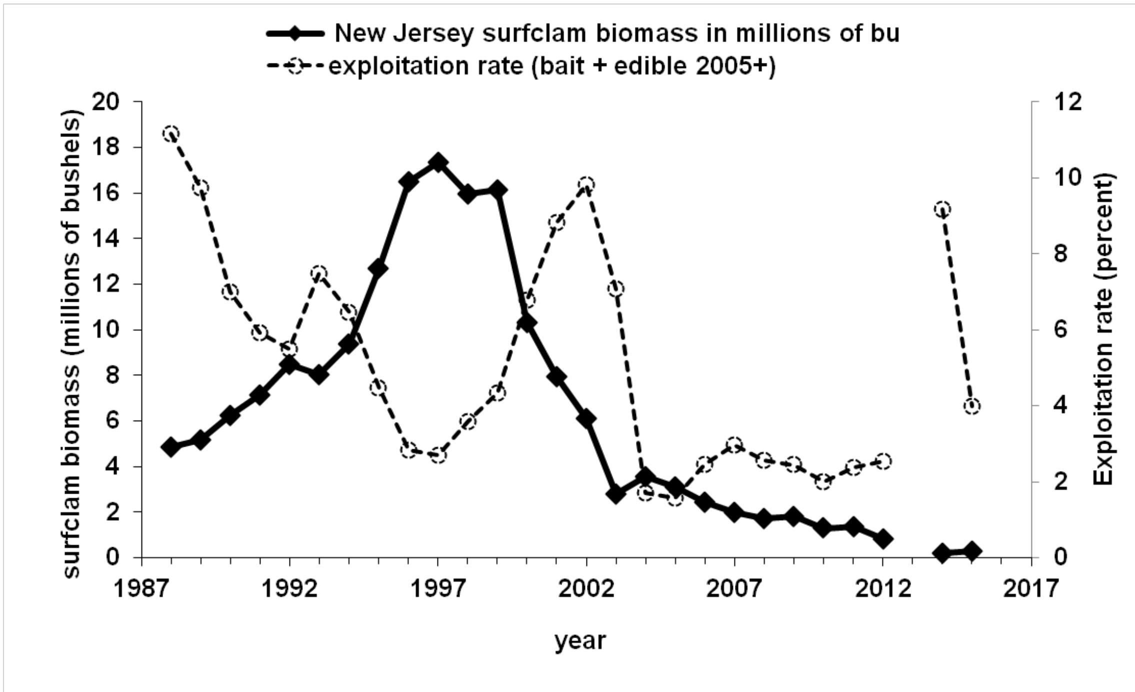


Figure 211: Exploitation rates (expressed as landings as a percentage of estimated biomass) and population biomass for New Jersey state Atlantic surfclam.

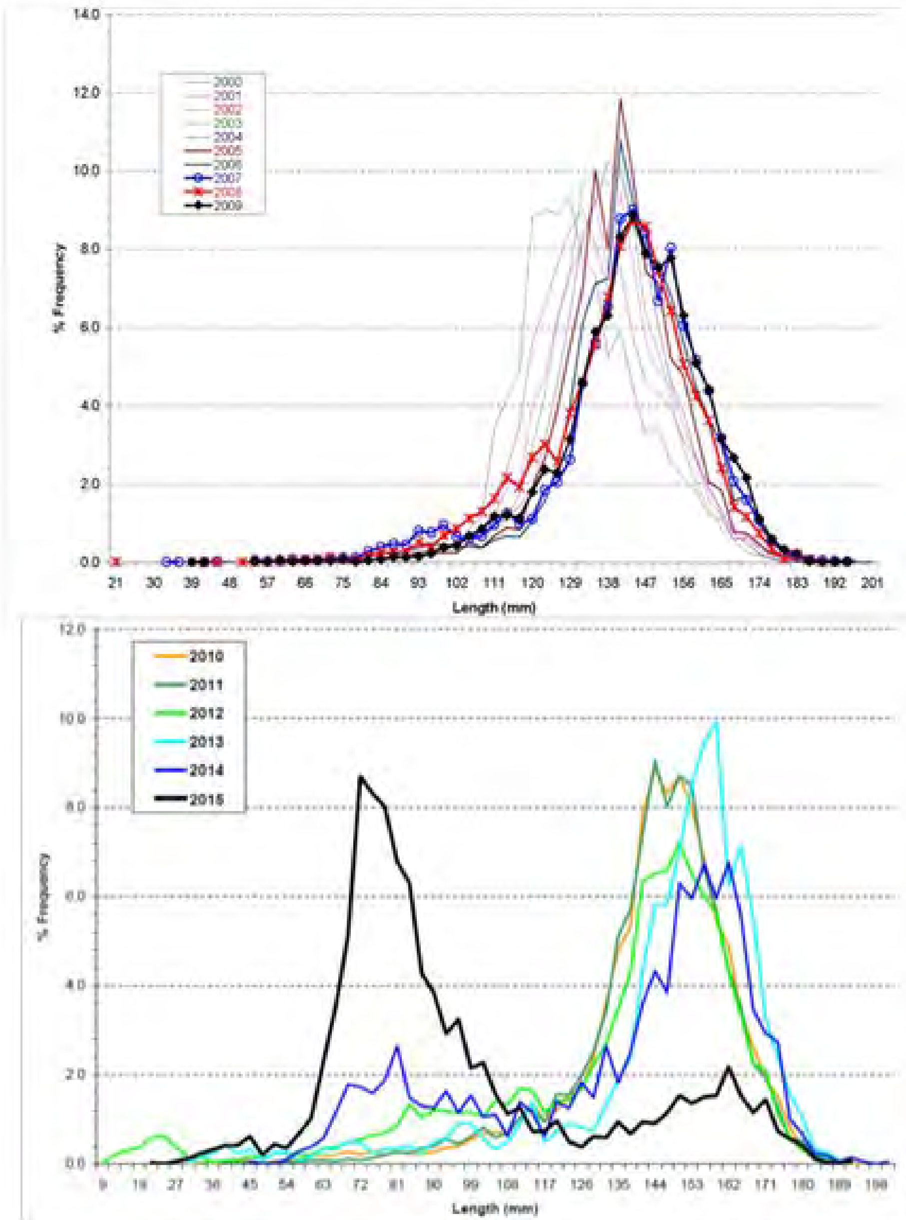


Figure 212: Length frequencies from the 2000-2009 (top) and 2010-2015 (bottom) New Jersey state Atlantic surfclam surveys. Not all strata were sampled in 2013 and 2014 but the most populous ones were. Note scales are different on both axes. Plots courtesy of Jeff Normant.

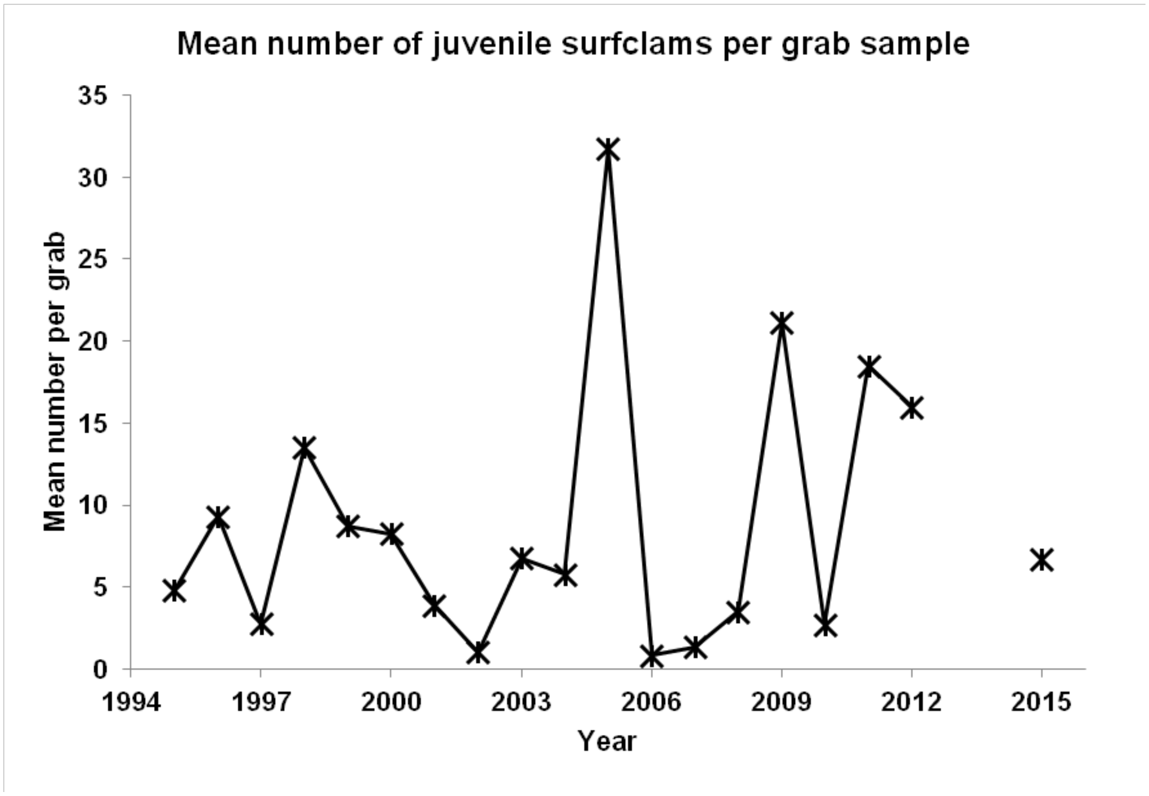


Figure 213: As part of the Atlantic surfclam survey, the state of New Jersey takes sediment grab samples, which contain juvenile Atlantic surfclam too small to be retained in the survey dredge. The clams are generally less than 10mm. About 300 grab samples were taken each year up until 2012, in 2013 and 2014 there were no grabs done, and 186 grabs were done in 2015. The area sampled is 1/10 of a square meter.

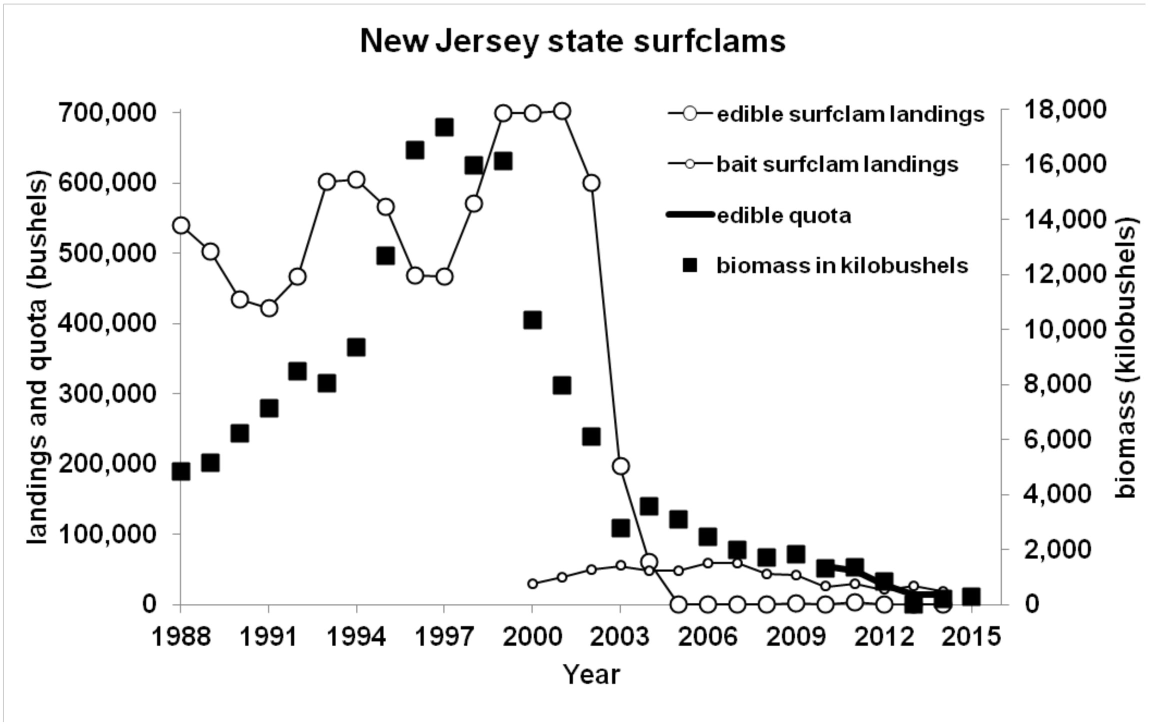


Figure 214: Landings of both edible and bait Atlantic surfclam, quota for edible Atlantic surfclam and survey-based Atlantic surfclam population estimates in New Jersey state waters. Landings and quota are scaled to the left axis and population is scaled to the right axis. There are no quotas or restrictions on harvest of bait clams at this time.

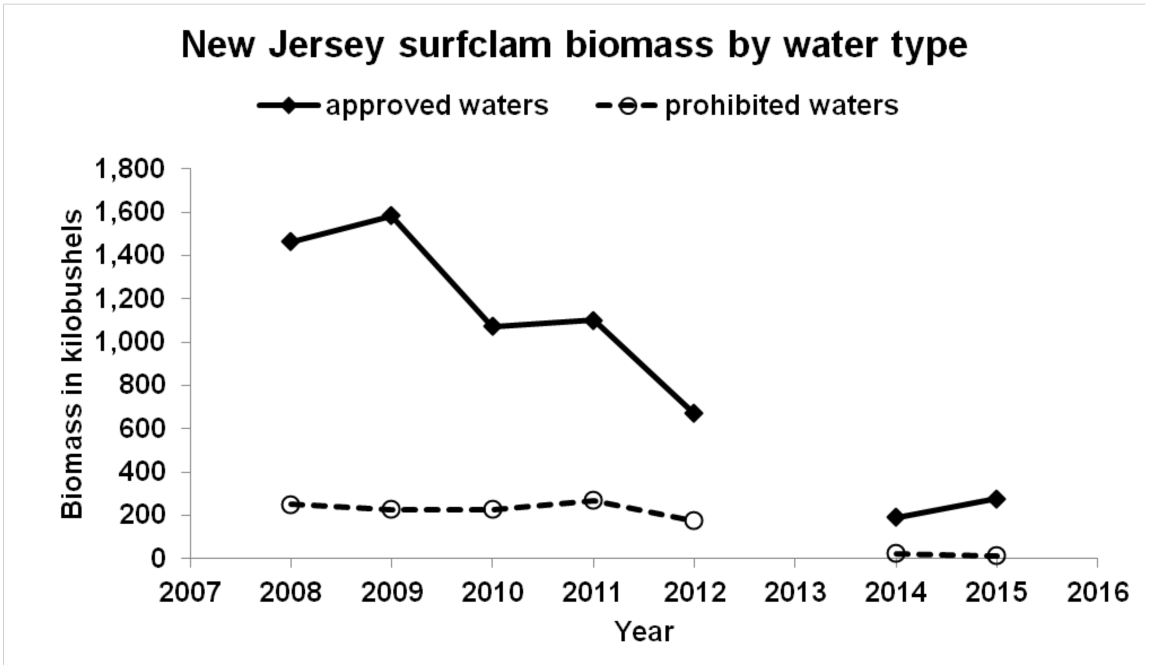


Figure 215: Standing stock in industry bushels from New Jersey state waters. Clams from approved waters can be sold for human consumption, while clams from prohibited waters are sold for bait only.

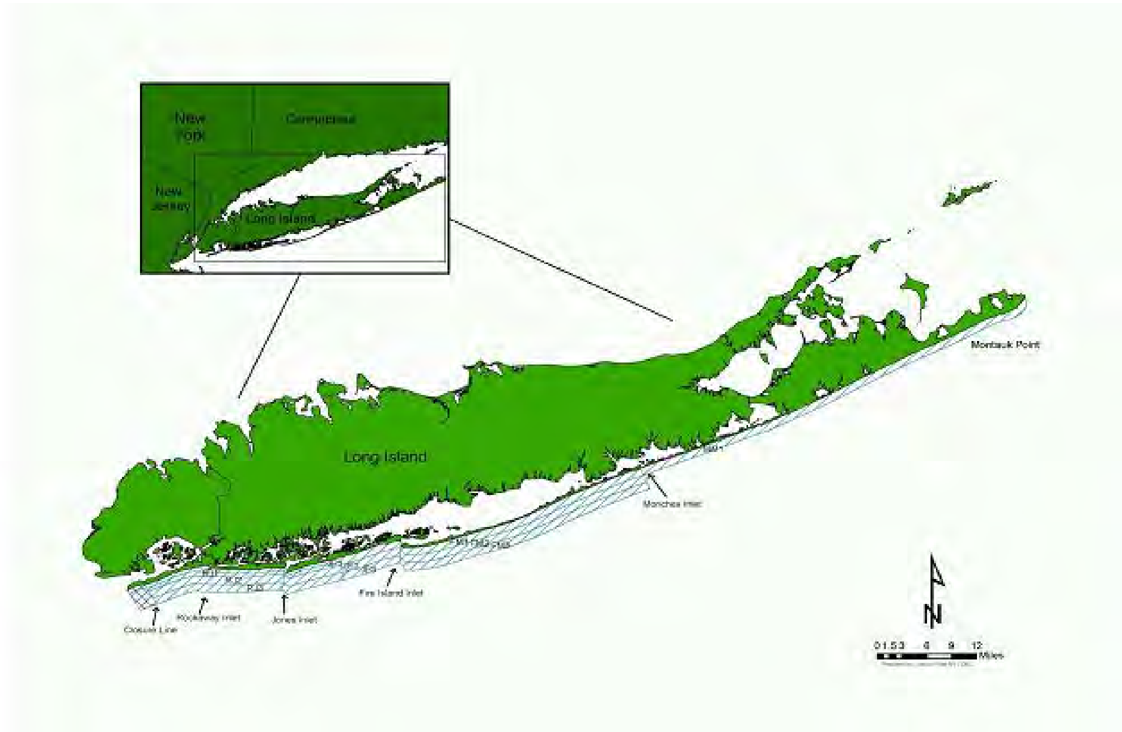


Figure 216: Map showing New York state sampling regions from west to east: RJ, JF and FM, which each have 3 depth strata, and MM which has one depth stratum. Map courtesy of New York State Department of Environmental Conservation.

Figure 217: The commercial clam vessel FV Ocean Girl, used for the New York state surveys, with dredge deployed. Photo courtesy of Jennifer O'Dwyer.

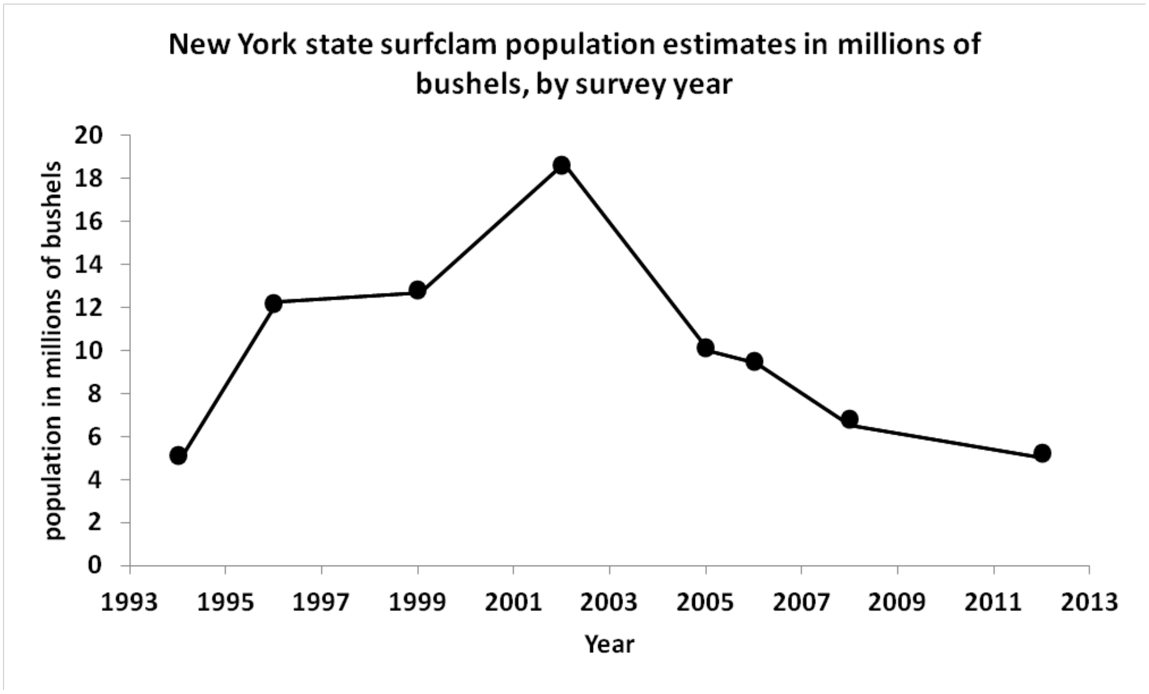


Figure 218: Atlantic surfclam population estimates for the surveyed area in New York state waters since 1994, in millions of bushels.

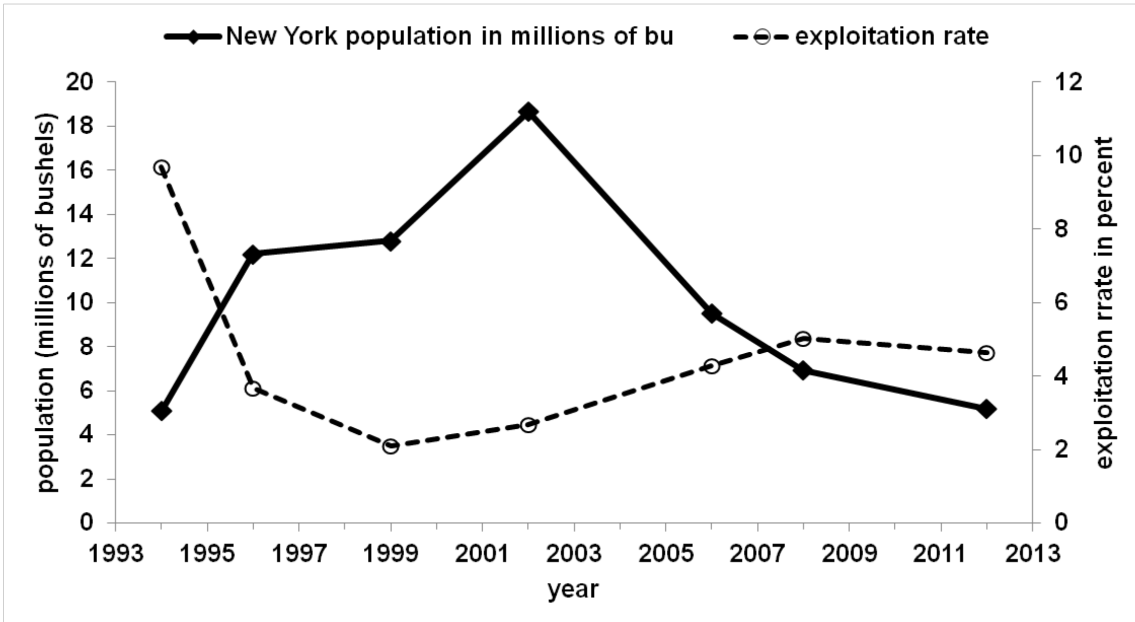


Figure 219: Exploitation rates (expressed as landings as a percentage of estimated biomass) and population biomass for New York state Atlantic surfclam.

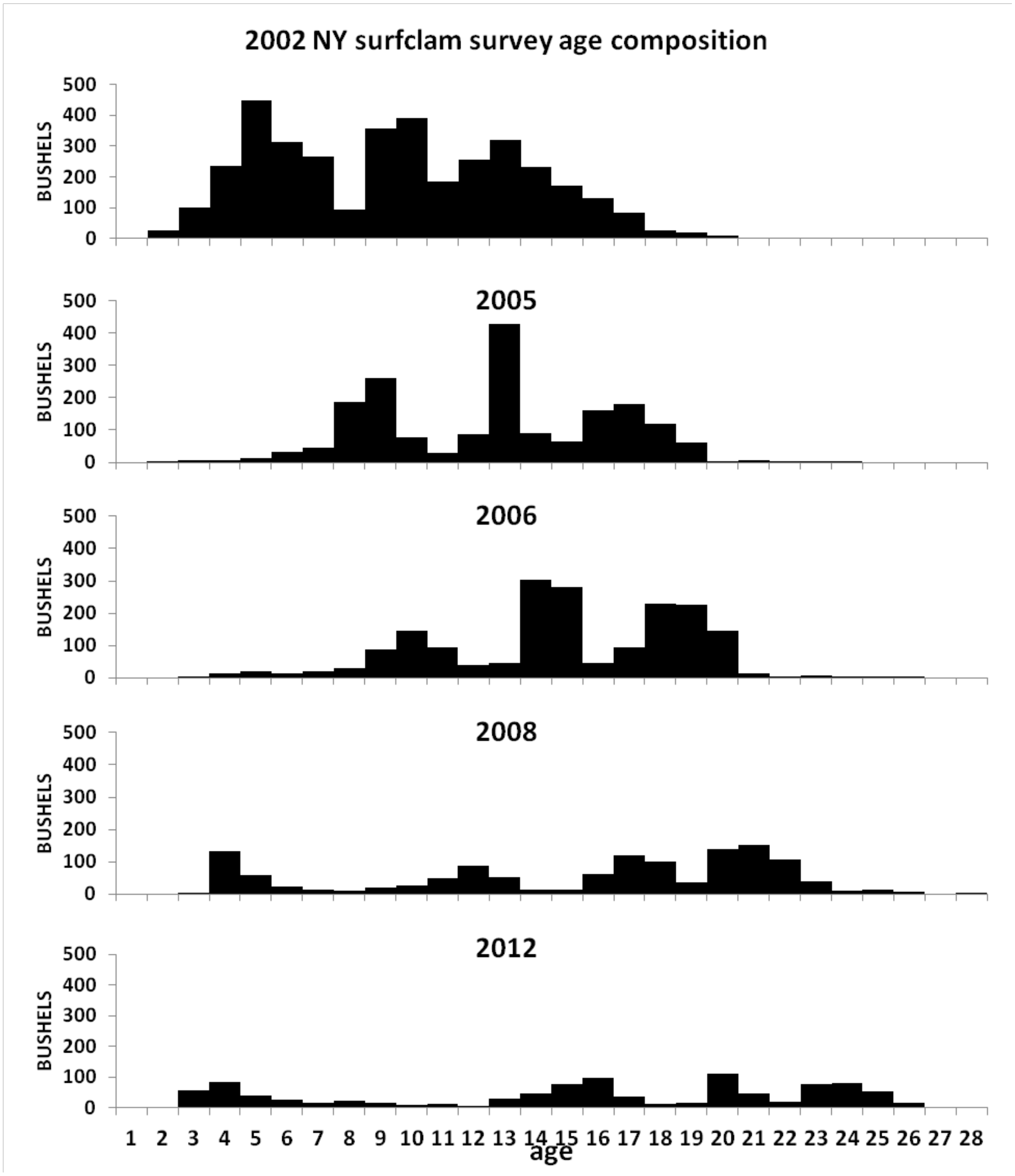


Figure 220: Age compositions from the 2002, 2005, 2006, 2008 and 2012 New York State Atlantic surfclam surveys, in bushels at age.

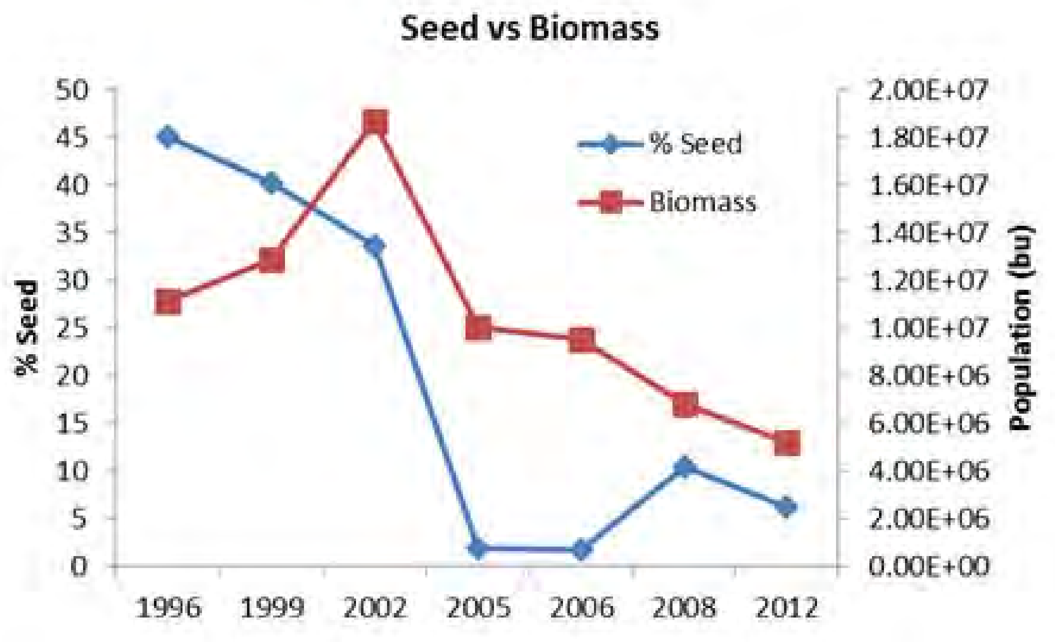


Figure 221: Population estimates for Atlantic surfclam in New York state waters and the percentage of the population considered seed clams (less than 100mm SL) by survey year. Plot courtesy of Jennifer O'Dwyer, NYDEC.

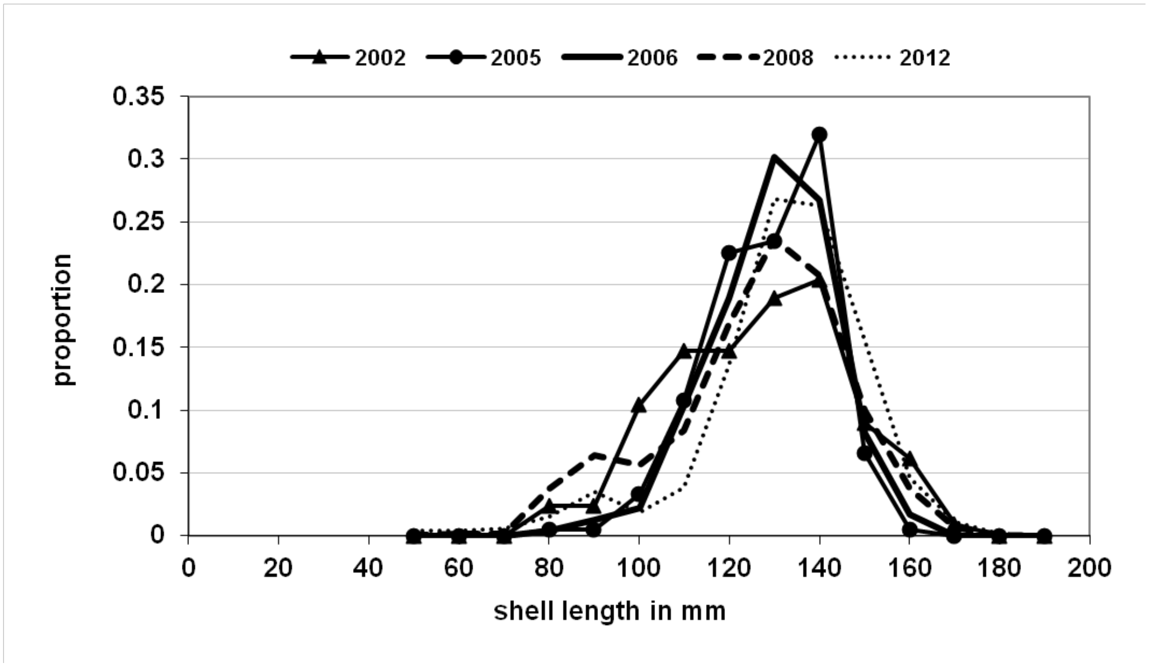


Figure 222: Length frequencies from the 2002, 2005, 2006, 2008 and 2012 New York state Atlantic surfclam survey.

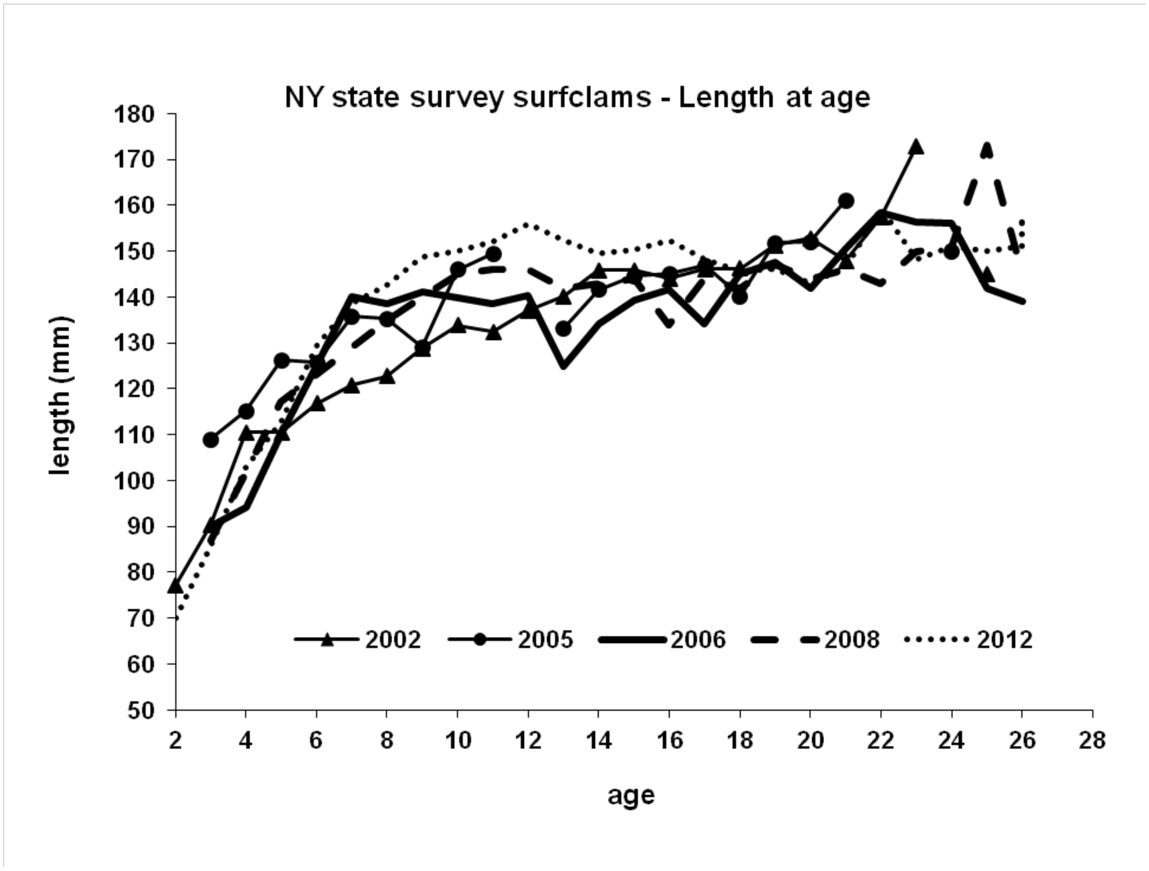


Figure 223: Atlantic surfclam length at age from the 2002, 2005, 2006, 2008 and 2012 New York state surveys.

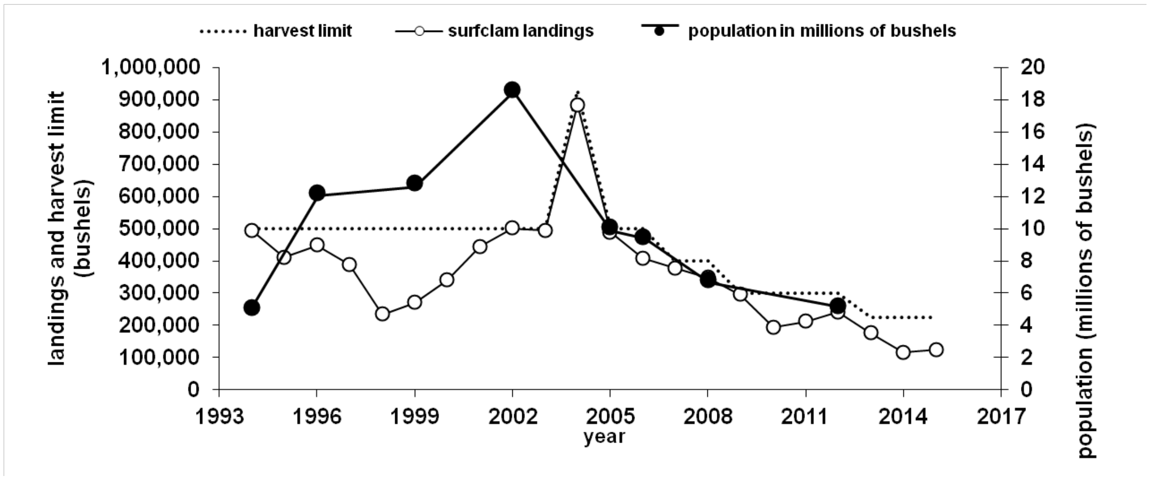


Figure 224: Landings, harvest limit and survey-based population estimates of Atlantic surfclam in New York state waters. Landings and harvest limit are scaled to the left axis and population is scaled to the right axis. The harvest limit was raised to 890,000 bushels for one year in 2004. Landings for 2015 are considered preliminary and an underestimate as not all catch reports were in.

Figure 225: The numerous Designated Shellfish Growing Areas (DSGAs) in Massachusetts state waters.

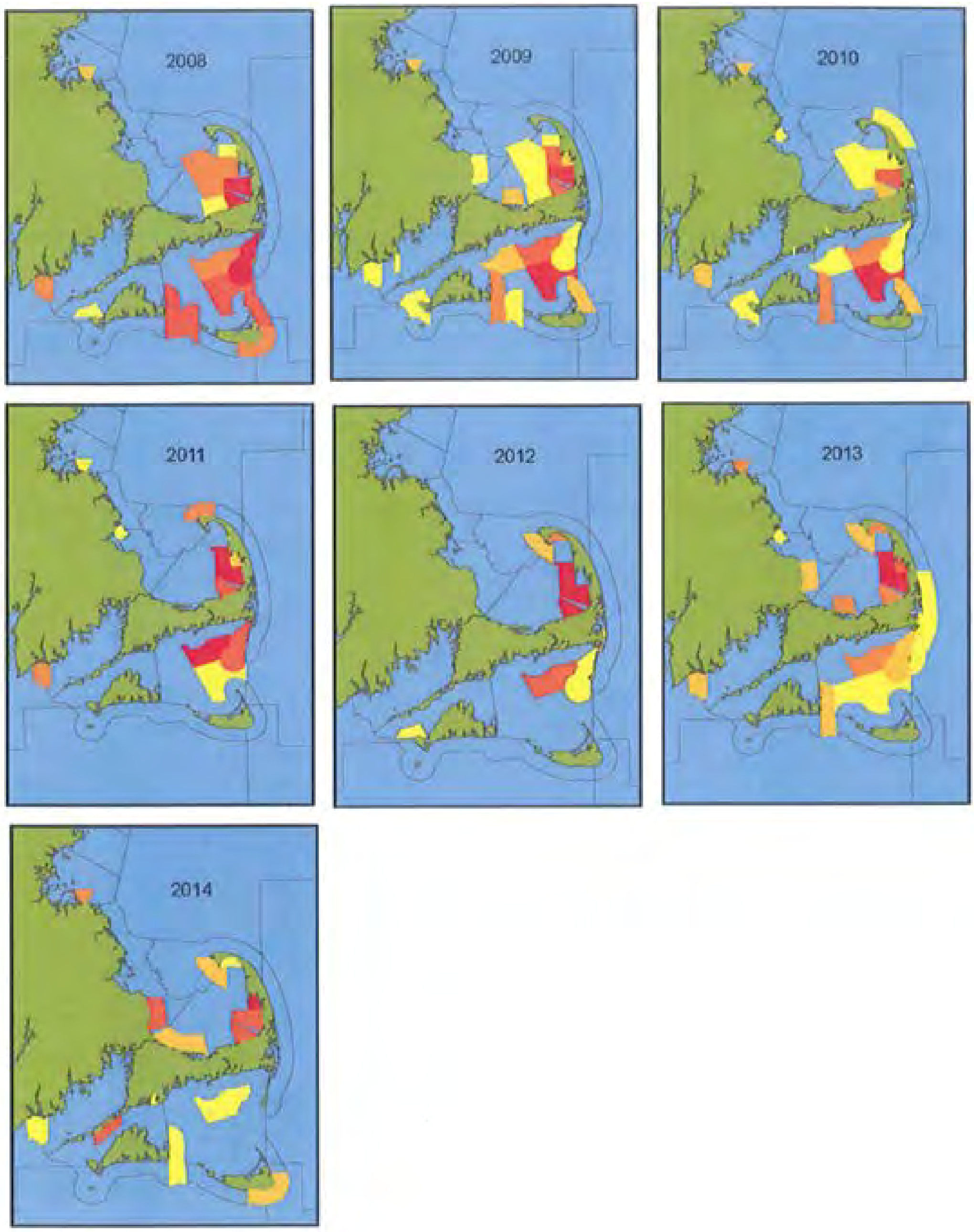


Figure 226: Massachusetts state waters Atlantic surfclam landings from each of the states' multiple Designated Shellfish Growing Areas, or DSGAs. There are more than 75 DSGAs in the waters surrounding the state. Red designates the areas with highest landings and yellow the lowest landings.

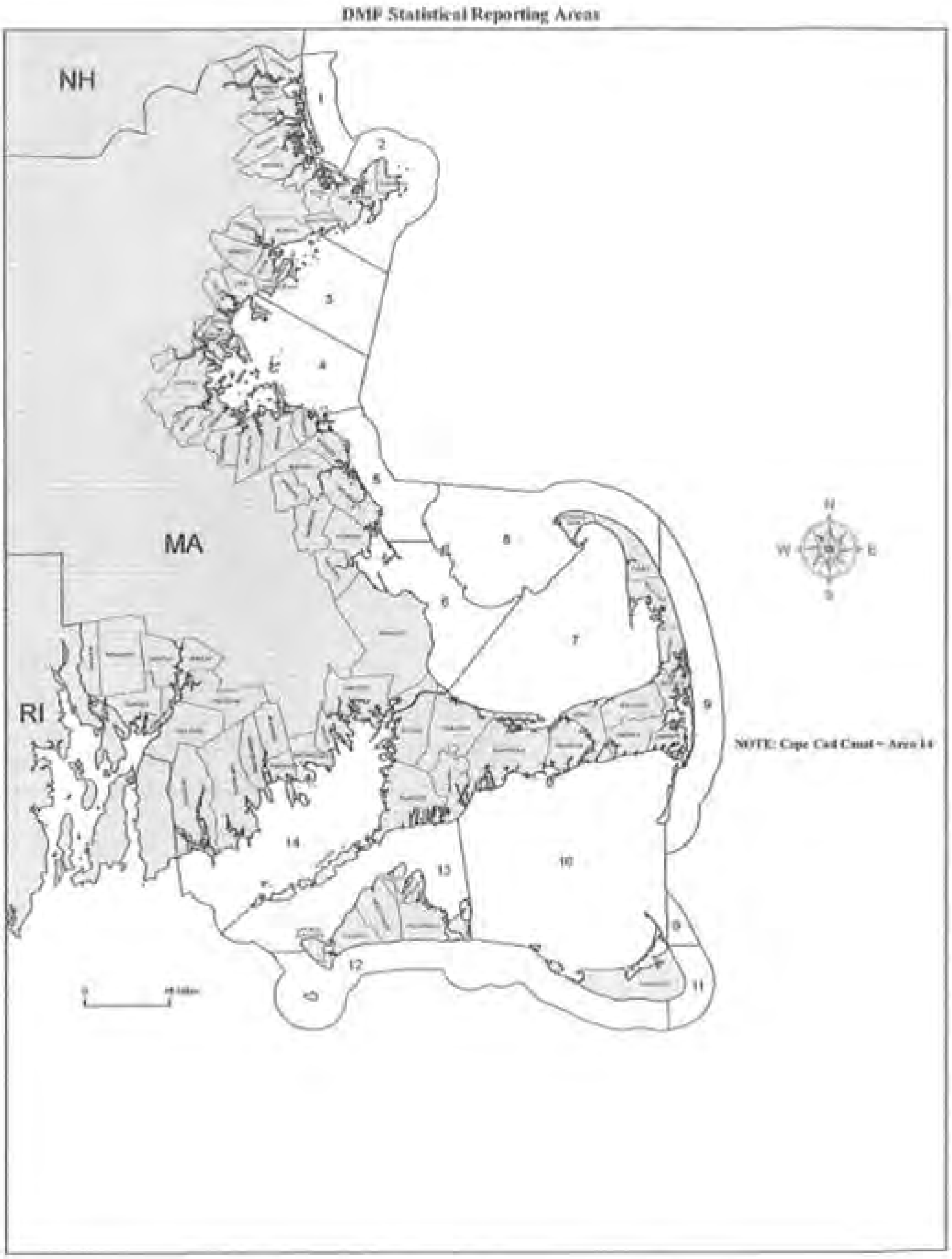


Figure 227: Statistical Reporting Areas (SRAs) in Massachusetts state waters.

SRA	2008	2009	2010	2011	2012	2013	2014
1			C		C	0.002	0.09
2			0.002				
3							
4	C	0.09	C	C		C	C
5							
6	C	C				C	C
7	3.62	2.85	2.02	1.43	2.20	1.78	0.65
8			C	C	C		
9					0.009	0.0004	
10	3.25	3.88	4.32	1.15	0.11	0.07	C
12	0.83	C	C				C
13	C	C	C		C		C
14	0.39	C	C	0.03		C	C

Figure 228: Landings of Atlantic surfclam from Massachusetts state waters by Statistical Reporting Area since 2008. Landings are in millions of live pounds. Information for SRA 11 was not available.

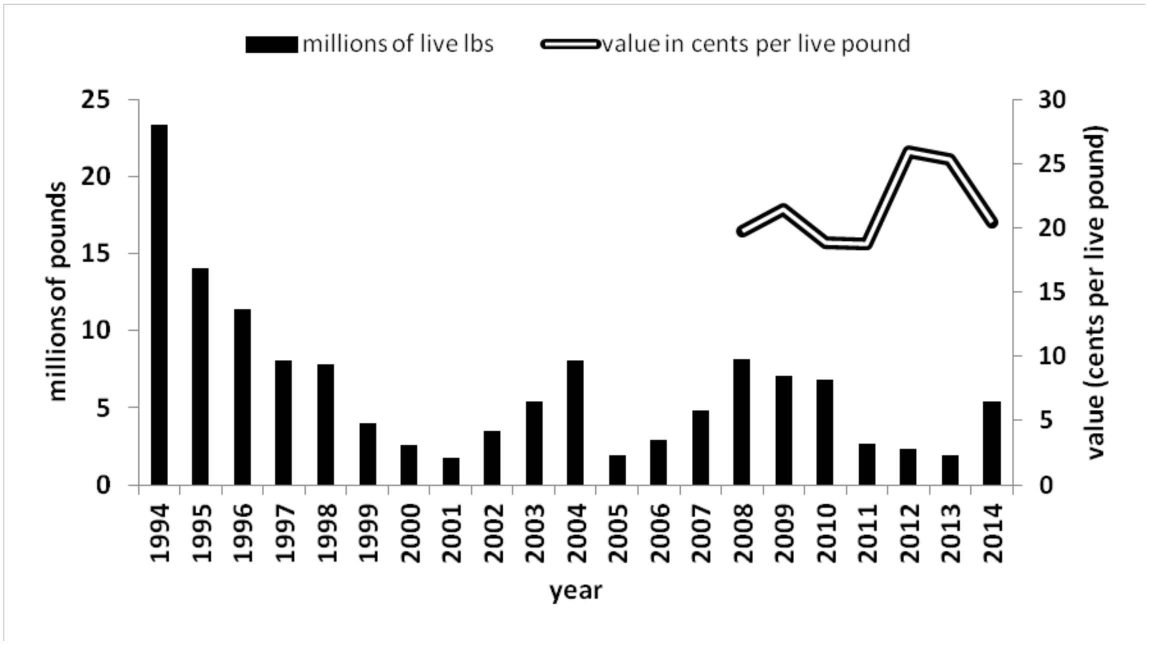


Figure 229: Total landings of Atlantic surfclam from Massachusetts state waters 1994-2014. The landings are shown in millions of live pounds and the values are cents per live pound.

Appendix 8 Appendix: Management strategy evaluation

Introduction

The Atlantic surfclam (*Spissula solidissima*) has supported an important US fishery for many years (Northeast Fisheries Science Center 2010). There are, however, outstanding questions regarding the optimal biological targets and thresholds for Atlantic surfclam management, which warrant additional exploration through this management strategy evaluation.

The current maximum fishing mortality rate threshold is $F = 0.15$, which is a proxy for F_{MSY} and was derived by setting it equal to the current estimate of natural mortality (M). The Atlantic surfclam fishery has historically been lightly fished; therefore, the dynamics of the resource under fishing pressure near threshold intensity are unknown. There are also regional dynamics to the fishery and biology (*i.e.*, recruitment, growth, and M), and changes in fishing pressure across regions over time. Given the levels of exploitation and what is known about the dynamics of this resource, is $F = 0.15$ an appropriate overfishing threshold for Atlantic surfclam? The current control rule biomass target, also a proxy, is a fraction (0.5) of the biomass estimated in an earlier year (1999), and the minimum stock size threshold is set at a fraction (0.5) of the current control rule target. The current control rule applies to the entire stock in the US EEZ, but the biomass for a segment of the population called the southern area, which runs from Southern Virginia to Southern New England, is below target (as of the last assessment Northeast Fisheries Science Center (2013)), while the remainder of the population, the northern area located on Georges Bank is above target. Are these control rule reference points appropriate for Atlantic surfclam?

The current stock assessment models the two segments of the population separately (southern and northern areas), and then combines them for management purposes. The basis for separating the stocks were differences in exploitation patterns, growth, recruitment and the timing of surveys. Given the differences between areas, would the management of the resource be improved if the stocks were also managed separately? These questions have not been formally evaluated.

Methods

Simulation model

The population simulation model was age structured, such that for ages a

$$N_{t,a} = \begin{cases} R_t & \text{if a=1} \\ N_{(t-1),(a-1)} * e^{-Z_{(t-1),(a-1)}} & \text{if } 1 < a < a_{max} \\ N_{(t-1),a_{max-1}} * e^{-Z_{(t-1),a_{max-1}}} + N_{(t-1),a_{max}} * e^{-Z_{(t-1),a_{max}}} & \text{if } a = a_{max} \end{cases} \quad (6)$$

where $a_{max} = 30$, $N_{t,a}$ was the number of animals in year t at age a, R_t was the number of recruits in year t (see below). $Z_{t,a}$ was the instantaneous total mortality defined by

$$Z_{t,a} = F_t * S_a + M \tag{7}$$

where F_t was the fully selected fishing mortality, S_a was the fishery selectivity in age a, converted from selectivity at length (see below) and M was the natural mortality rate, which was constant over time and age.

The spawning stock biomass for each age in each year $SSB_{t,a}$ was determined by

$$SSB_{t,a} = N_{t,a} * Mat_{t,a} * W_{t,a} \tag{8}$$

Maturity $Mat_{t,a}$ was 0.5 at age 1 and 1 at all other ages.

Weight at age was modelled as a function of mean length and age

$$W_a = \begin{cases} e^{-9.27} L_a^{2.73} & \text{southern area} \quad (9) \\ e^{-9.16} L_a^{2.73} & \text{northern area} \quad (10) \end{cases}$$

where W is the weight (g) and L_a is the predicted mean length at age a (mm) such that

$$L_a = \begin{cases} 162.6(1 - e^{(-0.23(a+0.14))}) & \text{southern area} \quad (11) \\ 145(1 - e^{(-0.29(a-0.64))}) & \text{northern area} \quad (12) \end{cases}$$

The parameters used in eq. (9 and 11) were averaged values for each region derived as in Northeast Fisheries Science Center (2013). W_a and L_a refer to weight and length at age a, respectively.

Fishery selectivity at age (S_a) measures the relative impact of fishing on different age groups. It was defined as the relative proportion of age a animals in the population encountered and caught. The selectivity curve was logistic and taken directly from the previous Atlantic surfclam assessment for the northern area (Northeast Fisheries Science Center 2013).

The yield from the fishery was calculated as

$$Y_t = \sum_a \frac{F_{t,a}}{F_{t,a} + M} * N_{t,a} * W_a * (1 - e^{-(F_{t,a}+M)}) \tag{13}$$

where $F_{t,a} = F_t * S_a$ (Baranov 1918).

Recruitment (R_t) followed Beverton Holt (Beverton and Holt 1957)

$$R_t = \frac{SSB_{t-1}}{\frac{SSBR_{f=0}(1-h)}{4h} + \frac{5h-1}{4hR_0} * SSB_{t-1}} \tag{14}$$

or Ricker (Ricker 1954) dynamics.

$$R_t = \alpha SSB_{t-1} e^{-\beta SSB_{t-1}} \tag{15}$$

where

$$\alpha = \frac{log(h) - log(0.2)}{0.8 R_0 SSBR_{f=0}} \tag{16}$$

$$\beta = \frac{e^{\alpha R_0 SSBR_{f=0}}}{SSBR_{f=0}} \tag{17}$$

and $SSBR_{f=0}$ was the equilibrium unfished spawning stock biomass per recruit, R_0 was equilibrium unfished recruitment and steepness (h) was a simulation specific random variable (Table 38). The bounds on h were based on He et al. (2006) and further modified based on the results of sensitivity testing in the assessment model. Half of the total simulation runs used Beverton Holt stock recruitment dynamics and the other half used Ricker.

Control rule

The current process for setting catch and associated landings limits (i.e., quotas) for the Atlantic surfclam fishery is complicated. For Mid-Atlantic Fishery Management Council (Council) managed stocks, acceptable biological catch limits (ABC) are set at a level less than the catch associated with the maximum fishing mortality threshold rate ($F = 0.15$) using a control rule that is a combination of the predetermined Councils risk policy (i.e., maximum tolerance for overfishing under specific conditions) and Scientific and Statistical Committee (SSC) decisions on the degree of uncertainty associated with the stock assessment. Because setting these catch limits involves a committee decision on the degree of uncertainty in the assessment, and is not a purely formulaic control rule, it is difficult to apply directly and requires some simplification for simulation in this MSE. The Councils risk policy which is used in the derivation of the Atlantic surfclam ABC is described on page 51 of Amendment 16 to the fishery management plan (MAFMC 2011; Figure 230). The risk policy is conditioned on the ratio of current stock biomass relative to the control rule (stock replenishment) threshold, and whether the life history is considered to be typical or atypical[5]. The policy includes a stock replenishment threshold defined as the ratio of $\frac{B}{BMSY} = 0.10$, to ensure the stock does not reach low levels from which it cannot recover. The probability of overfishing is 0 percent at $\frac{B}{BMSY} = 0.10$ and increases linearly until the inflection point of $\frac{B}{BMSY} = 1.0$, where a 40 percent probability of overfishing is utilized for stocks defined as typical, and a 35 percent probability for those defined as atypical. In addition, the risk policy has associated regulations that govern setting ABC for stocks under rebuilding plans and in instances where no maximum fishing mortality rate threshold has been identified. Neither of these cases apply to Atlantic surfclam.

[5]An atypical stock has a life history strategy that results in greater vulnerability to exploitation, and whose life history has not been fully addressed through the stock assessment and biological reference point development process.

Simulation set up

Simulations of a managed population like Atlantic surfclam must account for management actions, because the actions of managers will affect population dynamics. Management actions were simulated by including a simple control rule (based on a simplified version of the current Atlantic surfclam control rule) with target (the control rule inflection point described above) and stock replenishment threshold levels of SSB in the base simulation routine. The target was the desired level of SSB. The threshold was the minimum acceptable SSB. If SSB_t fell below SSB_{target}, F_{target} was reduced linearly, finally reaching 0 where $SSB_t = SSB_{threshold}$ (Restrepo and Powers 1999; Figure 231). This framework allowed a comparison of various candidate control rule reference points ($SSB_{threshold}$ and SSB_{target}) as well as an examination of the response of the population to management. Control rule reference points were $\frac{SSB_{target}}{SSB_0}$ and $\frac{SSB_{threshold}}{SSB_0}$, the fraction of unfished biomass (SSB_0) that correspond to target and threshold biomass levels respectively. $\frac{SSB_{threshold}}{SSB_0}$ levels between 0.05 and 0.5 and $\frac{SSB_{target}}{SSB_0}$ levels between 0.1 and 1.0 (in increments of 0.05) were tested by drawing randomly with replacement from the candidate values (Table 38).

Although the true Atlantic surfclam control rule is based on the probability of overfishing, rather than the fraction of SSB_0 remaining, and acts on the ABC, rather than the F_{target}, the functional response of the stock to management is similar. In both cases, the catch will be reduced in proportion to biomass, when biomass drops below a target value (the probability of overfishing depends on F_{target} and biomass; when biomass is low, F_{target} must be reduced proportionately to reduce the probability of overfishing). In both cases, fishing will no longer be allowed when the biomass drops below a threshold value.

All simulations included lognormal autocorrelated assessment error. Assessment error was included to mimic the uncertainty around biomass estimates from an assessment, and that error was autocorrelated to reflect a situation where an error in the assessment in one year was more likely to produce an error in the following assessment(s) (Deroba and Bence 2008). Assessment error was described by

$$S\hat{S}B_t = SSB_t * e^{\epsilon_t - \frac{\sigma^2_{At}}{2}} \tag{18}$$

$$\epsilon_t = \epsilon_{t-1} * \varphi * \eta + \sqrt{1 - \varphi^2} \tag{19}$$

where $\eta \sim N(0, \sigma^2_{At})$ was the assessment error, φ was the autocorrelation coefficient, and ϵ_t was the year specific autocorrelated random deviation. The parameterization of eq. 19 makes $S\hat{S}B_t$ an unbiased estimate of SSB_t (Deroba and Bence 2012).

A manager may decide on a particular F_{target} for a fishery, but that F_{target} may not be achieved exactly. This discrepancy is often referred to as implementation error. Implementation error was included by modifying F_t (where $F_1 = F_{target}$) such that

$$\hat{F}_t = F_t * e^{\epsilon_{Ft} - \frac{\sigma^2_{Ft}}{2}} \tag{20}$$

where $\hat{F}_t$ was an unbiased estimate of F_t, including lognormal implementation error ϵ_{Ft} with error variance σ^2_{Ft}.

Simulated management included an "assessment" at the end of each 3 years. That is, a decision to reduce F_t from it's initial value (F_{target}) was made at the end of each 3 year period depending on the value of $S\hat{S}B_t$ relative to SSB_{target} and $SSB_{threshold}$. The actual fishing mortality experienced by the simulated population ($\hat{F}_t$) was then based on the (potentially) reduced F_t using eq. 20.

Simulated management over different spatial scales

Recruitment, growth, and natural mortality in the US Atlantic surfclam population are not uniform across space. Simulation results might be altered by combining the results from independently recruiting areas experiencing different life history parameters. Because the Atlantic surfclam stock is assessed using two distinct areas, simulations were set up to mimic the biological parameters measured in each area. Simulations combined the two regions, which had independent growth, weight at age, steepness, and natural mortality parameters, using two contrasting spatial management scenarios. In all cases, recruitment events occurred separately in each region according to eq. 15. Growth in each region was determined by

$$L_a = \begin{cases} (162.6 + N(0, \sigma_{L\infty,S})) * & (21) \\ (1 - e^{((-0.23+N(0.0,\sigma_{k,S}))(a+(0.14+N(0.0,\sigma_{t0,S}))))}) & \text{southern area} \\ (145.6 + N(0, \sigma_{L\infty,N})) * & (22) \\ (1 - e^{((-0.29+N(0.0,\sigma_{k,N}))(a+(-0.64+N(0.0,\sigma_{t0,N}))))}) & \text{northern area} \end{cases}$$

where N were normally distributed random variables with parameters $(0,\sigma_{x,a})$, where x represents either k, $t0$ or $L\infty$, the growth parameters describing the curvature, location and asymptote (respectively) of the growth curve (von Bertalanffy 1938), and the subscript a represents the southern area (S) or the northern area (N). Simulation specific regional growth and natural mortality parameters were selected from the distributions described in Table 38 and then held constant for each region over that simulation. All other parameters (F_{target}, φ, σ_t^{A2}, σ^2_{Ft}, $\frac{SSB_{threshold}}{SSB_0}$ and $\frac{SSB_{target}}{SSB_0}$; Table 38) were simulation specific, but shared between the regions.

In the first management scenario, each region was managed separately (separate stocks, SS). Under SS, each region had its own assessment in which the biomass in that region was compared to the control rule reference points ($\frac{SSB_{threshold}}{SSB_0}$ equal for each region, though the SSB_0 for each might be somewhat different depending on regional life history parameters and stochastic recruitment variability during the unfished portion of each simulation) and then the F_t for that region was adjusted from F_{target} if necessary. SS regions were then fished according to their individual $\hat{F}_t$ after application of eq. (20). In the second management scenario (one stock, 1S), the sum of the biomasses from each region was compared to the control rule reference points ($\frac{SSB_{threshold}}{SSB_0}$ multiplied by the sum of the SSB_0 in the case of $B_{threshold}$), and F_t for all regions was adjusted if necessary. 1S regions were all fished according to the resulting $\hat{F}_t$ and yield was extracted from each according to eq. (13), but using the region specific M, $N_{t,a}$ and W_a. SS and 1S total yield and total biomass were the sum of the yield and biomass in each region, and the cv of yield was the mean of the cv of yield in each region. In both scenarios the period between assessments, and subsequent adjustments to fishing mortality rates, were 5 years to mimic a realistic assessment interval.

Simulation

Some parameters in the model had unknown true values, such as steepness (h) and natural mortality (M). Other parameters, such as potential values for management quantities like F_{target} or $\frac{SSB_{threshold}}{SSB_0}$, had unknown affects on biomass and yield. To understand how these parameters affected the outcome of simulations, a range of values for each was examined.

In each new simulation run a random variable was drawn for: h, M, F_{target}, φ, σ^2_{At}, σ^2_{Ft}, $\frac{SSB_{threshold}}{SSB_0}$ and $\frac{SSB_{target}}{SSB_0}$ (Table 38). These were constant for the duration of the run. The simulation was initialized by running a cohort based on the simulation specific M out to a_{max}. The proportion at age was then multiplied by R_0. All simulations included a period of 100 years without fishing intended to allow the population to stabilize. The simulation continued through 100 years with fishing and then new values were drawn for 49,999 subsequent runs.

Results from simulations (both with and without spatial complexity) were compared to values of F_{target}, $\frac{SSB_{threshold}}{SSB_0}$ and $\frac{SSB_{target}}{SSB_0}$, while considering the effects of φ, σ^{A2}_t, σ^2_{Ft}, M and h, to determine how reference points affected biomass and yield.

Analysis

To understand how the stochastic parameters affected simulation results, mean scaled biomass ($\frac{\overline{SSB}}{SSB_0}$), mean scaled yield ($\frac{\overline{Y}}{SSB_0}$), coefficient of variation in yield $cv(Y)$ and time without fishing due to implementation of the control rule ($t_{F=0}$) were compared to natural mortality M, steepness (h), target fishing mortality (F_{target}), $\frac{SSB_{threshold}}{SSB_0}$, $\frac{SSB_{target}}{SSB_0}$, φ, σ^2_{At}, and σ^2_{Ft}. Interactions and main effects were examined with generalized linear models (McCullagh and Nelder 1989). In an example predicting mean biomass, the saturated model contained all the main effects and selected interactions between the predictor variables as

$$(\frac{\overline{SSB}}{SSB_0}) = f(\overrightarrow{b}(1 + (h * F_{target} * \frac{SSB_{threshold}}{SSB_0} * M) + \sigma^2_{At} + \varphi + \sigma^2_{Ft}) \qquad (23)$$

where f represents the link function and $\overrightarrow{b}$ is the vector of coefficients estimated in the model. Models predicting biomass and yield were overdispersed relative to the Poisson distribution so the error structure for the models described generally by eq. 23, was quasipoisson with a log link function (R Core Team 2013; McCullagh and Nelder 1989). This distribution includes a dispersion parameter for variance and reduces the degrees of freedom for estimation accordingly.

The relative importance of predictors (e.g. h, F_{target}, and M) was determined using deviance tables. The number of simulations was large and simulation results are not data in the traditional sense. Therefore model selection approaches based on AIC would result in very complicated models in which nearly all covariates and interactions tested would be significant. The deviance table approach may also be better than conventional χ^2 tests, which are more sensitive to the order in which explanatory variables are tested (Ortiz and Arocha 2004).

Variables tested included each categorical and continuous predictor variable, and several interactions between them. Linear models for deviance table analyses were fitted by sequentially adding main effects and interactions. Explanatory variables were judged statistically significant as they entered the model if they reduced model deviance by at least 5% of the deviance associated with the null (intercept only) model. This allowed the exclusion of the explanatory variables that least affected the response variables of interest from further consideration.

Simulation results were also plotted and inspected visually for indications of nonlinearity. In particular after initial results showed that steepness was not an important predictor of biomass or yield, results were binned over steepness values to determine if the effects of steepness were being masked by the stronger effects such as fishing mortality.

Results

Simulations

Because $\frac{SSB_{target}}{SSB_0}$ and $\frac{SSB_{threshold}}{SSB_0}$ were highly correlated, results using each were similar and results showing $\frac{SSB_{threshold}}{SSB_0}$ only are discussed here for simplicity.

Deviance tables show that the effects of F_{target}, steepness (h), control rule (stock replenishment) threshold ($\frac{SSB_{threshold}}{SSB_0}$) and M were better predictors of mean biomass, yield, variation in yield and time without fishing than any of the other candidate predictors and interactions tested (Table 39). Biomass tended to decrease with F_{target}, while variation in yield and time without fishing tended to increase (Figures 232 – 233). Yield increased initially with F_{target} before decreasing at higher values of F_{target}. Increasing natural mortality resulted in higher yields, more variation in yield and less time without fishing. Higher steepness resulted in higher biomass and yield and less variation in yield and time without fishing. Higher control rule (stock replenishment) thresholds produced higher biomass, more time without fishing, and more variation around less yield.

An interactions involving $\frac{SSB_{threshold}}{SSB_0}$ and steepness was an important predictor time without fishing (Table 39). At high $\frac{SSB_{threshold}}{SSB_0}$ and low h, the population was not productive enough to trigger recovery and a cessation of the management actions that shut down the fishery. At low $\frac{SSB_{threshold}}{SSB_0}$ and high h, the population was productive enough and the control rule (stock replenishment) threshold low enough to never trigger a shut down.

Stock recruitment dynamics

The stock was more productive at higher F when recruitment dynamics were driven by the Ricker curve (Figure 234).

Simulated management over different spatial scales

The effect of spatial scale on management was substantial on average across most of the response variables tested (Table 40). Mean biomass was greater when the stocks were managed separately, but mean yield was greater under single stock management (Figure 235). The higher yields however, resulted in a tendency to over-harvest and a higher probability of fishery closures due to management intervention, as well as higher variability in yield.

Discussion

Management strategy evaluation can be a useful tool for determining reference points that work well for a variety of life history traits and possible states of nature. Currently, there are many aspects of Atlantic surfclam biology that are poorly understood. The response of the Atlantic surfclam stock to ocean warming is unknown, and the behavior of the fishery may change over time as well. This management strategy evaluation used a broad distribution of possible values intended to capture both the unknown biological parameters and a reasonable suite of potential fishery conditions. The F_{Target} and control rule reference points were simulated over 100 years using random combinations of important biological and fishery parameters. Therefore the results of these simulations should describe management quantities that will work well under many possible combinations of life history traits and fishery conditions.

Simulation

The simulations demonstrate the utility of potential reference points relative to metrics of fishery performance. For example, SSB is maximized at low F regardless of the control rule (stock replenishment) threshold or target used, while yield is maximized at intermediate levels of F and lower values of $\frac{SSB_{threshold}}{SSB_0}$ or $\frac{SSB_{target}}{SSB_0}$ (Figures 236 - 237). Examination of the relative SSB and yield at various F_{Target} and B_{Target} or $B_{Threshold}$ (Tables 41 - 44) allow for comparison of the likely performance of competing reference points.

Variation in yield and time without fishing due to closures were near minimum at all the values of $\frac{SSB_{threshold}}{SSB_0}$ or $\frac{SSB_{target}}{SSB_0}$ tested when $F < 0.15$. The current $F_{Threshold} = 0.15$. If we consider only $F_{Threshold} <= 0.15$ then there is no further need to concern ourselves with variation in yield or the probability of fishery closures.

The current $B_{Threshold}$ is $0.25 * B_{0,proxy}$ and the current B_{Target} is $0.5 * B_{0,proxy}$. Using these values, yield is maximized at $F_{Target} = 0.12$, while $SSB = 0.5 * B_0$ at $F_{Target} = 0.11$.

The Atlantic surfclam fishery is market limited and currently fished under quota (see 1.3). Therefore there is little interest from either industry or management to increase yield. Under these conditions, it might be advantageous to weight SSB somewhat more than yield when deciding on reference points.

Simulated management over different spatial scales

There does appear to be an advantage to managing the Atlantic surfclam population as separate stocks. In general it results in higher yield and biomass, less variability in yield, less fishery closures over all values of h and $\frac{SSB_{threshold}}{SSB_0}$. Managing for separate stocks also results in higher biomass over all values of F, but higher yield only when F is over approximately 0.12, a high value, relative to what the fishery is currently experiencing. The advantages in variation in yield and time without fishing due to closures also appear to accrue only at values of F that are somewhat higher than the Atlantic surfclam population is currently experiencing. Therefore, while it appears to be advantageous to manage the population as separate stocks, those advantages are less clear at low F and the switch to management as separate stocks may not be important unless the fishing mortality rate increases relative to its current state.

Tables

Table 38: Sampling distributions of random variables used in simulation. The variable h was steepness, M was natural mortality, F_{target} was fully selected fishing mortality target, φ was the autocorrelation coefficient for assessment error, σ_{At}, σ_{Ft} were the standard deviation of annual assessment and implementation error, respectively, $\sigma^S_{L\infty}$, $\sigma^{GBK}_{L\infty}$, σ^S_k, σ^{GBK}_k, σ^S_{t0}, σ^{GBK}_{t0} were standard deviations of the growth parameters for each area, $\frac{SSB_{threshold}}{SSB_0}$ was the control rule (stock replenishment) threshold, and $\frac{SSB_{target}}{SSB_0}$ was the control rule target for fishery management. A random value for each variable was drawn from the sampling distributions shown for each simulation run.

Variable	Sampling distribution
	Continuous
h	$Unif(0.3, 0.99)$
M	$Unif(0.1, 0.25)$
F_{target}	$Unif(0.0001, 0.5)$
φ	$Unif(0.0, 0.5)$
σ_{At}	$Unif(0.0, 0.25)$
σ_{Ft}	$Unif(0.0, 0.5)$
$\sigma^S_{L\infty}$	$Unif(0.0, 1.95)$
$\sigma^{GBK}_{L\infty}$	$Unif(0.0, 3.9)$
σ^S_k	$Unif(0.0, 0.025)$
σ^{GBK}_k	$Unif(0.0, 0.061)$
σ^S_{t0}	$Unif(0.0, 0.249)$
σ^{GBK}_{t0}	$Unif(0.0, 0.59)$
	Discrete
$\frac{SSB_{threshold}}{SSB_0}$	$\{0.05, 0.1, 0.15, 0.2, \ldots, 0.5\}$
$\frac{SSB_{target}}{SSB_0}$	$\{0.1, 0.15, 0.2, 0.25, \ldots, 1.0\}$
SR	Ricker or Beverton-Holt

Table 39: Deviance table results for models predicting mean Atlantic surfclam biomass ($\frac{\overline{SSB}}{SSB_0}$), mean ($\frac{\overline{Y}}{SSB_0}$), and cv of yield ($cv(Y)$) and years without fishing due to management ($t_{F=0}$), over ($n = 50,000$) 100 year simulations. The candidate predictors were fishing mortality target (F_{target}), steepness (h), natural mortality (M), the fraction of SSB_0 that corresponds to the control rule (stock replenishment) threshold ($\frac{SSB_{threshold}}{SSB_0}$), assessment error ($\sigma_{At}$), amount of auto correlation in assessment error (φ), implementation error (σ_{Ft}) as well as interactions of potential interest. Only predictors that explained $\geq 5\%$ of the deviance relative to the null model are shown.

Response	Significant predictors (% dev. explained)
	Biomass
$\frac{\overline{SSB}}{B_0}$	F_{target} (43.5), h (27.5), M (11.0)
	Yield
$\frac{\overline{Y}}{B_0}$	h (36.0), $\frac{SSB_{threshold}}{SSB_0}$ (22.9), M (20.4), SR (5.6)
$cv(Y)$	F_{target} (57.4), $\frac{SSB_{threshold}}{SSB_0}$ (10.4), h (11.8), M (7.9)
	Years without fishing
$t_{F=0}$	F_{target} (48.3), h (13.6), $\frac{SSB_{threshold}}{SSB_0}$ (14.2), h:$\frac{SSB_{threshold}}{SSB_0}$ (5.8)

Table 40: Deviance table results from simulations testing possible spatial structures of management. Inputs were models predicting mean Atlantic surfclam biomass, mean, and cv of yield and years without fishing due to management, over ($n = 50,000$) 100 year simulations. The total biomass and yield were based on summed values from two separately managed stocks and from two regions managed as one, each assessed every five years. The candidate predictors were fishing mortality target (F_{target}), steepness (h), natural mortality (M), the fraction of SSB_0 that corresponds to the control rule (stock replenishment) threshold ($\frac{SSB_{threshold}}{SSB_0}$), assessment error ($\sigma_{At}$), amount of auto correlation in assessment error (φ), implementation error (σ_{Ft}) and several interactions between them.

Response	Significant predictors (% dev. explained)
	Separate stocks
	Biomass
$\frac{\overline{SSB}}{B_0}$	F_{target} (89.7)
	Yield
$\frac{\overline{Y}}{B_0}$	F_{target} (24.4), $\frac{SSB_{threshold}}{SSB_0}$ (26.8), M (18.2), h (15.4)
$cv(F)$	F_{target} (66.0), $\frac{SSB_{threshold}}{SSB_0}$ (12.6), M (9.5), h (7.0)
	Years without fishing
$t_{F=0}$	F_{target} (55.8), $\frac{SSB_{threshold}}{SSB_0}$ (17.4), M (7.7), h (7.7)
	Single stock
	Biomass
$\frac{\overline{SSB}}{B_0}$	F_{target} (16.6), h (5.4), $\frac{SSB_{threshold}}{SSB_0}$ (54.1), F:$\frac{SSB_{threshold}}{SSB_0}$ (18.4)
	Yield
$\frac{\overline{Y}}{B_0}$	F_{target} (64.4), h (22.5)
$cv(F)$	F_{target} (55.7), $\frac{SSB_{threshold}}{SSB_0}$ (23.6), h (9.5), M (5.6)
	Years without fishing
$t_{F=0}$	F_{target} (55.1), $\frac{SSB_{threshold}}{SSB_0}$ (24.5), $\frac{SSB_{threshold}}{SSB_0}$ (6.7)

Table 41: Average biomass ($\frac{S\hat{S}B}{SSB_0}$) over 100 years of managed fishing simulations at different levels of biomass threshold (columns) and target fishing mortality (rows).

	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0	0.96	0.96	0.96	0.97	0.96	0.96	0.96	0.96	0.96	0.96
0.01	0.91	0.90	0.91	0.90	0.90	0.90	0.90	0.91	0.90	0.91
0.02	0.85	0.84	0.85	0.84	0.85	0.84	0.85	0.85	0.85	0.85
0.03	0.80	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.80	0.81
0.04	0.74	0.75	0.74	0.74	0.74	0.75	0.75	0.75	0.75	0.76
0.05	0.70	0.70	0.69	0.70	0.70	0.70	0.70	0.71	0.71	0.73
0.06	0.66	0.66	0.66	0.66	0.66	0.66	0.65	0.67	0.68	0.67
0.07	0.60	0.62	0.62	0.61	0.62	0.63	0.63	0.64	0.63	0.65
0.08	0.59	0.58	0.59	0.59	0.59	0.60	0.60	0.61	0.61	0.63
0.09	0.55	0.56	0.56	0.56	0.56	0.56	0.57	0.58	0.58	0.59
0.1	0.51	0.53	0.53	0.52	0.53	0.53	0.55	0.55	0.57	0.57
0.11	0.48	0.50	0.49	0.51	0.50	0.50	0.52	0.53	0.54	0.55
0.12	0.45	0.47	0.47	0.49	0.49	0.50	0.50	0.51	0.52	0.53
0.13	0.41	0.45	0.45	0.44	0.45	0.46	0.48	0.49	0.50	0.52
0.14	0.40	0.44	0.43	0.43	0.45	0.45	0.46	0.46	0.48	0.50
0.15	0.40	0.40	0.40	0.42	0.43	0.43	0.44	0.45	0.48	0.47
0.16	0.39	0.38	0.39	0.39	0.40	0.42	0.43	0.44	0.46	0.46
0.17	0.36	0.35	0.36	0.38	0.39	0.41	0.42	0.42	0.43	0.44
0.18	0.34	0.34	0.36	0.36	0.38	0.38	0.40	0.40	0.42	0.43
0.19	0.33	0.34	0.35	0.35	0.36	0.38	0.38	0.40	0.40	0.40
0.2	0.30	0.31	0.32	0.34	0.35	0.36	0.38	0.39	0.40	0.39
0.21	0.30	0.31	0.31	0.32	0.33	0.34	0.36	0.38	0.38	0.37
0.22	0.28	0.29	0.30	0.32	0.32	0.34	0.35	0.36	0.36	0.36
0.23	0.26	0.28	0.29	0.30	0.31	0.33	0.34	0.33	0.35	0.35
0.24	0.25	0.27	0.29	0.29	0.31	0.32	0.33	0.34	0.34	0.34
0.25	0.25	0.26	0.26	0.28	0.28	0.30	0.31	0.33	0.33	0.34
0.26	0.23	0.24	0.26	0.27	0.28	0.30	0.31	0.31	0.31	0.32
0.27	0.24	0.24	0.26	0.27	0.28	0.29	0.29	0.29	0.31	0.31

0.28	0.22	0.24	0.25	0.25	0.26	0.28	0.29	0.28	0.29	0.30
0.29	0.21	0.22	0.23	0.25	0.26	0.27	0.28	0.28	0.28	0.27
0.3	0.19	0.21	0.22	0.24	0.25	0.25	0.26	0.27	0.27	0.25
0.31	0.20	0.21	0.21	0.23	0.25	0.24	0.25	0.25	0.25	0.25
0.32	0.19	0.20	0.21	0.23	0.24	0.23	0.25	0.24	0.24	0.25
0.33	0.17	0.18	0.20	0.22	0.23	0.23	0.24	0.23	0.24	0.23
0.34	0.17	0.18	0.20	0.21	0.22	0.22	0.23	0.22	0.24	0.22
0.35	0.18	0.18	0.20	0.20	0.21	0.21	0.23	0.20	0.22	0.22
0.36	0.16	0.17	0.19	0.20	0.21	0.21	0.21	0.21	0.21	0.21
0.37	0.15	0.17	0.18	0.19	0.20	0.20	0.19	0.19	0.20	0.20
0.38	0.15	0.16	0.18	0.19	0.19	0.19	0.20	0.18	0.19	0.20
0.39	0.16	0.16	0.16	0.18	0.18	0.20	0.19	0.19	0.19	0.18
0.4	0.15	0.15	0.16	0.18	0.17	0.19	0.18	0.18	0.18	0.18
0.41	0.13	0.15	0.16	0.16	0.16	0.17	0.17	0.17	0.18	0.18
0.42	0.13	0.14	0.16	0.16	0.16	0.17	0.17	0.17	0.16	0.18
0.43	0.13	0.14	0.14	0.16	0.16	0.17	0.15	0.16	0.16	0.17
0.44	0.12	0.14	0.14	0.14	0.15	0.16	0.16	0.14	0.14	0.15
0.45	0.11	0.13	0.14	0.14	0.14	0.16	0.15	0.14	0.15	0.15
0.46	0.11	0.11	0.13	0.14	0.14	0.14	0.15	0.15	0.12	0.15
0.47	0.11	0.12	0.13	0.12	0.13	0.13	0.13	0.13	0.15	0.14
0.48	0.09	0.11	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13
0.49	0.09	0.11	0.11	0.12	0.13	0.12	0.11	0.12	0.13	0.13
0.5	0.07	0.11	0.11	0.15	0.11	0.12	0.10	0.14	0.08	0.12

Table 42: Average biomass ($\frac{S\hat{S}B}{SSB_0}$) over 100 years of managed fishing simulations at different levels of biomass target (columns) and target fishing mortality (rows).

	0.125	0.225	0.275	0.325	0.425	0.475	0.525	0.575	0.675	0.775	0.825	0.875	0.925
0.005	0.96	0.96	0.96	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.97
0.015	0.90	0.90	0.90	0.90	0.91	0.90	0.90	0.90	0.91	0.91	0.91	0.91	0.91
0.025	0.84	0.86	0.84	0.84	0.85	0.85	0.85	0.84	0.85	0.84	0.85	0.85	0.85
0.035	0.80	0.79	0.79	0.79	0.80	0.79	0.79	0.79	0.79	0.80	0.80	0.79	0.80
0.045	0.75	0.75	0.74	0.73	0.74	0.75	0.74	0.75	0.75	0.76	0.77	0.75	0.76
0.055	0.70	0.70	0.69	0.70	0.71	0.70	0.70	0.70	0.71	0.71	0.72	0.72	0.72
0.065	0.66	0.66	0.66	0.66	0.66	0.66	0.65	0.66	0.66	0.67	0.69	0.69	0.70
0.075	0.62	0.60	0.62	0.60	0.62	0.61	0.61	0.63	0.64	0.65	0.64	0.66	0.65
0.085	0.58	0.60	0.58	0.59	0.59	0.58	0.58	0.60	0.61	0.63	0.62	0.61	0.63
0.095	0.55	0.55	0.55	0.55	0.55	0.55	0.56	0.57	0.58	0.59	0.60	0.59	0.61
0.105	0.53	0.52	0.52	0.51	0.53	0.52	0.53	0.55	0.55	0.56	0.58	0.58	0.58
0.115	0.48	0.50	0.50	0.50	0.49	0.50	0.50	0.52	0.54	0.54	0.54	0.55	0.57
0.125	0.45	0.47	0.47	0.46	0.47	0.49	0.48	0.50	0.51	0.53	0.53	0.53	0.53
0.135	0.44	0.43	0.43	0.45	0.43	0.45	0.46	0.48	0.49	0.50	0.50	0.51	0.52
0.145	0.43	0.40	0.42	0.42	0.42	0.43	0.45	0.46	0.48	0.49	0.50	0.48	0.49
0.155	0.40	0.38	0.40	0.40	0.40	0.41	0.44	0.44	0.46	0.46	0.47	0.48	0.47
0.165	0.38	0.37	0.37	0.38	0.39	0.40	0.42	0.42	0.44	0.46	0.45	0.44	0.46
0.175	0.35	0.34	0.36	0.37	0.37	0.38	0.41	0.41	0.42	0.44	0.42	0.43	0.46
0.185	0.31	0.31	0.34	0.36	0.36	0.37	0.39	0.40	0.40	0.42	0.42	0.40	0.43
0.195	0.33	0.32	0.33	0.34	0.35	0.37	0.37	0.38	0.39	0.41	0.41	0.39	0.42
0.205	0.28	0.31	0.30	0.33	0.33	0.35	0.36	0.37	0.37	0.38	0.40	0.39	0.40
0.215	0.30	0.29	0.29	0.32	0.32	0.33	0.34	0.35	0.37	0.36	0.37	0.38	0.38
0.225	0.26	0.27	0.29	0.31	0.32	0.32	0.33	0.34	0.36	0.36	0.34	0.37	0.35
0.235	0.25	0.25	0.27	0.29	0.30	0.31	0.32	0.33	0.34	0.34	0.33	0.32	0.34
0.245	0.25	0.24	0.27	0.28	0.30	0.29	0.31	0.32	0.33	0.33	0.35	0.32	0.34
0.254	0.22	0.23	0.25	0.28	0.28	0.28	0.31	0.30	0.32	0.33	0.33	0.33	0.32
0.264	0.19	0.24	0.24	0.27	0.27	0.28	0.29	0.30	0.32	0.30	0.31	0.32	0.34
0.274	0.21	0.24	0.24	0.26	0.27	0.28	0.28	0.30	0.30	0.29	0.30	0.29	0.30

0.284	0.19	0.22	0.23	0.25	0.25	0.27	0.28	0.28	0.29	0.27	0.30	0.27	0.29
0.294	0.21	0.21	0.22	0.24	0.24	0.26	0.27	0.27	0.28	0.27	0.28	0.29	0.27
0.304	0.16	0.19	0.22	0.22	0.23	0.24	0.25	0.25	0.25	0.28	0.26	0.25	0.28
0.314	0.18	0.18	0.21	0.23	0.23	0.23	0.24	0.24	0.26	0.25	0.26	0.25	0.22
0.324	0.17	0.18	0.20	0.22	0.23	0.23	0.24	0.24	0.24	0.25	0.25	0.24	0.24
0.334	0.14	0.17	0.19	0.20	0.22	0.22	0.23	0.23	0.23	0.23	0.24	0.23	0.22
0.344	0.16	0.16	0.19	0.21	0.21	0.21	0.22	0.22	0.23	0.21	0.24	0.23	0.26
0.354	0.15	0.17	0.19	0.20	0.20	0.20	0.22	0.21	0.22	0.21	0.22	0.22	0.23
0.364	0.13	0.15	0.17	0.19	0.20	0.20	0.21	0.21	0.21	0.20	0.20	0.23	0.21
0.374	0.14	0.17	0.17	0.19	0.18	0.18	0.19	0.20	0.20	0.18	0.20	0.22	0.19
0.384	0.13	0.16	0.17	0.18	0.17	0.17	0.20	0.20	0.19	0.17	0.19	0.18	0.19
0.394	0.13	0.16	0.16	0.16	0.18	0.17	0.18	0.19	0.19	0.19	0.19	0.19	0.20
0.404	0.14	0.15	0.16	0.17	0.16	0.17	0.18	0.17	0.18	0.18	0.17	0.18	0.17
0.414	0.13	0.13	0.16	0.15	0.15	0.16	0.16	0.17	0.17	0.16	0.16	0.16	0.18
0.424	0.12	0.14	0.14	0.16	0.16	0.16	0.16	0.16	0.17	0.17	0.19	0.19	0.15
0.434	0.12	0.12	0.15	0.15	0.14	0.16	0.15	0.16	0.16	0.16	0.16	0.17	0.17
0.444	0.11	0.12	0.14	0.15	0.14	0.14	0.14	0.15	0.16	0.14	0.15	0.12	0.14
0.454	0.11	0.12	0.14	0.13	0.14	0.14	0.14	0.15	0.14	0.14	0.15	0.16	0.15
0.464	0.08	0.12	0.13	0.14	0.11	0.14	0.14	0.14	0.15	0.14	0.13	0.14	0.12
0.474	0.10	0.12	0.12	0.12	0.13	0.13	0.14	0.13	0.13	0.13	0.15	0.14	0.15
0.484	0.09	0.10	0.11	0.13	0.13	0.13	0.12	0.12	0.13	0.12	0.12	0.13	0.13
0.494	0.10	0.10	0.11	0.12	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13
0.504	0.09	0.05	0.12	0.15	0.11	0.09	0.12	0.12	0.10	0.16	0.07	0.15	0.11

Table 43: Relative average yield over 100 years of managed fishing simulations at different levels of biomass threshold (columns) and target fishing mortality (rows).

	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0	0.09	0.10	0.09	0.09	0.10	0.09	0.10	0.10	0.09	0.09
0.01	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.23	0.22
0.02	0.38	0.37	0.37	0.37	0.38	0.37	0.37	0.36	0.35	0.34
0.03	0.49	0.48	0.48	0.48	0.48	0.48	0.47	0.46	0.45	0.43
0.04	0.59	0.59	0.58	0.58	0.58	0.57	0.57	0.54	0.52	0.47
0.05	0.67	0.66	0.66	0.66	0.66	0.65	0.63	0.60	0.57	0.50
0.06	0.75	0.74	0.73	0.73	0.71	0.70	0.66	0.64	0.60	0.50
0.07	0.78	0.79	0.79	0.77	0.75	0.74	0.71	0.65	0.55	0.51
0.08	0.85	0.83	0.84	0.81	0.80	0.78	0.72	0.65	0.55	0.48
0.09	0.87	0.88	0.87	0.86	0.82	0.77	0.70	0.65	0.53	0.41
0.1	0.88	0.92	0.89	0.86	0.82	0.75	0.69	0.61	0.53	0.40
0.11	0.92	0.93	0.89	0.90	0.82	0.74	0.66	0.62	0.46	0.36
0.12	0.91	0.93	0.91	0.90	0.83	0.76	0.67	0.53	0.45	0.31
0.13	0.88	0.95	0.91	0.83	0.79	0.67	0.58	0.50	0.39	0.29
0.14	0.92	0.96	0.90	0.84	0.80	0.67	0.55	0.41	0.36	0.29
0.15	0.94	0.94	0.90	0.81	0.77	0.61	0.51	0.39	0.34	0.22
0.16	1.00	0.91	0.88	0.76	0.69	0.63	0.49	0.36	0.26	0.19
0.17	0.96	0.86	0.82	0.79	0.69	0.59	0.45	0.32	0.21	0.18
0.18	0.92	0.84	0.80	0.73	0.66	0.50	0.39	0.28	0.21	0.14
0.19	0.91	0.89	0.83	0.70	0.59	0.50	0.34	0.28	0.18	0.12
0.2	0.88	0.81	0.74	0.71	0.56	0.43	0.33	0.23	0.16	0.11
0.21	0.88	0.84	0.73	0.56	0.51	0.37	0.29	0.20	0.14	0.10
0.22	0.82	0.77	0.70	0.62	0.47	0.40	0.25	0.17	0.13	0.10
0.23	0.76	0.76	0.66	0.54	0.41	0.35	0.24	0.14	0.12	0.09
0.24	0.80	0.68	0.70	0.53	0.43	0.32	0.21	0.15	0.11	0.09
0.25	0.76	0.69	0.61	0.47	0.35	0.25	0.17	0.15	0.11	0.09
0.26	0.71	0.62	0.56	0.48	0.33	0.24	0.18	0.13	0.10	0.08
0.27	0.73	0.64	0.59	0.45	0.33	0.25	0.16	0.12	0.09	0.08

0.28	0.70	0.63	0.53	0.41	0.27	0.22	0.15	0.11	0.09	0.08
0.29	0.68	0.57	0.48	0.39	0.29	0.18	0.14	0.11	0.09	0.08
0.3	0.59	0.52	0.41	0.31	0.23	0.17	0.13	0.10	0.09	0.08
0.31	0.63	0.54	0.42	0.29	0.23	0.16	0.12	0.10	0.09	0.08
0.32	0.62	0.50	0.37	0.30	0.23	0.15	0.12	0.10	0.08	0.08
0.33	0.50	0.42	0.35	0.28	0.19	0.14	0.12	0.09	0.09	0.07
0.34	0.53	0.42	0.32	0.24	0.20	0.14	0.11	0.09	0.08	0.07
0.35	0.55	0.42	0.35	0.23	0.16	0.13	0.11	0.09	0.08	0.08
0.36	0.50	0.38	0.28	0.22	0.16	0.13	0.10	0.09	0.08	0.07
0.37	0.48	0.41	0.30	0.19	0.15	0.12	0.10	0.09	0.08	0.07
0.38	0.47	0.36	0.27	0.20	0.14	0.11	0.10	0.09	0.08	0.07
0.39	0.45	0.32	0.23	0.19	0.14	0.11	0.10	0.09	0.08	0.06
0.4	0.46	0.30	0.23	0.17	0.13	0.11	0.09	0.09	0.08	0.06
0.41	0.35	0.30	0.22	0.16	0.12	0.11	0.10	0.09	0.08	0.06
0.42	0.38	0.27	0.22	0.15	0.13	0.10	0.10	0.09	0.08	0.07
0.43	0.38	0.26	0.19	0.15	0.12	0.11	0.09	0.09	0.08	0.06
0.44	0.36	0.27	0.18	0.15	0.11	0.10	0.09	0.09	0.07	0.05
0.45	0.34	0.25	0.18	0.14	0.11	0.10	0.09	0.08	0.08	0.04
0.46	0.31	0.21	0.17	0.14	0.11	0.10	0.09	0.08	0.07	0.05
0.47	0.32	0.21	0.17	0.13	0.11	0.10	0.09	0.08	0.08	0.04
0.48	0.27	0.20	0.15	0.13	0.11	0.10	0.09	0.08	0.07	0.04
0.49	0.25	0.20	0.15	0.13	0.11	0.10	0.09	0.08	0.06	0.03
0.5	0.19	0.21	0.14	0.14	0.11	0.09	0.09	0.08	0.07	0.03

Table 44: Relative average yield over 100 years of managed fishing simulations at different levels of biomass target (columns) and target fishing mortality (rows).

	0.075	0.175	0.225	0.275	0.375	0.425	0.475	0.525	0.625	0.725	0.775	0.825	0.875
0	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08
0.01	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.22	0.20	0.20
0.02	0.35	0.36	0.36	0.36	0.36	0.36	0.35	0.35	0.35	0.33	0.32	0.30	0.29
0.03	0.46	0.47	0.46	0.46	0.47	0.46	0.46	0.46	0.45	0.43	0.40	0.36	0.34
0.04	0.56	0.57	0.56	0.55	0.55	0.56	0.56	0.55	0.52	0.49	0.47	0.42	0.37
0.05	0.63	0.64	0.63	0.63	0.64	0.63	0.63	0.62	0.58	0.51	0.49	0.45	0.38
0.06	0.72	0.70	0.70	0.71	0.70	0.70	0.68	0.67	0.61	0.54	0.52	0.45	0.41
0.07	0.77	0.75	0.76	0.74	0.76	0.75	0.73	0.71	0.63	0.54	0.49	0.45	0.35
0.08	0.81	0.82	0.80	0.82	0.81	0.79	0.76	0.73	0.63	0.57	0.47	0.36	0.35
0.09	0.83	0.83	0.84	0.85	0.83	0.83	0.80	0.73	0.61	0.53	0.46	0.38	0.32
0.1	0.89	0.88	0.88	0.86	0.87	0.83	0.79	0.72	0.58	0.46	0.45	0.37	0.35
0.11	0.88	0.90	0.91	0.90	0.87	0.82	0.77	0.69	0.54	0.45	0.39	0.35	0.32
0.12	0.89	0.91	0.92	0.89	0.88	0.86	0.77	0.68	0.54	0.42	0.40	0.27	0.26
0.13	0.93	0.90	0.92	0.92	0.83	0.80	0.73	0.63	0.51	0.38	0.35	0.28	0.23
0.14	0.95	0.92	0.93	0.91	0.85	0.81	0.70	0.59	0.47	0.36	0.33	0.25	0.16
0.15	0.95	0.93	0.94	0.87	0.82	0.74	0.72	0.56	0.43	0.32	0.26	0.25	0.16
0.16	0.97	0.95	0.92	0.83	0.81	0.71	0.67	0.52	0.38	0.32	0.24	0.17	0.15
0.17	0.96	0.93	0.90	0.87	0.76	0.66	0.65	0.50	0.34	0.31	0.18	0.16	0.15
0.18	0.86	0.91	0.90	0.84	0.73	0.64	0.57	0.45	0.30	0.22	0.19	0.12	0.10
0.19	1.00	0.91	0.91	0.78	0.72	0.67	0.57	0.41	0.27	0.21	0.18	0.10	0.09
0.2	0.88	0.93	0.82	0.82	0.67	0.62	0.52	0.39	0.24	0.18	0.14	0.09	0.08
0.21	0.98	0.89	0.82	0.74	0.61	0.53	0.45	0.33	0.24	0.15	0.12	0.09	0.07
0.22	0.86	0.87	0.77	0.69	0.65	0.54	0.37	0.33	0.22	0.15	0.09	0.08	0.05
0.23	0.84	0.83	0.73	0.63	0.55	0.48	0.41	0.29	0.19	0.13	0.10	0.08	0.05
0.24	0.91	0.81	0.76	0.63	0.54	0.45	0.37	0.28	0.17	0.11	0.11	0.06	0.03
0.25	0.80	0.78	0.68	0.61	0.44	0.37	0.32	0.23	0.15	0.12	0.09	0.08	0.03
0.26	0.71	0.80	0.62	0.54	0.41	0.37	0.30	0.21	0.15	0.10	0.09	0.05	0.04
0.27	0.77	0.83	0.63	0.53	0.48	0.36	0.27	0.22	0.13	0.10	0.08	0.05	0.03

0.28	0.78	0.79	0.59	0.46	0.35	0.32	0.28	0.17	0.12	0.09	0.09	0.05	0.02
0.29	0.89	0.72	0.52	0.37	0.32	0.32	0.25	0.17	0.12	0.09	0.08	0.06	0.03
0.3	0.56	0.63	0.55	0.36	0.28	0.26	0.21	0.15	0.11	0.09	0.08	0.03	0.02
0.31	0.73	0.59	0.49	0.43	0.30	0.24	0.19	0.15	0.11	0.09	0.07	0.03	0.01
0.32	0.63	0.59	0.47	0.33	0.32	0.25	0.19	0.14	0.10	0.08	0.07	0.03	0.01
0.33	0.42	0.47	0.44	0.33	0.27	0.21	0.17	0.13	0.10	0.08	0.07	0.03	0.01
0.34	0.58	0.53	0.40	0.34	0.23	0.20	0.16	0.13	0.10	0.08	0.07	0.02	0.01
0.35	0.59	0.54	0.40	0.34	0.24	0.18	0.16	0.12	0.09	0.08	0.06	0.03	0.01
0.36	0.48	0.44	0.35	0.29	0.23	0.19	0.14	0.12	0.10	0.07	0.05	0.02	0.01
0.37	0.45	0.52	0.30	0.27	0.20	0.16	0.14	0.11	0.09	0.07	0.05	0.03	0.01
0.38	0.48	0.46	0.32	0.22	0.16	0.15	0.13	0.11	0.09	0.07	0.05	0.02	0.01
0.39	0.50	0.49	0.28	0.20	0.18	0.15	0.13	0.11	0.09	0.07	0.05	0.02	0.01
0.4	0.57	0.44	0.26	0.20	0.17	0.15	0.12	0.10	0.09	0.07	0.04	0.02	0.00
0.41	0.41	0.27	0.29	0.18	0.16	0.14	0.12	0.10	0.09	0.07	0.04	0.02	0.00
0.42	0.45	0.36	0.25	0.17	0.16	0.14	0.12	0.10	0.09	0.07	0.05	0.01	0.00
0.43	0.41	0.25	0.28	0.17	0.15	0.13	0.11	0.10	0.09	0.06	0.04	0.01	0.00
0.44	0.37	0.28	0.23	0.18	0.14	0.13	0.11	0.10	0.08	0.06	0.03	0.00	0.00
0.45	0.36	0.31	0.21	0.15	0.15	0.12	0.11	0.10	0.08	0.06	0.03	0.01	0.00
0.46	0.22	0.28	0.18	0.16	0.13	0.12	0.11	0.10	0.08	0.06	0.03	0.01	0.00
0.47	0.26	0.31	0.19	0.15	0.14	0.12	0.11	0.10	0.08	0.05	0.03	0.00	0.00
0.48	0.23	0.22	0.17	0.14	0.13	0.12	0.11	0.10	0.08	0.05	0.03	0.00	0.00
0.49	0.29	0.21	0.16	0.15	0.12	0.12	0.10	0.10	0.08	0.05	0.01	0.00	0.00
0.5	0.26	0.15	0.20	0.16	0.12	0.10	0.10	0.09	0.08	0.07	0.01	0.00	0.00

Figures

Alternative Risk-G (Council-Preferred): Stock Status/Life History, Inflection at B/B_{MSY} = 1.0

Under this alternative, a stock replenishment threshold defined as the ratio of $B/B_{MSY} = 0.10$, will be utilized to ensure the stock does not reach low levels from which it cannot recover. The probability of overfishing will be 0 percent if the ratio of B/B_{MSY} is less than or equal to 0.10. Probability of overfishing increases linearly for stock defined as typical as the ratio of B/B_{MSY} increases, until the inflection point of $B/B_{MSY} = 1.0$ is reached and a 40 percent probability of overfishing is utilized for ratios equal to or greater than 1.0. Probability of overfishing increases linearly for stock defined as atypical as the ratio of B/B_{MSY} increases, until the inflection point of $B/B_{MSY} = 1.0$ is reached and a 35 percent probability of overfishing is utilized for ratios equal to or greater than 1.0. The SSC will determine whether a stock is typical or atypical each time an ABC is recommended. Generally speaking, an atypical stock has a life history strategy that results in greater vulnerability to exploitation, and whose life history has not been fully addressed through the stock assessment and biological reference point development process.

In addition, under this alternative for managed resources that are under rebuilding plans, the upper limit on the probability of exceeding $F_{REBUILD}$ would be 50 percent unless modified to a lesser value (i.e., higher probability of not exceeding $F_{REBUILD}$) through a rebuilding plan amendment. In instances where the SSC derives a more restrictive ABC recommendation, based on the application of the ABC control rule methods framework and risk policy, than the ABC derived from the use of $F_{REBUILD}$ at the MAFMC-specified overfishing risk level, the SSC shall recommend to the MAFMC the lower of the ABC values.

In addition, if no OFL is available (i.e., No F_{MSY} or F_{MSY} proxy provided through the stock assessment to identify it) and no OFL proxy is provided by the SSC at the time of ABC recommendations, then an upper limit (cap) on allowable increases in ABC will be established. ABC may not be increased until an OFL has been identified.

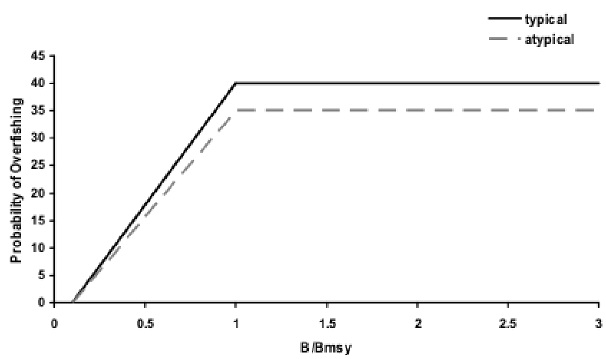


Figure 230: Mid-Atlantic Fisheries Management Council risk policy MAFMC 2011 (p. 51).

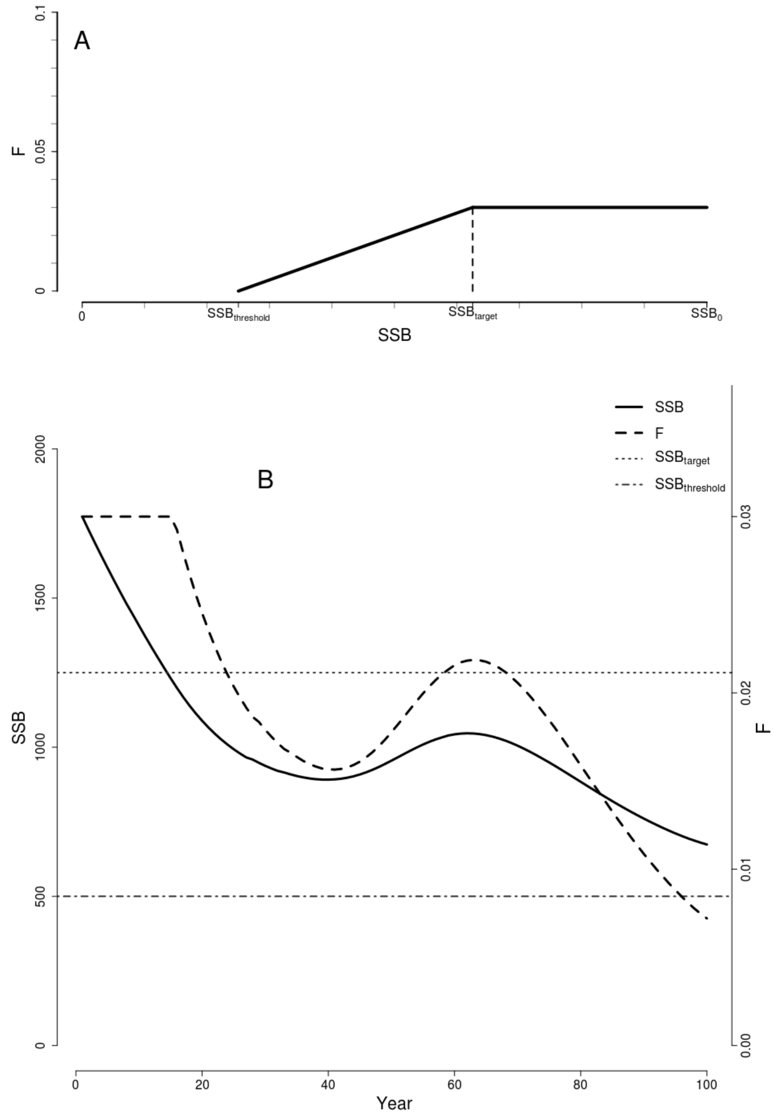


Figure 231: Panel (A) Control rule for Atlantic surfclam in terms of F and SSB. Fishing mortality is constant unless SSB drops below SSB_{target}, it then declines linearly until it reaches 0 at $SSB_{threshold}$. Panel (B) The control rule applied in a simulation run. Fishing mortality was constant when $SSB_t > SSB_{target}$, and was reduced when $SSB_t < SSB_{target}$. Simulated SSB units are 000 mt.

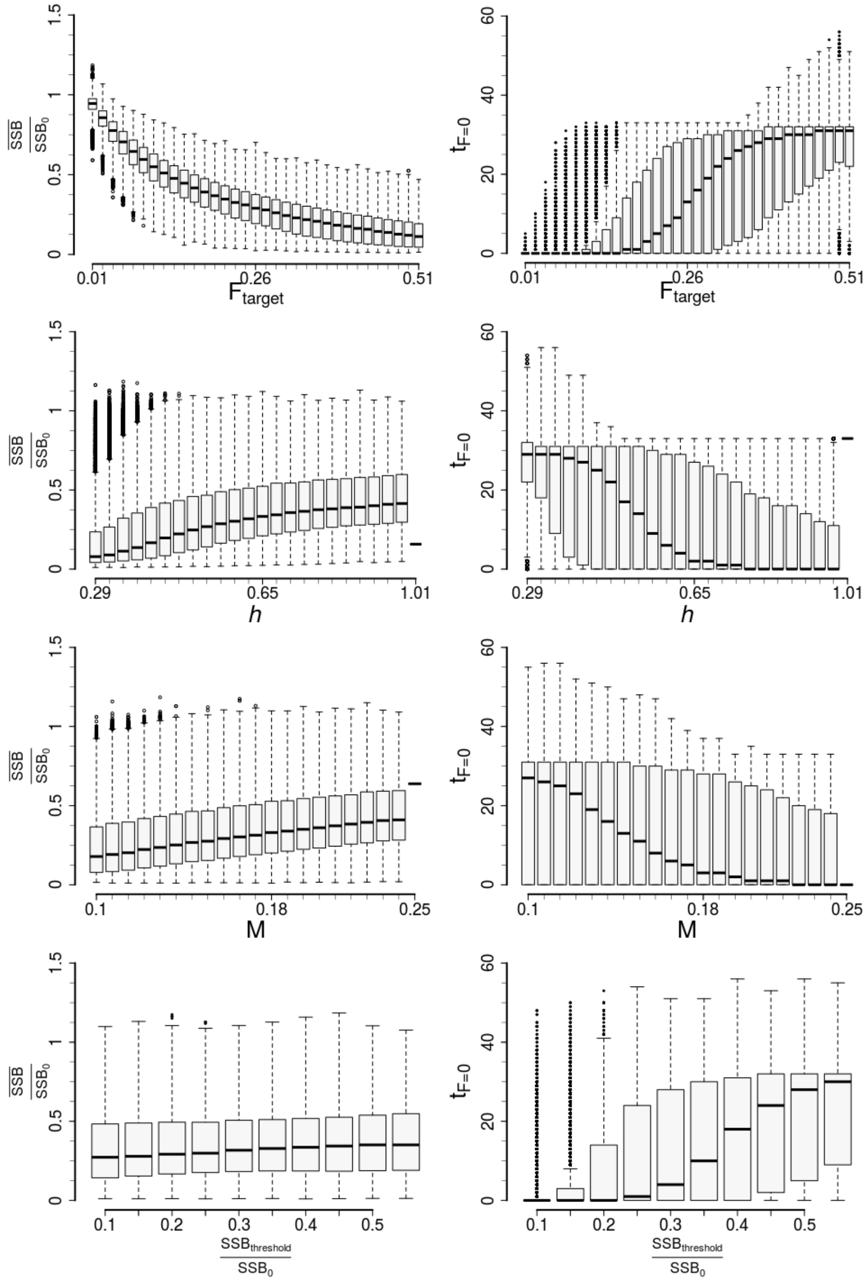


Figure 232: Mean biomass ($\frac{\overline{SSB}}{SSB_0}$), and time not fished due to management intervention ($t_{F=0}$) in 100 year simulations, by values of target fishing mortality (F_{target}), steepness (h), assessment error (σ_{At}), natural mortality (M) and the fraction of SSB_0 that corresponds to the control rule (stock replenishment) threshold ($SSB_{threshold}$). The boxes represent interquartile range, solid horizontal lines in each box are the medians, and the whiskers indicate the range between the 0.025 and 0.975 quanitles ($n = 500000$).

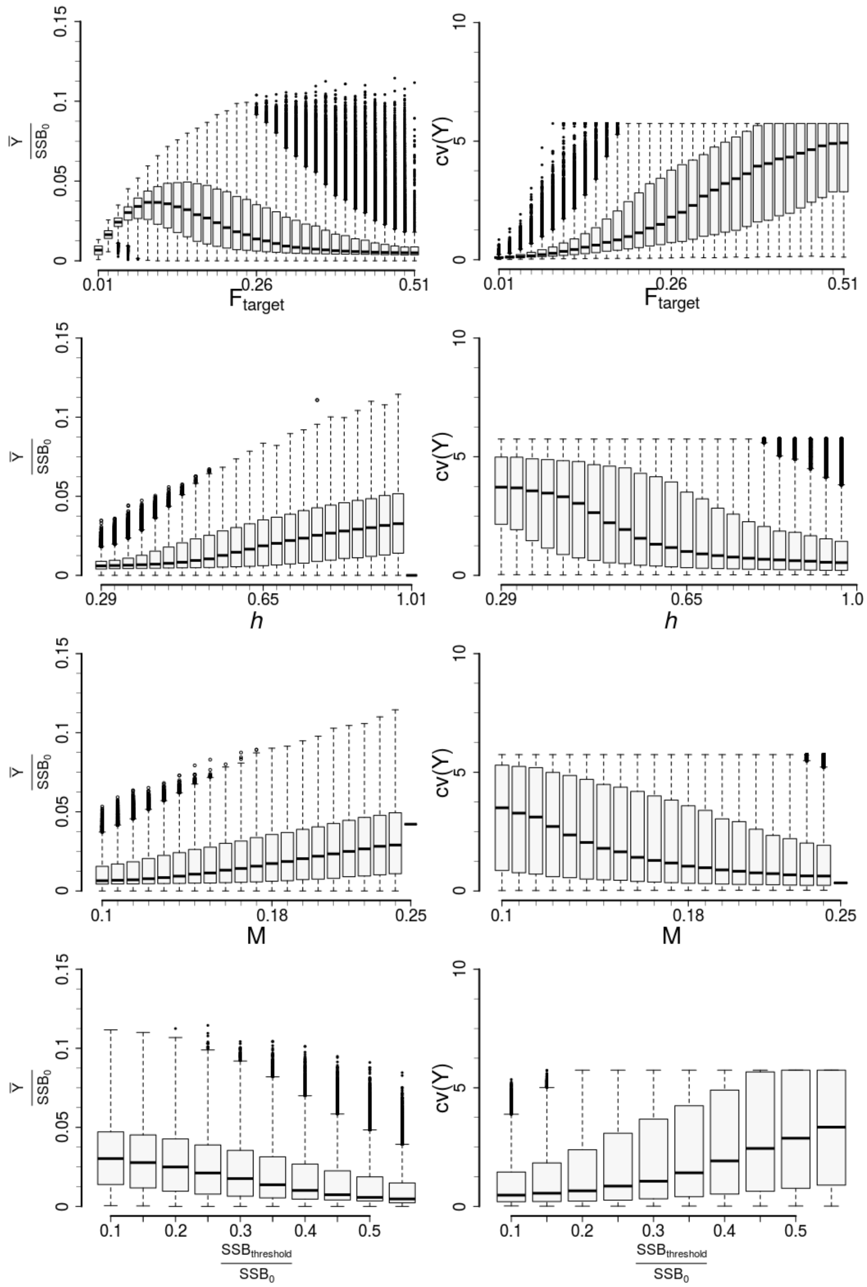


Figure 233: Mean yield ($\frac{\overline{Y}}{SSB_0}$) and cv yield in 100 year simulations, by values of target fishing mortality (F_{target}), steepness (h), natural mortality (M) and the fraction of SSB_0 that corresponds to the control rule (stock replenishment) threshold ($\frac{SSB_{threshold}}{SSB_0}$) ($n = 500000$).

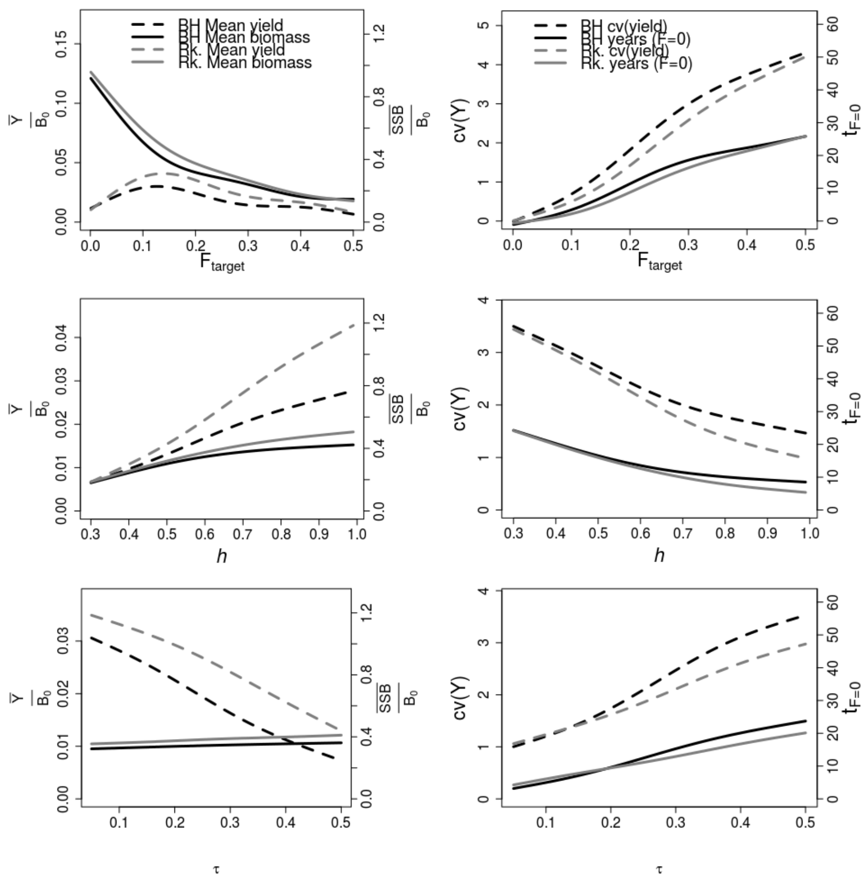


Figure 234: Mean yield, mean biomass, cv yield and years without fishing by F_{target}, h and $\frac{SSB_{threshold}}{SSB_0}$ from 100 year simulations for simulations where recruitment was driven by Beverton Holt (BH; $n = 60000$ for each) or Ricker (Rk) dynamics. The solid and dashed lines are fits to simple univariate generalized additive models (splines with basis dimension, $k = 5$). These are used to illustrate trends only.

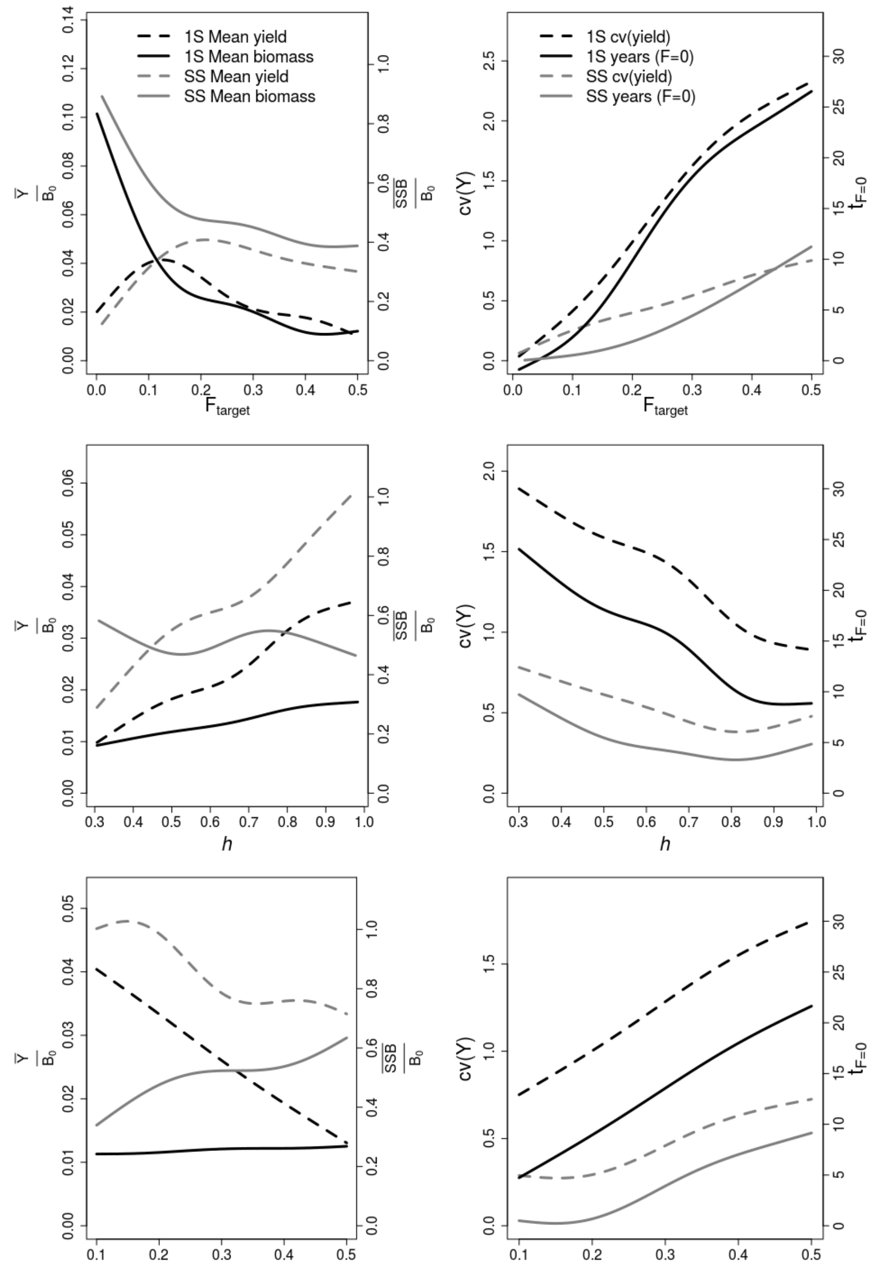


Figure 235: Mean yield, mean biomass, cv yield and years without fishing by F_{target}, h and $\frac{SSB_{threshold}}{SSB_0}$ from 100 year simulations for two regions with independent recruitment managed together, either as separate stocks (SS) or as a single stock ($1S$; $n = 60000$ for each). Both stocks were assessed every five years. The solid and dashed lines are fits to simple univariate generalized additive models (splines with basis dimension, $k = 5$). These are used to illustrate trends only.

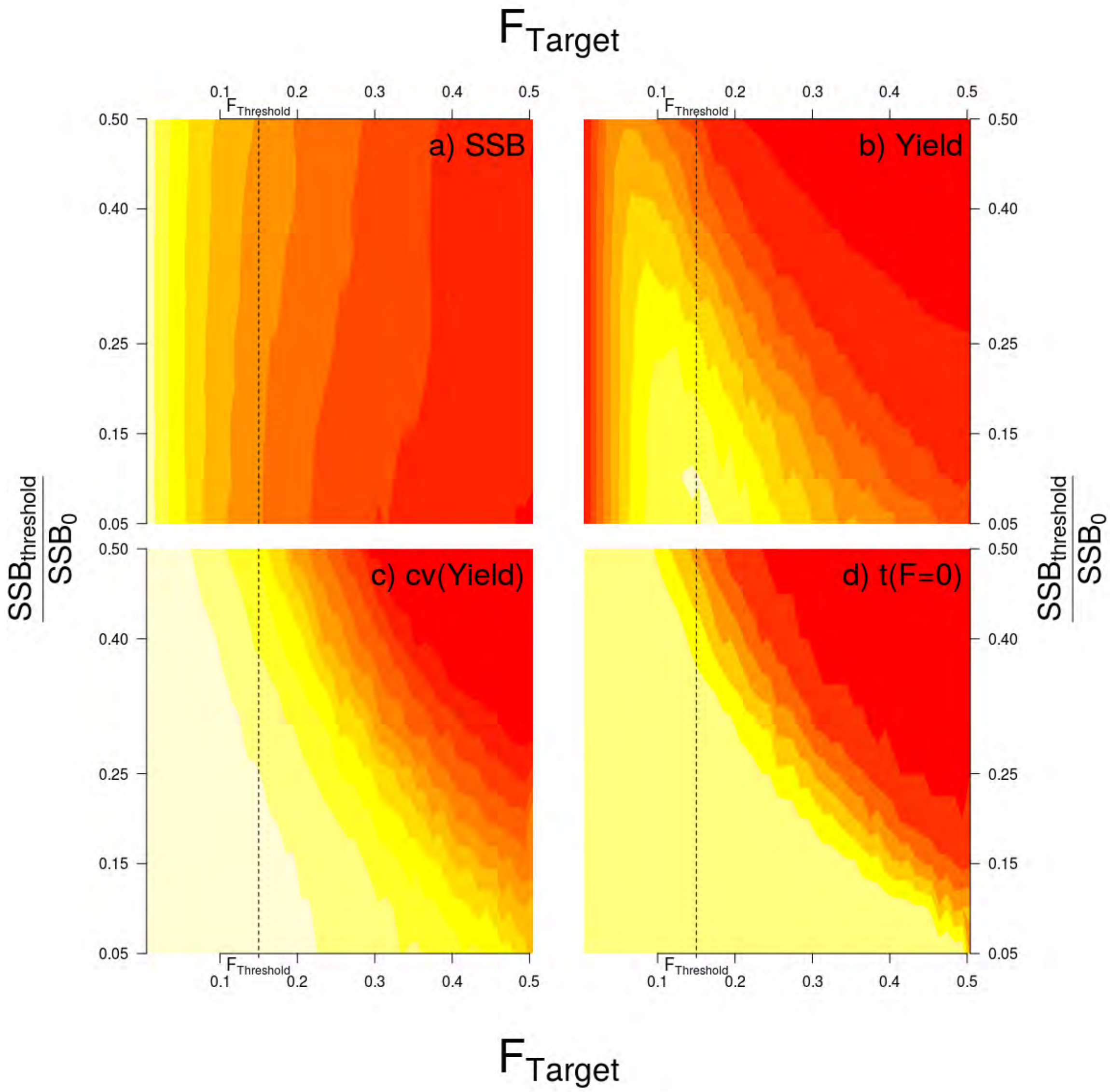


Figure 236: Contour plots showing the combined effects of F_{target} and the fraction of SSB_0 that corresponds to the control rule (stock replenishment) threshold ($\frac{SSB_{threshold}}{SSB_0}$) on: (a) $\frac{\overline{SSB}}{SSB_0}$, (b) $\frac{\overline{Y}}{SSB_0}$, (c) cv(Y) and (d) $t_{F=0}$. In each plot the darker colors are associated with less preferred values (*e.g.* in plot (a) the lowest $\frac{\overline{SSB}}{SSB_0}$ occurs on the right side, where F_{target} is high, and in plot (c) the highest variation in yield occurs on the right side, where F_{target} is high). The current $F_{threshold}$ (0.15; Northeast Fisheries Science Center 2013) is marked with a dashed line. These simulations were based on a single stock where recruitment followed either Beverton Holt or Ricker stock recruitment dynamics.

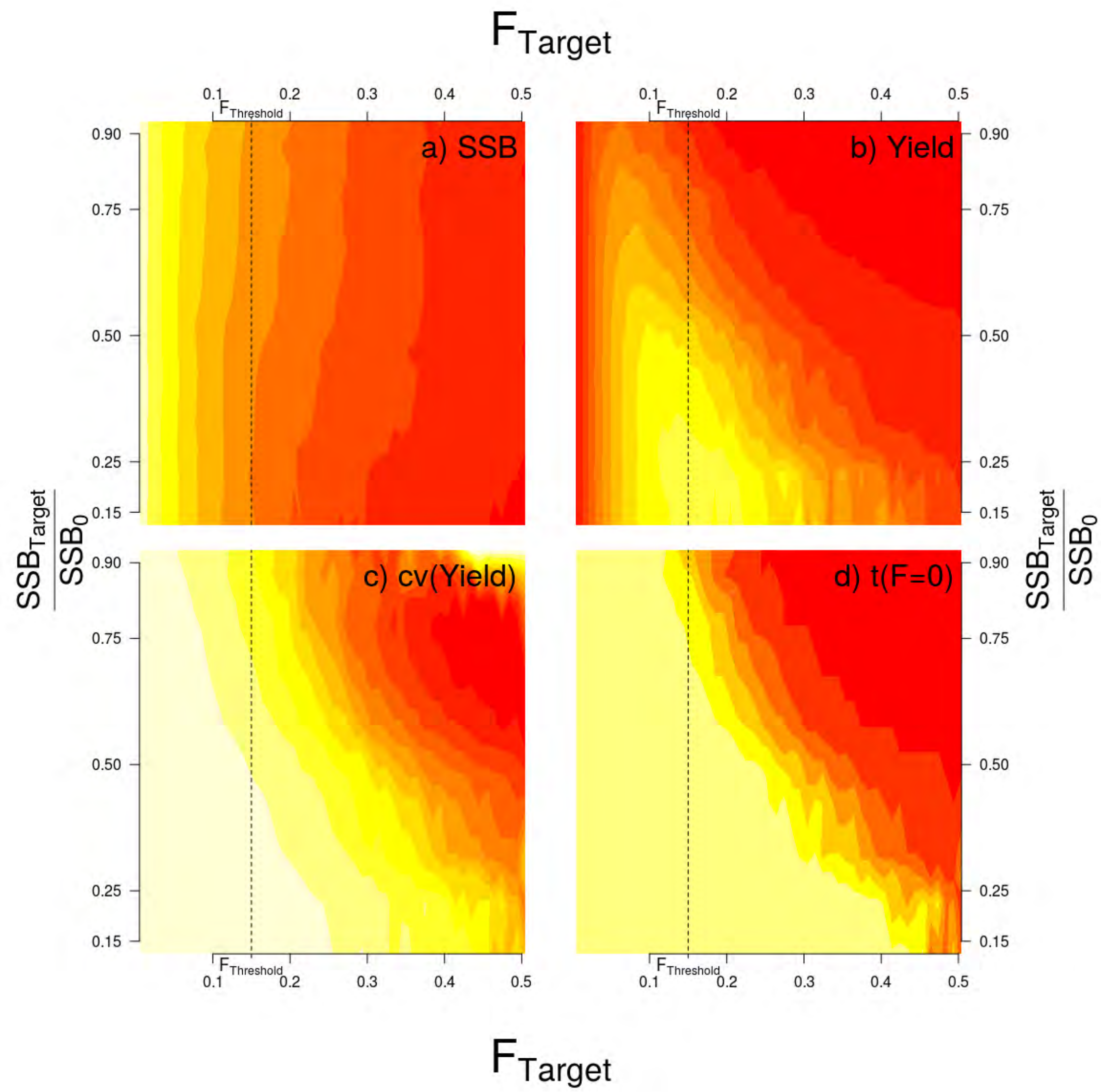


Figure 237: Contour plots showing the combined effects of F_{target} and the fraction of SSB_0 that corresponds to the control rule target ($\frac{SSB_{targer}}{SSB_0}$) on: (a) $\frac{\overline{SSB}}{SSB_0}$, (b) $\frac{\overline{Y}}{SSB_0}$, (c) cv(Y) and (d) $t_{F=0}$. In each plot the darker colors are associated with less preferred values (*e.g.* in plot (a) the lowest $\frac{\overline{SSB}}{SSB_0}$ occurs on the right side, where F_{target} is high, and in plot (c) the highest variation in yield occurs on the right side, where F_{target} is high). The current $F_{threshold}$ (0.15; Northeast Fisheries Science Center 2013) is marked with a dashed line. These simulations were based on a single stock where recruitment followed either Beverton Holt or Ricker stock recruitment dynamics.

Appendix 9 Comparing methods for combining F from different areas

Four different methods for combining estimates of fishing mortality from different areas were compared. The methods were: the arithmetic mean

$$\widehat{F_{W,arith}} = E[F_S + F_N] \tag{24}$$

where F_W is the whole stock fishing fishing mortality and F_S and F_N are the F form the southern and northern areas, respectively. The geometric mean

$$\widehat{F_{W,geo}} = e^{E[log(F_S)+lof(F_N)]} \tag{25}$$

the harmonic mean

$$\widehat{F_{W,har}} = \frac{2}{F_S^{-1} + F_N^{-1}} \tag{26}$$

and the abundance weighted mean

$$\widehat{F_{W,wt}} = \frac{N_S}{N_S + N_N} F_S + \frac{N_S}{N_S + N_N} F_N \tag{27}$$

where N_S and N_N are the abundances form the southern and northern areas, respectively.

Correlated lognormal random variables (n=10000) were drawn for F and N for each of two areas where

$$F_a \sim lognormal(\mu_{F,a}, \sigma_{S,a}) \tag{28}$$
$$N_a \sim lognormal(\mu_{N,a}, \sigma_{N,a}) \tag{29}$$

$\mu_{i,a}$ and $\sigma_{i,a}$ were the mean and variance of the parameter i (N or F) and simulated area a. The correlation between F_a and N_a (ρ) was varied experimentally. The distribution of each of $\widehat{F_{W,method}}$ from each of the different methods for combining F was compared to the true combined $F_W = E[\mu_{F,a}\mu_{N,a}]$.

The simulations showed that $\widehat{F_{W,arith}}$ is biased high and $\widehat{F_{W,har}}$ is biased low at all values of ρ (Figure 238). $\widehat{F_{W,wt}}$ was biased low when $\rho < -0.6$ and biased high when $\rho > -0.4$. $\widehat{F_{W,geo}}$ was close to F_W at all values of ρ and deemed the best choice for the combining the F in the Atlantic surfclam assessment where the correlation between biomass (and abundance) and fishing mortality is high (for example, from the base run for the southern area $\rho_{max} = -0.78$ and $\rho_{min} = -0.97$).

The results depended on the level of F. In particular when $F \cong 0.0$, the geometric and harmonic means were strongly negatively biased (Figure 239). When $F \cong 0.0$, the preferred method for combining F from different areas was the abundance weighted mean, based on less bias at all levels of correlation between F and abundance.

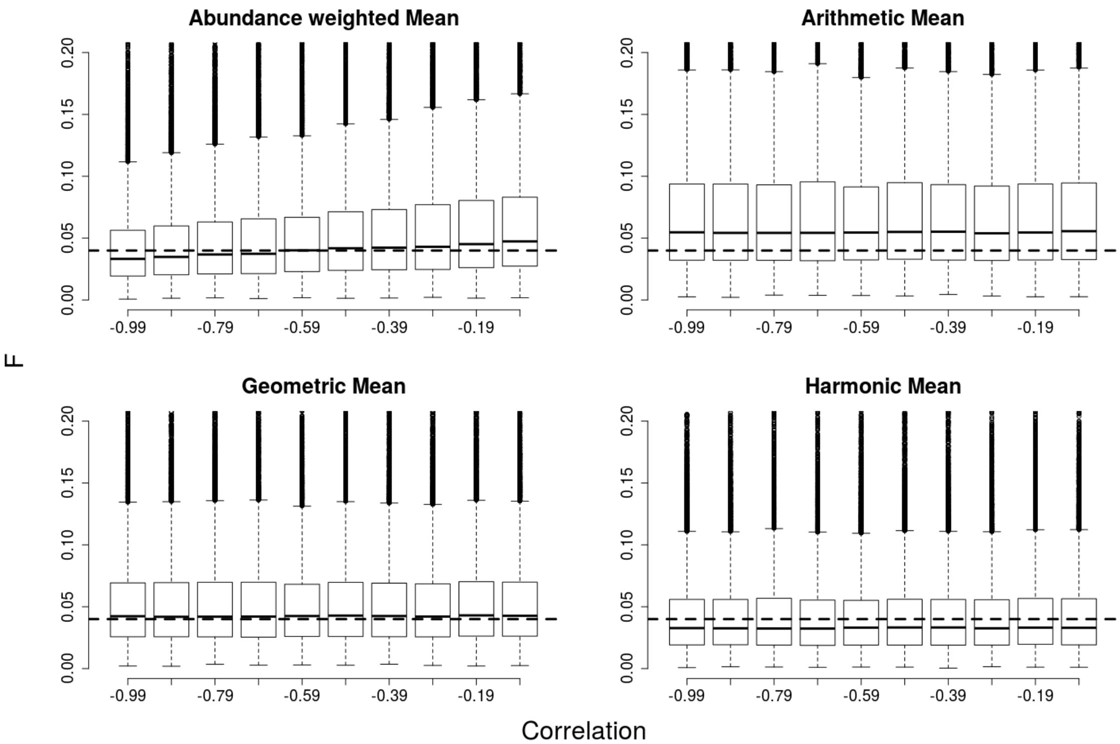


Figure 238: The distribution of estimates of the combined fishing mortality from two regions at varying levels of correlation between abundance and F, compared to the true combined fishing mortality (dashed line). The geometric mean was nearly unbiased at all correlation levels, while the bias in abundance weighted mean depended on the correlation between F and abundance.

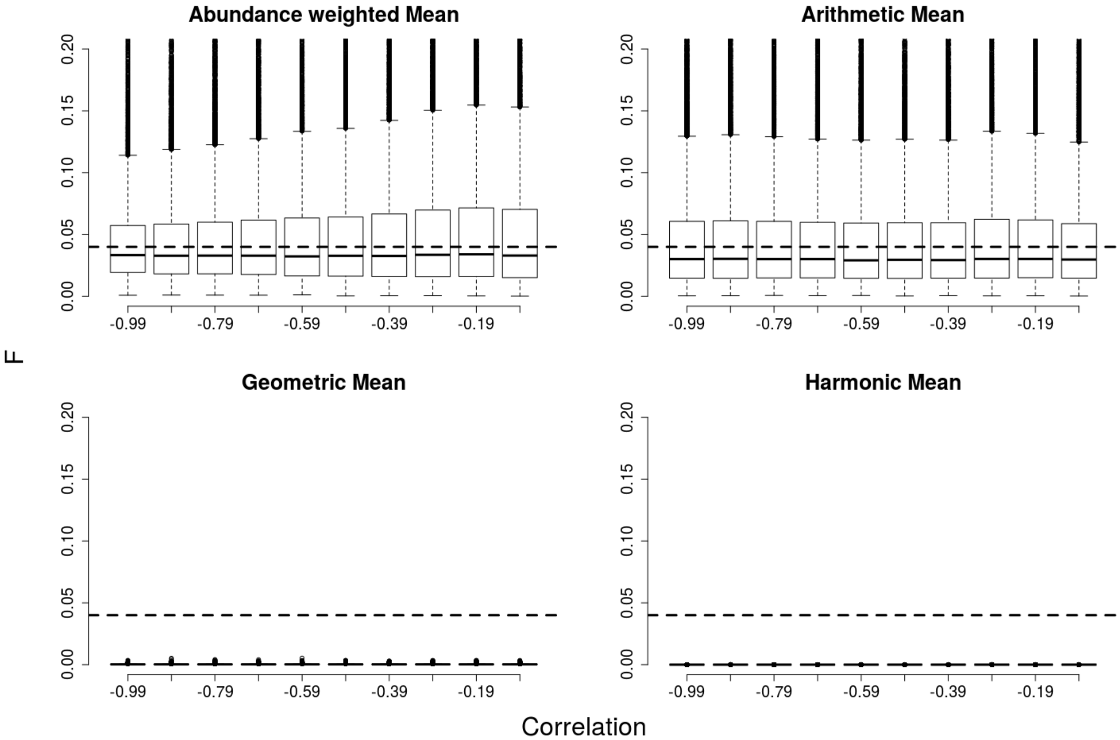


Figure 239: The distribution of estimates of the combined fishing mortality from two regions at varying levels of correlation between abundance and F, compared to the true combined fishing mortality (dashed line), when one the true F values is near 0 ($F = 0.00001$). In this case the geometric and harmonic means were strongly negatively biased and the abundance weighted average was the preferred method

Appendix 10 Sampling properties of presence-absence data for from NEFSC clam surveys

Changes in habitat overlap and co-occurrence of Atlantic surfclam and ocean quahogs affect the fisheries for both species because mixed catches are harder and more expensive to process for sale. Co-occurrence may be a simple metric for tracking climate change effects on habitat for both species. Here, we develop some mathematics that describe occurrence and co-occurrence of Atlantic surfclam and ocean quahogs in dredge survey tows as a function of individual densities using the RD clam survey as an example. In summary, occurrence and co-occurrence are sensitive indicators that one or both species are found in an area. However, they are insensitive to changes in density once encounter rates for both species reach about 15 individuals per tow (roughly 0.013 per m^2). Calculations are based on the RD, but the overall result applies to the MCD, which has higher capture efficiency for both species and sweeps a larger area, so that it is even more sensitive to the presence of either species and less useful as a measure of density (in the context of presence-absence).

The data used in this analysis are from random tows during NEFSC clam surveys during 1982-2011. The nominal area swept is 423 m^2 per tow, but varies with depth. We assume that the area swept by the survey dredge (1.82 m or 5 ft wide) is about 1140 m^2 per tow, based on a tow distance of about 700 m, where both species might be found (see Figure 240; Weinberg et al. (2002)). This crude approximation aids interpretation but does not affect the overall conclusion.

The probability of catching at least one Atlantic surfclam and one ocean quahog in the same tow depends on depth, species, and/or time dependent factors including: 1) capture efficiency of the gear, 2) area swept (tow distance x dredge width, m^2), 3) encounter rate and density (individuals per tow or m^2) and 4) the statistical distributions of the number of clams encountered in a tow (with parameters for the mean, variance and, implicitly, patchiness). The probability of catching at least one Atlantic surfclam (s) and one quahog (q) in a dredge tow is:

$$p(s, q \mid d) = p(s \mid d)p(q \mid d) \tag{30}$$

where $p(s \mid d)$ and $p(q \mid d)$ are the conditional probabilities of catching at least one Atlantic surfclam or quahog at depth d as independent events. These probabilities might depend on time, region, etc. but subscripts for such factors are not included. Using Atlantic surfclam as an example:

$$p(s \mid d) = \sum_{n=1}^{\infty} \left[P(E_s = n \mid d) \sum_{m=1}^{n} \binom{n}{m} e_s^m (1 - e_s)^{n-m} \right] \tag{31}$$

where $p(E_s = n \mid d)$ is the probability that the dredge encounters n individual Atlantic surfclam, e_s is capture efficiency ($0 < e_s < 1$), $\binom{n}{m}$ are binomial coefficients giving the number of ways to catch m clams if n are encountered, and $e_s^m(1-e_s)^{n-m}$ is the probability of catching m and missing $n - m$ individuals in the path of the dredge when n clams are encountered. The formula can be simplified because the

$$\sum_{m=1}^{n} \binom{n}{m} e_s^m (1 - e_s)^{n-m}$$

used to calculate the probability of catching at least one clam is the complement of the probability of catching none with probability $(1 - e_s)^n$, so that:

$$p(s \mid d) = \sum_{n=0}^{\infty} P(E_s = n \mid d)[1 - (1 - e_s)^n] \tag{32}$$

Note that the possibility that the dredge will not encounter any clams (even though they may be in the general area) is included. Such an event does not contribute to the probability of any catch because $1 - (1 - e_s)^0 = 0$. Thus, the probability of catching no clams could be omitted from the calculation without changing the results.

The encounter probability $P(E_s = n \mid d)$ is from an unknown statistical distribution with mean $(\mu_{s,d})$ and variance $(\sigma^2_{s,d}\ )$ parameters that may depend on any of the factors listed above. Patchiness is an inherent property of the statistical distribution that also affects the encounter probability because patchy organisms are captured less frequently than randomly distributed ones. The mean number of encounters per tow depends directly on the density of Atlantic surfclam (and overall abundance) and the area swept by the tow.

Using the Poisson distribution with parameters $\lambda_{s,d} = \mu_{s,d} = \sigma^2_{s,d}$, the probability distribution for encountering n individuals would be:

$$P(E_s = n \mid d) = \frac{\lambda^n_{s,d} e^(-\lambda_{s,d})}{n!} \tag{33}$$

The negative binomial distribution is another candidate distribution which may be appropriate given that Atlantic surfclam and ocean quahog catches during depletion experiments have been modeled successfully based on the distribution:

$$P(E_s = n \mid d) = \frac{\Gamma(n + k_{s.d})}{n!\Gamma(k_{s.d})} \left(\frac{k_{s.d}}{\mu_{s,d} + k_{s.d}}\right)^{k_{s.d}} \left(\frac{\mu_{s,d}}{\mu_{s,d} + k_{s.d}}\right)^{n} \tag{34}$$

where $k_{s.d}$ is a dispersion parameter and $\sigma^2_{s,d} = \mu_{s,d} + \frac{\mu^2_{s,d}}{k}$. By the method of moments, $k_{s.d} = \frac{\mu_{s,d}}{\left[\frac{\sigma^2_{s,d}}{(\mu_{s,d} - 1)}\right]}$.

It is important to remember that the probability density function for co-occurrence $p(s, q \mid d)$ can decline, for example, if either or both of $p(s \mid d)$ and $p(q \mid d)$ decline, if $p(s \mid d)$ declines substantially while $p(q \mid d)$ increases slightly, or if $p(s \mid d)$ increases substantially while $p(q \mid d)$ declines slightly. The probability may remain constant despite large ecological changes if a decline in density of Atlantic surfclam, for example, is offset by an increase in density of ocean quahogs. Very small changes in $p(s \mid d)$ are possible despite large changes in density if $(s \mid d)$ is close to one initially (and vice-versa). The probability of co-occurrence is therefore nearly the same as the probability of occurrence for a species at low density in a habitat where the other species is at high density.

The sampling characteristics of co-occurrence data can be evaluated using eq. (32) with assumed statistical distributions and parameter values (Table 45). The mean of 21 Delaware II dredge capture efficiency estimates in NEFSC (2013) for Atlantic surfclam 150+ mm SL was 0.413 (SE 0.098). The mean of 15 Delaware II dredge capture efficiency estimates in NEFSC (2009) for ocean quahogs 90+ mm SL was 0.263 (SE 0.057). The mean dispersion parameter (k) for catches in depletion studies was 9.83 (SD 11.6, SE 2.37) for Atlantic surfclam and 8.00 (SD 4.03, SE 0.88) for ocean quahogs.

The mean Atlantic surfclam catch (all sizes) was 83 (SD 237, SE 7.13) and the mean quahog catch was 239 (SD 895, SE 26.9) in random survey tows that caught both species during 1982-2011 (Table 45). The distributions of observed catches were highly skewed for both species. Based on catch and capture efficiency, the mean number of Atlantic surfclam encountered in tows that caught both species was mean catch/efficiency=83/0.413=201 (about 0.18 Atlantic surfclam per m^2) and the mean number of quahogs encountered was 239/0.263=909 (about 0.8 quahogs per m^2). These figures are under-estimates because of reduced capture efficiency for Atlantic surfclam $<$ 150 mm SL and for quahogs $<$ 90 mm SL.

The probabilities of catching at least one Atlantic surfclam, one ocean quahog or at least one of each species in a hypothetical survey tow is nearly one given the typical values described above using either the negative binomial or Poisson distribution (Table 45 and Figures 241-242). The probabilities are high because numbers encountered tend to be high ($>$ 100) for both species based on typical values and particularly because the probability of catching at least one clam is high for even modest numbers of encounters. Considering Atlantic surfclam with capture efficiency $e_{s.d} = 0.413$, the probability of capturing at least one individual with only five encounters (0.01 m^2) is $1-(1-0.413)^5 = 0.93$. For ocean quahogs, the corresponding probability is $1-(1-0.263)^5 = 0.78$.

The calculations above show that the probability of capture for both species and for co-occurrence is likely to be high at relatively low densities for both species and suggest that co-occurrence is a sensitive indicator that both species are present. To test this hypothesis, we calculated the probability catching at least one individual of both species, and the probability of co-occurrence for mean encounter rates ranging from 1 to 15 clams of each species per tow (0.0009 to 0.013 per m^2). Results indicate that the probability of co-occurrence is 0.10-0.15 when only one Atlantic surfclam and ocean quahog are encountered, 0.55-0.65 for five individuals of both species and at least 0.85 for ten individuals per tow (0.009 per m^2) of both species (Figure 240). However, the results also show that co-occurrence is insensitive to changes in encounter rates and density beyond fifteen individuals per tow. Average co-occurrence over many tows is unlikely to be useful for tracking trends in density of either species because typical catches in tows that caught both species were usually above 15 clams per tow for both Atlantic surfclam and ocean quahogs (Table 45).

Table 45: Typical parameters used in simulating occurrence and co-occurrence of Atlantic surfclam and ocean quahogs in survey tows. The probability of capturing at least one individual from eq. (32) under conditions in the table is shown in the last row. Statistic.

Statistic	Atlantic surfclam	Ocean quahogs
Mean number encountered	201	909
Approximate density assuming 500 m^2 per tow (see text)	0.40 per m^2	1.8 per m^2
Dispersion parameter	9.83	8.00
Capture efficiency	0.413	0.263
P(catch > 0)	1	1

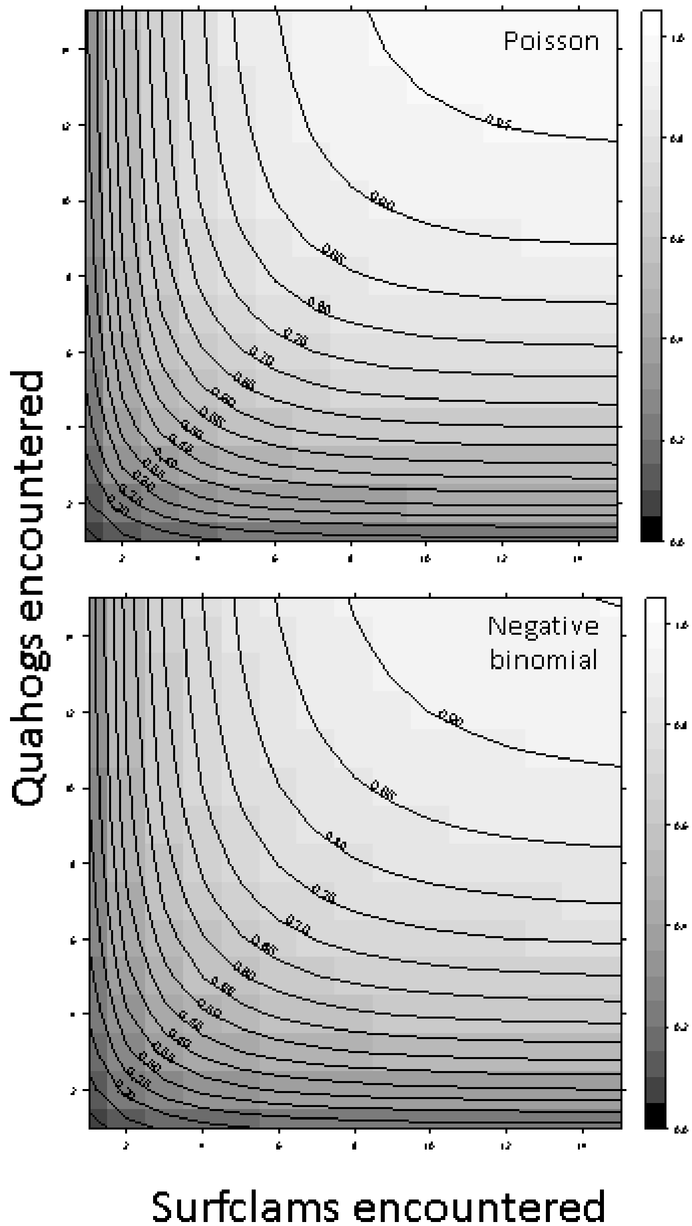


Figure 240: Isopleths for the probability of co-occurrence (at least one Atlantic surfclam and one ocean quahog in a hypothetical survey tow) given the number of Atlantic surfclam and ocean quahogs encountered.

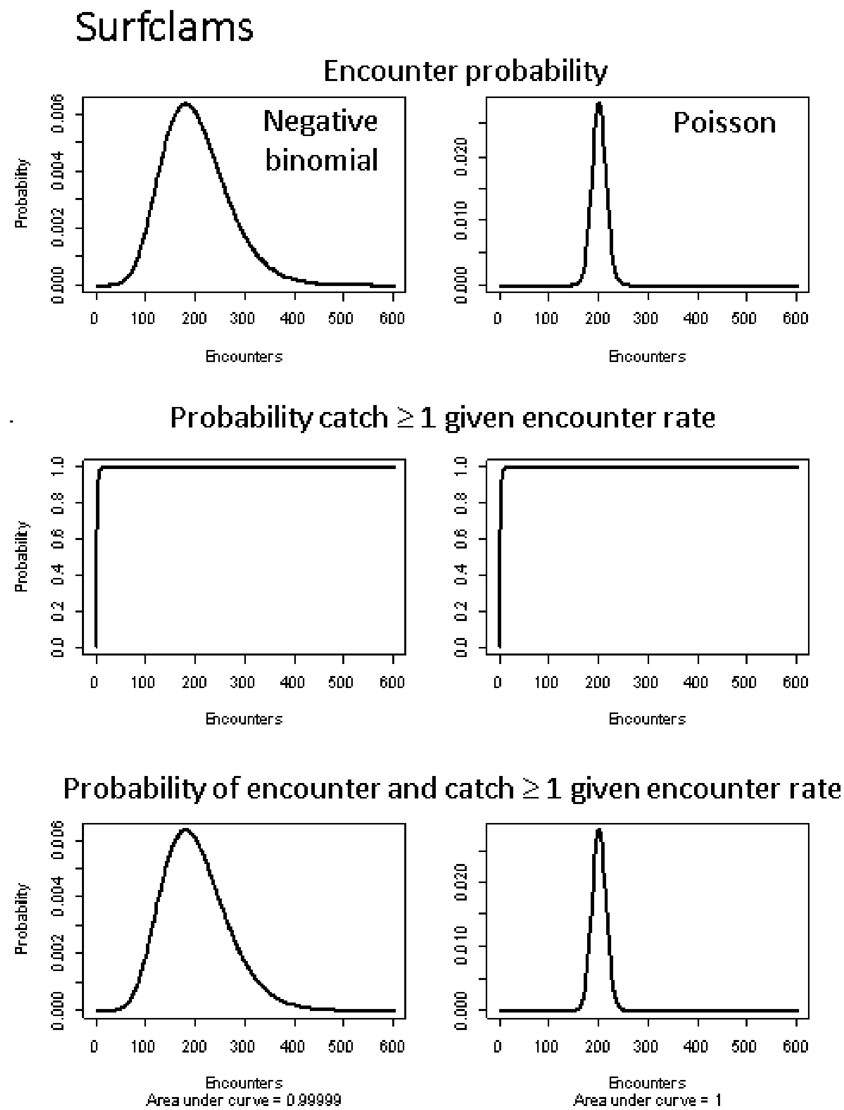


Figure 241: Intermediate calculations in calculating the probability that at least one individual is captured in a hypothetical survey tow assuming typical parameter values and either a negative binomial (left) or Poisson (right) distribution for encounter probability. The top row gives the probability density functions $P(E_s = n \mid d)$ for the number of clams encountered by the dredge given the assumed mean encounter rate (density) and statistical distribution. The middle row (same on left and right) shows the conditional probability $[1 - (1 - e_s)^n]$ that at least one clam is captured given the number of encounters on the x-axis. The bottom row shows the joint probability of the encounter rate and capture of at least one clam (the product of the curves in the top and middle rows). The area under the bottom curve is the total probability of catching at least one clam. The range of encounters on the x-axis differs markedly for the two species because ocean quahog densities are higher than Atlantic surfclam densities based on survey catches and because of capture efficiency assumptions.

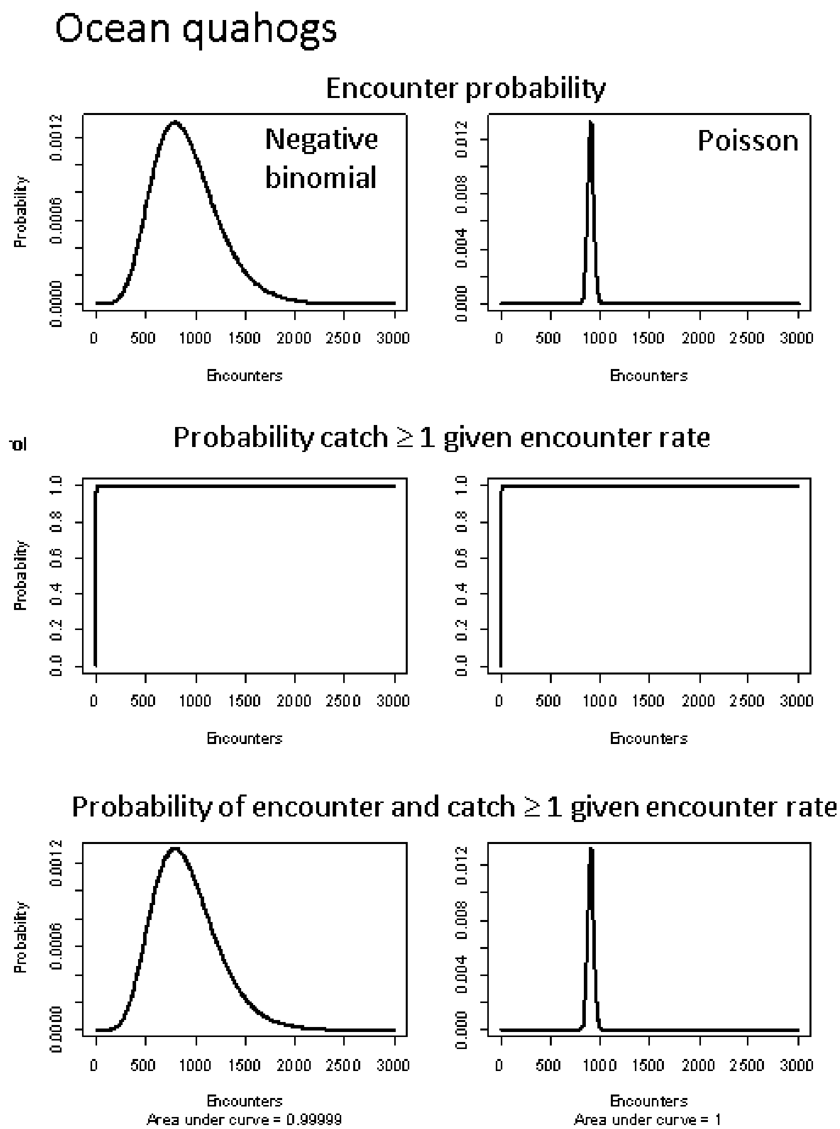


Figure 242: Intermediate calculations in calculating the probability that at least one individual is captured in a hypothetical survey tow assuming typical parameter values and either a negative binomial (left) or Poisson (right) distribution for encounter probability. The top row gives the probability density functions $P(E_s = n \mid d)$ for the number of clams encountered by the dredge given the assumed mean encounter rate (density) and statistical distribution. The middle row (same on left and right) shows the conditional probability $[1 - (1 - e_s)^n]$ that at least one clam is captured given the number of encounters on the x-axis. The bottom row shows the joint probability of the encounter rate and capture of at least one clam (the product of the curves in the top and middle rows). The area under the bottom curve is the total probability of catching at least one clam. The range of encounters on the x-axis differs markedly for the two species because ocean quahog densities are higher than Atlantic surfclam densities based on survey catches and because of capture efficiency assumptions.

Appendix 11 Trends in probability of Atlantic surfclam-ocean quahog co-occurrence in NEFSC clam surveys

Logistic regression models were used to detect trends in the probability of co-occurrence (Atlantic surfclam and ocean quahogs taken in the same tow) in NEFSC clam surveys during 1982-2011. Survey data collected after 2011 were not included because they involved different survey gear, were not comparable (Appendix 10), and because too few survey years were available for independent use. Only data from successful random tows were used. Poorly sampled strata with > 2 missing years were omitted. The dependent variable for each tow was a dummy variable for co-occurrence (1 if both Atlantic surfclam and ocean quahogs were captured and zero otherwise). In the R programming language, the models were specified $glm(d \sim y, family = binomial)$ where d is the dummy variable and y is year. The null hypothesis of no trend was rejected if $p \leq 0.1$.

Results show that the probability of co-occurrence decreased almost linearly during 1982-2011 in SNE while increasing almost linearly in the LI and NJ regions (Figure 243). Significant trends were detected for individual survey strata within each region except SNE (Table 46).

Table 46: Summary of strata with significant trends ($p \leq 0.1$) in co-occurrence of Atlantic surfclam and ocean quahogs in NEFSC clam surveys during 1982-2011.

Region	Stratum	Direction of trend	p-value	Strata depth range (m)	Area (nm2)
GBK	55	decline	0.08	55-73	364
GBK	69	increase	0.1	0-46	938
LI	29	increase	0.01	27-46	1096
LI	33	increase	0.01	27-46	363
NJ	22	increase	< 0.01	46-55	312
NJ	25	increase	0.01	27-46	648
DMV	9	decline	< 0.01	27-46	2171
SVA	6	decline	0.08	46-55	62

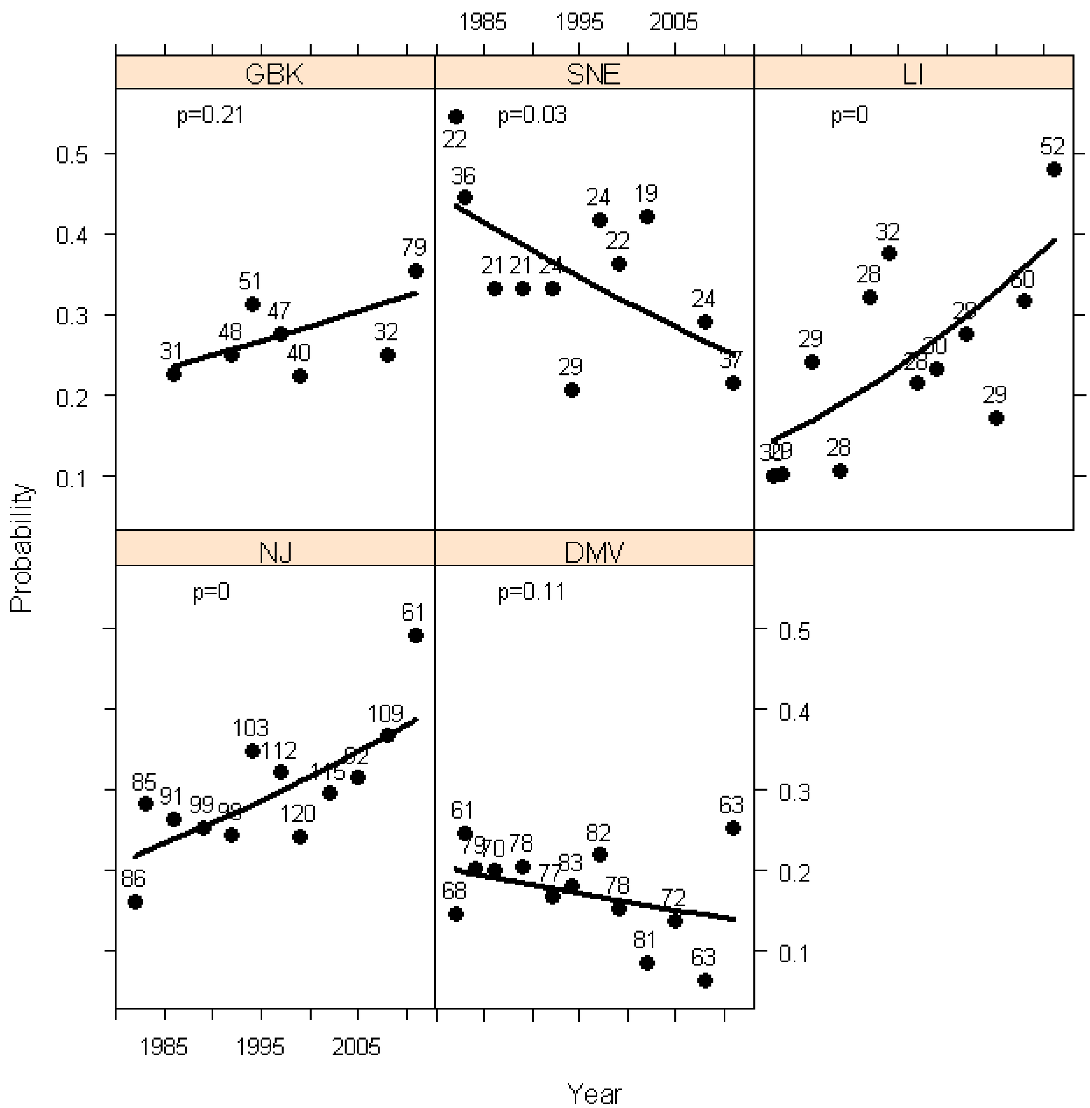


Figure 243: Trends in co-occurrence of Atlantic surfclam and ocean quahogs by region with p-values (top of each panel) and sample sizes in each year.

Appendix 12 Changes in habitat area for Atlantic surfclam in the Mid-Atlantic and GBK regions based on NEFSC clam survey data and presence-absence modeling

Survey data and model results suggest that habitat area declined in the south off DMV area due to losses in shallow water, increased along the central Mid-Atlantic Bight (NJ and LI areas) due to increases in deep water and varied without trend in the north (SNE and GBK areas). These changes were likely due to water temperatures increasing above the preferred range for Spp in nearshore coastal areas off DMV and above the lower bound of the preferred range in deep offshore waters off NJ and LI.

Presence-absence data for Spp in NEFSC clam survey tows are a sensitive indicator of whether clams exist in an area (Appendix 10). If clam habitat is defined as areas where clams are present, then statistical analysis and mapping based on presence-absence data can be used to study changes in habitat size over time. Habitat area estimates from presence-absence data amount to estimates of the total area in which Atlantic surfclam are found with almost no adjustment for differences in density or habitat quality. For example, carrying capacity in terms of abundance might change dramatically without changing the total habitat area based on presence-absence data as long as Atlantic surfclam were found on the same grounds in both cases.

Separate modeling analyses were carried out for each region. Only well sampled years and strata were used in the analysis (Table 47, Figure 244 and Appendix 10). Tows at locations beyond depths where Atlantic surfclam were observed were omitted in each region. The maximum depths used for each region were GBK=75 m, SNE=70 m, LI=60 m, and DMV=55 m.

The proportion of positive tows in each year and area were plotted as a rough check on model based trends (Figure 245). Trends in this simple measure of habitat area are variable or ambiguous for GBK and SNE in the north, increasing for LI Sound and NJ along the middle of the Mid-Atlantic Bight and decreasing off DMV in the south. Three coordinate systems were used to specify the location of survey stations for modeling, including one system that used depth to measure position across shelf. However, only results for latitude and longitude (decimal degrees) are shown because results were similar and because latitude and longitude are easy to visualize.

Seven logistic regression type GAM models (dependent variable 0/1 for presence/absence of Atlantic surfclam, logit link, binomial maximum likelihood) were tested for each region (Table 48). Models with and without year effects were included and there would be evidence of changes in habitat area over time if the best model chosen by AIC included year effects. Preliminary analyses showed that sample sizes were too low to reliably estimate spatial patterns for each year independently. It was therefore necessary to "borrow" data from adjacent surveys by smoothing over years. Thus, all models with year effects included spatial patterns that were the same every year or smoothed over time. Location effects in models were smooth functions with different levels of interaction between latitude and longitude.

Maps and trends in habitat area were made by constructing a "large" grid made up of cells which combined the full range of coordinates across each region (all possible combinations of the cells for each coordinate). Cells for latitude and longitude were about 0.45o on a side. Next, the coordinates of the stations actually sampled (years combined) were gridded in the same way to produce a list of the first and last longitude cell actually sampled along each row of latitude cells. The list was used to omit cells from the large grid outside of the range sampled. The best GAM model was then used to predict the probability of a positive tow across the remaining grid cells. The predictions at each cell were plotted to produce maps (Figures 246-250) .

Trends in total habitat were calculated by summing the predicted probabilities for each year and cell from the best model (Figures 246-250). Habitat area computed in this way is essentially a sum of cell areas weighted by the predicted probability.

The best models for each region and coordinate system included year effects with the exception of DMV where Model 4 (with a two dimensional smooth on latitude and longitude but no year effects) had the lowest AIC indicating insignificant changes in habitat over time (Table 48 and Figure 250). However, Model 5 (with year effects) had nearly the same AIC score (878.1 vs 877.8). We therefore chose to identify Model 4 as the best model and Model 5 as the best model for trends in the DMV region. Spatial patterns in results from the two models with latitude and longitude for DMV were similar.

Trends in habitat area estimates from GAM models (Figures 246-250) were similar to trends in proportion positive tows (Figure 2). Trends for Atlantic surfclam on GBK (where sampling was relatively sporadic) and in SNE were variable. Estimated habitat area increased dramatically in LI after 1986 and steadily in NJ after 1982 based on model estimates. Maps indicate that the increases were due to increasing utilization of offshore areas, probably due to warming (Figures 248-249). The best model for trends in DMV suggests that habitat area declined due to losses in shallow coastal areas (Figure 250).

Table 47: Sample size (number of survey tows) used to measure Atlantic surfclam habitat area.

Region	1982	1983	1984	1986	1989	1992	1994	1999	2002	2005	2008	2011	
GBK				31		48	51	47	40			32	79
SNE	19	34		18	18	21	24	21	19	16		21	30
LI	30	29		29	28	28	32	28	30	29	29	60	52
NJ	86	85		91	99	98	103	112	120	115	92	109	61
DMV	68	61	79	70	78	77	83	82	78	81	72	63	63

Table 48: AIC for models used to predict the probability of a positive tow and estimate habitat area for Atlantic surfclam. Bold font identifies the best model (lowest AIC) for each region. Terms in the formulas for each model (column 2) are "yr" for year as a continuous covariate, "yrf" for year as a categorical factor, "lat" for latitude and "lon" for longitude. The term "s()" is a smooth one- or two dimensional nonlinear spline function of the variables inside the brackets.

ID	Model	GBK	SNE	LI	NJ	DMV
1	s(lon) + s(lat)	625	228	361	760	971
2	s(lon) + s(lat) + yrf	614	223	359	757	974
3	s(lon) + s(lat) + s(yr)	608	221	349	753	966
4	s(lon,lat)	621	210	356	727	877.8
5	s(lon,lat) + yrf	603	201	357	721	878.1
6	s(lon,lat,yr)	625	245	392	910	993
7	s(lon,lat,yr) + yrf	631	124	399	915	1,004

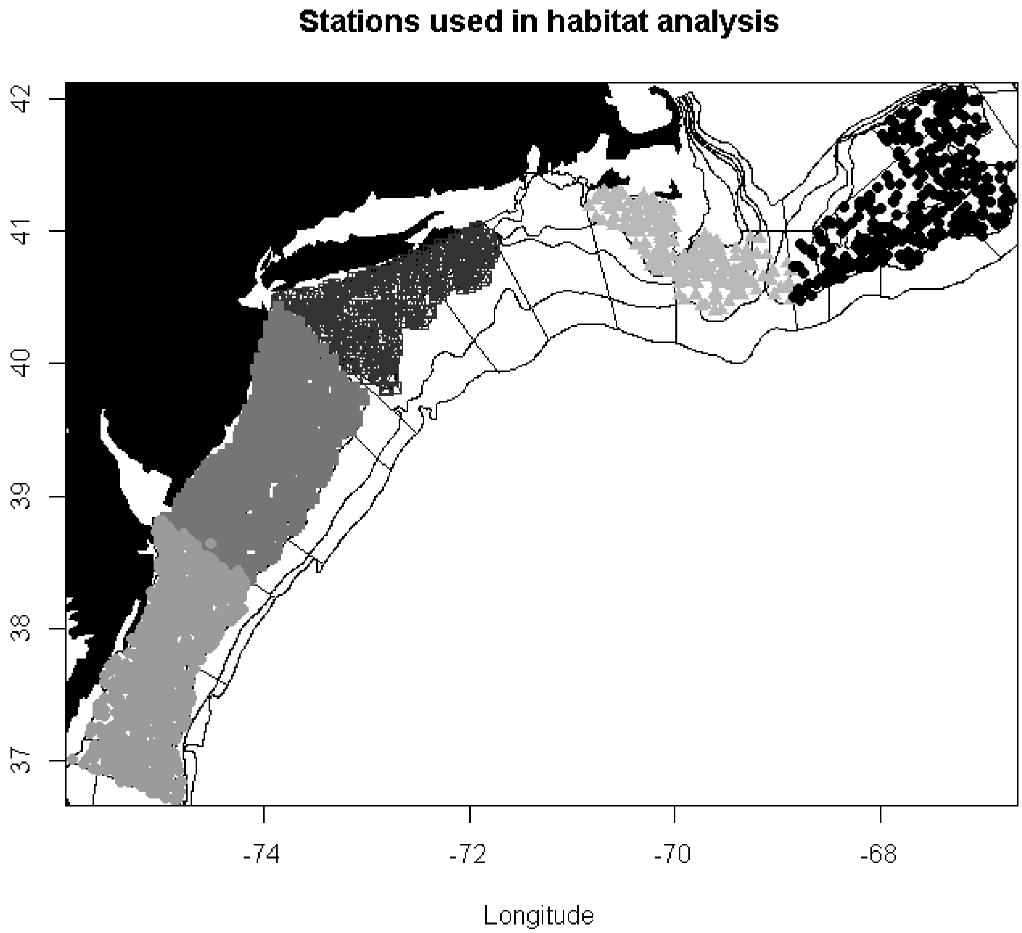


Figure 244: Location of survey stations used to measure Atlantic surfclam habitat area. Regions are identified using shades of grey. The regions from north to south are GBK, SNE, LI, NJ and DMV.

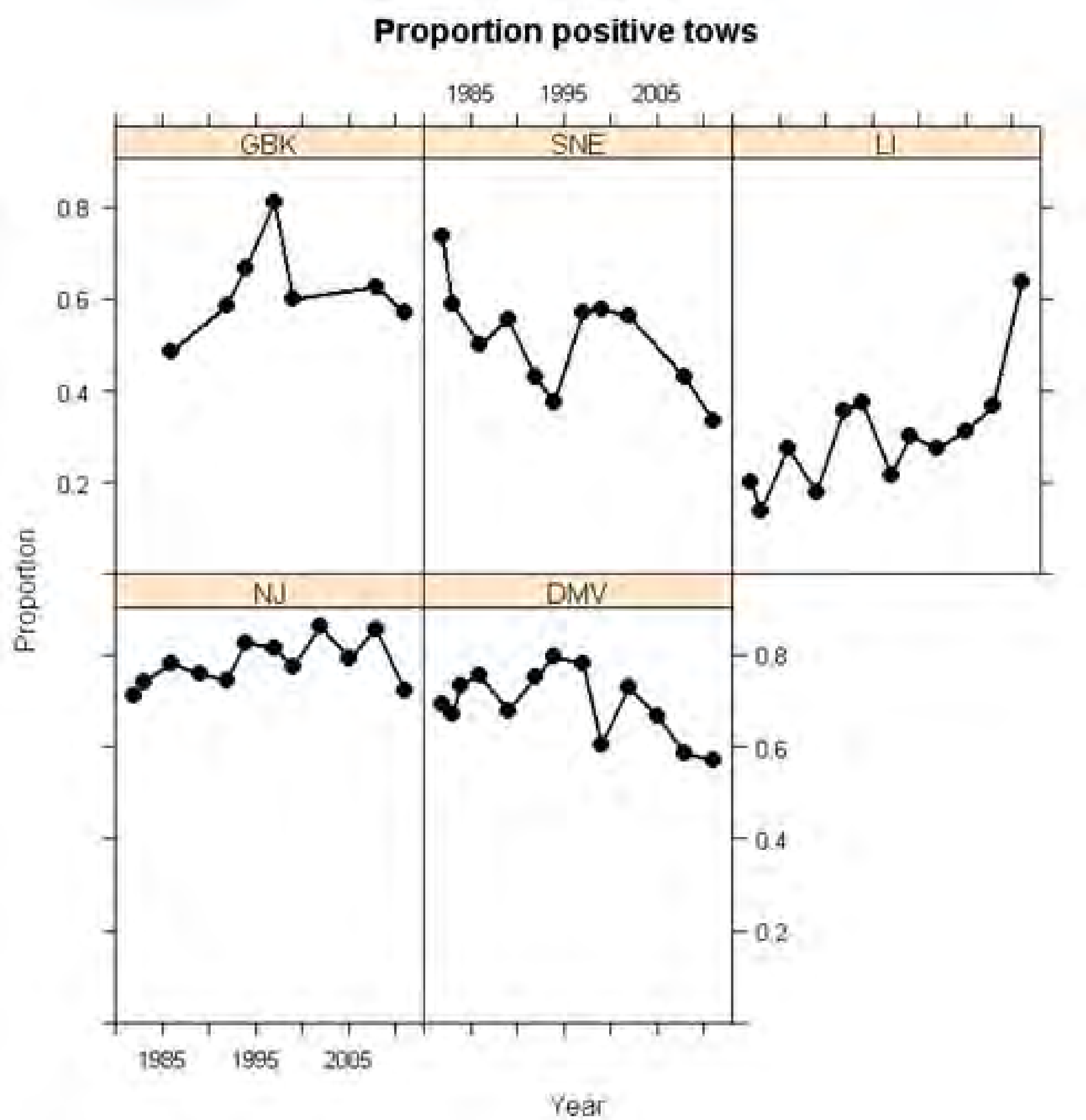


Figure 245: Trends in proportion positive tows based on raw survey data by region.

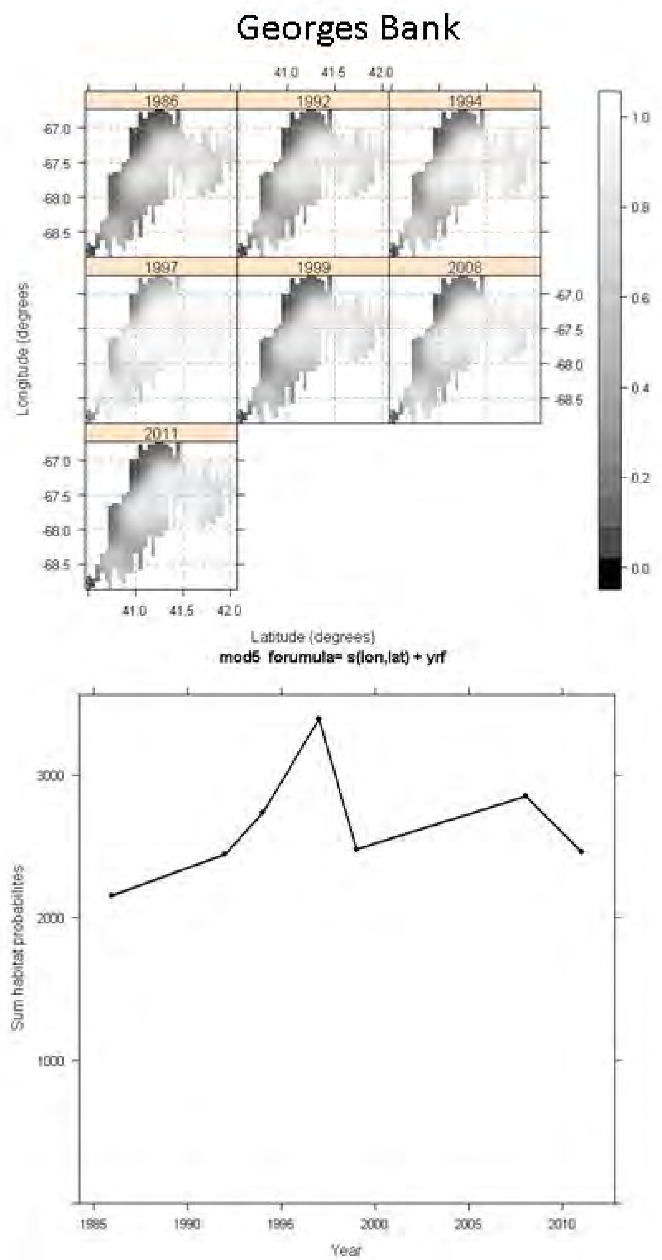


Figure 246: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

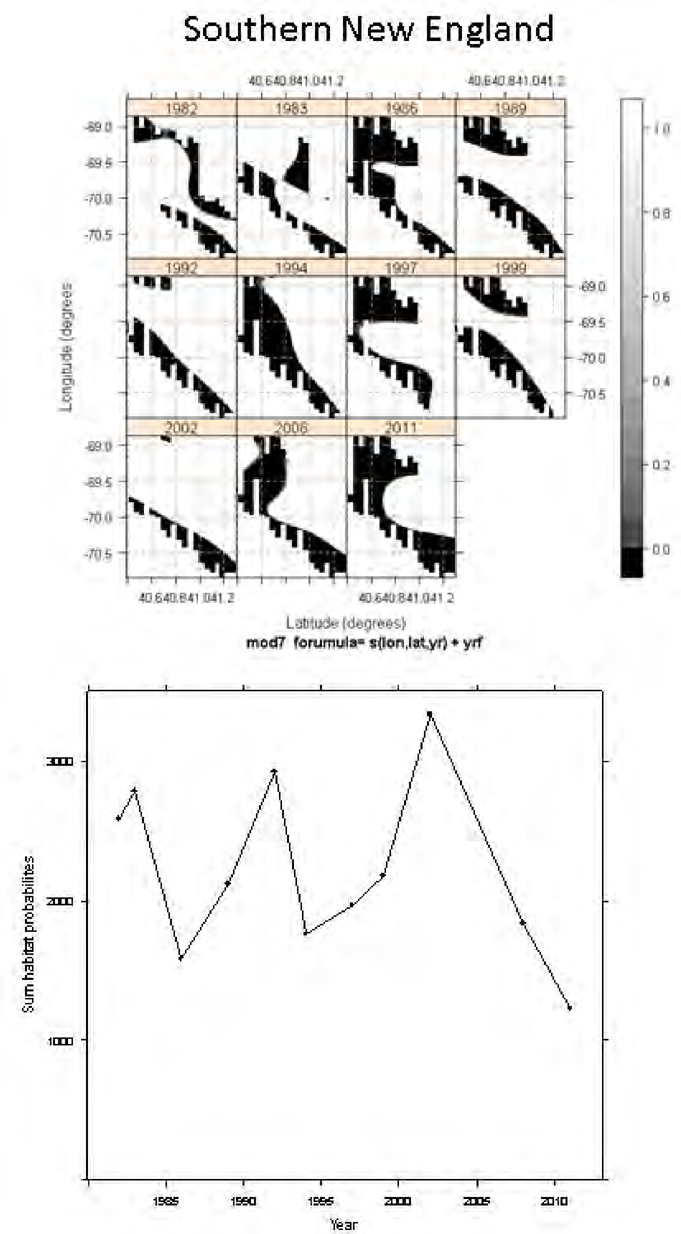


Figure 247: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

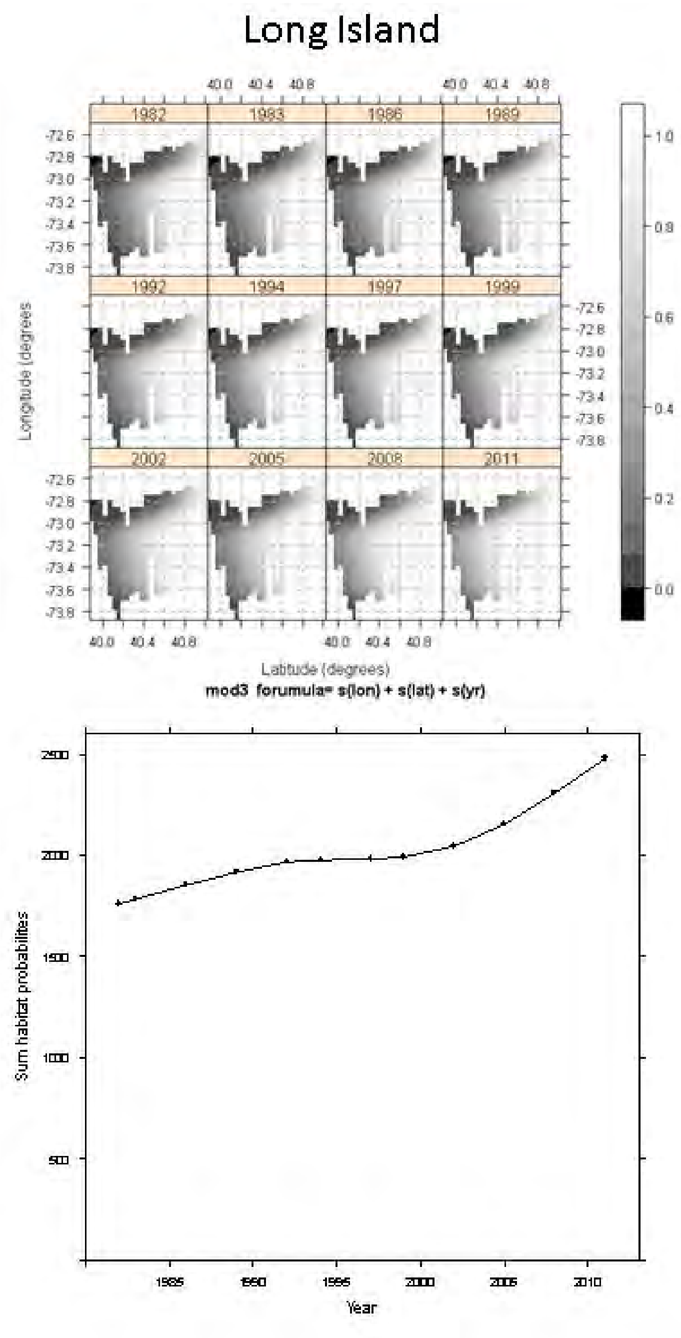


Figure 248: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

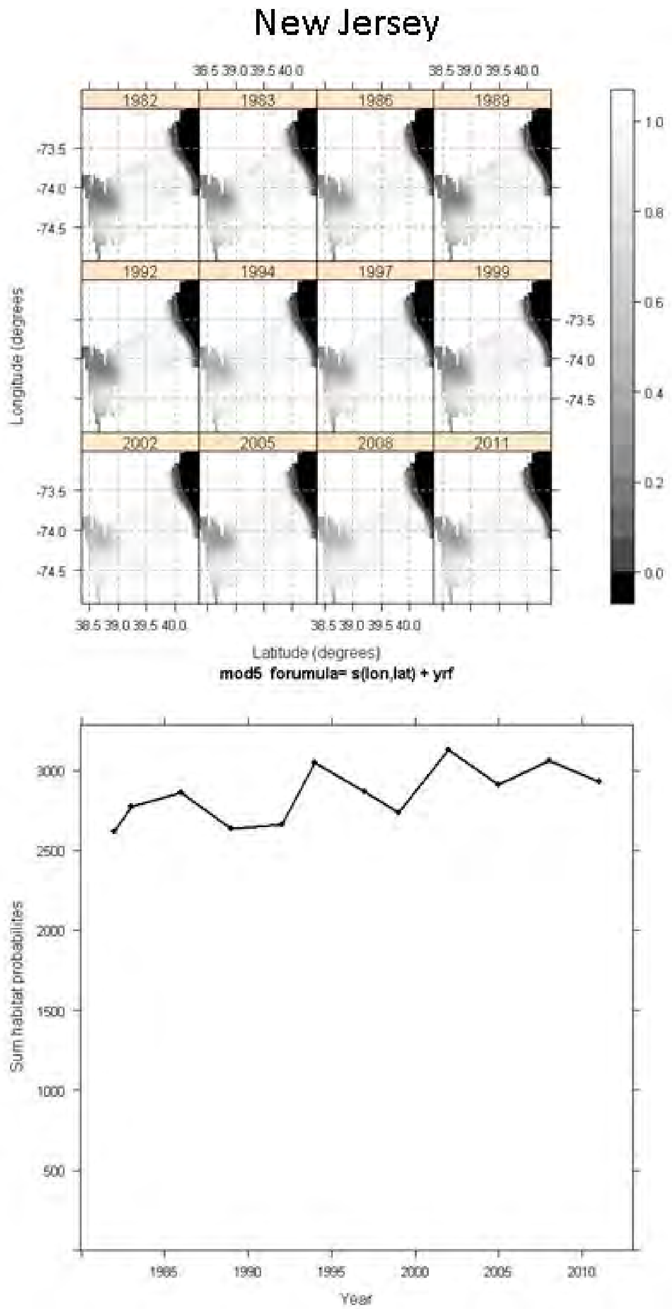


Figure 249: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

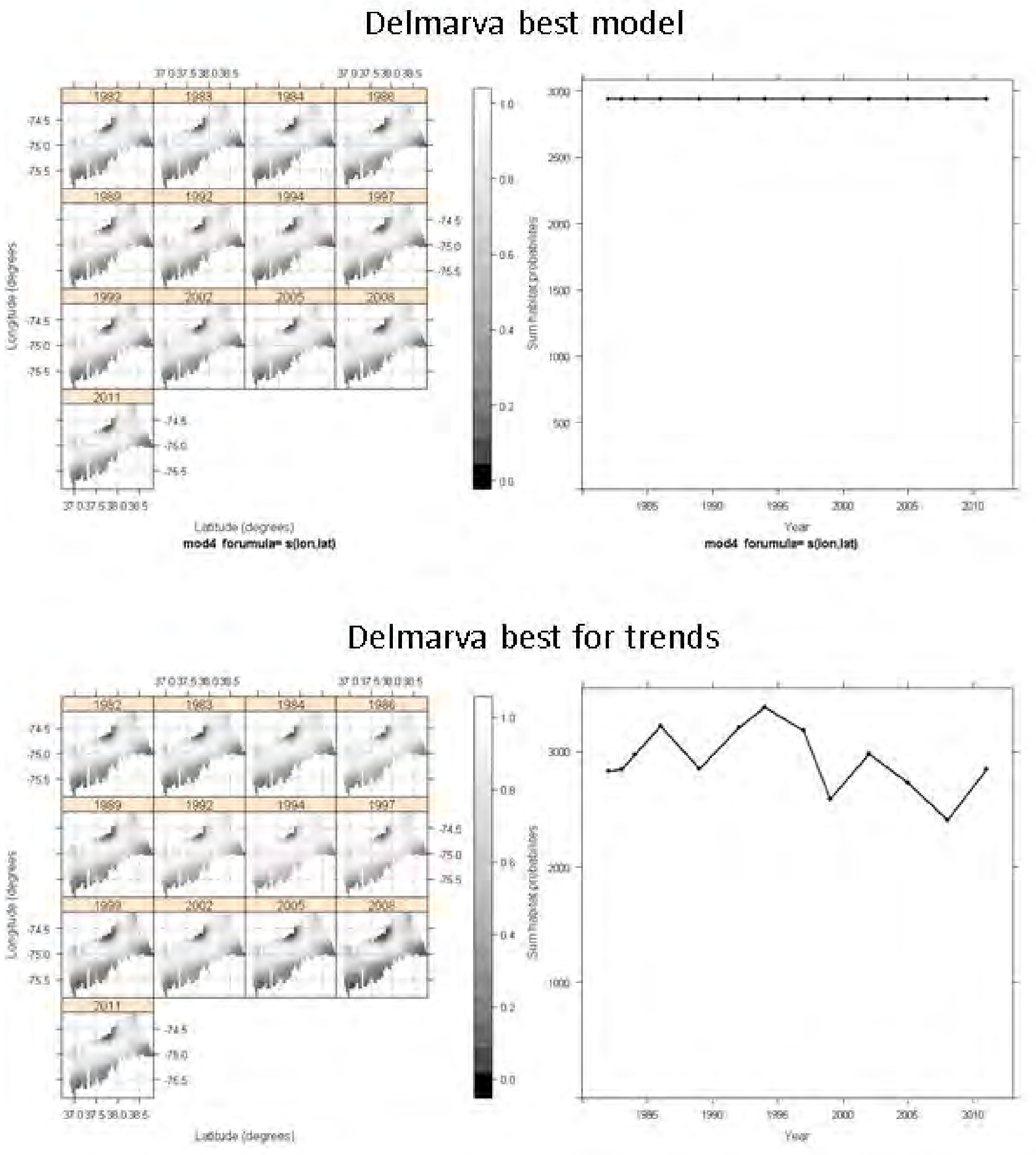


Figure 250: Predicted probability of occurrence for Atlantic surfclam in NEFSC clam survey tows by region from best models with lowest AIC. Top: bet model predictions as maps. Bottom: best model predictions summed to give annual trends that track changes in habitat area. The "Best for trends" model for DMV is different from the best model based on AIC although the two models had nearly identical AIC scores (see text).

Appendix 13 Appendix: Potential methods for locating and quantifying good Atlantic surfclam habitat and untowable ground/poor Atlantic surfclam habitat on Georges Bank

With the planned redesign of the NEFSC clam survey, the working group spent time discussing how to improve the survey in general and especially on Georges Bank. With Atlantic surfclam vessels now regularly fishing on Georges Bank after a hiatus of many years due to closures for health concerns, it is of renewed importance to estimate biomass as accurately as possible and monitor the affects of the fishery.

Unlike the mid-Atlantic, Georges Bank is a patchwork of sand, gravel, cobble and boulder bottom. This presents a challenge as the sandy areas are considered good Atlantic surfclam habitat, but patches of rough, rocky bottom, considered "untowable" and probably marginal habitat, often occur within the same strata. The new survey design will likely include some restratification of these areas into units of similar bottom. Areas composed of sandy substrate are more likely to contain higher densities of Atlantic surfclam, than areas composed of harder substrate. In order to increase the efficiency of the survey and the accuracy and precision of abundance estimates, good habitat should be sampled more frequently. Restratifying by substrate should result in fewer "untowable" survey stations and a more precise and accurate estimate of abundance, as well as a more targeted and perhaps less expensive survey.

An additional aspect of improving the survey on Georges Bank is determining what overall area is inhabited by Atlantic surfclam, and the fraction that is untowable (and probably poor clam habitat) and should be discounted when estimating swept-area biomass. For instance, if the overall Atlantic surfclam habitat area on Georges Bank is found to be 100 nm2 and there are 20 nm2 of untowable rocky bottom within that area, then the swept-area biomass would be extrapolated to 80% of the overall Atlantic surfclam area for a more accurate estimate.

To demarcate the overall area inhabited by Atlantic surfclam it is desirable to identify the limits of the population on Georges Bank, whether physical (temperature, depth, substrate) or ecological (food, predators, competition for habitat). An indicator of the presence of Atlantic surfclam would also serve to define habitat both in and outside the surveyed areas. Simply mapping survey catches is helpful, but the region analyzed needs to encompass areas outside the current Atlantic surfclam strata set as well, in case there is significant Atlantic surfclam habitat that should be added to the surveyed area. An example of this (although not on Georges Bank) is northern Nantucket shoals (see Part H).

Years of experience surveying the bank with a clam dredge has led to general knowledge of where there are boulder fields, and how to read the ship's depthfinder before a tow and know to move on to a new location. This hit or miss method can waste time and potentially damage equipment. However, detailed maps of the bottom have not been available to actually quantify the number of square miles inhospitable to both Atlantic surfclam and dredges. Today, with constantly improving technology and a new emphasis on habitat, the sea floor on Georges Bank is becoming known in more and more detail. It should be possible to bound the zones of bad bottom and calculate their areas for both restratification and biomass estimation.

In anticipation of the survey redesign the assessment working group reviewed several potential methods of evaluating habitat for the presence of Atlantic surfclam and for the delineation of areas of rough bottom, and they are summarized below. Some methods might work best in conjunction with others, and there will likely be suggestions of other techniques. This work is ongoing, and a formal committee experienced with survey design will be formed to make final decisions on any improvements or changes to the NEFSC clam survey.

Analysis of ancillary survey data for the Georges Shoals and Cultivator Shoals area of Georges Bank[6]

The following is a near-final analysis of ancillary survey data for the region of Georges Bank encompassing Cultivator Shoals and Georges Shoals. The analysis was funded by the NSF I/UCRC Science Center for Marine Fisheries (SCeMFiS). SCeMFiS has also funded a full analysis of Georges Bank. This update will be available some time in September.

Data Resources

Atlantic surfclam and ocean quahog survey data from 1982 to 2014 were obtained from the NMFS-NEFSC assessment database. These data included standardized catch of Atlantic surfclam, haul and gear codes, and, for years after 1999, comments for each tow with a non-zero haul and gear code. Additional information was obtained from survey data sheets for Atlantic surfclam and ocean quahog surveys from 1978 to 1999. All of these data sheets were digitized into PDF documents and the data obtained were entered into excel spreadsheets. Additional data from 2002 to 2014 were obtained from NEFSC survey electronic archives.

Analytical approach

Mapping the locations of various variables was carried out at the scale of an *ESS Pursuit* survey tow. This is a distance of approximately 0.29 minutes of latitude or 0.39 minutes of longitude. Survey tows within this distance apart were considered to be replicates even if taken in different years. In general, the most extreme value amongst replicates was taken for further analysis. Most non-living variables can be considered to be stable constituents over much, if not all, of the entirety of the survey time series. For shells, for example, taphonomic loss rates are low for Atlantic surfclam and ocean quahog shells and likely to be low for lesser clam constituents. Stability over time would not be the case for live animals, all but one of which has a life span less than the survey time series. These temporally more ephemeral variables should be interpreted to indicate the potential for occupation of a site. Regardless, no temporal variations have been tracked in this analysis.

[6]Contributed by: Eric Powell, University of Southern Mississippi

Haul and Gear Codes

These codes encompass a range of incidents that might have compromised the tow. Generally, these incidents fell into two broad categories: issues associated with the proper functioning of the dredge itself and issues associated with bottom type that might compromise a successful tow. Our focus was on the latter set of incidences. Unfortunately, the haul and gear codes used by NMFS-NEFSC were developed for the trawl survey; thus, an analysis was required to determine how these codes were applied to clam dredge hauls and the degree of consistency in that application across surveys. This analysis relied on annotations for each of these tows in the survey database for the period 2002-2014. Unfortunately, no annotations occur in the survey database prior to 2002. In order to investigate the consistency and meaning of haul and gear codes, the data for 2002-2014 were sorted by haul and gear code combination and comments were examined. A total of nine combinations of haul and gear codes indicated problems with the tows stemming from bottom obstruction (e.g. damage to the dredge or location dropped from the survey after scouting bottom). These tows were consolidated into one of three categories: 1.) locations where "bad bottom" was identified, such that the dredge was not deployed; 2.) locations where dredge damage occurred, including broken nipples, broken or bent knife blades, torn hoses, or damage to the dredge frame; and 3.) locations where rocks were caught by the dredge in sufficient number to be judged to have compromised the tow, but which did not cause significant/any damage to the dredge.

Tows for surveys from 2002-2014 could be assigned to these three categories without qualification. Unfortunately, with a few exceptions, haul and gear codes were not used predictably over the survey time series and often tows influenced by non-bottom-contact events (e.g., clogged pump, power supply issues) were given haul and gear codes also used for bottom contact events. Thus, earlier tows (1982-1999) with haul and gear codes could rarely be assigned to one of the three categories without qualification. However, for essentially all of these tows, annotations were recorded on the original data sheets. Accordingly, the raw data sheets were examined for tows prior to 2002, for which haul and gear comments were missing. Comments recorded on the raw data sheets permitted extraction of tows falling into the 3 afore-mentioned categories, so that the entire survey time series was assembled. Plots of these data identify the locations where each of the three incident types occurred (Figures 251 and 252).

Bycatch data - substrate

The term "bycatch" was used in a general way on the 1978-1999 data sheets to apply to a series of materials obtained in the dredge including substrate, shell, and a selection of live animals. Some species of live animals were not included in the bycatch category. Bycatch data from 1978 to 1999 was present on each digitized data sheet. Electronic data were available in the FSCS database. Terminology and category were relatively consistent between 1978 and 1982 and essentially identical from 1982 to 2011. Data ceased to be collected at the end of the 2011 survey.

The bycatch data comprise three categories: shell, substrate, and other invertebrates. Information regarding tows where gravel, rocks, cobbles, and boulders were present in the haul was extracted into a common database. The category "cobbles" encompassed anything smaller than six inches and larger than gravel, the size of which, however, was not specified. The category "rocks" encompassed material between six and twelve inches and "boulders" were anything larger than twelve inches.

Over the history of the survey, the annotations regarding substrate varied considerably. From 1978 to 1980 substrate data were recorded in either liters or bushels. The survey dredge used during this time period was considerably smaller than the dredge used from 1982 to 2011. Due to the extreme variability of recorded data from 1978 to 1980, presence and predominance values were assigned to the data. A value of 0 indicates an absence of a particular substrate (e.g., cobbles). A value of 1 was given to volumes =1 bushel or where presence was indicated without a volume given (e.g., "trace" was recorded in the place of a numerical value). A value of 2 was given to any volume > 1 bushel.

From 1982 to 1999 substrate data were recorded on the data sheet in terms of check marks (1 check for present and 2 checks for predominant) and categories include gravel as well as finer-grained substrates such as sand, mud, and clay; however, these substrate types are not further defined. The categories "cobble", "rock", and "boulder" were defined by the same sizes as used on the 1978-1980 data sheets. The survey dredge for this time period was larger than the dredge used from 1978 to 1980. Volume of bycatch was routinely recorded, as was the percent composition of the various components. In order to provide more quantitative and consistent values for substrate, the total volume of substrate in bushels was calculated for each tow for the period 1982 to 1999 from the percent of total volume. The total substrate volume was then divided equally by the sum of presence and predominance values (i.e. number of checks) in order to estimate a number of bushels of gravel, cobble, rocks, and boulders. For instances where the percent composition for substrate or total bycatch volume was not recorded, the data were entered as presence and predominance values (i.e. number of checks seen on datasheet) because a total substrate volume could not be calculated. These instances were relatively rare, however. In most cases, a volumetric estimate could be made. The data were then coded as 0 for absence or < 1 bushel, 1 where the volume of a particular category was < 30 bushels, and 2 where the volume was =30 bushels. For 2002-2011, the data were entered into FSCS as 0, 1, or 2. Substrate volumes were given in bushels (2002) or liters (post-2002) and percent composition was recorded in each case. An assumption was made initially that the criteria for presence and predominance were consistent across the transition from data sheets to FSCS files. However, subsequent statistical analysis showed that the substrate volumes recorded in the FSCS database were consistently lower per tow than those values on the pre-2002 data sheets, by a factor of 10. Further investigation, including interviews with people who participated in the survey across the 1999-2002 transition, did not elucidate an explanation for the differential, but evaluation across a series of surveys showed that the differential coincided with the transition from data sheet to FSCS files and that the differential was relatively consistent forwards and backwards in time from that point. To standardize the data, the FSCS substrate volumes were increased by a factor of 10.

The divisions at 0 and 1 bushel and 29 and 30 bushels used to distinguish absent, present, and predominant were obtained by examining the FSCS data from 2002-2011 where the tows for the entire survey could be analyzed as they were already in electronic format . The median and 75th percentile for all tows was 0 (no substrate larger than gravel collected) for these tows. That is, cobbles, rocks, and boulders were rarely encountered by the survey. The value of 30 fell between the 95th and 99th percentiles of all tows for these substrate types. The value 1 fell at or above the 90th percentile of all tows for these substrate types. Thus, we include as present all tows where at least one bushel of material was obtained and list as predominant the rare tows where 30 or more bushels were obtained. (See Figures 253 and 254).

Bycatch data - shell and miscellaneous invertebrates

For shell and other invertebrates, abundance data were entered as presence and predominance values. This information was also recorded by check marks on the pre-2002 data sheets. Abundance of shell was recorded in either liters or bushels from 1978 to 1980. Presence and predominance values were then assigned where 0 indicated absence, 1 indicated presence of =50% of the total shell volume, and 2 indicated presence of > 50% of the total shell volume. From 1982 to 1999, each of the shell types of concern were listed separately and given presence and predominance values seen as checks on the datasheets. For 2002-2011, the data were entered into FSCS as 0, 1, or 2. An assumption was made that the criteria for presence and predominance were consistent across the transition from data sheets to FSCS files. Interviews of survey personnel were confirmatory.

Generally, shell volume as a percentage of total bycatch was recorded for each tow. The afore-described analysis for substrate could be recapitulated for shell. However, our approach was to focus on the relative importance of shell types at each location rather than comparing the absolute quantity across all tows; thus, we relied on the number of check marks to assign values of 0, 1, and 2 for absent, present, and predominant within-tow. Shells of a series of miscellaneous clams were tracked (e.g. Astarte, Pitar). For presentation, we took the maximum value amongst these species (0, 1, 2) and assigned that to the "Clam shell" category.

The four species selected from the "Other Invertebrates" category are epibionts that indicate presence of substrate that is of a size that might be colonized (i.e. anything gravel sized or larger). These four were sponges, tunicates, anemones, and barnacles. Specific species are not identified on the data sheets. As with the shells, a volumetric conversion is present for most tows; however, our focus once again was on real presence and a within-tow evaluation of predominance. Thus, values are assigned based on check marks as 1 for present and 2 for predominant within-tow. A value for total bionts was calculated as the sum of the four values. See Figures 255, 256, 257, 258.

Species data - live animals

The numbers per tow for a suite of clams, asteroids, crabs, and gastropods were also recorded by survey species code. For 1978 to 1999, data were recorded and entered into a common database as the number of individuals. For 2002 to 2011, data regarding the number of individuals were obtained from the NMFS-NEFSC survey database. The number of individuals of asteroid species, spider crabs and hermit crabs, and gastropods were placed in three bins and data were entered as the sum of individuals from each of the three categories. Placopecten and Modiolus were retained as separate species. Total numbers per category were converted into a qualitative scale of 0, 1, 2, and 3 using 0 for absent, 1-2 for 1 (present), 3-10 for 2 (some), and > 10 for 3 (many).

Interpretation Relative to Re-stratification

Re-stratification of Georges Bank focuses on the need to limit the survey abundance estimates to areas inhabited by Atlantic surfclam and to limit the incidence of dredge damage on the bottom. The following are likely to be of most importance in assigning specific locations to a Atlantic surfclam and non-Atlantic surfclam stratum, wherein we use the term "non-Atlantic surfclam" to indicate areas where Atlantic surfclam are likely to be uncommon or where the catch of Atlantic surfclam with routine efficiency by the dredge is compromised.

1. The haul and gear code analysis has generated a comprehensive and consistent database establishing four bottom types.
a. No haul and gear code indicates a substrate potentially habitable by Atlantic surfclam (or ocean quahogs).
b. Untowable bottom or locations where gear damage occurred indicate regions of potentially complex habitat that very likely either do not harbor Atlantic surfclam or for which abundances are low due to the presence of substrate types that preclude Atlantic surfclam (e.g., boulders). In addition, continuing to sample these location risks dredge damage. However, these locations are spotty, that is, patches of sand clearly containing Atlantic surfclam exist within e.g., boulder fields.
c. The retention of many rocks in the dredge is a common occurrence and may permit allocation of the site to a non-Atlantic surfclam stratum.

2. Of the live animals recorded, the one that may provide additional guidance is the horse mussel Modiolus. It is unlikely that horse mussels are found in areas harboring large numbers of Atlantic surfclam. Thus, the large catches of horse mussels might provide additional assignment of sites to a non-Atlantic surfclam stratum.

3. The absence of abundant Atlantic surfclam shells may also indicate locations assignable to a non-Atlantic surfclam stratum.

4. Perusal of the plots of these variables shows that low abundance of Atlantic surfclam, presence of tows with haul and gear codes, presence of tows with high catches of rocks and boulders, and locations where horse mussel catches were high are not randomly distributed. Rather, there is a strong tendency for all of these tow types to group together, and this grouping might provide the basis for re-stratification.

One suggestion is that the survey database might be used to compare Atlantic surfclam catches in tows with few Atlantic surfclam shells, high catches of rocks or boulders, high mussel catches, and non-zero haul and gear codes to tows without any of these four conditions to see if Atlantic surfclam are differentially abundant in these two tow types. A consideration is that dredge efficiency is also likely to differ between these two groups of tows, but, of course, this would be true regardless of how the "non-Atlantic surfclam" locations are incorporated into strata. If a similar analysis for the entirety of Georges Bank continues to demonstrate some coherency in the location of indicators of habitat conducive to and disfavoring the presence of abundant Atlantic surfclam, then strata might be defined thusly and a biased allocation of tows to the Atlantic surfclam stratum might be considered.

For the Georges Shoals/Cultivator Shoals plots provided, the domain which encompasses the area as shown contains 206 survey tow cells (defined by the length of an F/V Pursuit tow) of which 71 recovered some combination of predominant catches of horse mussels, cobbles, rocks, or boulders, or for which gear damage occurred. Reducing the cell size to the length of an R/V Delaware II tow modestly increases both counts (210 and 74, respectively) as a few "replicates" occur in the database. Replicates are tows taken at the same or nearly the same location as defined by the cell size. Accordingly, 34.5% of the tows occurred in potentially complex habitat.

Using split-beam multi-frequency acoustic data to calculate hardness, roughness and slope of the bottom to help determine the extent of untowable areas on Georges Bank

This is data which could be used in conjunction with optical information to map the size and shape of boulder fields and allow them to be measured more precisely.

Michael Martin, NEFSC: Split-beam multi-frequency data from NOAA ships is used to estimate the hardness, roughness and slope of the seafloor in the Gulf of Maine and Georges Bank using interferometric techniques. Split-beam tranducers allow the user to infer the direction from which the sound reflected from the seafloor is returning. This information, when used with the estimated range, allows the slope of the seafloor over the ensonified area to be estimated. As the slope increases, less reflected sound energy is returned from the seafloor. The properties of the reflected sound returned from the bottom also allow inference about the hardness and roughness of the bottom as different seafloor sediments exhibit differential properties when interacting with sound waves at different frequencies (see Figures 259 and 260 for examples of the plotted data). Depth of the water will affect the interaction as more area is ensonified, so the same level of response does not necessarily mean the same kind of bottom. Up to 5 frequencies (18, 38, 70, 120, 200 Khz) are available aboard the latest class of NOAA ships. The data examined were collected on the FRVs Bigelow, Delaware II, and Pisces between 2007 and 2015.

It is hoped that these estimates can be used to help with stratification issues in both the Georges Bank clam survey and the Gulf of Maine longline survey. This data set is attractive for this purpose because of its geographical extent, which covers all the areas of interest. Approximately 4 million records were generated over these areas. Acoustic noise or interference was a prominent feature of much of the data and prevented estimation in approximately 25% of cases.

The next step is to perform quality assurance checks, and attempt to ground truth this information using other data sources. Here some of the optical or bad tow data we have could help to verify the acoustic data (it is not always possible to determine the bottom type from acoustic data only) while the acoustic data could help determine the size of particular patches of boulders and rough ground since a similar signal at similar depth usually indicates the same bottom type.

Using HabCam to provide optical information on the extent of untowable ground

The HabCam (Habitat Characterization Camera System) is an underwater system that (among other things) takes high-resolution photographs of the ocean floor as it is towed behind a survey ship. The vehicle flies close to the bottom and photographs an area approximately a meter wide at a rate that allows the individual photographs to overlap and create an unbroken photographic record of what the ship has passed over. The images yield a wealth of fish, invertebrate and substrate data. The images are currently processed by people but the goal is to have an automated system be able to pick out features such as scallops independently. The HabCam has been deployed as part of the NEFSC scallop survey on Georges Bank for several years (Figure 261).

As can be seen in Figure 261, there are HabCam data from Atlantic surfclam habitat on Georges Bank which could provide information on the size and shape of the untowable areas within the overall Atlantic surfclam habitat. Some of the images have already been processed and substrate information has been recorded. If one image is found that contains rough bottom, then surrounding images can be viewed to measure the width of the feature in the direction of travel of the HabCam.

Using HabCam data to create a Habitat Suitability model

Expecting content from: Scott Gallagher, WHOI

HabCam data can also be used to model the extent of Atlantic surfclam habitat based on substrate characteristics and other variables measured by the HabCam such as depth and temperature. Known as a Habitat Suitability Model, it uses the presence or absence of the target organism under certain conditions to predict the extent of the population. The model has been used for other species and has potential to help define suitable habitat for Atlantic surfclam on Georges Bank.

Using surficial sediment data from Harris and Stokesbury (2010) to locate untowable ground

Using underwater video camera data collected during numerous different surveys over 11 years, Harris and Stokesbury created composite substrate maps of all of Georges Bank, which they published in 2010 (see reference below for details of methods). The maps use sediment size and dominance characteristics determined from video footage taken by a camera facing down from the peak of a pyramid-shaped frame. The frame rests on the bottom as the video records movement of fish and invertebrates as well as sediment type. Maximum sediment size, dominant sediment type, average coarseness (mean size of types present) and sediment heterogeneity data were collected at each station. Data from each station were interpolated onto a 1 km grid and Figure 262 shows a resulting map of maximum size sediment (GIS files to make this map can be found with the electronic version of the Harris and Stokesbury paper).

The positive Atlantic surfclam tows overlaid on the sediment map show the need to enlarge the figure and look to see if there is a relationship between predicted sediment size and Atlantic surfclam catch or if the map is too low resolution to catch the untowable areas, which is helpful in itself for determining scale (Figure 263). However, if the areas with large boulders that are not available to the survey are located, and together with another source of optical data, a more precise extent of the boulder areas may be calculated, and the resulting areas discounted, from the Atlantic surfclam survey total swept area.

Harris, B. P. and Stokesbury, K. D. E. 2010. The spatial structure of local surficial sediment characteristics on Georges Bank, USA. Continental Shelf Research 30:1840-1853.

Using presence of dead shell to delineate habitat

We used NEFSC scallop survey data from 2010 through 2015 to map areas where dead shell has collected to see if that would be a marker for the presence of the live Atlantic surfclam or ocean quahogs. The scallop dredge often retains shell substrate, and the type and estimated amount of dead shell is recorded in the station log. It is not an exact measure: the total volume of “trash” (non-living matter brought up in the tow) is recorded, then an estimated percent of the volume comprising shell is made, and finally which species of shell were present and which species was dominant are noted. We found stations where Atlantic surfclam, ocean quahog or scallop (scallop just for comparison of distribution) shell was present, then estimated a rough volume by multiplying the total amount of trash by the proportion that was shell, then assuming the species marked “dominant” was 50% of the shell volume and any other species present were 25%. We mapped where shells of the three species were found over where the live animals were found, and the results can be seen in Figures 264 - 266. The maps of the three species of dead shell looked very similar and did not appear to designate where the species were, but instead where shell was concentrated by oceanographic processes. However, the estimation of shell volume by species was not very accurate and it may be worth another look at the trash data in more detail.

Using oceanographic data to delineate the extent of Atlantic surfclam habitat on Georges Bank

Temperature and salinity data from the NEFSC oceanography database were plotted with positive tows for Atlantic surfclam and ocean quahogs. The database contains all the CTD results from NOAA ships and NOAA cruises over many years. All the bottom temperature and bottom salinity data points (elevation less than 10 m) from 2011-2015 available for the month of April (representing the usual thermal minimum) and the months of September and October combined (representing the usual thermal maximum) were plotted on separate maps. Much of Georges Bank is known as a well-mixed, dynamic system, but there were gradients evident between different parts. Salinity was lower and temperature was higher on top of the Bank (in the shallower areas) at both times of year (Figures 267 - 270). Temperature and salinity were plotted using two colors to show the pattern.

With some additional data from other times of year and analysis of more specific temperature ranges, we may be able to plot isotherms that bound the Atlantic surfclam area on the bank and provide support for a designated Atlantic surfclam habitat area. Temperature is well known to limit populations, and with evidence Atlantic surfclam are moving into deeper waters in the MAB we understand it plays a role in the distribution of Atlantic surfclam and ocean quahogs. For instance, it looks like ocean quahogs on Georges Bank are limited by temperature maxima exceeding $\sim 16^o$ C (Figure 270), which is not new information, but supports the existence of the pattern on Georges Bank.

Increasing the footprint of the NEFSC clam survey to cover more of Nantucket shoals

Nantucket Shoals is an area not completely covered by the NEFSC clam survey that is densely populated with Atlantic surfclam, and supports a productive local Atlantic surfclam fishery (Figure 271). As part of the survey redesign, it has been suggested that there be an additional stratum added here to fill in the gap in the survey. How this will be accomplished and folded into the survey time series is yet to be determined, but areas where Atlantic surfclam fishing occur are not always stable over time and there should be a mechanism in place, or at least a process, to add new ground to the survey.

Figures

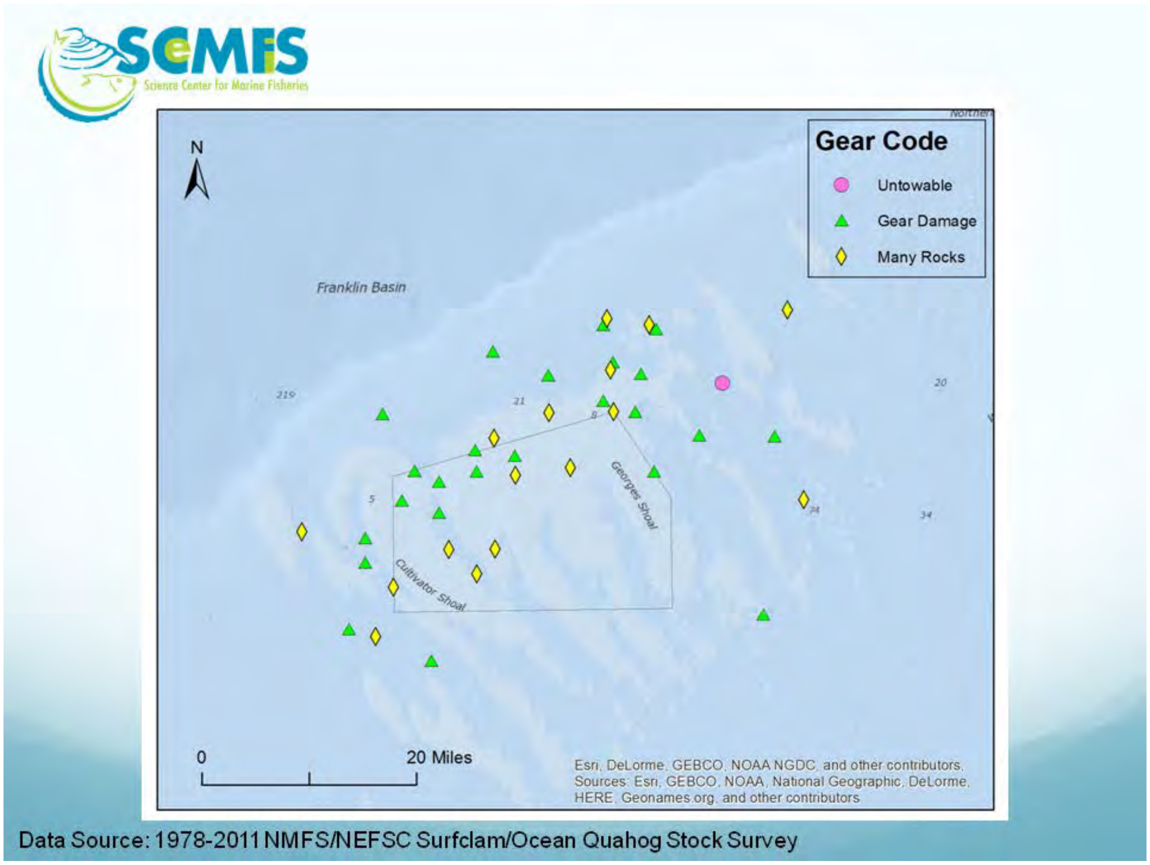


Figure 251: Locations on Georges Shoal and Cultivator Shoal (on Georges Bank) where gear codes or station comments from the NEFSC clam survey indicated untowble or rough ground.

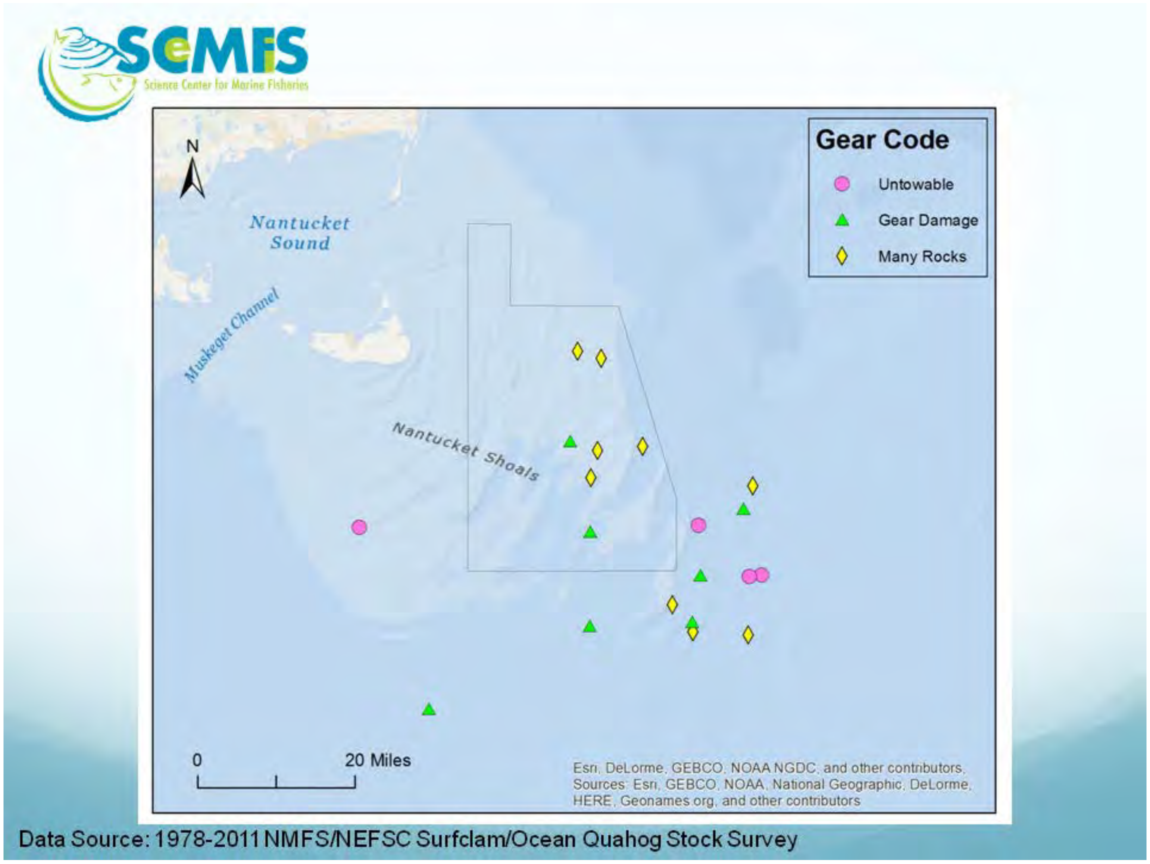


Figure 252: Locations on Nantucket Shoals where gear codes or station comments from the NEFSC clam survey indicated untowble or rough ground.

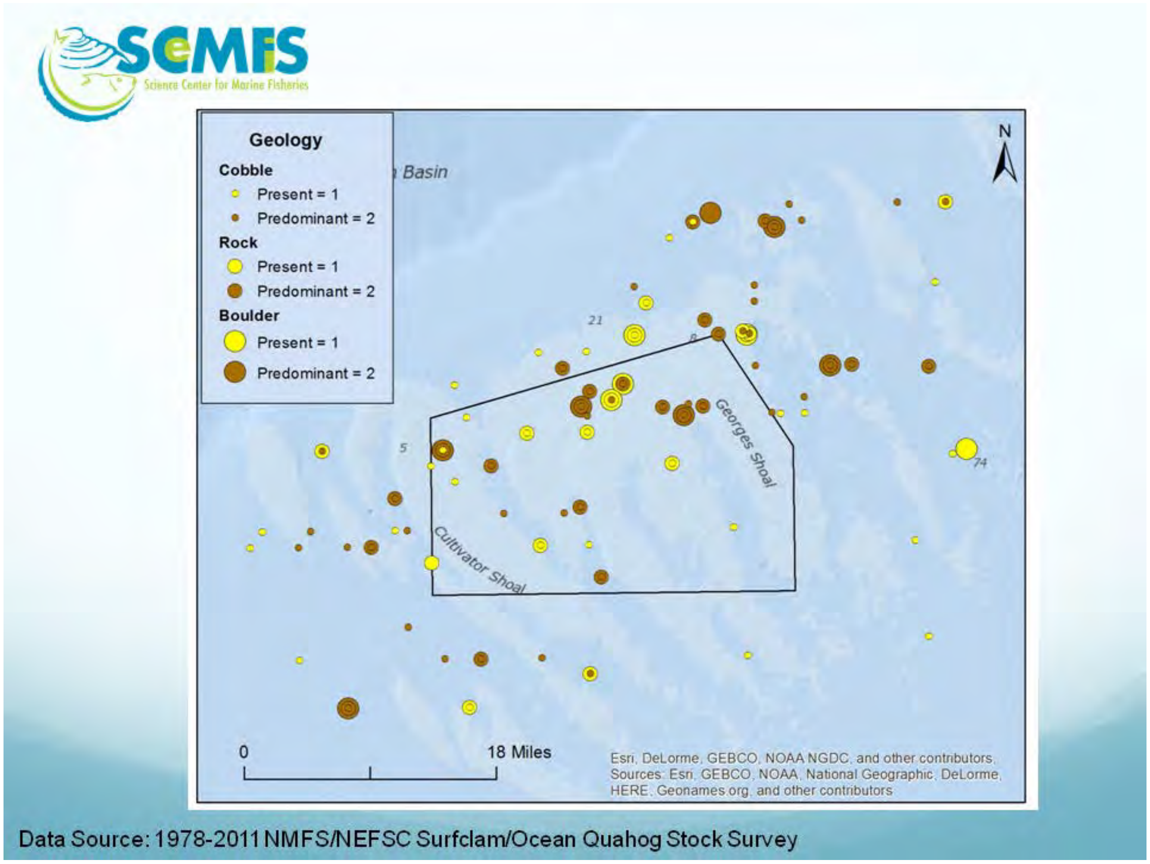


Figure 253: Locations where substrate bycatch data from the NEFSC clam survey included cobbles, rocks and boulders on Georges Shoal and Cultivator Shoal on Georges Bank.

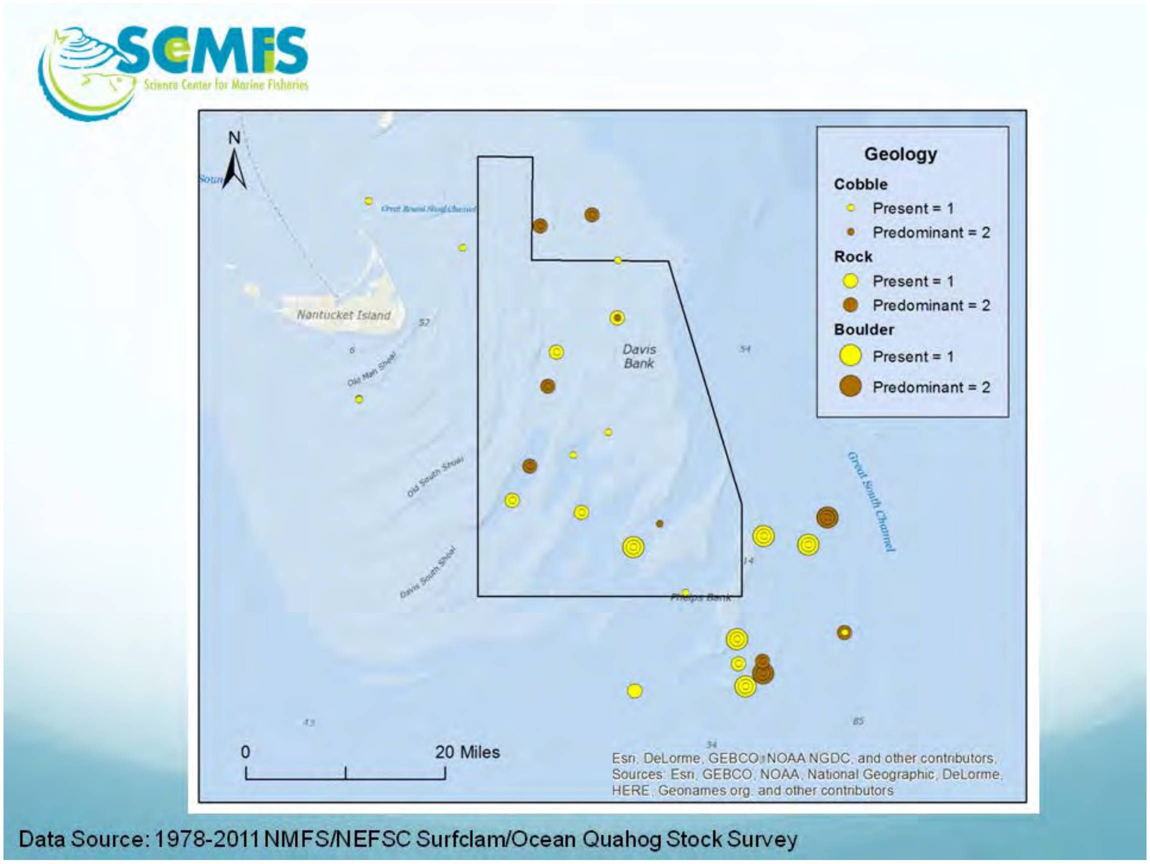


Figure 254: Locations where substrate bycatch data from the NEFSC clam survey included cobbles, rocks and boulders on Nantucket Shoals.

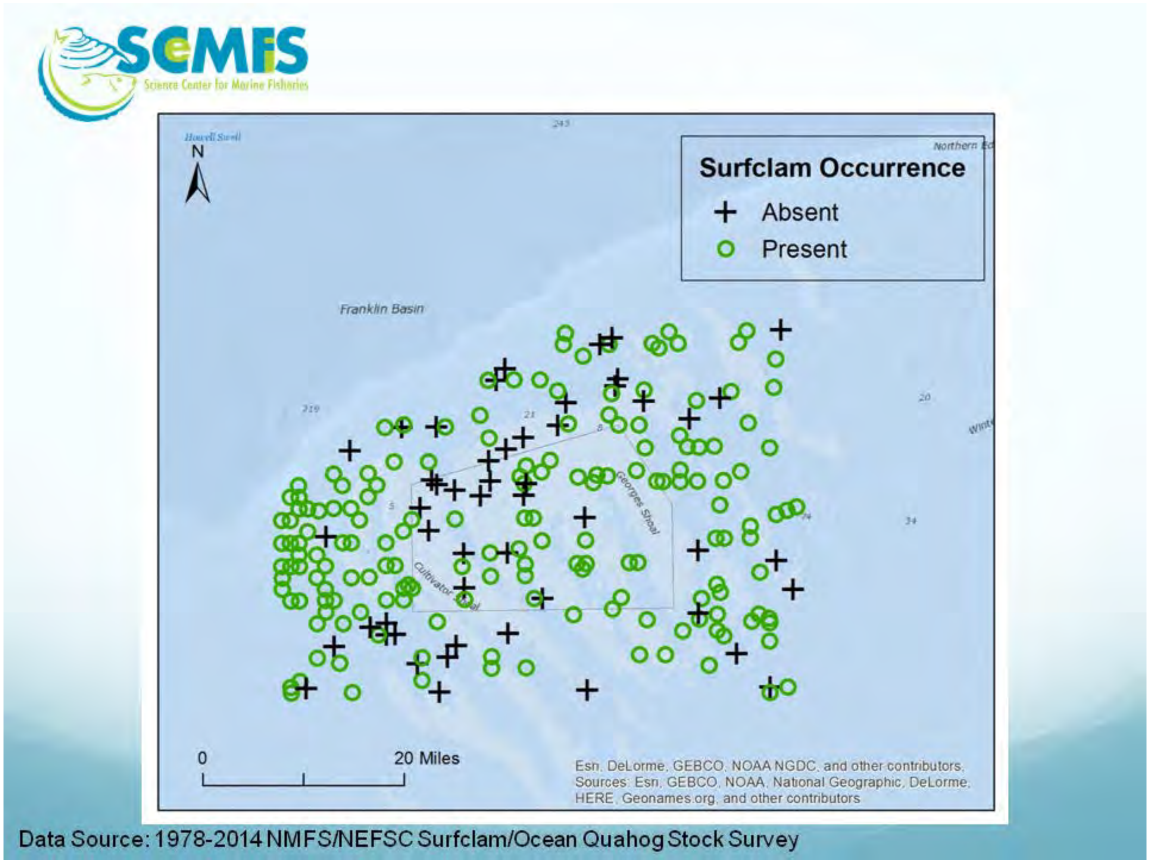


Figure 255: Locations where NEFSC clam survey tow results indicated the presence or absence of live Atlantic surfclam on Georges Shoal and Cultivator Shoal on Georges Bank.

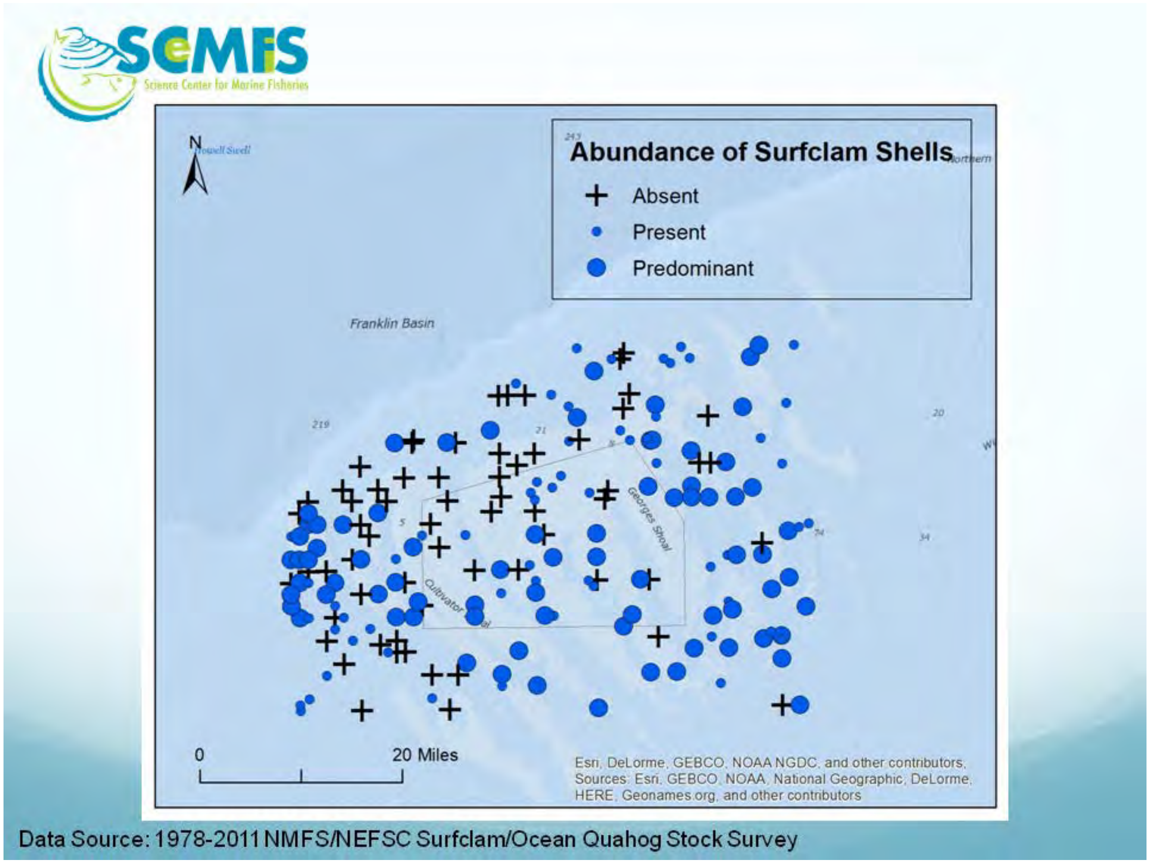


Figure 256: Locations where NEFSC clam survey bycatch data indicated the presence, dominance or absence of Atlantic surfclam dead shell on Georges Shoal and Cultivator Shoal on Georges Bank.

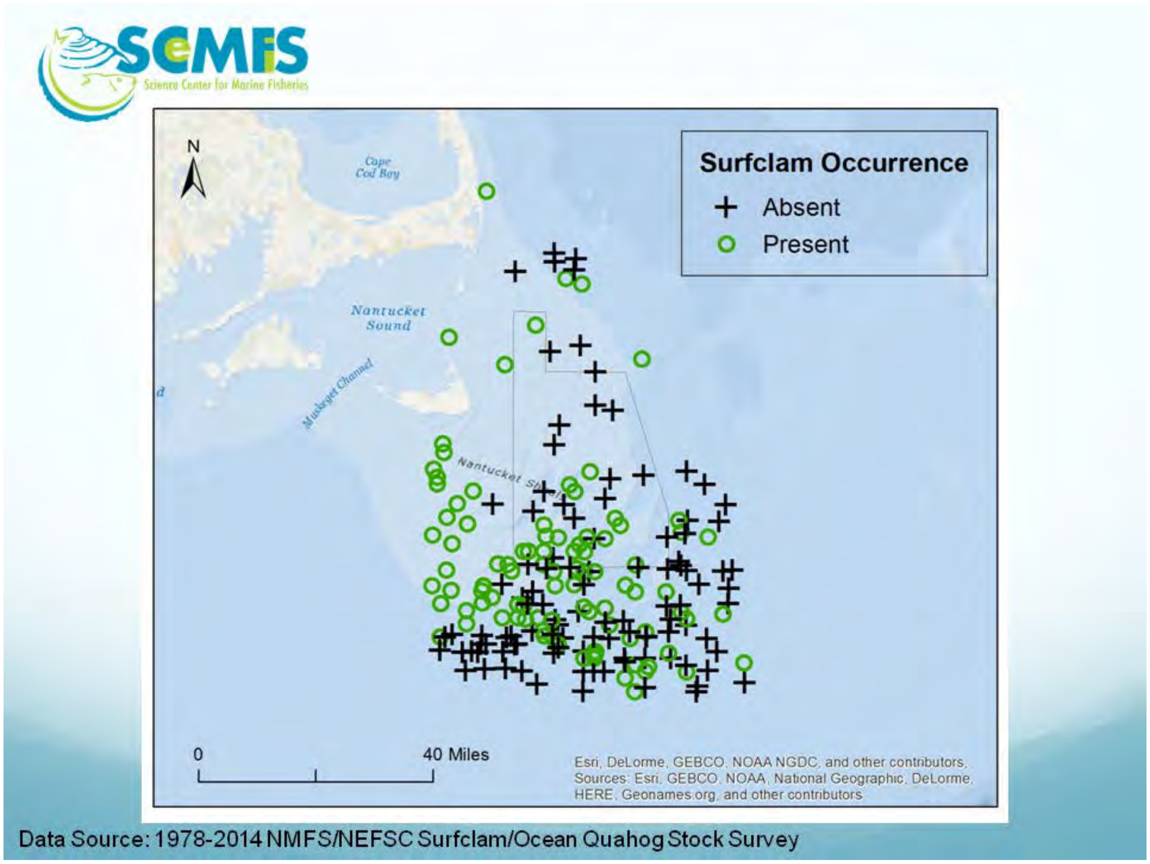


Figure 257: Locations where NEFSC clam survey tow results indicated the presence or absence of live Atlantic surfclam on Nantucket Shoals.

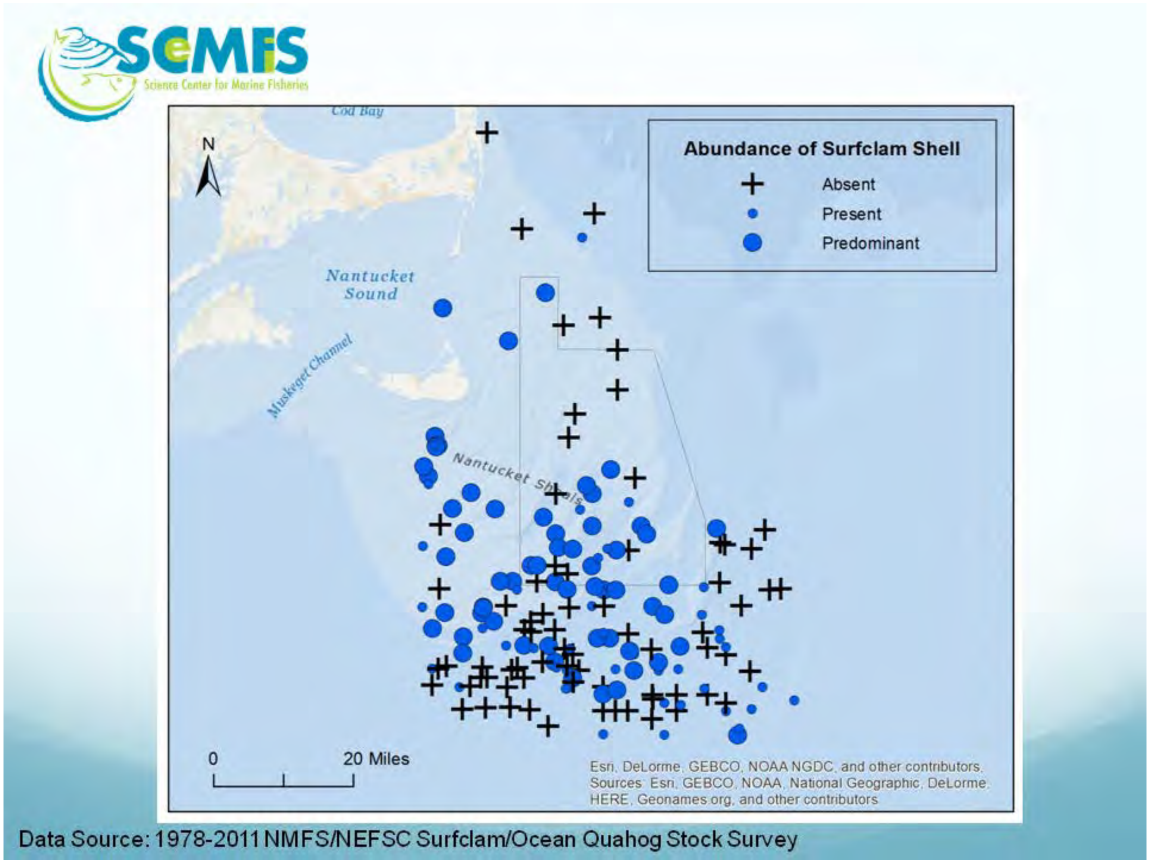


Figure 258: Locations where NEFSC clam survey bycatch data indicated the presence, dominance or absence of Atlantic surfclam dead shell on Nantucket Shoals.

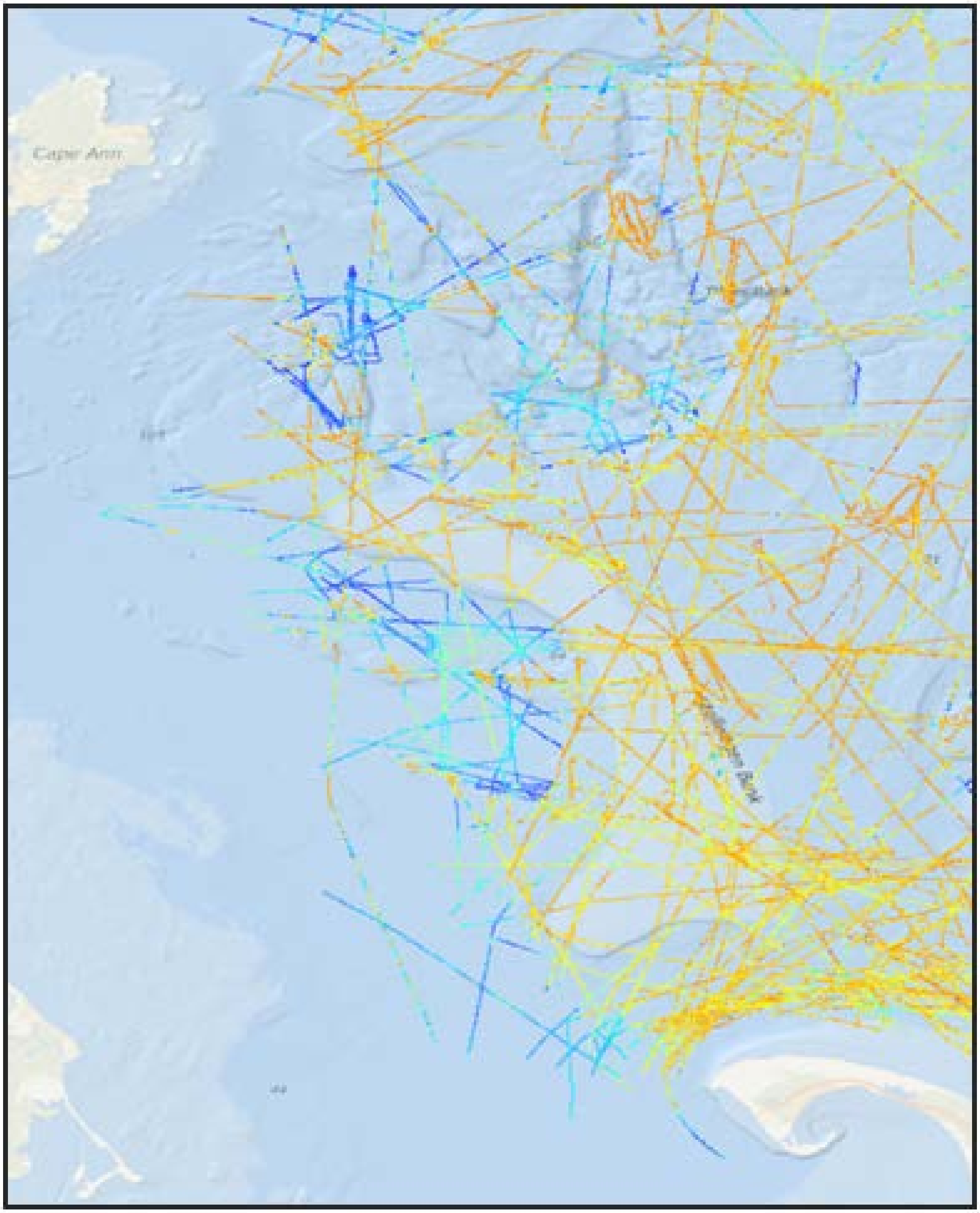


Figure 259: Hardness in the western Gulf of Maine estimated from mutlifrequency acoustic data collected along the tracks of NOAA ships. The data are displayed on a blue to red scale where redder colors are harder and bluer colors are less hard.

Figure 260: Hardness on Cultivator shoals, Georges Bank as estimated from mutlifrequency acoustic data collected along the tracks of NOAA ships. The data are displayed on a blue to red scale where redder colors are harder and bluer colors are less hard.

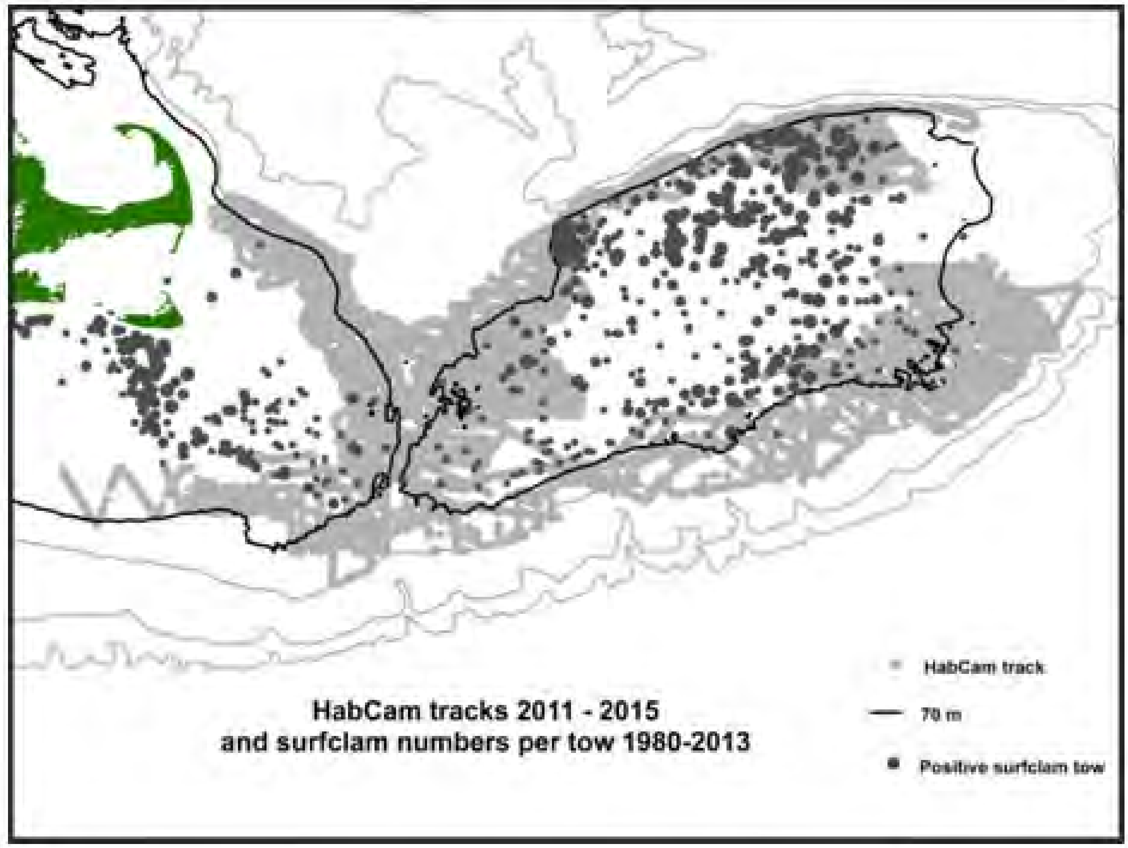


Figure 261: Tracklines of the HabCam towed by the NEFSC scallop survey vessel (gray shading) with the NEFSC clam survey Atlantic surfclam catches overlaid (black dots) and the 70 m isobath. In reality the tracklines are only about 1 meter wide.

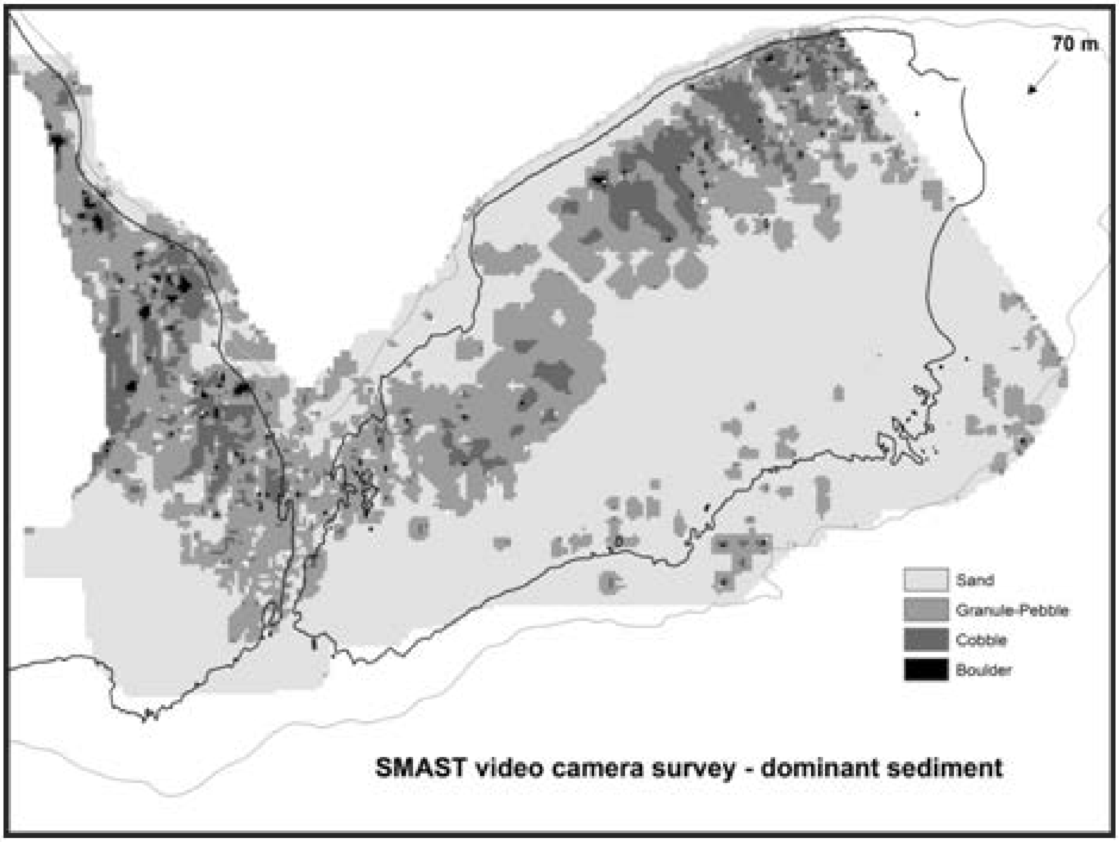


Figure 262: A map of the maximum sediment size visible from the underwater video at each station.

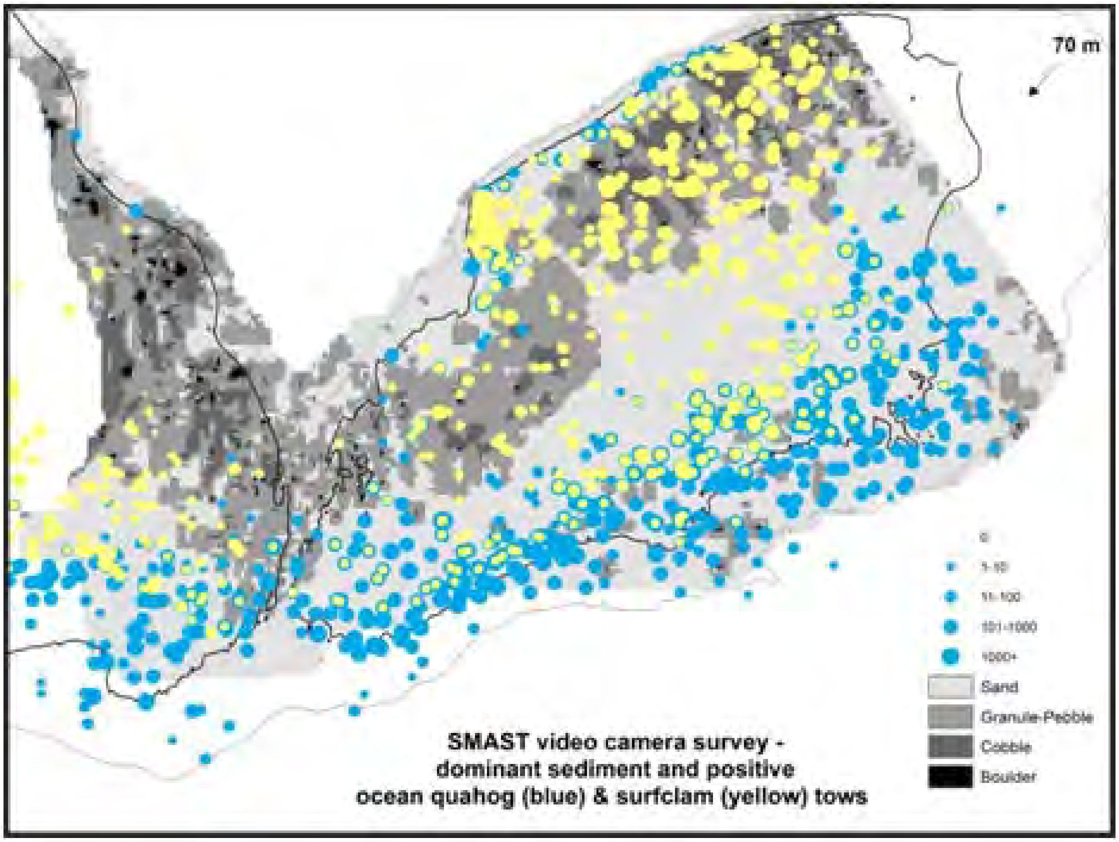


Figure 263: A map of the maximum sediment size visible from the underwater video at each station with positive tows for Atlantic surfclam (yellow dots) and ocean quahogs (blue dots) overlaid.

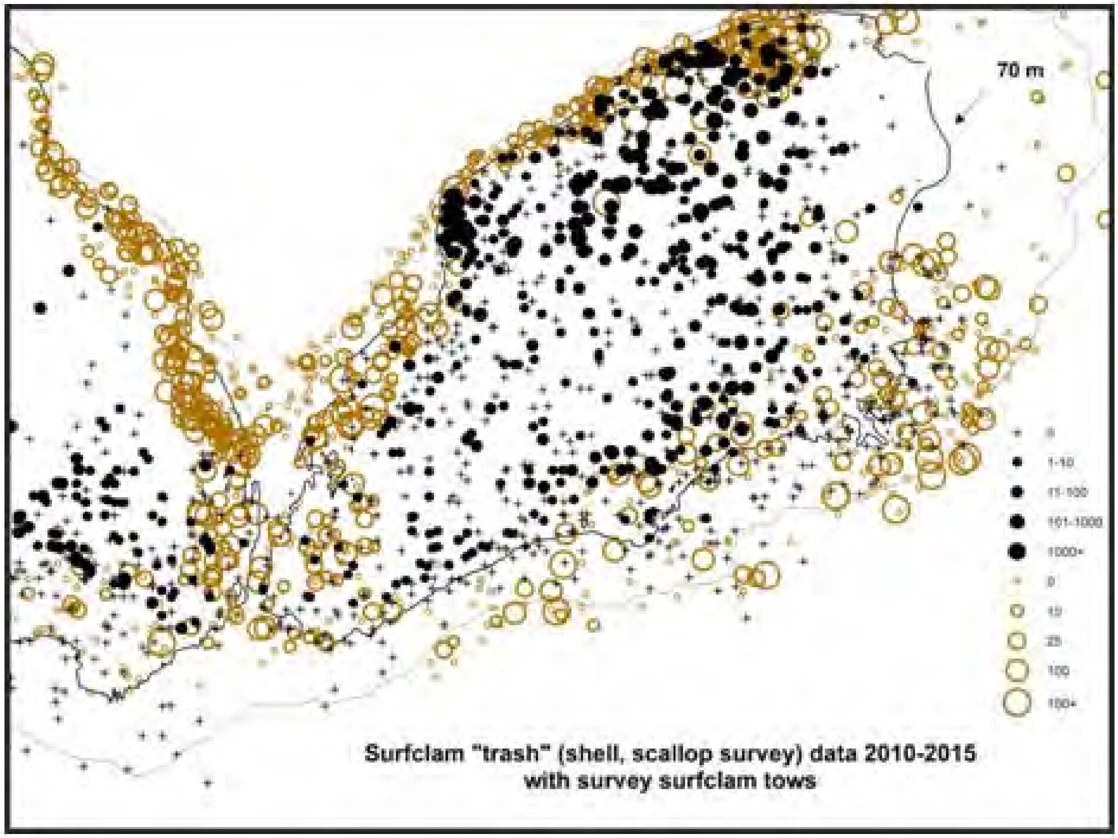


Figure 264: Brown circles represent Atlantic surfclam shell trash brought up in the NEFSC scallop survey dredge, in roughly-estimated liters. Black dots are positive tows for Atlantic surfclam from the NEFSC clam surveys 1980-2013.

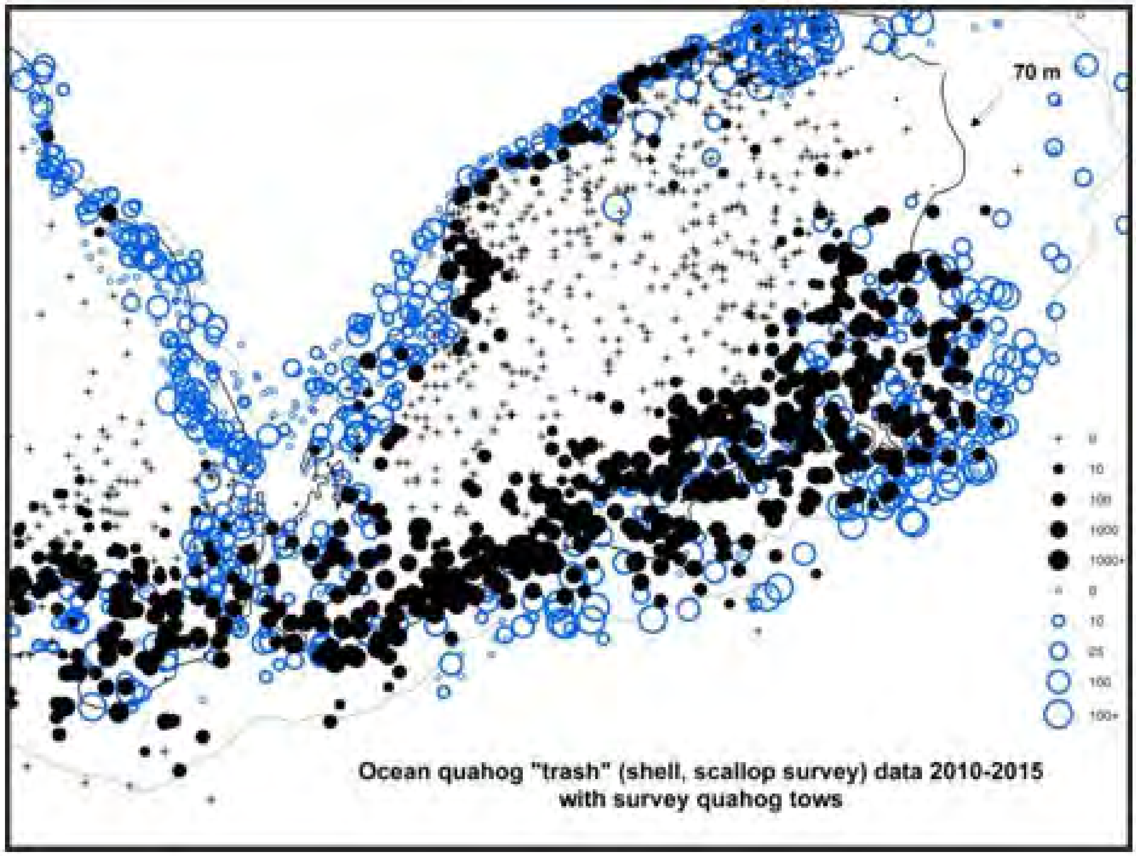


Figure 265: Blue circles represent ocean quahog shell trash brought up in the NEFSC scallop survey dredge, in roughly-estimated liters. Black dots are positive tows for ocean quahogs from the NEFSC clam surveys 1980-2013.

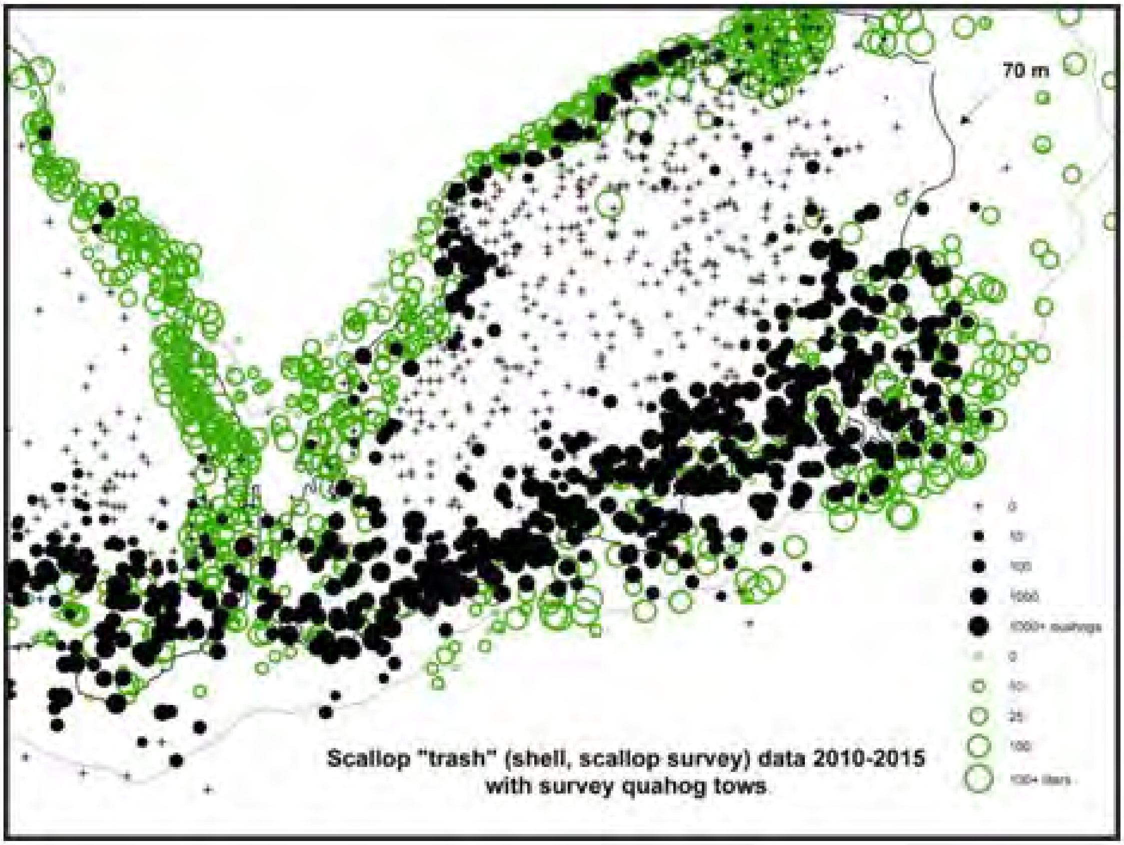


Figure 266: Green circles represent sea scallop shell trash brought up in the NEFSC scallop survey dredge, in roughly-estimated liters. Black dots are positive tows for ocean quahogs from the NEFSC clam surveys 1980-2013.

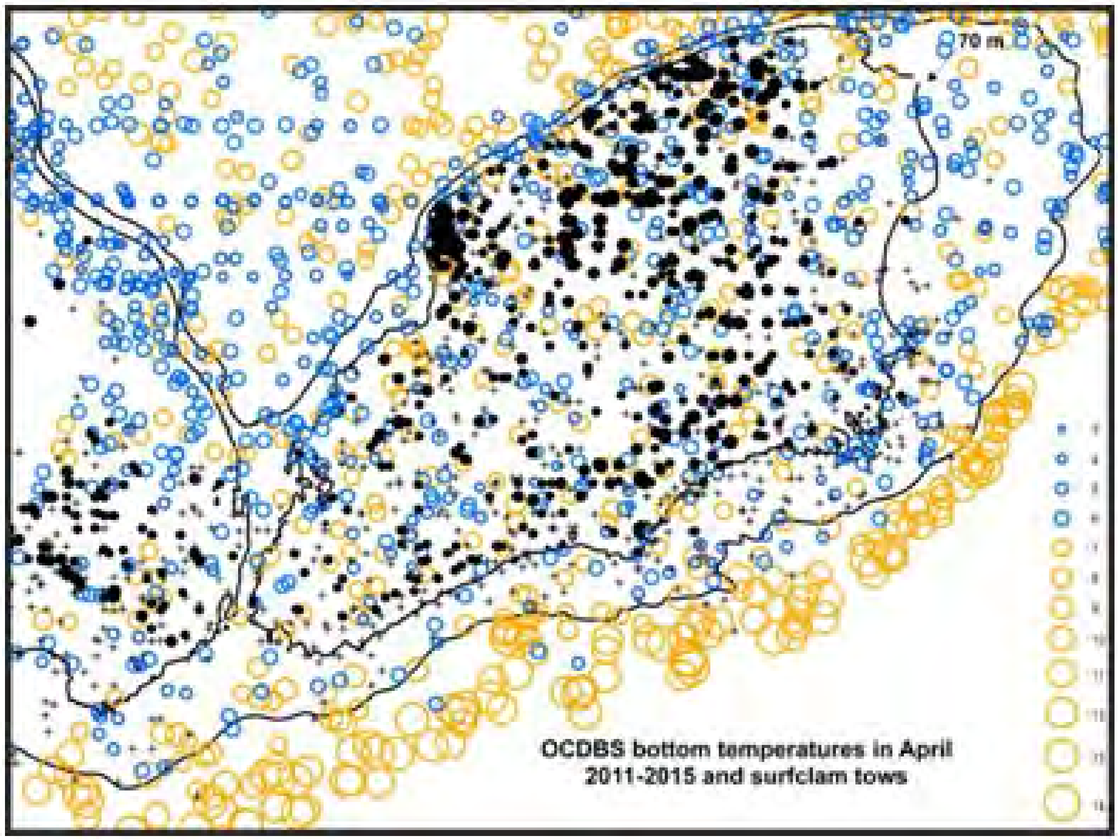


Figure 267: April bottom temperatures on Georges Bank plotted with NEFSC survey Atlantic surfclam catches 1980-2013.

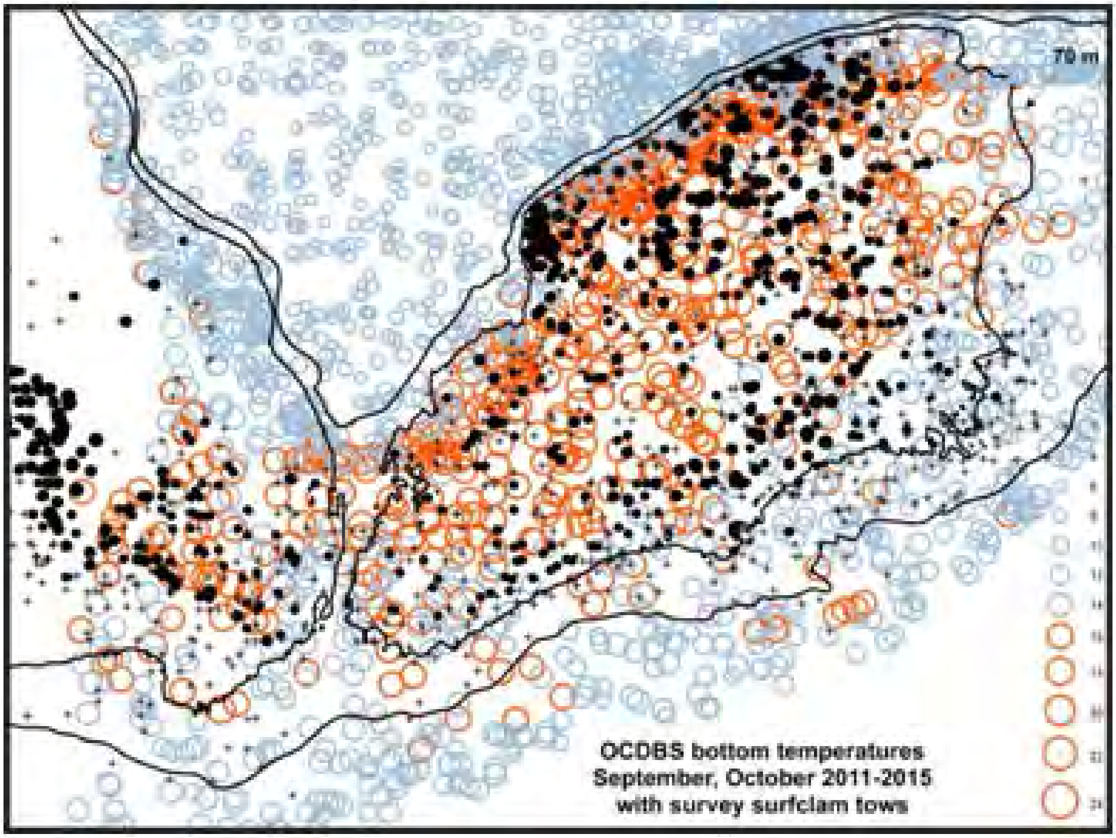


Figure 268: September-October bottom temperatures on Georges Bank plotted with NEFSC survey Atlantic surfclam catches 1980-2013.

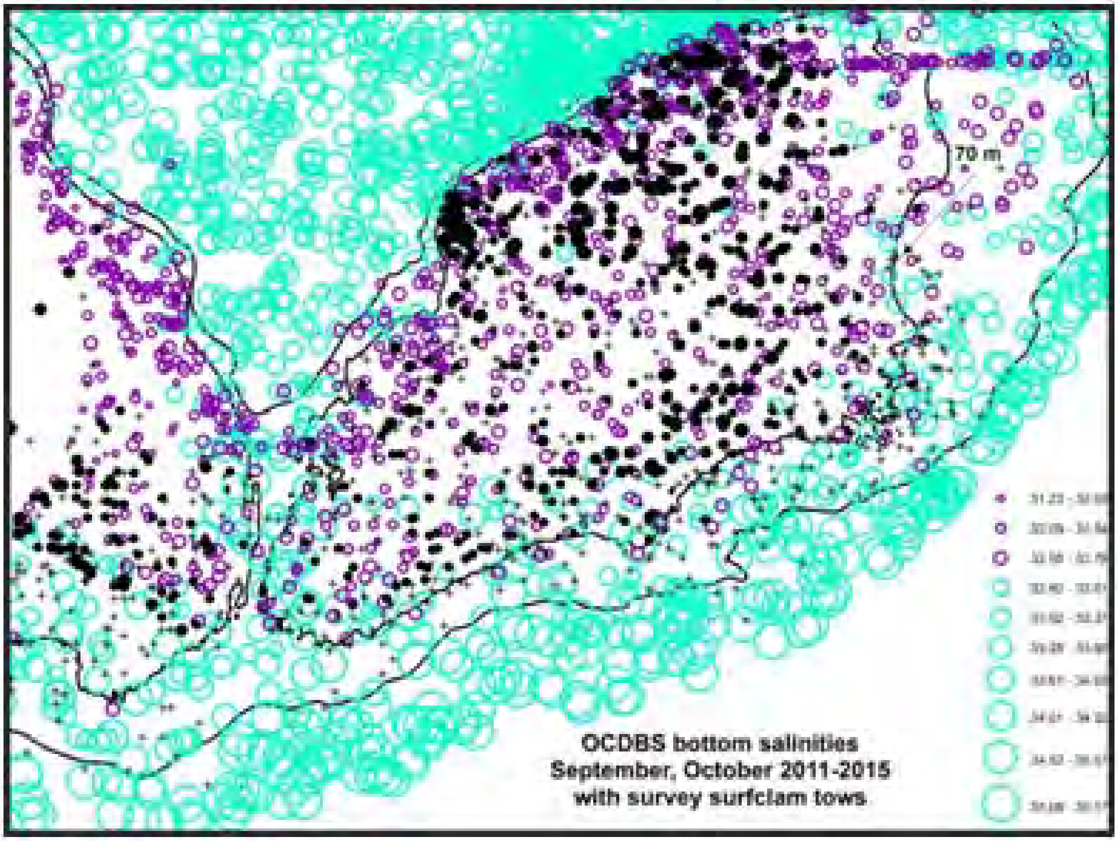


Figure 269: September-October bottom salinities on Georges Bank plotted with NEFSC survey Atlantic surfclam catches 1980-2013.

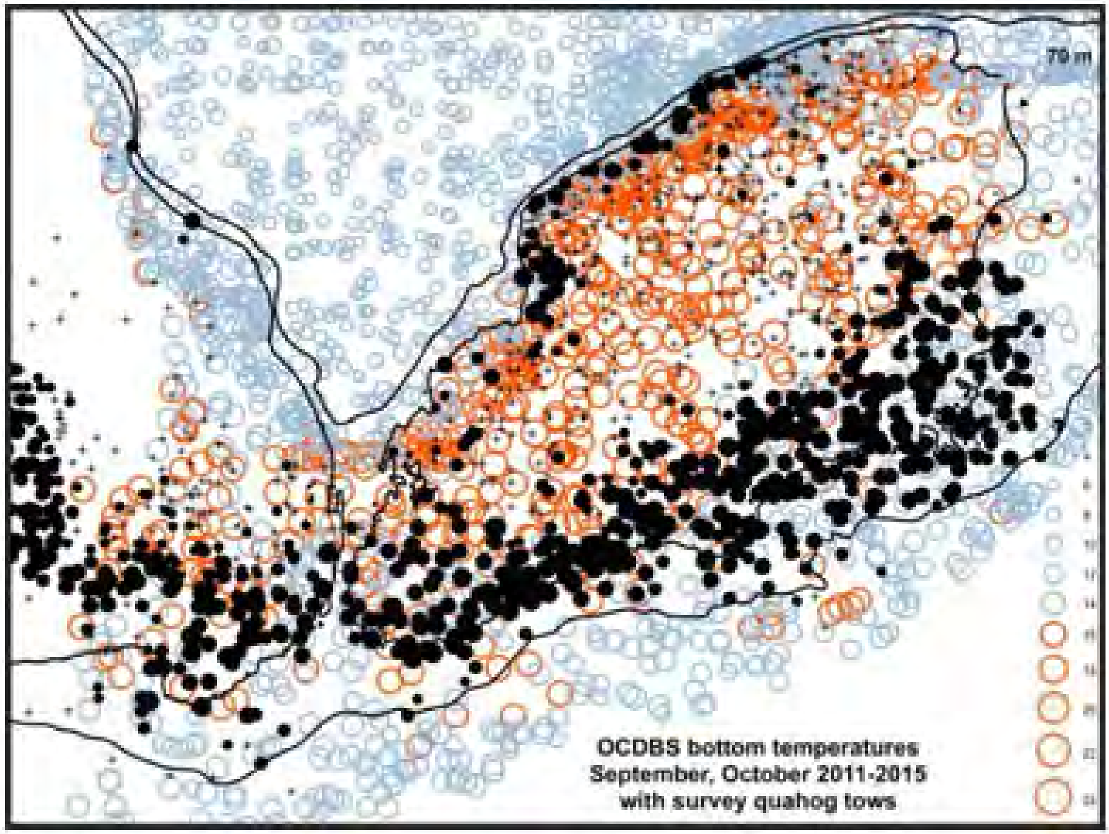


Figure 270: September-October bottom temperatures on Georges Bank plotted with NEFSC survey ocean quahog catches 1980-2013.

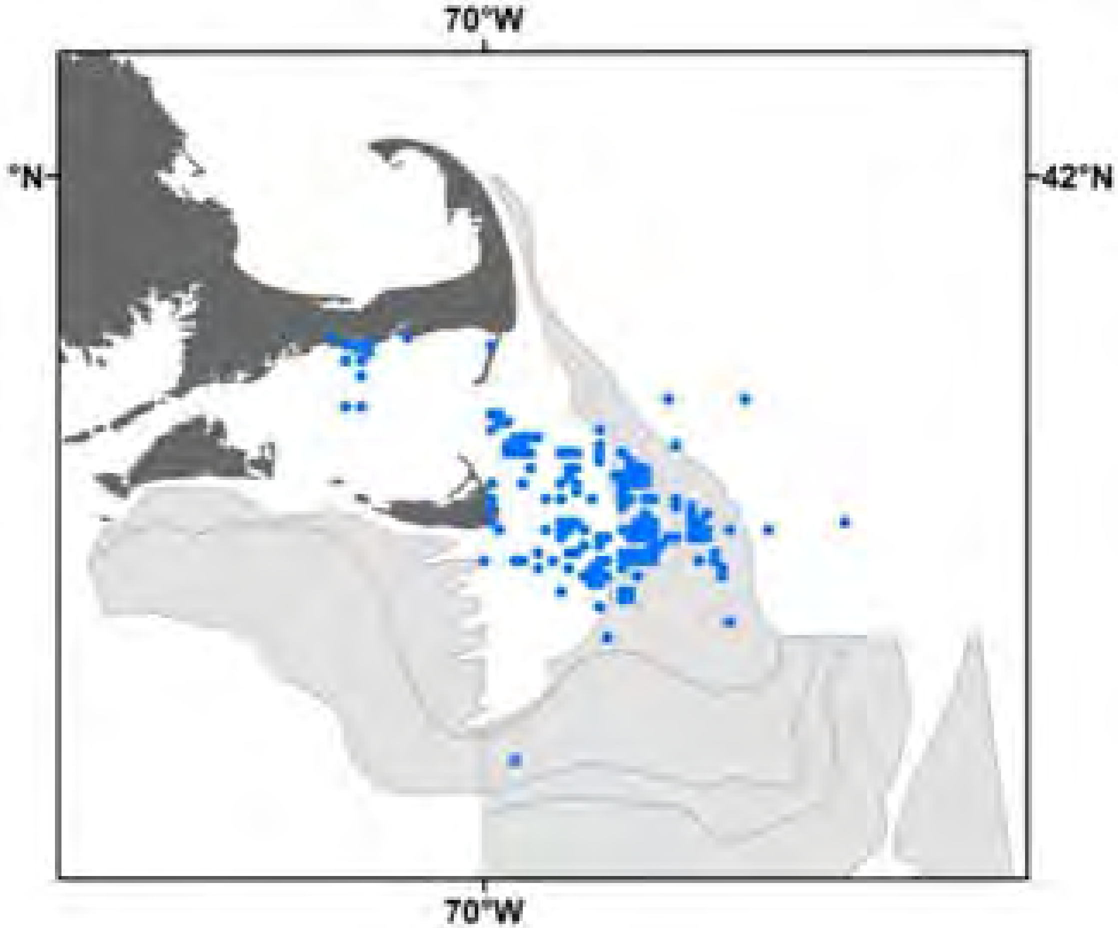


Figure 271: Locations of Atlantic surfclam fishing trips as reported in the clam logbooks from 2003 to 2012 (blue dots). The shaded areas are the strata surveyed and used to determine Atlantic surfclam biomass in the area.

Appendix 14 Empirical Atlantic surfclam assessment

Summary

Empirical stock assessment results from catch curves, exploitation rates ($E = \frac{Catch}{swept\,area\,biomass}$), and recruit abundance and biomass trends were provided for comparison to stock assessment model estimates. Empirical analyses were the main source of information about mortality, recruitment, and biomass in southern subregions (SNE, LI, NJ, DMV and SVA). Catch curve and other empirical analyses were complicated by domed survey size selectivity patterns before 2012, that caused a positive bias in mortality estimates, and survey gear changes after 2011, and low numbers of age samples for some years (particularly in the north).

Empirical results appear to support assessment model estimates. Total annual mortality estimates (probably biased high) from catch curves for the northern and southern areas averaged 0.14 y^{-1} and were near the current estimate of natural mortality (0.15 y^{-1}) indicating that fishing mortality rates were low (Figures 272-274). There was no clear evidence of trends in mortality over time. Empirical exploitation estimates for the south indicate that recent fishing mortality rates in the northern and southern areas were relatively low ($E < 0.05y^{-1}$, Figure 275).

Exploitation rates were low ($E < 0.06y^{-1}$) after 2011 in the LI NJ, DMV and SVA subregions regions but relatively high ($0.1 < E < 0.15$) in SNE (Figures 275–276). Biomass appears to be declining in in all areas south of SNE and in the south as a whole although changes in the survey complicate interpretation of trends (Figures 275–276). Results indicate that recruit abundance was relatively high in the south during 2015 and about average in the northern area during 2012 (Figures 278-279).

Catch curves

Catch curves based on survey age data were for individual cohorts (cohort catch curves) and for all of the cohorts captured during the same survey (snapshot catch curves). In both types of analyses, the logarithm of mean numbers per tow was regressed on age and the slope of the regression model was taken as an estimate of the average mortality rate (Z). Survey age composition data were based on age-length keys. Poorly sampled years with less than 300 ages per survey from the south or less than 200 ages from the north were omitted. Year classes observed less than five times in the generally triennial clam survey were omitted from cohort catch curve analyses.

Field estimates of size-selectivity for the survey dredge used during 1982-2011 are dome shaped with a broad peak from about 8 cm (about age 4 y) to 15 cm (Northeast Fisheries Science Center (2013)). The survey dredge used since 2012 has a logistic size selectivity shape with full selectivity at about 10 cm (about age 5 y). The change is survey selectivity means that 1982-2011 and 2012-2015 data cannot be combined.

The most important decision in catch curve analysis is the first age group included. Average fishery length composition data for the southern area indicate that Atlantic surfclam are fully recruited to commercial gear and should experience maximum mortality at about 15 cm SL. Based on the updated growth curve in this assessment, Atlantic surfclam in the southern area reach 15 cm at about age 11 y. It is difficult to translate 15 cm SL into age for Atlantic surfclam in the northern area because 15 cm is close to the maximum size predicted by the von Bertalanffy growth curve, but it appears that Atlantic surfclam in the northern area may be close to fully recruited at age 15 y or older. We therefore fit catch curves assuming full recruitment at age 11 y in the south and at age 15 y for the northern area. Sensitivity analyses (not shown) showed that mean mortality estimates from cohort and snapshot catch curves increased as starting age increased, probably due to the dome shaped size-selectivity in the survey.

Statistically significant ($p \leq 0.1$) cohort mortality rates for the south ranged 0.07-0.24 y^{-1} and averaged 0.14 (Figure 272). There was no clear trend in mortality rate estimates over time. Statistically significant ($p \leq 0.1$) snapshot mortality rates ranged 0.06-0.28 y^{-1} and averaged 0.14 (Figure 273). There was no clear trend in mortality rate estimates over time. Runs of positive and negative residuals were noted in some cases.

It was not possible to estimate cohort catch curves for Atlantic surfclam in the northern area because of limited sampling, but the data were sufficient to fit four snapshot catch curves from data collected during 1984, 1986, 1992 and 2008 (Figure 274). Statistically significant ($p \leq 0.1$) mortality rates ranged 0.09-0.18 y^{-1} and averaged 0.14. Catch was negligible in the northern area prior to 2010 so these estimates represent natural mortality and do not include fishing mortality. There was no clear trend in mortality rate estimates over time. Runs of positive and negative residuals were noted in some cases.

Catch/swept-area biomass estimates

As in the last assessment (Appendix A8 in Northeast Fisheries Science Center (2013)), swept-area biomass and exploitation rates were computed for Atlantic surfclam 12+ cm during 1997-2015 by assessment area and smaller regions. The survey data used here were adjusted for survey selectivity to compensate for the dome shaped survey selectivity pattern in Atlantic surfclam 12+ cm in the old survey during 1982-2011. Field experiments indicate that survey selectivity was flat at 12+ cm in the new survey after 2012 so that no selectivity adjustments were required. Sensor based tow distances and updated estimates for survey selectivity, shell length-meat weight and other parameters were used in calculating survey catch weight per tow. Swept-area biomass was calculated assuming median dredge efficiency estimates of 0.23 for 1997-2011 and 0.67 for 2012-2015 based on depletion and selectivity studies to provide an approximate empirical measure of relative scale. Only one set of swept-area estimates were available for the northern area after 2011. Two sets of surveys were available after 2011 for the southern area which may reflect recent trends and should be interpreted with care.

Swept-area biomass estimates for 1997-2011 and 2012-2015 were comparable in scale suggesting that efficiency and tow distance estimates for the two survey dredges are reasonably consistent (Figure 276-275). There is substantial uncertainty in interpreting the composite time series in recent years, but it appears that SNE biomass increased during 2012-2015. Atlantic surfclam biomass in the LI and NJ regions may have declined substantially during 2012-2015 while biomass in DMV remained steady and biomass in the SVA region remained low. Exploitation rates since 2011 were low ($E < 0.06y^{-1}$) in the LI, NJ, DMV, and SVA regions but relatively high (0.1 - 0.15 y^{-1}) in SNE. The high values in SNE may be due in part to the fact that a proportion of the catch is landed in an area (northern Nantucket Shoals) that is not surveyed. Empirical exploitation estimates for the south confirm assessment model estimates which indicate recent fishing mortality rates in both areas are low ($E < 0.05y^{-1}$).

Survey recruitment trends

Long term (1982-2015, but see below) trends in abundance of recruits (5-12 cm, before recruitment to the fishery) were computed by adjusting survey catch data based on nominal tow distances (distance traveled while the dredge was on the tow rope) and dredge efficiency (0.23 for 1997-2011 and 0.67 for 2012-2015). Selectivity curves based on field studies were used to adjust for differences in size selectivity during 1982-2011 and 2012-2015. Recruit abundance trends were similar ending in 2011 and starting in 2012 indicating that dredge efficiency and selectivity estimates were consistent (Figures 278-279).

Figures

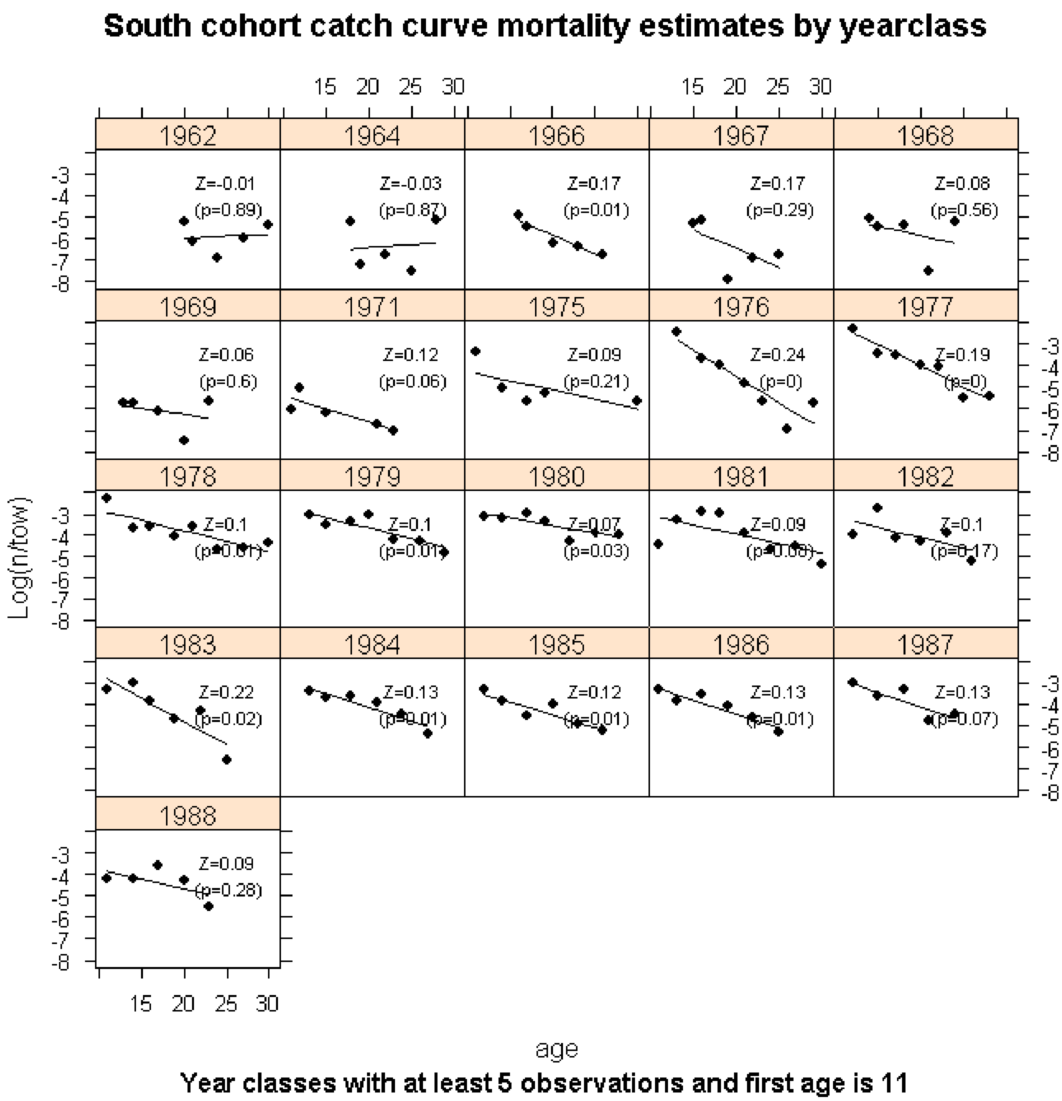


Figure 272: Cohort catch curves (one panel for each cohort) based on survey age composition data for Atlantic surfclam 15+ y in the southern area and omitting cohorts with fewer than five observations.

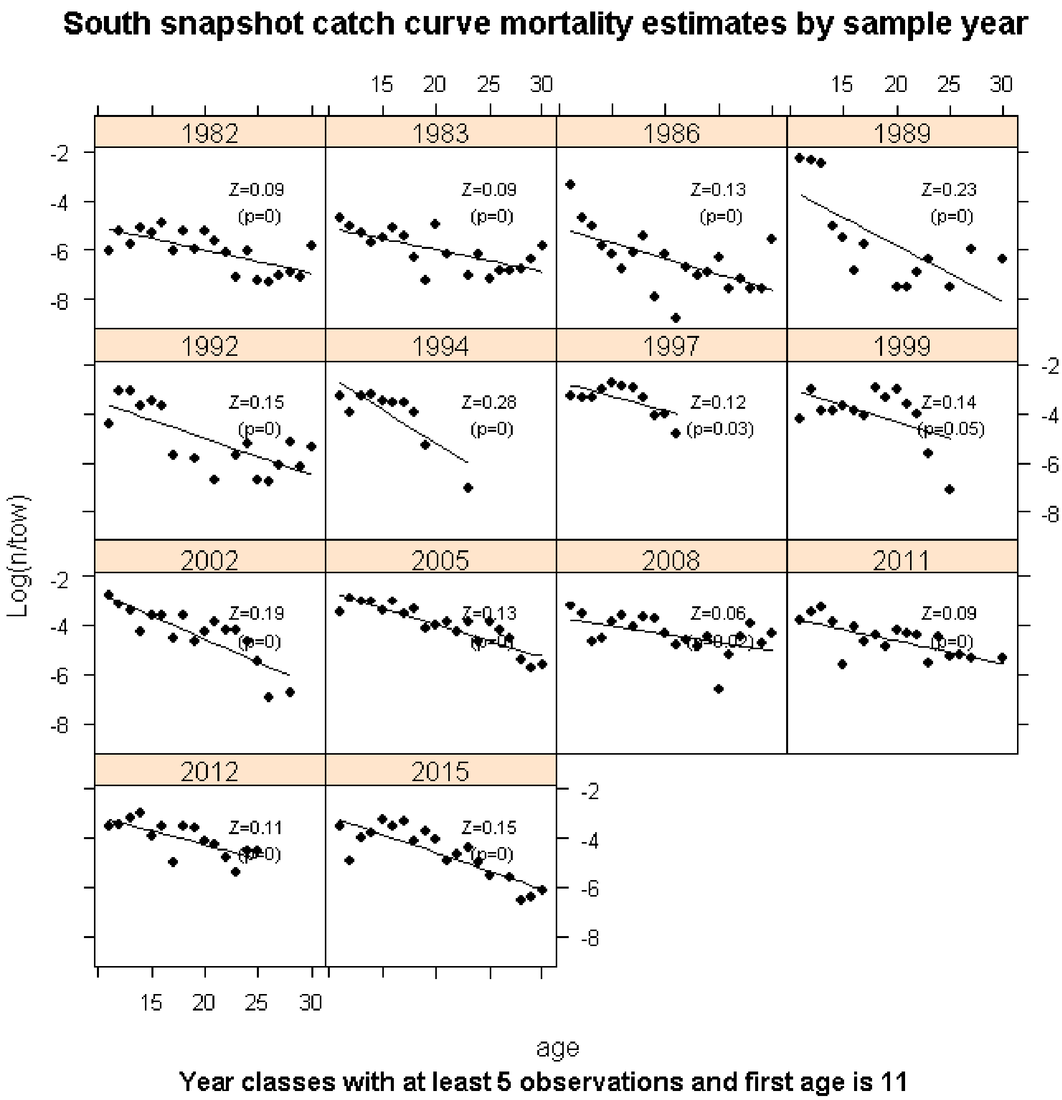


Figure 273: Snapshot catch curves (one panel for each cohort) based on survey age composition data for Atlantic surfclam 15+ y in the southern area and omitting cohorts with fewer than five observations.

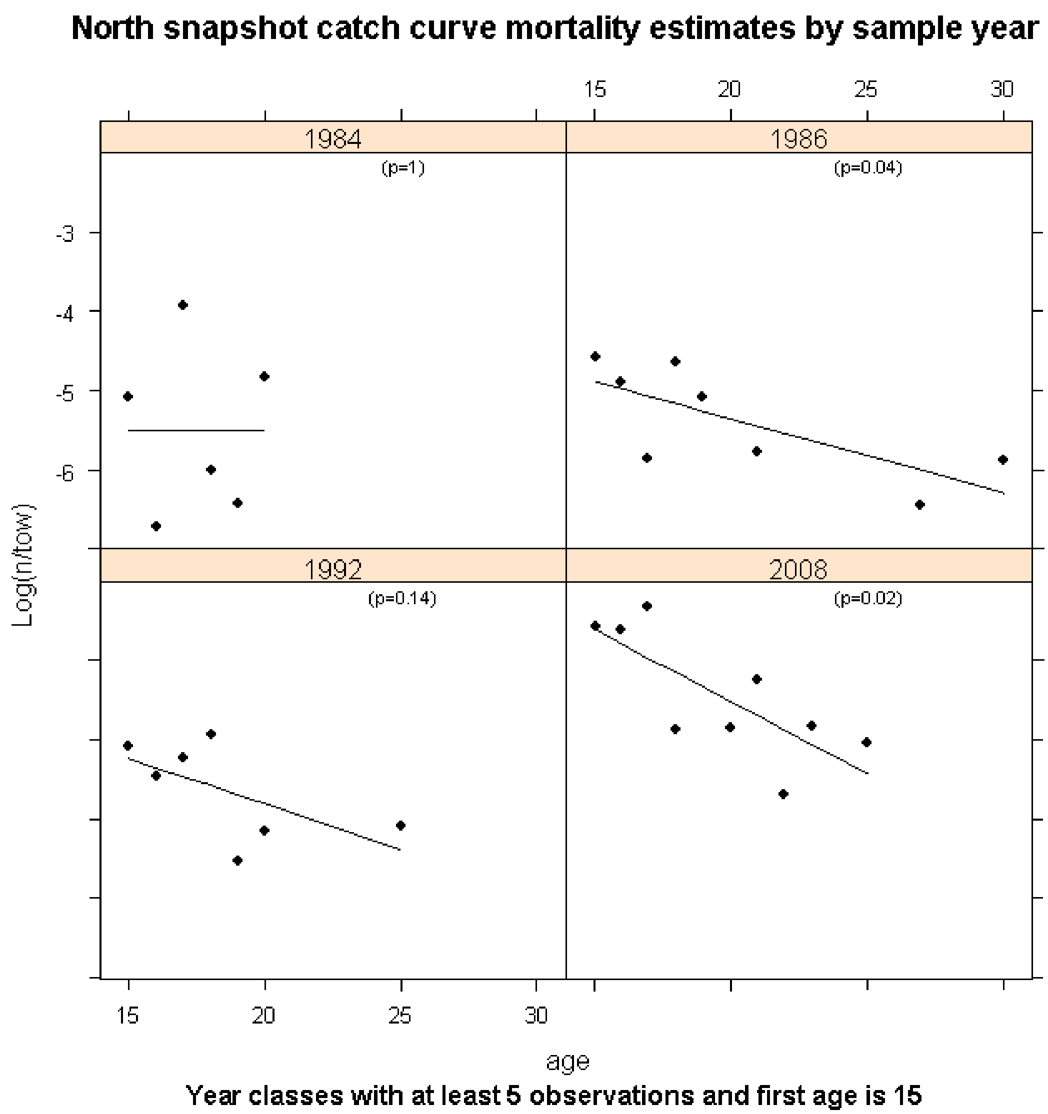


Figure 274: Snapshot catch curves (one panel for each cohort) based on survey age composition data for Atlantic surfclam 15+ y in the northern area and omitting cohorts with fewer than five observations.

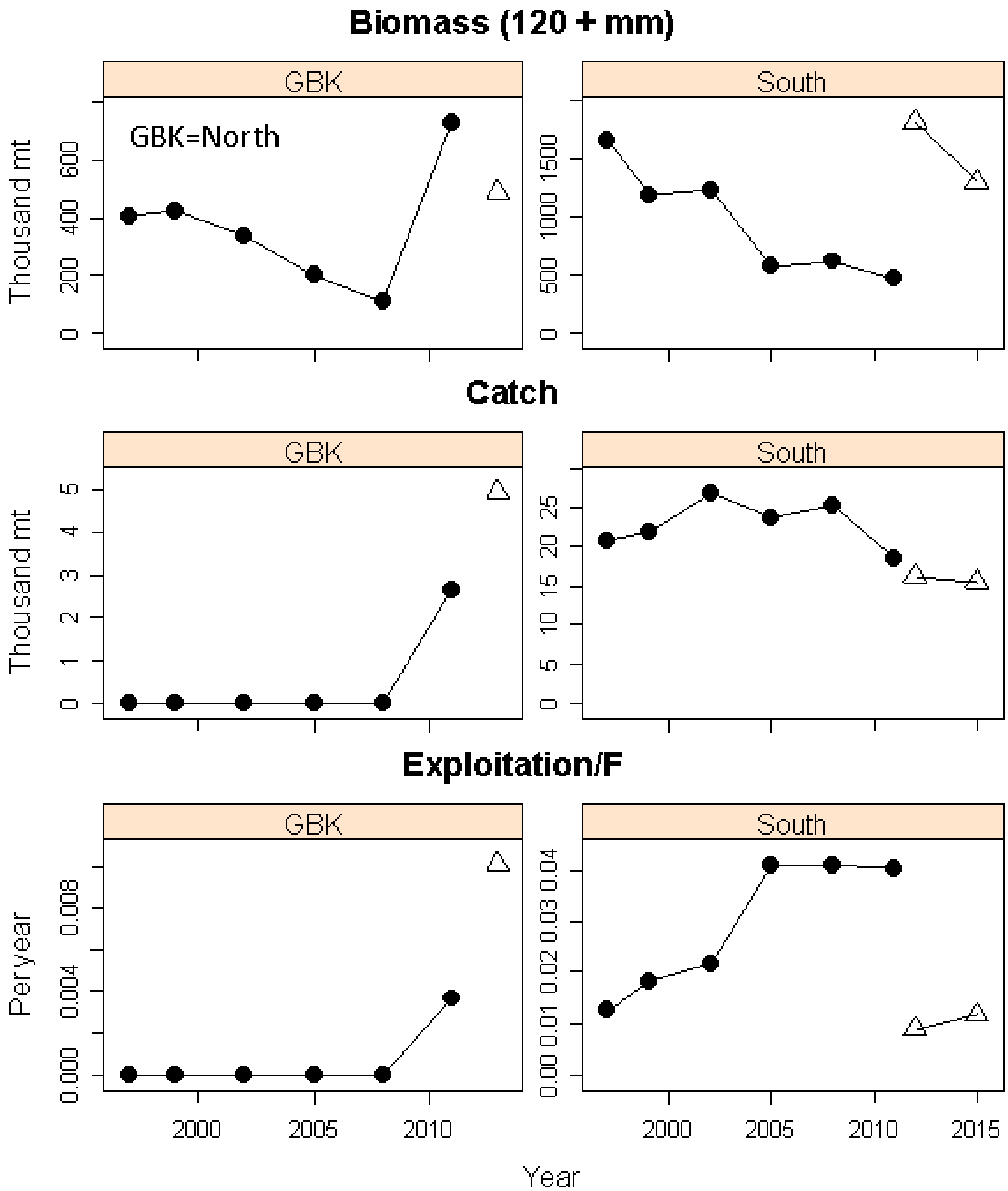


Figure 275: Swept-area biomass for Atlantic surfclam 12+ cm SL based on survey data adjusted for dome shaped selectivity (top), catch weight (landings + 12% for incidental mortality, middle) and exploitation rates (catch/biomass) for Atlantic surfclam in the Georges Bank (GBK) and Southern regions (bottom). Data and results for 1997-2011 (when the original survey dredge was used) and 2012-2015 when a modified commercial survey dredge was used are shown using different symbols. Median dredge efficiency and sensor based tow distances were used in computations.

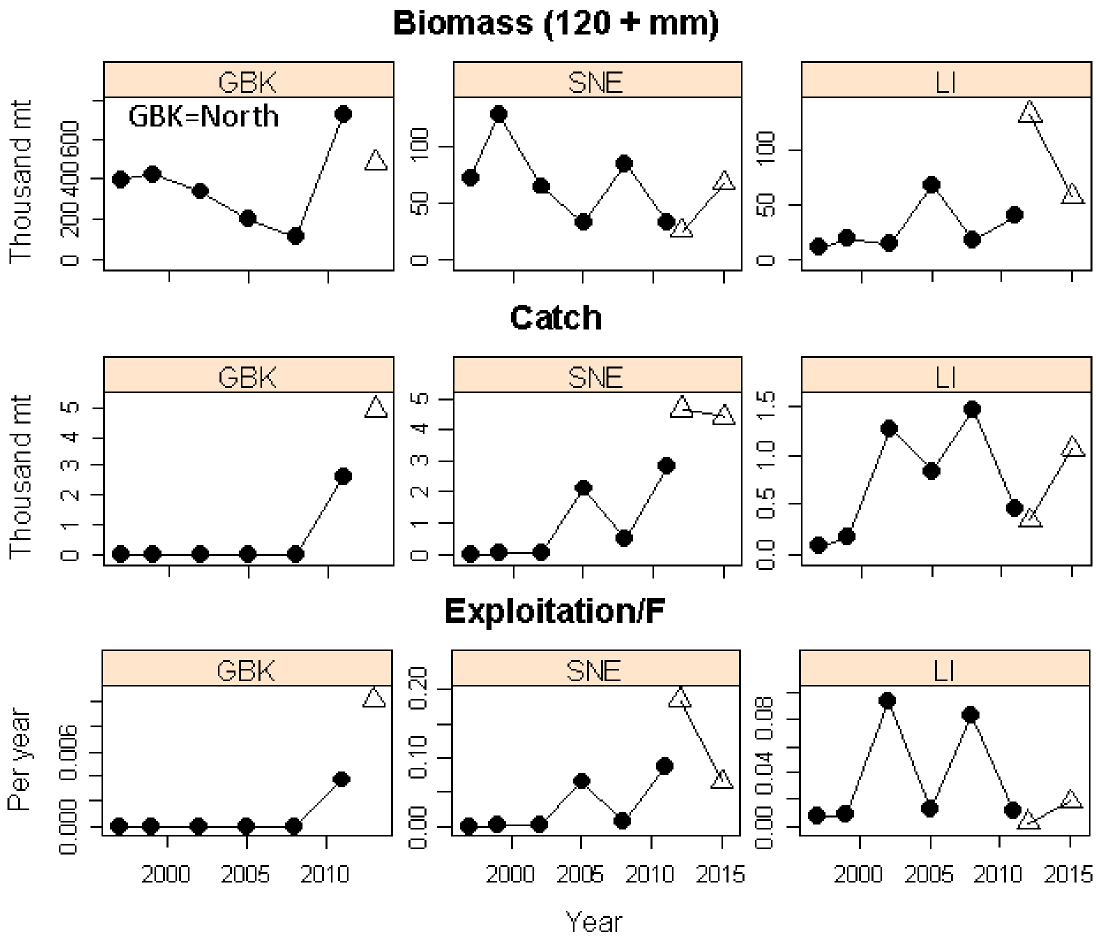


Figure 276: Swept-area biomass for Atlantic surfclam 12+ cm SL based on survey data adjusted for dome shaped selectivity (top), catch weight (landings + 12% for incidental mortality, middle) and exploitation rates (catch/biomass) for Atlantic surfclam in the Georges Bank (GBK), Southern New England (SNE) and Long Island (LI) regions (bottom). Data and results for 1997-2011 (when the original survey dredge was used) and 2012-2015 when a modified commercial survey dredge was used are shown using different symbols. Median dredge efficiency and sensor based tow distances were used in computations.

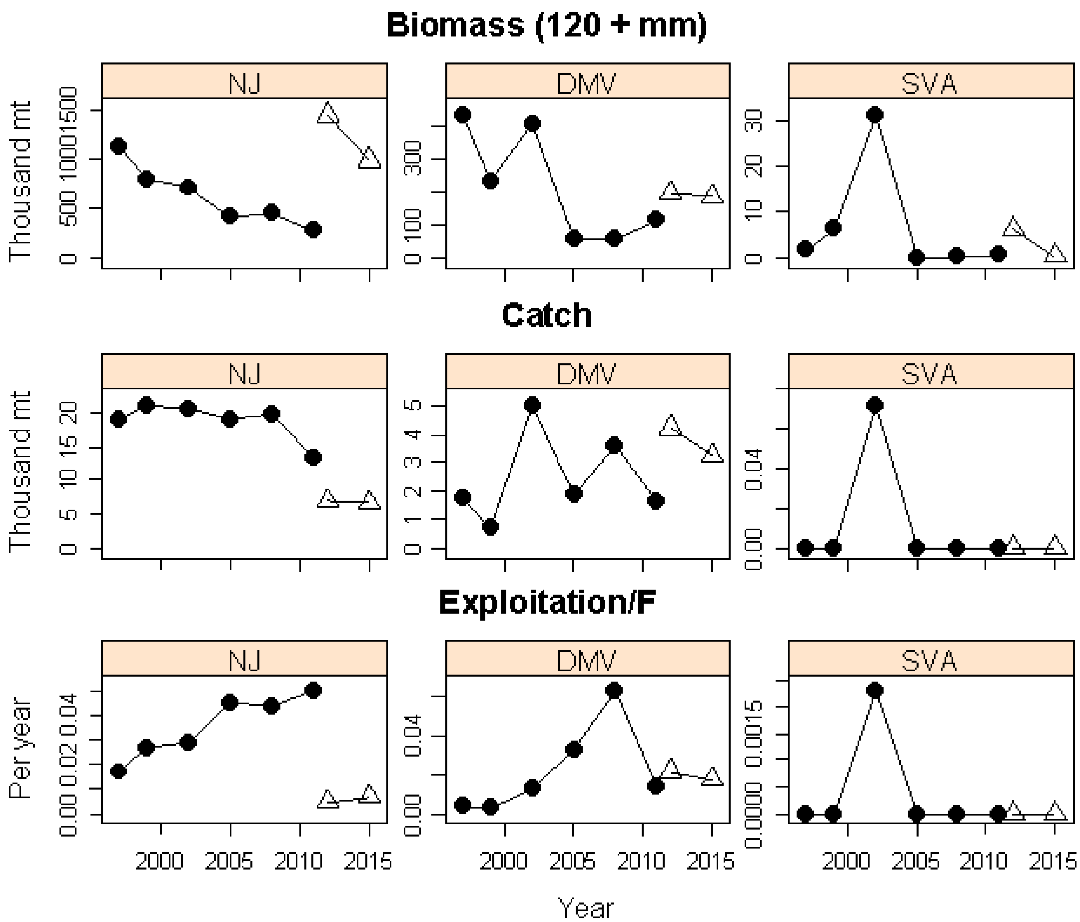


Figure 277: Swept-area biomass for Atlantic surfclam 12+ cm SL based on survey data adjusted for dome shaped selectivity (top), catch weight (landings + 12% for incidental mortality, middle) and exploitation rates (catch/biomass) for Atlantic surfclam in the New Jersey (NJ), Delmarva (DMV) , Southern Virginia (SVA) regions (bottom). Data and results for 1997-2011 (when the original survey dredge was used) and 2012-2015 when a modified commercial survey dredge was used are shown using different symbols. Median dredge efficiency and sensor based tow distances were used in computations.

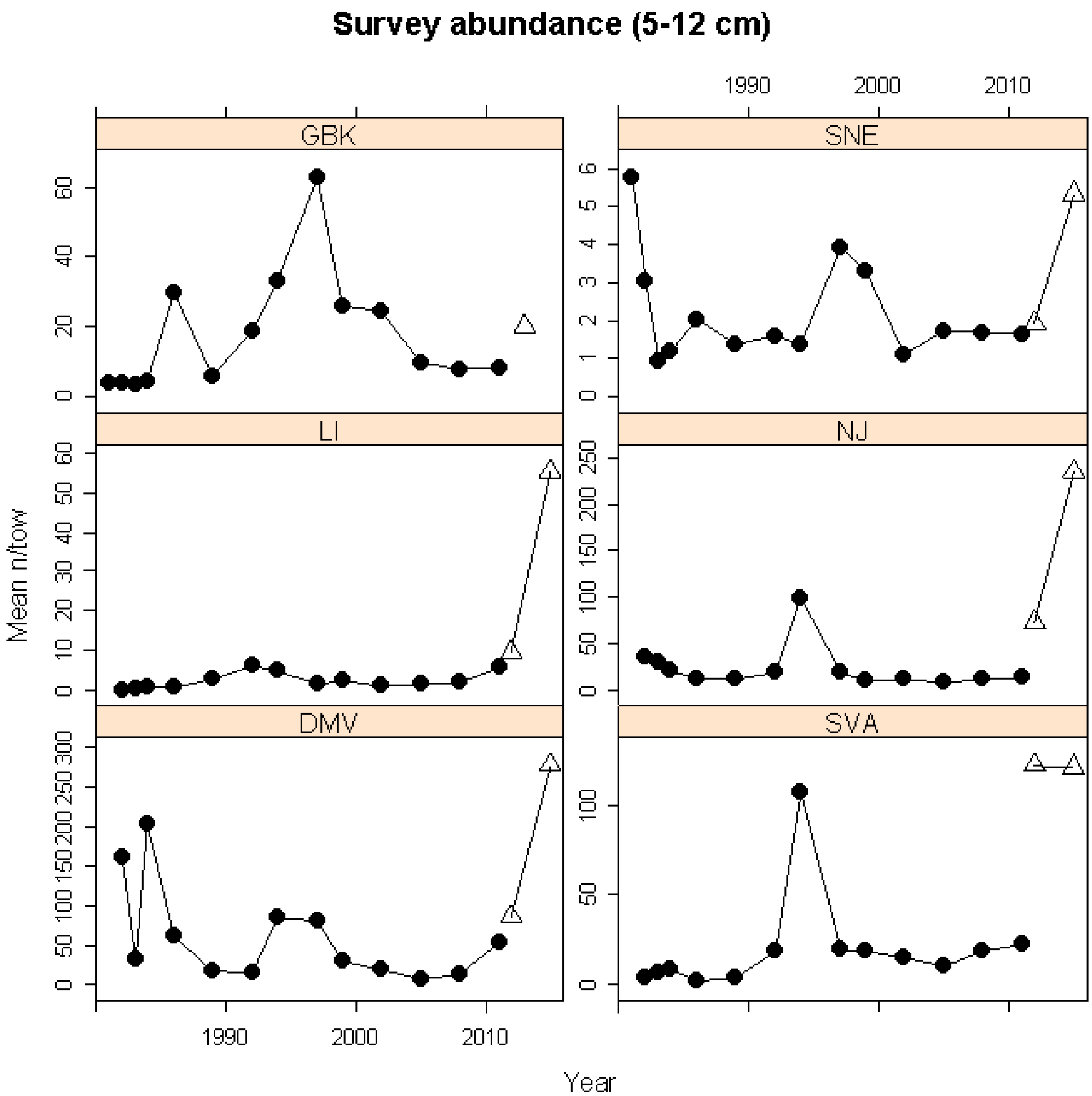


Figure 278: Trends in abundance of "recruit" Atlantic surfclam (5-12 cm SL) by area based on NEFSC clam surveys during 1982-2015. Data are adjusted for size-selectivity and dredge efficiency based field study results. Survey gear changed in 2012 so that comparison of trends up to and after 2011 may be misleading. Note that y-scales differ in each plot.

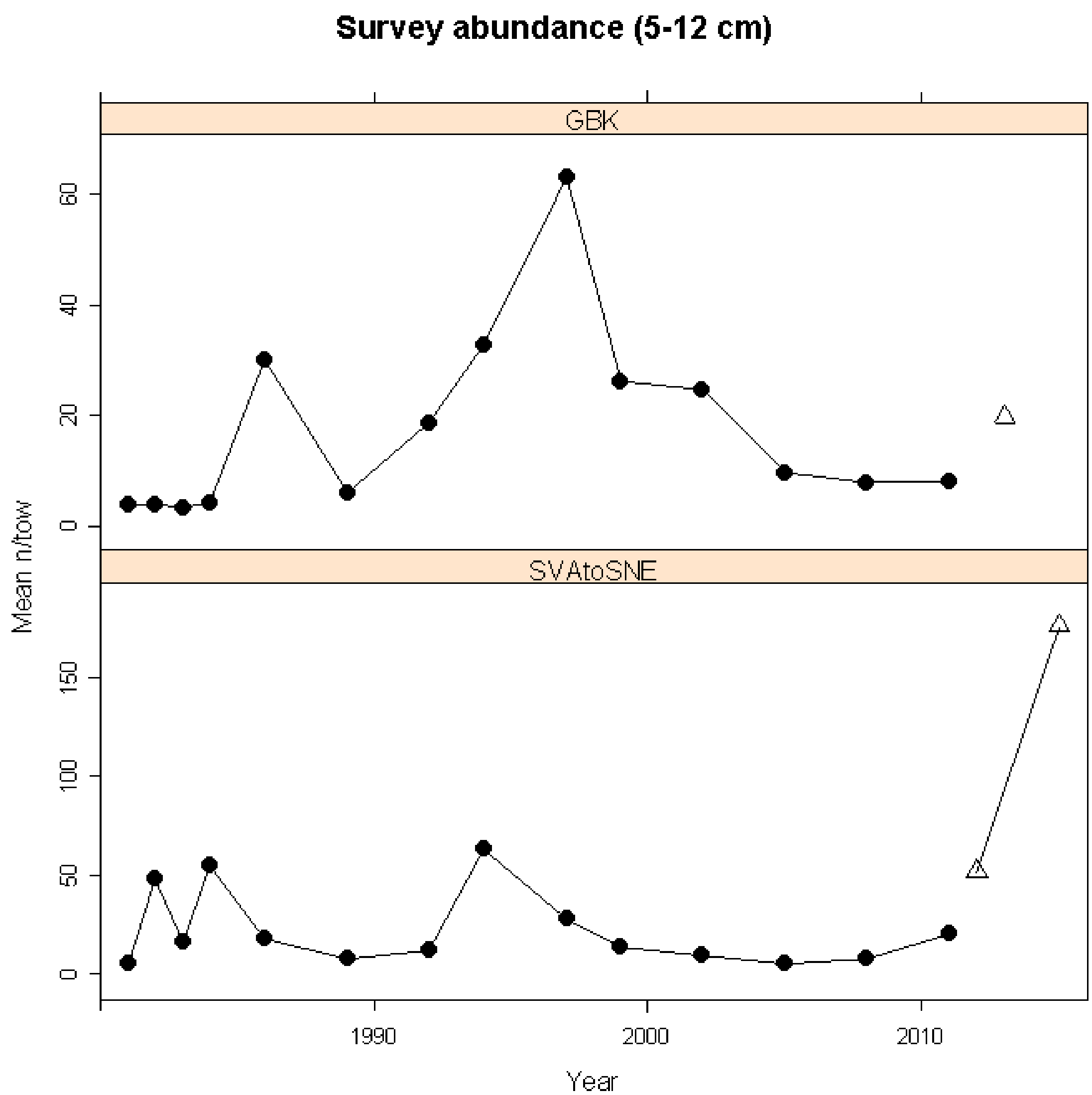


Figure 279: Trends in abundance of "recruit" Atlantic surfclam (5-12 cm SL) by stock assessment region based on NEFSC clam surveys during 1982-2015. Data are adjusted for size-selectivity and dredge efficiency based field study results. Survey gear changed in 2012 so that comparison of trends up to and after 2011 may be misleading. Note that y-scales differ in each plot.

Appendix 15 Appendix to the SAW Assessment TORs:

Clarification of Terms used in the SAW/SARC Terms of Reference

On “Acceptable Biological Catch” (DOC Nat. Stand. Guidel. Fed. Reg., v. 74, no. 11, 1-16-2009):

Acceptable biological catch (ABC) is a level of a stock or stock complex’s annual catch that accounts for the scientific uncertainty in the estimate of [overfishing limit] OFL and any other scientific uncertainty. . . ” (p. 3208) [In other words, OFL ABC.]

ABC for overfished stocks. For overfished stocks and stock complexes, a rebuilding ABC must be set to reflect the annual catch that is consistent with the schedule of fishing mortality rates in the rebuilding plan. (p. 3209)

NMFS expects that in most cases ABC will be reduced from OFL to reduce the probability that overfishing might occur in a year. (p. 3180)

ABC refers to a level of “catch” that is “acceptable” given the “biological” characteristics of the stock or stock complex. As such, [optimal yield] OY does not equate with ABC. The specification of OY is required to consider a variety of factors, including social and economic factors, and the protection of marine ecosystems, which are not part of the ABC concept. (p. 3189)

On “Vulnerability” (DOC Natl. Stand. Guidelines. Fed. Reg., v. 74, no. 11, 1-16-2009):

“Vulnerability. A stocks vulnerability is a combination of its productivity, which depends upon its life history characteristics, and its susceptibility to the fishery. Productivity refers to the capacity of the stock to produce MSY and to recover if the population is depleted, and susceptibility is the potential for the stock to be impacted by the fishery, which includes direct captures, as well as indirect impacts to the fishery (e.g., loss of habitat quality).” (p. 3205)

Participation among members of a SAW Assessment Working Group:

Anyone participating in SAW assessment working group meetings that will be running or presenting results from an assessment model is expected to supply the source code, a compiled executable, an input file with the proposed configuration, and a detailed model description in advance of the model meeting. Source code for NOAA Toolbox programs is available on request. These measures allow transparency and a fair evaluation of differences that emerge between models.

Appendix 16 Appendix: Survey performance 2013

Introduction

The 2013 survey covered a portion of the whole stock area including the SNE and most of GBK subareas. There were 149 total tows and four selectivity tows. One tow resulted in severe damage to the dredge and was aborted and eight other tows during which no sensor data was recovered. Therefore there were 136 standard survey tows on which sensors were deployed and sensor data was recorded.

The 2013 survey used a modified commercial dredge with 3 on board data recorders. There was an inclinometer (Star Oddi) and two (Madge Tech) pressure sensors: one in the pump manifold measuring the pressure in the hydraulic jets used to loosen the sediments around clams and one measuring the ambient pressure at fishing depth. The inclinometer measured the pitch roll and yaw of the dredge as it was towed and was used to determine if the dredge was in a fishing position, which was the basis for determining "time fishing" on each tow. The pressure sensors were used to make sure that the pump was achieving sufficient pressure to maintain capture efficiency.

Survey performance

Sensors deployed during the 2013 survey suggest that either the average pump pressure was some what less than 2012 (Figure 280), or the pressure sensor was mis-calibrated. The pressure sensor data was not analyzed until 2014, after the 2014 survey had been conducted and the sensors re-calibrated. Therefore there is no way to determine if the problem with the sensors was due to reduced pump pressure or sensor calibration. Speed over ground also appeared to be somewhat less than in previous years (Figure 280), but may be related to the type of substrate encountered and/or current strength. The ground fished was in some cases exceedingly rocky and difficult to dredge through, while currents on GBK and SNE are strong relative to areas further south. The tow speeds recorded were probably not sufficient in magnitude to cause concern regarding dredge efficiency and may represent the maximum advisable speed given the conditions. Neither pump pressure nor vessel speed appeared to be less than expected based on ship board instruments during operations, which may indicate problems with sensor calibration, but the discrepancy cannot be definitively resolved at this juncture.

Determination of time fishing

The determination of time fishing, the "fishing seconds" for each tow was based on a measurement of the pitch of the dredge during each second of the tow. Roll and yaw were relatively stable for the large modified commercial dredge and rarely fluctuated from baseline levels during fishing events. Pitch was recorded by a Star Oddi inclinometer which functioned consistently. Data from each instrument was smoothed using a 7 second moving average and then parsed for time above or below the median fishing angle for that tow.

In order to account for median pitch $> 0^o$, the determination of time fishing was based on a critical deviation from median pitch, rather than an absolute critical pitch angle. The choice of critical deviation has implications for the calculation of tow distance for each tow. When the dredge is above or below the critical deviation it is assumed to be pitched too steeply for the blade to penetrate the sediment. If the dredge is pitched within Δ_{crit} (the critical deviation) of $\tilde{\phi}_t$ (the median pitch for tow t), it assumed to be near enough to parallel to the bottom that the blade should penetrate and thus be actively fishing.

An ideal critical deviation is as close to zero as possible, but not so small that it includes poor dredge performance seconds. When the dredge is bouncing over rough terrain it is unlikely to be fishing effectively and those seconds should be excluded. There is however, a certain amount of pitch that is within fishing tolerance and a certain amount of noise in the data. If the critical deviation is too small, many seconds when the dredge is actually fishing would be excluded, which would tend to bias estimates of tow distance down. It is therefore important to find a critical deviation that is neither too small, nor too large.

The choice of Δ_{crit} was informed by an examination of the total and average tow distances based on different critical deviations. Total tow distance summed across all tow and average tow distance over all tows was compared when different values of Δ_{crit} were used. In general, higher values of Δ_{crit} result in longer tows because the dredge is considered to be in fishing position for a greater proportion of the tow (Figure 281). We selected a Δ_{crit} of $4°$ because it produced an average tow distance that was near the nominal tow distance (0.25 nm, a value equal to the nominal tow speed 3 kt multiplied by the nominal tow time 5 min) and because it seemed reasonable based on examination of the engineering schematic of the dredge being used (*Figure not yet available*)

Time fishing during the 2013 survey was less than the nominal tow time in most cases due to the lower average tow speed discussed above (Figure 282).

Effects of depth

Depth is typically associated with longer tows due to the scope of the towing wire that must be deployed to assure good dredge performance. Additional scope requires longer retrieval times and may result in some additional time fishing while the slack in the wire is spooled up. This effect was evident (though the data was noisy) during the 2013 survey (Figure 282).

Temperature

Temperature was recorded from the dredge and averaged over fishing seconds for all tows during the 2013 survey (Figure 283). Temperature was correlated with depth (Figure 283).

Figures

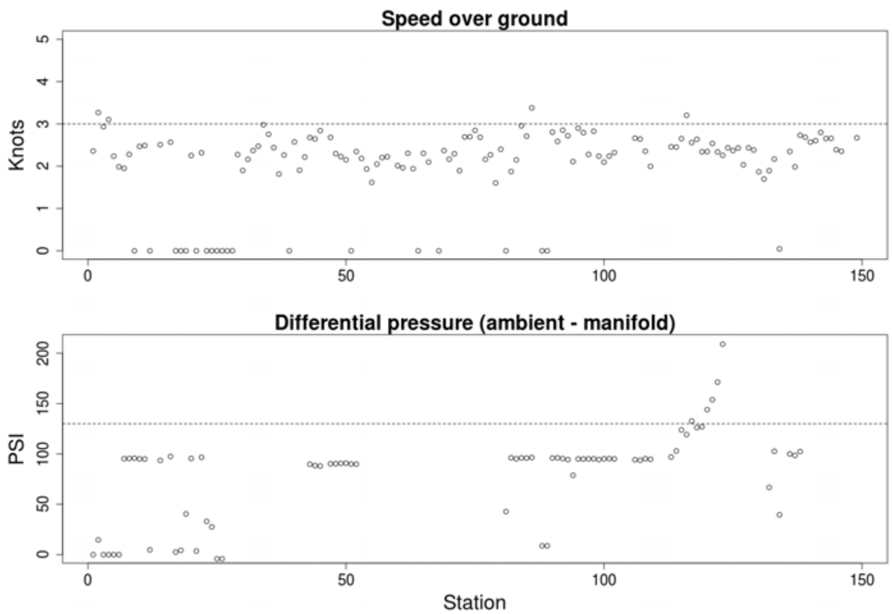


Figure 280: Speed over ground and differential pressure for each tow in the 2013 survey. The optimal speed over ground (3 kt) is marked with a horizontal dashed line. Differential pressure is the difference between the pressure in the dredge manifold, which indicates the absolute pressure realized by the dredges hydraulic jets, and the ambient pressure at fishing depth. The vertical line is plotted at 130 psi for reference only. Instrument failure or lost data are represented by differential pressure equal to 0.

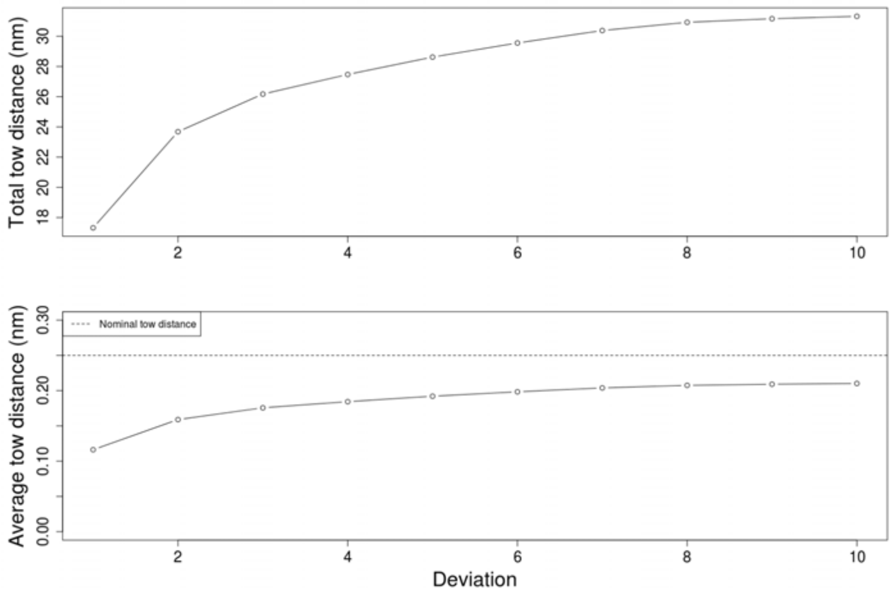


Figure 281: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

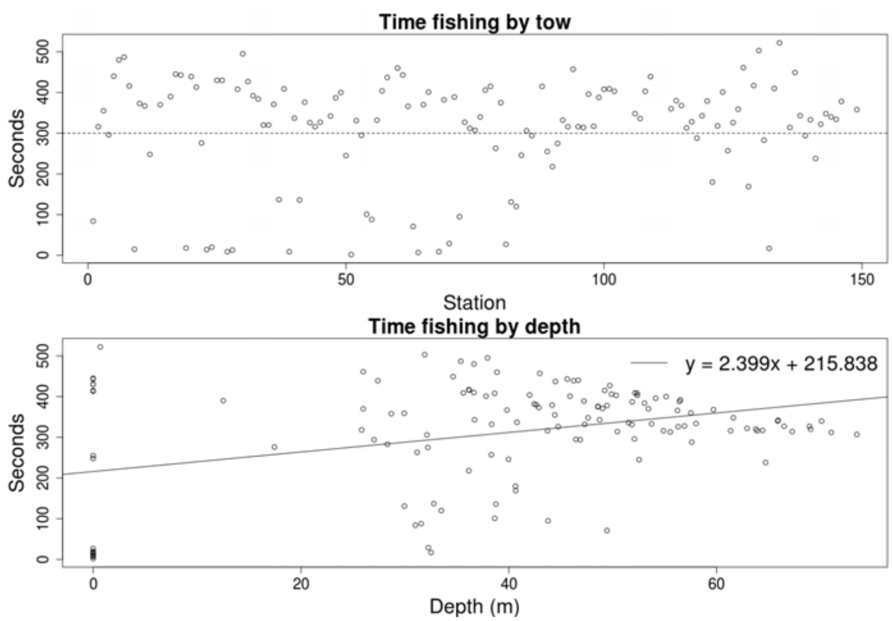


Figure 282: Time fished by station and depth. Depth significantly predicts tow time. The p value for slope was < 0.001, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

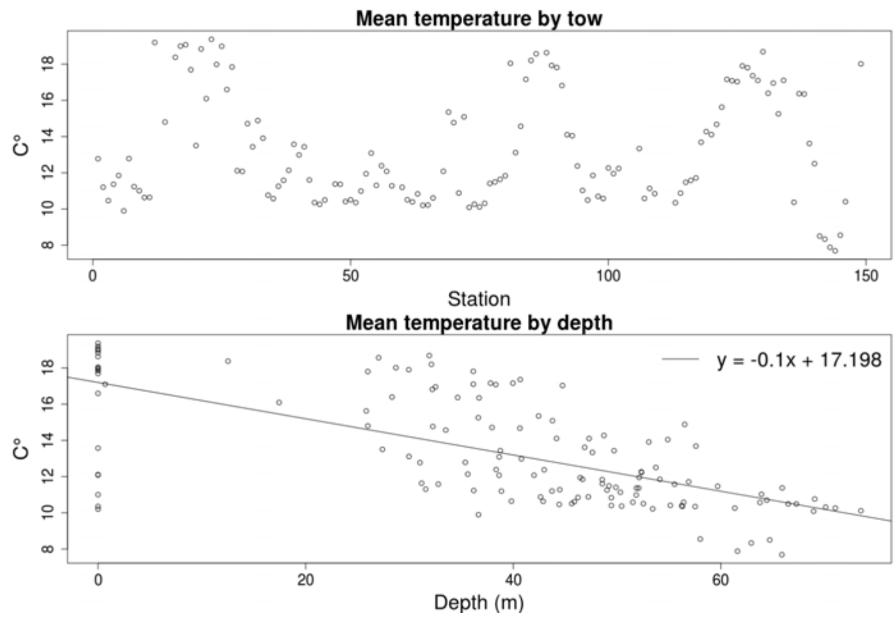


Figure 283: Temperature by station and depth. Depth significantly predicts temperature. The p value for slope was < 0.001 and $R^2 > 0.43$ for the regression line shown.

Appendix 17 Appendix: Survey performance 2014

Introduction

The 2014 survey covered portions of the SNE and GBK areas that were not sampled in 2013. There were 79 total tows and 49 experimental tows. Some sensor data was recorded on every completed tow except one. Therefore there were 29 standard survey tows on which sensors were deployed and sensor data was recorded.

The 2014 survey used a modified commercial dredge with 3 on board data recorders. There was an inclinometer (Star Oddi) and two (Madge Tech) pressure sensors: one in the pump manifold measuring the pressure in the hydraulic jets used to loosen the sediments around clams and one measuring the ambient pressure at fishing depth. The inclinometer measured the pitch roll and yaw of the dredge as it was towed and was used to determine if the dredge was in a fishing position, which was the basis for determining "time fishing" on each tow. The pressure sensors were used to make sure that the pump was achieving sufficient pressure to maintain capture efficiency.

Survey performance

Sensors deployed during the 2014 survey suggest that the average pump pressure was very close to the median pump pressure observed in 2012 (Figure 284). Speed over ground appeared to be somewhat less than in 2012 (Figure 284), but was well within the confidence bounds observed then and may be related to the type of substrate encountered and/or current strength. The ground fished was in some cases exceedingly rocky and difficult to dredge through, while currents on GBK and SNE are strong relative to areas further south. The tow speeds recorded were probably not sufficient in magnitude to cause concern regarding dredge efficiency and may represent the maximum advisable speed given the conditions. Neither pump pressure nor vessel speed appeared to be less than expected based on ship board instruments during operations. The values observed are probably well within normal operating tolerance and are probably not suggestive of changes in dredge performance.

Determination of time fishing

The determination of time fishing, the "fishing seconds" for each tow, was based on a measurement of the pitch of the dredge during each second of the tow. Roll and yaw were relatively stable for the large modified commercial dredge and rarely fluctuated from baseline levels during fishing events. Pitch was recorded by a Star Oddi inclinometer which functioned consistently. Data from each instrument was smoothed using a 7 second moving average and then parsed for time above or below the median fishing angle for that tow.

In order to account for median pitch $> 0^o$, the determination of time fishing was based on a critical deviation from median pitch, rather than an absolute critical pitch angle. The choice of critical deviation has implications for the calculation of tow distance for each tow. When the dredge is above or below the critical deviation it is assumed to be pitched too steeply for the blade to penetrate the sediment. If the dredge is pitched within Δ_{crit} (the critical deviation) of $\tilde{\phi}_t$ (the median pitch for tow t), it assumed to be near enough to parallel to the bottom that the blade should penetrate and thus be actively fishing.

An ideal critical deviation is as close to zero as possible, but not so small that it includes poor dredge performance seconds. When the dredge is bouncing over rough terrain it is unlikely to be fishing effectively and those seconds should be excluded. There is however, a certain amount of pitch that is within fishing tolerance and a certain amount of noise in the data. If the critical deviation is too small, many seconds when the dredge is actually fishing would be excluded, which would tend to bias estimates of tow distance down. It is therefore important to find a critical deviation that is neither too small, nor too large.

The choice of Δ_{crit} was informed by an examination of the total and average tow distances based on different critical deviations. Total tow distance summed across all tow and average tow distance over all tows was compared when different values of Δ_{crit} were used. In general higher values of Δ_{crit} result in longer tows because the dredge is considered to be in fishing position for a greater proportion of the tow (Figure 285). We selected a Δ_{crit} of 4° because it produced an average tow distance that was near the nominal tow distance (0.25 nm, a value equal to the nominal tow speed 3 kt multiplied by the nominal tow time 5 min) and because it seemed reasonable based on examination of the engineering schematic of the dredge being used (*Figure not yet available*)

Time fishing during the 2014 survey was less than the nominal tow time in most cases due to the lower average tow speed discussed above (Figure 286).

Effects of depth

Depth is typically associated with longer tows due to the scope of the towing wire that must be deployed to assure good dredge performance. Additional scope requires longer retrieval times and may result in some additional time fishing while the slack in the wire is spooled up. This effect was evident (though noisy) during the 2014 survey (Figure 286).

Temperature

Temperature was recorded from the dredge and averaged over fishing seconds for all tows during the 2014 survey (Figure 287). Temperature was correlated with depth (Figure 287).

Figures

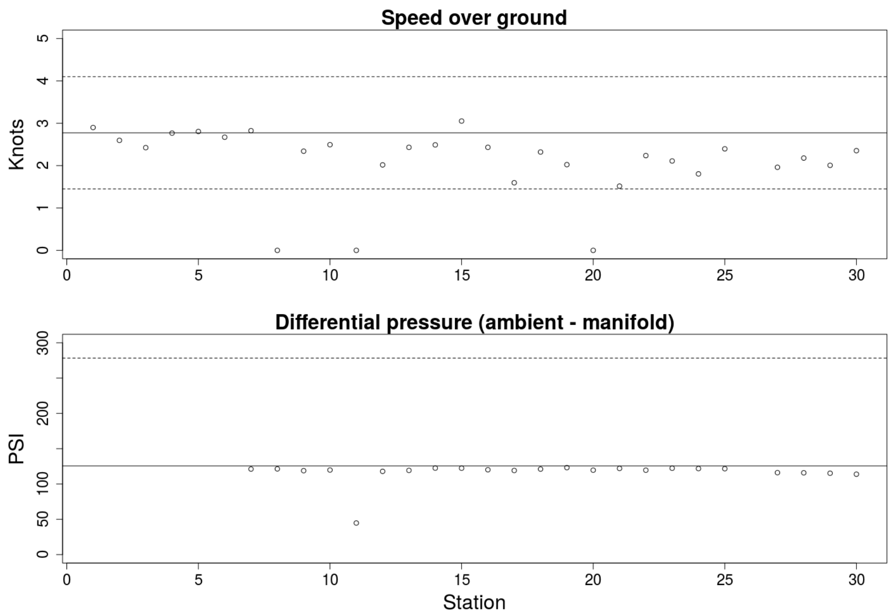


Figure 284: Speed over ground and differential pressure for each tow in the 2014 survey. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed speed over ground in 2012. Differential pressure is the difference between the pressure in the dredge manifold, which indicates the absolute pressure realized by the dredges hydraulic jets, and the ambient pressure at fishing depth. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed differential pressure in 2012. Instrument failure or lost data are represented by differential pressure equal to 0.

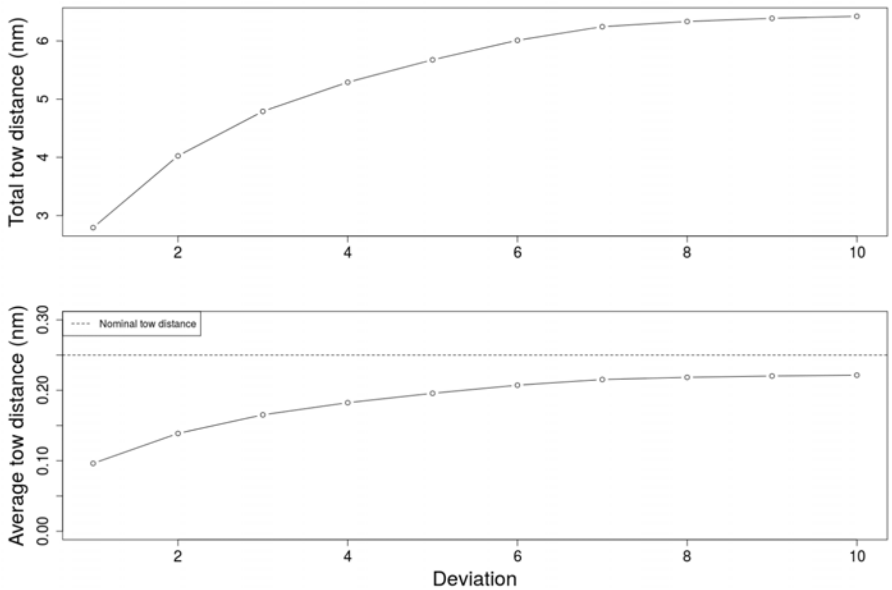


Figure 285: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

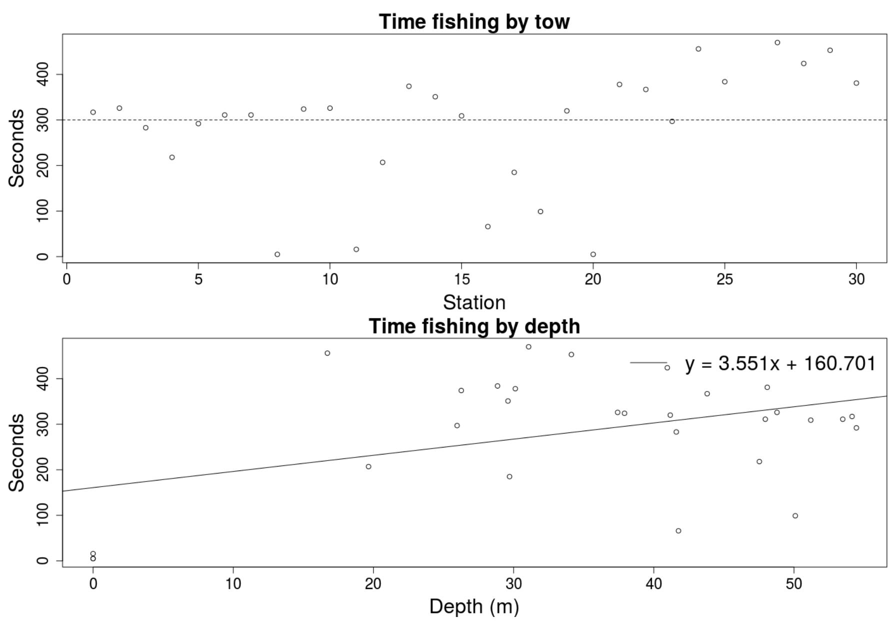


Figure 286: Time fished by station and depth. Depth significantly predicts tow time. The p value for slope was < 0.001, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

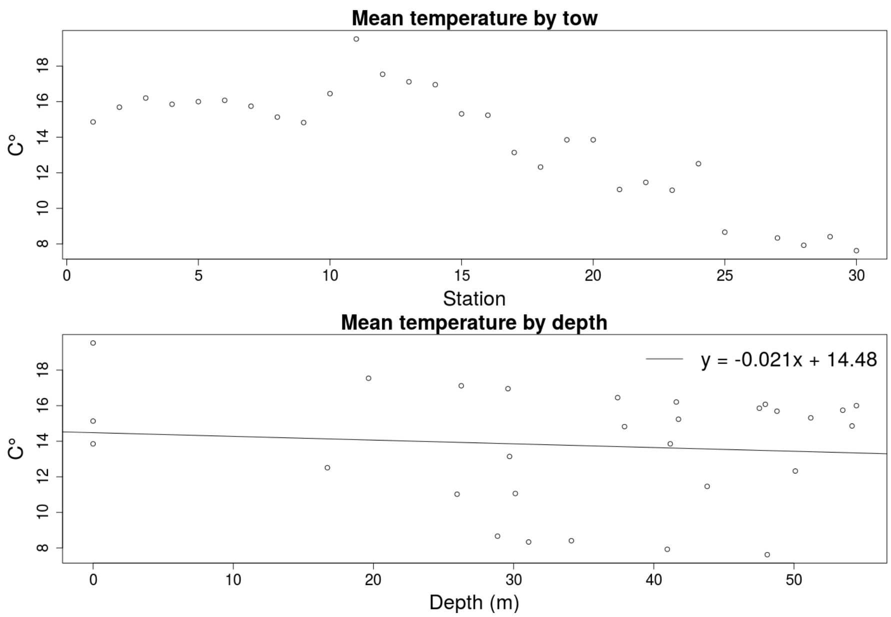


Figure 287: Temperature by station and depth. Depth significantly predicts temperature. The p value for slope was < 0.001 and $R^2 > 0.43$ for the regression line shown.

Appendix 18 Appendix: Survey performance 2015

Introduction

The 2015 survey covered a portion of the stock area including the SNE and most of GBK subareas. There were 189 total tows and two selectivity tows. At least some sensor information was recorded on every tow. Therefore there were 187 standard survey tows on which sensors were deployed and sensor data was recorded.

The 2015 survey used a modified commercial dredge with 3 on board data recorders. There was an inclinometer (Star Oddi) and two (Madge Tech) pressure sensors: one in the pump manifold measuring the pressure in the hydraulic jets used to loosen the sediments around clams and one measuring the ambient pressure at fishing depth. The inclinometer measured the pitch roll and yaw of the dredge as it was towed and was used to determine if the dredge was in a fishing position, which was the basis for determining "time fishing" on each tow. The pressure sensors were used to make sure that the pump was achieving sufficient pressure to maintain capture efficiency.

Survey performance

Sensors deployed during the 2015 survey suggest speed over ground was somewhat less than 2012, but consistent with the years since (Figure 288). Pump pressure was close to the 2012 median (Figure 288 and well within the confidence bounds observed then. Neither pump pressure nor vessel speed appeared to be less than expected based on ship board instruments during operations and the sensor data have substantial coefficients of variation. The values observed are probably well within normal operating tolerance and are probably not suggestive of changes in dredge performance.

Determination of time fishing

The determination of time fishing, the "fishing seconds" for each tow was based on a measurement of the pitch of the dredge during each second of the tow. Roll and yaw were relatively stable for the large modified commercial dredge and rarely fluctuated from baseline levels during fishing events. Pitch was recorded by a Star Oddi inclinometer which functioned consistently. Data from each instrument was smoothed using a 7 second moving average and then parsed for time above or below the median fishing angle for that tow.

In order to account for median pitch $> 0^o$, the determination of time fishing was based on a critical deviation from median pitch, rather than an absolute critical pitch angle. The choice of critical deviation has implications for the calculation of tow distance for each tow. When the dredge is above or below the critical deviation it is assumed to be pitched too steeply for the blade to penetrate the sediment. If the dredge is pitched within Δ_{crit} (the critical deviation) of $\tilde{\phi}_t$ (the median pitch for tow t), it assumed to be near enough to parallel to the bottom that the blade should penetrate and thus be actively fishing.

An ideal critical deviation is as close to zero as possible, but not so small that it includes poor dredge performance seconds. When the dredge is bouncing over rough terrain it is unlikely to be fishing effectively and those seconds should be excluded. There is however, a certain amount of pitch that is within fishing tolerance and a certain amount of noise in the data. If the critical deviation is too small, many seconds when the dredge is actually fishing would be excluded, which would tend to bias estimates of tow distance down. It is therefore important to find a critical deviation that is neither too small, nor too large.

The choice of Δ_{crit} was informed by an examination of the total and average tow distances based on different critical deviations. Total tow distance summed across all tow and average tow distance over all tows was compared when different values of Δ_{crit} were used. In general higher values of Δ_{crit} result in longer tows because the dredge is considered to be in fishing position for a greater proportion of the tow (Figure 289). We selected a Δ_{crit} of $4°$ because it produced an average tow distance that was near the nominal tow distance (0.25 nm, a value equal to the nominal tow speed 3 kt multiplied by the nominal tow time 5 min) and because it seemed reasonable based on examination of the engineering schematic of the dredge being used (*Figure not yet available*)

Time fishing during the 2015 survey was less than the nominal tow time in most cases due to the lower average tow speed discussed above (Figure 290).

Effects of depth

Depth is typically associated with longer tows due to the scope of the towing wire that must be deployed to assure good dredge performance. Additional scope requires longer retrieval times and may result in some additional time fishing while the slack in the wire is spooled up. This effect was evident (though noisy) during the 2015 survey (Figure 290).

Temperature

Temperature was recorded from the dredge and averaged over fishing seconds for all tows during the 2015 survey (Figure 291). Temperature was correlated with depth (Figure 291).

Figures

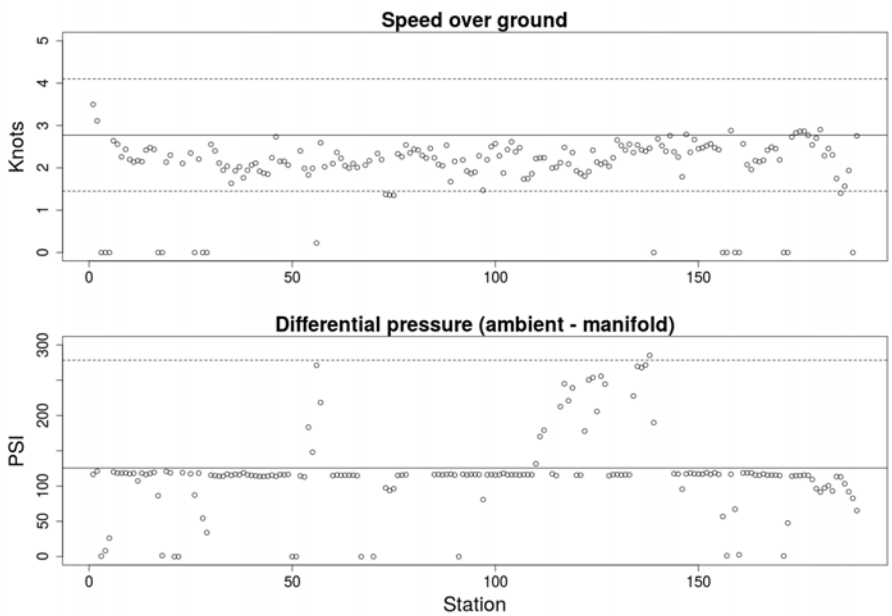


Figure 288: Speed over ground and differential pressure for each tow in the 2015 survey. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed speed over ground in 2012. Differential pressure is the difference between the pressure in the dredge manifold, which indicates the absolute pressure realized by the dredges hydraulic jets, and the ambient pressure at fishing depth. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed differential pressure in 2012. Instrument failure or lost data are represented by differential pressure equal to 0.

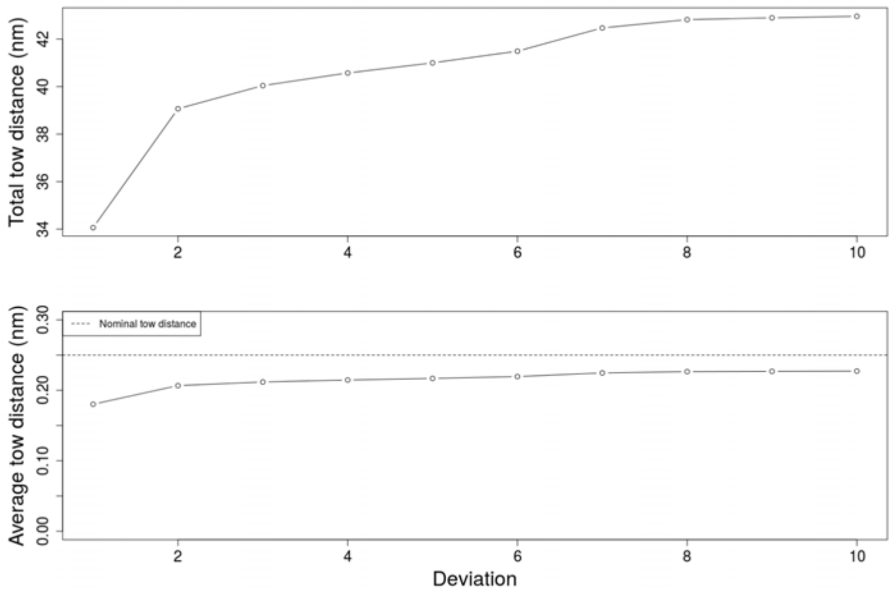


Figure 289: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

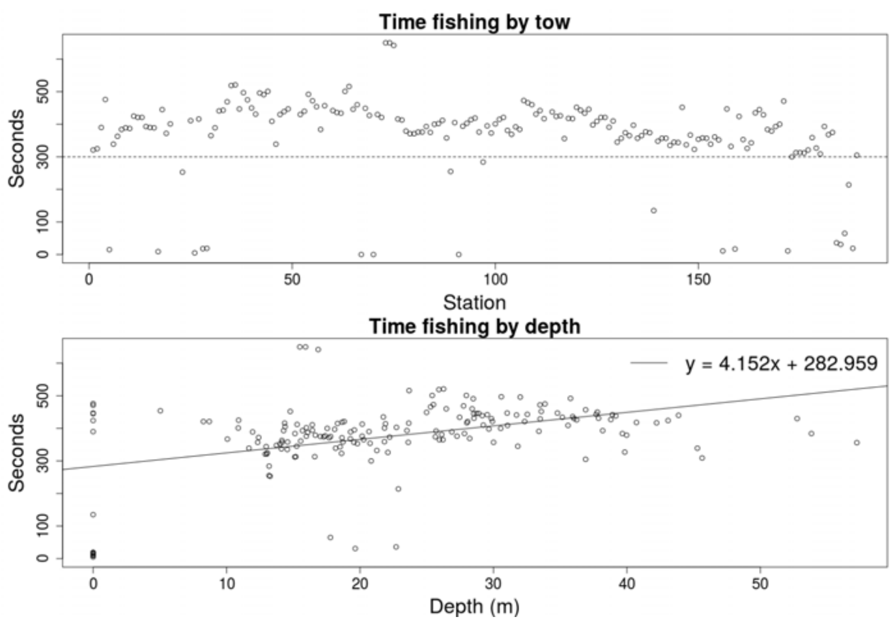


Figure 290: Time fished by station and depth. Depth significantly predicts tow time. The p value for slope was < 0.001, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

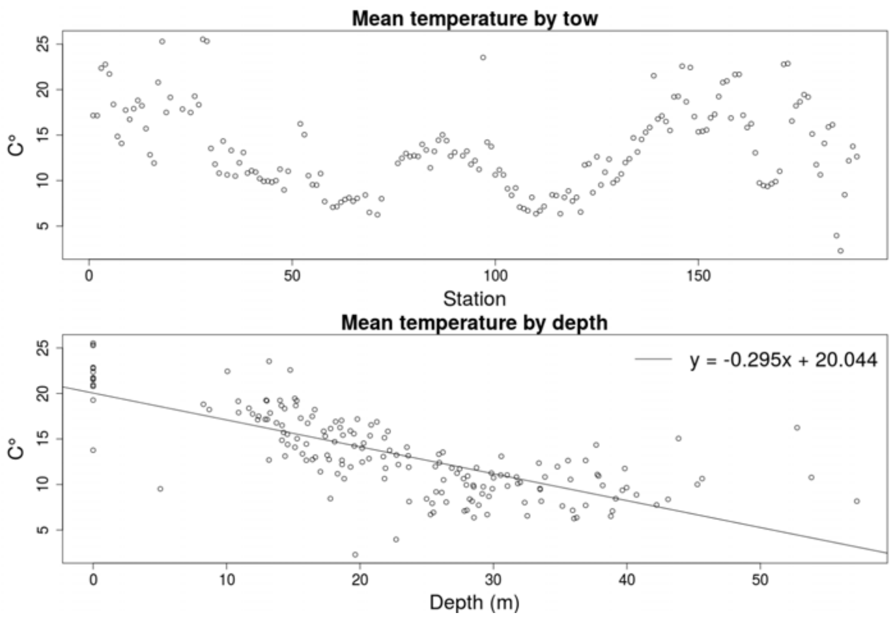


Figure 291: Temperature by station and depth. Depth significantly predicts temperature. The p value for slope was < 0.001 and $R^2 > 0.43$ for the regression line shown.

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The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Currently, there are three such media:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series typically includes: data reports of long-term field or lab studies of important species or habitats; synthesis reports for important species or habitats; annual reports of overall assessment or monitoring programs; manuals describing program-wide surveying or experimental techniques; literature surveys of important species or habitat topics; proceedings and collected papers of scientific meetings; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series typically includes: data reports on field and lab studies; progress reports on experiments, monitoring, and assessments; background papers for, collected abstracts of, and/or summary reports of scientific meetings; and simple bibliographies. Issues receive internal scientific review and most issues receive copy editing.

Resource Survey Report (formerly *Fishermen's Report*) -- This information report is a regularly-issued, quick-turnaround report on the distribution and relative abundance of selected living marine resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. This report undergoes internal review, but receives no technical or copy editing.

TO OBTAIN A COPY of a *NOAA Technical Memorandum NMFS-NE* or a *Northeast Fisheries Science Center Reference Document*, either contact the NEFSC Editorial Office (166 Water St., Woods Hole, MA 02543-1026; 508-495-2350) or consult the NEFSC webpage on "Reports and Publications" (http://www.nefsc.noaa.gov/publications/). To access *Resource Survey Report*, consult the Ecosystem Surveys Branch webpage (http://www.nefsc.noaa.gov/femad/ecosurvey/mainpage/).

NOAA's National Marine Fisheries Service

NOAA Fisheries Toolbox

Welcome to AIM

Welcome to **An Index Method (AIM) Version 2.5**.

An Index Method (AIM) allows the user to fit a relationship between time series of relative stock abundance indices and catch data. Underlying the methodology is a linear model of population growth, which characterizes the population response to varying levels of fishing mortality. If the underlying model is valid, **AIM** can be used to estimate the level of relative fishing mortality at which the population is likely to be stable. The index methodology can used to construct reference points based on relative abundance indices and catches and to perform deterministic or stochastic projections to achieve a target stock size.

Note: Version 2.5 no longer supports Lowess Smoothing

Version 2.1 introduces an improved graphical interface. This version also allows the user to perform Sensitivity Analysis on the numbers of years used to smooth Indices of Abundance and Relative Fishing Mortality. Version 2.2 adds Envelope Analysis.

The user will begin using the program by either opening an existing input data file or by creating a new case. After editing the input data, the user may launch the AIM calculation engine module and then review the model results in tables and graphs, or view an output report file.

North Pacific Fishery Management Council

Groundfish Species Profiles

2015

Biology • Management • Catch History • Economics • Assessment• Fishery

Since 1976, the North Pacific Fishery Management Council has provided responsible stewardship of the groundfish resources under its jurisdiction, resulting in sustainable and profitable fisheries off Alaska. The foundation for this success is the scientifically based annual catch limits that are established for each target groundfish stock, species, or species complex. The NMFS Alaska Fisheries Science Center provides the necessary scientific information, ranging from basic research data on life history parameters to fishery independent surveys and rigorous stock assessments. These stock assessments are peer reviewed by the BSAI and GOA Groundfish Plan Teams and the Scientific and Statistical Committee. Using this information, the Council establishes total allowable catch levels that do not exceed biologically sustainable catch limits set by the scientists. All catch accrues towards the total allowable catch levels, and catches are closely monitored by the NMFS Alaska Regional Office during the season based on data from mandatory electronic reporting by vessels and processing plants, and a comprehensive observer program.

This publication was developed to provide the public with readily available and accessible information about the federally managed groundfish fisheries. For more information on the Council's management program, I invite you to visit the website at www.npfmc.org.

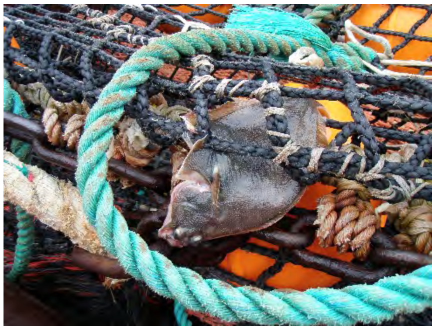
Dave Witherell

Deputy Director, NPFMC

This 2015 update was prepared by David Witherell and Jim Armstrong based on the annual Stock Assessment and Fishery Evaluation (SAFE) reports, which are assembled by the groundfish plan teams and include contributions from numerous assessment authors (see list of contributors at the end of the document). Front cover image courtesy of Julianne Curry, United Fishermen of Alaska, and back cover image courtesy of SeaAlliance and Alaska Groundfish Databank. Special thanks to those who provided editorial revisions and suggestions to improve the report: Sandra Lowe, Jim Ianelli, Grant Thompson, Steve Barbeaux, Jon Heifetz, Dana Hanselman, Chris Lunsford, Carey McGilliard, Olav Ormseth, Phil Rigby, Ingrid Spies, Paul Spencer, Cindy Tribuzio, Tom Wilderbuer, Elizabeth Conners, Martin Dorn, Teresa D'mar, Jack Turnock, and Diana Stram, as well as Mike Sigler who prepared many of the BSAI figures.

Species Profiles

Bering Sea/Aleutian Islands



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Gulf of Alaska

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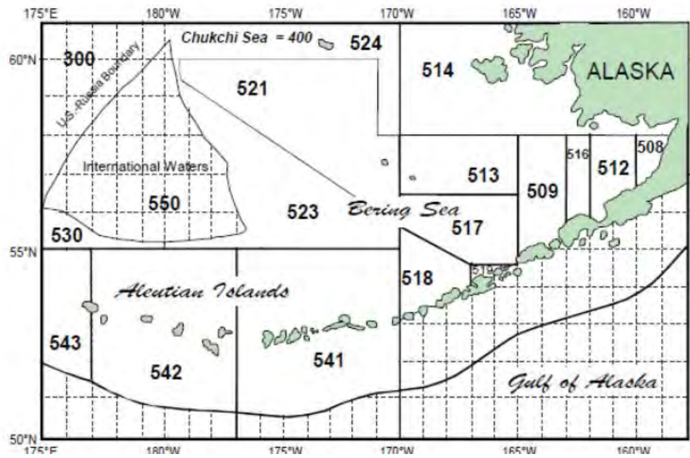
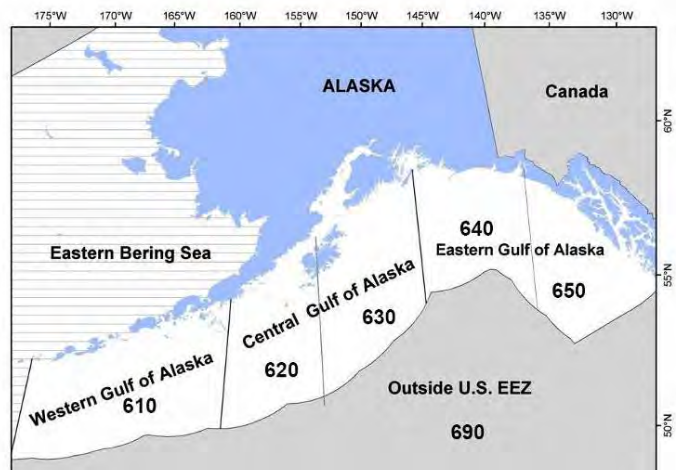
AFSC, NOAA Fisheries

Common Acronyms

ABC	Acceptable Biological Catch
ACL	Annual Catch Limit
AFA	American Fisheries Act
AI	Aleutian Islands
AP	Advisory Panel
ADF&G	Alaska Department of Fish and Game
AFSC	Alaska Fisheries Science Center
BSAI	Bering Sea and Aleutian Islands
CDQ	Community Development Quota
CP	Catcher Processor
CV	Catcher Vessel
EBS	Eastern Bering Sea
ESA	Endangered Species Act
F/V	Fishing Vessel
FMP	Fishery Management Plan
GOA	Gulf of Alaska
IFQ	Individual Fishing Quotas
LLP	License Limitation Program
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MSST	Minimum Stock Size Threshold
MSY	Maximum Sustainable Yield
mt	Metric Ton
NMFS	National Marine Fisheries Service
NPFMC	North Pacific Fishery Management Council
OFL	Overfishing Level
POP	Pacific ocean perch
PSC	Prohibited species catch
QS	Quota Share
SAFE	Stock Assessment and Fishery Evaluation
SSC	Scientific and Statistical Committee
TAC	Total allowable catch

Regulatory Areas

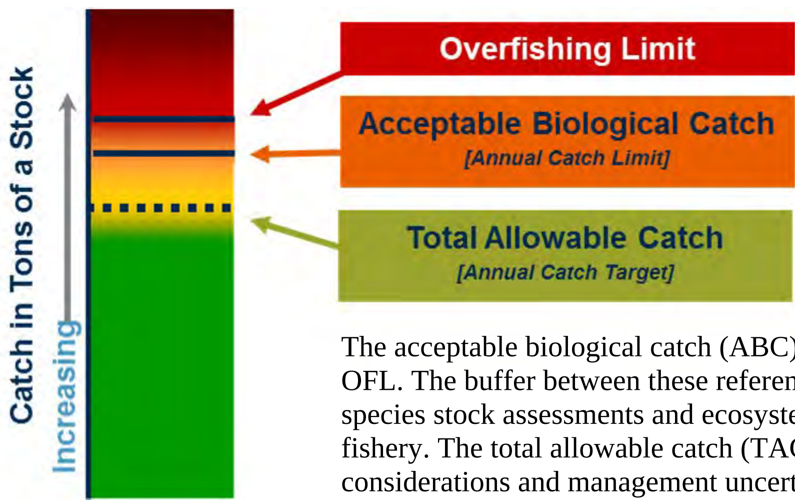




Steve Barbeaux, AFSC

Forward

Strict annual catch limits for every target fishery have proven an effective management tool for achieving sustainable fisheries. In the North Pacific, a rigorous process in place for over 35 years ensures that annual quotas are set at conservative, sustainable levels for each of our managed groundfish stocks. Below is a brief summary of the process for setting annual catch limits for Gulf of Alaska groundfish (comprised of 141 species) Bering Sea and Aleutian Islands groundfish (comprised of 148 species).



Three reference points are used for management of groundfish fisheries in the North Pacific. The overfishing level (OFL) is the catch limit which should never be exceeded. It is based on the fishing mortality rate associated with producing the maximum sustainable yield on a continuing basis. The acceptable biological catch (ABC) is the annual catch limit, and is set lower than the OFL. The buffer between these reference points allows for scientific uncertainty in single species stock assessments and ecosystem considerations, and operational management of the fishery. The total allowable catch (TAC) is the target catch level that incorporates economic considerations and management uncertainty. The fishery management plans prescribe that TAC may equal but never exceed ABC, such that **TAC≤ABC<OFL**. The sum of TACs for all groundfish stocks must also remain within the optimum yield range defined in the FMP. In the BSAI, the upper limit is 2 million mt, which can be constraining. TAC may be set lower than ABC for a variety of reasons, such as to remain under the 2 million mt optimum yield limit; to increase a rebuilding rate or address other conservation issues; to limit incidental bycatch; or to account for state water removals. Fisheries are managed in-season to achieve the TACs without exceeding the ABC or OFL. All catch taken in directed fisheries or caught incidentally in other fisheries, whether retained or discarded, accrues towards the TAC.

Catch Limit Control Rules for North Pacific Groundfish.

Tier 1: Reliable point estimates of B and B_{MSY} and pdf of F_{MSY} .
- 1a) Stock status: $B/B_{MSY} > 1$
  - $F_{OFL} = mA$, the arithmetic mean of the pdf
  - $F_{ABC} \leq mH$, the harmonic mean of the pdf
- 1b) Stock status: $\alpha < B/B_{MSY} \leq 1$
  - $F_{OFL} = mA \times (B/B_{MSY} - \alpha)/(1 - \alpha)$
  - $F_{ABC} \leq mH \times (B/B_{MSY} - \alpha)/(1 - \alpha)$
- 1c) Stock status: $B/B_{MSY} \leq \alpha$
  - $F_{OFL} = 0$; $F_{ABC} = 0$

Tier 2: Reliable point estimates of B, B_{MSY} , F_{MSY} , $F_{35\%}$, and $F_{40\%}$.
- 2a) Stock status: $B/B_{MSY} > 1$
  - $F_{OFL} = F_{MSY}$
  - $F_{ABC} \leq F_{MSY} \times (F_{40\%}/F_{35\%})$
- 2b) Stock status: $\alpha < B/B_{MSY} \leq 1$
  - $F_{OFL} = F_{MSY} \times (B/B_{MSY} - \alpha)/(1 - \alpha)$
  - $F_{ABC} \leq F_{MSY} \times (F_{40\%}/F_{35\%}) \times (B/B_{MSY} - \alpha)/(1 - \alpha)$
- 2c) Stock status: $B/B_{MSY} \leq \alpha$
  - $F_{OFL} = 0$; $F_{ABC} = 0$

Tier 3: Reliable point estimates of B, $B_{40\%}$, $F_{35\%}$, and $F_{40\%}$.
- 3a) Stock status: $B/B_{40\%} > 1$
  - $F_{OFL} = F_{35\%}$; $F_{ABC} \leq F_{40\%}$
- 3b) Stock status: $\alpha < B/B_{40\%} \leq 1$
  - $F_{OFL} = F_{35\%} \times (B/B_{40\%} - \alpha)/(1 - \alpha)$
  - $F_{ABC} \leq F_{40\%} \times (B/B_{40\%} - \alpha)/(1 - \alpha)$
- 3c) Stock status: $B/B_{40\%} \leq \alpha$
  - $F_{OFL} = 0$; $F_{ABC} = 0$

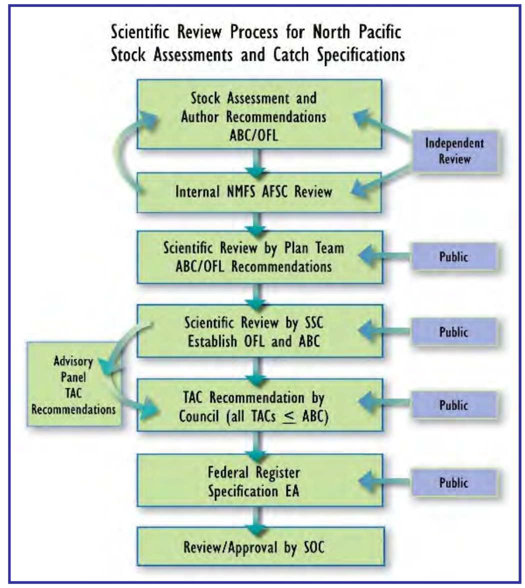
Tier 4: Reliable point estimates of B, $F_{35\%}$, and $F_{40\%}$.
- $F_{OFL} = F_{35\%}$; $F_{ABC} \leq F_{40\%}$

Tier 5: Reliable point estimates of B and natural mortality rate M.
- $F_{OFL} = M$; $F_{ABC} \leq 0.75 \times M$

Tier 6: Reliable catch history from 1978 through 1995.
- OFL = the average catch, unless an alternative value is established by the SSC.
- $ABC \leq 0.75 \times$ OFL

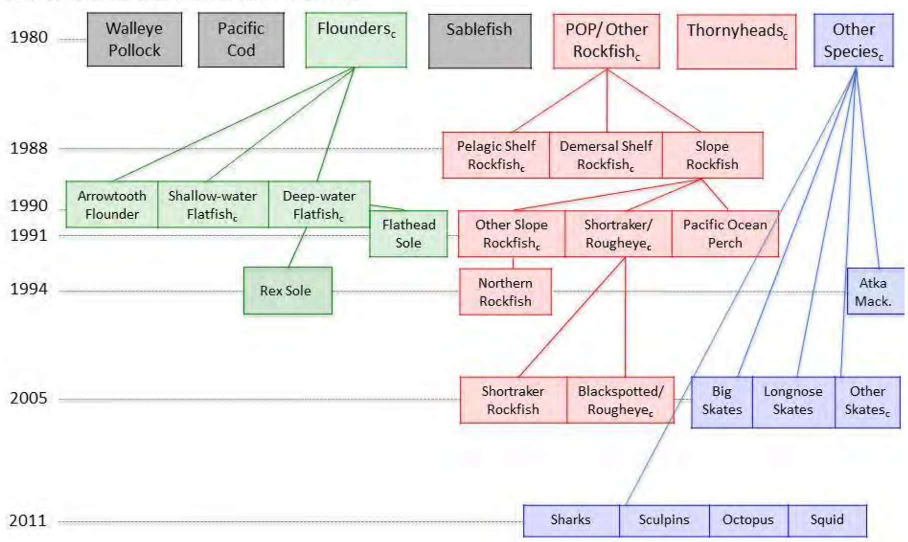
The catch limits are specified annually through an established public process. The annual process of determining OFL and ABC specifications begins with the assignment of each stock to one of six “tiers” based on the availability of information about that stock. Stocks in Tier 1 have the most information, and those in Tier 6, the least. Application of a control rule for each tier prescribes the resulting OFL and maximum ABC for each stock. For many groundfish stocks F_{ABC} is set at $F_{40\%}$. $F_{40\%}$ is the fishing mortality rate at which the spawning biomass per recruit is reduced to 40% of its value in the equivalent unfished stock. The control rules for Tiers 1-3 also provide for better chances of rebuilding, because if a stock falls below target biomass level, rates for computing ABC and OFL are reduced.

Scientists prepare an assessment of the status of each stock (or stock complex), and include alternate model simulations and tier assignments to arrive at recommendations for OFLs and ABCs. The Groundfish Plan Teams review the assessments and compile them into Stock Assessment and Fishery Evaluation (SAFE) reports, develop their own OFL and ABC recommendations (which may differ from the stock assessment author), and present this information to the Council and its Scientific and Statistical Committee (SSC) and Advisory Panel (AP). The SSC is responsible for setting the Council's OFLs and ABCs, using the SAFE reports and Plan Team recommendations. The SSC retains the flexibility to adjust ABC values downward from the control rule, based on factors such as multispecies interactions, ecosystem considerations, and additional scientific uncertainty. The Council then sets the TAC levels at or below the ABC levels, incorporating recommendations from the Advisory Panel and stakeholders. The public has an opportunity to provide input at each step in the process.

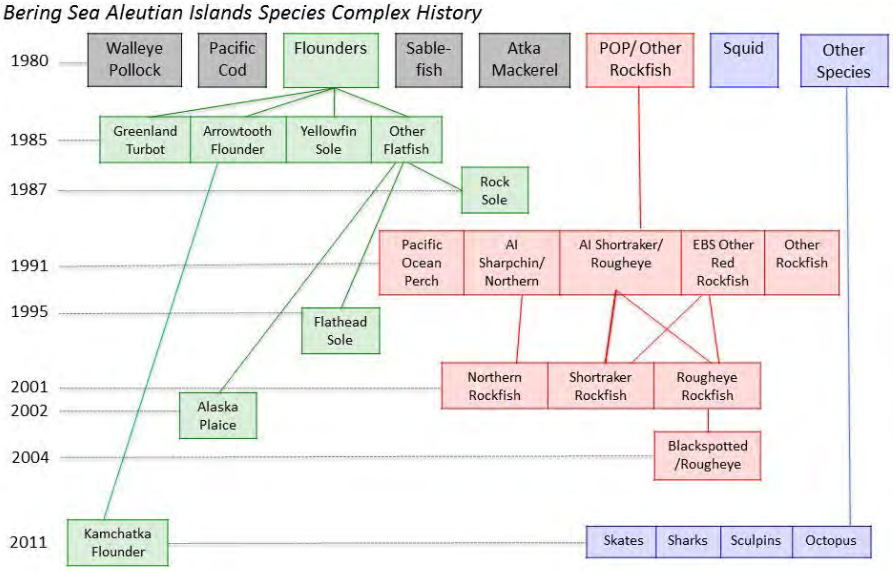


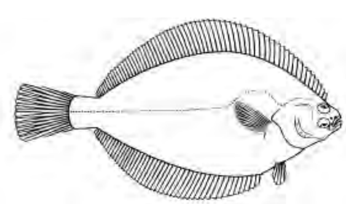
Groundfish stock groupings for establishing catch limits have evolved over time as new scientific information has become available and new markets have developed for certain species. The original fishery management plans set catch limits for the few major target species (e.g., Pollock, Cod, Sablefish), with the remaining species managed in a few complex groups (e.g., flounders, rockfish, other species). Over time, with new information and new fisheries developing, species were separated out from the complexes and assigned their own catch limits. Currently, there are nearly 50 separate single species groundfish stocks or species complexes that are assigned annual catch limits. For many of these stocks, catch limits are further subdivided into each regulatory area as a precautionary measure to prevent disproportionate exploitation rates in small areas, in case the stock consists of multiple populations.

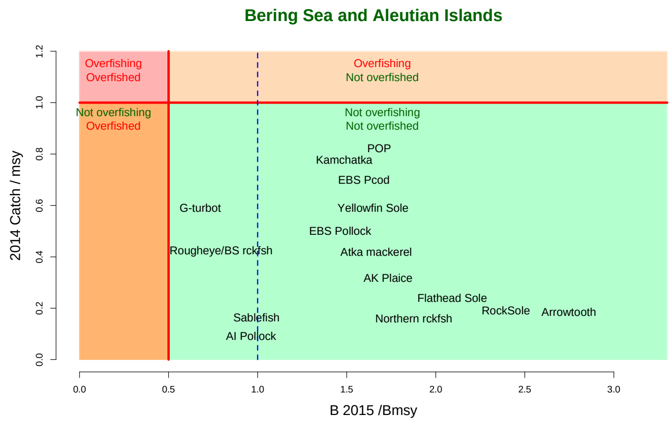
Gulf of Alaska Species Complex History

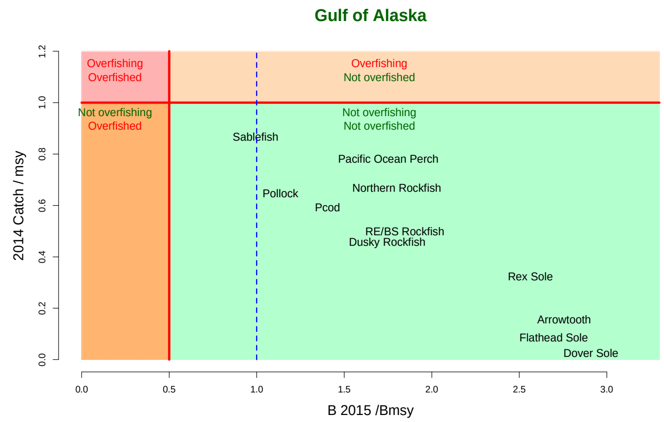


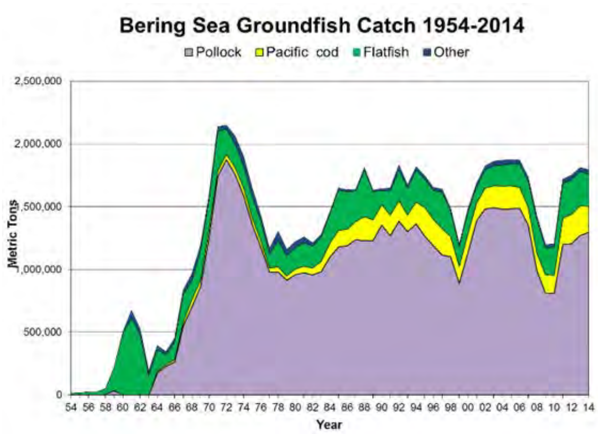
Bering Sea Aleutian Islands Species Complex History





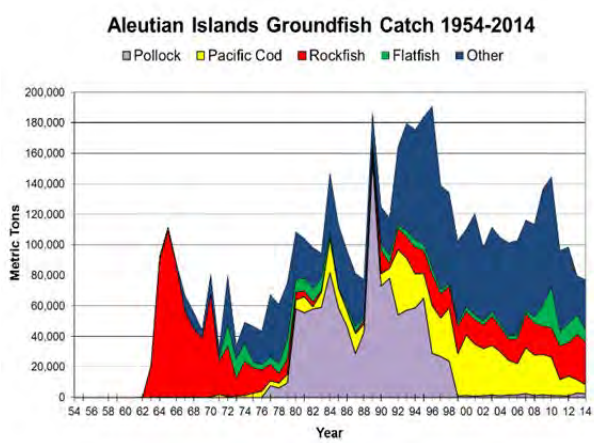


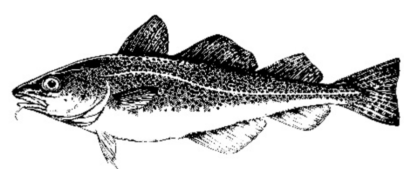


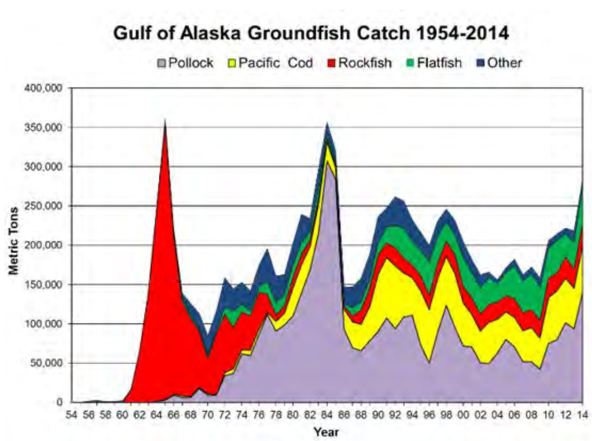


The Council's conservative catch limit policies, combined with favorable environmental conditions, have resulted in abundant fish stocks and sustainable fisheries. No groundfish stock is overfished or undergoing overfishing. Further, most stocks are well above the target biomass levels that produces maximum sustainable yield (B_{msy}).

The total catch and species composition of the catch has remained relatively stable since 1976 with the formation of the Council and development of the fishery management program. Prior to 1976, fisheries were only minimally regulated by bilateral agreements between the U.S. and foreign nations with fishing fleets off Alaska (Japan, USSR, South Korea, and Taiwan). Very high catches of Yellowfin Sole, rockfish, and Pollock were taken during this time. Catches and targets began to stabilize with the development of the U.S. fishing fleet through joint ventures in the 1980s. By the time the U.S. fishery was fully developed in 1991, the catch composition was more dependent on the TAC limits than on certain species being targeted. The variability in total groundfish catch in the Bering Sea and Gulf of Alaska is now due mainly to changes in Pollock biomass and resulting changes in annual catch limits.







Catch Specifications

At each December meeting, the Council specifies catch limits for a two year period, which when implemented (in early March) supersede the limits that were set the prior year to start the fishery (which opens January 1). For example, the adjacent specification tables adopted by the Council in December 2014 will be implemented for 2015 and 2016 fisheries, effectively replacing the catch limits that were previously recommended. The 2-year cycle allows for the use of the most recent biological information in the stock assessment while eliminating any potential delay or gap in setting the second year's limits.

Bering Sea & Aleutian Islands

Catch Specifications for 2015-2016 BSAI Groundfish

Species	Area	2015 OFL	2015 ABC	2015 TAC	2016 OFL	2016 ABC	2016 TAC
Pollock	EBS	3,330,000	1,637,000	1,310,000	3,490,000	1,554,000	1,310,000
	AI	36,005	29,659	19,000	38,699	31,900	19,000
	Bogoslof	21,200	15,900	100	21,200	15,900	100
Pacific cod	BS	346,000	255,000	240,000	389,000	255,000	240,000
	AI	23,400	17,600	9,422	23,400	17,600	9,422
Sablefish	BS	1,575	1,333	1,333	1,431	1,211	1,211
	AI	2,128	1,802	1,802	1,934	1,637	1,637
Yellowfin sole	BSAI	266,400	248,800	149,000	262,900	245,500	149,000
Greenland turbot	BSAI	3,903	3,172	2,648	6,453	5,248	2,648
	BS	n/a	2,448	2,448	n/a	4,050	2,448
	AI	n/a	724	200	n/a	1,198	200
Arrowtooth flounder	BSAI	93,856	80,547	22,000	91,663	78,661	22,000
Kamchatka flounder	BSAI	10,500	9,000	6,500	11,000	9,500	6,500
Northern rock sole	BSAI	187,600	181,700	69,250	170,100	164,800	69,250
Flathead sole	BSAI	79,419	66,130	24,250	76,504	63,711	24,250
Alaska plaice	BSAI	54,000	44,900	18,500	51,600	42,900	18,500
Other flatfish	BSAI	17,700	13,250	3,620	17,700	13,250	3,620
Pacific Ocean perch	BSAI	42,558	34,988	32,021	40,809	33,550	31,991
	BS	n/a	8,771	8,021	n/a	8,411	8,021
	EAI	n/a	8,312	8,000	n/a	7,970	7,970
	CAI	n/a	7,723	7,000	n/a	7,406	7,000
	WAI	n/a	10,182	9,000	n/a	9,763	9,000
Northern rockfish	BSAI	15,337	12,488	3,250	15,100	12,295	3,250
Blackspotted/Rougheye rockfish	BSAI	560	453	349	688	555	349
	EBS/EAI	n/a	149	149	n/a	178	149
	CAI/WAI	n/a	304	200	n/a	377	200
Shortraker rockfish	BSAI	690	518	250	690	518	250
Other rockfish	BSAI	1,667	1,250	880	1,667	1,250	880
	BS	n/a	695	325	n/a	695	325
	AI	n/a	555	555	n/a	555	555
Atka mackerel	BSAI	125,297	106,000	54,500	115,908	98,137	54,817
	EAI/BS	n/a	38,492	27,000	n/a	35,637	27,317
	CAI	n/a	33,108	17,000	n/a	30,652	17,000
	WAI	n/a	34,400	10,500	n/a	31,848	10,500
Skates	BSAI	49,575	41,658	25,700	47,035	39,468	25,700
Sculpins	BSAI	52,365	39,725	4,700	52,365	39,725	4,700
Sharks	BSAI	1,363	1,022	125	1,363	1,022	125
Squids	BSAI	2,624	1,970	400	2,624	1,970	400
Octopuses	BSAI	3,452	2,589	400	3,452	2,589	400

Gulf of Alaska

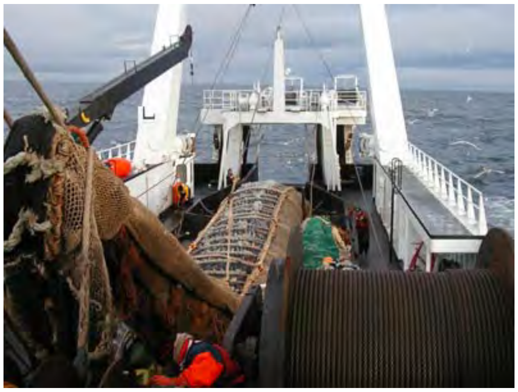
Catch Specifications for 2015-2016 GOA Groundfish

Species	Area	2015 OFL	2015 ABC	2015 TAC	2016 OFL	2016 ABC	2016 TAC
Pollock	W (61)	n/a	31,634	31,634	n/a	41,472	41,472
	C (62)	n/a	97,579	97,579	n/a	127,936	127,936
	C (63)	n/a	52,594	52,594	n/a	68,958	68,958
	WYAK	n/a	4,719	4,719	n/a	6,187	6,187
	Subtotal	256,545	191,309	186,526	321,067	250,824	244,553
	EYAK/SEO	16,833	12,625	12,625	16,833	12,625	12,625
	Total	273,378	203,934	199,151	337,900	263,449	257,178
Pacific Cod	W	n/a	38,702	27,091	n/a	38,702	27,091
	C	n/a	61,320	45,990	n/a	61,320	45,990
	E	n/a	2,828	2,121	n/a	2,828	2,121
	Total	140,300	102,850	75,202	133,100	102,850	75,202
Sablefish	W	n/a	1,474	1,474	n/a	1,338	1,338
	C	n/a	4,658	4,658	n/a	4,232	4,232
	WYAK	n/a	1,708	1,708	n/a	1,552	1,552
	SEO	n/a	2,682	2,682	n/a	2,436	2,436
	Total	12,425	10,522	10,522	11,293	9,558	9,558
Shallow-Water Flatfish	W	n/a	22,074	13,250	n/a	19,577	13,250
	C	n/a	19,297	19,297	n/a	17,114	17,114
	WYAK	n/a	2,209	2,209	n/a	1,959	1,959
	EYAK/SEO	n/a	625	625	n/a	554	554
	Total	54,207	44,205	35,381	48,407	39,204	32,877
Deep-Water Flatfish	W	n/a	301	301	n/a	299	299
	C	n/a	3,689	3,689	n/a	3,645	3,645
	WYAK	n/a	5,474	5,474	n/a	5,409	5,409
	EYAK/SEO	n/a	3,870	3,870	n/a	3,824	3,824
	Total	15,993	13,334	13,334	15,803	13,177	13,177
Rex Sole	W	n/a	1,258	1,258	n/a	1,234	1,234
	C	n/a	5,816	5,816	n/a	5,707	5,707
	WYAK	n/a	772	772	n/a	758	758
	EYAK/SEO	n/a	1,304	1,304	n/a	1,280	1,280
	Total	11,957	9,150	9,150	11,733	8,979	8,979
Arrowtooth Flounder	W	n/a	30,752	14,500	n/a	29,545	14,500
	C	n/a	114,170	75,000	n/a	109,692	75,000
	WYAK	n/a	36,771	6,900	n/a	35,328	6,900
	EYAK/SEO	n/a	11,228	6,900	n/a	10,787	6,900
	Total	226,390	192,921	103,300	217,522	185,352	103,300
Flathead Sole	W	n/a	12,767	8,650	n/a	12,776	8,650
	C	n/a	24,876	15,400	n/a	24,893	15,400
	WYAK	n/a	3,535	3,535	n/a	3,538	3,538
	EYAK/SEO	n/a	171	171	n/a	171	171
	Total	50,792	41,349	27,756	50,818	41,378	27,759

Species	Area	2015 OFL	2015 ABC	2015 TAC	2016 OFL	2016 ABC	2016 TAC
Pacific Ocean Perch	W		2,302	2,302		2,358	2,358
	C		15,873	15,873		16,184	16,184
	WYAK		2,014	2,014		2,055	2,055
	W/C/WYAK	23,406	20,189	20,189	23,876	20,597	20,597
	SEO	954	823	823	973	839	839
	E(subtotal)		2,837	2,837		2,894	2,894
	Total	24,360	21,012	21,012	24,849	21,436	21,436
Northern Rockfish	W	n/a	1,226	1,226	n/a	1,158	1,158
	C	n/a	3,772	3,772	n/a	3,563	3,563
	E	n/a	-		n/a	-	
	Total	5,961	4,998	4,998	5,631	4,721	4,721
Shortraker Rockfish	W	n/a	92	92	n/a	92	92
	C	n/a	397	397	n/a	397	397
	E	n/a	834	834	n/a	834	834
	Total	1,764	1,323	1,323	1,764	1,323	1,323
Dusky Rockfish	W	n/a	296	296	n/a	273	273
	C	n/a	3,336	3,336	n/a	3,077	3,077
	WYAK	n/a	1,288	1,288	n/a	1,187	1,187
	EYAK/SEO	n/a	189	189	n/a	174	174
	Total	6,246	5,109	5,109	5,759	4,711	4,711
Rougheye and Blackspotted Rockfish	W	n/a	115	115	n/a	117	117
	C	n/a	632	632	n/a	643	643
	E	n/a	375	375	n/a	382	382
	Total	1,345	1,122	1,122	1,370	1,142	1,142
Demersal shelf rockfish	Total	361	225	225	361	225	225
Thornyhead Rockfish	W	n/a	235	235	n/a	235	235
	C	n/a	875	875	n/a	875	875
	E	n/a	731	731	n/a	731	731
	Total	2,454	1,841	1,841	2,454	1,841	1,841
Other Rockfish (Other slope)	WGOA &	n/a			n/a		
	CGOA	n/a	1,031	1,031	n/a	1,031	1,031
	WYAK	n/a	580	580	n/a	580	580
	EYAK/SEO	n/a	2,469	200	n/a	2,469	200
	Total	5,347	4,080	1,811	5,347	4,080	1,811
Atka mackerel	Total	6,200	4,700	2,000	6,200	4,700	2,000
Big Skate	W	n/a	731	731	n/a	731	731
	C	n/a	1,257	1,257	n/a	1,257	1,257
	E	n/a	1,267	1,267	n/a	1,267	1,267
	Total	4,340	3,255	3,255	4,340	3,255	3,255
Longnose Skate	W	n/a	152	152	n/a	152	152
	C	n/a	2,090	2,090	n/a	2,090	2,090
	E	n/a	976	976	n/a	976	976
	Total	4,291	3,218	3,218	4,291	3,218	3,218
Other Skates	Total	2,980	2,235	2,235	2,980	2,235	2,235
Sculpins	GOA-wide	7,448	5,569	5,569	7,448	5,569	5,569
Sharks	GOA-wide	7,986	5,989	5,989	7,986	5,989	5,989
Squids	GOA-wide	1,530	1,148	1,148	1,530	1,148	1,148
Octopuses	GOA-wide	2,009	1,507	1,507	2,009	1,507	1,507
Total		870,064	685,597	536,158	910,895	731,049	590,161


Megan Peterson, UAF

Walleye Pollock


Diana Stram, NPFMC

Biology: Walleye Pollock *Gadus chalcogrammus* is the most abundant fish species in the Bering Sea. In the Eastern Bering Sea (EBS), pollock are found throughout the water column and adults are concentrated along the outer continental shelf. Seasonal migrations occur from overwintering areas along the outer shelf to shallower waters to spawn. Pollock feed on copepods, euphausiids (krill) and fish (primarily juvenile pollock) and are prey for other fish, marine mammals and seabirds.

Pollock is a relatively fast growing and short lived species. They begin to recruit to the fishery at age 3 and longevity extends to 12 years or more. Annual natural mortality is estimated at 25% (M=0.30). Most fish reach maturity between ages 3 and 5. Females produce 60,000 to 400,000 pelagic eggs. Peak spawning occurs in the in the southeastern BS and eastern AI along the outer continental shelf in late February. Smaller spawning aggregations also occur in the northern Bering Sea in mid-late April.

Fishery Management: The U.S. manages pollock as 3 separate stocks; the Eastern Bering Sea stock (Unimak Pass to the U.S.-Russia Convention line), the Aleutian Islands stock (the Aleutian Islands shelf region from 170°W to the U.S.-Russia Convention line), and the Central Bering Sea - Bogoslof Island stock.

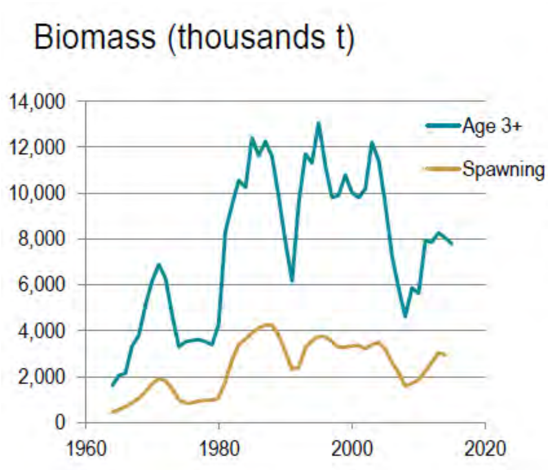
Stock assessment:

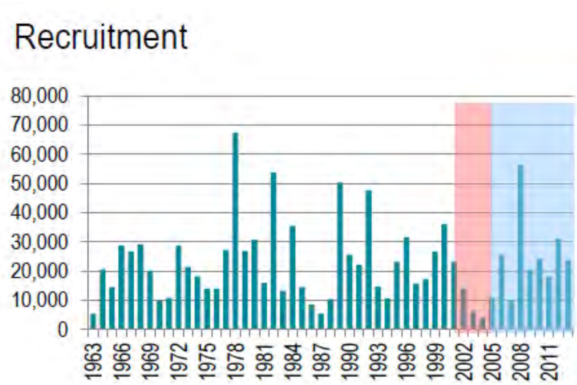
J. Ianelli, T. Honkalehto, S. Barbeaux, and S. Kotwicki. 2014. Assessment of Walleye Pollock in the Eastern Bering Sea.

www.afsc.noaa.gov/refm/stocks/assessments.htm

The American Fisheries Act (1998) established eligibility to participate in the BSAI pollock fishery and settled the contentious inshore/offshore allocation issue by establishing permanent allocations of pollock quota among sectors. CDQ groups are allocated 10% of EBS pollock TAC. The remaining TAC is divided up as follows; catcher vessels delivering inshore (50%), catcher processors offshore (40%) and catcher vessels delivering to motherships (10%). The 2004 Appropriations Act established that the non-CDQ pollock fishery in the AI is fully allocated to the Aleut Corporation, for the purpose of economic development in Adak, with a percentage allocated to vessels 60 feet or less in length overall.

The EBS pollock fishery has been redistributed spatially and seasonally to reduce the potential competition for prey with the endangered western stock of Steller sea lions, with fishery exclusion zones around sea lion rookeries. TACs have also been divided into





separate seasons since 2000; the "A-season" (Jan-Apr) and the "B-season" (Jun-Oct).

Catch History: Fisheries for Bering Sea pollock developed in 1964, and catches increased rapidly in the early 1970s and peaked in 1972 at 1.9 million mt. Early 1980s joint ventures were phased out by the domestic fleet by 1991. The international zone or "Donut Hole" also supported significant harvests of pollock through 1987, followed by a sharp decline and a fishing moratorium for the international zone beginning in 1993.

Stock Assessment: The EBS pollock assessment is based on a statistical age-structured model that incorporates fishery data and fishery independent data from annual bottom trawl surveys and biennial acoustic trawl surveys. Catch specifications for EBS pollock are established under Tier 1a of the ABC/OFL control rule. B_{msy} is equal to 1,948,000 mt. EBS catch specifications for 2015 are as follows; OFL=3,330,000, mt, ABC=1,637,000 mt, TAC=1,310,000 mt. The AI pollock ABC =29,659 mt and the Bogoslof ABC = 15,900 mt.

Biomass of EBS pollock declined steadily from 2004-2009 due to poor recruitment from the 2000-2005 year classes. The biomass is now increasing with recruitment of above average 2008 and 2010 year-classes.

Total catches, pre-season catch specifications, and exploitable biomass of age 3+ Walleye Pollock in the EBS 1980-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
1980	958,280	1,000,000	1,300,000	-	-
1981	973,502	1,000,000	1,300,000	-	-
1982	955,964	1,000,000	1,300,000	-	-
1983	981,450	1,000,000	1,300,000	-	-
1984	1,092,055	1,200,000	1,300,000	-	-
1985	1,139,676	1,200,000	1,300,000	-	-
1986	1,141,993	1,200,000	1,300,000	-	-
1987	859,416	1,200,000	1,300,000	-	-
1988	1,228,721	1,300,000	1,500,000	-	6,500,000
1989	1,229,600	1,340,000	1,340,000	-	5,300,000
1990	1,455,193	1,280,000	1,450,000	-	5,843,800
1991	1,195,646	1,300,000	1,676,000	-	6,667,146
1992	1,390,331	1,300,000	1,490,000	1,770,000	6,190,000
1993	1,326,601	1,300,000	1,340,000	1,340,000	5,900,000
1994	1,329,350	1,330,000	1,330,000	1,590,000	8,020,000
1995	1,264,245	1,250,000	1,250,000	1,500,000	8,080,000
1996	1,192,778	1,190,000	1,190,000	1,460,000	7,360,000
1997	1,124,430	1,130,000	1,130,000	1,980,000	6,120,000
1998	1,101,165	1,110,000	1,110,000	2,060,000	5,820,000
1999	989,816	992,000	992,000	1,720,000	7,040,000
2000	1,132,707	1,139,000	1,139,000	1,680,000	7,700,000
2001	1,387,194	1,400,000	1,842,000	3,536,000	10,060,000
2002	1,480,195	1,485,000	2,110,000	3,530,000	9,800,000
2003	1,490,899	1,491,760	2,330,000	3,530,000	11,100,000
2004	1,480,543	1,492,000	2,560,000	2,740,000	11,000,000
2005	1,483,286	1,478,500	1,960,000	2,100,000	8,410,000
2006	1,486,435	1,485,000	1,930,000	2,090,000	8,050,000
2007	1,354,097	1,394,000	1,394,000	1,640,000	6,360,000
2008	990,566	1,000,000	1,000,000	1,440,000	4,357,000
2009	810,784	815,000	815,000	977,000	6,240,000
2010	810,215	813,000	813,000	918,000	4,620,000
2011	1,199,069	1,252,000	1,267,000	2,447,000	9,620,000
2012	1,205,197	1,200,000	1,220,000	2,474,000	8,340,000
2013	1,270,745	1,247,000	1,375,000	2,550,000	8,140,000
2014	1,298,593	1,267,000	1,369,000	2,795,000	8,045,000
2015	-	1,310,000	1,637,000	3,330,000	9,203,000

[1]Catch data current through November 2014.
[2]TAC, ABC and OFL data from Federal Register Harvest Specifications.
[3]Biomass from annual SAFE report projections issued the previous year.

Fishery: The BSAI pollock fishery is prosecuted by relatively large vessels using pelagic trawls. A total of 77 catcher vessels delivering shoreside, 14 catcher vessels delivering to motherships, and 16 catcher processors participated in the 2014 fishery. The A-season fishery is focused in the southeast portion of the EBS and targets pre-spawning pollock. Roe, fillets and surimi are the main product forms of the A-season fishery, and approximately 40% of the TAC is caught during the A-season. The B-season fishery takes the remaining 60% of the quota and is distributed over the outer shelf edge of the Bering Sea extending to the Russian border.

Economics: Pollock fishery products include whole fish, head and gut, roe, deep-skin fillets, other fillets, surimi, minced fish, and fish meal. In 2013, production was 546,410 mt for all pollock products in Alaska, with a gross value of $1.33 billion. Surimi products comprised approximately 28% of the gross value of pollock products, roe comprised around 9%, and fillets about 42% of the gross value.

Ecosystem Components: Pollock are an important prey for fish, seabirds, and marine mammals (including Steller sea lions) in the BSAI.

Diana Evans, NPFMC

Pacific Cod

Biology: Pacific Cod *Gadus macrophalus* is a demersal species found in the EBS, the AI, and GOA south to California. Pacific Cod are distributed over the continental shelf at depths from shoreline to 500 m. Mature fish tend to concentrate on the outer continental shelf and prefer muddy or sandy soft sediment substrate. Juvenile Pacific cod feed primarily on small invertebrates and euphausiids, whereas adults feed on fish such as juvenile pollock, and invertebrates such as polychaetes, amphipods and crangonid shrimp. Predators of Pacific Cod include adult Pacific Cod, Pacific Halibut, salmon shark and Steller sea lions.

Pacific Cod are a relatively fast growing and short lived fish. Longevity can extend to 19 years. The size at 50% maturity is 58 cm (about 5 years). Females are highly fecund and can produce more than 1 million eggs. Adults form spawning aggregations from January to May in the BS. Natural mortality is estimated at M=0.34. Pacific Cod begin to recruit to the fisheries at age 3 and are 50% recruited by ages 4-5.

Catch History: Pacific Cod were taken by Japanese longline and trawl fisheries beginning in the early 1960s. Vessels from the USSR entered the fishery in 1971. Japanese and Russian fisheries harvested around 50,000 mt annually in the 1970s. Joint ventures became more prevalent in the early 1980s until they were entirely phased out by the domestic fleet a few years later. Catches have remained fairly stable since 1991, averaging just over 200,000 mt annually.

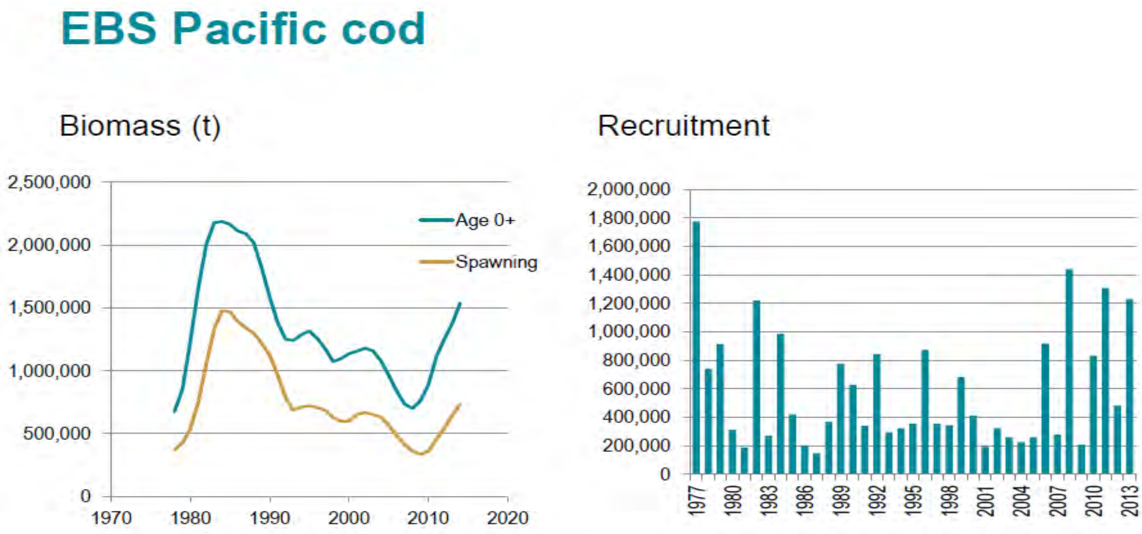
Jackie Patt, UAF

Fishery Management: Like most other groundfish, 10.7% of the TAC is allocated to CDQ fisheries. Since 2007 with implementation of Amendment 85, the remaining TAC is allocated among sectors as follows: 1.4% to jig gear; 2% to hook and line/pot catcher vessels < 60', 0.2% to hook and line/pot catcher vessels ≥ 60' LOA; 48.7% to hook and line catcher processors; 8.4% to pot catcher vessels > 60'; 1.5% to pot catcher processors; 2.3% to AFA trawl catcher processors; 13.4% to non-AFA trawl catcher processors; and 22.1% to trawl catcher vessels.

Stock assessment:

G. Thompson, 2014. Assessment of the Pacific Cod Stock in the Eastern Bering Sea.

www.afsc.noaa.gov/refm/stocks/assessments.htm



Stock Assessment: In the EBS, the Pacific Cod assessment is based on a Stock Synthesis model that uses both length-structured and age-structured data. This model incorporates fishery data and fishery-independent data from the NMFS EBS trawl surveys. Pacific Cod fall under Tier 3a of the ABC/OFL control rules. The 2015 Bering Sea Pacific Cod biomass is estimated at 1,680,000 mt. Catch specifications for Bering Sea cod in 2015 are as follows: OFL=346,000 mt (F_{OFL}=0.35), ABC=255,000 mt, TAC=240,000 mt. Catch specifications for Aleutian Islands stock of Pacific Cod in 2015 are: OFL=23,400 mt, ABC=17,600 mt, TAC=9,422 mt.

Estimated biomass of Pacific Cod has fluctuated over the last 40 years. The stock increased rapidly and peaked in the mid-1980s, then declined through 2008. Biomass has been increasing due to relatively good year classes produced in 2006, 2008, and 2011.

Total catches, pre-season catch specifications, and biomass of Pacific Cod in the BSAI, 1980-2013, and BS 2014 to present.

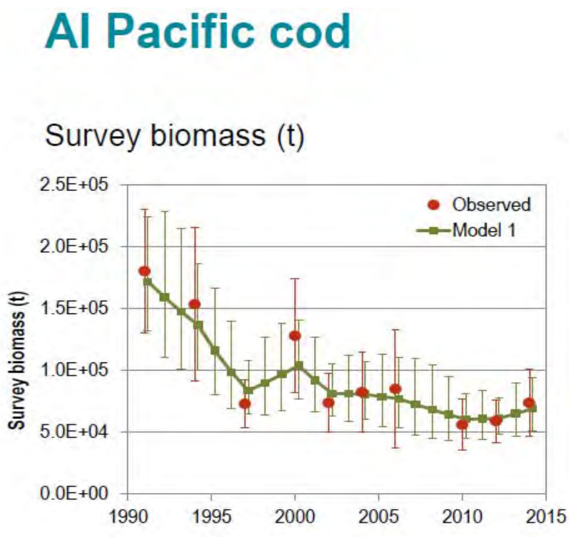
Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
1980	51,649	70,700	148,000	-	-
1981	63,941	78,700	160,000	-	-
1982	69,501	78,700	168,000	-	-
1983	103,231	120,000	298,200	-	-
1984	133,084	210,000	291,300	-	-
1985	150,384	220,000	347,400	-	-
1986	142,511	229,000	249,300	-	-
1987	163,110	280,000	400,000	-	-
1988	208,236	200,000	385,300	-	1,481,000
1989	182,865	230,681	370,600	-	1,190,000
1990	179,608	227,000	417,000	-	1,389,500
1991	172,158	229,000	229,000	-	1,030,000
1992	206,129	182,000	182,000	188,000	910,000
1993	167,390	164,500	164,500	192,000	655,000
1994	196,572	191,000	191,000	228,000	925,000
1995	245,030	250,000	328,000	390,000	1,620,000
1996	240,590	270,000	305,000	420,000	1,640,000
1997	234,641	270,000	306,000	418,000	1,590,000
1998	195,645	210,000	210,000	336,000	1,340,000
1999	162,361	177,000	177,000	264,000	1,210,000
2000	191,056	193,000	193,000	240,000	1,300,000
2001	176,659	188,000	188,000	248,000	1,320,000
2002	197,353	200,000	223,000	294,000	1,540,000
2003	211,059	207,500	223,000	324,000	1,680,000
2004	212,161	215,500	223,000	350,000	1,660,000
2005	205,635	206,000	206,000	265,000	1,290,000
2006	193,017	194,000	194,000	230,000	922,000
2007	174,486	170,720	176,000	207,000	960,000
2008	171,277	170,720	176,000	207,000	1,080,000
2009	175,756	176,540	182,000	212,000	1,260,000
2010	171,875	168,780	174,000	205,000	1,140,000
2011	220,109	227,950	235,000	272,000	1,560,000
2012	250,899	275,000	314,000	369,000	1,690,000
2013	250,274	260,000	307,000	359,000	1,510,000
2014	200,729	250,274	260,000	307,000	1,629,000
2015	-	240,000	255,000	346,000	1,680,000

[1]Catch data current through November 2014. BS and AI specifications set separately beginning in 2014; all numbers combined in this table.
[2]TAC, ABC and OFL data from annual SAFE report.
[3]Biomass from annual SAFE report projections issued the previous year.

Fishery: Pacific Cod are taken with trawl, longline, pot and jig gear. In 2013, a total of 47 vessels using longline gear (18 catcher vessels, 29 catcher processors), 59 pot gear vessels (56 catcher vessels, 3 catcher processors), and 72 vessels using trawl gear (54 catcher vessels, 18 catcher processors) caught Pacific Cod in the BSAI.

Economics: In 2013, ex-vessel value of Pacific Cod catch in the BSAI was $130 million, and production for all Pacific Cod products in Alaska was 145,490 mt, worth $390 million. Primary products included whole fish, headed and gutted fish, and fillets. Exvessel price averaged $0.24/lb for trawl gear and $0.25/lb for fixed gear.

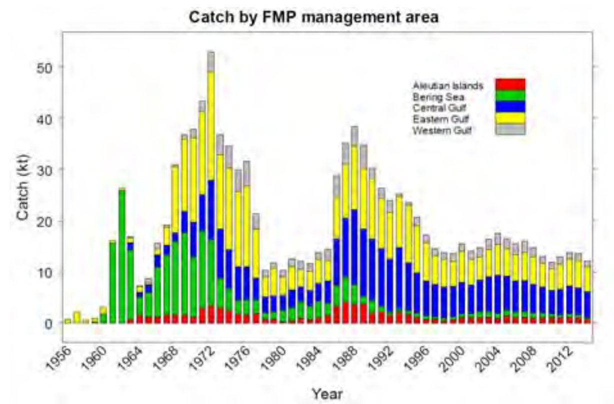
Ecosystem Components: Pacific Cod are an important prey item for SSLs, especially in winter months.



Sablefish

AFSC, NOAA Fisheries

Biology: Sablefish *Anoplopoma fimbria* distribution extends from the northern Mexico through the Gulf of Alaska, along the Aleutian Islands and into the Bering Sea. Adult Sablefish are generally found at depths greater than 200 m along the continental slope, shelf gullies and deep fjords. Juveniles (less than 40 cm) spend the first 2-3 years farther inshore along the continental shelf and begin to move out to the continental slope around age 4-5. Young-of-the-year feed primarily on euphausiids and copepods while adults are more opportunistic feeders, relying more heavily on fish such as pollock, Pacific Herring and Pacific Cod. Squid and jellyfish are important invertebrates in the adult Sablefish diet. Coho and Chinook salmon are the main predators of young-of-the-year.



Sablefish are relatively long lived. They begin to recruit to the fishery at age 4 or 5 and longevity often reaches 40 years (the oldest recorded Sablefish in Alaska was 94 years old). Female Sablefish size at 50% maturity is approximately 65 cm (age 6). Females are slightly larger than males, and fish in the BSAI generally tend to be smaller than in the GOA. Natural mortality is estimated at M=0.10. Off Alaska, Sablefish spawn near the edges of the continental slope at depths greater than 500 m between January and March.

Stock assessment:

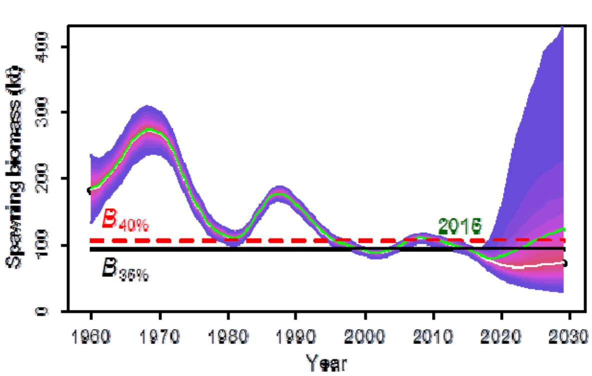
D. Hanselman, C. Lunsford, and C. Rodgveller. 2014. Assessment of the Sablefish stock in Alaska.

www.afsc.noaa.gov/refm/stocks/assessments.htm

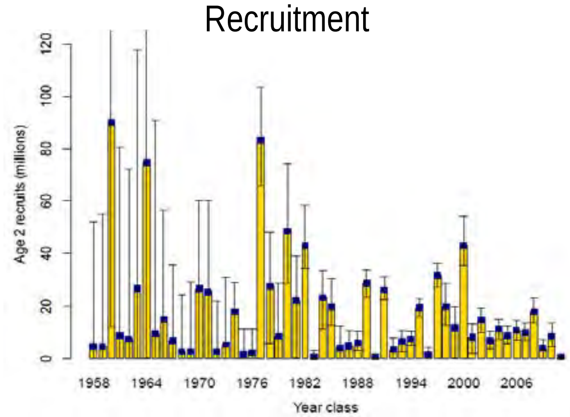
Catch History: U.S. fishermen have harvested Sablefish since the end of the 19th century as a byproduct of halibut fisheries. Harvests were relatively small, averaging 1,666 mt from 1930-1957. Japanese longlining began in the EBS around 1958 and expanded into the AI and GOA through the 1970s. Japanese fleet catches increased throughout the 1960s, and catch peaked 36,776 mt in 1972. High fishing pressure in the early 1970s may have resulted in a population decline of Sablefish in the mid-1970s. By 1988, U.S. fishermen took the majority of the Sablefish harvested in the GOA and BSAI. The fishery was a derby-style fishery in the late 1980s and early 1990s until Individual Fishing Quotas were implemented for the hook and line fishery in 1995.

Fishery Management: BSAI and GOA Sablefish are managed as one population in federal waters due to their highly migratory behavior during certain life history stages.

Biomass



Recruitment



In 1990, Amendment 13 to the BSAI FMP similarly allocated Sablefish quota by gear type; 50% to fixed gear and 50% to trawl gear in the BS; 75% to fixed gear and 25% to trawl gear in the AI. Amendment 20 to the GOA FMP and 15 to BSAI FMP established IFQ management for the Sablefish fishery and allocated 20% of the fixed gear quota to a CDQ reserve for the BSAI, effective 1990.

Stock Assessment: The Sablefish assessment is based on a statistical sex-specific age-structured model. This model incorporates fishery data and fishery independent data from domestic and Japan-U.S. cooperative longline surveys and the NMFS GOA trawl survey. Sablefish fall under Tier 3b of the ABC/OFL control rules. Specifications are apportioned among management areas based on a 5-year exponential weighting of the survey and fishery abundance indices. Catch specifications for 2015 Bering Sea Sablefish are as follows; OFL=1,575 mt, ABC=1,333 mt, TAC=1,333 mt. For the Aleutian Islands, OFL=2,128 mt, ABC=1,802 mt, TAC=1,802 mt.

Total catches, pre-season catch specifications, and exploitable biomass of Sablefish age 4+ in the BS and AI, 1980-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
1980	2,480	5,000	-	-	148,000
1981	3,137	5,000	-	-	159,000
1982	4,139	5,000	-	-	163,000
1983	3,368	5,000	-	-	173,000
1984	3,328	5,340	6,185	-	205,000
1985	3,796	4,500	6,080	-	213,000
1986	6,546	6,450	7,200	-	212,000
1987	8,012	7,700	7,700	-	187,000
1988	6,608	8,400	9,200	-	141,000
1989	4,500	5,270	6,200	-	137,000
1990	4,445	7,200	7,200	-	118,000
1991	3,199	6,300	6,300	-	80,000
1992	2,104	4,400	4,400	5,870	60,000
1993	2,747	4,100	4,100	4,500	50,000
1994	2,470	3,340	3,340	4,160	52,000
1995	2,048	3,800	3,800	4,900	58,000
1996	1,349	2,300	2,500	3,300	52,000
1997	1,326	2,300	2,675	5,610	48,000
1998	1,181	2,680	2,680	4,390	51,000
1999	1,211	3,200	3,200	4,980	61,000
2000	1,790	3,900	3,900	4,840	63,000
2001	1,937	4,060	4,060	4,980	70,000
2002	2,261	4,480	4,480	6,750	85,000
2003	2,048	6,000	6,000	8,880	86,000
2004	1,993	6,000	6,450	8,640	86,000
2005	2,539	5,060	5,060	6,120	87,000
2006	2,166	5,820	6,160	7,420	85,000
2007	2,322	5,790	5,790	9,840	85,000
2008	2,018	5,300	5,300	6,270	86,000
2009	1,939	4,920	4,920	5,810	84,000
2010	1,849	4,860	4,860	5,760	81,000
2011	1,729	4,750	4,750	5,610	59,000
2012	1,948	4,280	4,280	5,070	45,000
2013	1,696	3,720	3,720	4,400	62,000
2014	1,085	3,150	3,150	3,725	73,000
2015	-	3,135	3,135	3,703	58,000

[1]Catch data current through November 2014.
[2]TAC, ABC and OFL from annual Federal Register.
[3]Biomass from annual SAFE report projections.

Biomass of Sablefish has fluctuated over time. There were two high points in biomass in the early 1970s and mid-1980s and two decreases in the late 1970s and the mid-1990s. Relative abundance is near an all-time but may increase with recruitment of an average 2008 year class.

Fishery: Sablefish are taken with trawl, longline and pot gear. Most Sablefish are taken with longline gear in the Aleutian Islands and pot gear in the Bering Sea. The Sablefish season is open 7 months beginning in April, concurrent with the halibut fishing season. Primary species taken incidentally in the Sablefish fishery include Shortaker, Rougheye and Thornyhead Rockfish.

Sperm whale and killer whale depredation occurs when whales remove Sablefish from longline gear, damage the fish and/or fishing gear. Killer whale depredation predominates in the BSAI and sperm whale depredation is more common the GOA. Depredation can lead to significant economic losses in the form of reduced catch, extended travel distances, and damaged gear. Depredation may also reduce the accuracy of Sablefish stock assessment models. Additionally, depredating whales may be at greater risk of mortality or injury through vessel strikes or entanglement in gear.

Economics: In 2013, the ex-vessel value of Sablefish catch from the BSAI was $9.7 million. Exvessel prices for BSAI Sablefish in 2013 averaged $2.84/lb for fish caught on longline gear and $1.17/lb for fish taken with trawl gear. For both gear types, the primary product is frozen, head and gutted fish.

Diana Evans, NPFMC

Yellowfin Sole

Biology: Yellowfin Sole *Limanda aspera* are distributed from the Sea of Japan to British Columbia, with the highest abundance in the Bering Sea. Yellowfin Sole are the target of the largest flatfish fishery in the U.S. and are one of the most abundant flatfish species in the EBS. Adult Yellowfin Sole occupy the benthos and have separate winter spawning and summertime feeding grounds on the EBS shelf. Adults over-winter near the shelf margins and then migrate to inner shelf areas in April/May each year for spawning and feeding. Yellowfin Sole predate on bivalves, polychaetes, amphipods, mollusks and fish. They are prey for Pacific Cod, Pacific Halibut and skates.

Yellowfin Sole are relatively slow-growing and long-lived. They begin to recruit to the fishery at age 6, are fully selected by age 13 and longevity extends to 30+ years. Females reach 50% maturity at 30 cm (10.5 years old) and are highly fecund, producing 1.3-3.3 million eggs depending on size. Annual natural mortality of adults is estimated at 0.12. Spawning occurs in June/July in shallow waters from Bristol Bay to Nunivak Island.

Diana Evans, NPFMC

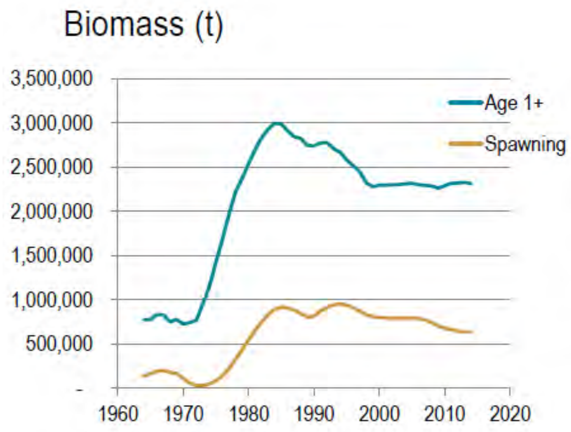
Fishery Management: BSAI Flatfish are regulated under the BSAI groundfish FMP through permits, limited entry, catch quotas (TACs), seasons, in-season adjustments, gear restrictions, closed waters, bycatch limits and rates (for halibut and crab), allocations, regulatory areas, record keeping, reporting requirements and observer monitoring.

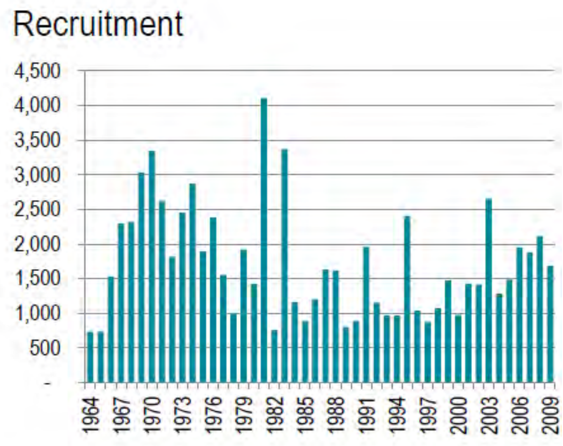
In 1985, the Flounder (Flatfish) category was broken into four management groups (Greenland Turbot, Arrowtooth Flounder, Yellowfin Sole, Other Flatfish) due to significant differences in stock robustness and product values. Northern Rock Sole was separated from the Other Flatfish complex in 1987. Flathead Sole was separated from the Other Flatfish complex in 1995, and Alaska Plaice was separated in 2002.

Stock assessment:

T. Wilderbuer, D. Nichol, and J. Ianelli. 2014. Assessment of Yellowfin Sole in the Bering Sea and Aleutian Islands.

www.afsc.noaa.gov/refm/stocks/assessments.htm





In 2008, BSAI FMP Amendment 80 established catch shares for the bottom trawl catcher-processor fleet. Flatfish resources were allocated among BSAI trawl harvesters according to their historic harvest patterns, monitoring requirements were increased, and fishermen were given the ability to form cooperatives. Up to 93% of the Yellowfin Sole TAC is allocated to the Amendment 80 fleet, depending on the TAC. Like other groundfish stocks except pollock, 10.7% of TAC is first allocated to CDQ groups.

Catch History: Yellowfin Sole have been harvested annually since the inception of the BS bottom trawl fishery in 1954. Overharvesting by foreign vessels occurred from 1959-1962, and catches averaged 404,000 mt annually during that period. Catches declined during the late 1960s and early 1970s as a result of reduced abundance. Domestic and joint venture fisheries for Yellowfin Sole emerged in the 1980s, and only domestic harvesting has occurred since 1990, and catches have increased in more recent years.

Total catches, pre-season catch specifications, and exploitable biomass of Yellowfin Sole in the BSAI, 1980-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
1980	87,391	117,000	169,000	-	-
1981	97,301	117,000	214,500	-	-
1982	95,712	117,000	214,500	-	-
1983	108,385	117,000	214,500	-	-
1984	159,526	230,000	310,000	-	-
1985	227,107	226,900	310,000	-	-
1986	208,597	209,500	230,000	-	-
1987	181,429	187,000	187,000	-	-
1988	223,156	254,000	254,000	-	1,408,000
1989	153,165	182,675	241,000	-	1,530,000
1990	80,584	207,650	278,900	-	1,640,000
1991	96,135	135,000	250,600	-	1,790,000
1992	146,946	235,000	372,000	452,000	2,660,000
1993	105,809	220,000	238,000	275,000	2,500,000
1994	144,544	150,325	230,000	269,000	1,925,000
1995	124,752	190,000	277,000	319,000	2,770,000
1996	130,163	200,000	278,000	342,000	2,850,000
1997	166,915	230,000	233,000	339,000	2,530,000
1998	101,315	220,000	220,000	314,000	3,010,000
1999	67,320	207,980	212,000	308,000	3,180,000
2000	84,070	123,262	191,000	222,600	2,820,000
2001	63,578	113,000	176,000	209,000	2,380,000
2002	74,985	86,000	115,000	136,000	1,597,000
2003	81,050	83,750	114,000	136,000	1,550,000
2004	75,510	86,075	114,000	135,000	1,560,000
2005	94,384	90,686	124,000	148,000	1,560,000
2006	99,138	95,701	121,000	144,000	1,680,000
2007	121,029	136,000	225,000	240,000	2,000,000
2008	148,894	225,000	248,000	265,000	2,200,000
2009	107,528	210,000	210,000	224,000	1,870,000
2010	118,624	219,000	219,000	234,000	1,960,000
2011	151,164	196,000	239,000	262,000	1,958,600
2012	147,183	202,000	203,000	222,000	1,950,000
2013	164,944	198,000	206,000	220,000	1,960,000
2014	145,900	184,000	239,800	259,700	2,113,000
2015	-	149,000	248,800	266,400	2,127,800

[1]Catch data current through November 2014.
[2]1988-2010 TAC, ABC and OFL data from annual Federal Register Harvest Specs. Pre-1988 TAC and ABC data from annual SAFE reports.
[3]Biomass from annual SAFE report projections.

Stock Assessment: The Yellowfin Sole assessment is a separable catch-age, sex-specific analysis. This model incorporates fishery data and fishery independent data from annual trawl surveys. Yellowfin Sole fall under Tier 1a of the ABC/OFL control rules. The 2015 projected age 6+ biomass is 2,127,800 mt. Catch specifications for 2015 are as follows; OFL=266,400 mt, ABC= 248,800 mt, TAC= 149,000 mt.

Yellowfin Sole biomass peaked in the early-1990s. The population has been in a slow decline as the strongest year classes have passed through the fishery, however, the population remains at fairly high/stable levels.

Fishery: Yellowfin Sole are primarily caught with trawl gear. Seven catcher vessel and 27 catcher processors participated in 2013 BSAI Yellowfin Sole fishery. Fishing effort is focused on the mid and inner BS shelf during ice-free conditions. A small area in Bristol Bay is open to bottom trawling from April 1 – June 15 to allow the fishery to target this species when they are aggregated and can be taken with low incidental catches of other species. Yellowfin Sole are usually headed and gutted or frozen whole for further processing. In 2013, the retention rate of Yellowfin Sole caught by the Amendment 80 sector was 97 percent.

Economics: In 2013, production was 169,150 mt for all flatfish products for a total gross value of $234 million. Ex-vessel value of all flatfish caught in the BSAI in 2013 was $96 million.

Arrowtooth Flounder

Arrowtooth Flounder
AFSC, NOAA Fisheries

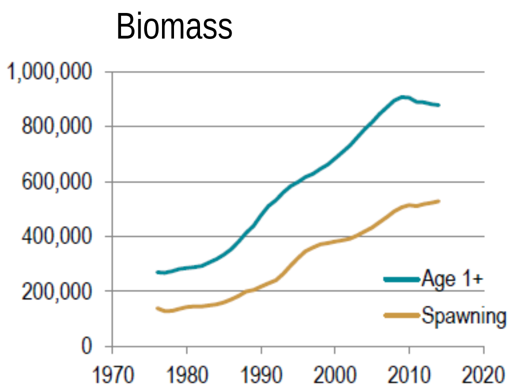
Biology: Arrowtooth Flounder *Atheresthes stomias* are distributed from the Kamchatka Peninsula to the BSAI south to central California. Adults migrate seasonally from shelf margins in the winter to the outer shelf in April/May with the onset of warmer waters temperatures. In the BSAI, Arrowtooth Flounder prey on juvenile pollock (47%), adult pollock (19%) and euphausiids (9%).

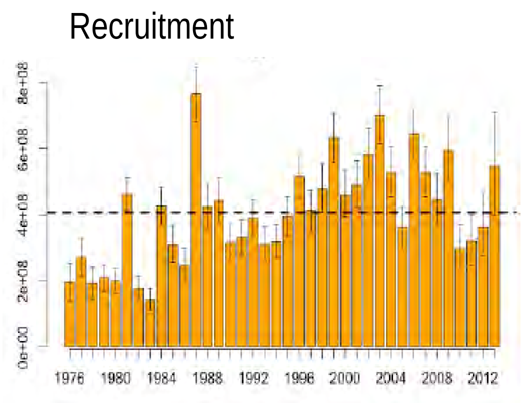
Arrowtooth Flounder length at 50% maturity is 28 cm for males (4 years) and 37 cm for females (5 years). Natural mortality is estimated at M=0.2 for females and M=0.35 for males. Adult males range in size from 30-50 cm, and females range in size from 30-70 cm. The spawning period for Arrowtooth Flounder is protracted and variable, ranging from September through March.

Stock assessment:

I. Spies, T. Wilderbuer, D. Nichol, and K. Aydin. 2014. Assessment of the Arrowtooth Flounder stock in the Bering Sea and Aleutian Islands.

www.afsc.noaa.gov/refm/stocks/assessments.htm





Catch History: USSR and Japan targeted Greenland Turbot and Arrowtooth Flounder during the 1960s. Catches peaked from 1974-1976 at 19,000-25,000 mt. Arrowtooth Flounder and Greenland Turbot were managed as a complex until 1985 due to their similar life history characteristics and distribution. Catches decreased following implementation of the Magnuson-Stevens Act in 1977.

Total catches, pre-season catch specifications, and exploitable biomass of Arrowtooth Flounder in the BSAI, 2000-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2000	13,228	131,000	131,000	160,000	785,000
2001	14,056	22,011	117,000	141,500	701,000
2002	11,853	16,000	113,000	137,000	671,000
2003	14,580	12,000	112,000	139,000	597,000
2004	18,139	12,000	115,000	142,000	696,000
2005	14,237	12,000	108,000	132,000	684,000
2006	13,361	13,000	136,000	160,000	964,000
2007	11,917	20,000	158,000	193,000	1,280,000
2008	21,884	75,000	244,000	297,000	1,780,000
2009	28,914	75,000	156,000	190,000	1,140,000
2010	38,881	75,000	156,000	191,000	1,120,000
2011	20,195	25,900	153,000	186,000	1,124,200
2012	22,379	25,000	150,000	181,000	1,130,000
2013	20,501	25,000	152,000	186,000	1,130,000
2014	18,119	25,000	106,599	125,642	1,023,440
2015	-	22,000	80,547	93,856	908,379

[1]Catch data current through November 2014.
[2]TAC, ABC and OFL data from Harvest Specifications. Kamchatka Flounder separated out in 2011; data not included thereafter.
[3]Biomass from annual SAFE report projections.

Stock Assessment: Arrowtooth Flounder and Kamchatka Flounder were assessed and managed together as a complex through 2010, when Kamchatka Flounder were split out as a separate target fishery. The assessment model is a length-based approach using survey and fishery lengths to estimate population numbers at age. Arrowtooth Flounder fall under Tier 3a of the ABC/OFL control rules.

Fishery: Arrowtooth Flounder has developed into a target fishery and retention rates have increased in response to developing markets and implementation of the Amendment 80 catch share cooperatives in 2008. From 2005-2007, at least 50% of Arrowtooth Flounder caught was discarded. In 2013, the retention rate of Arrowtooth Flounder caught by trawl gear was 85%.

Biology: Kamchatka Flounder *Atheresthes evermanni* are distributed from northern Japan to the Aleutian Islands and along the eastern Bering Sea slope. This species generally occurs in waters deeper than 200m, and the larger fish (> 50 cm) are most common at depths of 500m to 800 m.

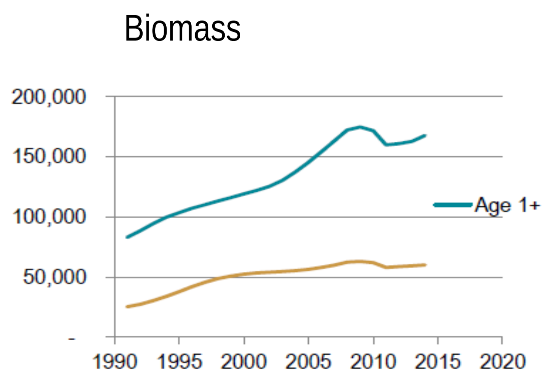
Kamchatka Flounder recruitment to the fishery begins at about 30 cm, and are fully recruited at about 45 cm. The age at 50% maturity is 10 years for females. Natural mortality is estimated at M=0.11. Kamchatka Flounder live to a maximum age of 35 years, and can grow to a maximum size of about 90 cm.

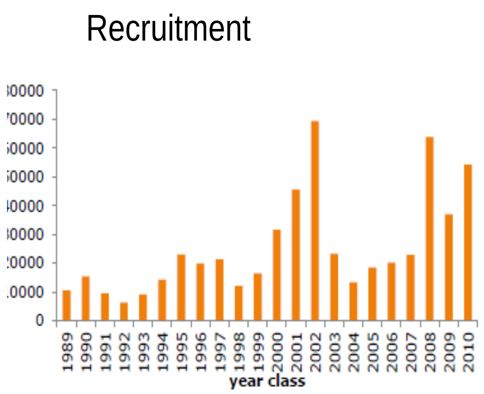
Catch History: From 1986 until 2011, Kamchatka Flounder and Arrowtooth Flounder were managed together under the Arrowtooth Flounder complex. However, a directed fishery for Kamchatka Flounder began to emerge, and catches were increasing. Because the ABC was based on the large amount of Arrowtooth Flounder relative to Kamchatka Flounder

Stock assessment:

T. Wilderbuer, J. Ianelli, D. Nichol, and R. Lauth. 2014. Assessment of Kamchatka Flounder in the Bering Sea and Aleutian Islands.

www.afsc.noaa.gov/refm/stocks/assessments.htm





(complex is about 93% Arrowtooth Flounder) the possibility arose of an overharvest of Kamchatka Flounder. So beginning in 2011, separate catch specifications were established.

Stock Assessment: The Kamchatka Flounder assessment uses a sex-specific length and age based approach. Kamchatka Flounder fall under Tier 3a of the ABC/OFL control rules. The 2015 projected biomass is 174,500 mt. Catch specifications for 2015 are as follows: OFL=10,500 mt, ABC= 9,000 mt, TAC= 6,500 mt.

Total catches, pre-season catch specifications, and exploitable biomass of Kamchatka Flounder in the BSAI, 2011-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2011	9,935	17,700	17,700	23,600	129,000
2012	9,514	17,700	18,600	24,800	125,000
2013	7,772	10,000	12,200	16,000	125,000
2014	6,395	7,100	7,100	8,270	136,600
2015	-	6,500	9,000	10,500	174,500

[1]Catch data current through November 2014.
[2]TAC, ABC and OFL data from Harvest Specifications.
[3]Biomass from annual SAFE report projections.

Fishery: The Kamchatka Flounder fishery developed in response to developing markets and implementation of the Amendment 80 catch share cooperatives. Retention rate of Kamchatka Flounder caught by trawl gear was 92% in 2013.

Ecosystem Components: Kamchatka Flounder prey on pollock, shrimp, and euphausiids.

Diana Evans, NPFMC

Rock Sole

Stock assessment:

T. Wilderbuer and D. Nichol. 2014. Assessment of Northern Rock Sole in the Bering Sea and Aleutian Islands.

www.afsc.noaa.gov/refm/stocks/assessments.htm

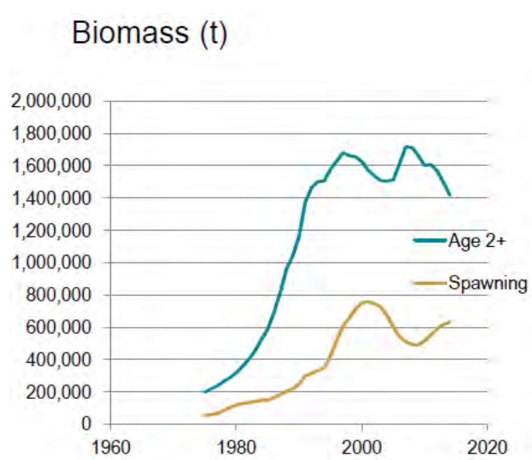
Biology: Two species of rock sole, Northern Rock Sole *Lepidopsetta polyxstra* and Southern Rock Sole *L. bilineatus*, occur in the North Pacific Ocean and are managed together as one complex in the BSAI, but separately in the GOA. Northern Rock Sole are the most commonly found species of rock sole in the BSAI. Adults are bottom dwellers and occupy separate winter and summer feeding ground along the continental shelf. As early juveniles, rock sole consume plankton and zooplankton, switching to bivalves, polychaetes, amphipods, mullosks and crustaceans as they age and become late juveniles and adults. Small rock sole are prey for Pacific Cod, Walleye Pollock, Yellowfin Sole, skates and Pacific Halibut.

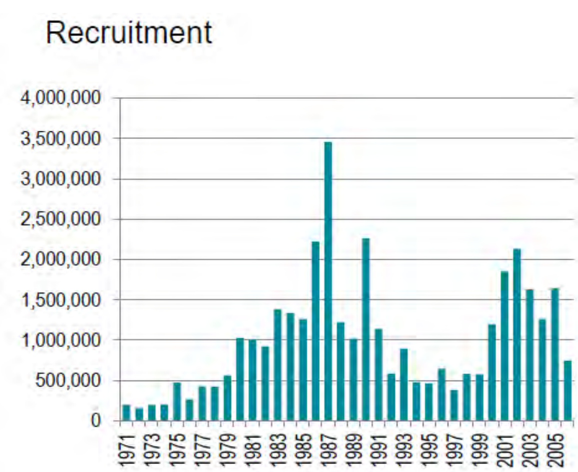
Recruitment to the fishery begins at age 4 and they are fully selected by age 11. Estimated length at 50% maturity is 31 cm (9 years). Natural mortality is estimated at M=0.15. Rock sole spawn from December to March in two separate concentrations in the BS along the continental shelf/slope break.

Catch History: Rock sole were harvested by Japanese and Soviet vessels beginning in 1963. Catches averaged 7,000 mt annually from 1963-1969 and increased during the early 1970s. Peak catch occurred in 1972 (61,000 mt). Catches declined until joint venture operations began in 1980. Catches again increased during the 1980s and peaked in 1988 (86,000 mt). The fishery was fully domesticated by 1990, and catches have remained fairly stable since 1990 (average 46,000 mt annually).

Fishery Management: Rock sole is regulated under the BSAI groundfish FMP through permits, limited entry, catch quotas (TACs), seasons, in-season adjustments, gear restrictions, closed waters, bycatch limits and rates, allocations, regulatory areas, record keeping, reporting requirements and observer monitoring. In 2008, BSAI FMP Amendment 80 modified rock sole fishery management, such that 100% of the directed fishery rock sole TAC is allocated among non-AFA trawl catcher processors according to their historic harvest patterns, groundfish retention standards were extended to catcher/processor fleet and fishermen were given the ability to form cooperatives. Like other groundfish, 10.7% of rock sole TAC is allocated to CDQ groups.

Stock Assessment: The rock sole assessment uses a separable catch-age analysis that estimates abundance, mortality and recruitment. This model incorporates fishery data and





fishery independent data from EBS and AI trawl surveys. Rock sole fall under Tier 1a of the ABC/OFL control rules. The 2015 projected age 6+ biomass is 1,233,400 mt and B_{msy}=260,000.

Strong recruitment and low fishing effort enabled rock sole biomass to increase significantly from 1985-1995. Estimated biomass peaked in the late 1990s and then declined by about 20% through 2005. The decline during the early 2000s was attributed to below average recruitment to the adult population during the 1990s. Estimated biomass began increasing again in 2005 as a result of a series of above average year-classes.

Fishery: Rock sole are caught by trawl catcher-processors targeting roe-bearing females. The primary product for the rock sole fishery is the high value roe. The fishery occurs from January-March and is focused in outer Bristol Bay and north of Unimak Island. A total of 7 catcher vessels and 27 catcher processors participated in the 2013 flatfish fisheries in the BSAI. From 1987-2000, over 50% of rock sole catch was discarded. Retention rate for rock sole by trawl gear increased to 87% by 2009, and to 95% in 2013.

Ecosystem Components: Northern Rock Sole recruitment has been linked to decadal scale climate variability, especially ocean forcing by onshelf/offshelf winds in the BS. After spawning in March, Northern Rock Sole larvae are subject to advection from wind, current and tidal forcing during the spring. Using an ocean surface current model, Northern Rock Sole larvae advection towards favorable nursery areas and resultant above-average recruitment occurred during years with onshelf (easterly) winds during the 1980s and again in 2001-2003. Conversely, periods of off-shelf (westerly) winds during the 1990s corresponded with average or poor recruitment.

Diana Evans, NPFMC

Total catches, pre-season catch specifications, and exploitable biomass of Rock Sole* in the BSAI, 1989-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
1989	68,912	90,762	171,000	-	1,277,900
1990	35,253	60,000	216,300	-	1,193,900
1991	46,681	90,000	246,500	-	1,363,700
1992	51,956	40,000	260,800	260,800	1,481,000
1993	64,260	75,000	185,000	270,000	1,550,000
1994	60,584	75,000	313,000	363,000	1,790,000
1995	55,028	60,000	347,000	388,000	2,330,000
1996	47,146	70,000	361,000	420,000	2,360,000
1997	67,520	97,185	296,000	427,000	2,390,000
1998	33,667	100,000	312,000	449,000	2,360,000
1999	40,511	120,000	309,000	444,000	2,320,000
2000	49,666	137,760	230,000	273,000	2,070,000
2001	29,475	75,000	228,000	271,000	1,940,000
2002	41,865	54,000	225,000	268,000	1,850,000
2003	37,339	44,000	110,000	132,000	877,000
2004	48,680	41,000	139,000	166,000	1,160,000
2005	37,361	41,500	132,000	157,000	1,380,000
2006	36,411	41,500	126,000	150,000	1,490,000
2007	36,768	55,000	198,000	200,000	1,670,000
2008	51,275	75,000	301,000	304,000	1,880,000
2009	48,649	90,000	296,000	301,000	1,630,000
2010	53,221	90,000	240,000	243,000	1,770,000
2011	60,401	85,000	224,000	248,000	1,868,400
2012	76,099	87,000	208,000	231,000	1,860,000
2013	59,773	92,380	214,000	241,000	1,470,000
2014	52,250	85,000	203,800	228,700	1,393,200
2015	-	69,250	181,700	187,600	1,233,400

*Rock Sole included in Other Flatfish category before 1989.
[1]Catch data current through November 2014.
[2]1989-2010 TAC, ABC and OFL data from annual Federal Register Harvest Specifications.
[3]Biomass from annual SAFE report projections.

NOAA Fisheries

Greenland Turbot

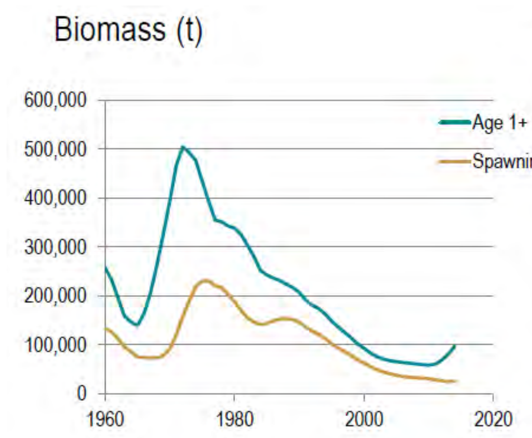
Biology: Greenland Turbot *Reinhardtius hippoglossoides* has a circumpolar distribution, occurring in both the North Pacific and North Atlantic Oceans. Juveniles inhabit shallow continental shelf waters (<200 m) for the first 3-4 years and move out to the deeper waters of the continental slope (200-1,000 m). Greenland Turbot predate on euphausiids, polychaetes and small fish (e.g. pollock) as they mature. In the North Pacific, juveniles are prey for Pacific Cod and Pacific Halibut.

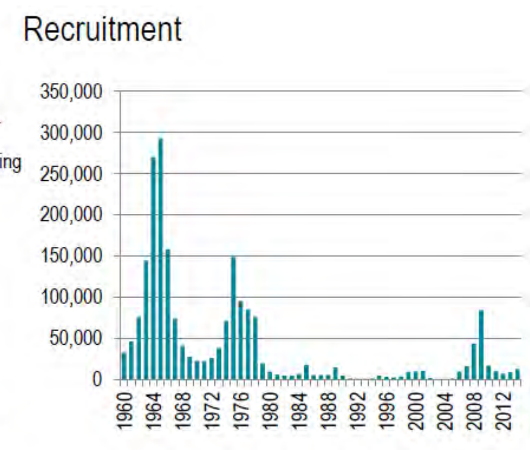
Greenland Turbot size at 50% maturity is around 60 cm (age 5-10). Greenland Turbot begin to recruit to longline fisheries at about 60 cm and are fully recruited at 90 cm. Natural mortality is estimated at M=0.112. Peak spawning period is from November – February in the EBS. Female fecundity is fairly low; females less than 83 cm release 25,000-150,000 eggs.

Stock assessment:

S. Barbeaux, J. Ianelli,, D. Nichol, and T. Hoff. 2014. Assessment of Greenland Turbot in the Eastern Bering Sea and Aleutian Islands Area.

www.afsc.noaa.gov/refm/stocks/assessments





Catch History: Catches averaged 30,000 mt annually during that during the 1960s when the USSR and Japan first targeted the Greenland Turbot fishery. Catches peaked in the mid-1970s, and declined after 1986 due to poor recruitment.

Total catches, pre-season catch specifications, and exploitable biomass of Greenland Turbot in the BS and AI, 2000-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2000	6,974	9,300	9,300	42,000	233,000
2001	5,312	8,400	8,400	31,000	210,000
2002	3,635	8,000	8,100	36,500	208,000
2003	3,530	4,000	5,800	17,800	112,000
2004	2,239	3,500	4,740	19,300	132,000
2005	2,579	3,500	3,930	19,200	98,300
2006	1,977	2,740	2,740	14,200	74,200
2007	2,003	2,440	2,440	15,600	119,000
2008	2,923	2,540	2,540	15,600	104,000
2009	4,511	7,380	7,380	14,800	105,000
2010	4,138	6,120	6,120	7,460	61,100
2011	3,646	5,050	6,140	7,220	73,981
2012	4,720	8,660	9,660	11,700	76,900
2013	1,745	2,060	2,060	2,540	81,000
2014	1,646	2.124	2,124	2,647	84,546
2015	-	2,648	3,172	3,903	122,298

[1]Catch data current through November 2014.
[2]TAC, ABC and OFL from Federal Register Harvest Specifications.
[3]Biomass from annual SAFE report projections.

Stock Assessment: The Greenland Turbot assessment is based on a stock synthesis model that incorporates fishery data and fishery independent data from EBS slope and shelf bottom-trawl surveys and the NMFS longline survey. Greenland Turbot fall under Tier 3b of the ABC/OFL control rules. Catch limits are further apportioned into BS and AI components. Biomass had declined since the early 1970s, but strong year classes produced in 2007-2009 are contributing to a steep increase in abundance.

Fishery: The Greenland Turbot fishery is prosecuted by both trawls and longline gear. Predominantly a longline fishery from 1993-2007, the trawl fishery began harvesting a larger share of the TAC beginning in 2008. Fishing effort is concentrated on the continental slope throughout the EBS and on both sides of the AI.

Current Issues: Killer whale depredation is problematic for Greenland Turbot longline fisheries in the EBS.

Diana Evans, NPFMC

Alaska Plaice

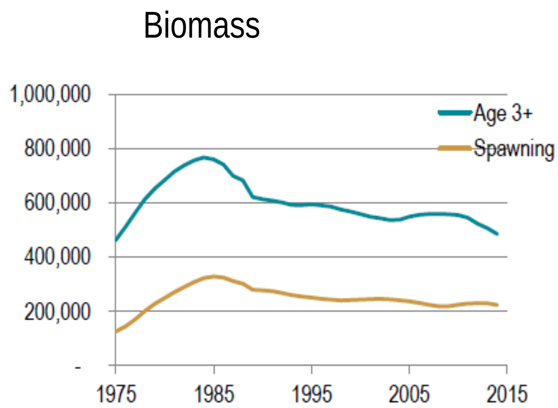
Biology: Alaska Plaice *Pleuronectes quadrituberculatus* distribution extends through the Sea of Japan, Chukchi Sea, BSAI and GOA. Alaska Plaice are generally found along the EBS continental shelf, with relatively few found in the AI region. Summer distribution of adults is generally confined to depths less than 110 m, with larger fish in deeper waters and smaller juveniles in shallower coastal waters. Alaska Plaice predate on polychaetes and amphipods and are prey for Pacific Cod, Pacific Halibut and Yellowfin Sole.

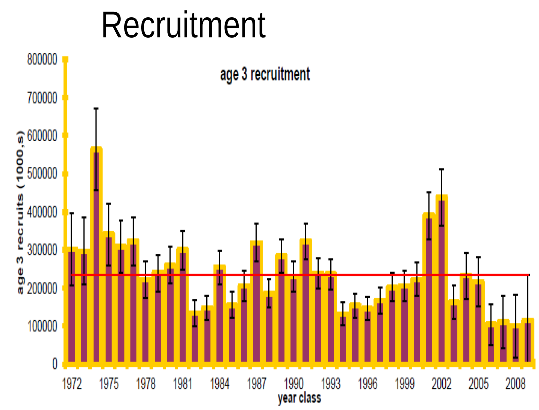
Alaska Plaice recruit to trawl fisheries at age 4, are full recruited by age 13. Females mature between ages 7 and 12. Natural mortality is estimated at M=0.13. Spawning usually occurs in March and April on hard sandy substrate in the EBS.

Stock assessment:

T. Wilderbuer, D. Nichol, and P. Spencer. 2014. Assessment of Alaska Plaice in the Bering Sea and Aleutian Islands.

www.afsc.noaa.gov/refm/stocks/assessments.htm





Catch History: Alaska Plaice were harvested by Japanese and Soviet vessels beginning in 1963. Catches increased from 1,000 mt in 1971 to a peak of 62,000 mt to in 1988. Joint ventures began in 1988, and the fishery was fully harvested by domestic vessels in 1991. Alaska Plaice are taken in a directed target fishery as well as a secondary catch in the Yellowfin Sole fishery.

Total catches, pre-season catch specifications, and exploitable biomass of Alaska Plaice* in the BSAI, 2002-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2002	-	-	-	-	1,100,000
2003	10,118	10,000	137,000	165,000	1,080,000
2004	7,888	8,000	203,000	258,000	1,050,000
2005	11,194	8,000	189,000	237,000	913,000
2006	17,318	8,000	188,000	237,000	1,008,000
2007	19,522	25,000	190,000	241,000	1,340,000
2008	17,376	50,000	194,000	248,000	1,850,000
2009	13,944	50,000	232,000	298,000	1,500,000
2010	16,165	50,000	224,000	278,000	2,260,000
2011	23,656	16,000	65,100	79,100	780,300
2012	16,612	24,000	53,400	64,600	606,000
2013	23,523	20,000	55,200	67,000	589,000
2014	19,000	24,500	55,100	66,800	576,300
2015	-	18,500	44,900	54,000	471,500

*Alaska Plaice removed from Other flatfish complex 2002.
[1]Catch data current through November 2014.
[2]TAC, ABC and OFL data from Federal Register.
[3]Biomass from annual SAFE report projections.

Stock Assessment: The assessment uses a sex-specific, age-structured model. This model incorporates fishery data and fishery independent data from trawl surveys. Alaska Plaice fall under Tier 3a of the ABC/OFL control rules. The 2015 projected biomass is 471,500 mt. Catch specifications for 2015 are as follows; OFL= 54,000 mt, ABC= 44,900 mt, TAC= 18,500 mt.

Fishery: Alaska Plaice are caught primarily by trawl catcher processors targeting higher-value flatfish species such as Yellowfin Sole. With the implementation of Amendment 80 in 2008, retention rates of Alaska Plaice increased from about 5% (2003-2005 average) to an average of 70% in the last few years.

AFSC, NOAA Fisheries

Flathead Sole and Bering Flounder

Stock assessment:

C. McGillard, D. Nichol, W. Palsson, and W. Stockhausen. 2014. Assessment of the Flathead Sole-Bering Flounder stock in the Bering Sea and Aleutian Islands.

www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: Flathead Sole is managed as a two-species complex including Flathead Sole *Hippoglossoides elassodon* and Bering Flounder *Hipogloissoides robustus.* Individuals of both species are morphologically similar; Flathead Sole are faster growing and achieve larger size. Flathead Sole are distributed in the Kuril Islands, BS, GOA and down to northern California. In the northern part of the Bering Sea, Flathead Sole distribution overlaps with Bering Flounder. Bering Flounder distribution extends from the Chukchi Sea into the northern BS. Bering Flounder generally represents less than 3% of the estimated survey biomass of the two species. Adult Flathead Sole overwinter near the shelf margins before migrating to the mid and outer continental shelf in April or May each year for feeding. Flathead Sole predate on pollock, polychaetes, brittle stars and crustaceans. They are prey for adult pollock and Pacific Cod.

Flathead Sole recruitment to the fishery begins at age 4, and longevity extends to 32 years. Estimated length at 50% maturity is 32 cm. Natural mortality is estimated at M=0.20. Flathead Sole spawn in March and April, primarily in deeper waters near the margins of the continental shelf. Females release from 70,000-600,000 eggs depending on size.

Catch History: Flathead Sole were harvested by Japanese and Soviet vessels beginning in 1963. Flathead Sole catches peaked in 1971 (51,000 mt). Catches declined to 15,000 mt in 1975 and remained under 10,000 mt until 1990. Catch levels have increased since the 1980s due to higher incidental catch rates and emerging markets for Flathead Sole, averaging 18,377 mt from 1995-2009.

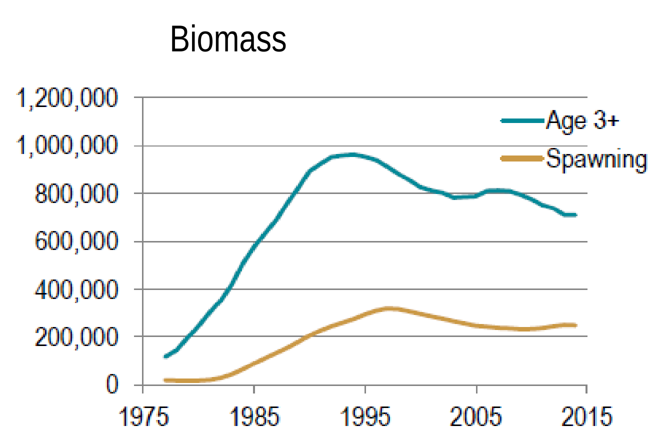
Total catches, pre-season catch specifications, and exploitable biomass of Flathead Sole* in the BSAI, 1995-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
1995	14,713	30,000	138,000	167,000	677,000
1996	17,344	30,000	116,000	140,000	593,000
1997	20,681	43,500	101,000	145,000	632,000
1998	24,597	100,000	132,000	190,000	824,000
1999	18,555	77,300	77,300	118,000	710,000
2000	20,439	52,652	73,500	90,000	660,000
2001	17,809	40,000	84,000	102,000	618,000
2002	15,547	25,000	82,600	101,000	695,000
2003	13,792	20,000	66,000	81,000	550,000
2004	16,850	19,000	61,900	75,200	505,000
2005	16,151	19,500	58,500	70,200	560,000
2006	17,947	19,500	59,800	71,800	636,000
2007	18,744	30,000	79,200	95,300	875,000
2008	24,539	50,000	71,700	86,000	820,000
2009	19,549	60,000	71,400	83,500	834,000
2010	20,125	60,000	69,200	83,100	785,000
2011	13,556	41,548	69,300	83,300	791,000
2012	11,366	34,134	70,400	84,500	811,000
2013	17,358	22,699	67,900	81,500	748,000
2014	15,906	24,500	66,293	79,633	745,237
2015	-	24,250	66,130	79,419	736,947

*Flathead Sole removed from Other Flatfish category 1995. Flathead Sole category includes Bering Flounder and Flathead Sole.
[1]Catch data from BSAI SAFE, through November 2014.
[2]TAC, ABC and OFL from annual Specifications.
[3]Biomass corresponds to the annual SAFE report projections.

Stock Assessment: The assessment uses a split-sex, age-based model with length-based formulations for fishery and survey selectivities. This model incorporates fishery data and fishery independent data from trawl surveys. Flathead Sole fall under Tier 3a of the ABC/OFL control rules.

Fishery: 100% of the directed fishery Flathead Sole TAC is allocated among non-AFA trawl catcher processors according to their historic harvest patterns. The fishery mainly occurs from January-June. Primary products are H&G with roe-in and kirimi.



Dover Sole
AFSC, NOAA Fisheries

Other Flatfish

Stock assessment:

T. Wilderbuer, and D. Nichol. 2014. Assessment of Other Flatfish in the Bering Sea and Aleutian Islands.

www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: The Other Flatfish complex consists of 15 species. Starry Flounder, Rex Sole, Longhead Dab, Dover Sole, and Butter Sole comprise the majority of harvested "Other Flatfish."

Data are limited for many of the species in this complex. Rex Sole and Dover Sole are distributed from Baja California, through the BSAI and widely throughout the GOA. Adult Rex Sole and Dover Sole are bottom dwellers and are generally found in water deeper than 300 m. Available natural mortalities are as follows; Rex Sole M=0.17, Dover Sole M=0.085, remaining Other Flatfish M=0.15.

Common Name	Scientific Name
Arctic Flounder	*Liopsetta glacialis*
Butter Sole	*Isopsetta isolepis*
Curlfin Sole	*Pleuronectes decurrens*
Deepsea Sole	*Embassichths bathybius*
Dover Sole	*Microstomus pacificus*
English Sole	*Parophrys vetulus*
Longhead Dab	*Limanda proboscidea*
Pacific Sanddab	*Citharichthys sordidus*
Petrale Sole	*Eopsetta jordani*
Rex Sole	*Glyptocephalus zachirus*
Roughscale Sole	*Clidodoerma asperrimum*
Sand Sole	*Psettichthys melanostictus*
Slender Sole	*Lyopsetta exilis*
Starry Flounder	*Platichthys stellatus*
Sakhalin Sole	*Limanda sakhalinensis*

Catch History: Other Flatfish have been incidentally captured in target flatfish fisheries since Japanese and Soviet fleets began fishing in the Bering Sea in 1963. Prior to its removal from the "Other Flatfish" complex in 2002, Alaska Plaice comprised the majority of harvested "Other Flatfish." Catch of Alaska Plaice and "Other Flatfish" peaked in 1988 at 137,418 mt. Since the removal of Alaska Plaice from the complex, annual catches have averaged about 3,500 mt from 2003-2010.

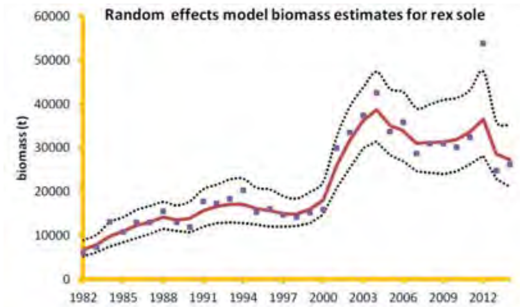
Stock Assessment: The Other Flatfish assessment is based on survey biomass estimates. Other Flatfish are managed under Tier 5 of the ABC/OFL control rules.

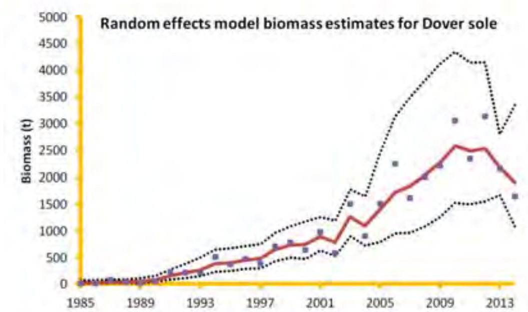
Fishery: Other Flatfish are caught primarily by trawl catcher processors targeting higher value flatfish species. Nevertheless, 47% of the other flatfish caught by trawl gear were retained in 2013.

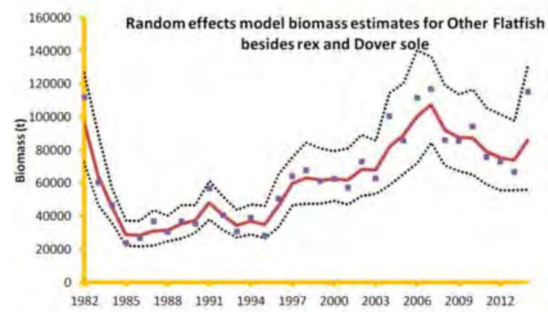
Total catches, pre-season catch specifications, and exploitable of Other Flatfish* in the BSAI, 2002-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2002	2,631	3,000	18,100	21,800	78,300
2003	2,749	3,000	16,000	21,400	107,000
2004	4,669	3,000	13,500	18,100	90,300
2005	4,599	3,500	21,400	28,500	143,000
2006	3,233	3,500	18,100	24,200	121,000
2007	5,840	10,000	21,400	28,500	149,000
2008	3,623	21,600	21,600	28,800	150,000
2009	2,163	17,400	17,440	23,100	121,000
2010	2,194	17,300	17,300	23,000	121,000
2011	3,176	3,000	14,500	19,500	127,329
2012	3,292	3,200	12,700	17,100	111,000
2013	1,536	3,500	13,300	17,800	114,000
2014	4,385	3,500	12,400	16,700	107,500
2015	-	3,620	13,250	17,700	143,000

*Alaska Plaice removed from Other flatfish complex 2002. Flathead Sole removed from Other Flatfish complex 1995.
[1]Catch data current through November 2014.
[2]1988-2010 TAC, ABC and OFL data from FR Specifications.
[3]Biomass from annual SAFE report projections.







AFSC, NOAA Fisheries

Pacific Ocean Perch

Stock assessment:

P. Spencer and J. Ianelli. 2014. Assessment of the Pacific ocean perch stock in the Bering Sea and Aleutian Island.

www.afsc.noaa.gov/refm/stocks/assessments.htm

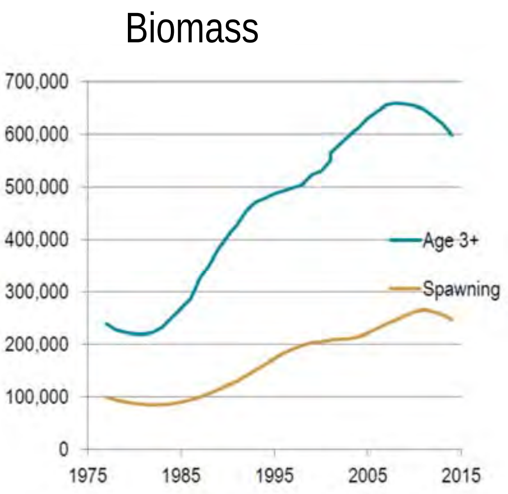
Biology: Pacific Ocean Perch (POP) *Sebastes alutus* distribution extends from Japan around the Pacific Rim south to California. POP are most abundant in AI, GOA and British Columbia and are found primarily offshore along the continental slope in depths from 180-420 m. POP are a demersal species found over cobble substrate. Seasonal changes in depth distribution occur, and adults migrate farther offshore to deeper waters during winter. During late spring and summer, POP migrate to shallower waters inshore for summer feeding. Populations often occur in patchy aggregations. Juveniles feed on calanoid copepods, whereas adults prey on euphausiids, shrimp and squids. POP are prey for Pacific Halibut, Sablefish, Pacific Cod and Arrowtooth Flounder.

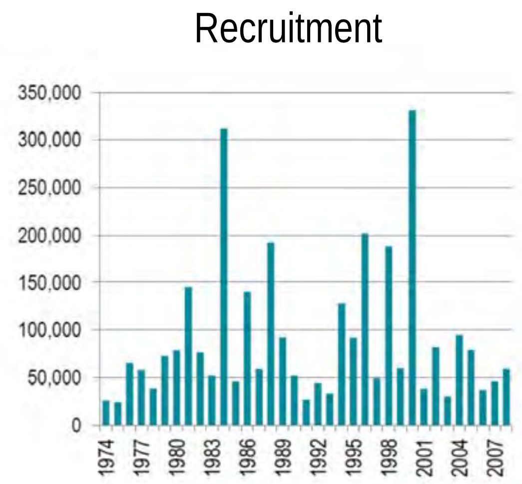
AFSC, NOAA Fisheries

POP is a slow-growing, long lived species. Recruitment to trawl fisheries begins at age 5, and they are fully recruited to the fishery around age 20 in recent years. Females reach 50% maturity at 9.1 years and longevity extends to 90 years (oldest recorded 98 years). Natural mortality is estimated to be M=0.062. Females are viviparous, retaining their fertilized eggs within the ovary until larval extrusion. Mating takes place in late fall, and larval extrusion occurs in early spring. Females release from 10,000-300,000 eggs each year, depending on size.

Stock Assessment: The assessment uses an age-structured population dynamics model that incorporates fishery data and fishery independent data from biennial trawl surveys. POP are managed under Tier 3a of the ABC/OFL control rules. The 2015 projected biomass (age 3+) is 577,967 mt. Catch specifications for 2015 are as follows; OFL=42,558 mt, ABC= 34,988 mt, TAC= 32,021 mt. Catch limits (ABC and TAC) are further apportioned by AI subarea.

Estimated biomass declined significantly from 1,131,000 mt in 1960 to 218,000 mt in 1981. Biomass recovered during the late 1980s due to above-average year classes in the AI and





reduced exploitation rates. Estimated biomass averaged 637,000 mt annually from 2004-2014.

Catch History: Soviet and Japanese trawl fisheries targeted POP throughout the 1960s. Catches in the EBS peaked at 47,000 mt in 1961 and in the AI in 1965 at 109,100 mt. Intense harvesting pressure reduced the stock biomass during that time, and catches declined through the mid-1980s. Foreign fisheries were replaced by joint ventures in the late1980s, and the fishery was fully domesticated by 1990, with catches reaching 18,324 mt. Catches averaged 14,4041 mt annually from 2004-2009.


Mark Fina, NPFMC

Fishery: POP are caught primarily in bottom trawl fisheries. Since 1996, the majority of the catch (by weight) occurred in the western Aleutians. In 2014, the discard rate for AI POP was <1%.

Fishery Management: In 1991, the POP and Other Red Rockfish complexes were separated from the POP/Other Rockfish complex. In 2001, the POP complex was separated into three management units; POP, Shortraker/Rougheye, and Sharpchin/Northern Rockfish. In 2002, Sharpchin Rockfish were dropped from the complex due to sparse catches, leaving Northern Rockfish as a single species management unit. In 2004, Shortraker and Rougheye Rockfish were split into single species management units. In 2008, the Rougheye Rockfish category was reclassified as a two species complex, Blackspotted and Rougheye Rockfish.

In 2008, BSAI FMP Amendment 80 allocated 90-98% (depending on sub-area) of the AI Pacific ocean perch TAC, along with flatfish and Atka Mackerel as catch shares among non-AFA trawl catcher processors according to their historic harvest patterns. Like other groundfish, 10.7% of rockfish is first allocated to CDQ groups.

Total catches, pre-season catch specifications, and exploitable biomass of Pacific Ocean Perch in the BSAI, 2004-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2004	11,896	12,580	13,300	15,800	375,000
2005	10,426	12,600	14,600	17,300	382,000
2006	12,859	12,600	14,800	17,600	385,000
2007	18,468	19,900	21,900	26,100	457,000
2008	17,436	21,700	21,700	25,700	453,000
2009	15,347	18,800	18,880	22,300	402,000
2010	17,852	18,860	18,860	22,400	403,000
2011	24,004	24,700	24,700	36,300	600,600
2012	24,143	24,700	24,700	35,000	594,000
2013	31,393	35,100	35,100	41,900	663,000
2014	25,889	33,122	33,122	39,585	639,505
2015	-	32,021	34,988	42,558	577,967

*POP removed from POP Complex 2004.
[1]Catch data current through November 2014.
[2]TAC, ABC and OFL data from annual Federal Register Harvest Specifications.
[3]Biomass from annual SAFE report projections.

Economics: In 2013, ex-vessel value of catch was $15.9 million for all BSAI Rockfish. Production was 29,170 mt for all rockfish products in Alaska, with a gross value $67.8 million. One catcher vessels and 16 catcher processor vessels participated in rockfish fisheries in the BSAI in 2013. Primary products are H&G and whole fish. Rockfish product price averaged $1.03/lb for at-sea processors and $1.16/lb for shoreside processors.

Ecosytem Components: POP habitat use shifts with ontogeny. Juveniles are thought to remain in more rugged, rocky benthic environments, whereas adults move into deeper, less rough habitats. POP were also found to be associated with epibenthic sea pens and sea whips along the BS slope.

AFSC, NOAA Fisheries

Northern Rockfish

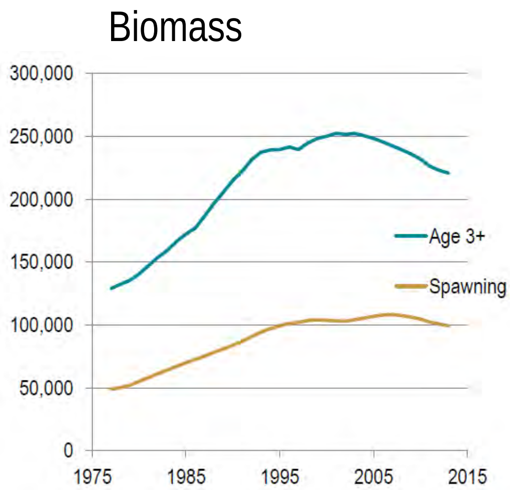
Biology: Northern Rockfish *Sebastes polyspinus* distribution extends from the Kamchatka Peninsula, through the BSAI, GOA and British Columbia. This species is most abundant in the central GOA to the western end of the AI. Northern Rockfish are demersal and are generally found in discrete aggregations with patchy distributions along the outer continental shelf from 75-150 m. Northern Rockfish prey on calanoid copepods, euphausiids and chaetognaths. Based on stomach content data for POP, Pacific Halibut and Sablefish likely prey on Northern Rockfish.

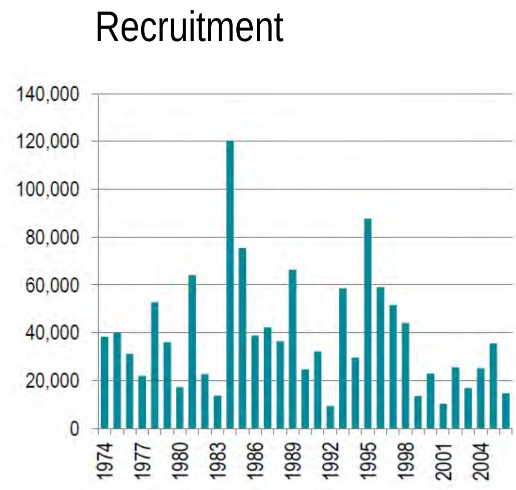
Northern Rockfish is a relatively slow-growing, long lived species. Age at 50% maturity is 8.2 years, and longevity extends to 70 years (the oldest recorded Northern Rockfish was 72 years old). Natural mortality is estimated to be M=0.049. Females are viviparous, retaining their fertilized eggs within the ovary until larval extrusion.

Stock assessment:

P. Spencer and J. Ianelli. 2014. Assessment of Northern Rockfish in the Bering Sea / Aleutian Islands.

www.afsc.noaa.gov/refm/stocks/assessments.htm





Total catches, pre-season catch specifications, and exploitable biomass of Northern Rockfish in the BSAI, 2001-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2001	-	-	-	-	150,000
2002	-	6,760	6,760	9,020	150,000
2003	-	6,000	7,101	9,468	156,000
2004	4,684	5,000	6,880	8,140	142,000
2005	3,964	5,000	8,260	9,810	200,000
2006	3,824	4,500	8,530	10,100	204,000
2007	4,021	8,190	8,190	9,750	212,000
2008	3,287	8,180	8,180	9,740	212,000
2009	3,111	7,160	7,160	8,540	200,000
2010	4,332	7,240	7,240	8,640	203,000
2011	2,764	4,000	8,670	10,600	201,000
2012	2,479	4,700	8,610	10,500	202,000
2013	2,038	3,000	9,850	12,200	195,000
2014	2,282	2,594	9,761	12,077	196,519
2015	-	3,250	12,488	15,337	218,901

*Northern Rockfish removed from Other Rockfish catetory 2001.
[1]Catch data current through November 2014.
[2]TAC, ABC and OFL from annual Federal Register.
[3]Biomass data corresponds to the annual SAFE report projections.

Catch History: Foreign trawl fisheries were replaced by joint ventures in the 1980s, and the fishery was fully domesticated by 1990. Catches of Northern Rockfish peaked in 1995 at 6,724 mt and ranged from 859-6,724 mt from 1990-2009. Catches from 2004-2009 averaged 3,800 mt annually.

Stock Assessment: The Northern Rockfish assessment uses an age-structured population dynamics model that incorporates fishery data and fishery independent data from biennial trawl surveys. Northern Rockfish are managed under Tier 3a of the ABC/OFL control rules.

Fishery: Northern Rockfish are generally caught in bottom trawl fisheries targeting other species. Catches in the BSAI primarily occur within the Atka Mackerel fishery, and historically, most (>80%) were discarded. Discard rates of Northern Rockfish have been decreasing over time, with an overall 2014 discard rate of 4% in the AI.

Blackspotted Rockfish
AFSC, NOAA Fisheries

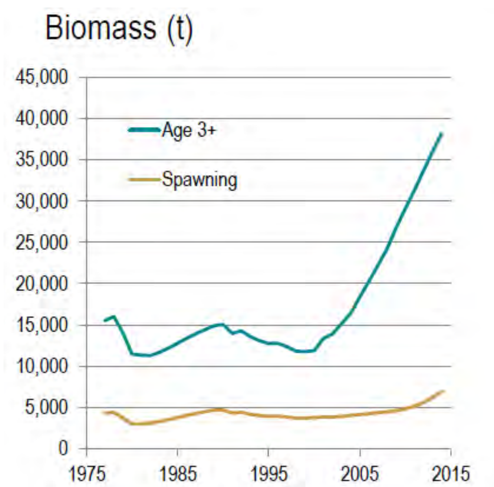
Blackspotted and Rougheye Rockfish

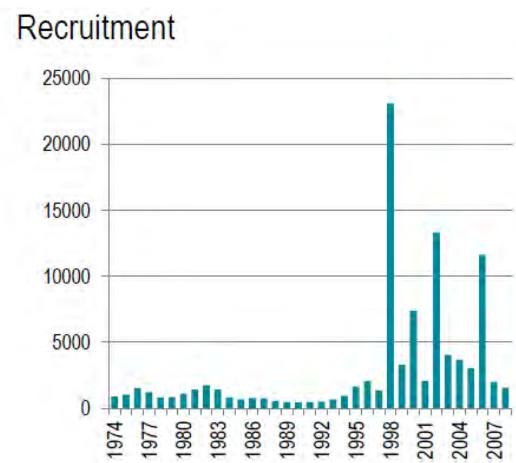
Biology: The Blackspotted and Rougheye Rockfish complex consists of 2 species: Blackspotted Rockfish *S. melanostictus* and Rougheye Rockfish *Sebastes aleutianus*. Blackspotted and Rougheye Rockfish are distributed from Japan, through the BSAI and GOA to southern California. Adults inhabit a narrow band along the upper continental slope at depths from 300-500 m. Data from recent bottom trawl surveys suggests that although the two species distributions overlap, Blackspotted Rockfish are predominant in the AI, while Rougheye Rockfish are more common in the GOA and southeastern BS. Blackspotted and Rougheye Rockfish length at 50% maturity is 44 cm. and longevity may extend to 200 years. Natural mortality is estimated at M=0.033. Blackspotted and Rougheye Rockfish prey primarily on shrimps, squids and myctophids.

Stock assessment:

P. Spencer and C. Rooper. 2014. Assessment of Blackspotted and Rougheye Rockfish Stock Complex in the Bering Sea and Aleutian Islands.

www.afsc.noaa.gov/refm/stocks/assessments.htm





Catch History: Rougheye Rockfish catches were relatively high during the late 1970s and peaked in 1979 at 3,553 mt. Catches then declined in the 1980s as the foreign fishery was reduced. Catches increased again during the 1990s with the domestication of the fishery, averaging 800 mt from 1990-1999. Catches have decreased since 2001, averaging 182 mt from 2004-2009.

Exploitable biomass (mt), pre-season catch specifications (mt), and total catches (mt, including discards) of Blackspotted and Rougheye Rockfish in the BSAI, 2004-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2004	208	195	195	259	10,400
2005	90	223	223	298	11,900
2006	203	224	224	299	11,900
2007	167	202	202	269	10,800
2008	214	202	202	269	10,800
2009	209	539	539	660	19,000
2010	256	547	547	669	21,200
2011	170	454	454	549	19,319
2012	201	475	475	576	23,400
2013	324	378	378	462	29,800
2014	194	416	416	505	30,447
2015	-	453	453	560	41,666

*Rougheye Rockfish removed from Other Rockfish catetory 2003.
[1]Catch data current through November 2014.
[2]TAC, ABC and OFL from annual Federal Register.
[3]Biomass data corresponds to the annual SAFE report projections issued the preceding year.

Stock Assessment: The Rougheye Rockfish assessment uses an age-structured population dynamics model that incorporates fishery data and fishery independent data from biennial trawl surveys. Rougheye Rockfish are assessed under Tier 3, and Blackspotted Rockfish are assessed under Tier 5 of the ABC/OFL control rules. The catch limits are split into two units: AI (2015 OFL = 516 mt, ABC = 420 mt) and EBS (2015 OFL= 44 mt, ABC = 33 mt).

Fishery: There is no directed fishery for these rockfish species in the BSAI. In the AI, they are primarily taken as incidental catch in the POP trawl fishery, and to a lesser extent the Atka Mackerel trawl fishery and the Pacific Cod longline fishery.

AFSC, NOAA Fisheries

Shortraker Rockfish

Stock assessment:

I. Spies, P. Spencer, J. Ianelli, and C. Rooper. 2014. Assessment of the Shortraker Rockfish stock in the Bering Sea and Aleutian Islands.

www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: Shortraker Rockfish *Sebastes borealis* are distributed from southeastern Kamchatka, north through the BSAI, the GOA and south to California. Adults are concentrated along the 300-500 m depth interval along the continental slope. Shortraker Rockfish predate on shrimps, squids and myctophids. Shortraker Rockfish is one of the most long-lived species in the northeast Pacific. Age at 50% maturity is 45 cm, and longevity can exceed 140 years. Natural mortality is estimated to be M=0.03. Information on early life history stages of Shortraker Rockfish is limited.

AFSC, NOAA Fisheries

Catch History: Shortraker Rockfish were included in the BS "Other Rockfish" category and AI Shortraker/Rougheye category prior to 2004. Catches of Shortraker Rockfish averaged 300 mt annually from 2009-2014.

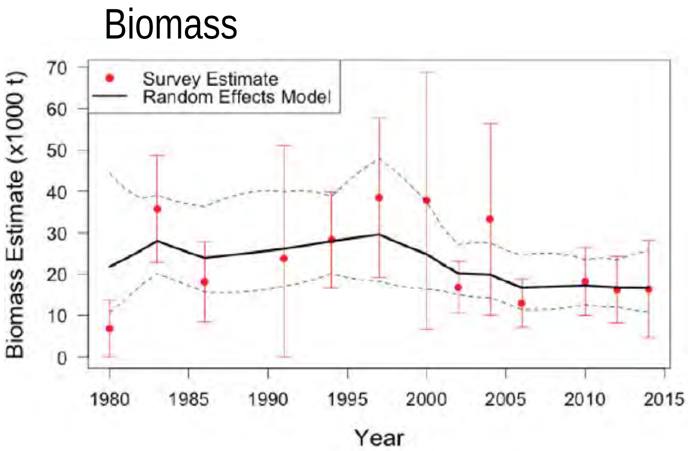
Stock Assessment: The Shortraker Rockfish assessment uses a random effects model incorporates fishery data and fishery independent data from biennial trawl surveys. Shortraker Rockfish are managed under Tier 5 of the ABC/OFL control rules.

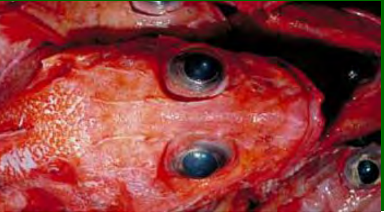
Fishery: Shortraker Rockfish in the Aleutian Islands are primarily taken in rockfish trawl fisheries and longline fisheries targeting Greenland Turbot, Sablefish, and Pacific Cod. The central Aleutians comprised 24% of the 2004-2014 AI Shortraker catch, followed by the western Aleutians (23%) eastern Aleutians (13%), and EBS (35%). In the Eastern Bering Sea, catches of Shortraker Rockfish largely occur in midwater pollock trawl fisheries and longline fisheries for Pacific Cod, Greenland Turbot, and halibut. In 2014, 45% of the Shortraker Rockfish were discarded.

Total catches, pre-season catch specifications, and exploitable biomass of Shortraker Rockfish* in the BSAI, 2004-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2004	240	526	526	701	23,400
2005	169	596	596	794	26,500
2006	210	580	580	774	25,800
2007	323	424	424	564	18,900
2008	133	424	424	564	18,900
2009	184	387	387	516	17,200
2010	300	387	387	516	17,200
2011	333	393	393	524	17,452
2012	344	393	393	524	17,500
2013	372	370	370	493	16,400
2014	187	370	370	493	16,447
2015	-	518	518	690	23,009

*Shortraker Rockfish removed from SR/RE category 2003.
[1]Catch data current through November 2014.
[2]TAC, ABC and OFL data from annual Federal Register.
[3]Biomass from annual SAFE report projections.





Shortspine Thornyhead Rockfish
AFSC, NOAA Fisheries

Biology: The Other Rockfish complex consists of 24 species. The 7 most commonly caught species are listed in the adjacent text box. Shortspine Thornyhead and Dusky Rockfish are the two most abundant species for this complex, accounting for about 80% of the survey biomass and fishery catch. Data are limited for many of the "Other Rockfish" complex species.

Common name	Scientific name
Redbanded Rockfish	*Sebastes babcocki*
Dusky Rockfish	*Sebastes variabilis*
Redstriped Rockfish	*Sebastes proriger*
Yelloweye Rockfish	*Sebastes ruberrimus*
Harlequin Rockfish	*Sebastes variegatus*
Sharpchin Rockfish	*Sebastes zacentrus*
Shortspine Thornyhead	*Sebastolobus alascanus*

Dusky Rockfish distribution extends from Japan into the BSAI and down to central Oregon. Dusky Rockfish are found along the outer continental shelf in patchy distributions. Natural morality is estimated at M=0.09. Dusky Rockfish are viviparous. Dusky Rockfish longevity is approximately 60 years. Shortspine Thornyhead is distributed from Japan to the BSAI down to central California. Shortspine Thornyheads are commonly found at depths from 150-450 m. Natural morality is estimated at M=0.03, and Shortspine Thornyhead longevity extends to 100 years or more. In contrast to many other *Sebastes spp*., the Shortspine Thornyhead is oviparous.

Stock assessment:

I. Spies and P. Spencer. 2014. Assessment of Other Rockfish stock complex in the Bering Sea / Aleutian Islands.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Catch History: Other Rockfish have been caught in trawl fisheries since Japanese and Soviet fleets began fishing in the BS in the 1960s. Catches of "Other Rockfish" have been tracked since 1977. Catches were relatively high in the BSAI from 1977-1983, ranging annually from 700-2,300 mt. Catches have remained relatively stable from 1993-2009, averaging 677 mt annually.

Stock Assessment: Other Rockfish are managed under Tier 5 of the ABC/OFL control rules. Catch specifications for 2015 include further subdivision of ABC limits by area such that BS ABC= 695 mt, and AI ABC=555 mt.

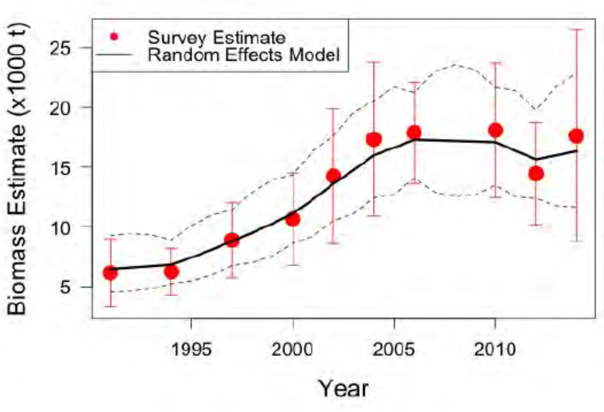
Total catches, pre-season catch specifications and exploitable biomass of Other Rockfish in the BSAI, 1995-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
1995	849	1,022	1,135	1,135	22,800
1996	642	1,304	1,449	1,449	20,700
1997	468	1,087	1,087	1,449	20,700
1998	588	1,054	1,054	1,492	20,300
1999	765	1,054	1,054	1,405	20,030
2000	840	1,054	1,054	1,405	20,030
2001	906	1,037	1,037	1,383	19,780
2002	952	1,037	1,037	1,383	19,780
2003	737	1,594	1,594	2,126	19,780
2004	655	1,594	1,594	2,126	20,400
2005	464	1,050	1,400	1,870	20,400
2006	579	1,050	1,400	1,870	26,600
2007	602	999	999	1,330	26,700
2008	524	999	999	1,330	36,700
2009	487	1,040	1,040	1,380	39,700
2010	657	1,040	1,040	1,380	39,200
2011	892	1,000	1,280	1,700	44,939
2012	816	1,070	1,280	1,700	48,900
2013	758	873	1,160	1,540	47,700
2014	794	773	1,163	1,550	47,700
2015	-	880	1,250	1,667	49,630

[1]Catch data current through November 2014.
[2]TAC, ABC and OFL from annual Federal Register.
[3]Biomass from annual SAFE report projections. Biomass includes Sharpchin Rockfish prior to 2003.

Fishery: There is no directed fishery for Other Rockfish in the BSAI. Dusky Rockfish are primarily taken in the Atka Mackerel fishery in the AI and the EBS Pacific Cod fishery. Shortspine Thornyhead are primarily taken in the AI Sablefish and Greenland Turbot longline fisheries and EBS pollock trawl fishery.

Aleutian Islands SST



Atka Mackerel

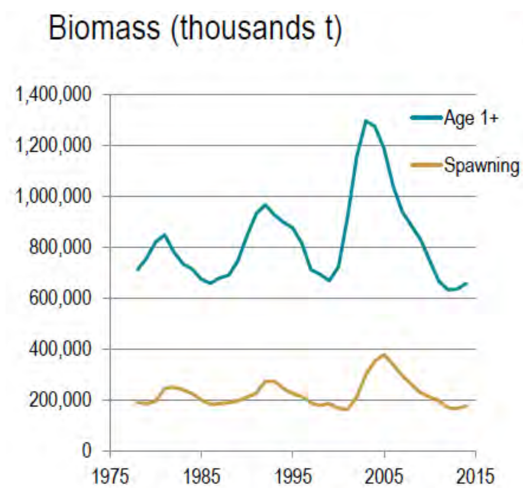
AFSC, NOAA Fisheries

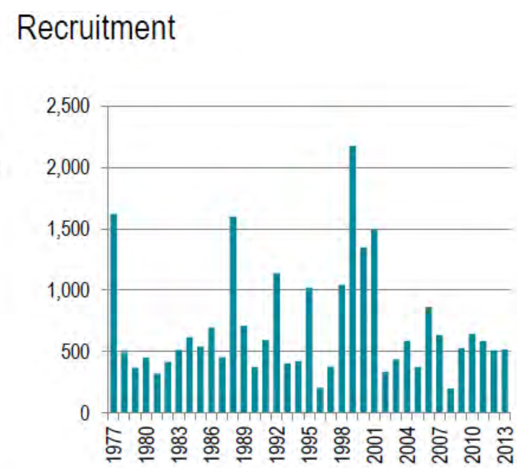
Biology: Atka Mackerel *Pleurogrammus monopterygius* is a schooling, semi-demersal species most commonly found in the AI. Adults occur in large localized aggregations at depths less than 200 m over rough, uneven bottom areas with high tidal currents. Atka Mackerel move off the bottom during daylight hours presumably to feed on their main prey items, euphausiids and copepods. Predators of Atka mackerel include Pacific Cod, Arrowtooth Flounder, Steller sea lions and seabirds. They begin to recruit to the fishery at age 3 and longevity can extend to 15 years. Females reach 50% maturity at 34 cm (3.6 years). Natural mortality is estimated at M=0.30. Atka Mackerel are a substrate spawning fish with male parental care. . During spawning, territorial males become bright yellow. Spawning occurs from July to October, peaking in early September. Eggs are adhesive and deposited in rock crevices in nests guarded by males until hatching, which occurs about 40-45 days later.

Stock assessment:

S. Lowe, J. Ianelli, and W. Palsson. 2014. Assessment of the Atka Mackerel stock in the Bering Sea/Aleutian Islands.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm





Total catches, pre-season catch specifications, and exploitable biomass of Atka Mackerel in the BSAI, 1998-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
1998	57,096	64,300	64,300	134,000	693,144
1999	53,644	66,400	73,300	148,000	668,375
2000	47,229	70,800	70,800	119,000	721,713
2001	61,560	69,300	69,300	138,000	915,282
2002	45,294	49,000	49,000	82,300	1,152,710
2003	59,350	60,000	63,000	99,700	1,295,170
2004	60,564	63,000	66,700	99,700	1,273,540
2005	62,014	63,000	124,000	178,500	1,185,810
2006	61,883	63,000	110,200	147,000	1,037,600
2007	58,831	63,000	74,000	86,900	939,110
2008	58,088	60,700	60,700	71,400	883,655
2009	72,806	76,400	83,800	99,400	828,308
2010	68,619	74,000	74,000	88,200	746,898
2011	51,818	53,080	85,300	101,000	665,884
2012	47,826	50,763	81,400	96,500	631,844
2013	23,181	25,920	50,000	57,700	634,682
2014	31,690	32,322	64,131	74,492	657,228
2015	-	54,500	106,000	125,297	694,421

[1]Catch data current through November 2014.
[2]1988-2010 TAC, ABC and OFL from Federal Register
[3]Biomass data from SAFE report projections.

Catch History: Beginning in 1970, USSR, Russia and Korea harvested Atka Mackerel; foreign catches peaked in 1978 at 24,000 mt. U.S. joint venture fisheries began in 1980 and dominated landings of Atka mackerel from 1982-1988. The last joint venture allocation of Atka mackerel off Alaska was in 1989. Peak domestic catch occurred in 1996 (104,000 mt).

Fishery Management: The Atka Mackerel fishery is heavily regulated to minimize the potential for prey competition with Steller sea lions, including seasonal allowances of TAC and spatial distribution of the fishery away from critical habitat. Since 2008, the fishery has operated as a catch share fishery, with participants operating as cooperatives.

Stock Assessment: The Atka Mackerel assessment model incorporates fishery data and fishery independent data from trawl surveys. Atka Mackerel fall under Tier 3a of the ABC/OFL control rules.

Fishery: Atka Mackerel are targeted by trawl catcher processors. Products include whole fish and H&G.

AFSC, NOAA Fisheries

Biology: There are 14 species in the "Squid" complex in the BSAI. The most commonly caught species in the BS is the Magistrate Armhook Squid *Berryteuthis magister*. Squid in the BSAI are generally pelagic, however, the North Pacific bobtail squid, and magistrate armhook squid are often found in close proximity to the bottom. Most species are associated with the slope and basin, with the highest species diversity along the slope region of BS between 200–1500 m.

Chiroteuthid sp.	*Chiroteuthis calyx*
Glass squid sp.	*Belonella borealis*
Glass squid sp.	*Galiteuthis phyllura*
Minimal Armhook Squid	*Berryteuthis anonychus*
Magistrate Armhook Squid	*Berryteuthis magister*
Armhook squid	*Eogonatus tinro*
Boreopacific Armhook Squid	*Gonatopsis borealis*
Berry Armhook Squid	*Gonatus berryi*
Armhook squid sp.	*Gonatus madokai*
Armhook squid sp.	*Gonatus middendorffi*
Clawed Armhook Squid	*Gonatus onyx*
Robust Clubhook Squid	*Moroteuthis robusta*
Boreal Clubhook Squid	*Onychoteuthis borealijaponicus*
North Pacific Bobtail squid	*Rossia pacifica*

Squids are productive, short-lived animals. Squid display rapid growth, patchy distribution and variable recruitment patterns. Populations of the Magistrate Armhook Squid are complex and are made up of multiple cohorts spawned throughout the year. Magistrate squid are dispersed throughout the summer months in the western BS but form large, dense schools over the continental slope between September and October. Three seasonal cohorts are identified in the region; summer-hatched, fall-hatched and winter-hatched. Growth, maturation and mortality rates vary between cohorts. Juvenile and adult magistrate squid also appear to be separated vertically in the water column. Most squid are generally thought to live less than 2-3 years.

Stock assessment:

O. Ormseth. 2014. Assessment of the squid stock complex in the Bering Sea and Aleutian Islands.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Catch history: Japanese and Korean trawl fisheries targeted squid during the 1960s and 1970s; catches peaked in 1978 at 9,000 mt. Catches have remained below 2,000 mt since 1984.

Stock Assessment: Squid fall under Tier 6 of the OFL/ABC control rules, and catch specifications are therefore based on the average catch of squid between1978-1995. Squid estimated biomass is unknown due to a lack of reliable survey data. Catch specifications for squid in 2015 are as follows: OFL= 2,620 mt, ABC= 1,970 mt, TAC= 400 mt.

Total catches and pre-season catch specifications of Squid in the BSAI, 2007-2015.

Year	Catch	TAC	ABC	OFL
2007	1,188	1,970	1,970	2,620
2008	1,542	1,970	1,970	2,620
2009	360	1,970	1,970	2,620
2010	410	1,970	1,970	2,620
2011	336	425	1,970	2,620
2012	688	425	1,970	2,620
2013	300	700	1,970	2,620
2014	1,668	310	1,970	2,620
2015	-	400	1,970	2,620

*Squid biomass data unavailable.

Fishery: Squid are not a target fishery, and are primarily taken as incidental catch in the pelagic trawl pollock fishery. Discard rates have ranged from about 40 to 70 % in recent years.

Ecosystem Components: Squid important components in the diets of many seabirds, fish and marine mammals. Overall fishing removals of squid are very low (especially relative to natural predation).

Bigmouth Sculpin
AFSC, NOAA Fisheries

Sculpins

Biology: There are a total of 48 species of sculpins in the BSAI, with 41 species identified in the Eastern Bering Sea and 22 species in the Aleutian Islands region. Sculpins occupy all benthic habitats and depths. The six species with the highest biomasses include Great Sculpin (*Myoxocephalus polyacanthocephalus*), Threaded Sculpin (*Gymnocanthus pistillger*) Plain Sculpin (*M. jaok*), Warty Sculpin (*M. verrucosus)*, Bigmouth Sculpin (*Hemitripterus bolini)*, and Yellow Irish Lord (*H. jordani*).

There is limited BSAI-specific data on age and growth, maturity, or reproductive biology for sculpins identified in this management region. Most if not all sculpins lay adhesive eggs in nests, and many exhibit parental care for eggs.

Stock assessment:

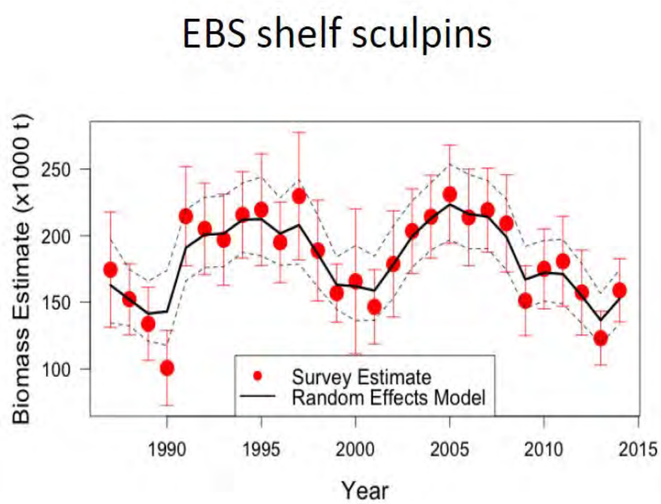
I. Spies, D. Nichol, O. Ormseth and T. TenBrink. 2014. Assessment of the sculpin stock comples in the Bering Sea and Aleutian Islands.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Catch history: Based on total catch estimates from 1998-2008, sculpins comprised 19-28% of the total Other Species catch during this time period. Catches from 2000-2008 ranged from 5,735 mt to 7,670 mt per year.

Stock Assessment: Prior to 2011, sculpins were managed as part of the BSAI Other Species complex that included sculpins, skates, sharks, and octopuses. Sculpins fall under Tier 5 of the OFL/ABC control rules. A complex wide natural mortality rate of M=0.29 is applied.

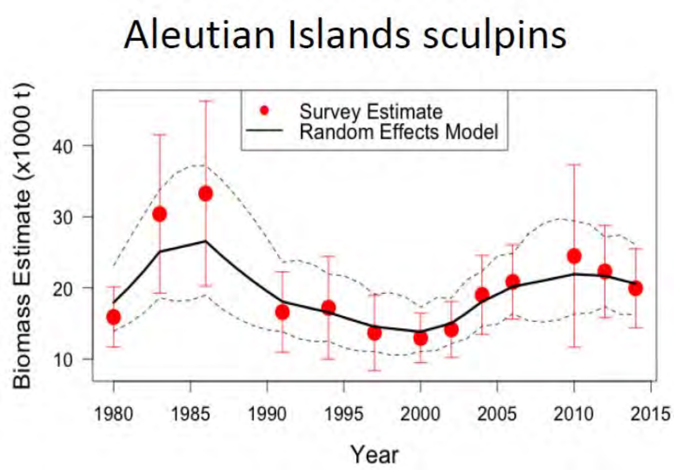
Fishery: There is currently no target fishery for sculpins in the BSAI, and virtually all are discarded or made into meal. Incidental catches of sculpins are taken in the Pacific Cod and Atka Mackerel fisheries in the AI, and in the Pacific Cod rock sole, and Yellowfin Sole fisheries in the BS.



Total catches, pre-season catch specifications, and exploitable biomass of Sculpins in the BSAI, 2008-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2008	6,682	-	-	-	-
2009	5,915	-	-	-	-
2010	4,227	-	-	-	-
2011	5,146	5,200	43,700	58,300	208,000
2012	5,420	5,200	43,700	58,300	208,000
2013	5,194	5,600	42,300	56,400	216,000
2014	4,204	5,750	42,318	56,424	215,713
2015	-	4,700	42,852	56,487	194,783

[1]Catch data current through November 2014.
[2]TAC, ABC and OFL from SAFE
[3]Biomass data from SAFE report projections.



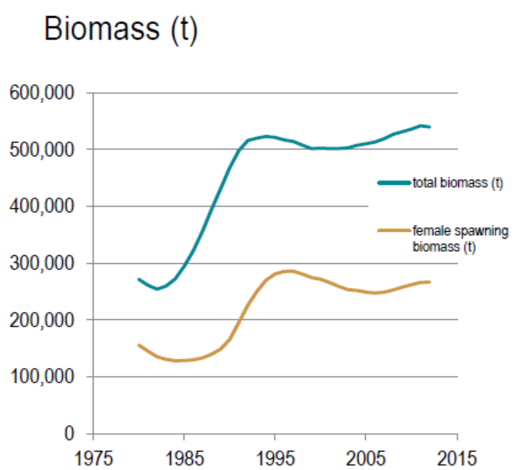
Alaska Skate
Beth Matta
AFSC, NOAA Fisheries

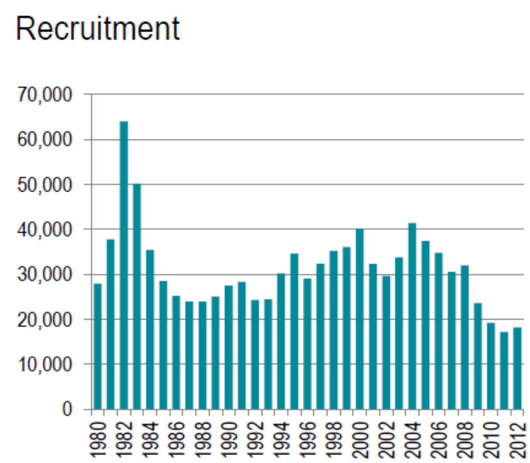
<u>Biology:</u> Skates are cartilaginous fishes with large pectoral "wings" attached to the sides of the head. There are 15 species of skates in the BSAI in four genera, *Raja*, *Bathyraja*, *Beringraja*, and *Amblyraja.* The EBS shelf skate complex is dominated by a single species, the Alaska Skate (*Bathyraja parmifera*), occurring at depths of 50 to 200 m. The Bering or sandpaper Skate (*B. interrupta*) is the next most common species on the EBS shelf, and is distributed on the outer continental shelf. The dominant species on the EBS slope is the Aleutian Skate (*B. aleutica*). A number of other species are found on the EBS slope in significant numbers, including the Alaska Skate, Commander Skate (*B. lindbergi*), Whiteblotched Skate (*B. maculata*), Whitebrow Skate (*B. minispinosa*), roughtail Skate (*B. trachura*), and mud Skate (*B. taranetzi*). Two rare species, the Deepsea Skate (*B. abyssicola*) and Roughshoulder Skate (*Amblyraja badia*), have only recently been reported from EBS slope bottom trawl surveys. The skate complex in the AI is quite distinct from the EBS shelf and slope complexes, with different species dominating the biomass, as well as at least one endemic species, the recently described Butterfly Skate, *Bathyraja mariposa*, as well as the newly identified Leopard Skate. In the AI, the most abundant species is the Whiteblotched Skate, *B. maculate.*

Stock assessment:

O. Ormseth. 2014. Assessment of the skate stock complex in the Bering Sea and Aleutian Islands.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm





Skate life cycles are similar to sharks, with relatively low fecundity, slow growth to large body sizes, and dependence of population stability on high survival rates of a few well developed offspring. Alaska Skates reach 50% maturity at ages 9-10 years, and have life spans of up to 17 years, based on observations to date.

Total catches, pre-season catch specifications, and exploitable biomass of Skates in the BSAI, 2008-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2008	20,469	-	-	-	-
2009	19,442	-	-	-	634,000
2010	16,515	-	-	-	608,000
2011	23,005	16,500	31,500	37,800	612,000
2012	23,873	24,700	32,600	39,100	645,000
2013	26,165	24,000	38,800	45,800	745,000
2014	21,319	26,000	35,383	41,849	698,204
2015	-	25,700	41,849	49,575	628,314

[1]Catch data current through November 2014.
[2]TAC, ABC and OFL from SAFE
[3]Biomass from SAFE report projections.

<u>Stock Assessment</u>: Until 2011, skate species were managed as part of the "Other species" management category within the BSAI FMP. Catch specifications for the Alaska Skate is based on Tier 3a, and for other skates Tier 5 of the ABC/OFL control rules. Total skate biomass is projected at 628,314 mt in 2015.

<u>Fishery</u>: There is currently no target fishery for skates in the BSAI. Most of the skate is caught incidentally in the hook and line fishery for Pacific Cod, and trawl fisheries for pollock and flatfish. About 35% of the skate catch is retained.

Sharks

Salmon Shark
AFSC, NOAA Fisheries

Biology: The shark complex consists of 8 species. The species most likely to be encountered in BSAI fisheries and surveys are the Pacific Sleeper Shark (*Somniosus pacificus*), the Spiny Dogfish (*Squalus acanthias*), and the Salmon Shark (*Lamna ditropis*). Sharks are long-lived species with slow growth to maturity, a large maximum size, and low fecundity. Spiny Dogfish tend to segregate by sex and by size. Age-at-50%-maturity for Spiny Dogfish is estimated to be 35 years for females, and 19 years for males. Spiny Dogfish may live up to 100 years, and exhibit very slow growth rates. Spiny dogfish are aplacental viviparous, and embryos are nourished solely by their yolk sac, with a gestation period of 18-24 months. Pacific Sleeper Sharks can attain large size, with maximum lengths of 440 cm for females and 400 cm for males, although there are reports of individuals of 700 cm in length. Like Spiny Dogfish, Pacific Sleeper Sharks are aplacental viviparous. Salmon Sarks also grow relatively large, attaining a maximum length of 215 cm precaudal length for females and about 190 cm for males. Maximum ages for Salmon Sharks are 17 years for males and 30 years for females. They are thought to live up to 30 years.

Stock assessment:

C. Tribuzio, K. Echave, C. Rodgveller, and P-J. Hulson. 2014. Assessment of the shark complex in the Bering Sea and Aleutian Islands.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Catch history: Incidental catches of shark species in the BSAI fisheries have been very small compared to catches of target species. Sharks have only been reported to species in the catch since 1997. Pacific Sleeper Shark make up about 60% of the total shark catch in the BSAI, followed by unidentified sharks at 20%, Salmon Shark at 9% and Spiny Dogfish at 2%.

Fishery Management: Shark species were managed as part of the "Other species" management category until 2011, when sharks became a separate management complex with shark specific OLF, ABC, and TAC.

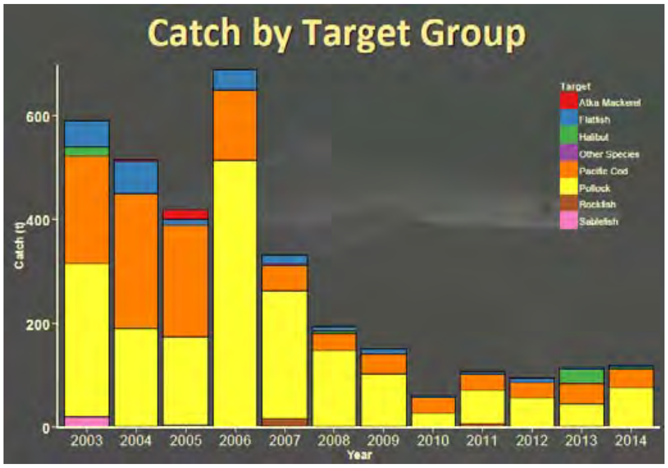
Stock Assessment: Sharks fall under Tier 6 of the OFL/ABC control rules, and catch specifications are based on the maximum catch from 1997-2007 (1,362 mt in 2002). Sharks estimated biomass is undefined due to a lack of reliable survey data. Directed fishing for this species has not been authorized.

Fishery: There is currently no target fishery for sharks in federally or state managed waters of the BSAI, and most incidentally captured sharks are not retained. Spiny Dogfish are at the northern edge of their range in the BSAI but a few are taken in Pacific Cod longline fishery. About majority of the salmon sharks are taken in the Pollock fishery. Sleeper Sharks are taken mainly in the Pacific Cod and Pollock fisheries.

Total catches, pre-season catch specifications, and exploitable biomass of Sharks in the BSAI, 2008-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2008	194	-	-	-	-
2009	151	-	-	-	-
2010	60	-	-	-	-
2011	107	50	1,020	1,360	Unknown
2012	96	200	1,020	1,360	Unknown
2013	116	100	1,020	1,360	Unknown
2014	184	125	1,022	1,363	Unknown
2015	-	125	454	605	Unknown

[1]Catch data current through November 2014.
[2]TAC, ABC and OFL from SAFE
[3]Biomass from SAFE report projections.



Giant Pacific Octopus
Rex Murphy

Biology: There are at least 7 species of octopus present in the BSAI, and the species composition both of natural communities and commercial harvest is unknown. Some species, particularly *G. boreapacifica*, are primarily distributed at greater depths than are commonly fished. At depths less than 200 meters *E. dofleini* appears to be the most abundant species.

Giant Pacific Octopus	*Enteroctopus dofleini*
Smoothskin Octopus	*Benthoctopus leioderma*
Flapjack Devilfish	*Opisthoteuthis californiana*
Small Pelagic Octopus	*Japatella diaphana*
Stubby Octopus	*Sasakiopus salebrosus*
A deepwater octopus	*Graneledone boreopacifica*
A deepwater octopus	*Benthoctopus oregonesis*

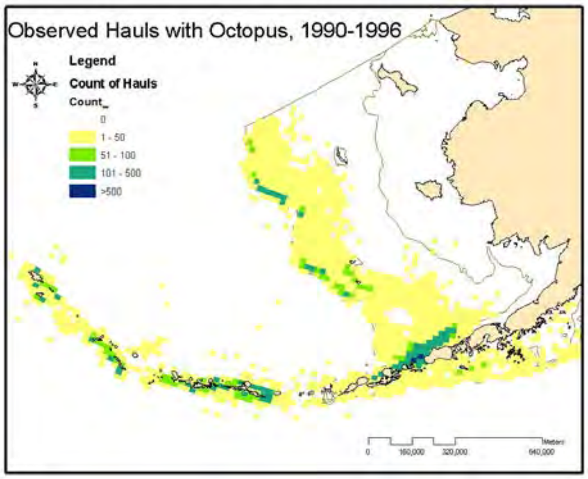
Octopus life spans are either 1-2 years or 3-5 years depending on the species. *E. dofleini* are estimated to mature at 1.5 – 3 years. *E. dofleini* is a terminal spawner, females die after the eggs hatch while males die shortly after mating. The fecundity of this species in Japanese waters has been estimated at 30,000 to 100,000 eggs per female. Based on larval data, *E. dofleini* is the only octopus in the Bering Sea with a planktonic larval stage.

Stock assessment:

M.E. Conners, C. Conrath, and K. Aydin. 2014. Assessment of the Octopus Stock Complex in the Bering Sea and Aleutian Islands.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Fishery Management: Until 2011, octopus were managed as part of the "Other species" management category within the BSAI FMP. Octopuses have been managed as a single complex with specific OFL, ABC, and TAC since 2011.



Stock Assessment: Octopus fall under Tier 6 of the OFL/ABC control rules. Catch specifications are based on a natural mortality approach using the geometric mean of annual consumption of octopus by its main predator, Pacific Cod. There are no historical catch records for octopus, and their biomass has not been estimated. Catch specifications for octopus in 2015 are as follows; OFL=3,452 mt, ABC=2,589 mt, TAC=400 mt. Directed fishing for this species is normally prohibited each year.

Total catches, pre-season catch specifications, and exploitable biomass of Octopus in the BSAI, 2008-2015.

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
2008	212	-	-	-	-
2009	72	-	-	-	-
2010	177	-	-	-	-
2011	587	150	396	528	Unknown
2012	86	900	2,590	3,450	Unknown
2013	223	500	2,590	3,450	Unknown
2014	233	225	2,590	3,450	Unknown
2015	-	400	2,589	3,452	Unknown

[1]Catch data current through November 2014.
[2]TAC, ABC and OFL from SAFE
[3]Biomass from SAFE report projections.

Fishery: There is currently no target fishery for octopus in the BSAI. Octopus are taken as incidental catch in trawl, longline, and pot fisheries throughout the BSAI; the highest catch rates are from Pacific Cod pot fisheries in the three statistical areas around Unimak Pass. The species composition of the octopus community is not well documented, but recent research indicates that the giant Pacific Octopus *Enteroctopus dolfleini* is most abundant in shelf waters and predominates in commercial catch.

Walleye Pollock
AFSC, NOAA Fisheries

Walleye Pollock

Biology: Walleye Pollock *Gadus chalcogrammus* is an abundant fish species in the GOA, found throughout the shelf regions at depths less than 300 m. Seasonal migrations occur from overwintering areas along the outer shelf to shallower waters (30-140 m) to spawn. Pollock feed on copepods, euphausiids and fish and are prey for other fish, marine mammals and seabirds. Pollock begin to recruit to the fishery at age 3 and live to 12 years or more (the oldest Pollock recorded in the GOA is 22 years). Females reach 50% maturity at approximately 43 cm (ages 4-6), and adults produce 60,000 to 400,000 pelagic eggs. Annual natural mortality is estimated to be M=0.30. Peak spawning in the GOA occurs from February to March in the Shumagin Islands and late March in the Shelikof Strait.

Stock assessment:

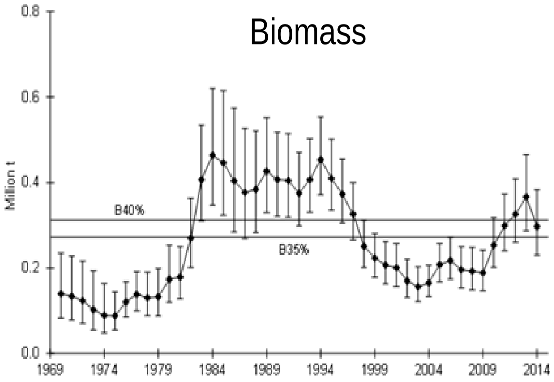
M. Dorn, K. Aydin, D. Jones, W. Palsson, K. Spalinger. 2014. Assessment of the Walleye Pollock stock in the Gulf of Alaska.

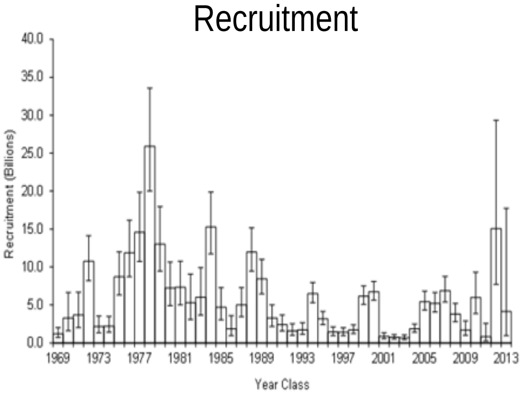
http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Catch History: Foreign fisheries for pollock developed in the GOA in the early 1970s and peak foreign catches occurred in 1981 at 130,324 mt. A late spawning aggregation was discovered in Shelikof Strait in 1981, and a valuable pollock roe fishery was established in the region. U.S. vessels entered the pollock fishery in 1977 and by 1988, the fishery was fully harvested by the domestic fleet.

AFSC, NOAA Fisheries

Fishery Management: The GOA pollock fishery is regulated under the GOA groundfish FMP through permits and limited entry, catch quotas (TACs), seasons, in-season adjustments, gear restrictions, closed waters, bycatch limits and rates, allocations, regulatory areas, record keeping, reporting requirements and observer monitoring. In 1993, 100% of GOA pollock was apportioned to the inshore sector (vessels that catch fish to deliver to shore based processing plants). In 1998, trawl gear was prohibited east of 140°W, and 100% retention was required for pollock.





Since 1992, GOA pollock catch has been apportioned spatially and temporally to reduce fishery impacts on Steller sea lions (SSLs). Additional SSL protection measures implemented in 2001 established 4 seasons in the Central and Western GOA beginning in January, March, August and October (25% TAC to each season). Additionally, a harvest control rule was implemented that requires suspension of directed pollock fishing if spawning biomass declines below 20% of unfished spawning biomass.

Stock Assessment: The GOA pollock assessment is based on an age-structured model. This model incorporates fishery data and fishery independent data from annual bottom trawl surveys and acoustic trawl surveys. GOA pollock fall under Tier 3b of the ABC/OFL control rules. The 2015 age 3+ biomass is estimated at 1,940,031 mt. Gulf wide catch specifications for 2015 are as follows; OFL=273,378 mt, ABC=203,934 mt, TAC=199,151 mt. The catch limits are further spatially apportioned into Western, Central area 62, Central area 63, West Yakutat, and Eastern GOA.

Total catches, pre-season catch specifications, and exploitable biomass of age 3+ Walleye Pollock in the GOA, 1980-2015 (in mt).

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
1980	115,158	-	-	-	1,743,000
1981	147,818	-	-	-	2,694,000
1982	169,045	-	-	-	2,935,000
1983	215,625	-	-	-	2,771,000
1984	307,541	-	-	-	2,425,000
1985	286,900	293,250	-	-	1,983,000
1986	86,910	116,600	116,600	-	1,624,000
1987	68,070	108,000	112,000	-	1,996,000
1988	63,391	93,000	93,000	-	1,910,000
1989	75,585	60,200	63,400	-	1,731,000
1990	88,269	93,000	93,000	-	1,575,000
1991	100,488	133,400	133,400	-	1,757,000
1992	90,858	87,400	99,400	227,900	2,118,000
1993	108,909	114,400	160,400	295,020	1,845,000
1994	107,335	109,300	109,300	246,600	1,539,000
1995	72,618	65,360	65,360	280,400	1,286,000
1996	51,263	54,810	54,810	86,400	1,077,000
1997	90,130	79,980	79,980	112,270	1,108,000
1998	125,460	124,730	130,000	186,100	982,000
1999	95,638	100,920	100,920	146,000	782,000
2000	73,080	100,000	100,000	139,370	689,000
2001	72,077	95,875	105,810	126,360	655,000
2002	51,934	58,250	58,250	84,0 90	821,000
2003	50,684	54,350	54,350	78,020	1,025,000
2004	63,844	71,260	71,260	99,750	835,000
2005	80,978	91,710	91,710	153,030	687,000
2006	71,976	86,807	86,807	118,309	588,000
2007	52,714	68,307	68,307	95,429	561,000
2008	52,584	51,940	51,940	83,150	856,000
2009	44,247	49,900	49,900	69,630	1,292,000
2010	76,745	84,745	84,745	115,536	1,468,000
2011	81,357	86,970	86,970	118,030	1,367,000
2012	103,982	116,444	116,444	158,082	1,263,000
2013	96,363	121,046	121,046	165,183	1,321,000
2014	139,753	174,976	174,976	228,831	1,201,000
2015	-	199,151	203,934	273,378	1,940,031

[1]Catch data through November 8, 2014.
[2]1988-2014 TAC, ABC and OFL data from annual Federal Register Harvest Specifications. Does not include EYAK and SEO.
[3]Biomass from annual SAFE report projections.

Age 3+ GOA pollock model-estimated biomass was high during the early 1980s. Biomass declined through the late 1980s and dropped below target as a result of below average recruitment. More recently, the stock size has shown a strong upward trend, and is now close to target.

Fishery: The directed fishery is prosecuted by vessels using trawl gear, primarily with pelagic trawls. Small amounts of pollock are also taken as bycatch in other fisheries. A total of 91 catcher vessels participated in the 2013 GOA directed pollock trawl fishery.

Economics: In 2013, ex-vessel value of the catch was $36.4 million for GOA pollock. Average ex-vessel price paid for GOA pollock in 2013 was $0.18/lb. round weight. Primary products were surimi, roe, fillets, H&G, and other products.

Ecosystem Components: In the GOA, the main predators of pollock are Arrowtooth Flounder, Pacific Halibut, Pacific Cod, and Steller sea lions. For pollock less than 20 cm, Arrowtooth Flounder represents close to 50% of total mortality, and the abundance of Arrowtooth Flounder has increased dramatically in the GOA since the 1980s.

Pacific Cod
Diana Evans, NPFMC

Biology: Pacific Cod *Gadus macrocephalus* is a demersal species found in the eastern BS, the AI, and GOA down to central California. Juveniles are typically distributed over the inner continental shelf at depths from 60-150 m. Adults are found at depths from shoreline to 500 m. Mature fish tend to concentrate on the outer continental shelf and prefer muddy or sandy sediment. Juveniles feed primarily on small invertebrates and euphausiids. Adult Pacific Cod feed on fish such as juvenile pollock, and invertebrates such as polychaetes, amphipods and crangonid shrimp. Predators of Pacific Cod include adult Pacific Cod, Pacific Halibut, Salmon Shark and Steller Sea Lion.

Pacific Cod are a relatively fast growing and short-lived fish. Longevity can extend to 19 years. Pacific Cod begin to recruit to the fishery around age 3 and are 50% recruited by age 7. Natural mortality is estimated at M=0.38. Females reach 50% maturity at 50 cm (4-5 years) and larger fish can produce more than 1 million eggs. Adults form spawning aggregations from January to May in the GOA.

Stock assessment:

T. A'mar and W. Palsson 2014. Assessment of the Pacific Cod stock in the Gulf of Alaska.

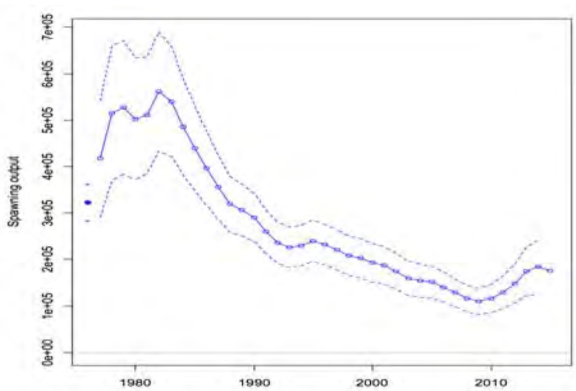
http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Catch History: Pacific Cod were harvested by foreign fleets targeting higher-value species during the 1970s. By 1976, catches increased to 6,800 mt, and the foreign fishery peaked in 1981 at 35,000 mt. A small joint venture fishery existed through 1988, averaging about 1,400 mt annually. The domestic fishery increased through 1986 and tripled its catch in 1987 to a catch of nearly 31,000 mt. The GOA Pacific Cod fishery was fully harvested by domestic vessels in 1987.

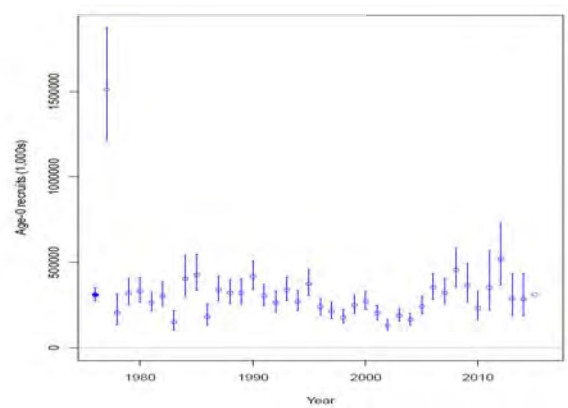
SeaAlliance/AGDB

Fishery Management: The Pacific Cod fishery is regulated under the GOA groundfish FMP through permits, limited entry, catch quotas (TACs), seasons, in-season adjustments, gear restrictions, closed waters, bycatch limits and rates, allocations, regulatory areas, record keeping, reporting requirements and observer monitoring. In 1992, Amendment 23 allocated 90% of GOA Pacific Cod to the inshore sector and 10% to the offshore sector. In 1998, 100% retention of Pacific Cod was required.

Biomass



Recruitment



Separate TACs are currently identified for Pacific Cod in the Western, Central and Eastern GOA regulatory areas. Within the Central and Western Regulatory Areas, 60% of each component's portion of the TAC is allocated to the A season (January 1 through June 10) and the remainder is allocated to the B season (June 11 through December 31). Longline and trawl fisheries are also associated with a Pacific Halibut mortality limit, which can constrain the magnitude and timing of harvests taken by these two gear types.

Stock Assessment: The Pacific Cod assessment is based on a Stock Synthesis model that uses both length-structured and age-structured data. This model incorporates fishery data and fishery independent data from the NMFS trawl surveys. Pacific Cod catch limits are set by a Tier 3a ABC/OFL control rule. The 2014 age 3+ biomass is estimated at 422,000 mt for GOA Pacific Cod. Since 1997, the Council has reduced the TAC in each area by up to 25% to account for removals in the State waters Pacific Cod fishery.

Total catches, pre-season catch specifications, and exploitable biomass of age 3+ Pacific Cod in the GOA, 1980-2015 (in mt).

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
1980	35,345	60,000	-	-	-
1981	36,131	70,000	-	-	-
1982	29,465	60,000	-	-	-
1983	36,540	60,000	-	-	-
1984	23,896	60,000	-	-	-
1985	14,428	60,000	136,000	-	-
1986	25,012	75,000	125,000	-	-
1987	32,939	50,000	125,000	-	-
1988	33,802	80,000	99,000	-	481,700
1989	43,293	71,200	71,200	-	558,700
1990	72,517	90,000	90,000	-	498,044
1991	76,328	77,900	77,900	-	424,100
1992	80,747	63,500	63,500	87,600	363,000
1993	56,488	56,700	56,700	78,100	324,000
1994	47,485	50,400	50,400	71,100	296,000
1995	68,985	69,200	69,200	126,000	573,000
1996	68,280	65,000	65,000	88,000	557,000
1997	77,018	69,115	81,500	180,000	650,000
1998	72,525	66,060	77,900	141,000	785,000
1999	81,785	67,835	84,400	134,000	648,000
2000	66,560	59,800	76,400	102,000	567,000
2001	51,542	52,110	67,800	91,200	526,000
2002	54,483	44,230	57,600	77,100	428,000
2003	52,579	40,540	52,800	70,100	428,000
2004	56,625	48,033	62,810	102,000	484,000
2005	47,585	44,433	58,100	86,200	472,000
2006	47,854	52,264	68,859	95,500	453,000
2007	51,428	52,264	68,859	97,600	375,000
2008	58,949	50,269	64,493	88,660	233,310
2009	52,931	41,807	55,300	66,000	520,000
2010	78,027	59,563	79,100	94,100	701,200
2011	84,841	65,100	86,800	102,600	428,000
2012	78,022	65,700	87,600	104,000	521,000
2013	51,792	60,600	80,800	97,200	449,300
2014	59,633	64,738	88,500	107,300	422,000
2015	-	75,202	102,850	140,300	583,800

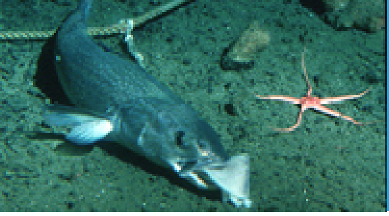
[1] Catch data f through November 2014, includes state waters fishery catch.
[2]TAC, ABC and OFL data from Federal Register.
[3]Biomass from annual SAFE report projections issued the preceding year.

Estimated biomass of Pacific Cod peaked in the early 1980s, and then slowly declined as the exceptional 1977 year class gradually exited the population. Estimated biomass appears to be increasing in the short term due to above average recruitment in recent years.

Fishery: The Pacific Cod fishery is the second major species (after pollock) targeted in the commercial groundfish catch in the GOA. Pacific Cod are taken with trawl, longline, pot and jig gear. Participants in the 2009 GOA directed fishery included 240 vessels using longlines or jig gear, 125 vessels using pot gear, and 64 vessels using trawl gear.

Economics: In 2013, ex-vessel value of Pacific Cod catch in the GOA was $37.2 million, and ex-vessel fixed-gear price averaged $0.27/lb round weight. Primary products include whole fish, H&G and fillets.

Ecosystem components: Pacific Cod are a prey item for Steller Sea Lions in the GOA and BSAI.



Sablefish

Sablefish
AFSC, NOAA Fisheries

Stock assessment:

D. Hanselman, C. Lunsford, and C. Rodgveller. 2014. Assessment of the Sablefish stock in Alaska.

www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: Sablefish *Anoplopoma fimbria* distribution extends from the northern Mexico through the Gulf of Alaska, the AI and into the BS. Adult Sablefish are generally found at depths greater than 200 m along the continental slope, shelf gullies and deep fjords. Juvenile Sablefish (less than 40 cm) spend the first 2-3 years farther inshore along the continental shelf and begin to move out to the continental slope around age 4. Young-of-the-year Sablefish feed primarily on euphausiids and copepods while adults are more opportunistic feeders, relying more heavily on pollock, Pacific Herring, Pacific Cod, squid and jellyfish. Coho and Chinook Salmon are the main predators of young-of-the-year Sablefish.

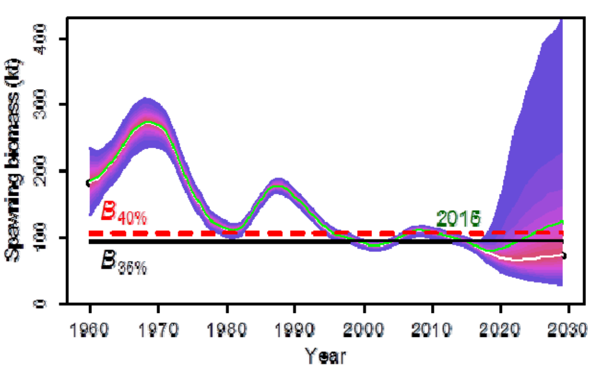
Sablefish are relatively long lived. They begin to recruit to the fishery at age 4 or 5 and longevity often reaches 40 years (the oldest recorded Sablefish in Alaska was 94 years old). Female size at 50% maturity is around 65 cm (approximately age 6.5). Females are slightly larger than males, and natural mortality is estimated at M=0.10. Off Alaska, Sablefish spawn at depths near the edges of the continental slope (500 m) between January and April.

Catch History: U.S. fishermen have harvested Sablefish (also called black cod) since the end of the 19th century as a byproduct of halibut fisheries. Harvests were relatively small, averaging 1,666 mt from 1930-1957. Japanese longlining began in the EBS around 1958 and expanded into the AI and GOA through the 1970s. Japanese fleet catches increased throughout the 1960s, and peak Sablefish catch reached 36,776 mt in 1972. High fishing pressure in the early 1970s by Japanese and USSR vessels may have resulted in a population decline of Sablefish in the mid-1970s. By 1988, U.S. fishermen took the majority of the Sablefish harvested in the GOA and BSAI. Sablefish was increasingly harvested as a derby-style fishery in the late 1980s and early 1990s until Individual Fishing Quotas were implemented for the hook and line fishery in 1995.

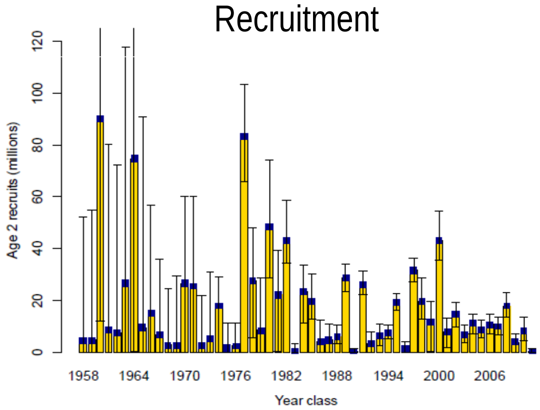
Fishery Management: BSAI and GOA Sablefish are managed as one population in federal waters due to their highly migratory behavior during certain life history stages. There are four management areas in the GOA; Western, Central West Yakutat and East Yakutat/Southeast Outside.

In 1985, Amendment 14 to the GOA FMP allocated Sablefish TAC by gear type; 80% to fixed gear (including pots) and 20% to trawl in the Western and Central GOA, 95% to fixed gear and 5% to trawl gear in the Eastern GOA. Amendment 20 to the GOA FMP established IFQ management for the GOA Sablefish fishery, which began in 1995.

Biomass



Recruitment



Stock Assessment: The Sablefish assessment is based on a statistical sex-specific age-structured model. This model incorporates fishery data and fishery independent data from domestic and Japan-U.S. cooperative longline surveys and the NMFS GOA trawl survey. Sablefish fall under Tier 3b of the ABC/OFL control rule. Separate ABCs and TACs are established for each GOA subregion: Western, Central, West Yakutat, and Southeast Outside.

Fishery: The Sablefish IFQ fishery season opening date is concurrent with the halibut fishery for the purposes of reducing bycatch and regulatory discards between the two fisheries. In the GOA, the directed fishery for Sablefish is prosecuted with longline gear (pot gear is prohibited for directed Sablefish fishing in the GOA). Sablefish are also taken by trawl gear in directed fisheries for rockfish and deepwater flatfish. Primary incidental catch species in the directed Sablefish fishery include Shortraker, Rougheye and Thornyhead Rockfishes.

Total catches, pre-season catch specifications and exploitable biomass of Sablefish in the GOA, 1980-2015 (in mt).

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass[3]
1980	8,543	13,000	13,000	-	-
1981	9,917	14,350	14,350	-	-
1982	8,556	12,300	12,300	-	-
1983	9,002	9,480	9,480	-	-
1984	10,230	8,980	8,980	-	-
1985	12,479	8,980	8,980	-	-
1986	21,614	15,000	18,800	-	-
1987	26,325	20,000	25,000	-	383,000
1988	29,903	28,000	35,000	-	520,000
1989	29,842	26,000	30,900	-	426,000
1990	25,701	26,000	26,200	-	312,000
1991	19,580	22,500	22,500	-	194,000
1992	20,451	20,800	20,800	28,200	179,000
1993	22,671	20,900	20,900	27,750	190,400
1994	21,338	25,500	25,500	31,700	218,000
1995	18,631	21,500	21,500	25,730	194,900
1996	15,826	17,080	17,080	22,800	169,500
1997	14,129	14,520	14,520	39,950	199,920
1998	12,758	14,120	14,120	23,450	166,000
1999	13,918	12,700	12,700	19,720	150,000
2000	13,779	13,330	13,330	16,660	169,000
2001	12,127	12,840	12,840	15,720	188,000
2002	12,246	12,820	12,820	19,350	188,000
2003	14,345	14,890	14,890	20,020	182,000
2004	15,630	16,550	16,550	22,160	179,000
2005	13,997	15,940	15,940	19,280	185,000
2006	13,367	14,840	14,840	17,880	152,000
2007	12,265	14,310	14,310	16,906	158,000
2008	12,326	12,730	12,730	15,040	167,000
2009	10,910	11,160	11,160	13,190	149,000
2010	9,998	10,370	10,370	12,270	140,000
2011	11,148	11,290	11,290	13,340	149,000
2012	11,914	12,960	12,960	15,330	180,000
2013	11,945	12,510	12,510	14,780	167,000
2014	10,375	10,572	10,572	12,500	149,000
2015	-	10,522	10,522	12,425	130,000

[1]Catch data through November 2014.
[2]TAC, ABC and OFL from annual Federal Register.
3Biomass from SAFE report projections for following year.

Economics: In 2013, the ex-vessel value of Sablefish catch from the GOA was $83.6 million. Ex-vessel prices for GOA Sablefish in 2013 averaged $3.22/lb for fish caught on longline gear and $2.43/lb for fish taken with trawl gear. For both gear types, the primary product is frozen, head and gutted fish.

Current Issues: Sperm whale and killer whale depredation is problematic for Sablefish fisheries in the GOA and BSAI. Depredation occurs when whales remove Sablefish from longline gear, damage the fish and/or fishing gear. Killer whale depredation predominates in the BSAI and sperm whale depredation is more common the GOA. Depredation can lead to economic losses in the form of reduced catch, extended travel distances, extended wait times and damaged gear. Depredation may also reduce the accuracy of Sablefish stock assessment models. Additionally, depredating whales may be at greater risk of mortality or injury through vessel strikes or risk of entanglement in gear.

PVOA

Northern Rock Sole
Washington DFW

Shallow-water Flatfish

Stock assessment:

B. Turnock W. and T. A'mar. 2014. Assessment of Shallow Water Flatfish in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: The shallow-water flatfish complex is comprised of 8 flatfish species. Northern Rock Sole, Southern Rock Sole, Butter Sole and Yellowfin Sole account for the majority of the current biomass of shallow-water flatfish. All flatfish are demersal but have varying depth ranges. Shallow-water flatfish feed on euphausiids, bivalves, polychaetes, amphipods, mollusks and fish. They are prey for Pacific Cod, Pacific Halibut and skates.

Northern Rock Sole	*Lepidopsetta polyxystra*
Southern Rock Sole	*Lepidopsetta bilineata*
Butter Sole	*Pleuronectes isolepis*
Yellowfin Sole	*Pleuronectes asper*
Starry Flounder	*Platichthys stellatus*
English Sole	*Pleuronectes vetulus*
Alaska Plaice	*Pleuronectes quadrituberculatus*
Sand Sole	*Psettichthys melanostictus*

Yellowfin Sole distribution extends from the Sea of Japan, through the Chukchi Sea and south to British Columbia. Yellowfin Sole are the second most abundant finfish species (after pollock) in Cook Inlet and are also found in Prince William Sound. Yellowfin Sole spawning period is protracted and likely extends from May to August, occurring primarily in shallow water. Females are relatively fecund, ranging from 1.3-3.3 million eggs depending on size. Yellowfin Sole begin to recruit to the fishery at age 6 and are fully selected by age 13. The estimated age of 50% maturity is 10.5 years for females. Natural mortality is estimated at M=0.12-0.16, and longevity extends to 31 years.

The rock sole stock in the GOA consists of both Northern and Southern Rock Sole. The two species are similar in appearance but have different life history characteristics. Northern Rock Sole stock spawns beginning in midwinter and peaking during the spring, and the Southern Rock Sole stock spawns during the summer. The estimated age of 50% maturity is 9 years for Southern Rock Sole and 7 years for Northern Rock Sole. For both species, natural mortality is estimated to be M=0.18-0.20 for females, and M=0.25-0.26 for males, and longevity can extend to 30 years. Rock sole are most abundant in the Kodiak and Shumagin areas. Adults occupy separate winter spawning and summertime feeding distributions on the continental shelf margins.

Starry Flounder
AFSC, NOAA Fisheries

Catch History: The flatfish fishery was predominantly a foreign fishery targeting non-flatfish species until 1981. With the cessation of foreign fishing in 1986, joint venture fishing began to account for the majority of flatfish catch, and the fishery was fully domestic by 1988. Shallow-water flatfish catch was 5,455 mt in 1978. Catch declined to a low of 957 mt in 1986 then increased to 9,715 mt in 1993. Shallow-water flatfish catch is often constrained by Pacific Halibut bycatch limits.

Fishery Management: The Council divided the "Flatfish" complex into 3 categories (Deep-water flatfish, Shallow-water flatfish, and Arrowtooth Flounder) in 1990 due to significant differences in halibut bycatch rates, biomass and commercial value in directed fisheries for shallow and Deep-water flatfish. Flathead Sole was separated out from the Deep-water flatfish complex in 1991 due to its distributional overlap between both shallow and deep-water groups.

All flatfish species under the GOA groundfish FMP are regulated through permits, limited entry, catch quotas (TACs), seasons, in-season adjustments, gear restrictions, closed waters, bycatch limits and rates, allocations, regulatory areas, record keeping, reporting requirements and observer monitoring. GOA flatfish species or complexes are managed with area-specific ABC and TAC apportionments to avoid the potential for localized depletions.

Stock Assessment: The Northern and Southern Rock Sole stock assessments are based on Stock Synthesis models that use both length-structured and age-structured data. These models incorporate fishery data and fishery independent data from the NMFS trawl surveys. The Northern and Southern Rock Sole catch limits are set by a Tier 3a ABC/OFL control rule. The 2015 projected biomass is 287,534 mt. Catch specifications for 2015 are as follows; OFL=54,207 mt, ABC= 44,205 mt, TAC= 35,381 mt.

Survey biomass for all species in the shallow-water complex has declined from 2009 to 2013, except English Sole and Alaska Plaice, which have shown no trend. Northern Rock Sole survey biomass declined about 22% from 2009 to 2013, while Southern Rock Sole and Yellowfin Sole survey biomass declined about 31%.

Total catches, pre-season catch specifications and exploitable biomass of Shallow Water Flatfish* in the GOA, 1991-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL	Biomass
1991	5,298	12,000	74,000	-	333,900
1992	8,783	11,740	50,480	70,900	257,338
1993	9,715	16,240	50,480	70,860	261,724
1994	9,343	18,630	34,420	44,670	261,720
1995	5,430	18,630	52,270	60,262	355,590
1996	9,350	18,630	52,270	60,262	355,590
1997	7,775	18,630	43,150	59,540	314,960
1998	3,565	18,630	43,150	59,540	315,590
1999	2,577	18,770	43,150	59,540	314,960
2000	6,928	19,400	37,860	45,330	299,100
2001	6,162	19,400	37,860	45,330	299,100
2002	6,195	20,420	49,550	61,810	349,992
2003	4,465	21,620	49,340	61,810	349,990
2004	3,094	20,740	52,070	63,840	375,950
2005	4,769	20,740	52,070	63,840	375,950
2006	7,641	19,972	51,450	62,418	365,766
2007	8,793	19,972	51,450	62,418	103,300
2008	9,708	22,256	60,989	74,364	436,590
2009	8,483	22,256	60,989	74,364	436,590
2010	5,410	20,062	56,242	67,768	398,961
2011	3,974	20,062	56,242	67,768	398,961
2012	4,022	37,029	50,683	61,681	329,217
2013	5,515	37,077	45,484	55,680	433,869
2014	3,917	33,679	40,805	50,007	384,134
2015	-	35,381	44,205	54,207	287,534

*Separated from "Flounders" category 1990.
[1] Catch data through November 2014.
[2]Biomass from annual SAFE report projections.

Fishery: Since 1988 the majority of shallow-water flatfish harvest has occurred on the continental shelf and slope east of Kodiak Island in the Central regulatory area. Shallow-water flatfish are generally harvested with trawl gear. Rock sole is the predominant target species in the complex.

Economics: The bottom trawl fishery in the GOA primarily targets rock soles, Rex Sole and Dover Sole. Primary products include whole fish, H&G and fillets. Ex-vessel value of all flatfish caught in the GOA in 2013 was $8.6 million. The price per pound for GOA shallow water flatfish products averaged $0.98/lb for shoreside processors. A total of 31 catcher vessels and 5 catcher processors prosecuted the GOA flatfish fishery in 2013.

Butter Sole
Washington DFW

Deepwater Flatfish

Dover Sole
AFSC, NOAA Fisheries

Stock assessment:

C. McGilliard 2014. Assessment of Deepwater Flatfish stock in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: The GOA Deep-water flatfish complex is comprised of 3 flatfish species; Greenland Turbot *Reinhardtius hippoglossoides*, Dover Sole *Microstomus pacificus*, and Deep-Sea Sole *Embassichthys bathybius*. GOA Dover Sole constitutes the majority of the survey biomass and deep-water flatfish catch (generally over 98%). Dover sole move to deeper water as they age and older Dover sole migrate seasonally from deep water on the outer continental shelf and upper slope where spawning occurs to shallower water mid-shelf in summer time to feed. Dover Sole are especially adapted to feeding on small-detrital consuming invertebrates such as polychaetes, amphipods, mollusks, and brittle stars. Dover Sole are batch spawners, releasing around 83,000 advanced oocytes in about 9 batches per spawning season. The peak spawning period occurs from January through May. Female Dover Sole reach 50% maturity at 12-13 years of age. Dover Sole recruit to the fishery at 35 cm. The maximum age observed for Dover Sole in the GOA is 59 years. Greenland Turbot has a circumpolar distribution in the Atlantic and Pacific. Greenland Turbot are typically found from 200-1600 m. Biological data is limited for GOA Greenland Turbot and Deep-Sea Sole.

Catch History: Deep-water flatfish catches peaked in 1992 at 11,379 mt, and then declined in 1993, remaining fairly stable from 1993-1999 (average 2,800 mt). After 1999, catches declined, reaching a low of 225 mt in 2013.

Total catches, pre-season catch specifications, and exploitable biomass of Deep Water Flatfish* in the GOA, 1990-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL	Biomass[2]
1990	2,380	22,000	108,400	-	-
1991	10,195	15,000	50,500	-	201,500
1992	8,495	19,740	39,280	51,500	169,132
1993	6,705	19,740	45,530	59,650	227,656
1994	3,077	11,080	16,510	19,280	132,030
1995	2,211	11,080	14,590	17,040	116,710
1996	2,190	11,080	14,590	17,040	116,570
1997	3,659	7,170	7,170	9,440	101,430
1998	2,286	7,170	7,170	9,440	101,430
1999	2,282	6,050	6,050	8,070	78,300
2000	981	5,300	5,300	6,980	74,370
2001	803	5,300	5,300	6,980	74,460
2002	559	4,880	4,880	6,430	68,623
2003	951	4,880	4,880	6,430	68,260
2004	686	6,070	6,070	8,010	99,620
2005	418	6,820	6,820	8,490	102,395
2006	405	8,665	8,665	11,008	132,297
2007	281	8,707	8,707	10,431	103,300
2008	573	8,903	8,903	11,343	132,625
2009	475	9,168	9,168	11,578	133,025
2010	544	6,190	6,190	7,680	89,682
2011	466	6,305	6,305	7,823	89,691
2012	290	5,126	5,126	6,834	77,531
2013	242	5,126	5,126	6,834	173,853
2014	346	13,472	13,472	16,159	182,727
2015		13,334	13,334	15,993	182,160

*Separated from "Flounders" category 1990.
[1] Catch data through November 2014.
[2] Biomass from annual SAFE report projections.

Stock Assessment: The Deep-water flatfish complex assessment uses a split-sex, age-structured model for Dover Sole and mean historical catch data from 1978-1995 for Greenland Turbot and Deep-Sea Sole. Dover Sole catch limits are set by a Tier 3a control rule, and Greenland Turbot and Deep-Sea Sole fall under Tier 6 due to highly variable survey biomass estimates. The 2015 projected Deepwater Flatfish biomass is 182,160 mt. Catch specifications for 2015 are as follows; OFL=15,993 mt, ABC= 13,334 mt, TAC= 13,334 mt.

Abundance estimates for Greenland Turbot and Deep-Sea Sole are highly uncertain. Dover sole survey biomass estimates have ranged from approximately 71,624 to 107,286 mt since 1990. Survey biomass estimates in the 1980s were low, but considered less reliable because survey methodology was different in those years.

Fishery: Deep-water flatfish are harvested with trawl gear. Dover Sole is the predominant target species in the complex.

Rex Sole
AFSC, NOAA Fisheries

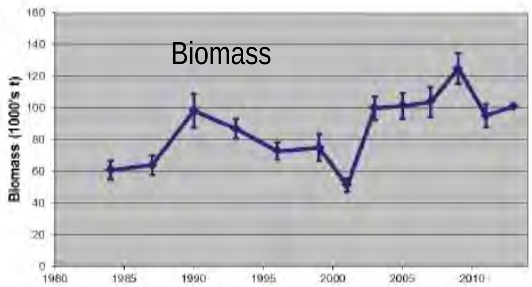
Stock assessment:

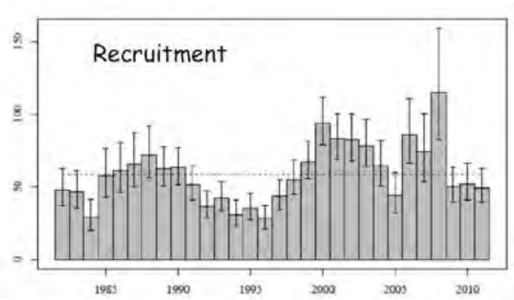
C. McGilliard 2014. Assessment of the Rex Sole stock in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: Rex Sole *Glyptocephalus zachirus* are distributed from Baja California to the BS, with concentrations in the GOA. Rex Sole closely associate with soft bottom benthic communities and are generally found at depths from less than 100 m to 800 m. Adult Rex Sole overwinter near the shelf margins and migrate onto the mid and outer continental shelf each year in April/May. Rex Sole exhibit latitudinal changes in growth rates and size at sexual maturity. Size at sexual maturity was greater for Rex Sole in the GOA than for those in Oregon. Rex Sole feed on polychaetes, euphausiids, amphipods and shrimp and are prey for skates, Spiny Dogfish, and Arrowtooth Flounder.

Recruitment to the fishery is estimated to occur at ages 8-10. Age at 50% maturity for females was estimated at 5.6 years (35.2 cm) in Alaska. Natural mortality is thought to be around M=0.17, and the oldest observed GOA Rex Sole was 27 years old. Rex Sole are batch spawners with a protracted spawning period in the GOA (peak spawning period occurs April/May).





Total catches, pre-season catch specifications, and exploitable biomass of Rex Sole* in the GOA, 1994-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL	Biomass[2]
1994	3,642	10,140	11,950	13,960	95,630
1995	4,021	9,690	11,210	13,091	89,660
1996	5,945	9,690	11,210	13,091	89,660
1997	3,296	9,150	9,150	11,920	72,330
1998	2,671	9,150	9,150	11,920	72,330
1999	3,059	9,150	9,150	11,920	72,330
2000	3,592	9,440	9,440	12,300	74,600
2001	2,942	9,440	9,440	12,300	81,020
2002	3,016	9,470	9,470	12,320	71,326
2003	3,499	9,470	9,470	12,320	71,330
2004	1,467	12,650	12,650	16,480	99,950
2005	2,179	12,650	12,650	16,480	99,950
2006	3,295	9,200	9,200	12,000	83,600
2007	2,851	9,100	9,100	12,000	82,403
2008	2,707	9,132	9,132	11,933	82,801
2009	4,753	8,996	8,996	11,756	81,572
2010	3,635	9,729	9,729	12,714	88,221
2011	2,876	9,565	9,565	12,499	86,729
2012	2,426	9,612	9,612	12,561	87,162
2013	3,706	9,560	9,560	12,492	86,684
2014	3,565	9,341	9,341	12,207	84,702
2015		9,150	9,150	11,957	82,972

*Separated from Deep Water Flatfish category 1994
[1]Catch data through November 2014.
[2]Biomass data corresponds to the annual SAFE report projections issued the preceding year.

Catch History: Prior to 1981, Rex Sole was caught incidentally in foreign fisheries targeting higher value species. Catches of Rex Sole have remained fairly stable since 1994, ranging from 1,464 mt in 2004 to a peak of 5,874 mt in 1996.

Stock Assessment: Rex Sole limits are set by a Tier 5 control rule. The 2015 projected biomass is 82,972 mt. Catch specifications for 2015 are as follows; OFL=11,957 mt, ABC= 9,150 mt, TAC= 9,150 mt. The ABC and TAC specifications are further subdivided among GOA subareas.

Fishery: GOA Rex Sole are caught using trawl gear in a directed fishery and fisheries targeting other species such as POP, Pacific Cod and Pollock. Fishing seasons are dictated by seasonal halibut PSC apportionments, with approximately 7 months of fishing occurring between January and November. Catches of Rex Sole occur primarily in the Central management area in the GOA.

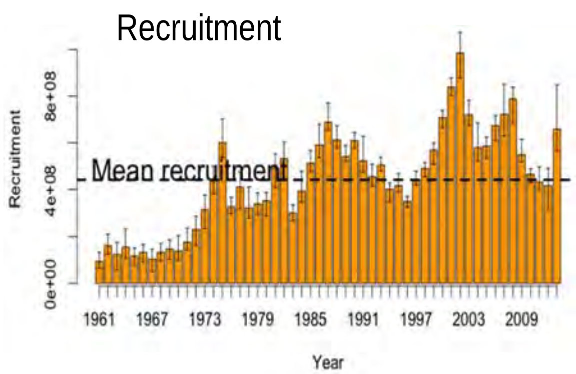
Arrowtooth Flounder
AFSC, NOAA Fisheries

Stock assessment:

I. Spies and B. Turnock. 2014. Assessment of Arrowtooth Flounder stock in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: Arrowtooth Flounder *Astheresthes stomias* are distributed from the Kamchatka Peninsula, through the BSAI down to central California. Arrowtooth Flounder are most abundant at depths from 100-500 m. Adults migrate seasonally from shelf margins in the winter to the inner and middle shelf in April/May with the onset of warmer waters temperatures. Smaller GOA Arrowtooth Flounder predate on euphausiids, capelin and herring while fish over 40 cm rely primarily on pollock. Predators of Arrowtooth Flounder include Pacific Cod, Pollock and skates



Arrowtooth Flounder recruitment to the fishery begins at about 3 years, and females are fully recruited by age 10. The estimated length at 50% maturity is 28 cm for males (4 years) and 37 cm for females (5 years) based on samples collected from Washington, and longevity extends to 21 years. Female natural mortality is estimated at M=0.2. Male natural mortality has a range estimate (M=0.27-0.36). Adult males range in size from 30-50 cm, and females range in size from 30-70 cm. The spawning period for Arrowtooth Flounder occurs from December to February at depths of 100-360 m. Spawning in the GOA occurs from Kodiak to Yakutat Bay.

Total catches, pre-season catch specifications, and exploitable biomass of Arrowtooth Flounder* in the GOA, 1990-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL	Biomass[2]
1990	7,705	32,000	194,600	-	-
1991	10,035	20,000	340,100	-	2,000,800
1992	15,970	25,000	303,800	427,000	1,787,583
1993	15,560	30,000	321,290	451,690	1,889,922
1994	23,560	30,000	236,240	275,930	1,889,920
1995	18,430	35,000	198,130	231,416	1,585,040
1996	22,183	35,000	198,130	231,416	1,640,000
1997	16,319	35,000	197,840	280,800	1,971,170
1998	12,974	35,000	208,340	295,570	2,062,740
1999	16,209	35,000	217,110	308,880	2,126,714
2000	24,252	35,000	145,360	173,910	1,571,670
2001	19,964	38,000	148,150	173,550	1,586,830
2002	21,230	38,000	146,260	171,060	1,760,000
2003	23,320	38,000	155,140	181,390	1,302,000
2004	15,304	38,000	194,930	228,130	2,453,390
2005	19,770	38,000	216,900	253,900	2,453,390
2006	27,653	38,000	177,844	207,678	2,140,170
2007	25,364	43,000	184,008	214,828	2,146,360
2008	29,293	43,000	226,470	266,914	2,244,870
2009	24,937	43,000	221,512	261,022	1,295,050
2010	23,015	43,000	215,882	254,271	2,139,000
2011	30,890	43,000	213,150	251,068	2,139,000
2012	20,714	103,300	212,882	250,100	2,161,690
2013	21,620	103,300	210,451	247,196	2,055,560
2014	35,026	103,300	195,358	229,248	1,978,340
2015		103,300	192,921	226,390	1,957,970

*Separated from "Flounders" category 1990.
[1] Catch data through November 2014.
[2]Biomass from SAFE report projections.

Catch History: Prior to 1981, Arrowtooth Flounder was caught incidentally in foreign fisheries targeting higher value species. From 1991-2000, Arrowtooth Flounder catches ranged from 10,034 mt-22,583 mt, and have since increased with a 2014 catch of 35,026 mt.

Stock Assessment: The Arrowtooth Flounder assessment uses an automatic differentiation software developed as a set of libraries under C++ (AD Model Builder). This model incorporates fishery data and fishery independent data from NMFS and IPHC trawl surveys. Arrowtooth Flounder catch limits are set by a Tier 3a control rule. The 2015 projected biomass is 1,978,340 mt.

Arrowtooth Flounder biomass has increased steadily since the early 1990s. Estimated biomass averaged 1.7 million mt annually from 2000-2004 and about 2 million mt from 2004-2014.

Fishery: A directed fishery has recently developed in the GOA. In addition, Arrowtooth Flounder are an important byproduct of more valuable target trawl and longline fisheries, such as Pacific Cod and Pollock.

Flathead Sole
AFSC, NOAA Fisheries

Flathead Sole

Stock assessment:

C. McGilliard 2014. Assessment of Flathead Sole stock in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: Flathead Sole *Hippoglossoides elassodon* are distributed in the Kuril Islands, BS, GOA and south to California. Adult Flathead Sole exhibit a benthic lifestyle and overwinter near the shelf margins before migrating to the mid and outer continental shelf in April or May each year for feeding. They occur primarily on mixed mud and sand bottoms in depths less than 300 m. Pandalid shrimp and brittle stars are the most important prey for adult Flathead Sole in the GOA, while euphausiids and mysids constitute the most important prey items for juvenile Flathead Sole. Pacific Cod and Pacific Halibut are major predators on adults, while Arrowtooth Flounder, sculpins, Walleye Pollock and Pacific Cod are major predators on juveniles. However, 65% of adult mortality and 20% of juvenile mortality is unexplained.

Flathead Sole recruitment to the fishery is estimated to occur between the ages of 5 and 10, and longevity extends to 32 years. Estimated length at 50% maturity is 33 cm (8.7 years). Natural mortality is thought to be around M=0.20. Flathead Sole spawn in March and April, in deeper waters near the margins of the continental shelf, and feed on the mid- and outer-continental shelf in the summertime. Females release from 70,000-600,000 eggs.

Catch History: Flathead Sole catches increased from 452 mt in 1978 to 2,068 mt in 1980, and subsequently declined to a low of about 150 mt in 1986. After 1986, catches increased and reached a peak catch of 3,842 mt in 2010.

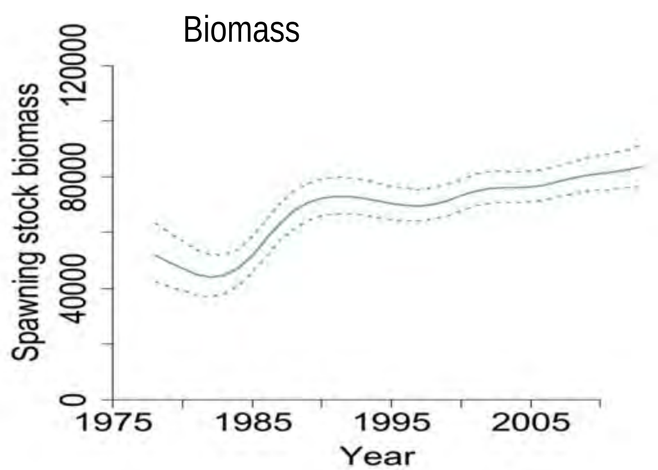
Stock Assessment: The Flathead Sole assessment uses a split-sex, age-based model with estimated age-based fishery and survey selectivity. This model incorporates fishery data and fishery independent data from triennial (1984-1999) and biennial (2001-2009) surveys. Flathead Sole catch limits are set by a Tier 3a control rule. Estimated Flathead Sole biomass is thought to have increased slowly and steadily since 1990.

Fishery: GOA Flathead Sole are caught using trawl gear in a directed fishery and fisheries targeting other species such as POP, Pacific Cod and Pollock. The majority of Flathead Sole in the GOA is taken in the Shelikof Strait and on Albatross Bank. About 90% of the catch is retained.

Total catches, pre-season catch specifications, and exploitable biomass of Flathead Sole* in the GOA, 1991-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL	Biomass[2]
1991	1,237	10,000	50,300	-	251,800
1992	2,315	10,000	48,280	63,100	240,615
1993	2,824	10,000	49,450	64,780	247,250
1994	2,525	10,000	35,850	39,310	199,000
1995	2,180	10,000	28,790	31,557	198,470
1996	3,074	9,740	28,790	31,557	198,470
1997	2,441	9,040	26,110	34,010	206,340
1998	1,731	9,040	26,110	34,010	206,340
1999	897	9,040	26,110	34,010	206,340
2000	1,548	9,060	26,270	34,210	207,520
2001	1,912	9,060	26,270	34,210	207,520
2002	2,146	9,280	22,690	29,530	170,915
2003	2,459	11,150	41,390	51,560	132,260
2004	2,398	10,880	51,270	64,750	292,670
2005	2,552	10,390	45,100	56,500	292,670
2006	3,142	9,077	37,820	47,003	291,441
2007	3,130	9,148	39,110	48,658	297,353
2008	3,446	11,054	44,735	55,787	103,300
2009	3,663	11,181	46,464	57,911	323,937
2010	3,841	10,411	47,422	59,295	328,862
2011	2,729	10,587	49,133	61,412	325,367
2012	2,167	30,316	47,407	59,380	292,189
2013	2,816	30,496	48,738	61,036	288,536
2014	2,525	27,746	41,231	50,664	252,361
2015		27,756	41,349	50,792	254,602

[1] Catch data through November 2014.
[2]Biomass from annual SAFE report projections.



Pacific Ocean Perch

Pacific Ocean Perch
AFSC, NOAA Fisheries

Biology: Pacific Ocean Perch (POP) *Sebastes alutus* distribution extends from Japan around the Pacific Rim, the BS and south to California. POP are most abundant in AI, GOA and British Columbia and are found primarily offshore along the continental slope at depths from 150-420 m. POP are generally considered a demersal species and are found over sandy and cobble substrate. Seasonal changes in depth distribution occur, and adults migrate farther offshore to deeper waters during winter. During late spring and summer, POP migrate to shallower waters inshore for summer feeding. Adults perform diel migrations off the sea floor to feed. POP populations occur in patchy aggregations, and POP are generally planktivorous. Smaller POP feed on calanoid copepods, whereas larger POP rely on euphausiids, shrimp and squids. POP are prey for Pacific Halibut, Sablefish, Pacific Cod and Arrowtooth Flounder.

SeaAlliance/AGDB

POP is a slow-growing, long lived species. Recruitment to trawl fisheries begins at age 5, and full recruitment to the fishery occurs around age 8. Females reach 50% maturity at 10.5 years in the GOA, and longevity extends to 80 plus years (oldest recorded 84 years in the GOA). Natural mortality is estimated to be M=0.06. Females are viviparous, retaining fertilized eggs within the ovary until larval extrusion. Mating takes place in late fall, and larval extrusion occurs in early spring. Females release from 10,000-300,000 larvae each year, depending on size.

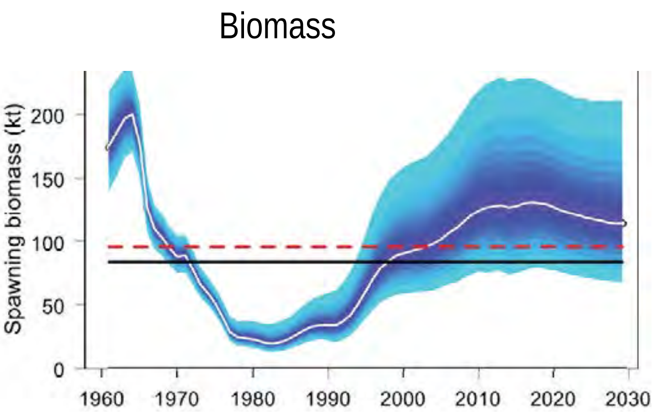
Stock assessment:

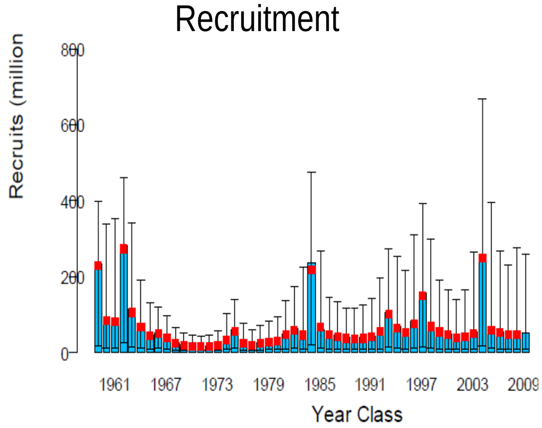
P-J. Hulson, D. Hanselman, S. K. Shotwell, C. Lunsford, and J. Ianelli 2014. Assessment of Pacific Ocean Perch stock in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Catch History: POP was harvested in the GOA by the USSR and Japan beginning in the early 1960s. The fishery developed rapidly, and catches peaked in 1965 at 350,000 mt. High fishing effort by the foreign fleet caused a major decline in POP abundance/catches through the late 1960s. Catches continued to decline, and in 1985 foreign trawling in the GOA was prohibited.

The domestic fishery for POP in the GOA began in the early 1980s and expanded each year until 1991. POP catches remained relatively low through the 1990s, averaging 7,072 mt annually from 1991-2000. Catches have increased since 2000. The largest U.S. catch in the time series was in 2014 at 17,368 mt.





Fishery Management: In 1991, POP and the Shortraker/Rougheye complex were separated from the "Slope Rockfish" complex to prevent overfishing. A reduction in TACs after 1991 to promote POP stock rebuilding was also implemented. In 2004, Shortraker and Rougheye Rockfish were separated into their own management units due to disproportionally high harvests of Shortraker Rockfish. GOA rockfish stocks and complexes are managed with area-specific ABC and TAC apportionments to avoid the potential for localized depletions. Amendment 41, effective in 2000, prohibited trawling in the Eastern area east of 140°W longitude, an area previously fished for POP.

The Central GOA Rockfish Pilot Program, effective for 2007 through 2011, rationalized the rockfish and related trawl fisheries. The program provides cooperatives with exclusive catch shares (95% of the CGOA TAC) for target species of POP, Northern Rockfish, and pelagic shelf rockfish, as well as a allocated a portion of the TAC for suite of secondary species (Sablefish, cod, and thornyhead, Shortraker and Rougheye Rockfish), and a halibut prohibited species catch limit allocation. Cooperatives receive allocations based on catch history of cooperative member vessels. Sideboard limits for the target rockfish species are established in the Western GOA. A slightly revised program was adopted by the Council in 2010 for implementation in 2012.

Mark Fina, NPFMC

Total catches, pre-season catch specifications, and exploitable biomass of Pacific Ocean Perch* in the GOA, 1990-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL	Biomass[2]
1991	6,632	5,800	5,800	-	-
1992	6,158	5,200	5,730	5,730	229,100
1993	2,119	2,560	3,378	3,378	156,300
1994	1,853	2,550	3,030	3,940	101,800
1995	5,742	5,630	6,530	8,232	142,465
1996	8,459	6,960	8,060	10,165	163,220
1997	9,531	9,190	12,990	19,760	301,084
1998	9,266	10,780	12,820	18,090	242,300
1999	10,802	12,590	13,120	18,490	228,190
2000	10,157	13,020	13,020	15,390	200,310
2001	10,860	13,510	13,510	15,390	211,160
2002	11,729	13,190	13,190	15,670	293,240
2003	10,911	13,660	13,660	16,240	298,820
2004	11,528	13,340	13,340	15,840	266,960
2005	11,440	13,575	13,575	16,266	286,367
2006	13,590	14,261	14,261	16,927	312,968
2007	13,046	14,635	14,636	17,158	315,507
2008	12,400	14,999	14,999	17,807	317,511
2009	12,985	15,111	15,111	17,940	318,336
2010	15,520	17,584	17,584	20,243	334,797
2011	14,211	16,997	16,997	19,566	330,480
2012	14,911	16,918	16,918	19,498	348,168
2013	13,183	16,412	16,412	18,919	345,260
2014	17,368	19,309	19,309	22,319	410,712
2015		21,012	21,012	24,360	416,140

* Separated from Slope Rockfish in 1991.
1 Catch data through November 2014.
2 Biomass from annual SAFE report projections.

Stock Assessment: The POP assessment uses an age-structured model using AD Model Builder software. POP catch limits are set under Tier 3a OFL and ABC control rules. This model incorporates fishery data and fishery independent data from biennial trawl surveys. The 2015 projected biomass is 416,140 mt.

Estimated total biomass of POP was relatively low during the early 1990s, averaging 158,577 mt from 1991-1995. Since then, biomass has steadily increased from 211,160 mt in 2000 to 416,140 mt in 2015.

Fishery: POP are caught primarily in directed bottom trawl fisheries. The percentage of POP in the GOA taken in pelagic trawls increased from 2% in 1990 to 31% in 2008. The majority of POP are caught in the Central regulatory area, and TACs allocated for each area are generally met (except Southeastern area due to prohibited trawling).

Economics: In 2013, production was 12,300 mt for GOA rockfish products. Ex-vessel value of the rockfish catch in the GOA was $11.2 million.

Northern Rockfish

Northern Rockfish
AFSC, NOAA Fisheries

<u>Biology</u>: Northern Rockfish *Sebastes polyspinus* distribution extends from the Kamchatka Peninsula, through the BSAI, GOA and British Columbia. The species is most abundant in the central GOA to the western end of the AI. Adults concentrate at discrete sites along the outer continental shelf from 75-150 m. Northern Rockfish are demersal and are generally found in aggregations with patchy distributions. Northern Rockfish prey on calanoid copepods, euphausiids and chaetognaths. Based on stomach content data, Pacific Halibut and Sablefish likely prey on Northern Rockfish.

Northern Rockfish is a slow-growing, long-lived species. Age at 50% maturity is 12.8 years in the GOA, and longevity extends to 50 years (oldest recorded 67 in the GOA). GOA Northern Rockfish grow faster and reach a larger maximum length than the AI Northern Rockfish. Natural mortality is estimated to be M=0.06. Females are viviparous, retaining their fertilized eggs within the ovary until larval extrusion.

Stock assessment:

P-J. Hulson, C. Lunsford, J. Heifitz, D. Hanselman, K. Shotwell, and J. Ianelli. 2014. Assessment of Northern Rockfish stock in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

<u>Catch History</u>: Northern Rockfish were initially harvested by Soviet and Japanese trawlers in the early 1960s. Foreign fishing effort increased quickly in the 1960s, and catches of rockfish in the GOA peaked in 1965 at 350,000 mt. It is likely that GOA Northern Rockfish comprised some portion of the early foreign catch (exact Northern Rockfish catch unknown for this period). Northern Rockfish was separated from the slope rockfish assemblage in 1993, and catches have remained fairly stable since 1994, ranging from a low of 2,947 mt in 1997 to a high of 5,968 in 1994 (average annual catch equals 4,262 mt from 1994-2009).

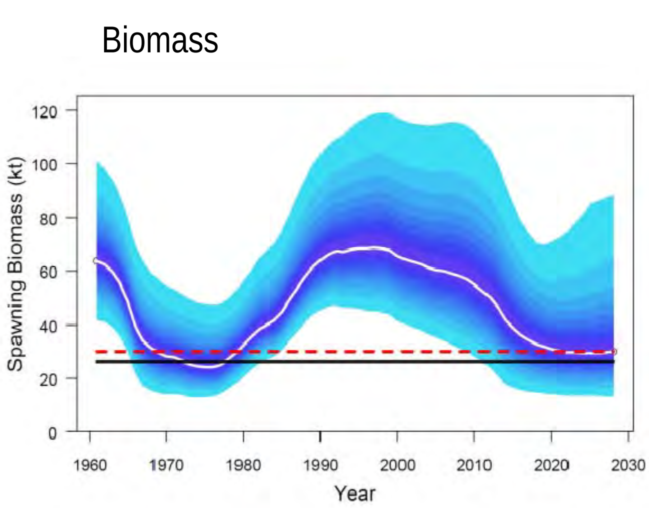
<u>Stock Assessment</u>: The Northern Rockfish assessment uses a separable, age-structured model using AD Model Builder software. This model incorporates fishery data and fishery independent data from biennial trawl surveys. Northern Rockfish catch limits are set under Tier 3a of the ABC/OFL control rules. The 2014 projected biomass is 102,893 mt.

Total catches, pre-season catch specifications, and exploitable biomass of Northern Rockfish* in the GOA, 1993-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL	Biomass[2]
1993	4,846	5,760	5,760	10,360	76,800
1994	5,968	5,760	5,760	10,360	76,800
1995	5,634	5,270	5,270	9,926	87,845
1996	3,356	5,270	5,270	9,926	87,850
1997	2,947	5,000	5,000	9,420	83,890
1998	3,058	5,000	5,000	9,420	83,870
1999	5,412	4,990	4,990	9,420	83,870
2000	3,325	5,120	5,120	7,510	85,360
2001	3,150	4,880	4,880	5,780	93,850
2002	3,337	4,980	4,980	5,910	94,350
2003	5,349	5,530	5,530	6,560	108,830
2004	4,806	4,870	4,870	5,790	95,150
2003	4,806	5,091	5,091	6,050	108,274
2006	4,956	5,091	5,091	7,673	136,311
2007	4,187	4,938	4,938	5,890	94,271
2008	4,052	4,549	4,549	5,430	93,391
2009	3,925	4,362	4,362	5,204	90,557
2010	3,871	5,098	5,098	6,070	103,300
2011	3,440	4,854	4,854	5,784	100,463
2012	5,063	5,507	5,507	6,574	104,155
2013	4,880	5,130	5,130	6,124	99,089
2014	4,212	5,322	5,322	6,349	102,893
2015		4,998	4,998	5,961	98,409

Separated from Other Slope Rockfish category 1993.
[1]Catch data through November 2014.
[2]Biomass from annual SAFE report projections.

<u>Fishery</u>: Northern Rockfish are fully allocated as a target species in the CGOA trawl rockfish program, with 95-98% of the CGOA TAC and sideboarded at 74.3% of the WGOA TAC.



Shortraker Rockfish

Shortraker Rockfish
AFSC, NOAA Fisheries

Stock assessment:

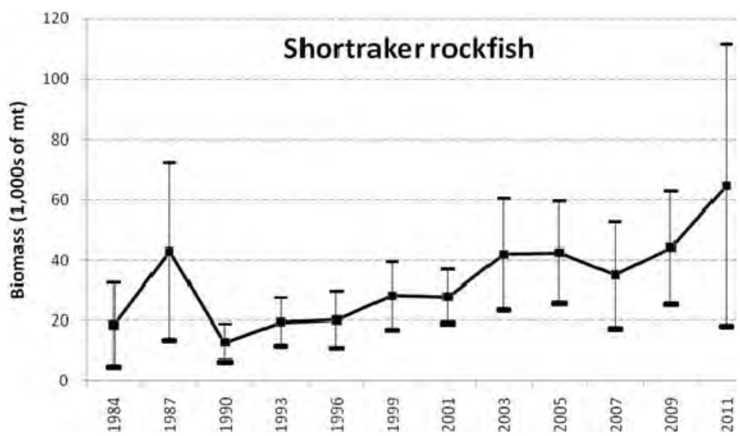
K. Echave and S. K. Shotwell 2014. Assessment of Shortraker Rockfish and "Other Slope Rockfish" stocks in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: Shortraker Rockfish *Sebastes borealis* are distributed from Japan around the Pacific Rim to Southern California, including the BSAI and the GOA. In Alaska, adults are especially concentrated along the continental slope in the 300-500 m depth interval. Shortraker Rockfish prey on shrimps, squids, and myctophids. Shortrakers attain the largest size of all *Sebastes*, with a maximum reported length of 120 cm. Shortraker Rockfish is one of the most long-lived species in the northeast Pacific, and longevity may exceed 120 years. Natural mortality is estimated to be M=0.03. Information on early life history stages of Shortraker Rockfish is limited.

Catch History: From 1991 to 2004, the NPFMC managed Shortraker Rockfish in the GOA together with Rougheye Rockfish as an assemblage. Combined catches for the two species ranged from 702 to 2,250 mt, averaging 1,617 mt annually. Shortraker was separated into a single species management unit in 2005, and catches of Shortraker Rockfish averaged 584 mt annually from 2005-2009.

Biomass



Stock Assessment: Due to limited biological data, the Shortraker Rockfish assessment uses a biomass-based approach for calculating ABCs, incorporating fishery independent data from trawl surveys. Shortraker Rockfish catch limits are set under Tier 5 ABC/OFL control rules. The 2015 projected biomass is 58,797 mt.

Total catches, pre-season catch specifications, and exploitable biomass of Shortraker Rockfish* in the GOA, 2005-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL	Biomass[2]
2005	498	753	753	982	32,723
2006	664	843	843	1,124	37,461
2007	608	843	843	1,124	37,461
2008	598	898	898	1,197	39,905
2009	550	898	898	1,197	39,905
2010	457	914	914	1,219	40,626
2011	546	914	914	1,219	40,626
2012	728	1,081	1,081	1,441	48,048
2013	730	1,081	1,081	1,441	48,048
2014	649	1,323	1,323	1,764	58,797
2015		1,323	1,323	1,764	58,797

Separated from Slope Rockfish in 1991 and Shortraker/Rougheye in 2004.
[1]Catch data through November 2014.
[2]Biomass from annual SAFE report projections.

Fishery: Shortraker Rockfish in the GOA are taken in both longline and trawl fisheries; each gear comprises about 50% of the annual catch. Shortrakers in the CGOA are allocated as a secondary species in the CGOA rockfish program. A total of 40% of the CGOA Shortraker TAC is allocated to the catcher processor sector.

Other Rockfish

Sharpchin Rockfish
AFSC, NOAA Fisheries

Stock assessment:

C. Tribuzio and K. Echave 2014. Assessment of "Other Rockfish" stock complex in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: The Other Rockfish complex consists of 25 rockfish species, although Sharpchin, Harlequin, Silvergray, Redstripe, and Redbanded Rockfish comprise the majority of the biomass in the GOA. The center of abundance for most of these species is farther south off British Columbia or the U.S. west coast. However, Harlequin Rockfish are most common in Alaskan waters, and Silvergray Rockfish appear to be most abundant in southeast Alaska and British Columbia. Within the GOA, Other Rockfish are most abundant in the eastern GOA and become increasingly scarce in areas farther west.

Blackgill Rockfish	*Sebastes melanostomus*
Bocaccio	*Sebastes paucispinis*
Canary Rockfish	*Sebastes pinniger*
Chilipepper	*Sebastes goodei*
China Rockfish	*Sebastes nebulosus*
Copper Rockfish	*Sebastes caurinus*
Darkblotched Rockfish	*Sebastes crameri*
Greenstriped Rockfish	*Sebastes elongatus*
Harlequin Rockfish	*Sebastes variegatus*
Northern Rockfish	*Sebastes polyspinis*
Pygmy Rockfish	*Sebastes wilsoni*
Quillback Rockfish	*Sebastes maliger*
Redbanded Rockfish	*Sebastes babcocki*
Redstripe Rockfish	*Sebastes proriger*
Rosethorn Rockfish	*S. helvomaculatus*
Sharpchin Rockfish	*Sebastes zacentrus*
Silvergray Rockfish	*Sebastes brevispinis*
Splitnose Rockfish	*Sebastes diploproa*
Stripetail Rockfish	*Sebastes saxicola*
Tiger Rockfish	*Sebastes nigrocinctus*
Vermilion Rockfish	*Sebastes miniatus*
Widow Rockfish	*Sebastes entomelas*
Yelloweye Rockfish	*Sebastes ruberrimus*
Yellowmouth Rockfish	*Sebastes reedi*
Yellowtail Rockfish	*Sebastes flavidus*

Life history data is limited for most Other Rockfish species. For Sharpchin Rockfish, size at 50% maturity is 26.5 cm (10 years). Natural mortality is estimated to be M=0.05 for Sharpchin and Silvergray Rockfish, M=0.10 for Redstripe Rockfish, and M=0.06 for harlequin and Redbanded Rockfish and all the minor species in the group.

Catch History: In 2012, additional species were added to the Other Rockfish complex including the former pelagic shelf rockfish species (not Dusky Rockfish), and the demersal shelf rockfish complex not in the Eastern Gulf. The current catch is a combination of former Other Slope and Pelagic Shelf Rockfish catches, and catch estimates of non-eastern GOA Demersal Shelf Rockfish. Since the mid-1990s, catches for Other Rockfish in the GOA have generally been less than 1,000 mt. The EGOA trawl closure that has been in effect since 1998 has limited the catch of Other Rockfish in the GOA.

Total catches, pre-season catch specifications, and exploitable biomass of Other Rockfish in the GOA, 1993-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL	Biomass[2]
1993	2,810	5,383	8,300	9,850	134,400
1994	1,613	2,235	8,300	9,850	76,500
1995	1,397	2,235	7,110	8,395	112,812
1996	881	2,020	7,110	8,395	112,810
1997	1,217	2,170	5,260	7,560	103,710
1998	861	2,170	5,260	7,560	103,710
1999	788	5,270	5,270	7,560	103,710
2000	577	4,900	4,900	6,390	102,510
2001	559	1,010	4,900	6,390	102,510
2002	774	990	5,040	6,610	107,960
2003	1,078	990	5,050	6,610	107,960
2004	885	670	3,900	5,150	89,460
2005	715	670	3,900	5,150	103,300
2006	931	1,480	4,152	5,394	93,552
2007	690	1,482	4,154	5,394	93,552
2008	809	1,730	4,297	5,624	90,283
2009	881	1,730	4,297	5,624	90,283
2010	798	1,192	3,749	4,881	76,867
2011	872	1,195	3,752	4,881	76,867
2012	760	1,080	4,045	5,305	85,774
2013	819	1,080	4,045	5,305	85,774
2014	1,030	1,811	4,081	5,347	83,383
2015		1,811	4,080	5,347	83,383

[1] Catch data through November 2014.
[2] Biomass from annual SAFE report projections.

Stock Assessment: Other Rockfish are managed under Tier 5 (Sharpchin Rockfish are managed under Tier 4). The 2015 projected biomass is 83,383 mt.

Fishery: There is no directed fishery for Other Rockfish in the GOA. Other Rockfish in the GOA are taken in trawl fisheries targeting higher value species.

Dusky Rockfish
AFSC, NOAA Fisheries

Dusky Rockfish

Biology: Dusky Rockfish *Sebastes variabilis* is an abundant species in the GOA. Adult Dusky Rockfish are concentrated around offshore banks and near gullies on the outer continental shelf at depths of 100 to 200 m. It is likely that Dusky Rockfish benthic distribution is associated with hard, rocky bottoms and epibenthic habitats. Dusky Rockfish prey on Pacific Sandlance and euphausiids. Dusky Rockfish age at 50% maturity is approximately 11.3 years. Mortality is estimated to be M=0.07, and longevity extends to 60 years. Dusky Rockfish are ovoviviparous with fertilization, embryonic development, and larval hatching occurring inside the mother. Parturition is believed to occur in the spring in the GOA.

Stock assessment:

C. Lunsford, S. K. Shotwell, P-J. Hulson, and D. Hanselman. 2014. Assessment of Dusky Rockfish in the Gulf of Alaska.

Catch History: Dusky Rockfish catch in the GOA generally increased after the rockfish management groups were first separated in 1988. Catches have remained fairly stable since 1994 and peaked in 1999 at 4,826 mt.

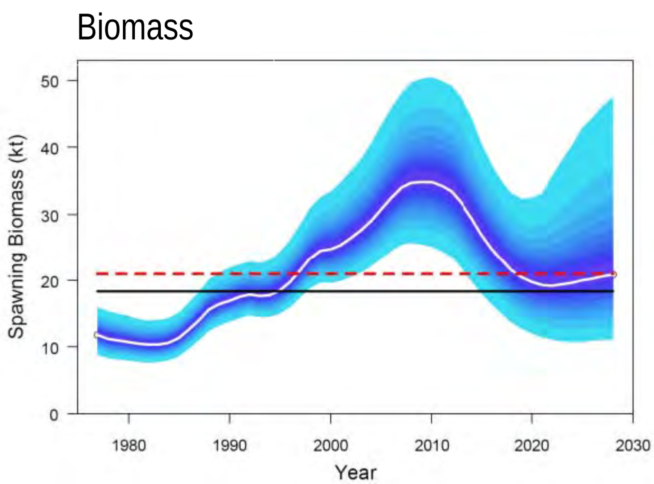
Stock Assessment: In 2012, Dusky Rockfish became a separate management category. Dusky Rockfish were formally grouped with Yellowtail Rockfish *S. flavidus* and Widow Rockfish *S. entomelas* in the Pelagic Shelf Rockfish stock complex. Since 2012, Yellowtail and Widow Rockfish have been managed in the Other Rockfish category. Dusky Rockfish are managed under Tier 3 of the ABC/OFL control rules. The 2015 projected biomass is 66,629 mt.

Fishery: In the CGOA, 95% of the Dusky Rockfish TAC is allocated to the CGOA Rockfish program. Catches of Dusky Rockfish are concentrated at a number of offshore banks of the outer continental shelf, west of Yakutat and around Kodiak in areas such as Portlock Bank and Albatross Bank.

Total catches, pre-season catch specifications, and exploitable biomass of Dusky Rockfish* in the GOA, 1988-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL	Biomass[2]
1988	1,086	3,300	3,300	-	169,700
1989	1,739	3,300	6,600	-	164,300
1990	1,647	8,200	8,200	-	164,000
1991	2,342	4,800	4,800	-	96,300
1992	3,440	6,890	6,890	11,360	75,110
1993	3,193	6,740	6,740	11,300	74,900
1994	2,990	6,890	6,890	11,550	76,500
1995	2,891	5,190	5,190	8,704	57,644
1996	2,302	5,190	5,190	8,704	56,502
1997	2,629	5,140	5,140	8,400	54,220
1998	3,111	5,260	5,260	8,040	55,580
1999	4,826	4,880	4,880	8,190	54,220
2000	3,730	5,980	5,980	9,040	66,440
2001	3,008	5,980	5,980	9,040	66,440
2002	3,318	5,490	5,490	8,220	62,489
2003	2,975	5,490	5,490	8,220	62,500
2004	2,674	4,470	4,470	5,570	57,400
2005	2,235	4,553	4,553	5,680	103,300
2006	2,446	5,436	5,436	6,662	97,368
2007	3,318	5,542	5,542	6,458	99,829
2008	3,634	5,227	5,227	6,400	70,823
2009	3,057	4,781	4,781	5,803	66,603
2010	3,097	5,059	5,059	6,142	66,603
2011	2,531	4,754	4,754	5,770	66,498
2012	4,012	5,118	5,118	6,257	66,771
2013	3,159	4,700	4,700	5,746	63,515
2014	3,050	5,486	5,486	6,708	69,371
2015		5,109	5,109	6,246	66,629

*Separated from Other Rockfish 1988. Dusky only since 2012.
[1]Catch data through November 2014.
[2]Biomass from annual SAFE report projections.



Rougheye and Blackspotted Rockfish

Blackspotted Rockfish
AFSC, NOAA Fisheries

Biology: The Rougheye and Blackspotted Rockfish (RE/BS) complex consists of 2 species; Rougheye Rockfish *Sebastes aleutianus* and Blackspotted Rockfish *Sebastes melanostictus*, recently identified by genetic research as distinct from Rougheye. The species are often difficult to differentiate from each other at sea. RE/BS distribution extends from Japan, through the BSAI, GOA to southern California. Adults primarily inhabit a narrow band along the upper continental slope at depths from 300-500 m. Although the two species distributions overlap, Blackspotted Rockfish are predominant in the AI, while Rougheye Rockfish are more common in the GOA and southeastern BS.

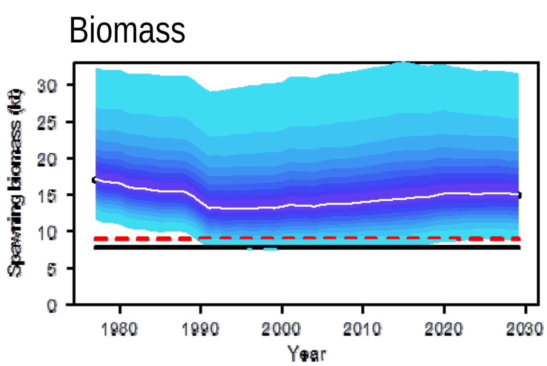
Rougheye Rockfish length at 50% maturity is 44 cm, and longevity may extend to 200 years. Natural mortality for RE/BS is estimated to be M=0.03. As with other rockfish, RE/BS are presumed to be viviparous. RE/BS Rockfish prey on pandalid shrimps, euphausiids, lanternfishes, and crabs. Predators of RE/BS include Pacific Halibut, Pacific Cod and Sablefish.

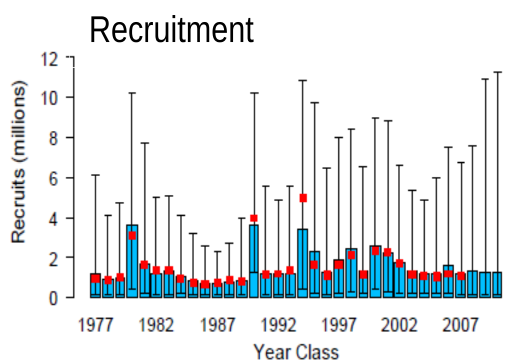
Stock assessment:

S. K. Shotwell, D. Hanselman, P. Hulson, and J. Heifetz. 2014. Assessment of Rougheye and Blockspotted Rockfish stock in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Catch History: Gulf- wide catches of the Rougheye Rockfish and Blackspotted Rockfish ranged from 130-2,418 mt. from 1977-1990. RE/BS Rockfish are generally caught with either bottom trawls or longline gear. RE/BS Rockfish have been managed as a "bycatch" only species since the creation of the Shortraker/Rougheye Rockfish management subgroup in the Gulf of Alaska in 1991. RE/BS Rockfish were separated into their own management unit in 2004, and catches of RE/BS Rockfish averaged 345 mt annually from 2005- 2009.





Total catches, pre-season catch specifications, and exploitable biomass of Rougheye and Blackspotted Rockfish* in the GOA, 2005-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL	Biomass[2]
2005	294	1,007	1,007	1,531	40,281
2006	358	983	983	1,180	37,449
2007	417	988	988	1,148	39,506
2008	389	1,286	1,286	1,548	46,121
2009	280	1,284	1,284	1,545	46,385
2010	447	1,302	1,302	1,568	45,751
2011	543	1,312	1,312	1,579	45,907
2012	593	1,223	1,223	1,472	42,856
2013	574	1,232	1,232	1,482	42,883
2014	733	1,244	1,244	1,497	42,810
2015		1,122	1,122	1,345	36,584

*Separated from Slope Rockfish in 1991 and Shortraker/Rougheye Rockfish in 2004.
[1]Catch data through November 2014.
[2]Biomass from annual SAFE report projections.

Stock Assessment: The RE/BS Rockfish assessment uses a separable age-structured model that incorporates fishery data and fishery independent data from biennial trawl and annual longline surveys. RE/BS Rockfish limits are set by a Tier 3a control rule.

Fishery: RE/BS Rockfish in the GOA are primarily taken in rockfish bottom trawl fisheries and longline fisheries targeting Sablefish and Pacific Halibut.

Rougheye Rockfish
AFSC, NOAA Fisheries

Yelloweye Rockfish
ADF&G

Demersal Shelf Rockfish

<u>ology</u>: The Demersal Shelf Rockfish (DSR) complex consists of 7 species and are a management unit in the Southeast Outside area only (east of 140 W longitude). Elsewhere in the Gulf of Alaska, these species are managed as part of the "Other rockfish" complex.

Canary Rockfish	*Sebastes pinniger*
China Rockfish	*Sebastes nebulosus*
Copper Rockfish	*Sebastes caurimus*
Quillback Rockfish	*Sebastes maliger*
Rosethorn Rockfish	*Sebastes helvomaculatus*
Tiger Rockfish	*Sebastes nigrocinctus*
Yelloweye Rockfish	*Sebastes ruberrimus*

DSR are generally nearshore, bottom-dwelling species, located on the continental shelf and associated with rugged, rocky habitat. DSR species exhibit K-selected life history traits including slow growth and extreme longevity. DSR are viviparous, and parturition occurs from February through September with the majority of the species extruding larvae in spring.

Stock assessment:

K. Green and K. Van Kirk. 2014. Assessment of the Demersal Shelf Rockfish stock in the SEO District of the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

The primary species of the fishery is Yelloweye Rockfish. The oldest recorded Yelloweye Rockfish is 118 years, and natural mortality is estimated at M=0.02. Yelloweye reach a maximum length of about 91 cm with the length at 50% maturity at 45 cm (18 years). Yelloweye feed on shrimp, small crabs and a variety of fishes including small rockfish, herring and sandlance. Yelloweye are in turn prey for larger rockfish, lingcod, salmon and Pacific Halibut.

<u>Catch History</u>: The directed fishery for DSR began in 1979 as a small, shore-based, hook and line in Southeast Alaska, which targeted the entire DSR complex. Total DSR catch increased from 120 mt in 1982 to a peak of 778 mt in 1987.

Exploitable biomass, pre-season catch specifications, and total catches (including discards) of Demersal Shelf Rockfish* in the Southeast Outside sub-district of the GOA, 1992-2015 (in mt).

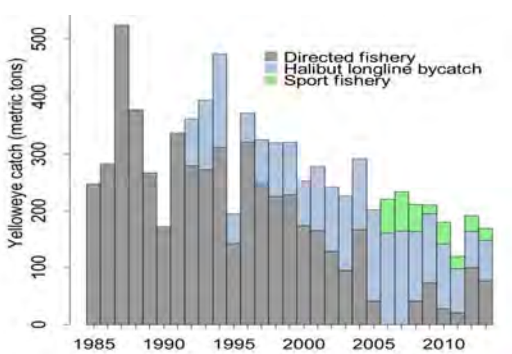
Year	Catch[1]	TAC	ABC	OFL	Biomass[2]
1992	511	550	550	732	-
1993	558	800	800	1,600	48,366
1994	540	960	960	1,680	49,280
1995	219	580	580	1,044	26,093
1996	401	950	950	1,702	42,552
1997	406	950	950	1,450	42,552
1998	552	560	560	950	25,031
1999	297	560	560	950	25,031
2000	406	340	340	420	15,100
2001	301	330	330	410	14,695
2002	292	350	350	480	15,615
2003	229	390	390	540	17,510
2004	260	450	450	690	20,168
2003	187	410	410	640	18,508
2006	166	410	410	650	19,558
2007	250	410	410	650	19,558
2008	149	382	382	611	18,329
2009	138	362	362	580	17,390
2010	127	295	295	472	14,321
2011	82	300	300	479	14,395
2012	180	240	293	467	14,307
2013	218	249	303	487	14,588
2014	104	274	274	438	13,274
2015		225	225	361	10,933

*Separated from Rockfish in 1991.
[1] Catch data through November 2014.
[2]Biomass from annual SAFE report projections.

<u>Fishery Management:</u> DSR are managed jointly by ADF&G and NMFS. Directed fishery quotas are set by management area and are based on the remaining ABC after subtracting the estimated DSR incidental catch (landed and at sea discard) in other fisheries. If there is sufficient directed quota available for DSR to hold a fishery, then this will be opened in late January and will be closed prior to the start of the halibut season in March.

<u>Stock Assessment</u>: Yelloweye Rockfish biomass is estimated from submersible transect density and area estimates of DSR habitat. DSR catch limits managed as a Tier 4 species, but the catch limits are set below maximum permissible by setting F=M.

<u>Fishery:</u> The directed fishery for DSR is almost entirely prosecuted by longline gear.



Thornyhead Rockfish

Shortspine Thornyhead
AFSC, NOAA Fisheries

Stock assessment:

S. K. Shotwell, J. Ianelli, and J. Heifetz. 2014. Assessment of the Thornyhead Stock Complex in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: The Thornyhead Rockfish Complex consists of 3 species; Shortspine *Sebastolobus alascanus*, Longspine *Sebastolobus altivelis,* and Broadfin *Sebastolobus macrochir* Thornyheads. Thornyheads are distinguished from "true" rockfish (*Sebastes*) due to their reproductive biology. Whereas *Sebastes spp*. rockfish are viviparous, thornyheads are oviparous, releasing fertilized eggs in floating gelatinous masses. Thornyheads are also differentiated from *Sebastes spp.* in lacking a swim bladder.

NOAA Fisheries Service

Shortspine Thornyheads are distributed in deep-water habitats throughout the North Pacific, and are concentrated between 150-450 m in the cooler, northern part of their range and are generally found in deeper habitats up to 1000 m in the warmer waters of their southern range. Females reach 50% maturity at about 22 cm, and longevity extends to 100 years or more. Natural mortality is estimated to be M=0.03. Shortspine Thornyheads feed on shrimps, crabs, zooplankton and amphipods and are in turn prey for Arrowtooth Flounder, Sablefish, sperm whales and sharks. Longspine Thornyheads are found only in the eastern North Pacific, around the Shumagin Islands, GOA and south to California. Longspines are generally found in deeper habitats from 200-1,750 m.

Catch History: The greatest reported harvest of Thornyheads in the GOA occurred from 1979-1983. Catches declined in 1984 and 1985 due to U.S. management restrictions and a transition to domestic fisheries. U.S. catches continued to increase through 1989, peaking at 3,055 mt.

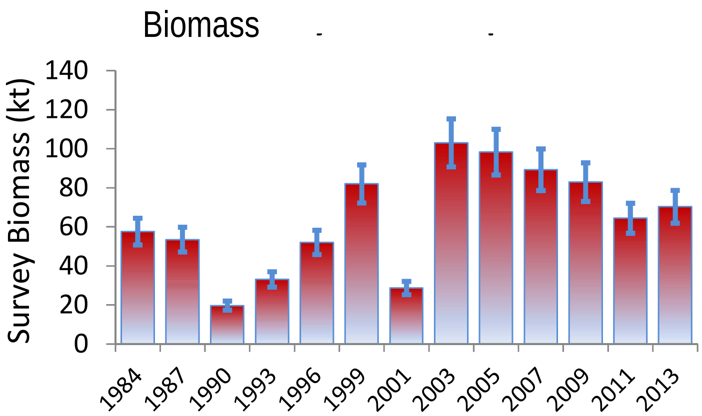
Total catches, pre-season catch specifications, and exploitable biomass of age 5+ Thornyhead Rockfish* in GOA, 1992-2015 (mt).

Year	Catch[1]	TAC[2]	ABC	OFL	Biomass
1992	2,020	1,800	1,800	2,440	25,700
1993	1,369	1,062	1,180	1,441	26,207
1994	1,320	1,180	1,180	1,440	103,300
1995	1,113	1,900	1,900	2,660	30,341
1996	1,100	1,248	1,560	2,200	26,244
1997	1,240	1,700	1,700	2,400	46,108
1998	1,136	2,000	2,000	2,840	52,271
1999	1,282	1,990	1,990	2,800	53,216
2000	1,307	2,360	2,360	2,820	52,950
2001	1,339	2,310	2,310	2,770	52,100
2002	1,125	1,990	1,990	2,330	77,840
2003	1,159	2,000	2,000	3,050	85,760
2004	818	1,940	1,940	2,590	86,200
2005	719	1,940	1,940	2,590	86,200
2006	779	2,209	2,209	2,945	98,158
2007	701	2,209	2,209	2,945	98,158
2008	741	1,910	1,910	2,540	84,774
2009	666	1,910	1,910	2,540	84,775
2010	553	1,770	1,770	2,360	78,795
2011	612	1,770	1,770	2,360	78,795
2012	746	1,665	1,665	2,220	73,990
2013	1,153	1,665	1,665	2,220	73,990
2014	1,121	1,841	1,841	2,454	81,816
2015		1,841	1,841	2,454	81,816

* includes Longspine and Shortspine Thornyheads.
[1]Catch data through November 2014.
[2]TAC, ABC and OFL from annual Federal Register.

Stock Assessment: Thornyhead rockfish catch limits are set using a Tier 5 control rule. The 2015 projected biomass is 81,816 mt. Catch specifications for 2015 are as follows; OFL=2,454 mt, ABC= 1,841 mt, TAC= 1,841 mt.

Fishery: Thornyheads are caught by bottom trawl as a secondary target species in the CGOA Rockfish program and are also taken incidentally in the Sablefish longline fishery. Thornyheads are a valuable rockfish species, and most of the domestic harvest is exported to Japan.



Atka Mackerel

Atka Mackerel
AFSC, NOAA Fisheries

Biology: Atka Mackerel *Pleurogrammus monopterygius* are distributed along the continental shelf. Atka Mackerel is a schooling, semi-demersal species most commonly found in the AI, but also in the Western and Central GOA. Adult Atka Mackerel occur in large localized aggregations at depths less than 200 m over rough, uneven bottom areas with high tidal currents. Atka Mackerel feed on euphausiids and copepods and are prey for Pacific Cod, Arrowtooth Flounder, Stellar sea lions, and seabirds.

Atka Mackerel begin to recruit to the fishery at age 3 and longevity can extend to 15 years. Females reach 50% maturity at 38.2 cm (3.6 years). Natural mortality is estimated at M=0.30. Atka Mackerel is a substrate-spawning fish with male parental care. Behavioral studies have shown that the Atka Mackerel mating system is very complex. A significant characteristic is the bright and distinct coloration developed by territorial males during the spawning season. Spawning occurs from July to October, peaking in early September. Atka Mackerel have relative low fecundity, with females releasing around 30,000 eggs each year. Eggs are adhesive and deposited in rock crevices in nests guarded by males until hatching, which occurs about 40-45 days later.


Jackie Patt, UAF

Stock assessment:

S. Lowe. 2014. Assessment of Atka Mackerel stock in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Catch History: Atka Mackerel supported a targeted foreign fishery (primarily Soviet vessels) in the Central GOA during the 1970s and 1980s. Catches peaked in 1975 at about 27,000 mt then declined dramatically to less than 5 mt in 1986. Joint venture operations participated in the Atka Mackerel fishery from 1983-1985, and the fishery was fully domestic by 1986.

Total catches, and pre-season catch specifications of Atka Mackerel* in the GOA, 1994-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL
1994	3,538	3,500	4,800	19,040
1995	701	3,240	3,240	11,700
1996	1,580	3,240	3,240	9,800
1997	331	1,000	1,000	6,200
1998	317	600	600	6,200
1999	262	600	600	6,200
2000	170	600	600	6,200
2001	76	600	600	6,200
2002	85	600	600	6,200
2003	578	600	600	6,200
2004	819	600	600	6,200
2005	799	600	600	6,200
2006	876	1,500	4,700	6,200
2007	1,453	1,500	4,700	6,200
2008	2,109	1,500	4,700	6,200
2009	2,222	3,328	3,328	6,200
2010	2,409	2,000	4,700	6,200
2011	1,615	2,000	4,700	6,200
2012	1,187	2,000	4,700	6,200
2013	1,277	2,000	4,700	6,200
2014	981	2,000	4,700	6,200
2015		2,000	4,700	6,200

*Added to Other Species category in 1988 and separated from Other Species in 1994.
[1]Catch data through November 2014.

Fishery Management:. In 1988, Atka Mackerel were combined with the Other Species category due to low abundance. In 1994, Atka Mackerel were removed from the Other Species category and treated once again as a single species target stock. There has not been a directed Atka Mackerel fishery in the GOA since 1996.

Stock Assessment: The existing GOA bottom trawl survey data has limited utility for either absolute abundance estimates or indices for Atka Mackerel. Atka Mackerel fall under the Tier 6 control rule. The 2015 catch specifications for Atka Mackerel are as follows; OFL=6,200 mt, ABC=4,700 mt, TAC=2,000 mt.

Fishery: Atka Mackerel has been a “bycatch” only fishery in the GOA since 1996.

Ecosystem Components: Because Atka Mackerel is a common prey item for Steller sea lions, all directed fishing for Atka Mackerel is prohibited in the GOA.

Jackie Patt, UAF

Big Skates, Longnose Skates, Other Skates

Stock assessment:

O. Ormseth. 2014. Assessment of the skate stock complex in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: The GOA Skate complex is comprised of at least 15 skate species. Big Skate and Longnose Skate dominate the skate biomass in the GOA. *Bathyraja sp*. compose about a third of total GOA skate biomass, with the majority of these being the Aleutian Skate and Bering Skate. Skate biomass is concentrated in the Central GOA. Skates feed on bottom invertebrates, such as crustaceans, mollusks and polychaetes and fish. Skates are prey for sharks, Steller sea lions and sperm whales.

The highest biomass of skates in the GOA is found in continental shelf waters less than 100 m deep, and is dominated by the Big Skate. In continental shelf waters from 100-200 m depth, Longnose Skate dominates skate biomass, and *Bathyraja* skate species are dominant in the deeper waters extending from 200 to 1000 m or more in depth. Big and Longnose Skate are generally found in shallower waters in the GOA, and their distribution extends from the Bering Sea to southern Baja California. The Aleutian Skate ranges throughout the north Pacific from northern Japan to northern California and has been found at depths between 16-1602 m. The Alaska Skate is restricted to higher latitudes from the Sea of Okhotsk to the eastern GOA at depths from 17-392 m.

Big Skate	*Beringraja binoculata*
Longnose Skate	*Raja rhina*
Other skates	
Aleutian Skate	*Bathyraja aleutica*
Bering Skate	*Bathyraja interrrupta*
Alaska Skate	*Bathyraja parmifera*
Deepsea Skate	*Bathyraja abyssicola*
Commander Skate	*Bathyraja lindbergi*
Whiteblotched Skate	*Bathyraja maculata*
Butterfly Skate	*Bathyraja mariposa*
Whitebrow Skate	*Bathyraja minispinosa*
Leopard Skate	*Bathyraja pamifera sp.*
Mud Skate	*Bathyraja taranetzi*
Roughtail Skate	*Bathyraja trachura*
Okhotsk Skate	*Bathyraja violacea*
Roughshoulder Skate	*Bathyraja badia*

Big Skate
Megan Peterson, UAF

Skates are generally K-selected, with slow-growth, low fecundity and relatively large body size. Skates are oviparous; fertilization is internal, and eggs are deposited in horny cases for incubation. There are 1-7 embryos per egg case in locally occurring *Raja sp*., but little is known about the frequency of breeding or egg deposition for any of the local species. It is estimated that annual fecundity per females may be less than 50 eggs per year. The Big Skate is the largest skate in the GOA, with maximum sizes observed over 200 cm in the directed fishery in 2003. Observed sizes for the Longnose Skate range from 165-170 cm. The maximum observed lengths for *Bathyraja* species from bottom trawl surveys of the GOA range from 86-154 cm. Life history parameter data are limited for GOA skates. The AFSC Age and Growth Program has recently reported a maximum observed age of 25 years for the Longnose Skate in the GOA and a maximum observed age for GOA Big Skate of 15 years.

Catch History: Skates were caught as a bycatch only species in the GOA at about 1,000-2,000 mt per year from 1992-1995, principally by the longline Pacific Cod and bottom trawl pollock and flatfish fisheries. Most skates during this time period were not retained. A directed skate fishery developed in the GOA in 2003 due to an increase in the ex-vessel value of skates. The skate fishery was prosecuted generally by longline vessels less than 60 feet around Kodiak Island. Lower ex-vessel prices and a possible reduction in skate catch-per-unit effort resulted in a sharp decline in skate catches in 2004-2005.

Directed fishing for skates in the GOA has been prohibited since 2005. Annual average catches of Big Skate, Longnose Skate and other skates from 2005- 2014 have averaged 1,811 mt, 1,150 mt, and 1,280 mt respectively. Catches are highest in the central GOA regulatory area.

Fishery Management: Since the beginning of domestic fishing in the late 1980s through 2003, all species of skates in the GOA were managed under the Other Species FMP category (skates, sharks, squids, sculpins, and octopuses). Catch limits were determined for all Other Species as 5% of the sum of the TACs for GOA target species. Under Amendment 63 in 2003, GOA skates were removed from the Other Species category in 2004 for separate management in response to a developing fishery. Big and Longnose Skate were managed together under a single TAC in the Central GOA. The remaining skates were managed as an “Other Skates” species complex in the Central GOA, and all skates were managed as an “Other Skates” species complex in the Western and Eastern GOA.

In 2005, Big Skate and Longnose Skate were separated into single species management groups due to concerns about disproportionate harvests. The remaining skates (genus *Bathyraja*) continue to be managed as a gulf-wide species complex because they were not the targets of the fishery and are more difficult to identify. There has been no directed fishing for skates in the GOA since 2005.

Stock Assessment: The Skates stock assessment used estimated biomass data from NMFS summer bottom trawl surveys from 2003-fwd. Skates are managed under Tier 5 of the ABC/OFL control rule, based on an overall natural mortality rate of 0.10 applied to survey biomass estimates for each species group. Gulf wide catch specifications (mt) for 2015 are as follows.

	2015 Biomass	OFL	ABC	TAC	2014 Catch
Big Skate	43,398	4,340	3,225	3,225	1,379
Longnose Skate	42,911	4,291	3,218	3,218	1,148
Other skates	29,797	2,980	2,235	2,235	1,559

Note that the ABC and TAC are further broken out into Western, Central, and Eastern Gulf of Alaska for Big Skate and Longnose skate.

Fishery: GOA Skates have been a bycatch only fishery since 2005. Skates are generally caught as bycatch in Pacific Halibut and Pacific Cod longline fisheries and flatfish trawl fisheries, especially in the GOA Central regulatory area. The incidental catch of Big Skate in the Central area has the potential to constrain fisheries.

Ecosystem Components: Skates have few natural predators. In the GOA, skate predators include marine mammals such as Steller sea lions and sperm whales (which may consume adult or juvenile skates), and Spiny Dogfish (which likely consume juvenile skates).

Spiny Dogfish
AFSC, NOAA Fisheries

Sharks

Stock assessment:

C. Tribuzio, P. Hulson, K. Echave, and C. Rodgeveller. 2014. Assessment of the shark stock complex in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: The GOA Shark complex is composed of 8 shark species. The most abundant species in the GOA are the Spiny Dogfish, the Salmon Shark and the Pacific Sleeper Shark. GOA sharks exhibit K-selected life history traits including slow growth to maturity, low fecundity and large size. Spiny dogfish, Pacific sleeper shark and Salmon Sharks reproduce through aplacental vivipary. Shark diets vary with species and in general sharks are opportunistic feeders, but forage fish, crustaceans, squid and salmon are among the most common prey items.

Spiny dogfish	*Squalus acanthias*
Salmon shark	*Lamna ditropis*
Pacific sleeper shark	*Somniosus pacificus*
Brown cat shark	*Apristurus brunneus*
White shark	*Carcharodon carcharias*
Basking shark	*Cetorhinus maximus*
Sixgill shark	*Hexanchus griseus*
Blue shark	*Prionace glauca*

Spiny Dogfish are distributed from California to Alaska, through the Aleutian chain to the Asian coast and south to Japan. Spiny Dogfish are found at depths ranging from the intertidal to 900 m. Spiny Dogfish growth rates are among the slowest of all shark species. Estimates of Spiny Dogfish age-at-50%-maturity are 20 years for males to 34 years for females. Longevity is estimated to reach between 80 and 100 years. Natural mortality is estimated at M=0.097. Spiny Dogfish have one of the longest known gestation periods, approximately 18-24 months.

Spiny Dogfish, Mark Fina, NPFMC

Pacific Sleeper Sharks are found along the North Pacific continental shelf and slope, ranging from Japan to the Bering Sea. Distribution extends as far north as the Chukchi Sea and as far south as Baja California. At higher latitudes, Pacific Sleeper Sharks are found shallower from littoral zones to surface waters. At lower latitudes, they reside much deeper and down to 2000 m. Pacific Sleeper Sharks make extensive, nearly continuous vertical movements. The maximum lengths of captured Pacific Sleeper Sharks are 440 cm for females and 400 cm for males. Pacific Sleeper Sharks 150-250 cm in length are most common in Alaska. Pacific Sleeper Shark age and reproduction data are limited.

Salmon Shark, Ken Goldman, ADF&G

Salmon Shark distribution in the northern Pacific extends from Japan into the Sea of Okhotsk to the Bering Sea and possibly south as far as Baja California Mexico. Salmon Sharks live in areas with sea-surface temperatures between 5˚C and 18˚C and in depths up to 150 m. However, Salmon Sharks are primarily found in waters less than 50 m deep. While some Salmon Sharks migrate south during the winter months, others remain in the GOA throughout the year. Longevity estimates for Salmon Sharks are between 20-30 years with maturity occurring at 3-5 years for males and 6-9 years for females. Natural mortality is estimated at M=0.18.

Catch History: There are currently no directed commercial fisheries for shark species in federal or state managed waters of the GOA, and most incidentally caught sharks are not retained. A small number of Spiny Dogfish landings in Kodiak were reported in 2004, 2005 and 2007 (approximately 1 mt each year). Spiny Dogfish and Salmon Sharks are also caught in recreational fisheries in the GOA. Estimates of historic catches of sharks range from 308 mt in 1995 to a peak of 2,390 mt in 1998. Catches annually averaged 895 mt from 1992-1999 and 982 mt from 2000-2014.

Spiny dogfish, Cindy Tribuzio, AFSC, NOAA Fisheries

Total catches, and pre-season catch specifications of Sharks* in the GOA, 1994-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL
1994	360	-	-	-
1995	308	-	-	-
1996	484	-	-	-
1997	1,041	-	-	-
1998	2,390	-	-	-
1999	1,036	-	-	-
2000	1,117	-	-	-
2001	853	-	-	-
2002	427	-	-	-
2003	751	-	-	-
2004	573	-	-	-
2005	1,101	-	-	-
2006	1,603	-	-	-
2007	1,406	-	-	-
2008	619	-	-	-
2009	1,167	-	-	-
2010	603	-	-	-
2011	523	6,197	6,197	8,262
2012	636	6,028	6,028	8,037
2013	2,166	6,028	6,028	8,037
2014	1,188	5,989	5,989	7,986
2015		5,989	5,989	7,986

*Split from Other Species in 2011.
[1]Catch data through November 2014.

Fishery Management: Until 2011, sharks were managed under the Other Species FMP category (sharks, squids, sculpins, and octopuses). Beginning in 2011, sharks have been managed in a separate complex.

Stock Assessment: Catch specifications for sharks are based on Tier 6. A Tier 5-like method is used for dogfish sharks, with natural mortality (M=0.097) applied to biomass estimate (79,257 mt). Standard tier 6 methodology is used for other sharks based on average historical catch from 1997-2007. Catch specifications for sharks in 2015 are as follows; OFL=7,986 mt, ABC=5,989 mt, and TAC=5,989 mt.

Fishery: GOA sharks are managed as a bycatch only fishery. On average, over 90% of the sharks are discarded. Spiny Dogfish were caught primarily in the longline Pacific Cod and bottom trawl flatfish fisheries. Over 90% of Pacific Sleeper Sharks and Salmon Sharks were caught in the Pollock fishery.

AFSC, NOAA Fisheries

Squid

Biology: There are at least 15 species of squid in the Gulf of Alaska and these are managed as a squid complex. The most common squid near the continental shelf are in the genus *Berryteuthis*. Further offshore, Boreopacific Armhook Squid and *Gonatus* squids appear to be the most common. Much more research is needed to adequately characterize squid distribution in the Gulf of Alaska.

Squids are active predators that swim by jet propulsion, reaching swimming speeds of up to 40 km/hr, the fastest of any aquatic invertebrate. Squids are short-lived (<4 years), maturing just prior to spawning and dying afterwards. Squid populations consist of multiple cohorts that school with similar sized individuals, and may occupy different areas of the shelf and slope.

Chiroteuthid sp.	*Chiroteuthis calyx*
Glass squid sp.	*Belonella borealis*
Glass squid sp.	*Galiteuthis phyllura*
Minimal Armhook Squid	*Berryteuthis anonychus*
Magistrate Armhook Squid	*Berryteuthis magister*
Armhook Squid	*Eogonatus tinro*
Boreopacific Armhook Squid	*Gonatopsis borealis*
Berry Armhook Squid	*Gonatus berryi*
Armhook squid sp.	*Gonatus madokai*
Armhook squid sp.	*Gonatus middendorffi*
Clawed Armhook Squid	*Gonatus onyx*
Robust Clubhook Squid	*Moroteuthis robusta*
Boreal Clubhook Squid	*Onychoteuthis borealijaponicus*
Red Flying Squid	*Ommastrephes bartramii*
North Pacific Bobtail Squid	*Rossia pacifica*

Fishery Management: Squid were defined as an "other species" in the GOA until 2011 when the "other species" complex was separated out into distinct species groupings.

Stock assessment:

O. Ormseth. 2014. Assessment of the squid stock complex in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Stock Assessment: Catch specifications for Squid are set using a modified Tier 6 control rule, with catch specifications are based on the highest catch during 1997-2008. Squid estimated biomass in unknown. Catch specifications for squid in 2015 were as follows; OFL=1,530 mt, ABC=1,148 mt, TAC=1,148 mt.

Total catches, and pre-season catch specifications of Squid* in the GOA, 1997-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL
1997	97	-	-	-
1998	59	-	-	-
1999	41	-	-	-
2000	19	-	-	-
2001	91	-	-	-
2002	43	-	-	-
2003	97	-	-	-
2004	162	-	-	-
2005	636	-	-	-
2006	1,530	-	-	-
2007	416	-	-	-
2008	98	-	-	-
2009	345	-	-	-
2010	139	-	-	-
2011	238	1,148	1,148	1,530
2012	22	1,148	1,148	1,530
2013	321	1,148	1,148	1,530
2014	92	1,148	1,148	1,530
2015		1,148	1,148	1,530

*Split from Other Species in 2011.
[1]Catch data through November 2014.

Fishery: There is currently no target fishery for squid in the GOA. GOA squid are primarily (> 90%) taken as incidental catch in the pelagic trawl pollock fishery. They are also taken in smaller numbers in bottom trawl fisheries. About 90% of the squid catch has been retained in recent years.

Tim Evers

Ecosystem Components: Squid are not currently a commercially valuable species in the North Pacific. However they play a critical prey role in ecosystems, as squid are important components in the diets of many seabirds, fish and marine mammals. Overall fishing removals of squid are low (especially relative to natural predation).

Giant Pacific Octopus
Linda Kozak

Octopus

Stock assessment:

M.E. Conners and C. Conrath. 2014. Assessment of the Octopus Stock Complex in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm

Biology: There are at least 7 species of octopus present in federal waters of the GOA, and the species composition both of natural communities and commercial harvest is unknown. At depths less than 200 meters, the giant Pacific octopus *E. dofleini* appears to be the most abundant species. Octopus life spans are either 1-2 years or 3-5 years depending on the species. *E. dofleini* are estimated to mature at 1.5 – 3 years. male *E. dofleini* were found to mature at around 12.5 kg with females thought to mature at larger sizes. *E. dofleini* is a terminal spawner, females die after the eggs hatch while males die shortly after mating. The fecundity of this species in Japanese waters has been estimated at 30,000 to 100,000 eggs per female. There are two other common species of octopus in the GOA: the smoothskin octopus and the flapjack devilfish. The smoothskin octopus occurs from 250-1400 m. and produces few eggs that remain benthic after hatching. The flapjack devilfish is found from 300-1000m deep and spawn up to 2,400 eggs in multiple batches.

Giant Pacific octopus	*Enteroctopus dofleini*
Smoothskin octopus	*Benthoctopus leioderma*
Flapjack devilfish	*Opisthoteuthis californiana*
Pelagic octopus	*Japatella diaphana*
Red octopus	*Octopus californicus*
Black octopus	*Vampyroteuthis infernalis*
a small octopus	*Octopus sp. A*

Fishery Management: Until 2011, octopus were managed as part of the "Other species" management category within the GOA FMP. Beginning in 2011, octopuses have been managed as a single complex with its own ABC and OFL.

Stock Assessment: Octopus catch limits are specified using a modified Tier 6 control rule, with an estimate of natural mortality (M=0.53) applied to the biomass of the three most recent NMFS bottom trawl surveys. While the biomass is deemed unreliable for purposes of Tier 5, it does provide a minimum estimate of biomass. Catch specifications for octopus in 2015 are as follows; OFL=2,009 mt, ABC=1,507 mt, TAC=1,507 mt.

Megan Peterson, UAF

Total catches, and pre-season catch specifications of Octopus* in the GOA, 1997-2015 (in mt).

Year	Catch[1]	TAC	ABC	OFL
1997	232	-	-	-
1998	112	-	-	-
1999	166	-	-	-
2000	156	--	-	-
2001	88	-	-	-
2002	298	-	-	-
2003	210	-	-	-
2004	286	-	-	-
2005	151	-	-	-
2006	159	-	-	-
2007	262	-	-	-
2008	339	-	-	-
2009	310	-	-	-
2010	324	-	-	-
2011	917	954	954	1,272
2012	421	1,455	1,455	1,941
2013	441	1,455	1,455	1,941
2014	1,057	1,507	1,507	2,009
2015		1,507	1,507	2,009

*Split from Other Species in 2011.
[1]Catch data through November 2014.

Fishery: There is currently no target fishery for octopus in federal waters of the GOA. About 90% of the octopus catch is taken as incidental catch in the Pacific Cod pot fisheries in the western and central GOA. In 2014, approximately 529 mt of octopus were retained for human consumption or for bait for the halibut fishery. The species composition of the octopus catch is unknown, but based on research trawl data, the giant Pacific octopus is most abundant in shelf waters and predominates in commercial catch. Preliminary research suggests high survival for octopus released from pot gear.

Sculpins

Great Sculpin
AFSC, NOAA Fisheries

Biology: There are 39 species of sculpins identified in the Gulf of Alaska and managed as a sculpin complex. The most common sculpin species taken incidentally in GOA fisheries are the Yellow Irish Lord *Hemilepidotus jordani* making up over 60% of the catch, followed by Great Sculpin *Myoxocephalus polyacanthocephalus* , Bigmouth Sculpin *Hemitripterus bolini* and Plain Sculpin *M. joak*. Sculpins lay adhesive eggs in nests, and many exhibit parental care for eggs. Irish lords and great sculpins have an age at 50% maturity of about 7 years.

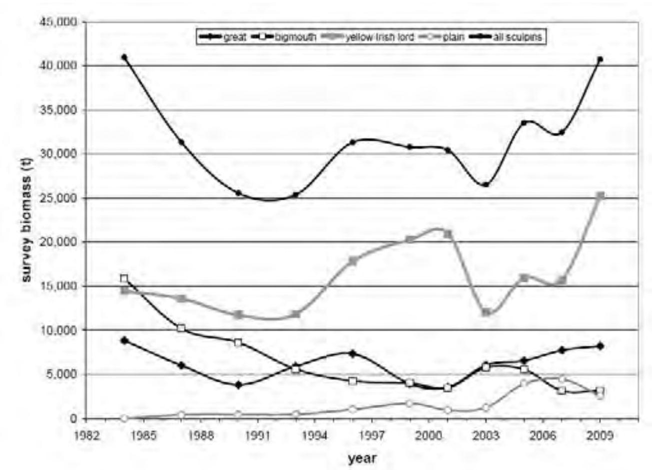
Catch history: There is no directed fishing for any sculpin species in the GOA at this time. Catch of sculpins in the last 15 years has been averaged about 900 mt per year, reaching a peak in 2008 of 1,943 mt.

Fishery Management: Prior to 2011, sculpins were managed as part of the GOA Other Species complex that included sculpins, skates, sharks, squid and octopus, with an aggregate OFL, ABC, and TAC. Beginning in 2011 sculpins were removed from Other Species and managed as a separate group, as were the remaining species groups. Sculpins are currently taken only as incidental catch in fisheries directed at other target species, and it is likely that catch of sculpins in the near future will continue to be dependent on the distribution and limitations placed on target fisheries, rather than on any harvest level established for this category.

Stock assessment authors:

I. Spies, D. Nichol, and T. Tenbrink. 2014. Assessment of the Sculpin Stock Complex in the Gulf of Alaska.

http://www.afsc.noaa.gov/refm/stocks/assessments.htm



Catches, pre-season catch specifications and estimated biomass (t) of Sculpins in the GOA, 1997-2015.

Year	Catch	ABC	OFL	Biomass[2]
1997	898	-	-	-
1998	526	-	-	-
1999	544	-	-	30,783
2000	940	-	-	-
2001	587	-	-	30,418
2002	919	-	-	-
2003	629	-	-	26,514
2004	816	-	-	-
2005	626	-	-	33,519
2006	583	-	-	-
2007	960	-	-	32,468
2008	1,943	-	-	-
2009	1,146	-	-	40,726
2010	735	-	-	-
2011	691	5,496	7,328	33,307
2012	875	5,731	7,641	34,610
2013	1,959	5,884	7,614	34,732
2014	1,075	5,569	7,448	33,550
2015	5,569	5,569	7,448	33,550

*Sculpins removed from Other Species in 2011
[1] Estimated catch data through November 2014.
[2] Biomass estimate (t) from trawl surveys.

Stock Assessment: Sculpins are managed under Tier 5 of the OFL/ABC guidelines, and catch specifications are based on natural mortality for the complex (M=0.22) applied to average survey biomass.

Fishery: There is currently no target fishery for sculpins in the GOA, and virtually all are either discarded or made into meal. Incidental catches of sculpins are taken in the Pacific Cod, shallow water flatfish, and rockfish fisheries, as well as the halibut longline fishery.

Bigmouth Sculpin,
AFSC, NOAA Fisheries

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Amendment 43 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region

July 27, 2017

Environmental Assessment Regulatory Impact Review Regulatory Flexibility Analysis Fishery Impact Statement

A publication of the South Atlantic Fishery Management Council pursuant to National Oceanic and Atmospheric Administration Award Number FNA15NMF4410010

Abbreviations and Acronyms Used in the FMP

ABC acceptable biological catch

ACL annual catch limits

AM accountability measures

ACT annual catch target

B a measure of stock biomass in either weight or other appropriate unit

B_{MSY} the stock biomass expected to exist under equilibrium conditions when fishing at F_{MSY}

B_{OY} the stock biomass expected to exist under equilibrium conditions when fishing at F_{OY}

B_{CURR} the current stock biomass

CPUE catch per unit effort

DEIS draft environmental impact statement

EA environmental assessment

EEZ exclusive economic zone

EFH essential fish habitat

F a measure of the instantaneous rate of fishing mortality

$F_{30\%SPR}$ fishing mortality that will produce a static SPR = 30%

F_{CURR} the current instantaneous rate of fishing mortality

F_{MSY} the rate of fishing mortality expected to achieve MSY under equilibrium conditions and a corresponding biomass of B_{MSY}

F_{OY} the rate of fishing mortality expected to achieve OY under equilibrium conditions and a corresponding biomass of B_{OY}

FMP fishery management plan

FMU fishery management unit

M natural mortality rate

MARMAP Marine Resources Monitoring Assessment and Prediction Program

MFMT maximum fishing mortality threshold

MMPA Marine Mammal Protection Act

MRFSS Marine Recreational Fisheries Statistics Survey

MRIP Marine Recreational Information Program

MSFCMA Magnuson-Stevens Fishery Conservation and Management Act

MSST minimum stock size threshold

MSY maximum sustainable yield

NEPA National Environmental Policy Act

NMFS National Marine Fisheries Service

NOAA National Oceanic and Atmospheric Administration

OFL overfishing limit

OY optimum yield

RFA Regulatory Flexibility Act

RIR Regulatory Impact Review

SAFMC South Atlantic Fishery Management Council

SEDAR Southeast Data Assessment and Review

SEFSC Southeast Fisheries Science Center

SERO Southeast Regional Office

SIA social impact assessment

SPR spawning potential ratio

SSC Scientific and Statistical Committee

Amendment 43 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region

Proposed action:	Revise the Process to Determine the Annual Catch Limits for Red Snapper.
Lead agency:	FMP Actions – South Atlantic Fishery Management Council Environmental Assessment – National Marine Fisheries Service (NMFS) Southeast Regional Office
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Summary

Why is the Council considering action?

The South Atlantic Fishery Management Council (Council) is considering action to allow fishermen to harvest red snapper while preventing overfishing and allowing the stock to rebuild. Harvest of red snapper from federal waters has not been allowed since 2014 due to the total removals of red snapper (landings plus dead discards) exceeding the acceptable biological catch established in Amendment 28 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region (Amendment 28) (SAFMC 2013). Amendment 28 amendment established a process that would set the annual catch limit to zero (no mini-season) if total removals (landings plus dead discards) exceeded the acceptable biological catch in the previous year. Dead discards were included in the process to determine the annual catch limit because a portion of red snapper released die as a result of hooking injuries, barotrauma, and/or predation. The estimated number of red snapper that die due to injuries when released exceeded the acceptable biological catch in 2014, 2015, and 2016 and the annual catch limit was set to zero in 2015, 2016, or 2017.

The health of the stock was investigated using a benchmark stock assessment completed 2016 and revised in 2017 with data through 2014 (SEDAR 41 2017). SEDAR 41was presented in April 2016 to the Council's Scientific and Statistical Committee, an advisory body to the Council that recommends acceptable biological catch levels, and was deemed best scientific information. SEDAR 41 indicated that the stock was overfished and overfishing was occurring over the last 20 years of the assessment (1994-2014). In April 2017, the Scientific and Statistical Committee was presented a revised SEDAR 41 due to changes made in the headboat at-sea discard index (SEDAR 2017). The changes in the index did not result in changes to the stock status, but they result in changes to spawning stock biomass, minimum stock size threshold, and maximum sustainable yield. The Scientific and Statistical Committee tabled discussions of revising the acceptable biological catch due to data uncertainties.

The acceptable biological catch recommendation based on the SEDAR 41 (2017) included both landings and dead discards. The National Marine Fisheries Service has stated that the use of an ABC based primarily on recreational discard estimates is likely ineffective for monitoring red snapper removals due to uncertainty in the estimate of discards and there upcoming changes to the effort estimation for calculating recreational effort (see **Appendix J**). Until the changes to the recreational survey are complete, the Council's Scientific and Statistical Committee recommended that Marine Recreational Information Program (MRIP) discard estimates from private recreational and charter vessels should not be used for managing red snapper (SAFMC 2017).

While the acceptable biological catch estimate is revised and the estimates from the Marine Recreational Information Program for private recreational and charter vessel are calibrated, the Council is considering conservative measures beginning in 2018 to allow a mini-season. Such measures would remain in place until modified. The alternatives the Council is considering are based on red snapper landings that occurred in 2012, 2013, and 2014 with some of the alternatives adjusted based on increases in red snapper abundance observed through a scientific survey. The landings used in the analysis included commercial logbook data, headboat logbook data, South Carolina charter boat logbook data, a Georgia charter boat survey, a survey of vessels using methods in Sauls et al. (2017), and other sources (see **Appendix N** and **O**). The scientific survey of the population is done with fish traps and has been conducted with similar methods since 1991 (see **Appendix L**)[1]. In 2015, the survey (using the time series recommended in SEDAR 41 (2017)) indicated that the red snapper stock increased by 35% compared to 2014. The population increased by another 12% in 2016 and is at the highest point since 1991. This increase in the population is an encouraging sign that management has been effective in addressing overfishing and continued to rebuild the stock (see **Appendix J**). The Scientific and Statistical Committee stated at their April 2017 meeting that "Although estimates of discards may be highly uncertain, a continuing upward trend in the fishery independent index has a high probability of reflecting increases in population size." (SAFMC 2017) Additionally, since the population size appears to be larger based on the fishery independent index (**Appendix L**), the risk of overfishing is likely reduced if annual catch limits are limited to recent catch levels. Overfishing is essentially a ratio of landings compared to population size. If landings are limited to recent levels and the population has grown, then the resulting fishing mortality and risk of overfishing is decreased.

Allowing a limited amount of harvest would likely reduce the social and economic impacts of a year-round closure. Allowing some harvest will enable additional scientific information on red snapper and the fishery. Fishery regulations for red snapper changed substantially in 2010 and fishery-dependent information, data collected from fishermen, has been limited during closed years. During the open seasons, scientists can collect information on the size of fish harvested, age of fish harvested, fishery selectivity, and fishermen's behavior on private recreational vessels. A recent publication from the Southeast Fishery Science Center has stated that collecting more age information for the snapper grouper fishery has the greatest influence on the accuracy of assessments (Siegfried et al. 2016).

What action being proposed in this amendment?

Amendment 43 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region (Amendment 43) proposes the following action for red snapper:

1. Revise the Process to Determine the Annual Catch Limits (ACL) for Red Snapper.

Alternative 1 (No Action). The commercial and recreational ACLs for red snapper are zero. The process and formula established in Snapper Grouper Amendment 28 specifies current fishing year annual catch limits if the National Marine Fisheries

[1] Video data were not available through 2016 when developing this amendment.

Service determines that the previous year's estimated red snapper landings and dead discards are less than the acceptable biological catch.

Alternative 2. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify a total annual catch limit equal to 23,623 fish. Commercial annual catch limit equals 69,360 pounds (whole weight) and recreational annual catch limit equals 16,480 fish.

Alternative 3. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify a total annual catch limit equal to 44,411 fish. Commercial annual catch limit equals 130,396 pounds (whole weight) and recreational annual catch limit equals 30,982 fish.

Alternative 4. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify a total annual catch limit equal to 42,510 fish. Commercial annual catch limit equals 124,815 pounds (whole weight) and recreational annual catch limit equals 29,656 fish.

Alternative 5. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify a total annual catch limit equal to 79,919 fish. Commercial annual catch limit equals 234,652 pounds (whole weight) and recreational annual catch limit equals 55,753 fish.

Note: In Alternatives 2 through 5, the sector annual catch limits were calculated using the established allocation in the Comp ACL Amendment (2011). The allocation is 28.07% commercial and 71.93% recreational based on weight.

The current red snapper annual catch limit is set in numbers of fish in order to account for discards (SAFMC 17A 2010). The sector annual catch limits are apportioned based on allocation percentages determined by the Council established in the Comprehensive Annual Catch Limit Amendment (SAFMC 2011). The methods used to develop the commercial and recreational sector allocation are included in **Appendix K**. Annual catch limits for the recreational sector are specified in numbers of fish because it is a more reliable estimate for the sector than weight of fish. Surveys that estimate recreational landings collect information on the number of fish and convert those numbers to weights using biological samples. The commercial sector's annual catch limit is set in pounds of fish because that is how the commercial sector reports landings and thus weight is a more accurate representation of commercial landings.

Proposed ACLs in **Alternative 2** through **Alternative 5** are based on landings from 2012 to 2014, when mini-seasons were open for red snapper. **Alternative 2** is based on the average landings from 2012 to 2014. **Alternative 3** is based on the average of landings from 2012 to 2014, multiplied by an adjustment factor intended to account for the observed population growth since 2012-2014. The adjustment factor is based on the observed increase in numbers of red snapper from a long-term scientific survey (MARMAP and SEFIS). The scientific survey indicated the average population of red snapper increased by 1.88 when comparing the time period 2012 to 2014 to the time period 2015 to 2016 (**Figure S-1** and **Appendices K** and **L**).

Alternative 4 is based on the highest observed landings that occurred in a single year from 2012 to 2014. The highest landings occurred in 2014 with 42,510 red snapper being landed. **Alternative 5** is the highest landings that occurred in a single year from 2012 to 2014, multiplied by the adjustment factor (described above).

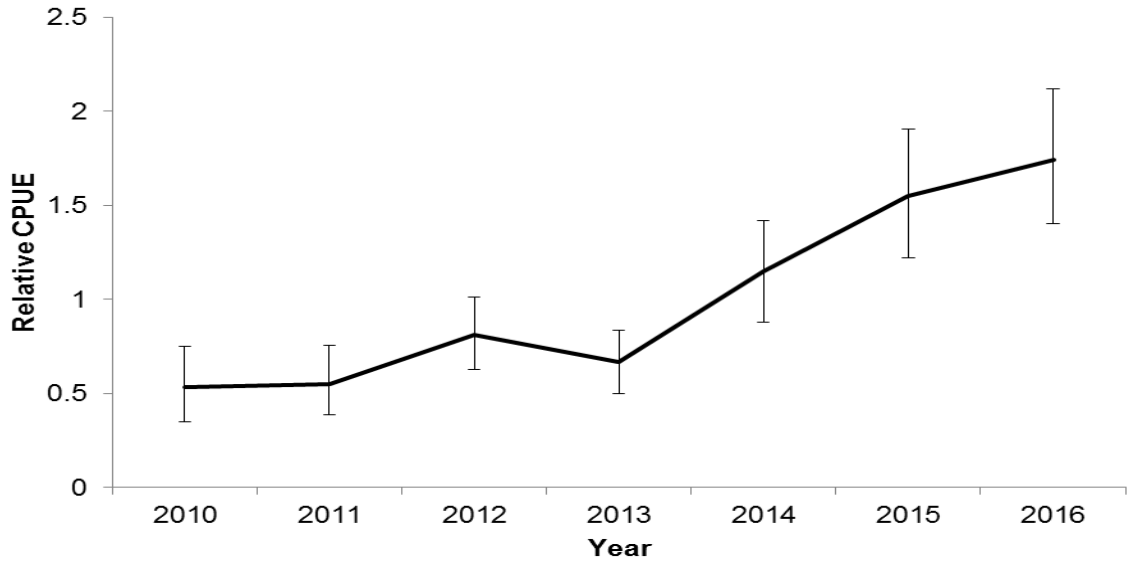

Figure S.1. Relative catch per unit effort (CPUE) with error bars from a scientific study of red snapper abundance in the South Atlantic region, 2010 to 2016.

Purpose for Action

The *purpose* of Snapper Grouper Amendment 43 is to revise annual catch limits for red snapper to provide fishing access.

Need for Action

The *need* for Snapper Grouper Amendment 43 is to prevent overfishing, continue to rebuild the stock, and, to the extent practicable, reduce adverse social and economic effects as per the Magnuson Stevens Fishery Conservation and Management Act.

Chapter 1. Introduction

1.1 What action is being proposed in this amendment?

Amendment 43 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region (Amendment 43) proposes to revise the annual catch limit (ACL) for red snapper in the South Atlantic region. The ACL has been set to zero since 2014 based on the process established in Amendment 28 (SAFMC 2013). According to that process, if the National Marine Fisheries Service (NMFS) determined that the estimated red snapper landings and dead discards that occurred in the previous year were equal to or greater than the projected acceptable biological catch (ABC) for that year, no harvest would be allowed in upcoming fishing season. If NMFS determined that the estimated landings and dead discards that occurred in the previous year were less than the ABC, harvest would be allowed if the projected commercial and recreational fishing seasons were over three days long. The ABC was exceeded in 2014, 2015, and 2016 and no red snapper landings were allowed in those years. The South Atlantic Fishery Management Council (Council) is considering revising the ACLs for red snapper to enable a season beginning in 2018.

1.2 Who is proposing the amendment?

The Council develops the amendment and submits it to the NMFS which, on behalf of the Secretary of Commerce, ultimately approves, disapproves, or partially approves the amendment. NMFS implements the actions in the amendment through the development of regulations through rulemaking. NMFS is an office of the National Oceanic and Atmospheric Administration. The Council and NMFS are also responsible for making this document available for public comment.

The South Atlantic Fishery Management Council

- Responsible for conservation and management of fish stocks in the South Atlantic Region
- Consists of 13 voting members who are appointed by the Secretary of Commerce, 1 representative from each of the 4 South Atlantic states, the Southeast Regional Administrator of NMFS, and 4 non-voting members
- Responsible for developing fishery management plans and amendments under the Magnuson-Stevens Act; recommends actions to NMFS for implementation
- Management area is from 3 to 200 nautical miles off the coasts of North Carolina, South Carolina, Georgia, and east Florida through Key West, with the exception of Mackerel which is from New York to Florida, and Dolphin-Wahoo, which is from Maine to Florida

1.3 Where is the Project Located?

Management of the federal snapper grouper fishery located off the southeastern United States (South Atlantic) in the 3-200 nautical miles U.S. Exclusive Economic Zone (EEZ) is conducted under the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region (Snapper Grouper FMP) (SAFMC 1983) (**Figure 1.3.1**). Red snapper is among the 55 species managed by the Council under the Snapper Grouper

FMP

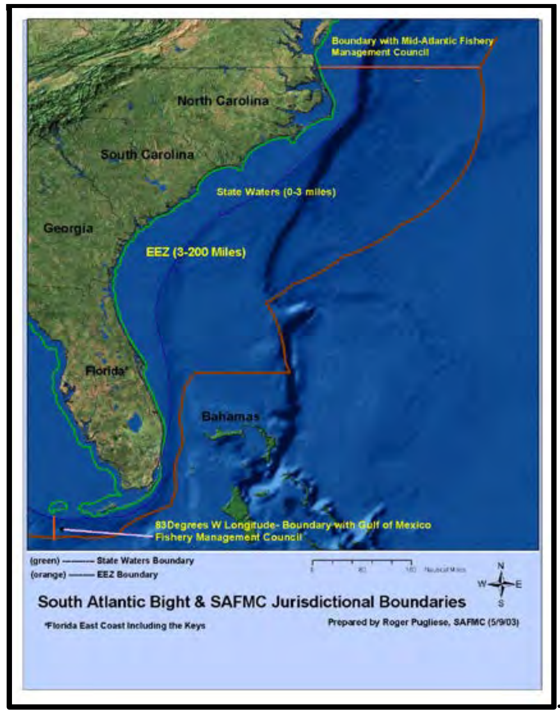

Figure 1.3.1. Jurisdictional boundaries of the Council.

1.4 Why is this action being considered (Purpose and Need)?

The Council intends to specify recreational and commercial ACLs for red snapper beginning in 2018, while the NMFS Southeast Fisheries Science Center (SEFSC) develops a method to specify a an acceptable biological catch for red snapper. The Council's goal is to minimize adverse socio-economic effects to fishermen and fishing communities that utilize red snapper as part of the snapper grouper fishery. Allowing limited harvest beginning in 2018 will promote beneficial economic and social effects to fishermen and fishing communities (see **Section 3.3**) while preventing overfishing from occurring and continuing to rebuild the stock (see **Section 1.7**).

Although there may be some concern that opening the red snapper fishery to limited harvest could cause overfishing because SEDAR 41 (2017) indicated that overfishing was occurring during 2012-2014, the available fishery independent index of abundance suggests the population has increased substantially since 2014. The Scientific and Statistical Committee (SSC) commented in April 2017 that "...a continuing upward trend in the fishery independent index has a high probability of reflecting increases in population size." Survey catch per unit effort (CPUE) values, which increased 35% in 2015 compared to 2014 and increased an additional 12% in 2016 compared to 2015, are currently highest in the entire time series (1990-2016). Additional supporting evidence of an increasing population is the increase in the number of discards reported in the recreational sector based on the MRIP survey, which in the past has corresponded to increasing population abundance and strong year classes moving through the fishery. The estimates of red snapper discards from 2015 and 2016, although uncertain and not recommended for use in management, are the two highest estimates since 1990, and even though the current preliminary estimate for 2017 only includes four months it would rank as the 6th highest since 1990. The increase in the population size is important to evaluating whether a given harvest level carries unacceptable risk of overfishing because fishing mortality levels are essentially based on the ratio of landings or removals to the population abundance.

Purpose for Action

The *purpose* of Snapper Grouper Amendment 43 is to revise annual catch limits for red snapper to allow fishing access.

Need for Action

The *need* for Snapper Grouper Amendment 43 is to prevent overfishing, continue to rebuild the red snapper stock, and, to the extent practicable, reduce adverse social and economic effects as per the Magnuson Stevens Fishery Conservation and Management Act.

1.5 What are annual catch limits and accountability measures and why are they required?

The reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) in 2007 required implementation of ACLs and accountability measures (AM) to end and/or prevent overfishing to achieve the optimum yield (OY) from a fishery. An ACL is the level of annual catch of a stock that, if met or exceeded, triggers some corrective action. The AMs are the corrective actions, and they are management controls to prevent ACLs from being exceeded and to correct overages of ACLs if they occur. For example, a common AM is implementation of an in-season closure if catch is projected to reach the ACL. Amendment 43 includes alternatives that would revise the current ACLs for red snapper.

1.6 What are the current red snapper ACLs and how are fishing seasons determined?

Amendment 28 to the Snapper Grouper FMP (SAFMC 2013) set the commercial and recreational red snapper ACLs at zero and established a process for setting fishing seasons to allow limited harvest of red snapper in the South Atlantic EEZ. The current red snapper ABC was recommended by the SSC in November 2010 (SAFMC 2010) and is based on rebuilding projections in the Southeast Data Assessment and Review (SEDAR 24 2010) red snapper stock assessment.

Limited red snapper landings were allowed in 2012, 2013, and 2014. However, combined landings and estimated dead discards in 2014, 2015, and 2016 have exceeded the total ABCs for those years and no harvest has been allowed since 2014 (**Table 1.6.1**).

Table 1.6.1. Red snapper ABCs recommended by the SSC from projections included in SEDAR 24 (2010). Landings and estimates of dead discards of red snapper from the South Atlantic region since 2012, including during mini-seasons from 2012 to 2014. Bold values indicate landings plus dead discards exceeded the ABC.

Year	Total ABC (Numbers of Fish)	Landings (Numbers of Fish)	Landings + Dead Discards* (Numbers of Fish)
2012	86,000	16,591	80,516
2013	96,000	11,767	72,881
2014	106,000	42,510	**205,859**
2015	114,000	2,850	**276,729**
2016	121,000	830	**407,025**
2017	128,000		

*Values were reported in the SEFSC annual report on red snapper landings. Reports were presented at June Council meetings from 2013-2016.

Process implemented by Snapper Grouper Amendment 28

The annual ABCs for red snapper were recommended by the SSC in numbers of fish based on projections in SEDAR 24 (2010). If NMFS determines that the estimated landings and dead discards that occurred in the previous year were equal to or greater than the projected ABC, no harvest would be allowed in upcoming fishing season. If NMFS determined that the estimated landings and dead discards that occurred in the previous year were less than the ABC, harvest *might* be allowed. (Note: The commercial and recreational fishing seasons would not open if the projected season length is three days or less.)

NMFS calculates the total ACL following the formula implemented through the amendment and the sector ACLs based on the South Atlantic Council's approved allocations. NMFS projects the length of the commercial and recreational fishing seasons.

If harvest is allowed, NMFS announces the pre-determined commercial and recreational fishing year start dates. The commercial red snapper season closes when the commercial sector ACL was met or projected to be met. The recreational red snapper season is projected and announced before the start of the season. The NMFS Regional Administrator has the authority to delay the opening of red snapper fishing seasons in the event of a tropical storm or hurricane affecting the South Atlantic Council's area of authority.

The process would be repeated each year unless modified.

1.7 Will the Action Prevent Overfishing and Continue to Rebuild the Stock?

The most recent stock assessment for South Atlantic red snapper, completed through SEDAR 41, reviewed by the Council's SSC in May 2016 (SAFMC 2016), and revised in April 2017 (SEDAR 2017) suggested overfishing was occurring from 2012 to 2014 because the terminal exploitation status (fishing mortality based on the average over the last three years represented in the model) exceeded the maximum fishing mortality threshold.

The SSC reviewed the assessment in May 2016 and accepted the assessment as providing information useful for management and adequate to support fishing level recommendations. The SSC also noted there was considerable uncertainty in the exploitation status and thus estimates of the degree of overfishing are highly uncertain. The SSC indicated that the "most significant sources of uncertainty include: the stock-recruitment relationship, natural mortality at age, the age structure of the unfished population, the composition and magnitude of recreational discards, potential changes in CPUE catchability, and the selectivities for the different fishery fleets" (SAFMC 2016). The SSC commented further in April 2017 after receiving the revised SEDAR 41 that they could not provide an ABC for red snapper based on SEDAR 41 (SAFMC 2017).

The SEFSC also reported to the Council in February 2017 that the uncertainty with the assessment is large (**Appendix J**). The SEFSC further elaborated that the fishing mortality rates in the last few years of the assessment are very sensitive to 2014 data, and retrospective analyses indicate the fishing mortality rates are considerably lower if these data are excluded. The SEFSC also noted that the overfishing determination was ascertained using fishing mortality when there were mini-seasons (2012-2014) and that there were no fishing seasons for red snapper in 2015 and 2016.

Rebuilding an overfished stock:

In 2009, the NMFS notified the Council that the red snapper stock was overfished and overfishing was occurring based on the results of SEDAR 15 benchmark stock assessment, which suggested that the stock was overfished (SEDAR 2009). In response, the South Atlantic Council approved, and NMFS implemented, a 35-year rebuilding plan in 2010. The stock was reassessed in 2010 (SEDAR 24 2010). The results of SEDAR 24 suggested that red snapper were overfished and undergoing overfishing; however, the rate of overfishing found in SEDAR 24 was less than the rate of overfishing found in the previous assessment (SEDAR 15). The results of SEDAR 24 were used as the basis for Snapper Grouper Regulatory 10 (SAFMC 2011a) and for Amendment 28 (SAFMC 2013).

In 2017, NMFS notified the Council that the red snapper stock was still overfished and overfishing was occurring but the stock was rebuilding based on the results of the SEDAR 41 benchmark stock assessment including information through 2014 (SEDAR 2017, **Appendix J**). SEDAR 41 results suggest an increase in stock biomass since 2010 and increasing abundance of older age classes (ages greater than 6). At the June 2016 Council meeting, the SSC chair stated that when taking all of the available information into account, particularly the fishery-independent data, the progress in rebuilding of red snapper was unquestionable. NMFS informed the Council in a letter (dated 03/03/2017; **Appendix J**) that sufficient steps had been taken to address overfishing of red snapper and continue to rebuild the stock through harvest prohibitions in 2015 and 2016.

Abundance of snapper grouper species, including red snapper, has been monitored by the Marine Resources Monitoring Assessment and Prediction (MARMAP) Program since 1978. MARMAP is the only existing long-term program off the Atlantic coast of the southeastern U.S. that monitors reef fish length frequency, abundance, and life history based on fishery-independent data. These data provide critical input for the assessments of stock status conducted through the SEDAR process. The NMFS SEFSC SouthEast Fishery-Independent Survey (SEFIS) was established in 2010 to complement MARMAP with identical gear types and sampling methodology, and to expand the sample size and spatial distribution of the ongoing MARMAP trap survey.

The latest results of the chevron trap index from MARMAP and SEFIS were presented at the June 2017 South Atlantic Council meeting. The presentation included updated information on the relative abundance for red snapper from 1990 to present. After the meeting, a revised analysis was conducted and the shown in (**Figure 1.7.1)**.

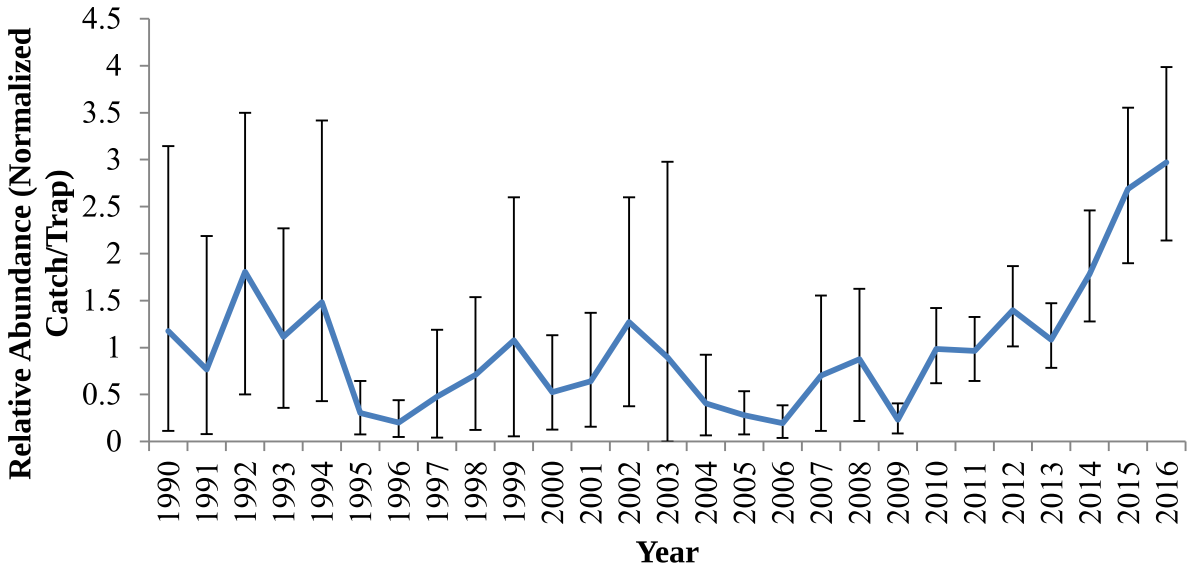

Figure 1.7.1. Relative abundance of red snapper collected in chevron traps in the South Atlantic Region calculated using methods developed in SEDAR 41 (2017). See **Appendix L** for more details.

Southeast Reef Fish Survey (SERFS)

- Includes 3 fishery independent sampling surveys.
  - MARMAP – since 1978
  - SEAMAP-SA – since 1986
  - SEFIS – since 2010
- Continuous sampling since 1972.
- Gear Used:
  - Fish traps (chevron)
  - Longlines
  - Rod and reel
  - Video
- Surveys conducted from April to October

The long-term fishery independent survey shows a very steep upward trend in relative abundance, reaching the highest levels to date in 2016 (**Figure 1.7.1**). The increase has occurred despite landings during the 2012-2014 mini-seasons and the large number of estimated dead discards since the moratorium on red snapper fishing was put in place in 2010. The SSC stated at their April 2017 meeting that "Although estimates of discards may be highly uncertain, a continuing upward trend in the fishery independent index has a high probability of reflecting increases in population size." (SAFMC 2017). This is important because the determination of overfishing is based on the level of removals and the population size. If the population increases, as the survey has indicated, then the fishing mortality estimate associated with a level of removals is decreased. Overfishing is defined in the Magnuson-Stevens Act as "a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce the maximum sustainable yield on a continuing basis" (16 U.S. C. 1802(10)). The removal levels in 2014 (highest since 2010) did not appear to jeopardize the stock because the population increased substantially despite 2014 landings. Thus, based on the SSC reports and fishery independent abundance index trends, allowing limited harvest of red snapper is expected not to result in overfishing nor prevent continued stock rebuilding.

ABC and Future Work:

Amendment 28 (SAFMC 2013) included an ABC for red snapper, which was recommended by the SSC based on projections from SEDAR 24 (2010). The SSC reviewed the SEDAR 41 assessment of red snapper in May 2016, concluding that the assessment provided adequate information for management and supporting fishing level recommendations. However, the SSC noted that "…many of the assessment limitations and uncertainties were caused by data issues and limitations." These are detailed more fully in their report (SAFMC 2016). The Council began work on Amendment 43 to address red snapper management and the ABC recommendations provided by the SSC.

However, in response to the South Atlantic Council's January 18, 2017, request for additional red snapper projections under a discards-only scenario, the SEFSC (02/15/2017; Appendix J) stated that providing an ABC based on discard-only projections was not possible due to the length of time since the terminal year of data for the stock assessment (SEDAR 2017), uncertainty in the recreational landings and discards associated with MRIP, and future changes likely in 2018 to MRIP due to methodology revisions. The South Atlantic Council discussed this response at their March 2017 meeting and requested that the SSC and SEFSC work together to recommend an appropriate ABC for red snapper.

In April 2017 the SSC considered a request from the Council to consider approaches for deriving ABC recommendations for red snapper in light of the recent the guidance from the agency regarding red snapper projections and uncertainties as detailed above (SAFMC 2017). The following statements were provided by the SSC:

- *Clarification was provided by NMFS to the SSC that the assessment is still considered BSIA (Best Scientific Information Available). However, the data available to monitor the landings and discards are too uncertain to track any projected ABC. Therefore, an index-based approach is being proposed to track and monitor the condition of Red Snapper.*
- *The current projected yield streams are still considered BSIA, but are not useful for management and monitoring because of the uncertainty in the catch data (as most of the catch is discarded).*
- *The SSC acknowledged that at this point it is unable to provide an ABC recommendation for Red Snapper.*
- *Although estimates of discards may be highly uncertain, a continuing upward trend in the fishery independent index has a high probability of reflecting increases in population size.*

Based on these recommendations from the SSC, the ABC for red snapper is currently unknown, a continuing upward trend in the fishery-independent index has a high probability of reflecting increases in population size, and a departure from traditional techniques and further investigation of an index based approach to provide fishing level recommendations is advised.

The Council has moved additional actions related to red snapper management contained in previous drafts of Amendment 43 to a separate amendment (Amendment 46). Amendment 46 will revisit red snapper management reference points, recreational reporting, and best fishing practices. Additionally, the SEFSC is exploring alternative methods to develop future ABCs for red snapper.

1.8 What is the history of management for red snapper?

The snapper grouper fishery is highly regulated; red snapper has been regulated since the development of the snapper grouper fishery management plan in 1983. A detailed history of management for all species in the snapper grouper fishery management unit may be found in **Appendix C**. Below is an annotated list of fishery management plan/amendments that contained actions specifically related to red snapper.

Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region (1983)

The original Fishery Management Plan (FMP) included provisions to prevent growth overfishing in thirteen species in the snapper grouper complex and established a procedure for preventing overfishing in other species; established minimum size limits for red snapper, yellowtail snapper, red grouper, Nassau grouper, and black sea bass; established a 4-inch trawl mesh size to achieve a 12-inch total length minimum size limit for vermilion snapper; and included additional harvest and gear limitations.

Amendment 4 (1991)

Amendment 4 prohibited the use of various gear, including fish traps, the use of bottom longlines for wreckfish, and powerheads in special management zones off South Carolina; established bag limits and minimum size limits for several species (20 inch total length minimum size limit and two fish bag limit for red snapper); required permits (commercial and for-hire) and specified data collection regulations; and required that all snapper grouper species possessed in the South Atlantic EEZ must have heads and fins intact through landing.

Amendment 11 (1998)

Amendment 11 amended the FMP to make definitions of maximum sustainable yield (MSY), optimum yield (OY), overfishing, and overfished consistent with National Standard Guidelines. Amendment 11 also identified and defined fishing communities, addressed bycatch management measures, and defined the red snapper F_{MSY} proxy as $F_{30\%SPR}$.

Interim Rule for Red Snapper (2009)

In 2008 the Council received notification (letter dated July 8) that the South Atlantic red snapper stock was undergoing overfishing and was overfished. In March 2009 the Council requested that the NMFS establish interim measures to reduce overfishing and fishing pressure on the red snapper stock. Interim measures became effective on January 4, 2010. The interim rule was effective until June 2, 2010, but was extended for an additional 186 days since the Council was developing long-term management measures in Snapper Grouper Amendment 17A to end overfishing of red snapper and rebuild the stock.

Amendment 17A (2010)

Actions in Amendment 17A (SAFMC 2010) included a harvest prohibition for red snapper and an area closure for all snapper grouper species. The area closure was 4,827 square miles and extended from southern Georgia to northern Florida where harvest and possession of all snapper grouper species would be prohibited (except when fishing with black sea bass pots or spearfishing gear for species other than red snapper). The red snapper prohibition was effective on January 3, 2011; however, NMFS delayed the effective date of the area closure until June 1, 2011, via an emergency rule, to allow time to review the results of a new red snapper stock assessment (SEDAR 24 2010).

The results of SEDAR 24 showed red snapper to be overfished and undergoing overfishing; however, the rate of overfishing found in SEDAR 24 was less than the rate of overfishing found in the previous stock assessment (SEDAR 15 2008). Based on the results from SEDAR 24, evidence of decreased effort in the recreational sector, and recommendations from their Scientific and Statistical Committee (SSC), the Council determined that the snapper grouper area closure approved in Amendment 17A, in addition to the harvest prohibition, was more conservative than what was necessary to end overfishing of red snapper.

Amendment 17A also required the use of non-stainless steel circle hooks when fishing for snapper grouper species with hook-and-line gear and natural baits in the South Atlantic EEZ north of 28 degrees North latitude and specified a fishery-independent monitoring program for red snapper.

Comprehensive Annual Catch Limits (ACL) Amendment (Snapper Grouper Amendment 25) (2011b)

Established sector allocations for many snapper grouper species, including red snapper, using an allocation formula based on historic and recent average landings. The commercial allocation for red snapper was set at 28.07% and the recreational allocation was set at 71.93%.

Regulatory Amendment 10 (2011a)

In December 2010, the Council

Definitions

Annual Catch Limits (ACL)
The level of annual catch (pounds or numbers) that triggers accountability measures to ensure that overfishing is not occurring.

Annual Catch Targets (ACT)
The level of annual catch (pounds or numbers) that is the management target of the fishery, and accounts for management uncertainty in controlling the actual catch at or below the ACL.

Accountability Measures (AM)
Management controls to prevent ACLs, including sector ACLs, from being exceeded, and to correct or mitigate overages of the ACL if they occur.

Allocations
A division of the overall ACL among sectors (e.g., recreational and commercial) to create sector ACLs.

Maximum Sustainable Yield (MSY)
Largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions.

Optimum Yield (OY)
The amount of catch that will provide the greatest overall benefit to the nation, particularly with respect to food production and recreational opportunities and taking into account the protection of marine ecosystems.

Minimum Stock Size Threshold (MSST)
A status determination criterion. If current stock size is below MSST, the stock is overfished.

approved Regulatory Amendment 10 for review by the Secretary of Commerce by a unanimous vote. The action in Regulatory Amendment 10 eliminated the snapper grouper area closure approved in Amendment 17A. Regulatory Amendment 10 was implemented and became effective on May 31, 2011.

Emergency Rule (2012)

The rule established red snapper seasons for the commercial and recreational sectors in the South Atlantic EEZ in 2012.

Amendment 28 (2013)

The amendment set the commercial and recreational ACLs and seasons to allow limited harvest of red snapper in 2013. In addition, the amendment established a process to determine whether limited commercial and recreational fishing seasons in the South Atlantic EEZ could occur during a given fishing year, and specified management measures should limited harvest be allowed.

Regulatory Amendment 21 (2014a)

The amendment changed the Minimum Stock Size Threshold (MSST) definition for eight snapper grouper species including red snapper from MSST = [(1-M) or 0.5 whichever is greater]* B_{MSY} to 0.75* B_{MSY}.

Chapter 2. Proposed Actions and Alternatives

2.1 Action 1. Revise the Process to Determine the Annual Catch Limits (ACL) for Red Snapper

Alternative 1 (No Action). The commercial and recreational ACLs for red snapper are zero. The process and formula established in Snapper Grouper Amendment 28 specifies current fishing year annual catch limits if the National Marine Fisheries Service determines that the previous year's estimated red snapper landings and dead discards are less than the acceptable biological catch.

Alternative 2. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify a total annual catch limit equal to 23,623 fish. Commercial annual catch limit equals 69,360 pounds (whole weight) and recreational annual catch limit equals 16,480 fish.

Alternative 3. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify a total annual catch limit equal to 44,411 fish. Commercial annual catch limit equals 130,396 pounds (whole weight) and recreational annual catch limit equals 30,982 fish.

Alternative 4. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify a total annual catch limit equal to 42,510 fish. Commercial annual catch limit equals 124,815 pounds (whole weight) and recreational annual catch limit equals 29,656 fish.

Alternative 5. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify a total annual catch limit equal to 79,919 fish. Commercial annual catch limit equals 234,652 pounds (whole weight) and recreational annual catch limit equals 55,753 fish.

Note: In Alternatives 2 through 5, the sector annual catch limits were calculated using the Council's established allocation from the Comprehensive ACL Amendment (2011). The allocation is 28.07% commercial and 71.93% recreational.

2.1.1 Comparison of Alternatives

The overall red snapper annual catch limit (ACL) in **Alternative 1 (No Action)** is set in numbers of fish in order to account for discards. The sector annual catch limits are apportioned to each sector based on allocation percentages determined by the Council (see **Appendix K** for calculation of annual catch limits). ACL for the recreational sector are specified in numbers of fish because it is a more reliable estimate for that sector than specifying the ACL in weight of fish. Surveys that estimate recreational landings collect information on numbers of fish and convert those numbers to weights using biological samples. The commercial sector's ACL is set in pounds of fish because that is how the commercial sector reports landings and thus weight is a more accurate representation of commercial landings.

Alternative 2 through **Alternative 5** are based on landings from 2012 to 2014, when mini-seasons were open for red snapper. **Alternative 2** is the average of landings from 2012 to 2014. **Alternative 3** is the average of landings from 2012 to 2014, multiplied by an adjustment factor intended to account for the observed population growth since 2012-2014. The adjustment factor is based on the observed increase in numbers of red snapper from a long-term scientific survey (MARMAP and SEFIS combined). The scientific survey indicated the average population of red snapper increased by 1.88 when comparing the time period 2012 to 2014 to the time period 2015 to 2016 (**Figure 2.1.1**, see **Appendices K** and **L**).

Alternative 4 is based on the highest observed landings that occurred in a single year from 2012 to 2014. The highest landings occurred in 2014 with 42,510 red snapper being landed. **Alternative 5** is the highest landings that occurred in a single year from 2012 to 2014, multiplied by the adjustment factor (described above). Proposed ACLs under each alternative are shown in **Table 2.1.2**.

Process proposed in Amendment 43

NMFS would announce the pre-determined commercial and recreational fishing season start dates. The commercial red snapper season would close when the commercial ACL is met or projected to be met. The recreational red snapper season would be projected and announced before the start of the recreational season based on catch rates from previous years. The NMFS Regional Administrator would have the authority to delay the opening of red snapper fishing seasons in the event of a tropical storm or hurricane affecting the Council's area of authority.

The commercial fishing season would begin at 12:01 am on the second Monday in July. The recreational fishing season (weekends) would begin 12:01 am on the first Friday in July.

There would be no minimum size limit for either the commercial or recreational sector.

The commercial trip limit would be 75 pounds gutted weight (lbs gw).

The recreational bag limit would be 1 fish per person per day.

Table 2.1.1. Red snapper ABCs recommended by the SSC from projections included in SEDAR 24 (2010). Landings and estimates of dead discards of red snapper from the South Atlantic region since 2012, including during mini-seasons from 2012 to 2014.

Year	Landings ABC (Numbers of Fish)	Dead Discards ABC (Number of Fish)	Total ABC (Numbers of Fish)	ACL for Landings only (Numbers of Fish)	Landings (Numbers of Fish)	Landings + Dead Discards* (Numbers of Fish)
2012	45,000	41,000	86,000	13,067	16,591	80,516
2013	52,000	44,000	96,000	13,325	11,767	72,881
2014	59,000	47,000	106,000	31,387	42,510	205,859
2015	64,000	50,000	114,000	0	2,850	276,729
2016	69,000	52,000	121,000	0	830	407,025
2017	74,000	54,000	128,000	0**		
				Average 2012 to 2014	23,623	
				Max observed 2012 to 2014	42,510	

*Values were reported in the SEFSC annual report on red snapper landings. Reports were presented at June Council meetings from 2013-2016.
**NMFS announced the ACL for red snapper was zero for 2017 at the June 2017 Council meeting.

Table 2.1.2. Proposed total, commercial, and recreational red snapper ACLs for 2018 calculated in numbers of fish and whole weight.

Alternative	ACL Number	ACL Weight (ww)	Commercial ACL Weight (ww)	Commercial ACL Number	Recreational ACL Weight (ww)	Recreational ACL Number
Alt 1	TBD					
Alt 2	23,623	247,097	75,537	7,143	177,737	16,480
Alt 3	44,411	464,539	130,396	13,429	334,143	30,982
Alt 4	42,510	444,655	124,815	12,854	319,840	29,656
Alt 5	79,919	835,953	234,652	24,166	601,301	55,753

The conversion factor used to derive number of fish from weight is 9.71 pounds and is based on the average weight of commercially caught red snapper from 2012 to 2014 (SEDAR 41 2017). The recreational ACL, expressed in weight and number of fish, is the difference between total ACL weight/number and commercial weight/number.

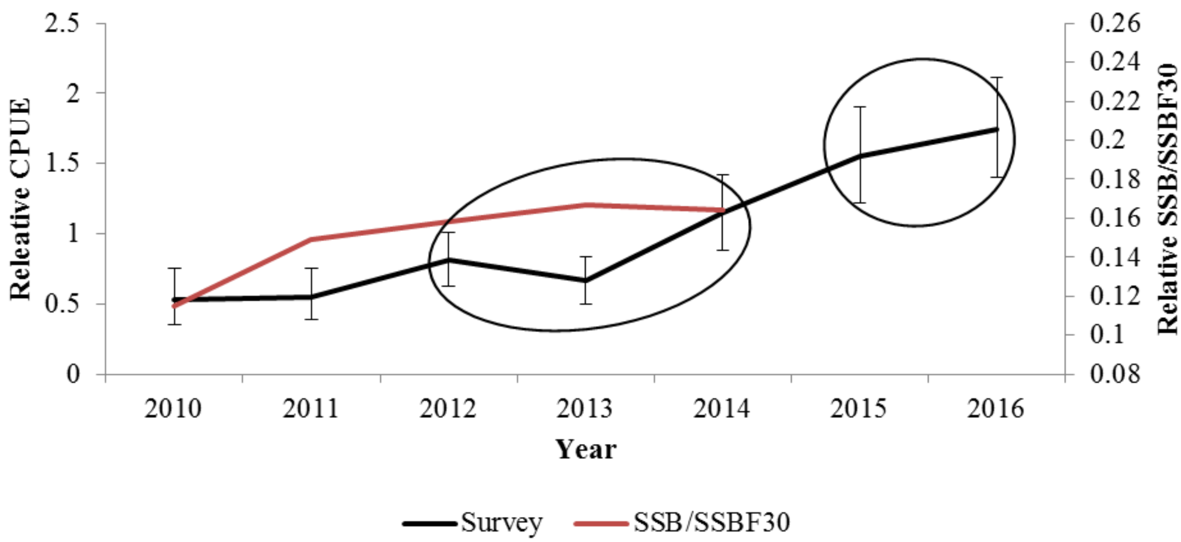

Figure 2.1.1. Relative catch per unit effort (CPUE) from the MARMAP and SEFIS chevron trap survey standardized with the ratio of annual spawning stock biomass compared to spawning stock biomass at F30% from SEDAR 41 (2017). Circles represent the two time periods that were compared to develop the adjustment factor. See **Appendix L** for more information on the index.

Alternative 1 (No Action), would result in no commercial or recreational harvest of red snapper allowed in 2018 due to exceeding the ABC in 2017. While allowing no harvest might be biologically beneficial to a stock, it is expected that the resulting level of dead discards would continue to increase. The long-term biological effects of continued high bycatch and resulting mortality on the red snapper stock are unknown because the red snapper stock has continued to increase after high levels of bycatch based on survey data. **Alternative 1 (No Action)** has the least economic and social benefits and a continued administrative burden to calculate the ACL each year. **Alternatives 3** and **5** propose ACLs above recent catch levels since they are adjusted to account for perceived recent population growth by a factor of 1.88. Therefore, these alternatives might result in negative biological effects over the status quo since it is not known how the stock might be impacted and whether such levels of harvest could result in overfishing. **Alternative 5** has the largest economic benefit and most social benefits followed by **Alternative 3**. **Alternatives 2** and **4** would be less likely to result in negative biological effects than **Alternatives 3** and **5** since **Alternatives 2** and **4** propose ACLs based on 2012-2014 catch levels and data suggest red snapper abundance increased from 2014 levels by 35% in 2015 and an additional 12% in 2016. **Alternative 4** has greater economic and social benefits than **Alternative 2** but less than **Alternatives 3** and **5**.

Table 2.1.3. A summary and comparison of the effects of the alternatives.

Alternatives		Effects			
		Biological	**Economic**	**Social**	**Administrative**
1	No Action ACL would be 0 in 2018	+ lowest risk of overfishing -Bycatch of red snapper continued	Commercial Ex-Vessel Revenue: $0 Recreational Consumer surplus=$0	-No allowable harvest	No change. -Continued process to calculate ACL each year.
2	Revise and set ACL =23,623 fish	-2nd lowest risk of overfishing + Some red snapper bycatch would be converted to landings.	Commercial Ex-Vessel Revenue: $318,362 Recreational Consumer surplus=$1,334,880	+ Allows red snapper harvest	-Rule-making, data monitoring, outreach, and enforcement
3	Revise and set ACL =44,411 fish	-2nd Highest risk of overfishing + Some red snapper bycatch would be converted to landings.	Commercial Ex-Vessel Revenue: $545,981 to $598,518 Recreational Consumer surplus=$2,509,542	+ Allows red snapper harvest	-Rule-making, data monitoring, outreach, and enforcement
4	Revise and set ACL =42,510 fish	-3rd lowest risk of overfishing + Some red snapper bycatch would be converted to landings.	Commercial Ex-Vessel Revenue: $545,981 to $572,901 Recreational Consumer surplus=$2,402,136	+ Allows red snapper harvest	-Rule-making, data monitoring, outreach, and enforcement
5	Revise and set ACL =79,919 fish	-Highest risk of overfishing + Some red snapper bycatch would be converted to landings.	Commercial Ex-Vessel Revenue: $545,981 to $731,614 Recreational Consumer surplus=$4,515,993	+Allows red snapper harvest	-Rule-making, data monitoring, outreach, and enforcement

Chapter 3. Affected Environment

This section describes the affected environment in the proposed project area. The affected environment is divided into four major components:

- **Habitat environment** (Section 3.1)
- **Biological and Ecological environment** (Section 3.2)
- **Economic and Social environment** (Sections 3.3)
- **Administrative environment** (Section 3.4)

3.1 Habitat Environment

3.1.1 Inshore/Estuarine Habitat

Many snapper grouper species utilize both pelagic and benthic habitats during several stages of their life histories; larval stages of these species live in the water column and feed on plankton. Most juveniles and adults are demersal (bottom dwellers) and associate with hard structures on the continental shelf that have moderate to high relief (e.g., coral reef systems and artificial reef structures, rocky hard-bottom substrates, ledges and caves, sloping soft-bottom areas, and limestone outcroppings). Juvenile stages of some snapper grouper species also utilize inshore seagrass beds, mangrove estuaries, lagoons, oyster reefs, and embayment systems. In many species, various combinations of these habitats may be utilized during daytime feeding migrations or seasonal shifts in cross-shelf distributions. Additional information on the habitat utilized by species in the Snapper Grouper Complex is included in Volume II of the Fishery Ecosystem Plan[2] (FEP; SAFMC 2009) and incorporated here by reference. The life history of red snapper is summarized in **Section 3.2.1**.

3.1.2 Offshore Habitat

Predominant snapper grouper offshore fishing areas are located in live bottom and shelf-edge habitats where water temperatures range from 11º to 27º C (52º to 81º F) due to the proximity of the Gulf Stream, with lower shelf habitat temperatures varying from 11º to 14º C (52º to 57º F). Water depths range from 16 to 55 meters (54 to 180 ft) or greater for live-bottom habitats, 55 to

[2] http://safmc.net/ecosystem-management/fishery-ecosystem-plan/

110 meters (180 to 360 ft) for the shelf-edge habitat, and from 110 to 183 meters (360 to 600 ft) for lower-shelf habitat areas.

The exact extent and distribution of productive snapper grouper habitat in South Atlantic continental shelf habitats is unknown. Current data suggest from 3% to 30% of the shelf is suitable habitat for these species. These live-bottom habitats may include low relief areas, supporting sparse to moderate growth of sessile (permanently attached) invertebrates, moderate relief reefs from 0.5 to 2 meters (1.6 to 6.6 ft), or high relief ridges at or near the shelf break consisting of outcrops of rock that are heavily encrusted with sessile invertebrates such as sponges and sea fan species. Live-bottom habitat is scattered irregularly over most of the shelf north of Cape Canaveral but is most abundant offshore from northeastern Florida. South of Cape Canaveral the continental shelf narrows from 56 to 16 kilometers (35 to 10 mi) wide off the southeast coast of Florida and the Florida Keys. The lack of a large shelf area, presence of extensive, rugged living fossil coral reefs, and dominance of a tropical Caribbean fauna are distinctive benthic characteristics of this area.

Rock outcroppings occur throughout the continental shelf from Cape Hatteras, North Carolina to Key West, Florida (MacIntyre and Milliman 1970; Miller and Richards 1979; Parker et al. 1983), which are principally composed of limestone and carbonate sandstone (Newton et al. 1971), and exhibit vertical relief ranging from less than 0.5 to over 10 meters (33 ft). Ledge systems formed by rock outcrops and piles of irregularly sized boulders are also common. Parker et al. (1983) estimated that 24% (9,443 km^2) of the area between the 27 and 101 meter (89 and 331 ft) depth contours from Cape Hatteras, North Carolina to Cape Canaveral, Florida is reef habitat. Although the bottom communities found in water depths between 100 and 300 meters (328 and 984 ft) from Cape Hatteras, North Carolina to Key West, Florida is relatively small compared to the whole shelf, this area, based upon landing information of fishers, constitutes prime reef fish habitat and probably significantly contributes to the total amount of reef habitat in this region.

Artificial reef structures are also utilized to attract fish and increase fish harvests; however, research on artificial reefs is limited and opinions differ as to whether or not these structures promote an increase of ecological biomass or merely concentrate fishes by attracting them from nearby, natural un-vegetated areas of little or no relief. There are several notable shipwrecks along the southeast coast in state and federal waters including *Lofthus* (eastern Florida), *SS Copenhagen* (southeast Florida), *Half Moon* (southeast Florida), *Hebe* (Myrtle Beach, South Carolina), *Georgiana* (Charleston, South Carolina), *U.S.S. Monitor* (Cape Hatteras, North Carolina), *Huron* (Nags Head, North Carolina), and *Metropolis* (Corolla, North Carolina).

The distribution of coral and live hard bottom habitat as presented in the Southeast Marine Assessment and Prediction Program (SEAMAP) bottom mapping project is a proxy for the distribution of the species within the snapper grouper complex. Maps are available on the South Atlantic Council's Habitat and Ecosystem Atlas[3].

[3] http://ocean.floridamarine.org/safmc_atlas/

Plots of the spatial distribution of offshore species were generated from the Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP) data. The plots serve as point confirmation of the presence of each species within the scope of the sampling program. These plots, in combination with the hard bottom habitat distributions previously mentioned, can be employed as proxies for offshore snapper grouper complex distributions in the South Atlantic region. Maps of the distribution of snapper grouper species by gear type based on MARMAP data can also be generated through the Council's Internet Mapping System at the above address.

Additional information on the habitat utilized by snapper grouper species is included in Volume II of the Fishery Ecosystem Plan (FEP; SAFMC 2009).

3.1.3 Essential Fish Habitat

Essential Fish Habitat (EFH) is defined in the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act as "those waters and substrates necessary to fish for spawning, breeding, feeding, or growth to maturity" (16 U.S. C. 1802(10)). Specific categories of EFH identified in the South Atlantic Bight, which are utilized by federally managed fish and invertebrate species, include both estuarine/inshore and marine/offshore areas. Specifically, estuarine/inshore EFH includes: estuarine emergent and mangrove wetlands, submerged aquatic vegetation, oyster reefs and shell banks, intertidal flats, palustrine emergent and forested systems, aquatic beds, and estuarine water column. Additionally, marine/offshore EFH includes: live/hard bottom habitats, coral and coral reefs, artificial and manmade reefs, *Sargassum* species, and marine water column.

EFH utilized by snapper grouper species in this region includes coral reefs, live/hard bottom, submerged aquatic vegetation, artificial reefs, and medium to high profile outcroppings on and around the shelf break zone from shore to at least 183 meters [600 ft (but to at least 2,000 ft for wreckfish)] where the annual water temperature range is sufficiently warm to maintain adult populations of members of this largely tropical fish complex. EFH includes the spawning area in the water column above the adult habitat and the additional pelagic environment, including *Sargassum*, required for survival of larvae and growth up to and including settlement. In addition, the Gulf Stream is also EFH because it provides a mechanism to disperse snapper grouper larvae.

For specific life stages of estuarine-dependent and near shore snapper grouper species, EFH includes areas inshore of the 30 meter (100-ft) contour, such as attached macroalgae; submerged rooted vascular plants (seagrasses); estuarine emergent vegetated wetlands (saltmarshes, brackish marsh); tidal creeks; estuarine scrub/shrub (mangrove fringe); oyster reefs and shell banks; unconsolidated bottom (soft sediments); artificial reefs; and coral reefs and live/hard bottom habitats.

3.1.4 Habitat Areas of Particular Concern

Areas which meet the criteria for Essential Fish Habitat-Habitat Areas of Particular Concern (EFH-HAPC) for species in the snapper grouper management unit include medium to high profile offshore hard bottoms where spawning normally occurs; localities of known or likely periodic spawning aggregations; near shore hard bottom areas; The Point, The Ten Fathom Ledge, and Big Rock (North Carolina); The Charleston Bump (South Carolina); mangrove habitat; seagrass habitat; oyster/shell habitat; all coastal inlets; all state-designated nursery habitats of particular importance to snapper grouper (e.g., Primary and Secondary Nursery Areas designated in North Carolina); pelagic and benthic *Sargassum*; Hoyt Hills for wreckfish; the Oculina Bank Habitat Area of Particular Concern; all hermatypic coral habitats and reefs; manganese outcroppings on the Blake Plateau; Council-designated Artificial Reef Special Management Zones (SMZs); and deep-water Marine Protected Areas (MPAs). Areas that meet the criteria for EFH-HAPC include habitats required during each life stage (including egg, larval, postlarval, juvenile, and adult stages).

In addition to protecting habitat from fishing related degradation though fishery management plan regulations, the Council, in cooperation with NMFS, actively comments on non-fishing projects or policies that may impact EFH. With guidance from the Habitat Advisory Panel, the Council has developed and approved policies on: energy exploration, development, transportation and hydropower re-licensing; beach dredging and filling and large-scale coastal engineering; protection and enhancement of submerged aquatic vegetation; alterations to riverine, estuarine and near shore flows; offshore aquaculture; and marine and estuarine invasive species.

The potential impacts the action in this amendment may have on EFH and EFH-HAPC, are discussed in **Chapter 4** of this document.

3.2 Biological and Ecological Environment

3.2.1 Fish Populations Affected by this Amendment

The reef environment in the South Atlantic management area affected by actions in this environmental assessment is defined by two components (**Figure 3.2.1**). Each component will be described in detail in the following sections.

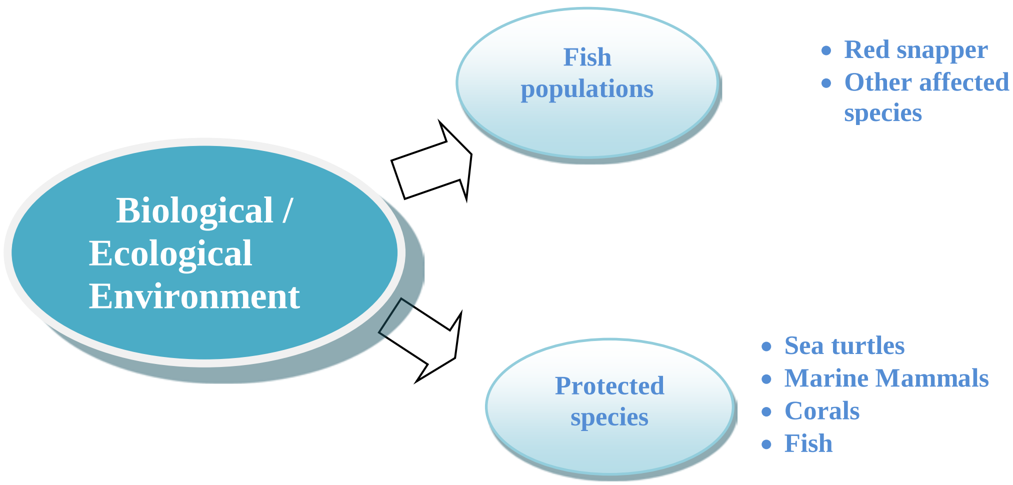

Figure 3.2.1. Two components of the biological environment described in this document.

The waters off the South Atlantic coast are home to a diverse population of fish. The snapper grouper fishery management unit contains 55 species of fish, many of them neither "snappers" nor "groupers." These species live in depths from a few feet (typically as juveniles) to hundreds of feet. As far as north/south distribution, the more temperate species tend to live in the upper reaches of the South Atlantic management area (e.g., black sea bass, red porgy) while the tropical species' core residence are in the waters off south Florida, Caribbean Islands, and northern South America (e.g., black grouper, mutton snapper). These are reef-dwelling species that live amongst each other. These species rely on the reef environment for protection and food. There are several reef tracts that follow the southeastern coast. The fact that these fish populations congregate dictates the nature of the fishery (multi-species) and further forms the type of management regulations proposed in this document.

Red Snapper

The red snapper is found from North Carolina to the Florida Keys and throughout the Gulf of Mexico to the Yucatan Peninsula (Robins and Ray 1986). It can be found at depths from 10 to 190 m (33-623 ft). Adults usually occur over rocky bottoms. Juveniles inhabit shallow waters and are common over sandy or muddy bottom habitat (Allen 1985).

Juvenile red snapper are rarely encountered in the U.S. South Atlantic. SEAMAPs fishery-independent trawling survey collected three in 1999, two in 2000, seven in 2013, and four in 2014 in nearshore (<30 ft deep) habitat. A headboat fisherman landed one age-0 red snapper during the 2012 mini-season. One age-0 fish was landed in the commercial fishery in 1980. Fishermen have reported observing juvenile red snapper on artificial reefs in shallow water. Estimates of juvenile red snapper mortality have been developed in the Gulf of Mexico; however, little information is available for the U.S. South Atlantic (SEDAR 41 2017).

The maximum size reported for this species is 100 cm (40 in) total length (TL) (Allen 1985; Robins and Ray 1986) and 22.8 kg (50 lbs) (Allen 1985). For samples collected from North Carolina to eastern Florida, maximum reported age is 45 years (White and Palmer 2004). The most recent maximum observed age for red snapper is 51 years. This fish was a 904 mm (36 in) TL female, and was caught in 2003 at 67 meters depth off Florida by a charter boat fisherman (SEDAR 41 2017).

Red snapper Life History
An Overview

- Extend from North Carolina to the Florida Keys, and throughout the Gulf of Mexico to the Yucatan Peninsula
- Waters ranging from 33-623 feet
- Red snapper do not migrate but can move long distances
- The spawning season extends from May to October, peaking in July through September.
- Can live for at least 51 years

In the U.S. South Atlantic, recent analyses (SEDAR 41 2017) estimate that 50% of female red snapper are mature at 1.3 years old and 325 mm (12.8 in) TL. Fifty percent of male red snapper are mature at 166 mm (6.5 in) TL (SEDAR 41 2017). Grimes (1987) found that the spawning season of this species varies with location, but in most cases occurs nearly year round. Farmer et al. (2017 and references therein) report spawning activity in the South Atlantic occurring from May through October peaking in June through September. According to SEDAR 41 (2017) spawning along the Atlantic coast of the southeastern U.S. generally occurs from April through October and peaks during June through August based on the presence of females with spawning indicators (i.e., the occurrence of hydrated oocytes and/or postovulatory follicles).

Red snapper eat fishes, shrimps, crabs, worms, cephalopods, and some planktonic items (Szedlemayer and Lee 2004).

3.2.2 Bycatch

The snapper grouper fishery is a multi-species fishery, which uses mostly hook and line gear although some trips use other gears such as pots/traps and spears. While the red snapper component of the snapper grouper fishery has been closed, red snapper have been bycatch in the fishery. Bycatch of red snapper is commonly associated with catches of black sea bass, red grouper, gag, scamp, greater amberjack, vermilion snapper, and gray triggerfish. The action in this amendment is not expected to result in significant changes in bycatch of red snapper and may reduce bycatch of red snapper during limited open seasons (**Appendix D**). In addition, the

Council, the NMFS, and the SEFSC have implemented and plan to implement numerous management measures and reporting requirements that have improved, or are likely to improve monitoring efforts of discards and discard mortality in the snapper grouper fishery. Therefore, no additional action is needed to minimize bycatch or bycatch mortality within the snapper grouper fishery. See **Appendix D** for detailed descriptions of bycatch when fishing for red snapper.

3.2.3 Other Species Affected

For details on the life histories and ecology of co-occurring species, the reader is referred to Volume II of the Fishery Ecosystem Plan (SAFMC 2009)[4].

3.2.4 The Stock Assessment Process

The Southeast Data, Assessment, and Review (SEDAR) process is a cooperative Fishery Management Council initiative to improve the quality and reliability of fishery stock assessments in the South Atlantic, Gulf of Mexico, and U.S. Caribbean. The Caribbean, Gulf of Mexico, and South Atlantic Fishery Management Councils manage SEDAR in coordination with the NMFS and the Atlantic and Gulf States Marine Fisheries Commissions. SEDAR seeks improvements in the scientific quality of stock assessments, constituent and stakeholder participation in assessment development, transparency in the assessment process, and a rigorous and independent scientific review of completed stock assessments.

SEDAR is organized around three workshops. First is the Data Workshop, during which fisheries monitoring and life history data are reviewed and compiled. Second is the Assessment Workshop, which may be conducted via a workshop and several webinars, during which assessment models are developed and population parameters are estimated using the information provided from the Data Workshop. Third and final is the Review Workshop, during which independent experts review the input data, assessment methods, and assessment products. The completed assessment, including the reports of all three workshops and all supporting documentation, are then forwarded to the Council's Scientific and Statistical Committee (SSC). The SSC considers whether the assessment represents the best available science and develops fishing level recommendations for Council consideration.

SEDAR workshops are public meetings organized by SEDAR. Workshop participants appointed by the lead Council are drawn from state and federal agencies, non-government organizations, Council members, Council advisors, and the fishing industry with a goal of including a broad range of disciplines and perspectives. All participants are expected to contribute to this scientific process by preparing working papers, contributing data, providing

[4] http://safmc.net/ecosystem-management/fishery-ecosystem-plan/

assessment analyses, evaluating and discussing information presented, and completing the workshop report.

3.2.5 Red snapper Stock Status

Manooch et al. (1998) conducted the first formal assessment of red snapper in the South Atlantic. The authors concluded that the status of the stock was not ideal but seemed to be responding to management action. Potts and Brennan (2001) revisited the results of that assessment and suggested a broader range of reduction in fishing mortality (F), from 30% to 80%.

The red snapper stock in the South Atlantic was assessed through the SEDAR process in 2007-2008. That assessment applied a statistical catch-age model using data through 2006 (SEDAR 15 2008). The assessment found that overfishing had been occurring since the 1960s and the red snapper stock was overfished. Although quantitative results varied, the qualitative results of overfishing a depleted stock were consistent across all catch-age model configurations examined during and after the assessment process (approximately 40 sensitivity runs), as well as with an alternative model formulation (surplus-production model).

In 2010, a benchmark assessment using the Beaufort Assessment Model (BAM) with data through 2009 was completed (SEDAR 24 2010). BAM is a statistical catch-age model developed by the analysts at the Beaufort, NC NMFS SEFSC laboratory, and is customizable to the data available. A surplus production model called ASPIC (Prager 1994; Prager 2004) was used as a complement for comparison purposes. Based on the assessment provided from the BAM, the SEDAR Review Panel concluded that the red snapper stock was overfished and overfishing was occurring. Similar to SEDAR 15 (2008), more than 40 sensitivities were run, all of which resulted in the same status determinations.

A benchmark assessment was completed in 2016 (SEDAR 41 2017) with data through 2014. Although the SEDAR Review Panel concluded that assessment results represent the best available science, the Panel identified several areas of uncertainty including the composition and magnitude of recreational discards, the stock-recruitment relationship, potential changes in CPUE catchability, and the selectivities for the different fishery fleets. The SSC reviewed the assessment and provided fishing level recommendations at their May 2016 meeting based on $F_{30\%SPR}$ as a proxy for F_{MSY}. The base assessment run suggested that in the terminal year of 2014 the stock remained overfished. The SSC did not have confidence in the terminal fishing mortality estimates; however, they recommended that the assessment results suggested overfishing was likely occurring in the terminal years of the assessment (2012-2014) although the degree to which overfishing was occurring at that time could not be reliably quantified from the assessment results (see May 2016 Final SSC report).

SEDAR 41 (2017) estimated the long-term maximum sustainable yield (MSY) to be about 25% of what it was estimated to be in SEDAR 24 (2010), and projected catch levels from SEDAR 41 at the fishing mortality level predicted to rebuild the stock in the specified timeframe ($F_{Rebuild}$) were approximately 21% of the catch levels projected for 2017 based on SEDAR 24

(2010). Given this, and the various sources of uncertainty in the SEDAR 41 (2017) assessment, the Council sought the SSC's recommendations on additional projection runs and reference point criteria, reliability of MRIP estimates for red snapper (landings and discards), and the risk associated with using different values of MSY (see October 2016 Final SSC Report, **Appendix M**). In addition, the Council requested that projections under a discards-only scenario be provided for discussion at their March 2017 meeting. However, the SEFSC indicated (via letter dated February 15, 2017 and included in **Appendix J**) the projections could not be completed due to the length of time since the completion of the assessment, uncertainty in the landings since most landings are coming from discards, and the change in MRIP methodology for estimating landings and discards. Moreover, the Council received a letter from the NMFS (dated March 3, 2017 and included in **Appendix J**) stating the Council has likely taken sufficient action to address overfishing of red snapper in the South Atlantic and should focus efforts on a methodology to obtain an ABC for red snapper. SEDAR 41 was updated due to revisions in the headboat index and presented to the SSC in April 2017. The SSC indicated they could not provide an ABC that was useful in management (SAFMC 2017). Hence, and due to the issues laid out by the SEFSC, the Council requested that the SEFSC and the SSC collaborate to explore approaches to arrive at an ABC for red snapper that can be applied to a long-term management approach.

3.2.6 Protected Species

There are at least 51 species, or distinct population segments (DPSs) of species, protected by federal law that may occur in the exclusive economic zone (EEZ) of the South Atlantic Region. Thirty-one of these species are marine mammals protected under the Marine Mammal Protection Act (MMPA) (Wynne and Schwartz 1999, Waring et al. 2013). The MMPA requires that each commercial fishery be classified by the number of marine mammals they seriously injure or kill. NMFS's List of Fisheries (LOF) classifies U.S. commercial fisheries into three categories based on the number of incidental mortality or serious injury they cause to marine mammals. More information about the LOF can be found online[5].

Four of the marine mammal species (sperm, sei, fin, blue, and North Atlantic right whales (NARW)) protected by the MMPA, are also listed as endangered under the Endangered Species Act (ESA). In addition to those five marine mammals, six species or DPSs of sea turtles (green North Atlantic and South Atlantic DPSs, hawksbill, Kemp's ridley, leatherback, and the loggerhead NWA DPS); the smalltooth sawfish; five DPSs of Atlantic sturgeon; Nassau grouper, and seven species of coral [elkhorn coral (*Acropora palmata*), staghorn coral (*A. cervicornis*) ("*Acropora*" collectively); lobed star coral (*Orbicella annularis*), mountainous star coral (*O. faveolata*), boulder star (*O. franksi*); rough cactus coral (*Mycetophylia ferox*), and pillar coral (*Dendrogyra cylindrus*)] are also protected under the ESA and occur within the action area of the snapper grouper fishery. Portions of designated critical habitat for NARW, the Northwest Atlantic (NWA) DPS of loggerhead sea turtles, and *Acropora* corals occur within the South Atlantic Council's jurisdiction.

[5] http://www.nmfs.noaa.gov/pr/interactions/fisheries/2017_list_of_fisheries_lof.html

NMFS has conducted specific analyses ("Section 7 consultations") to evaluate the potential adverse effects from the South Atlantic snapper grouper fishery on species and critical habitat protected under the ESA. On December 1, 2016, NMFS completed its most recent biological opinion on the snapper grouper fishery of the South Atlantic Region (NMFS 2016). In this biological opinion, NMFS concluded that the snapper grouper fishery's continued authorization is likely to adversely affect but is not likely to jeopardize the continued existence of the NARW, loggerhead sea turtle Northwest Atlantic DPS, leatherback sea turtle, Kemp's ridley sea turtle, green sea turtle North Atlantic DPS, green sea turtle South Atlantic DPS, hawksbill sea turtle, smalltooth sawfish U.S. DPS, or Nassau grouper. NMFS also concluded that designated critical habitat and other ESA-listed species in the South Atlantic Region were not likely to be adversely affected. Summary information on the species that may be adversely affected by the snapper-grouper fishery and how they are affected is presented below. The 2016 biological opinion provides additional information on these species, how they are affected by the snapper grouper fishery, and the authorized incidental take levels of these species in the snapper-grouper fishery.

3.2.6.1 North Atlantic Right Whales

The NARW, *Eubalaena glacialis* (Rosenbaum et al. 2000), is a large baleen whale. NARWs feed on larger species of zooplankton and almost exclusively on copepods. Feeding takes place subsurface (subsurface feeding) or at the water's surface (surface skim feeding), depending on the vertical distribution of their food species. NARW dive as deep as 306 m (1,003 ft) (Mate et al. 1992).

The coastal waters of the southeastern United States are a wintering and sole known calving area for NARW. NARW generally occur off South and North Carolina from November 1 through April 30 (NMFS 2008d) and have been sighted as far as about 30 nm offshore (Knowlton et al. 2002; Pabst et al. 2009). Sighting records of NARW spotted in the core calving area off Georgia and Florida consist of mostly mother-calf pairs and juveniles but also some adult males and females without calves (Cole et al. 2013; Kraus and Rolland 2007; Parks et al. 2007a). Based on preliminary photo-identification analysis of right whale photographs collected in the southeastern U.S., the median number of NARWs (including calves, but excluding reported or assumed calf mortalities) documented in the southeastern U.S. from the 2009-2013 calving seasons is 165 (Right Whale Consortium 2014; K. Jackson, personal communication, July 21, 2016; Waring et al. 2016). Right whale concentrations are highest in the core calving area from November 15 through April 15 (71 FR 36299, June 26, 2006); on rare occasions, right whales have been spotted as early as September and as late as July (Taylor et al. 2010). Most calves are likely born early in the calving season. NARW distribution off Georgia and Florida is restricted to the south and east by the warm waters of the Gulf Stream, which serves as a thermal limit for NARW (Keller et al. 2006). Water temperature, bathymetry, and surface chop are factors in the distribution of calving NARW in the southeastern U.S. (Good 2008; Keller et al. 2012). Systematic surveys conducted off the coast of North Carolina during the winters of 2001 and 2002 sighted 8 calves, suggest the calving grounds may extend as far north as Cape Fear. Four of the calves were not sighted by surveys conducted further south. One of the cows photographed was new to researchers, having effectively eluded identification over the period of its maturation (McLellan et al. 2003).

Commercial and recreational fishers in the South Atlantic snapper-grouper fishery use hook-and-line gear, spear/powerheads, and pot/traps to target black sea bass). The black seas bass pot component of the snapper-grouper fishery is the only component of the fishery that NMFS determined may adversely affect NARWs; NMFS discounted effects from all the other gear types in the biological opinion. NMFS estimated that the number of annual lethal takes for NARWs from black sea bass trap/pot gear ranged from an estimated minimum of 0.005 to a maximum of 0.08. This equates to 1 estimated lethal entanglement approximately every 25 to 42 years.

3.2.6.2 ESA-Listed Sea Turtles

Green, hawksbill, Kemp's ridley, leatherback, and loggerhead sea turtles are all highly migratory and travel widely throughout the South Atlantic. This section includes a brief overview of the general life history characteristics of the sea turtles found in the South Atlantic region. Several volumes exist that cover the biology and ecology of these species more thoroughly (i.e., Lutz and Musick (eds.) 1997, Lutz et al. (eds.) 2002).

Green sea turtle hatchlings are thought to occupy pelagic areas of the open ocean and are often associated with *Sargassum* rafts (Carr 1987, Walker 1994). Pelagic stage green sea turtles are thought to be carnivorous. Stomach samples of these animals found ctenophores and pelagic snails (Frick 1976, Hughes 1974). At approximately 20 to 25 cm carapace length, juveniles migrate from pelagic habitats to benthic foraging areas (Bjorndal 1997). As juveniles move into benthic foraging areas a diet shift towards herbivory occurs. They consume primarily seagrasses and algae, but are also know to consume jellyfish, salps, and sponges (Bjorndal 1980, 1997; Paredes 1969; Mortimer 1981, 1982). The diving abilities of all sea turtles species vary by their life stages. The maximum diving range of green sea turtles is estimated at 110 m (360 ft) (Frick 1976), but they are most frequently making dives of less than 20 m (65 ft.) (Walker 1994). The time of these dives also varies by life stage. The maximum dive length is estimated at 66 minutes with most dives lasting from 9 to 23 minutes (Walker 1994).

The **hawksbill's** pelagic stage lasts from the time they leave the nesting beach as hatchlings until they are approximately 22-25 cm in straight carapace length (Meylan 1988, Meylan and Donnelly 1999). The pelagic stage is followed by residency in developmental habitats (foraging areas where juveniles reside and grow) in coastal waters. Little is known about the diet of pelagic stage hawksbills. Adult foraging typically occurs over coral reefs, although other hard-bottom communities and mangrove-fringed areas are occupied occasionally. Hawksbills show fidelity to their foraging areas over several years (Van Dam and Diéz 1998). The hawksbill's diet is highly specialized and consists primarily of sponges (Meylan 1988). Gravid females have been noted ingesting coralline substrate (Meylan 1984) and calcareous algae (Anderes Alvarez and Uchida 1994), which are believed to be possible sources of calcium to aid in eggshell production. The maximum diving depths of these animals are not known, but the maximum length of dives is estimated at 73.5 minutes. More routinely, dives last about 56 minutes (Hughes 1974).

Kemp's ridley hatchlings are also pelagic during the early stages of life and feed in surface waters (Carr 1987, Ogren 1989). Once the juveniles reach approximately 20 cm carapace length they move to relatively shallow (less than 50 m) benthic foraging habitat over unconsolidated substrates (Márquez-M. 1994). They have also been observed transiting long distances between foraging habitats (Ogren 1989). Kemp's ridleys feeding in these nearshore areas primarily prey on crabs, though they are also known to ingest mollusks, fish, marine vegetation, and shrimp (Shaver 1991). The fish and shrimp Kemp's ridleys ingest are not thought to be a primary prey item but instead may be scavenged opportunistically from bycatch discards or from discarded bait (Shaver 1991). Given their predilection for shallower water, Kemp's ridleys most routinely make dives of 50 m or less (Soma 1985, Byles 1988). Their maximum diving range is unknown. Depending on the life stage, Kemp's ridleys may be able to stay submerged anywhere from 167 minutes to 300 minutes, though dives of 12.7 minutes to 16.7 minutes are much more common (Soma 1985, Mendonca and Pritchard 1986, Byles 1988). Kemp's ridleys may also spend as much as 96% of their time underwater (Soma 1985, Byles 1988).

Leatherbacks are the most pelagic of all ESA-listed sea turtles and spend most of their time in the open ocean. Although they will enter coastal waters and are seen over the continental shelf on a seasonal basis to feed in areas where jellyfish are concentrated. Leatherbacks feed primarily on cnidarians (medusae, siphonophores) and tunicates. Unlike other sea turtles, leatherbacks' diets do not shift during their life cycles. Because leatherbacks' ability to capture and eat jellyfish is not constrained by size or age, they continue to feed on these species regardless of life stage (Bjorndal 1997). Leatherbacks are the deepest diving of all sea turtles. It is estimated that these species can dive in excess of 1,000 m (Eckert et al. 1989) but more frequently dive to depths of 50 m to 84 m (Eckert et al. 1986). Dive times range from a maximum of 37 minutes to more routines dives of 4 to 14.5 minutes (Standora et al. 1984, Eckert et al. 1986, Eckert et al. 1989, Keinath and Musick 1993). Leatherbacks may spend 74% to 91% of their time submerged (Standora et al. 1984).

Loggerhead hatchlings forage in the open ocean and are often associated with *Sargassum* rafts (Hughes 1974, Carr 1987, Walker 1994, Bolten and Balazs 1995). The pelagic stage of these sea turtles eat a wide range of organisms including salps, jellyfish, amphipods, crabs, syngnathid fish, squid, and pelagic snails (Brongersma 1972). Stranding records indicate that when pelagic immature loggerheads reach 40-60 cm straight-line carapace length they begin to live in coastal inshore and nearshore waters of the continental shelf throughout the U.S. Atlantic (Witzell 2002). Here they forage over hard- and soft-bottom habitats (Carr 1986). Benthic foraging loggerheads eat a variety of invertebrates with crabs and mollusks being an important prey source (Burke et al. 1993). Estimates of the maximum diving depths of loggerheads range from 211 m to 233 m (692-764ft.) (Thayer et al. 1984, Limpus and Nichols 1988). The lengths of loggerhead dives are frequently between 17 and 30 minutes (Thayer et al. 1984, Limpus and Nichols 1988, Limpus and Nichols 1994, Lanyan et al. 1989) and they may spend anywhere from 80 to 94% of their time submerged (Limpus and Nichols 1994, Lanyan et al. 1989).

Sea turtles are vulnerable to capture by bottom longline and vertical hook-and-line gear. Hook-and-line gear used in the fishery includes commercial bottom longline gear and commercial and recreational vertical line gear (e.g., handline, bandit gear, and rod-and-reel). The magnitude of the interactions between sea turtles and the South Atlantic snapper grouper fishery was most recently evaluated in the 2016 biological opinion (i.e., NMFS (2016). In **Table 3.2.1** the 3-year estimated captures and mortalities authorized for the fishery in the 2016 biological opinion are specified. Section 5.2 of the 2016 biological opinion presents a summary of the data sources considered for the sea turtle analyses, estimation methods, and data limitations and assumptions associated with the estimates for each fishery component. Loggerhead sea turtles are the species most affected by the proposed action. The majority of estimated sea turtle captures appear to occur in the recreational vertical lines targeting snapper grouper species due to the large amount of recreation fishing effort. However, it is also important to recognize that the sea turtle capture estimates for the recreational vertical line are also likely the most uncertain.

Table 3.2.1. Estimated 3-year sea turtle (T) and mortalities (M) estimates in the South Atlantic Snapper-Grouper Fishery by fishery component and overall.

Fishery Component	Loggerhead		Kemp's ridley		Green		Hawksbill		Leatherback	
	T	M	T	M	T	M	T	M	T	M
Commercial Bottom Longline*	9	5	1	1	1	1	1	1	3	2
Commercial Vertical Line**	62	26	18	8	11	5	1	1	1	1
Recreational Vertical Line ***	546	165	159	48	96	30	2	1	1	1
All Components Combined	617	196	178	57	108	36	5	3	5	4

*Only 10 hardshell sea turtles combined are estimated to be captured every 3 years; only 1 hawksbill, Kemp's ridley or green sea turtle is expected to be captured and killed every 3 years in this component. **No more than 90 hardshell sea turtles combined are estimated for this component. ***No more than 801 hardshell sea turtle combined are estimated for this component.

Regulations implemented through Amendment 15B to the Snapper Grouper FMP (74 FR 31225; June 30, 2009; SAFMC 2008) require all commercial or charter/headboat vessels with a South Atlantic snapper grouper permit, carrying hook-and-line gear on board, to possess required literature and release gear to aid in the safe release of incidentally caught sea turtles. Comprehensive Ecosystem-Based Amendment 2 modified these requirements (76 FR 82183; December 30, 2011; SAFMC 2011e) by requiring different gear for vessels with different freeboard heights, mirroring the requirements in the Gulf of Mexico. These regulations are thought to decrease the mortality associated with accidental interactions with sea turtles.

Snapper-grouper vessels transiting to and from fishing areas and moving during fishing activity also pose a potential threat to sea turtles (NMFS 2016). As explained in the 2016 biological opinion, it is very difficult to definitively or even approximately evaluate the potential risk to sea turtles stemming from specific vessel traffic from any action because of the numerous variables (e.g., vessel type, speed, traffic, environmental conditions, sea turtle abundance in area transited) that may impact vessel strike rates. This difficulty is compounded by a general lack of information on vessel use trends, particularly in regard to offshore vessel traffic.

3.2.6.3 ESA-Listed Marine Fish

Historically the **smalltooth sawfish** in the U.S. ranged from New York to the Mexico border. Their current range is poorly understood but believed to have contracted from these historical areas. In the South Atlantic region, they are most commonly found in Florida, primarily off the Florida Keys (Simpfendorfer and Wiley 2004). Only two smalltooth sawfish have been recorded north of Florida since 1963 [the first was captured off North Carolina in 1963 and the other off Georgia in 2002 (National Smalltooth Sawfish Database, Florida Museum of Natural History)]. Historical accounts and recent encounter data suggest that immature individuals are most common in shallow coastal waters less than 25 meters (Bigelow and Schroeder 1953, Adams and Wilson 1995), while mature animals occur in waters in excess of 100 meters (Simpfendorfer pers. comm. 2006). Smalltooth sawfish feed primarily on fish. Mullet, jacks, and ladyfish are believed to be their primary food sources (Simpfendorfer 2001). Smalltooth sawfish also prey on crustaceans (mostly shrimp and crabs) by disturbing bottom sediment with their saw (Norman and Fraser 1938, Bigelow and Schroeder 1953).

On June 29, 2016, NMFS published a final rule in the *Federal Register* listing Nassau grouper as threatened under the Endangered Species Act due to a decline in its population (81 FR 42268). The final rule became effective on July 29, 2016. The Nassau grouper's confirmed distribution currently includes “Bermuda and Florida (USA), throughout the Bahamas and Caribbean Sea” (e.g., Heemstra and Randall 1993, Hill and Sadovy de Mitcheson, 2013). The Nassau grouper is primarily a shallow-water, insular fish species that has long been valued as a major fishery resource throughout the wider Caribbean, South Florida, Bermuda, and the Bahamas (Carter et al. 1994). As larvae, Nassau grouper are planktonic. After an average of 35-40 days and at an average size of 32 millimeters total length (TL), larvae recruit from an oceanic environment into demersal habitats (Colin 1992, Eggleston 1995). Juvenile Nassau grouper (12-15 centimeters TL) are relatively solitary and remain in specific areas (associated with macroalgae, and both natural and artificial reef structure) for months (Bardach 1958). As juveniles grow, they move progressively to deeper areas and offshore reefs (Tucker et al. 1993, Colin et al. 1997). Smaller juveniles occur in shallower inshore waters (3.7-16.5 meters [m]) and larger juveniles are more common near deeper (18.3-54.9 m) offshore banks (Bardach et al. 1958, Cervigón 1966, Silva Lee 1974, Radakov et al. 1975, Thompson and Munro 1978). Adult Nassau grouper also tend to be relatively sedentary and are commonly associated with high-relief coral reefs or rocky substrate in clear waters to depths of 130 m. Generally, adults are most common at depths less than 100 m (Hill and Sadovy de Mitcheson 2013) except when at spawning aggregations where they are known to descend to depths of 255 m (Starr et al. 2007). Nassau grouper form spawning aggregations at predictable locations around the winter full moons, or between full and new moons (Smith 1971, Colin 1992, Tucker et al. 1993, Aguilar-Perera 1994, Carter et al. 1994, Tucker and Woodward 1994). The most serious threats to the status of Nassau grouper today are fishing at spawning aggregations and inadequate law enforcement protecting spawning aggregations in many foreign nations. are no known spawning aggregations within the South Atlantic Region.

Of the 3 basic types of gear used in the South Atlantic snapper-grouper fishery by commercial and/or recreational fishers (i.e., hook-and-line gear, spear/powerheads, and black sea bass pots), we believe only snapper-grouper hook-and-line gear may adversely affect smalltooth sawfish and Nassau grouper. Interactions with smalltooth sawfish are limited to off of Florida;

and are quite rare. In the 2016 biological opinion, NMFS anticipates only 8 smalltooth sawfish interactions every three years in all snapper-grouper hook-and-line-gear components combined and they are anticipated to all be non-lethal. Nassau grouper incidental captures appear to be more frequent. Farmer (2016) estimated that over the last 10 years, a total of approximately 1,387 Nassau grouper have been captured annually in the fishery. Based on an estimated 20% mortality rate, Farmer (2016) estimated an annual average expected mortality of approximately 282 fish. Future anticipated captures and mortalities are expected to remain at these same levels.

3.3 Economic and Social Environment

3.3.1 Economic Environment

Details on red snapper, and the South Atlantic snapper grouper fishery in general, can be found in Snapper Grouper Amendment 17A (SAFMC 2010) and the Comprehensive ACL Amendment for the South Atlantic Region (SAFMC 2011b), respectively.

3.3.1.1 Economic Description of the Commercial Sector

The major sources of data summarized in this description are the NMFS SERO Permits Information Management System (PIMS) and the SEFSC Social Science Research Group (SSRG) Socioeconomic Panel[6] data set. Inflation adjusted revenues and prices are reported in 2016 dollars.

Permits

Any fishing vessel that harvests and sells any of the snapper grouper species from the South Atlantic EEZ must have a valid South Atlantic commercial snapper grouper permit, which is a limited access permit. As of July 10, 2017, there were 544 valid or renewable South Atlantic Snapper Grouper Unlimited Permits and 114 valid or renewable 225-lb Trip-limited Permits. After a permit expires, it can be renewed or transferred up to one year after the date of expiration. The number of valid or renewable snapper grouper permits declined steadily from 2012 through 2016 (**Table 3.3.1**).

Table 3.3.1. Number of valid or renewable South Atlantic commercial snapper grouper permits.

	Unlimited	225-lb Trip-limited
2012	604	132
2013	592	129
2014	584	125
2015	571	121

[6] This data set is compiled by the SEFSC SSRG from Federal Logbook System (FLS) data, supplemented by average prices calculated from the Accumulated Landings System (ALS). Because these landings are self-reported, they may diverge slightly from dealer-reported landings presented elsewhere.

2016	565	116
Average	583	125

Source: NMFS SERO Permits Dataset, 2017.

Landings, Value, and Effort

The number of federally permitted commercial vessels that landed South Atlantic red snapper increased from 2012 through 2014 and then dropped sharply in 2015 and 2016, during which time there was no federal commercial red snapper season (**Table 3.3.2**). Landings of red snapper followed a similar pattern. The landings reported in 2015 and 2016 are either from state water catches or misreported/out-of-season harvests. On average (2012 through 2016), vessels that landed red snapper did so on approximately 9% of their South Atlantic trips and red snapper accounted for only 2% of their annual all species revenue, including revenue from Gulf trips (**Table 3.3.2** and **Table 3.3.3**). Average all species vessel-level revenue for these vessels rose steadily from 2012 through 2016, increasing by approximately 45% overall. During this time period, the average annual price per pound gutted weight (gw) of red snapper ranged from $4.21 to $5.28 (2016 dollars) (**Table 3.3.3**).

Table 3.3.2. Number of vessels, number of trips, and landings (lbs gw) by year for South Atlantic red snapper, 2012-2016.

Year	# of vessels that caught red snapper (> 0 lbs gw)	# of trips that caught red snapper	Red snapper landings (lbs gw)	Other species' landings jointly caught w/ red snapper (lbs gw)	# of South Atlantic trips that only caught other species	Other species' landings on South Atlantic trips w/o red snapper (lbs gw)	All species landings on Gulf trips (lbs gw)
2012	74	171	14,668	111,275	1,997	1,452,577	285,312
2013	137	477	27,640	265,754	3,348	2,715,941	295,712
2014	164	999	60,881	538,255	5,046	3,354,953	504,522
2015	24	30	4,334	45,323	927	418,223	244,482
2016	24	29	13,662	22,078	736	467,136	254,278
Average	85	341	24,237	196,537	2,411	1,681,766	316,861

Source: SEFSC-SSRG Socioeconomic Panel v.4 July 2017

Table 3.3.3. Number of vessels and ex-vessel revenue by year (2016 dollars) for South Atlantic red snapper, 2012-2016.

Year	# of vessels that caught red snapper (> 0 lbs gw)	Dockside revenue from red snapper	Dockside revenue from 'other species' jointly caught w/ red snapper	Dockside revenue from 'other species' caught on South Atlantic trips w/o red snapper	Dockside revenue from 'all species' caught on Gulf trips	Total dockside revenue	Average total dockside revenue per vessel
2012	74	$68,560	$335,372	$4,109,121	$930,464	$5,443,517	$73,561
2013	137	$142,152	$895,319	$8,071,918	$1,049,147	$10,158,536	$74,150
2014	164	$321,452	$1,850,626	$9,867,241	$1,877,779	$13,917,098	$84,860
2015	24	$18,909	$176,013	$1,267,443	$935,197	$2,397,562	$99,898
2016	24	$57,463	$69,436	$1,424,709	$1,013,682	$2,565,290	$106,887
Average	85	$121,707	$665,353	$4,948,086	$1,161,254	$6,896,401	$87,871

Source: SEFSC-SSRG Socioeconomic Panel v.4 July 2017

Imports

Imports of seafood products compete in the domestic seafood market and have in fact dominated many segments of the seafood market. Imports aid in determining the price for domestic seafood products and tend to set the price in the market segments in which they dominate. Seafood imports have downstream effects on the local fish market. At the harvest level for snapper species, including red snapper, imports affect the returns to fishermen through the ex-vessel prices they receive for their landings. As substitutes to domestic production of snappers, imports tend to cushion the adverse economic effects on consumers resulting from a reduction in domestic landings. The following describes the imports of fish products that directly compete with domestic harvest of snappers, including red snapper.

Imports[7] of fresh snapper were 22.7 million lbs product weight (pw) in 2012. They increased steadily to 30.5 million lbs pw in 2016. Total revenue from fresh snapper imports increased from $69.4 million (2016 dollars[8]) in 2012 to a five-year high of $90.2 million in 2016. Imports of fresh snappers primarily originated in Mexico or Central America, and entered the U.S. through the port of Miami. Imports of fresh snapper were highest on average (2012 through 2016) during the months of March through July.

[7] NOAA Fisheries Service purchases fisheries trade data from the Foreign Trade Division of the U.S. Census Bureau. Data are available for download at http://www.st.nmfs.noaa.gov/st1/trade/index.html.
[8] Converted to 2016 dollars using the annual, not seasonally adjusted GDP implicit price deflator provided by the U.S. Bureau of Economic Analysis.

Imports of frozen snapper were substantially less than imports of fresh snapper from 2012 through 2016. The annual value of frozen snapper imports ranged from $25 million (2016 dollars) to $38 million during the time period, with a peak in 2016. Imports of frozen snapper primarily originated in South America (especially Brazil), Indonesia, Mexico, and Central America. The majority of frozen snapper imports entered the U.S. through the ports of Miami, New York, and San Juan. Imports of frozen snappers tended to be lowest during March through May when fresh snapper imports were high.

Business Activity

The commercial harvest and subsequent sales and consumption of fish generates business activity as fishermen expend funds to harvest the fish and consumers spend money on goods and services, such as red snapper purchased at a local fish market and served during restaurant visits. These expenditures spur additional business activity in the region(s) where the harvest and purchases are made, such as jobs in local fish markets, grocers, restaurants, and fishing supply establishments. In the absence of the availability of a given species for purchase, consumers would likely spend their money on substitute goods, such as other finfish or seafood products, and services, such as visits to different food service establishments. As a result, the analysis presented below represents a distributional analysis only; that is, it only shows how economic effects may be distributed through regional markets and should not be interpreted to represent the impacts if these species are not available for harvest or purchase.

Estimates of the U.S. average annual business activity associated with the commercial harvest of red snapper, and all species harvested by the vessels that harvested these red snapper, were derived using the model[9] developed for and applied in NMFS (2017) and are provided in **Table 3.3.4**. This business activity is characterized as jobs (full- and part-time), income impacts (wages, salaries, and self-employed income), output (sales) impacts (gross business sales), and value-added impacts, which represent the contribution made to the U.S. Gross Domestic Product (GDP). These impacts should not be added together because this would result in double counting. It should be noted that the results provided should be interpreted with caution and demonstrate the limitations of these types of assessments. These results are based on average relationships developed through the analysis of many fishing operations that harvest many different species. Separate models to address individual species are not available. For example, the results provided here apply to a general reef fish category rather than just red snapper, and a harvester job is "generated" for approximately every $32,000 (2016 dollars) in ex-vessel revenue. These results contrast with the number of harvesters (vessels) with recorded landings of red snapper presented in **Table 3.3.2**.

Table 3.3.4. Average annual business activity (2012 - 2016) associated with the commercial harvest of red snapper and the harvest of all species by vessels that landed red snapper. All monetary estimates are in 2016 dollars.*

[9] A detailed description of the input/output model is provided in NMFS (2011).

Species	Average Ex-vessel Value ($ thousands)	Total Jobs	Harvester Jobs	Output (Sales) Impacts ($ thousands)	Income Impacts ($ thousands)	Value Added ($ thousands)
Red snapper	$122	16	4	$1,207	$443	$626
All species harvested by vessels that landed red snapper.	$6,896	921	219	$68,390	$25,115	$35,485

Source: Calculated by NMFS SERO using the model developed for and applied in NMFS (2017).
*Converted to 2016 dollars using the annual, not seasonally adjusted GDP implicit price deflator provided by the U.S. Bureau of Economic Analysis.

3.3.1.2 Economic Description of the Recreational Sector

The South Atlantic recreational sector is comprised of the private and for-hire modes. The private mode includes anglers fishing from shore (all land-based structures) and private/rental boats. The for-hire mode is composed of charter boats and headboats (also called partyboats). Charter boats generally carry fewer passengers and charge a fee on an entire vessel basis, whereas headboats carry more passengers and payment is per person. The type of service, from a vessel- or passenger-size perspective, affects the flexibility to search different fishing locations during the course of a trip and target different species since larger concentrations of fish are required to satisfy larger groups of anglers.

Angler Effort

Recreational effort derived from the Marine Recreational Information Program (MRIP) database can be characterized in terms of the number of trips as follows:

- Target effort - The number of individual angler trips, regardless of duration, where the intercepted angler indicated that the species or a species in the species group was targeted as either the first or the second primary target for the trip. The species did not have to be caught.
- Catch effort - The number of individual angler trips, regardless of duration and target intent, where the individual species or a species in the species group was caught. The fish did not have to be kept.
- Total recreational trips - The total estimated number of recreational trips in the South Atlantic, regardless of target intent or catch success.

A target trip may reveal an angler’s preference for a certain species, and thus may carry more relevant information when assessing the economic effects of regulations on the subject species than the other two measures of recreational effort. The majority of red snapper target trips in the South Atlantic, as estimated by MRIP, were recorded in Florida on private vessels from 2012 through 2016 (**Table 3.3.5**). Estimates of red snapper target effort for additional years, and other measures of directed effort, are available online[10].

During the short red snapper seasons that occurred in 2012, 2013, and 2014, both Florida and Georgia also collected some recreational effort data as part of their state-run survey programs.[11] Florida estimated the total number of private recreational boat trips that targeted red snapper and these estimates are incorporated herein by reference (Sauls et al. 2017). Direct comparison of these estimates to the MRIP estimates is not possible because MRIP data are recorded at the angler level rather than the vessel level. Georgia conducted telephone surveys of for-hire (charter vessel and headboat) captains to collect catch and effort data during the 2012-2014 recreational red snapper seasons and also administered a voluntary, private angler electronic catch survey during that time. These estimates are also incorporated herein by reference (Knowlton 2015). The number of for-hire red snapper target trips recorded by Georgia was greater than what was estimated by MRIP, but the number of voluntarily reported private angler trips was significantly lower than the MRIP estimate (**Table 3.3.6**). North Carolina and South Carolina did not collect target red snapper effort data in 2012-2014.

[10] http://www.st.nmfs.noaa.gov/recreational-fisheries/access-data/run-a-data-query/queries/index.
[11] These survey programs were designed to maximize sampling opportunities during the mini-seasons.

Table 3.3.5. South Atlantic red snapper target trips, by mode and state, 2012-2016.*

	Florida	Georgia	North Carolina	South Carolina	Total
	Charter Mode				
2012	0	65	727	0	792
2013	673	0	0	0	673
2014	3,743	0	0	0	3,743
2015	0	0	0	0	0
2016	0	0	0	0	0
Average	883	13	145	0	1,042
	Private/Rental Mode				
2012	16,215	1,215	0	586	18,016
2013	32,154	345	0	0	32,500
2014	64,397	2,219	0	1539	68,155
2015	1,408	0	0	0	1,408
2016	1,013	0	0	0	1,013
Average	23,037	756	0	425	24,218
	All Modes				
2012	16,215	1,280	727	586	18,807
2013	32,827	345	0	0	33,173
2014	68,141	2,219	0	1539	71,898
2015	1,408	0	0	0	1,528
2016	1,013	0	0	0	1,013
Average	23,921	769	145	425	25,284

Source: MRIP database, SERO, NMFS.
*Headboat data are unavailable.

Table 3.3.6. Georgia estimates of angler trips that targeted red snapper, 2012-2014.

Year	For-hire (charter and headboat) angler trips*	Private angler trips
2012	100	31
2013	70	53
2014	312	120

Source: Knowlton (2015).
*There were 76, 47, and 180 charter angler trips targeting red snapper in 2012, 2013, and 2014, respectively.

Similar analysis of recreational angler trips (with the exception of the Georgia-based telephone survey) is not possible for the headboat mode because headboat data are not collected at the angler level. Estimates of effort by the headboat mode are provided in terms of angler days, or the total number of standardized full-day angler trips.[12] Headboat effort in the South Atlantic, in terms of angler days, increased substantially in Florida through Georgia from 2012 through 2014, and then leveled off through 2016. In North Carolina and South Carolina, it was mostly stable during this time period (**Table 3.3.7**). Headboat effort was the highest, on average, during the summer months of June through August (**Table 3.3.8**).

Table 3.3.7. South Atlantic headboat angler days and percent distribution by state, 2012-2016.

	Angler Days			Percent Distribution		
	FL/GA*	**NC**	**SC**	**FL/GA**	**NC**	**SC**
2012	139,623	20,743	41,003	69.33%	10.31%	20.36%
2013	165,679	20,766	40,963	72.86%	9.13%	18.01%
2014	195,890	20,547	42,025	75.79%	7.95%	16.26%
2015	194,979	22,691	39,702	75.76%	8.82%	15.43%
2016	196,660	22,716	42,207	75.18%	8.68%	16.14%
Average	178,566	21,497	41,180	74%	9%	17%

*East Florida and Georgia are combined for confidentiality purposes.
Source: NMFS Southeast Region Headboat Survey (SRHS).

Table 3.3.8. South Atlantic headboat angler days and percent distribution by month, 2012-2016.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Headboat Angler Days											
2012	9,230	9,663	17,307	19,587	18,232	27,819	35,115	25,052	15,894	8,677	6,564	8,252
2013	10,182	10,892	14,541	16,129	20,969	33,079	39,463	33,830	16,335	14,534	6,698	10,537
2014	8,748	13,512	19,808	22,570	25,764	39,115	44,066	32,886	15,203	15,235	9,088	14,611
2015	12,661	11,148	21,842	25,128	25,172	36,907	42,558	30,772	15,649	13,375	9,623	12,562
2016	9,818	12,243	23,872	22,217	27,374	37,454	45,744	29,223	17,061	9,202	12,820	13,404
Avg	10,128	11,492	19,474	21,126	23,502	34,875	41,389	30,353	16,028	12,205	8,959	11,873
	Percent Distribution											
2012	5%	5%	9%	10%	9%	14%	17%	12%	8%	4%	3%	4%
2013	4%	5%	6%	7%	9%	15%	17%	15%	7%	6%	3%	5%
2014	3%	5%	8%	9%	10%	15%	17%	13%	6%	6%	3%	6%
2015	5%	4%	8%	10%	10%	14%	17%	12%	6%	5%	4%	5%
2016	4%	5%	9%	9%	11%	14%	18%	11%	7%	4%	5%	5%
Avg	4%	5%	8%	9%	10%	14%	17%	13%	7%	5%	4%	5%

Source: NMFS Southeast Region Headboat Survey (SRHS).

[12] Headboat trip categories include half-, three-quarter-, full-, and 2-day trips. A full-day trip equals one angler day, a half-day trip equals .5 angler days, etc. Angler days are not standardized to an hourly measure of effort and actual trip durations may vary within each category.

Permits

For-hire vessels are required to have a for-hire snapper grouper permit to fish for or possess snapper grouper species in the South Atlantic EEZ. As of July 10, 2017, there were 1,649 valid for-hire snapper grouper permits. This sector operates as an open access fishery and not all permitted vessels are necessarily active in the fishery. Some vessel owners may have obtained open access permits as insurance for uncertainties in the fisheries in which they currently operate. The number of for-hire vessel permits issued for the South Atlantic snapper grouper fishery reached a five-year high of 1,867 permits in 2016 (**Table 3.3.9**). The majority of snapper grouper for-hire permitted vessels were home-ported in Florida; a relatively high proportion of these permitted vessels were also home-ported in North Carolina and South Carolina. Many vessels with South Atlantic for-hire snapper grouper permits were home-ported in states outside of the SAFMC's area of jurisdiction. On average (2012 through 2016), these vessels accounted for approximately 11% of the total number of for-hire snapper grouper permits issued.

Table 3.3.9. Number of South Atlantic for-hire snapper grouper permits, by homeport state, 2012-2016.

Home Port	2012	2013	2014	2015	2016	Average
North Carolina	313	308	294	308	331	311
South Carolina	138	150	160	188	212	170
Georgia	26	30	34	45	53	38
Florida	1,121	1,120	1,062	1,071	1,100	1,095
Gulf (AL-TX)	93	91	81	73	69	81
Others	106	100	96	94	102	100
Total	1,797	1,799	1,727	1,779	1,867	1,794

Source: NMFS SERO Permits Dataset, 2017.

Although the for-hire permit application collects information on the primary method of operation, the permit itself does not identify the permitted vessel as either a headboat or a charter vessel and vessels may operate in both capacities. However, only federally permitted headboats are required to submit harvest and effort information to the NMFS Southeast Region Headboat Survey (SRHS). Participation in the SRHS is based on determination by the Southeast Fishery Science Center (SEFSC) that the vessel primarily operates as a headboat. As of February 17, 2017, 63 South Atlantic headboats were registered in the SRHS (K. Fitzpatrick, NMFS SEFSC, pers. comm.). The majority of these headboats were located in Florida/Georgia (36), followed by North Carolina (16) and South Carolina (11).

There are no specific permitting requirements for recreational anglers to harvest snapper grouper species. Instead, anglers are required to possess either a state recreational fishing permit that authorizes saltwater fishing in general, or be registered in the federal National Saltwater Angler Registry system, subject to appropriate exemptions. As a result, it is not possible to identify with available data how many individual anglers would be expected to be affected by this proposed amendment.

Economic Value

Participation, effort, and harvest are indicators of the value of saltwater recreational fishing. However, a more specific indicator of value is the satisfaction that anglers experience over and above their costs of fishing. The monetary value of this satisfaction is referred to as consumer surplus (CS). The value or benefit derived from the recreational experience is dependent on several quality determinants, which include fish size, catch success rate, and the number of fish kept. These variables help determine the value of a fishing trip and influence total demand for recreational fishing trips. The estimated value of the CS for catching and keeping a second red snapper on an angler trip is approximately $81 (values updated to 2016 dollars[13]), and decreases thereafter (approximately $54 for a third red snapper, $40 for a fourth red snapper, and $31 for a fifth red snapper in 2016 dollars) (Carter and Liese 2012).

The foregoing estimates of economic value should not be confused with economic impacts associated with recreational fishing expenditures. Although expenditures for a specific good or service may represent a proxy or lower bound of value (a person would not logically pay more for something than it was worth to them), they do not represent the net value (benefits minus cost), nor the change in value associated with a change in the fishing experience.

With regards to for-hire businesses, economic value can be measured by producer surplus (PS) per passenger trip (the amount of money that a vessel owner earns in excess of the cost of providing the trip). Estimates of the PS per for-hire passenger trip are not available. Instead, net operating revenue (NOR), which is the return used to pay all labor wages, returns to capital, and owner profits, is used as a proxy for PS. The estimated NOR value for an average South Atlantic charter angler trip is $165 (2016 dollars) and the estimated NOR value for a South Atlantic headboat angler trip is $45 (2016 dollars) (C. Liese, NMFS SEFSC, pers. comm.). Estimates of NOR per red snapper target trip are not available.

Business Activity

The desire for recreational fishing generates economic activity as consumers spend their income on various goods and services needed for recreational fishing. This spurs economic activity in the region where recreational fishing occurs. It should be clearly noted that, in the absence of the opportunity to fish, the income would presumably be spent on other goods and services and these expenditures would similarly generate economic activity in the region where the expenditure occurs. As such, the analysis below represents a distributional analysis only.

Estimates of the business activity (economic impacts) associated with recreational angling for South Atlantic red snapper were calculated using average trip-level impact coefficients derived from the 2015 Fisheries Economics of the U.S. report (NMFS 2017) and underlying data provided by the National Oceanic and Atmospheric Administration (NOAA) Office of Science and Technology. Economic impact estimates in 2015 dollars were adjusted to 2016 dollars using

[13] Converted to 2016 dollars using the annual, not seasonally adjusted GDP implicit price deflator provided by the U.S. Bureau of Economic Analysis.

the annual, not seasonally adjusted GDP implicit price deflator provided by the U.S. Bureau of Economic Analysis.

Business activity (economic impacts) for the recreational sector is characterized in the form of jobs (full- and part-time), income impacts (wages, salaries, and self-employed income), output (sales) impacts (gross business sales), and value-added impacts (contribution to the GDP in a state or region). Estimates of the average annual economic impacts (2012-2016) resulting from South Atlantic red snapper target trips are provided in **Table 3.3.10**. These estimates are low due to the small number of estimated red snapper target trips that occurred during the mini-seasons in 2012-2014 and during the subsequent closed seasons in 2015 and 2016. The average impact coefficients, or multipliers, used in the model are invariant to the "type" of effort and can therefore be directly used to measure the impact of other effort measures such as red snapper catch trips. To calculate the multipliers from **Table 3.3.10**, simply divide the desired impact measure (sales impact, value-added impact, income impact or employment) associated with a given state by the number of target trips for that state.

The estimates provided in **Table 3.3.10** only apply at the state-level. Addition of the state-level estimates to produce a regional (or national) total may underestimate the actual amount of total business activity, because state-level impact multipliers do not account for interstate and interregional trading. It is also important to note, that these economic impacts estimates are based on trip expenditures only and do not account for durable expenditures. Durable expenditures cannot be reasonably apportioned to individual species. As such, the estimates provided in **Table 3.3.10** may be considered a lower bound on the economic activity associated with those trips that targeted red snapper.

Estimates of the business activity associated with headboat effort are not available. Headboat vessels are not covered in MRIP, so, in addition to the absence of estimates of target effort, estimation of the appropriate business activity coefficients for headboat effort has not been conducted.

Table 3.3.10. Estimated annual average economic impacts (2012-2016) from South Atlantic recreational red snapper target trips, by state and mode, using state-level multipliers. All monetary estimates are in 2016 dollars.

	NC	SC	GA*	FL
	Charter Mode			
Target Trips	145	0	61	883
Value Added Impacts	$50,201	$0	$15,256	$358,425
Sales Impacts	$93,938	$0	$27,913	$647,923
Income Impacts	$34,124	$0	$10,412	$230,365
Employment (Jobs)	1	0	0	5
	Private/Rental Mode			
Target Trips	0	425	756	23,037
Value Added Impacts	$0	$8,627	$15,190	$476,689
Sales Impacts	$0	$15,656	$26,349	$811,147
Income Impacts	$0	$5,169	$9,107	$274,117
Employment (Jobs)	0	0	0	7

Source: effort data from MRIP; economic impact results calculated by NMFS SERO using NMFS (2017) and underlying data provided by the NOAA Office of Science and Technology.
*Georgia estimates of charter angler trips for 2012-2014 from Knowlton (2015) were used in place of the MRIP estimates.

3.3.2 Social Environment

This amendment affects commercial and recreational management of red snapper. This section provides the background for the proposed actions, which will be evaluated in **Chapter 4**. Commercial and recreational landings by state are included to provide information on the geographic distribution of fishing involvement. Descriptions of the top communities involved in commercial red snapper are included along with the top recreational fishing communities based on recreational engagement. Community level data are presented in order to meet the requirements of National Standard 8 of the Magnuson-Stevens Act, which requires the consideration of the importance of fishery resources to human communities when changes to fishing regulations are considered. Lastly, social vulnerability data are presented to assess the potential for environmental justice concerns. Additional information on the South Atlantic recreational and commercial red snapper fishery is provided in the Economic Environment in **Section 3.3**.

3.3.2.1 Landings by State

The South Atlantic red snapper season was closed in 2010, 2011, 2015, and 2016 and was open for a short season during 2012, 2013, and 2014. Landings by state for the years of 2012 through 2014 are described below because these data represent the most recent years that red snapper was open in federal waters. Red snapper were landed during 2015 and 2016; however because fishing was closed in federal waters and in all state waters except for Florida, the majority of landings were from waters adjacent to Florida with some reported landings from North Carolina and South Carolina (MRIP and SRHS Datasets).

Commercial

The majority of commercial red snapper landings came from waters adjacent to Florida (82.7% on average for years 2012-2014, SERO and SEFSC ACL Files), followed by South Carolina (9%) and North Carolina and Georgia (approximately 8.1%). Data for North Carolina are combined with Georgia in order to maintain confidentiality, but the majority of the landings reported for the combined category occurred in North Carolina. From 2012 to 2014, commercial landings ranged from 7,627 lbs ww to 65,807 lbs ww (SERO and SEFSC ACL Files).

Recreational

The majority of recreational red snapper landings come from waters adjacent to Florida (88.3% on average for years 2012-2014), followed by North Carolina (6.3%), Georgia (4.8%), and South Carolina (0.5%). From 2012 to 2014, recreational landings have ranged from 6,629 fish to 31,069 fish. Recreational landings were a combination of both MRIP and red snapper state surveys done by the individual states of the South Atlantic region. An ad-hoc group reviewed the MRIP and state survey results, and determined the better estimate of recreational red snapper landings for each state and year.

3.3.2.2 Fishing Communities

The descriptions of South Atlantic communities include information about the top communities based on a "regional quotient" (RQ) of commercial landings and value for red snapper. The RQ is the proportion of landings and value out of the total landings and value of that species for that region, and is a relative measure. These communities would be most likely to experience the effects of the proposed actions that could change the red snapper fishery and impact participants, associated businesses, and communities within the region. If a community is identified as a red snapper community based on the RQ, this does not necessarily mean that the community would experience significant impacts due to changes in the fishery if a different species or number of species was also important to the local community and economy. Additional detailed information about communities with the highest RQs can be found for South Atlantic communities at the Southeast Regional Office's Community Snapshots website[14].

In addition to examining the RQs to understand how communities are engaged and reliant on fishing, indices were created using secondary data from permit and landings information for the commercial sector (Jepson and Colburn 2013, Jacob et al. 2013). Fishing engagement is primarily the absolute numbers of permits, landings, and value for all species. For commercial fishing, the analysis used the number of vessels designated commercial by homeport and owner address, value of landings, and total number of commercial permits for each community for all species. Fishing reliance includes the same variables as fishing engagement divided by population to give an indication of the per capita influence of this activity. Fishing engagement

[14] http://sero.nmfs.noaa.gov/sustainable_fisheries/social/community_snapshot/

and reliance data rely on fishing data up to the year 2014 and population data from the U.S. Census American Community Survey (ACS) 2010 through 2014 five-year estimates.

Using a principal component and single solution factor analysis, each community receives a factor score for each index to compare to other communities. Factor scores of both engagement and reliance were plotted for the communities with the highest RQs. Two thresholds of one and one-half standard deviation above the mean are plotted to help determine a threshold for significance. The factor scores are standardized; therefore, a score above a value of 1.0 is also above one standard deviation. A score above one-half standard deviation is considered engaged or reliant with anything above one standard deviation to be very engaged or reliant.
The reliance index uses factor scores that are normalized. The factor score is similar to a z-score in that the mean is always zero, positive scores are above the mean, and negative scores are below the mean. Comparisons between scores are relative; however, like a z-score, the factor score puts the community on a point in the distribution. Objectively, that community will have a score related to the percent of communities with similar attributes. For example, a score of 2.0 means the community is two standard deviations above the mean and is among the 2.27% most vulnerable places in the study (normal distribution curve). Reliance score comparisons between communities are relative; however, if the community scores greater than two standard deviations above the mean, this indicates that the community is dependent on fishing. Examining the component variables on the reliance index and how they are weighted by factor score provides a measurement of commercial reliance. The reliance index provides a way to gauge change over time in these communities and also provides a comparison of one community with another.

Landings for the recreational sector are not available by species at the community level; therefore, it is not possible with available information to identify communities as dependent on recreational fishing for red snapper. Because limited data are available concerning how recreational fishing communities are engaged and reliant on specific species, indices were created using secondary data from permit and infrastructure information for the southeast recreational fishing sector at the community level (Jepson and Colburn 2013, Jacob et al. 2013). Recreational fishing engagement is represented by the number of recreational permits and vessels designated as “recreational” by homeport and owners address. Fishing reliance includes the same variables as fishing engagement, divided by population. Factor scores of both engagement and reliance were plotted. **Figure 3.4.3** identifies the top communities that are engaged and reliant upon recreational fishing in general.

A description of the social environment, including analysis of communities engaged in red snapper fishing, was provided in Amendment 28 for snapper grouper (SAFMC 2013b) and is incorporated herein by reference. The referenced description focuses on available geographic and demographic data to identify top commercial red snapper communities using 2009 Accumulated Landings System (ALS) data and engagement, reliance, and social vulnerability indicators from 2009. This section has been updated using 2014 ALS data and 2014 community social vulnerability indicators data, the most recent year available.

Commercial Fishing Communities

Figure 3.4.1 includes the top red snapper communities by regional quotient landings and value during 2014, the most recent year with a federal season for red snapper. The majority of the top red snapper communities are located in Florida; however, a few of top communities are located in South Carolina and North Carolina. About 53% of red snapper is landed in the top four communities (Cocoa, Mayport, Port Orange, and Cape Coral, Florida), representing about 52% of the South Atlantic-wide ex-vessel value for the species. The remaining top communities collectively represent about 32% of South Atlantic red snapper landings and 33% of ex-vessel value (including approximately 24% of landings and 24% of value for the Florida communities of Saint Augustine, Titusville, Melbourne, Ormond Beach, Key West, Winter Springs, Sebastian, and Merritt Island and approximatively 8% of landings and 9% of value for the South Carolina and North Carolina communities of Murrells Inlet, South Carolina and Morehead City and Beaufort, North Carolina).

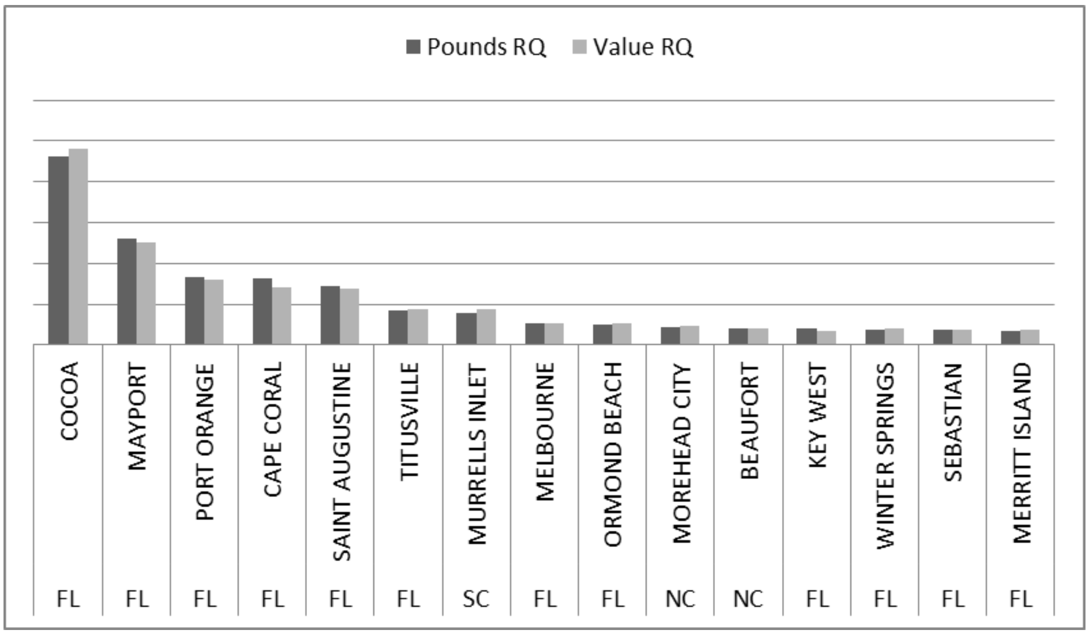

Figure 3.4.1. Top South Atlantic communities ranked by pounds and value regional of quotient (RQ) of red snapper.
The actual RQ values (y-axis) are omitted from the figure to maintain confidentiality.
Source: SERO, Community ALS 2014.

The commercial engagement and reliance indices of the top commercial red snapper communities are included in **Figure 3.4.2**. The details of how these indices are generated are explained at the beginning of the Fishing Communities section. Two thresholds of one and one-half standard deviation above the mean were plotted to help determine a threshold for significance. The primary communities that demonstrate high levels of commercial fishing engagement include Mayport, Cape Coral, Saint Augustine, Key West, Sebastian, and Merritt Island, Florida and Morehead City and Beaufort, North Carolina. The community with substantial commercial reliance is Mayport, Florida.

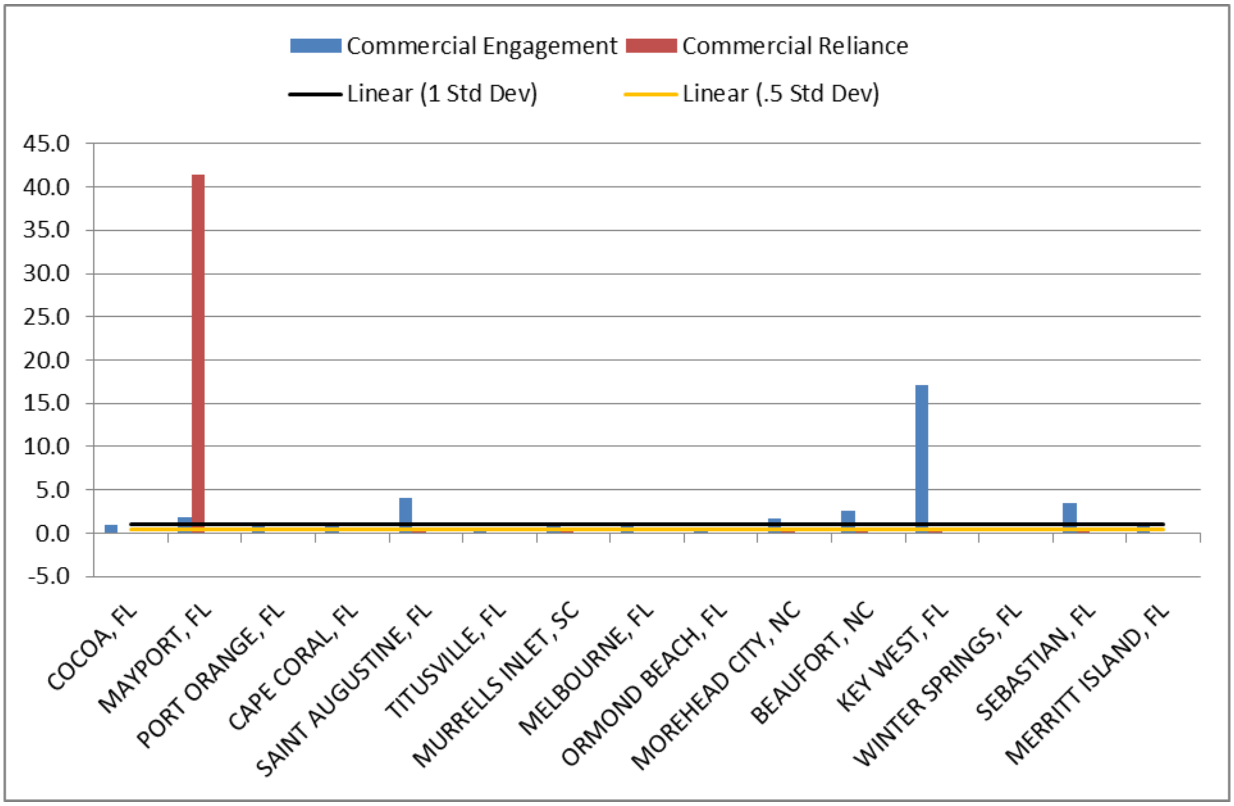

Figure 3.4.2. Commercial engagement and reliance for South Atlantic red snapper fishing communities. Source: SERO, Community Social Vulnerability Indicators Database 2014 (ACS 2010-2014).

Recreational Fishing Communities

Figure 3.4.3 identifies the top 20 recreational communities located in the South Atlantic that are the most engaged and reliant on recreational fishing, in general. All included communities demonstrate high levels of recreational engagement. Six communities (Key West, Florida; Marathon, Florida; Islamorada, Florida; Hatteras, North Carolina; Manteo, North Carolina; and Atlantic Beach, North Carolina) demonstrate high levels of recreational reliance.

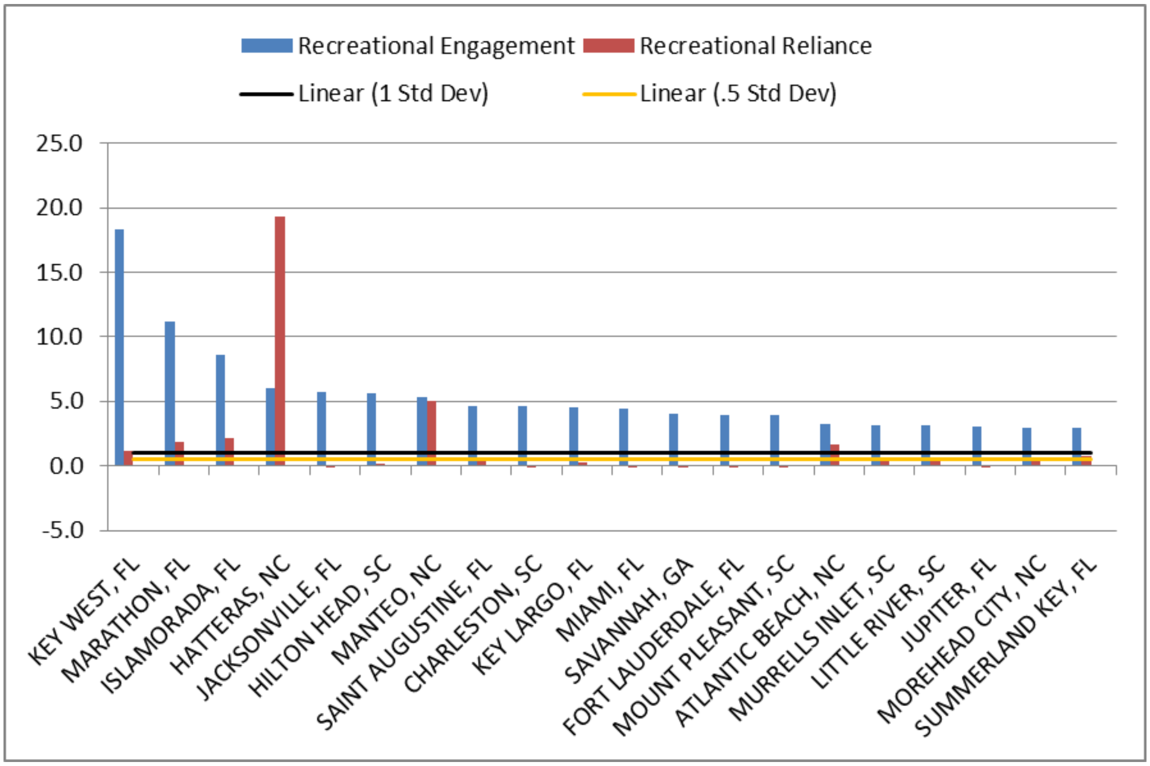

Figure 3.4.3. Top recreational fishing communities' engagement and reliance.
Source: SERO, Community Social Vulnerability Indicators Database 2014 (ACS 2010-2014).

3.3.2.3 Environmental Justice Considerations

Executive Order 12898 requires federal agencies conduct their programs, policies, and activities in a manner to ensure individuals or populations are not excluded from participation in, or denied the benefits of, or subjected to discrimination because of their race, color, or national origin. In addition, and specifically with respect to subsistence consumption of fish and wildlife, federal agencies are required to collect, maintain, and analyze information on the consumption patterns of populations who principally rely on fish and/or wildlife for subsistence. The main focus of Executive Order 12898 is to consider "the disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations in the United States and its territories…" This executive order is generally referred to as environmental justice (EJ).

Commercial and recreational fishermen and associated industries could be impacted by the proposed actions. However, information on the race and income status for groups at the different participation levels (individual fishermen and crew) is not available. Although information is available concerning communities overall status with regard to minorities and poverty (e.g., census data), such information is not available specific to fishermen and those involved in the industries and activities, themselves. To help assess whether any environmental justice concerns arise from the actions in this amendment, a suite of indices were created to examine the social vulnerability of coastal communities. These indices rely on data from the U.S. Census ACS 2010 through 2014 five-year estimates. The three indices are poverty, population composition, and personal disruptions. The variables included in each of these indices have been identified through the literature as being important components that contribute to a community's vulnerability. Indicators such as increased poverty rates for different groups, more single female-headed households and households with children under the age of five, disruptions such as higher separation rates, higher crime rates, and unemployment all are signs of populations experiencing vulnerabilities. Again, for those communities that exceed the threshold it would be expected that they would exhibit vulnerabilities to sudden changes or social disruption that might accrue from regulatory change.

Figure 3.4.4 and **Figure 3.4.5** provide the social vulnerability of the top commercial and recreational communities. Several South Atlantic communities exceed the threshold of one-half standard deviation for at least one of the social vulnerability indices: Cocoa, Marathon, Miami, and St. Augustine, Florida; Savannah, Georgia; and Beaufort, Manteo, and Morehead City, North Carolina. The communities of Cocoa, Florida; Miami, Florida; and Savannah, Georgia exceed the threshold for all three social vulnerability indices. These communities have substantial vulnerabilities and may be susceptible to further effects from any regulatory changes depending upon the direction and extent of that change.

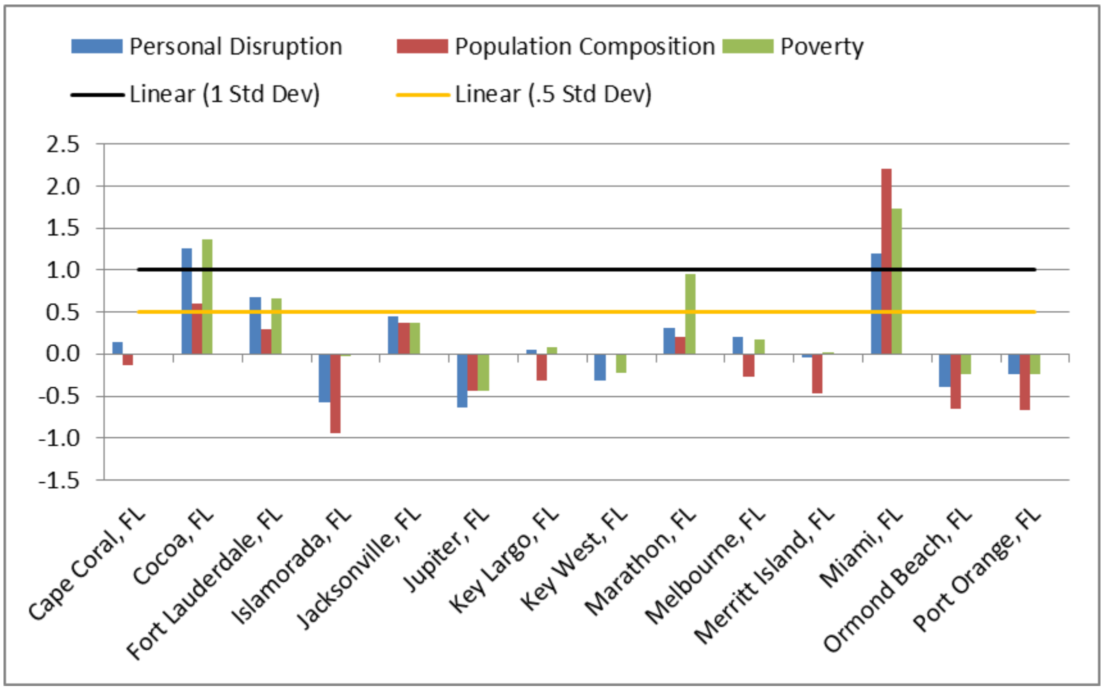

Figure 3.4.4. Social vulnerability indices for top commercial and recreational communities.
Source: SERO, Community Social Vulnerability Indicators Database 2014 (ACS 2010-2014).

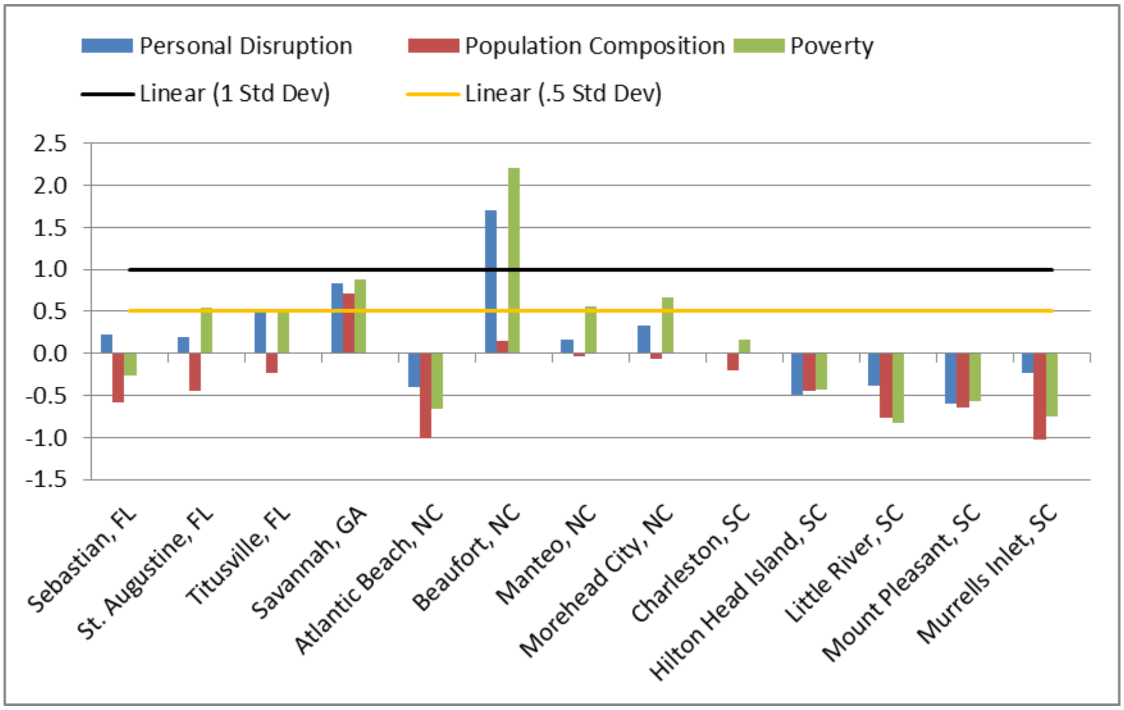

Figure 3.4.4. Social vulnerability indices for top commercial and recreational communities continued. Source: SERO, Community Social Vulnerability Indicators Database 2014 (ACS 2010-2014).

People in these communities may be affected by fishing regulations in two ways: participation and employment. Although these communities may have the greatest potential for EJ concerns, no data are available on the race and income status for those involved in the local fishing industry (employment), or for their dependence on red snapper specifically (participation). Although no EJ issues have been identified, the absence of potential EJ concerns cannot be assumed.

3.4 Administrative Environment

3.4.1 The Fishery Management Process and Applicable Laws

3.4.1.1 Federal Fishery Management

Federal fishery management is conducted under the authority of the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) (16 U.S.C. 1801 et seq.), originally enacted in 1976 as the Fishery Conservation and Management Act. The Magnuson-Stevens Act claims sovereign rights and exclusive fishery management authority over most fishery resources within the EEZ, an area extending 200 nm from the seaward boundary of each of the coastal states, and authority over U.S. anadromous species and continental shelf resources that occur beyond the U.S. EEZ.

Responsibility for federal fishery management decision-making is divided between the U.S. Secretary of Commerce (Secretary) and eight regional fishery management councils that represent the expertise and interests of constituent states. Regional councils are responsible for preparing, monitoring, and revising management plans for fisheries needing management within their jurisdiction. The Secretary is responsible for collecting and providing the data necessary for the councils to prepare fishery management plans and for promulgating regulations to implement proposed plans and amendments after ensuring that management measures are consistent with the Magnuson-Stevens Act and with other applicable laws. In most cases, the Secretary has delegated this authority to NMFS.

The Council is responsible for conservation and management of fishery resources in federal waters of the U.S. South Atlantic. These waters extend from 3 to 200 miles offshore from the seaward boundary of North Carolina, South Carolina, Georgia, and east Florida to Key West. The Council has thirteen voting members: one from NMFS; one each from the state fishery agencies of North Carolina, South Carolina, Georgia, and Florida; and eight public members appointed by the Secretary. On the Council, there are two public members from each of the four South Atlantic States. Non-voting members include representatives of the U.S. Fish and Wildlife Service, U.S. Coast Guard, State Department, and Atlantic States Marine Fisheries Commission (ASMFC). The Council has adopted procedures whereby the non-voting members serving on the Council Committees have full voting rights at the Committee level but not at the full Council level. The Council also established two voting seats for the Mid-Atlantic Council on the South Atlantic Mackerel Committee. Council members serve three-year terms and are recommended by state governors and appointed by the Secretary from lists of nominees submitted by state governors. Appointed members may serve a maximum of three consecutive terms.

Public interests also are involved in the fishery management process through participation on Advisory Panels and through council meetings, which, with few exceptions for discussing personnel and legal matters, are open to the public. The Council uses its Scientific and Statistical Committee (SSC) to review the data and science being used in assessments and fishery management plans/amendments. In addition, the regulatory process is in accordance with the Administrative Procedure Act, in the form of "notice and comment" rulemaking.

3.4.1.2 State Fishery Management

The state governments of North Carolina, South Carolina, Georgia, and Florida have the authority to manage fisheries that occur in waters extending three nautical miles from their respective shorelines. North Carolina's marine fisheries are managed by the Marine Fisheries Division of the North Carolina Department of Environmental Quality. The Marine Resources Division of the South Carolina Department of Natural Resources regulates South Carolina's marine fisheries. Georgia's marine fisheries are managed by the Coastal Resources Division of the Department of Natural Resources. The Marine Fisheries Division of the Florida Fish and Wildlife Conservation Commission is responsible for managing Florida's marine fisheries. Each state fishery management agency has a designated seat on the Council. The purpose of state representation at the Council level is to ensure state participation in federal fishery management decision-making and to promote the development of compatible regulations in state and federal waters.

The South Atlantic States are also involved through the Atlantic States Marine Fisheries Commission (ASMFC) in management of marine fisheries. This commission was created to coordinate state regulations and develop management plans for interstate fisheries. It has significant authority, through the Atlantic Striped Bass Conservation Act and the Atlantic Coastal Fisheries Cooperative Management Act, to compel adoption of consistent state regulations to conserve coastal species. The ASFMC is also represented at the Council level, but does not have voting authority at the Council level.

NMFS's State-Federal Fisheries Division is responsible for building cooperative partnerships to strengthen marine fisheries management and conservation at the state, inter-regional, and national levels. This division implements and oversees the distribution of grants for two national (Inter-jurisdictional Fisheries Act and Anadromous Fish Conservation Act) and two regional (Atlantic Coastal Fisheries Cooperative Management Act and Atlantic Striped Bass Conservation Act) programs. Additionally, it works with the ASMFC to develop and implement cooperative State-Federal fisheries regulations.

3.4.1.3 Enforcement

Both the NMFS Office for Law Enforcement (NOAA/OLE) and the United States Coast Guard (USCG) have the authority and the responsibility to enforce Council regulations. NOAA/OLE agents, who specialize in living marine resource violations, provide fisheries expertise and investigative support for the overall fisheries mission. The USCG is a multi-mission agency, which provides at sea patrol services for the fisheries mission.

Neither NOAA/OLE nor the USCG can provide a continuous law enforcement presence in all areas due to the limited resources of NOAA/OLE and the priority tasking of the USCG. To supplement at sea and dockside inspections of fishing vessels, NOAA entered into Cooperative Enforcement Agreements with all but one of the states in the Southeast Region (North Carolina), which granted authority to state officers to enforce the laws for which NOAA/OLE has jurisdiction. In recent years, the level of involvement by the states has increased through Joint Enforcement Agreements, whereby states conduct patrols that focus on federal priorities and, in some circumstances, prosecute resultant violators through the state when a state violation has occurred.

The NOAA Office of General Counsel Penalty Policy and Penalty Schedule is available online[15].

[15] http://www.gc.noaa.gov/enforce-office3.html.

Chapter 4. Environmental Effects and Comparison of Alternatives

4.1 Action 1. Revise the Process to Determine the Annual Catch Limits (ACL) for Red Snapper

4.1.1 Biological Effects

The following documents outline the biological effects of the current red snapper management regime and provide the background for the biological effects of **Alternative 1 (No Action)**:

- Emergency rule to establish a limited 2012 fishing season (NMFS 2012a,b)
- Amendment 28 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region (Snapper Grouper Amendment 28) (SAFMC 2013)

The reader is directed to these documents for details on the effects of the current management of red snapper. Amendment 28 is available at www.safmc.net, and hereby incorporated by reference.

> ***Alternatives****
>
> **Alternative 1 (No Action):** The commercial and recreational annual catch limits for red snapper are zero. Process in place to allow limited harvest based on ABC.
>
> **Alternative 2**. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify Total ACL = 23,623 fish. Commercial ACL = 69,360 lbs (whole weight). Recreational ACL = 16,480 fish.
>
> **Alternative 3**. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify Total ACL = 44,411 fish. Commercial ACL = 130,396 lbs (whole weight). Recreational ACL = 30,982 fish.
>
> **Alternative 4**. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify Total ACL = 42,510 fish. Commercial ACL = 124,815 lbs (whole weight). Recreational ACL = 29,656 fish.
>
> **Alternative 5**. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify Total ACL = 79,919 fish. Commercial ACL = 234,652 lbs (whole weight). Recreational ACL = 55,753 fish.
>
> * Refer to Chapter 2 for detailed language of alternatives

In summary, the South Atlantic Fishery Management Council (Council) and National Marine Fisheries Service (NMFS) determined that retention of a limited number of red snapper in 2012, along with appropriate management controls, would not jeopardize the rebuilding of the red snapper stock and established a limited season through emergency action in 2012. In 2013, Amendment 28 implemented a process to determine if a red snapper fishing season would occur each year, including specification of the allowable harvest and season lengths for the commercial and recreational sectors (78 FR 44461, July 24, 2013). Amendment 28 also included a formula to determine the annual catch limit (ACL) for each sector; as well as management measures (limited fishing seasons, no minimum size limit, one fish per person per day recreational bag limit, and 75 pounds (lbs) commercial trip limit), if fishing were allowed. Following the management measures of Amendment 28, the total removals exceeded the accepted biological catch (ABC) in 2014, 2015, and 2016, and the harvest of red snapper has been prohibited since 2015 (**Table 4.1.1**).

Table 4.1.1. Total removals (landings and dead discards) of red snapper during the limited fishing seasons for the commercial and recreational sectors in 2012, 2013, and 2014.

Year	Allowable Removals (numbers of fish)	Total Removals (numbers of fish)	Commercial Fishing Season	Recreational Fishing Season
2012	86,000	Commercial= 13,317 HB= 4,606 Charter= 9,264 Private= 53,329 Total= 80,516	Sept 17-24; Reopened Nov 13-21 and Dec 12-19 (22 days)	Sept 14-17, and Sept 21-24 (6 days)
2013	96,000	Commercial=16,779 HB=20,683 Charter (FL study)=5,395 Private (FL study)=29,919 Total (FL study)=72,776	Aug 26-Oct 8 (43 days)	Aug 23-Aug 26 (3 days)
2014	106,000	Commercial=24,827 HB=22,063 Charter=20,619 Private=138,350 Total=205,859	Jul 14-Sept 9 (57 days)	Jul 11-14, Jul 18-21, Jul 26-27(8 days)

Under **Alternative 1 (No Action)**, the commercial and recreational ACLs for red snapper would be zero in 2018. **Alternative 2** through **5** would allow limited harvest of red snapper beginning in 2018 (**Table 4.1.2**). The existing management measures such as season start dates, commercial trip limit, and recreational bag limit would remain unchanged from those implemented by the final rule for Amendment 28 (78 FR 44461, July 24, 2013). When possible, the South Atlantic Council prefers specifying the recreational ACL in numbers of fish and the commercial ACL in pounds whole weight. The rationale is that recreational landings are already tracked in numbers of fish while commercial landings are tracked in pounds. However, the total ACL is specified in numbers of fish. To ensure that allocation is derived using the formula established in the Comprehensive ACL Amendment (SAFMC 2011b), the numbers of fish were converted to weight of red snapper (see **Appendix K** for more details). Based on the allocation formula implemented by the Comprehensive ACL Amendment (SAFMC 2011b), the commercial allocation is 28.07% of the total landings in pounds and recreational allocation is

71.93%. The commercial and recreational ACLs for each sector under each of the proposed alternatives are provided in **Table 4.1.2.**

Table 4.1.2. Proposed total, commercial, and recreational red snapper ACLs for 2018 in numbers of fish and pounds whole weight.

Alternative	Total ACL Number	Total ACL Weight (lbs ww)	Commercial ACL Weight (lbs ww)	Commercial ACL Number	Recreational ACL Weight (lbs ww)	Recreational ACL Number
Alt 1	0	0	0	0	0	0
Alt 2	23,623	247,097	75,537	7,143	177,737	16,480
Alt 3	44,411	464,539	130,396	13,429	334,143	30,982
Alt 4	42,510	444,655	124,815	12,854	319,840	29,656
Alt 5	79,919	835,953	234,652	24,166	601,301	55,753

Commercial conversion factor is 9.71 lbs based on average weight of commercially caught red snapper from 2012 to 2014 in SEDAR 41 (2017). Recreational weight and number is the difference between total ACL weight/number and commercial weight/number.

ACLs proposed under **Alternatives 2** and **3** use the average landings from 2012 to 2014 (**Table 4.1.2**). **Alternative 2** is based on the average landing from 2012 to 2014. **Alternative 3** is based on the average landings from 2012 to 2014 multiplied by an adjustment factor based on the increase in the average catch rate of red snapper observed in the scientific survey in 2015 and 2016 compared to average catch rate from 2012, 2013, and 2014 (1.88 times, **Figure 4.1.1**).

Alternatives 4 and **5** propose using maximum recorded landings to establish the ACL (**Table 4.1.2**). **Alternative 4** is set equal to the maximum landings from 2012 to 2014. **Alternative 5** is the maximum landings multiplied by the adjustment factor discussed above (**Table 4.1.2**). **Alternative 5** is higher than landings from 2012 to 2014.

Alternative 3 and **Alternative 5** are different that values that were in a draft Amendment 43 presented at the June Council meeting. The revised values reflect NMFS SEFSC's guidance to use a calculation more similar to the approach used in SEDAR 41 (2017). Revised values were provided using the improved methodology and further described in **Appendix K**.

Recreational landings of red snapper in the South Atlantic EEZ was not allowed in 2010, 2011, 2015 and 2016, and was only open for short periods of time in 2012 (6 days), 2013 (3 days), and 2014 (8 days). Recreational landings ranged from 6,629 fish to 31,069 during 2012-2014 (**Table 4.1.3**). The total number of red snapper landed in 2014 value in **Table 4.1.3** is different than the **Alternative 4** recreational sector ACL (**Table 4.1.2**) because the ACL had to be divided among the recreational and commercial sectors using the allocation established in the Comprehensive ACL Amendment (2011b). The total ACL in number of fish had to be converted to weight to use the allocation. These conversions led to differences in the reported recreational landings (**Table 4.1.3**) and the recreational sector ACL (**Table 4.1.2**).

Table 4.1.3. Recreational landings (numbers of fish) for red snapper by wave, 2012-2016.

	Jan/Feb	Mar/Apr	May/June	Jul/Aug	Sep/Oct	Nov/Dec	Total
2012	1	478	353	79	14,080	0	14,991
2013	0	2	403	2,050	4,160	14	6,629
2014	1,151	45	722	28,798	19	334	31,069
2015	0	847	467	486	56	14	1,870
2016	0	1	188	205	3	6	403

Note: Landings in Florida state waters is allowed for red snapper.

NMFS completed the red snapper season analysis for 2018 based on the process in Amendment 28. At the present time commercial landings are available from January 1st to July 11, 2017, and recreational landings and discards are available from January 1st to April 30, 2017. **Table 4.1.4** summarizes the available 2017 landings and discards in numbers of fish. The total removals in 2017 (152,459 fish) already exceed the ABC for 2017 (128,000 fish). Since the ABC has already been exceeded in 2017, the ACL for 2018 would be set to zero according the process in Amendment 28 (**Alternative 1 (No Action))**.

Table 4.1.4. Estimated landings and dead discards by sector equaling total removals for South Atlantic red snapper in 2017.

Variable	Number of Fish 2017
Commercial Landings	93
Recreational Headboat Landings	3
Recreational Charter Dead Discards	12,806
Recreational Private Dead Discards	139,557
Total Removals	152,459

The short recreational openings in 2012, 2013, and 2014, occurred over different months; therefore, landings from different months and years were combined to predict future landings (see **Appendix O** for more details on the data analysis and projections for the recreational sector). **Table 4.1.5** shows the predicted landings and closure dates in 2018, assuming the recreational sector opens to harvest on Jul 13, 2018. The “Predicted Landings” scenario is a prediction of future landings, and the “High Landings” scenario is an adjusted prediction using a 1.88 adjustment factor following the assumption of a larger stock size. Under the “Predicted Landings” scenario, the recreational fishery would be open for as short as 4 days (**Alternative 2**) and as long as 28 days (**Alternative 5**); and would be open for 7 days under **Alternative 4 (Table 4.1.5)**. Under the “High Landings” scenario, the recreational fishery would be open for as short as 2 days (**Alternative 2**) and as long as 8 days (**Alternative 5**); and would be open for 4 days under **Alternatives 3** and **4 (Table 4.1.5)**.

Table 4.1.5. Predicted closure dates (number of open days) for the recreational sector under the different proposed ACL alternatives for 2018.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
ACL	**TBD**	**16,480 Fish**	**30,982 Fish**	**29,656 Fish**	**55,753 Fish**
Predicted Landings	TBD	21-Jul (4)	28-Jul (7)	28-Jul (7)	15-Sep (28)
High Landings	TBD	15-Jul (2)	21-Jul (4)	21-Jul (4)	29-Jul (8)

Note: These closure dates assume the recreational sector starts on Friday, July 13, 2018. Under **Alternative 1 (No Action),** according to preliminary estimates, the fishery has exceeded the ABC in 2017 and the ACL would be set to zero in 2018. See **Appendix O** for more details.

The South Atlantic red snapper commercial fishery was closed in 2010, 2011, 2015 and 2016, and was only open for short periods of time in 2012 (22 days, harvesting 6,872 lbs), 2013 (43 days, 27,309 lbs), and 2014 (57 days, 54,887 lbs)[16]. **Figure 4.1.1** shows the pounds per commercial trip harvested for the two most recent years (2013 and 2014) under the 75 pounds gutted weight (lbs gw) trip limit.

The short commercial openings in 2012, 2013, and 2014 occurred over different months; therefore, landings from different months and years were combined to predict future landings (**Table 4.1.6**, see Appendix N for more details). **Table 4.1.6** shows the predicted landings and closure dates in 2018, assuming the commercial sector opens to harvest on July 9, 2018. The "Predicted Landings" scenario is a prediction of future landings, and the "High Landings" is the prediction of future landings with a 34% increase in landings following the assumption that more fishermen will meet the trip limit of 75 lbs gw due to an increased stock size. Under **Alternatives 3** through **5** and using the "Predicted Landings" scenario, the commercial fishery would not close **(Table 4.1.6)**. Under **Alternative 2** and using the "Predicted Landings", the commercial fishery would close September 17, 2018. If the "High Landings" scenario is used, the commercial fishery would close for all alternatives except **Alternative 5**. Closing dates range from August 23 to October 21.

[16] http://sero.nmfs.noaa.gov/sustainable_fisheries/acl_monitoring/commercial_sa/historical/index.html).

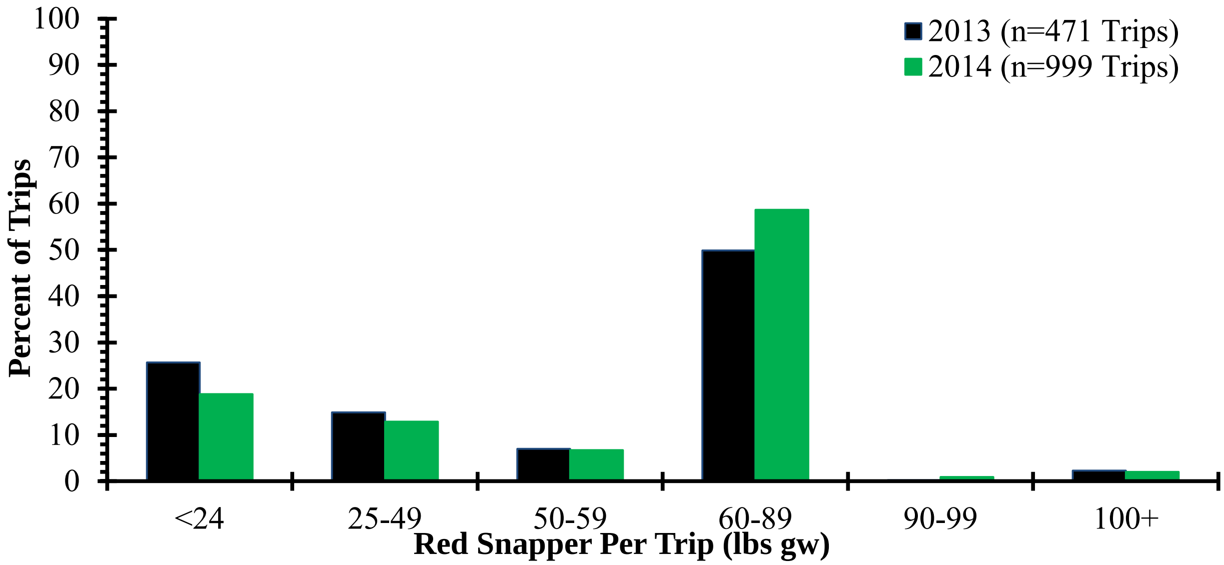

Figure 4.1.1. Distribution of commercial red snapper harvested per trip (lbs gw) in 2013 and 2014. Source: Commercial logbook dataset.

Table 4.1.6. Predicted closure dates for the commercial sector under the different proposed ACL alternatives for 2018.

	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**
ACL		**69,360 lbs ww**	**130,396 lbs ww**	**124,815 lbs ww**	**234,652 lbs ww**
Predicted Landings	TBD	17-Sep	No Closure	No Closure	No Closure
High Landings	TBD	23-Aug	26-Nov	21-Oct	No Closure

Note: These closure dates assume the recreational sector starts on Monday, July 9, 2018. Under **Alternative 1 (No Action),** according to preliminary estimates, the fishery has exceeded the ABC in 2017 and the ACL would be set to zero in 2018. See **Appendix O** for more details.

Alternative 1 (No Action), would result in no commercial or recreational harvest of red snapper allowed in 2018 due to exceeding the ABC in 2017. While allowing no harvest might be biologically beneficial to a stock, it is expected that the resulting level of dead discards would continue to increase, possibly resulting in negative biological effects. Estimated removals from 2012 to 2016 ranged from 72,881 fish in 2013 to 407,025 fish in 2016 (**Table 2.1.1**). These estimates of removals were not recommended for use in management due to uncertainty in Marine Recreational Information Program estimates (**Appendix J**), and ACL alternatives were developed using a combination of estimates from other monitoring programs (see **Appendix O**). Meanwhile, fishery-independent data suggest that the red snapper population in the South Atlantic is steadily increasing, indicating that the recent level of removals has not negatively affected recent population growth since 2014. Therefore, the long-term biological effects of continued high bycatch and resulting mortality on the red snapper stock are unknown. **Alternatives 3** and **5** propose ACLs above recent catch levels since they are adjusted to account for perceived recent population growth by a factor of 1.88. Therefore, these alternatives might result in negative biological effects over the status quo since it is not known how the stock might be impacted and whether such levels of harvest could result in overfishing. **Alternatives 2** and **4** would be less likely to result in negative biological effects since they propose ACLs based on 2012-2014 catch levels and data suggest red snapper abundance increased from 2014 levels by 35% in 2015 and an additional 12% in 2016. SEDAR 41 (2017) suggested that overfishing could occur due to the level of landings that occurred in 2014, the terminal year of the assessment; however, this remains uncertain since such a determination is based on the ratio of landings compared to population size and, according to fishery-independent data, red snapper abundance has increased since 2014. Hence, the greatest beneficial effects to the biological environment are expected under **Alternative 1 (No Action)**, followed by **Alternatives 2**, **4**, **3** and **5**.

Alternative 2 through **5** have the potential benefit of providing data for future stock assessments. Red snapper are a long-lived fish reaching ages up to 50 years old. Because they are a long-lived fish, age-based stock assessment models, which have been used to assess red snapper in SEDARs 15 (2008), 24 (2010), and 41 (2016), are likely the best type to determine the status of the stock. Ages are an important component to determine status of the stock and may be more important than other pieces of information because the decline in abundance at age is critical information for determining mortality rates (Yin and Sampson 2004, Siegfried et al. 2016). These age data are informative even when the level of removals is uncertain, as is the case with red snapper. Fishery-dependent age composition data from recreational and commercial catches are unavailable for years after 2014 because there have been no landings to sample for ages. The only available data for ages is from the fishery-independent SERFS index. While this survey is a great source of information, the survey alone may not be sufficient to produce adequate data for an age-based stock assessment. A primary concern is that ages collected from a single survey or fishery have been shown to result in biased age and growth curves (Huse et al. 1999, Binion et al. 2009). Bias in age composition data can lead to issues with estimating fishery selectivity, fishing levels, and biomass (Bertignac and Pontual 2007, Hulson and Hanselman 2014). While information on the selectivity of the survey can be used to reduce bias, the lack of information on the ages or sizes of fish not represented in the survey can greatly increase assessment uncertainty. Allowing some level of landings through **Alternative 2** through **5** that facilitate collecting representative age data would be extremely beneficial to future stock assessments needed to track the recovery of red snapper. Ensuring that representative age data are available for future assessments can potentially reduce the chance of inaccurately characterizing the status of the stock.

Observers are collecting red snapper length data on headboats from Florida to North Carolina and on charter boats from Florida. These data need to be combined with age data to determine the age structure of the caught fish because it can be difficult to estimate the age of a red snapper based on its length. For example, a red snapper that is 20 inches (508 mm TL; the former size limit) can be anywhere from 2 to 10 years old based on observed data in SEDAR 41 (2017).

Therefore, age distributions based on past length distributions alone may not accurately describe the current age distribution of the stock.

The Bycatch Practicability Analysis (**Appendix D**) evaluates the practicability of taking additional action to minimize bycatch and bycatch mortality using the ten factors provided at 50 CFR section 600.350(d)(3)(i). The action proposed in Amendment 43 has the potential to reduce bycatch of red snapper during a limited opening of the recreational and commercial sectors as some bycatch is turned into retained catch. The action is not expected to result in significant changes in bycatch of red snapper. In addition, the Council, NMFS, and the SEFSC have developed and plan to implement numerous management measures and reporting requirements that have improved, or are likely to improve monitoring efforts of discards and discard mortality.

In the 2016 biological opinion, NMFS analyzed the effects of commercial and recreational hook-and line hook-and-line gear in the snapper-grouper fishery on sea turtles, smalltooth sawfish, and Nassau grouper assuming 2012-2015 average hook-and-line effort levels are representative of future effort levels in the snapper-grouper fishery (NMFS 2016). Thus, for three of the four years (i.e., 2012-2014) used to project average effort levels, the recreational and commercial red snapper fishery was open for short periods of time, as now being considered again in this Amendment

Thus continued fishing effort levels under the status quo would potentially reduce overall effort in the fishery from 2012-2015 average hook-and-line effort levels and thus decrease potential bycatch in the fishery. Overall fishing effort could increase in the commercial and recreational sectors slightly in response to the limited reopening(s) of red snapper under Alternatives 2 through 5, and therefore, increase the potential for bycatch, relative to the status quo. However, as stated in Chapter 2 and analyzed in detail in Chapter 4, the reopening(s) would be of short duration in the recreational sector and limited to an incidental catch limit (75 lbs) in the commercial sector (see Chapter 6 for details), therefore potential increases in overall fishing effects would be very small and potential increases in incidental captures given their rarity unlikely.

4.1.2 Economic Effects

As described in **Section 4.1.1**, it is expected that the red snapper stock will continue to rebuild under **Alternatives 1, 2**, and **4**, despite allowing for a limited harvest of red snapper, and it is unknown how the stock will respond under **Alternatives 3** and **5**. It is also expected that no harvest will be allowed for either sector under **Alternative 1 (No Action)**, as the high level of discards of red snapper that have kept the fishery closed to harvest over the past two years are unlikely to improve as the stock continues to rebuild. **Alternative 1 (No Action)** would be expected to have no impact on the rebuilding rate of the red snapper stock; however, because no fishing would be allowed to occur in the foreseeable future, it would result in foregone direct, short-term economic benefits to the commercial and recreational sectors.

The expected changes in commercial ex-vessel revenue and recreational consumer surplus (CS) relative to the status quo (**Alternative 1 (No Action)**) under **Alternative 2**, **Alternative 3**, **Alternative 4**, and **Alternative 5** are provided in **Table 4.1.7**. For the commercial sector, the ex-vessel revenue is presented as a range, using two sets of projected landings. The lower bound is based on predicted landings under the current stock size and the upper bound is based on higher predicted landings that are adjusted for an increased stock size (see **Appendix N** and **Appendix O**). Although some small level of state landings have occurred in recent years during the federal closures, it is not expected that the current action would affect state landings and so they are excluded from this analysis.

Under **Alternative 2**, **Alternative 3**, **Alternative 4**, and **Alternative 5**, it is estimated that ex-vessel revenue would increase, relative to the status quo (**Alternative 1 (No Action)**), by a range of approximately $318,000 to $732,000 (2016 dollars; **Table 4.1.7**)[17]. Under these alternatives the commercial season would be open for 45 to 175 days in 2018. Estimates vary depending on the alternative being examined and the landings assumption used. With regard to economic effects on the recreational sector, it is estimated that recreational CS and season length would scale up proportionally to the ACL that is implemented and range from approximately $1.34 million to $4.52 million[18]. The recreational season would be open for 2 to 28 days in 2018.

Table 4.1.2.1. Estimated change in commercial ex-vessel revenue, recreational consumer surplus (CS), and season length relative to the status quo.

	Commercial ex-vessel revenue (2016 dollars)	Commercial season length (days)*		Recreational consumer surplus (2016 dollars)	Recreational season length (days)**
Alternative 1 (No Action)	0	0		0	0
Alternative 2	$318,362	45 to 70		$1,334,880	2 to 4
Alternative 3	$545,981 to $598,518	140 to 175		$2,509,542	4 to 7
Alternative 4	$545,981 to $572,901	104 to 175		$2,402,136	4 to 7
Alternative 5	$545,981 to $731,614	175		$4,515,993	8 to 28

Source: SERO LAPP/DM (Appendix N and O) for landings and season length projections; WTP per red snapper from Carter and Liese (2012) (see **Section 3.3.2**); Ex-vessel average annual price (2012-2014 only) of $4.59 (2016 dollars) from SERO ACL dataset (May 2017).
*The commercial red snapper season would open on July 9, 2018 until which time the ACL is projected to be met.
*The recreational red snapper season would open on July 13, 2018 for Fridays, Saturdays, and Sundays only, until which time the ACL is projected to be met.

[17] Only 2012-2014 (the years when commercial harvest of red snapper in federal waters of the South Atlantic was open) were used for average price calculations. This is to minimize potential bias from misreported landings or variations in the size and quality of state- versus federally-caught fish during fully-closed years.
[18] The estimates of CS are based on a willingness to pay of $81 for a second fish harvested on a trip (Carter and Liese 2012; 2016 dollars) (**Section 3.3.2**). An estimate for the first red snapper harvested on an angler trip is not available. Given the current one fish per person bag limit and the assumption of diminishing marginal utility per fish harvested, the CS estimate provided may potentially underestimate the value of allowing for red snapper harvest beginning in 2018.

By allowing for recreational red snapper harvest, there is the potential that angler demand for for-hire (charter and headboat) trips would increase as well, resulting in increased booking rates and for-hire business net operating revenue (NOR). Due to the complex nature of angler behavior and the for-hire industry, it is not possible to quantify these potential economic effects with available data.[19] As such, no estimates of the change in for-hire NOR are provided, although they may exist. The estimates of NOR per charter and headboat trip in the South Atlantic are provided in **Section 3.3.2**. It is expected that as the ACL increases, so would the potential for increases in for-hire NOR. This is because a larger ACL would result in a longer red snapper fishing season, affording for-hire businesses greater opportunity to market and sell their services.

As discussed in **Section 3.3.1** and **Section 3.3.2**, commercial and recreational fishing for red snapper spurs business activity (economic impacts) in the region in which it occurs. This action may be reasonably expected to increase such business activity relative to the status quo, by increasing recreational and commercial expenditures on goods and services necessary for fishing and by increasing the supply of red snapper into the seafood value chain. Although retail prices for red snapper would likely be tempered by substitute finfish species and snapper imports, fresh locally-caught red snapper may fetch a price premium in seafood markets and restaurants, resulting in an increase in producer surplus. In addition, because seafood consumers may have strong preferences for locally-caught red snapper over other seafood options, it could result in an increase in consumer surplus as well. These potential economic benefits cannot be quantified with available data.

In addition to the short-term economic effects described above, medium to long-term indirect negative economic effects could ensue from this action as a result of its effects on the red snapper stock, future management decisions, and future catch rates. It is not known if any of the alternatives would be likely to jeopardize the sustainability of the stock but the negative economic effects would be more likely with **Alternatives 3** and **5** as these two alternatives set ACLs above recently observed levels of harvest for the species.

Given the increasing economic benefits associated with higher ACLs for red snapper, **Alternative 5** will provide the largest positive economic effects, at least in the short-term, followed by **Alternative 3**, **Alternative 4**, **Alternative 2**, and **Alternative 1 (No Action)**.

4.1.3 Social Effects

The communities with the largest levels of red snapper landings, in addition to communities with highest engagement and reliance on commercial and recreational fishing are described in **Section 3.3.2**. Red snapper is an extremely popular species, especially for participants in the

[19] Anglers have heterogeneous preferences and may target and/or harvest a diverse mix of snapper grouper and other species on a trip. The absence of the opportunity to fish for any single species may or may not affect their overall desire to take/pay for trips.

recreational fishery. The absence of a fishing season for red snapper in recent years has been highly controversial with negative effects on recreational anglers, for-hire businesses and commercial vessels, especially when compared to the benefits to fishermen during the allowed seasons in 2012, 2013, and 2014. The social effects of the proposed alternatives are expected to be associated with restricted access to the red snapper resource for several years, combined with distrust in science and management due to inconsistency in what fishermen see on the water versus the scientific models. Additionally, there will be social effects associated with transforming discards into landings if there is a fishing season, along with social effects of improved data collection during a fishing season.

Alternative 1 (No action) would keep the current system that determines if red snapper harvest will be allowed each year, based on removals from the previous year. In the most recent two years (2015, 2016, and 2017), there has been no red snapper season, even for a few days. The rebuilding plan for red snapper implemented through Amendment 17A (SAFMC 2010) is considered to be working successfully, and this should lead to expected benefits to the fishermen. However, the outcome of the successful rebuilding plan is that interactions with red snapper have become more difficult to avoid, which leads to the discard rate that calculates to high levels of removals each year. Under current conditions, it is likely that there will be no open fishing seasons for red snapper in the foreseeable future under **Alternative 1 (No action)**.

Input from fishermen indicate that they are more and more frustrated with the perceived waste of the resource due to discards of red snapper. Additionally, under **Alternative 1 (No action)**, there is distrust in the science because harvest is prohibited, but fishermen report that there are plenty of red snapper. The current system sends a conflicting message to fishermen in that regulations are intended to protect stocks and rebuild overfished stocks, but there will be no benefit to the fishermen because the Council and NMFS cannot allow any harvest of red snapper.

By allowing an ACL for red snapper in **Alternative 2** through **5**, there should be positive social effects as it would allow fishermen to harvest this popular species, in addition to revenue generated for charter/headboat and commercial businesses when compared to **Alternative 1 (No action)**. It is assumed that with available ACL, there would be increased fishing opportunities for private, for-hire and commercial fishermen, and that there would be fewer discards as these fish are landed. Therefore, with the expected ACLs under the proposed alternatives, the most social benefits would be expected under **Alternative 5**, followed by **Alternative 3**, **Alternative 4**, **Alternative 2,** and then **Alternative 1 (No Action).**

4.1.4 Administrative Effects

Chapter 5. Council's Choice for the Preferred Alternatives

5.1 Action 1. Revise the Process to Determine the Annual Catch Limits (ACLs) for Red Snapper

5.1.1 Snapper Grouper Advisory Panel (AP) Comments and Recommendations

The Snapper Grouper AP discussed actions in Amendment 43 during their April 17-19, 2017 meeting. At that time, however, Amendment 43 contained different actions than the one currently proposed. Hence the Snapper Grouper AP did not have recommendations for setting the ACL for red snapper. Regarding possible management measures, AP members offered the following comments:

- Regarding a possible commercial trip limit, the AP stated that specifying it in numbers of fish might lead to high grading. If the allowable harvest results in a low trip limit, then don't consider a size limit.
- Because of the depths where commercial harvest takes place, there shouldn't be a minimum size limit requirement. Consider full retention for the commercial sector.
- Red snapper should continue to be managed as a bycatch fishery in the commercial sector.
- Consider initially allowing a recreational harvest two days per week to make it easier for fishermen to plan trips and for enforcement.

Alternatives*

Alternative 1 (No Action): The commercial and recreational annual catch limits for red snapper are zero. Process in place to allow limited harvest based on ABC.

Alternative 2. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify Total ACL = 23,623 fish. Commercial ACL = 69,360 lbs (whole weight). Recreational ACL = 16,480 fish.

Alternative 3. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify Total ACL = 44,411 fish. Commercial ACL = 130,396 lbs (whole weight). Recreational ACL = 30,982 fish.

Alternative 4. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify Total ACL = 42,510 fish. Commercial ACL = 124,815 lbs (whole weight). Recreational ACL = 29,656 fish.

Alternative 5. Remove the process and equation used to determine the red snapper ACL as specified in Snapper Grouper Amendment 28. Specify Total ACL = 79,919 fish. Commercial ACL = 234,652 lbs (whole weight). Recreational ACL = 55,753 fish.

* Refer to Chapter 2 for detailed language of alternatives

5.1.2 Law Enforcement AP Comments and Recommendations

The Law Enforcement AP discussed Amendment 43 during their May 18-19, 2017 meeting. At that time, however, Amendment 43 contained different actions than the one currently proposed. Hence the Law Enforcement AP did not have recommendations for setting the ACL for red snapper. Regarding possible management measures, Law Enforcement AP members offered the following comments:

- For small trip limit amounts (i.e., 25 pounds) it would be easier to specify trip limit in numbers of fish
- Highgrading is a concern and not easy to prevent; using numbers instead of weight would be useful for enforcement.

5.1.3 Scientific and Statistical Committee (SSC) Comments and Recommendations

The SSC discussed Amendment 43 during their April 25-27, 2017 meeting. At that time Amendment 43 included options for red snapper bag, trip, and size limits and seasons for recreational and commercial sectors as well as potential area and season combinations. Also included were options to establish a permit and reporting requirements for private recreational fishermen and best fishing practices. Below are summarized comments/recommendations from the meeting report on the red snapper stock assessment:

- The SSC received a presentation from Southeast Fisheries Science Center (SEFSC) staff on revisions to the red snapper assessment (SEDAR 41). The revisions addressed the headboat discard index SEFSC staff indicated that the differences between the original and corrected assessment were minimal but the new likelihood estimator was not investigated in the corrected assessment. However, the SSC noted that the corrected Maximum Sustainable Yield is 7% lower than in the original assessment, and a side by side comparison was not included in the report. The results of the corrected assessment were not further discussed as the SSC was unable to provide an acceptable biological catch (ABC) recommendation for red snapper.
- SEFSC staff clarified that the red snapper assessment is still considered Best Scientific Information Available (BSIA). However, the data available to monitor the landings and discards are too uncertain to track any projected ABC. Therefore, an index-based approach is being proposed to track and monitor the condition of red snapper.
- The projected yield streams from SEDAR 41 are still considered BSIA, but are not useful for management and monitoring because of the uncertainty in the catch data (as most of the catch is discarded).

The SSC provided further commetns and recommendations on red snapper management that are not directly relevant to the action proposed in Amendment 43. Refer to the April 2017 SSC report for additional details.

5.1.4 Public Comments and Recommendations

The Council held public scoping meetings from January 23 to February 8, 2017 at various locations in the four South Atlantic states. The actions included for scoping at that time differ from what is being considered currently in Amendment 43. A summary of public comments received during those meetings was provided to the Snapper Grouper Committee at the March 2017 Council meeting in Jekyll Island, GA. The summary also included written comments received via the online comment form on the Council's website or other means such as by mail, fax, or email. In total, there were 144 comments provided during the public comment period that ended on February 10, 2017. Of these, 69 were submitted verbally and 77 were submitted in writing. The summary of comments can be found on the March 2017 meeting brefing book available on the Council's website.

The Council will hold public hearings on Amendment 43 via webinar on August 3-10, 2017 and during the September 11-15, 2017, Council meeting.

5.1.5 Council's Rationale

Annual catch limits are established with accountability measures to prevent overfishing. Typically the annual catch limit is established below the acceptable biological catch; however, the Scientific and Statistical Committee was unable to provide an acceptable biological catch recommendation for red snapper based on the revised SEDAR 41 assessment (SSC 2017). The landings and discard data were too uncertain to track any projected acceptable biological catch. The Scientific and Statistical Committee also indicated that the stock status was still valid, the increasing number of discards had a high probability of reflecting increases in population size, and a short season to obtain representative age samples would require a scientific design. While the Scientific and Statistical Committee and National Marine Fisheries Serive continue to work on developing methods to develop an acceptable biological catch that can be tracked, the Council is proposing to establish a conservative annual catch limit based on past red snapper landings.

Alternative 4 proposes a higher annual catch limit than **Alternative 2** and therefore would have a greater social and economic benefit, which meets the purpose of the action. **Alternative 4** relies on an observed landings level and does not assume an increase in red snapper abundance thereby reducing the chances that allowing that level of harvest would lead to overfishing. However, **Alternative 4** proposes a lower annual catch limit than **Alternatives 3** and **5** and therefore is expected to result in lower social and economic benefit. However, **Alternatives 3** and **5** propose scaling the landings based on fishery-independent survey observations and may cause overfishing since the correlation between survey data and the true population abundance is unknown.

In-seasons closures will be used to prevent landings from exceeding the ACL. For the recreational sector, season length would be calculated based on past fishing rates and the Natinal Marine Fisheries Service would issue a notification specifying a season. For the commercial sector, landings would be tracked using the weekly reporting system and harvest would close when the commercial annual catch limit is met or is projected to be met. These accountability measures combined with the ACL proposed in **Alternative X**, would best meet the purpose of revising the ACL for the red snapper component of the snapper grouper fishery to increase socio economic benefits to fishermen while preventing overfishing.

5.1.6 How is this Action Addressing the Vision Blueprint for the Snapper Grouper Fishery?

The Vision Blueprint for the Snapper Grouper Fishery (Vision Blueprint) was approved in December 2015 and is intended to inform management of the snapper grouper fishery through 2020. As such, the Vision Blueprint serves as a "living document" to help guide future management, builds on stakeholder input and how the Council envisions future management of the fishery, guides the development of new amendments that address priority objectives and strategies, and illustrates actions that could be developed through the regular amendment process. The Vision Blueprint is organized into four strategic goal areas: (1) Science, (2) Management, (3) Communication, and (4) Governance. Each goal area has a set of objectives, strategies, and actions.

Action 1 to revise the annual catch limit for red snapper in the South Atlantic would address Objective 3: "Ensure that management decisions help maximize social and economic opportunity for all sectors" under the Management Goal. Specifically, the action would respond to Strategy 3.2: "Consider development of management approaches that support recreational fishing and allow increased opportunity for trip satisfaction". Allowing limited recreational harvest of red snapper in the South Atlantis is expected to increase fishing opportunities and trip satisfaction for fishermen who have very limited access to red snapper in recent years. In addition, Action B under Strategy 3.2 to "Consider mechanisms based on abundance and availability of easily accessible species" is also being addressed through the action in Amendment 43 since allowing a limited harvest of red snapper is being considered based partly on recent increases in abundance as indicated by a scientific survey. As the red snapper stock in the South Atlantic region continues to rebuild, fishermen are interacting with red snapper more frequently as evidenced by the estimates of discarded fish and fishermen's testimony. Further, the action being considered in Amendment 43 to specify the timeframe during which retention of red snapper would be allowed responds to a "hot topic" under Objective 3 to "Set a fishing season at the beginning of the fishing year with known open and close dates."

Chapter 6. Cumulative Effects

6.1 Affected Area

The immediate impact area would be the federal 200-mile limit of the Atlantic off the coasts of North Carolina, South Carolina, Georgia, and east Florida to Key West, which is also the South Atlantic Fishery Management Council's (Council) area of jurisdiction. In light of the available information, the extent of the boundaries would depend upon the degree of fish immigration/emigration and larval transport, whichever has the greatest geographical range. The ranges of affected species are described in **Section 3.2**. For the actions found in Amendment 43, the cumulative effects analysis (CEA) includes an analysis of data from ….

6.2 Past, Present, and Reasonably Foreseeable Actions Impacting the Affected Area

Fishery managers implemented the first significant regulations pertaining to red snapper in 1983 through the Snapper Grouper FMP (SAFMC 1983). The regulations included a 12-inch total length minimum size limit for red snapper. Listed below are other past, present, and reasonably foreseeable actions occurring in the South Atlantic region. These actions, when added to the proposed management measures, may result in cumulative effects on the biophysical and socio-economic environment. The complete history of management of the snapper grouper fishery can be found in **Appendix C (History of Management)**.

Past Actions

The South Atlantic Headboat Reporting Amendment was implemented on January 27, 2014, and requires that all federally-permitted headboats on the South Atlantic report their landings information electronically, and on a weekly basis in order to improve the timeliness and accuracy of harvest data.

The Generic Dealer Reporting Amendment, which became effective on August 7, 2014, established one dealer permit for the Gulf of Mexico and South Atlantic regions and increased the reporting frequency requirements for species managed by the Gulf of Mexico and Councils. This amendment is expected to improve fisheries data collection, through more timely and accurate dealer reporting, and streamline the dealer permit system.

Amendment 29 to the Snapper Grouper FMP, which became effective on July 1, 2015, updated the Council's acceptable biological catch (ABC) control rule to incorporate methodology for determining the ABC of "Only Reliable Catch Stocks"; (2) adjusted ABCs for the affected unassessed species; (3) specified annual catch limits (ACLs) for 7 species based on the updated ABCs; and (4) modified management measures for gray triggerfish in federal waters of the South Atlantic region (SAFMC 2014b).

The Generic Accountability Measures (AM) and Dolphin Allocation Amendment, in part, modified AMs for snapper grouper species (including mutton snapper) to make them more consistent with AMs already implemented for other species and other fishery management plans. The regulations became effective on February 22, 2016.

Present Actions

Amendment 36 to the Snapper Grouper FMP would establish new Spawning Special Management Zones to protect spawning areas for snapper grouper species. The regulations became effective on July 31, 2017.

Amendment 37 to the Snapper Grouper FMP would modify the hogfish fishery management unit, specify fishing levels for the two South Atlantic hogfish stocks, establish a rebuilding plan for the Florida Keys/East Florida stock, and establish/revise management measures for both hogfish stocks in the South Atlantic Region, such as size limits, recreational bag limits, and commercial trip limits. The regulations will become effective on August 24, 3017.

Amendment 41 to the Snapper Grouper FMP updates the MSY, ABC, ACL, OY, minimum stock size threshold, designate spawning months for regulatory purposes, and revise management measures for mutton snapper.

The South Atantic For-Hire Electronic Reporting Amendment would require charter vessels to regularly report their landings information electronically. Including charter boats in the recreational harvest reporting system would further improve the agency's ability to monitor recreational catch rates in-season.

Reasonably Foreseeable Future Actions

The Vision Blueprint Recreational Amendment (Amendment 26) for the Snapper Grouper Fishery of the South Atlantic considers actions to evaluate and modify the composition of the recreational aggregate snapper bag limit, recreational aggregate grouper bag limit, and the recreational aggregate for species without a bag limit. The amendment would also consider modifying the current recreational prohibition on harvest and possession of shallow water groupers, remove the recreational minimum size limit for deep-water species, and modify the recreational minimum size limit for black sea bass.

The Vision Blueprint Commercial Amendment (Amendment 27) for the Snapper Grouper Fishery of the South Atlantic is currently under development.

The Bycatch Reporting Amendment contains an action to improve bycatch reporting for the snapper grouper fishery.

A Joint Commercial Logbook Reporting Amendment would require electronic reporting of logbook information by federally-permitted vessels.

Expected Impacts from Past, Present, and Future Actions

6.3 Consideration of Climate Change and Other Non-Fishery Related Issues

Climate Change

Global climate changes could have significant effects on South Atlantic fisheries, though the extent of these effects on the snapper grouper fishery is not known at this time. The Environmental Protection Agency's climate change webpage (https://www.epa.gov/climate-indicators/marine-species-distribution), and NOAA's Office of Science and Technology climate webpage (https://www.st.nmfs.noaa.gov/ecosystems/climate/index), provides background information on climate change, including indicators which measure or anticipate effects on oceans, weather and climate, ecosystems, health and society, and greenhouse gases. The United Nations Intergovernmental Panel on Climate Change's Fifth Assessment Report also provides a compilation of scientific information on climate change (November 2, 2014). Those findings are summarized below.

Ocean acidification, or a decrease in surface ocean pH due to absorption of anthropogenic carbon dioxide emissions, affects the chemistry and temperature of the water. Increased thermal stratification alters ocean circulation patterns, and causes a loss of sea ice, sea level rise, increased wave height and frequency, reduced upwelling, and changes in precipitation and wind patterns. Changes in coastal and marine ecosystems can influence organism metabolism and alter ecological processes such as productivity, species interactions, migration, range and distribution, larval and juvenile survival, prey availability, and susceptibility to predators. The "center of biomass," a geographical representation of each species' weight distribution, is being used to identify the shifting of fish populations. Warming sea temperature trends in the southeast have been documented, and animals must migrate to cooler waters, if possible, if water temperatures exceed survivable ranges (Needham et al. 2012). Harvesting and habitat changes also cause geographic population shifts. Changes in water temperatures may also affect the distribution of native and exotic species, allowing invasive species to establish communities in areas they may not have been able to survive previously. The combination of warmer water and expansion of salt marshes inland with sea-level rise may increase productivity of estuarine-dependent species in the short term. However, in the long term, this increased productivity may be temporary because of loss of fishery habitats due to wetland loss (Kennedy et al. 2002). The numerous changes to the marine ecosystem may cause an increased risk of disease in marina biota. An increase in the occurrence and intensity of toxic algae blooms will negatively influence the productivity of keystone animals, such as corals, and critical coastal ecosystems such as wetlands, estuaries, and coral reefs (IPCC 2014; Kennedy et al. 2002).

Climate change may impact snapper grouper species in the future, but the level of impacts cannot be quantified at this time, nor is the time frame known in which these impacts will occur.

In the near term, it is unlikely that the management measures contained in Amendment 43 would compound or exacerbate the ongoing effects of climate change on snapper grouper species.

Weather Variables

Hurricane season is from June 1 to November 30, and accounts for 97% of all tropical activity affecting the Atlantic basin. These storms, although unpredictable in their annual occurrence, can devastate areas when they occur. Although these effects may be temporary, those fishing-related businesses whose profitability is marginal may go out of business if a hurricane strikes.

Deepwater-Horizon Oil Spill

On April 20, 2010, an explosion occurred on the Deepwater Horizon MC252 oil rig, resulting in the release of an estimated 4.9 million barrels of oil into the Gulf of Mexico (Gulf). In addition, 1.84 million gallons of Corexit 9500A dispersant were applied as part of the effort to constrain the spill. The cumulative effects from the oil spill and response may not be known for several years. The oil spill affected more than one-third of the Gulf area from western Louisiana east to the panhandle of Florida and south to the Campeche Bank in Mexico. The impacts of the Deepwater Horizon MC252 oil spill on the physical environment are expected to be significant and may be long-term. Oil is dispersed on the surface, and because of the heavy use of dispersants, oil is also documented as being suspended within the water column, some even deeper than the location of the broken well head. Floating and suspended oil washed onto shore in several areas of the Gulf, as well as non-floating tar balls. Whereas suspended and floating oil degrades over time, tar balls are more persistent in the environment and can be transported hundreds of miles. Oil on the surface of the water could restrict the normal process of atmospheric oxygen mixing into and replenishing oxygen concentrations in the water column. In addition, microbes in the water that break down oil and dispersant also consume oxygen; this could lead to further oxygen depletion. Zooplankton that feed on algae could also be negatively impacted, thus allowing more of the hypoxia-fueling algae to grow. The highest concern is that the oil spill may have impacted spawning success of species that spawn in the summer months, either by reducing spawning activity or by reducing survival of the eggs and larvae. Effects on the physical environment, such as low oxygen, could lead to impacts on the ability of larvae and post-larvae to survive, even if they never encounter oil. In addition, effects of oil exposure may create sub-lethal effects on the eggs, larva, and early life stages. The stressors could potentially be additive, and each stressor may increase the susceptibility to the harmful effects of the other. The oil from the spill site was not detected in the South Atlantic region, and does not likely pose a threat to the South Atlantic species addressed in this amendment. However, the effects of the oil spill on fish species would be taken into consideration in future Southeast Data Assessment and Review assessments. Indirect and inter-related effects on the biological and ecological environment of the fisheries in concert with the Deepwater Horizon MC252 oil spill are not well understood. Changes in the population size structure could result from shifting fishing effort to specific geographic segments of populations, combined with any anthropogenically induced natural mortality that may occur from the impacts of the oil spill. The impacts on the food web from phytoplankton, to zooplankton, to mollusks, to top predators may be significant in the future.

6.4 Overall Impacts Expected from Past, Present, and Future Actions

6.5 Monitoring and Mitigation

Chapter 7. List of Interdisciplinary Plan Team (IPT) Members

Name	Agency/Division	Title
Manny Antonaras	SERO/OLE	Deputy Special Agent in Charge
Myra Brouwer	SAFMC	Fishery Biologist
David Carter	SEFSC	Economist
Brian Cheuvront	SAFMC	Deputy Executive Director
Chip Collier	SAFMC	Interdisciplinary plan team (IPT) Lead/ Biologist
Scott Crosson	SEFSC	Economist
David Dale	SERO/HC	EFH Specialist
Rick Devictor	SERO/SF	Assistant Regional Adminstrator
Tracy Dunn	SERO/OLE	Assistant Director
Mike Errigo	SAFMC	Data Analyst
Nick Farmer	SERO/SF	Data Analyst
John Hadley	SAFMC	Economist
Frank Helies	SERO/SF	IPT Lead/Fishery Biologist
David Records	SERO/SF	Economist
Mike Larkin	SERO/SF	Biologist
Jennifer Lee	SERO/PR	Fishery Biologist
Jack McGovern	SERO/SF	Assistant Regional Administrator
Kari McLauchlin	SAFMC	Social Scientist
Nikhil Mehta	SERO/SF	IPT Lead/Fishery Biologist
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David Records	SERO/SF	Economist
Scott Sandorf	SERO/SF	Technical Writer and Editor
Kate Siegfried	SEFSC	Research Fishery Biologist
Noah Silverman	NMFS/SER	Regional NEPA Coordinator
Monica Smit-Brunello	NOAA GC	General Counsel

NMFS = National Marine Fisheries Service, SAFMC = South Atlantic Fishery Management Council, SF = Sustainable Fisheries Division, PR = Protected Resources Division, SERO = Southeast Regional Office, HC = Habitat Conservation Division, GC = General Counsel

Chapter 8. Agencies and Persons Consulted

Responsible Agency

South Atlantic
South Atlantic Fishery Management Council
4055 Faber Place Drive, Suite 201
Charleston, South Carolina 29405
(843) 571-4366 (TEL)
Toll Free: 866-SAFMC-10
(843) 769-4520 (FAX)
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NMFS, Southeast Region
263 13th Avenue South
St. Petersburg, Florida 33701
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Environmental Assessment:

List of Agencies, Organizations, and Persons Consulted
SAFMC Law Enforcement Advisory Panel
SAFMC Snapper Grouper Advisory Panel
SAFMC Scientific and Statistical Committee
North Carolina Coastal Zone Management Program
South Carolina Coastal Zone Management Program
Georgia Coastal Zone Management Program
Florida Coastal Zone Management Program
Florida Fish and Wildlife Conservation Commission
Georgia Department of Natural Resources
South Carolina Department of Natural Resources
North Carolina Division of Marine Fisheries
North Carolina Sea Grant
South Carolina Sea Grant
Georgia Sea Grant
Florida Sea Grant
Atlantic States Marine Fisheries Commission
Gulf and South Atlantic Fisheries Development Foundation
Gulf of Mexico Fishery Management Council
National Marine Fisheries Service

- Washington Office
- Office of Ecology and Conservation
- Southeast Regional Office
- Southeast Fisheries Science Center

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Appendix A. Considered But Rejected Alternatives

No actions or alternatives were removed from further analysis. Several actions considered in an early version of Amendment 43 were moved into Amendment 46.

Appendix B. Glossary

Allowable Biological Catch (ABC): Maximum amount of fish stock than can be harvested without adversely affecting recruitment of other components of the stock. The ABC level is typically higher than the total allowable catch, leaving a buffer between the two.

ALS: Accumulative Landings System. NMFS database which contains commercial landings reported by dealers.

Biomass: Amount or mass of some organism, such as fish.

B_{MSY}: Biomass of population achieved in long-term by fishing at F_{MSY}.

Bycatch: Fish harvested in a fishery, but not sold or kept for personal use. Bycatch includes economic discards and regulatory discards, but not fish released alive under a recreational catch and release fishery management program.

Caribbean Fishery Management Council (CFMC): One of eight regional councils mandated in the Magnuson-Stevens Fishery Conservation and Management Act to develop management plans for fisheries in federal waters. The CFMC develops fishery management plans for fisheries off the coast of the U.S. Virgin Islands and the Commonwealth of Puerto Rico.

Catch Per Unit Effort (CPUE): The amount of fish captured with an amount of effort. CPUE can be expressed as weight of fish captured per fishing trip, per hour spent at sea, or through other standardized measures.

Charter Boat: A fishing boat available for hire by recreational anglers, normally by a group of anglers for a short time period.

Cohort: Fish born in a given year. (See year class.)

Control Date: Date established for defining the pool of potential participants in a given management program. Control dates can establish a range of years during which a potential participant must have been active in a fishery to qualify for a quota share.

Constant Catch Rebuilding Strategy: A rebuilding strategy where the allowable biological catch of an overfished species is held constant until stock biomass reaches B_{MSY} at the end of the rebuilding period.

Constant F Rebuilding Strategy: A rebuilding strategy where the fishing mortality of an overfished species is held constant until stock biomass reached BMSY at the end of the rebuilding period.

Directed Fishery: Fishing directed at a certain species or species group.
Discards: Fish captured, but released at sea.

Discard Mortality Rate: The % of total fish discarded that do not survive being captured and released at sea.

Derby: Fishery in which the TAC is fixed and participants in the fishery do not have individual quotas. The fishery is closed once the TAC is reached, and participants attempt to maximize their harvests as quickly as possible. Derby fisheries can result in capital stuffing and a race for fish.

Effort: The amount of time and fishing power (i.e., gear size, boat size, horsepower) used to harvest fish.

Exclusive Economic Zone (EEZ): Zone extending from the shoreline out to 200 nautical miles in which the country owning the shoreline has the exclusive right to conduct certain activities such as fishing. In the United States, the EEZ is split into state waters (typically from the shoreline out to 3 nautical miles) and federal waters (typically from 3 to 200 nautical miles).

Exploitation Rate: Amount of fish harvested from a stock relative to the size of the stock, often expressed as a percentage.

F: Fishing mortality.

Fecundity: A measurement of the egg-producing ability of fish at certain sizes and ages.

Fishery Dependent Data: Fishery data collected and reported by fishermen and dealers.

Fishery Independent Data: Fishery data collected and reported by scientists who catch the fish themselves.

Fishery Management Plan: Management plan for fisheries operating in the federal produced by regional fishery management councils and submitted to the Secretary of Commerce for approval.

Fishing Effort: Usually refers to the amount of fishing. May refer to the number of fishing vessels, amount of fishing gear (nets, traps, hooks), or total amount of time vessels and gear are actively engaged in fishing.

Fishing Mortality: A measurement of the rate at which fish are removed from a population by fishing. Fishing mortality can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in one year. Instantaneous is that percentage of fish dying at any one time.

Fishing Power: Measure of the relative ability of a fishing vessel, its gear, and its crew to catch fishes, in reference to some standard vessel, given both vessels are under identical conditions.

$F_{30\%SPR}$: Fishing mortality that will produce a static SPR = 30%.

$F_{45\%SPR}$: Fishing mortality that will produce a static SPR = 45%.

F_{OY}: Fishing mortality that will produce OY under equilibrium conditions and a corresponding biomass of B_{OY}. Usually expressed as the yield at 85% of F_{MSY}, yield at 75% of F_{MSY}, or yield at 65% of F_{MSY}.

F_{MSY}: Fishing mortality that if applied constantly, would achieve MSY under equilibrium conditions and a corresponding biomass of B_{MSY}.

Fork Length (FL): The length of a fish as measured from the tip of its snout to the fork in its tail.

Framework: An established procedure within a fishery management plan that has been approved and implemented by NMFS, which allows specific management measures to be modified via regulatory amendment.

Gear restrictions: Limits placed on the type, amount, number, or techniques allowed for a given type of fishing gear.

Growth Overfishing: When fishing pressure on small fish prevents the fishery from producing the maximum poundage. Condition in which the total weight of the harvest from a fishery is improved when fishing effort is reduced, due to an increase in the average weight of fishes.

Gulf of Mexico Fishery Management Council (GFMC): One of eight regional councils mandated in the Magnuson-Stevens Fishery Conservation and Management Act to develop management plans for fisheries in federal waters. The GFMC develops fishery management plans for fisheries off the coast of Texas, Louisiana, Mississippi, Alabama, and the west coast of Florida.

Headboat: A fishing boat that charges individual fees per recreational angler onboard.

Highgrading: Form of selective sorting of fishes in which higher value, more marketable fishes are retained, and less marketable fishes, which could legally be retained are discarded.

Individual Fishing Quota (IFQ): Fishery management tool that allocates a certain portion of the TAC to individual vessels, fishermen, or other eligible recipients.

Longline: Fishing method using a horizontal mainline to which weights and baited hooks are attached at regular intervals. Gear is either fished on the bottom or in the water column.

Magnuson-Stevens Fishery Conservation and Management Act: Federal legislation responsible for establishing the fishery management councils and the mandatory and discretionary guidelines for federal fishery management plans.

Marine Recreational Information Program (MRIP): Survey operated by NMFS in cooperation with states that collects marine recreational data.

Maximum Fishing Mortality Threshold (MFMT): The rate of fishing mortality above which a stock's capacity to produce MSY would be jeopardized.

Maximum Sustainable Yield (MSY): The largest long-term average catch that can be taken continuously (sustained) from a stock or stock complex under average environmental conditions.

Minimum Stock Size Threshold (MSST): The biomass level below which a stock would be considered overfished.

Modified F Rebuilding Strategy: A rebuilding strategy where fishing mortality is changed as stock biomass increases during the rebuilding period.

Multispecies fishery: Fishery in which more than one species is caught at the same time and location with a particular gear type.

National Marine Fisheries Service (NMFS): Federal agency within NOAA responsible for overseeing fisheries science and regulation.

National Oceanic and Atmospheric Administration: Agency within the Department of Commerce responsible for ocean and coastal management.

Natural Mortality (M): A measurement of the rate at which fish are removed from a population by natural causes. Natural mortality can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in one year. Instantaneous is that percentage of fish dying at any one time.

Optimum Yield (OY): The amount of catch that will provide the greatest overall benefit to the nation, particularly with respect to food production and recreational opportunities and taking into account the protection of marine ecosystems.

Overfished: A stock or stock complex is considered overfished when stock biomass falls below the minimum stock size threshold (MSST) (e.g., current biomass < MSST = overfished).

Overfishing: Overfishing occurs when a stock or stock complex is subjected to a rate of fishing mortality that exceeds the maximum fishing mortality threshold (e.g., current fishing mortality rate > MFMT = overfishing).
Quota: % or annual amount of fish that can be harvested.

Recruitment (R): Number or percentage of fish that survives from hatching to a specific size or age.

Recruitment Overfishing: The rate of fishing above which the recruitment to the exploitable stock becomes significantly reduced. This is characterized by a greatly reduced spawning stock, a decreasing proportion of older fish in the catch, and generally very low recruitment year after year.

Scientific and Statistical Committee (SSC): Fishery management advisory body composed of federal, state, and academic scientists, which provides scientific advice to a fishery management council.

Selectivity: The ability of a type of gear to catch a certain size or species of fish.

South Atlantic Fisheries Management Council (SAFMC): One of eight regional councils mandated in the Magnuson-Stevens Fishery Conservation and Management Act to develop management plans for fisheries in federal waters. The SAFMC develops fishery management plans for fisheries off North Carolina, South Carolina, Georgia, and the east coast of Florida.

Spawning Potential Ratio (Transitional SPR): Formerly used in overfished definition. The number of eggs that could be produced by an average recruit in a fished stock divided by the number of eggs that could be produced by an average recruit in an unfished stock. SPR can also be expressed as the spawning stock biomass per recruit (SSBR) of a fished stock divided by the SSBR of the stock before it was fished.

% Spawning Per Recruit (Static SPR): Formerly used in overfishing determination. The maximum spawning per recruit produced in a fished stock divided by the maximum spawning per recruit, which occurs under the conditions of no fishing. Commonly abbreviated as %SPR.

Spawning Stock Biomass (SSB): The total weight of those fish in a stock which are old enough to spawn.

Spawning Stock Biomass Per Recruit (SSBR): The spawning stock biomass divided by the number of recruits to the stock or how much spawning biomass an average recruit would be expected to produce.

Total Allowable Catch (TAC): The total amount of fish to be taken annually from a stock or stock complex. This may be a portion of the Allowable Biological Catch (ABC) that takes into consideration factors such as bycatch.

Total Length (TL): The length of a fish as measured from the tip of the snout to the tip of the tail.

Appendix C. History of Management

South Atlantic Snapper Grouper History of Management
Last Updated: 6/23/17

The snapper grouper fishery is highly regulated; some of the species included in this amendment have been regulated since 1983. The following table summarizes actions in each of the amendments to the original Snapper Grouper Fishery Management Plan (FMP), as well as some events not covered in amendment actions.

*Shaded rows indicate FMP Amendments

Document	All Actions Effective By:	Proposed Rule Final Rule	Major Actions. Note that not all details are provided here. Please refer to Proposed and Final Rules for all impacts of listed documents.
FMP (1983)	08/31/83	PR: 48 FR 26843 FR: 48 FR 39463	-12" total length (TL) limit – red snapper, yellowtail snapper, red grouper, Nassau grouper; -8" limit – black sea bass; -4" trawl mesh size; -Gear limitations – poisons, explosives, fish traps, trawls; -Designated modified habitats or artificial reefs as Special Management Zones (SMZs).
Regulatory Amendment #1 (1987)	03/27/87	PR: 51 FR 43937 FR: 52 FR 9864	-Prohibited fishing in SMZs except with hand-held hook-and-line and spearfishing gear; -Prohibited harvest of goliath grouper in SMZs.
Amendment #1 (1988a)	01/12/89	PR: 53 FR 42985 FR: 54 FR 1720	-Prohibited trawl gear to harvest fish south of Cape Hatteras, NC and north of Cape Canaveral, FL; -Directed fishery defined as vessel with trawl gear and ≥200 lb s-g on board; -Established rebuttable assumption that vessel with s-g on board had harvested such fish in the exclusive economic zone (EEZ).
Regulatory Amendment #2 (1988b)	03/30/89	PR: 53 FR 32412 FR: 54 FR 8342	-Established 2 artificial reefs off Ft. Pierce, FL as SMZs.
Emergency Rule	8/3/90	55 FR 32257	-Added wreckfish to the fishery management unit (FMU); -Fishing year beginning 4/16/90; -Commercial quota of 2 million pounds; -Commercial trip limit of 10,000 pounds per trip.
Fishery Closure Notice	8/8/90	55 FR 32635	- Fishery closed because the commercial quota of 2 million pounds was reached.
Notice of Control Date	09/24/90	55 FR 39039	-Anyone entering federal wreckfish fishery in the EEZ off S. Atlantic states after 09/24/90 was not assured of future access if limited entry program developed.
Regulatory Amendment #3	11/02/90	PR: 55 FR 28066 FR: 55 FR 40394	-Established artificial reef at Key Biscayne, FL as SMZ;

Document	All Actions Effective By:	Proposed Rule Final Rule	Major Actions. Note that not all details are provided here. Please refer to Proposed and Final Rules for all impacts of listed documents.
(1989)			-Fish trapping, bottom longlining, spear fishing, and harvesting of Goliath grouper prohibited in SMZ.
Amendment #2 (1990a)	10/30/90	PR: 55 FR 31406 FR: 55 FR 46213	-Prohibited harvest/possession of goliath grouper in or from the EEZ; -Defined overfishing for goliath grouper and other species.
Emergency Rule Extension	11/1/90	55 FR 40181	-Extended the measures implemented via emergency rule on 8/3/90.
Amendment #3 (1990b)	01/31/91	PR: 55 FR 39023 FR: 56 FR 2443	-Added wreckfish to the FMU; -Defined optimum yield (OY) and overfishing; -Required permit to fish for, land or sell wreckfish; -Required catch and effort reports from selected, permitted vessel; -Established control date of 03/28/90; -Established a fishing year for wreckfish starting April 16; -Established a process to set annual quota, with initial quota of 2 million pounds; provisions for closure; -Established 10,000 pound trip limit; -Established a spawning season closure for wreckfish from January 15 to April 15; -Provided for annual adjustments of wreckfish management measures.
Notice of Control Date	07/30/91	56 FR 36052	-Anyone entering federal snapper grouper fishery (other than for wreckfish) in the EEZ off S. Atlantic states after 07/30/91 was not assured of future access if limited entry program developed.
Amendment #4 (1991)	01/01/92	PR: 56 FR 29922 FR: 56 FR 56016	-Prohibited gear: fish traps except black sea bass traps north of Cape Canaveral, FL; entanglement nets; longline gear inside 50 fathoms; bottom longlines to harvest wreckfish; powerheads and bangsticks in designated SMZs off S. Carolina. -Defined overfishing/overfished and established rebuilding timeframe: red snapper and groupers ≤ 15 years (year 1 = 1991); other snappers, greater amberjack, black sea bass, red porgy ≤ 10 years (year 1 = 1991); -Required permits (commercial & for-hire) and specified data collection regulations; -Established an assessment group and annual adjustment procedure (framework); -Permit, gear, and vessel id requirements specified for black sea bass traps; -No retention of snapper grouper spp. caught in other fisheries with gear prohibited in snapper grouper fishery if captured snapper grouper had no bag limit or harvest was prohibited. If had a bag limit, could retain only the bag limit; -8" TL limit – lane snapper;

Document	All Actions Effective By:	Proposed Rule Final Rule	Major Actions. Note that not all details are provided here. Please refer to Proposed and Final Rules for all impacts of listed documents.
			-10" TL limit – vermilion snapper (recreational only); -12" TL limit – red porgy, vermilion snapper (commercial only), gray, yellowtail, mutton, schoolmaster, queen, blackfin, cubera, dog, mahogany, and silk snappers; -20" TL limit – red snapper, gag, and red, black, scamp, yellowfin, and yellowmouth groupers; -28" fork length (FL) limit – greater amberjack (recreational only); -36" FL or 28" core length – greater amberjack (commercial only); -Bag limits – 10 vermilion snapper, 3 greater amberjack -Aggregate snapper bag limit – 10/person/day, excluding vermilion snapper and allowing no more than 2 red snappers; -Aggregate grouper bag limit – 5/person/day, excluding Nassau and goliath grouper, for which no retention (recreational & commercial) is allowed; -Spawning season closure – commercial harvest greater amberjack > 3 fish bag prohibited in April; -Spawning season closure – commercial harvest mutton snapper >snapper aggregate prohibited during May and June; -Charter/headboats and excursion boat possession limits extended.
Amendment #5 (1992a)	04/06/92	PR: 56 FR 57302 FR: 57 FR 7886	For wreckfish: -Established limited entry system with individual transferable quotas (ITQs); -Required dealer to have permit; -Rescinded 10,000 lb. trip limit; -Required off-loading between 8 am and 5 pm; -Reduced occasions when 24-hour advance notice of offloading required for off-loading; -Established procedure for initial distribution of percentage shares of total allowable catch (TAC).
Emergency Rule	8/31/92	57 FR 39365	For Black Sea Bass (bsb): -Modified definition of bsb pot; -Allowed multi-gear trips for bsb; -Allowed retention of incidentally-caught fish on bsb trips.
Emergency Rule Extension	11/30/92	57 FR 56522	For Black Sea Bass: -Modified definition of bsb pot; -Allowed multi-gear trips for bsb; -Allowed retention of incidentally-caught fish on bsb trips.

Document	All Actions Effective By:	Proposed Rule Final Rule	Major Actions. Note that not all details are provided here. Please refer to Proposed and Final Rules for all impacts of listed documents.
Regulatory Amendment #4 (1992b)	07/06/93	FR: 58 FR 36155	-For Black Sea Bass: -Modified definition of bsb pot; -Allowed multi-gear trips for bsb; -Allowed retention of incidentally-caught fish on bsb trips.
Regulatory Amendment #5 (1992c)	07/31/93	PR: 58 FR 13732 FR: 58 FR 35895	-Established 8 SMZs off South Carolina, where only hand-held, hook-and-line gear and spearfishing (excluding powerheads) was allowed.
Amendment #6 (1993)	07/27/94	PR: 59 FR 9721 FR: 59 FR 27242	-Set up separate commercial TAC levels for golden tilefish and snowy grouper; -Established commercial trip limits for snowy grouper, golden tilefish, speckled hind, and warsaw grouper; -Included golden tilefish in grouper recreational aggregate bag limits; -Prohibited sale of warsaw grouper and speckled hind; -100% logbook coverage upon renewal of permit; -Creation of the *Oculina* Experimental Closed Area; -Data collection needs specified for evaluation of possible future individual fishing quota system.
Amendment #7 (1994a)	01/23/95	PR: 59 FR 47833 FR: 59 FR 66270	-12” FL – hogfish; -16” TL – mutton snapper; -Required dealer, charter and headboat federal permits; -Allowed sale under specified conditions; -Specified allowable gear and made allowance for experimental gear; -Allowed multi-gear trips in NC; -Added localized overfishing to list of problems and objectives; -Adjusted bag limit and crew specs. for charter and head boats; -Modified management unit for scup to apply south of Cape Hatteras, NC; -Modified framework procedure.
Regulatory Amendment #6 (1994b)	05/22/95	PR: 60 FR 8620 FR: 60 FR 19683	-Established actions which applied only to EEZ off Atlantic coast of FL: Bag limits – 5 hogfish/person/day (recreational only), 2 cubera snapper/person/day > 30” TL; 12” TL – gray triggerfish.
Notice of Control Date	04/23/97	62 FR 22995	-Anyone entering federal black sea bass pot fishery off South Atlantic states after 04/23/97 was not assured of future access if limited entry program developed.
Interim Rule Request	1/16/98		-The South Atlantic Fishery Management Council (Council) requested all Amendment 9 measures except black sea bass pot construction changes be implemented as an interim request under the

Document	All Actions Effective By:	Proposed Rule Final Rule	Major Actions. Note that not all details are provided here. Please refer to Proposed and Final Rules for all impacts of listed documents.
			Magnuson-Stevens Act.
Action Suspended	5/14/98		-NMFS informed the Council that action on the interim rule request was suspended.
Emergency Rule Request	9/24/98		-Council requested Amendment 9 be implemented via emergency rule.
Amendment #8 (1997)	12/14/98	PR: 63 FR 1813 FR: 63 FR 38298	-Established program to limit initial eligibility for snapper grouper fishery: -Must have demonstrated landings of any species in the snapper grouper FMU in 1993, 1994, 1995 or 1996; and have held valid snapper grouper permit between 02/11/96 and 02/11/97; -Granted transferable permit with unlimited landings if vessel landed ≥ 1,000 pounds (lb) of snapper grouper species in any of the years; -Granted non-transferable permit with 225 lb trip limit to all other vessels; -Modified problems, objectives, OY, and overfishing definitions; -Expanded the Council's habitat responsibility; -Allowed retention of snapper grouper species in excess of bag limit on permitted vessel with a single bait net or cast nets on board; -Allowed permitted vessels to possess filleted fish harvested in the Bahamas under certain conditions.
Request not Implemented	1/22/99		-NMFS informed the Council that the final rule for Amendment 9 would be effective 2/24/99; therefore they did not implement the emergency rule.
Regulatory Amendment #7 (1998a)	01/29/99	PR: 63 FR 43656 FR: 63 FR 71793	-Established 10 SMZs at artificial reefs off South Carolina.

Document	All Actions Effective By:	Proposed Rule Final Rule	Major Actions. Note that not all details are provided here. Please refer to Proposed and Final Rules for all impacts of listed documents.
Amendment #9 (1998b)	2/24/99	PR: 63 FR 63276 FR: 64 FR 3624	-Red porgy: 14" TL (recreational and commercial); 5 fish rec. bag limit; no harvest or possession > bag limit, and no purchase or sale, in March and April; -Black sea bass: 10" TL (recreational and commercial); 20 fish rec. bag limit; required escape vents and escape panels with degradable fasteners in bsb pots; -Greater amberjack: 1 fish rec. bag limit; no harvest or possession > bag limit, and no purchase or sale, during April; quota = 1,169,931 lb; began fishing year May 1; prohibited coring; -Specified size limits for several snapper grouper species (indicated in parentheses in inches TL): including yellowtail snapper (12), mutton snapper (16), red snapper (20); red grouper, yellowfin grouper, yellowmouth grouper, and scamp (20) ; -Vermilion snapper: 11" TL (recreational), 12" TL commercial; -Gag: 24" TL (recreational); no commercial harvest or possession > bag limit, and no purchase or sale, during March and April; -Black grouper: 24" TL (recreational and commercial); no harvest or possession > bag limit, and no purchase or sale, during March and April; -Gag and Black grouper: within 5 fish aggregate grouper bag limit, no more than 2 fish may be gag or black grouper (individually or in combination); -All snapper grouper without a bag limit: aggregate recreational bag limit 20 fish/person/day, excluding tomtate and blue runner; -Vessels with longline gear aboard may only possess snowy, warsaw, yellowedge, and misty grouper, and golden, blueline and sand tilefish.
Emergency Action	9/3/99	64 FR 48326	-Reopened the Amendment 8 permit application process.
Emergency Interim Rule	09/08/99, expired 08/28/00	64 FR 48324 and 65 FR 10040	-Prohibited harvest or possession of red porgy.
Amendment #10 Comprehensive Essential Fish Habitat Amendment (1998c)	07/14/00	PR: 64 FR 37082 and 64 FR 59152 FR: 65 FR 37292	-Identified essential fish habitat (EFH) and established habitat areas of particular concern (HAPC) for species in the snapper grouper FMU.

Document	All Actions Effective By:	Proposed Rule Final Rule	Major Actions. Note that not all details are provided here. Please refer to Proposed and Final Rules for all impacts of listed documents.
Amendment #11 Comprehensive Sustainable Fisheries Act Amendment (1998d)	12/02/99	PR: 64 FR 27952 FR: 64 FR 59126	-Maximum sustainable yield (MSY) proxy: goliath and Nassau grouper = 40% static spawning potential ratio (SPR); all other species = 30% static SPR; -OY: hermaphroditic groupers = 45% static SPR; goliath and Nassau grouper = 50% static SPR; all other species = 40% static SPR -Overfished/overfishing evaluations: BSB: overfished (minimum stock size threshold (MSST)=3.72 mp, 1995 biomass=1.33 mp); undergoing overfishing (maximum fishing mortality threshold (MFMT)=0.72, F1991-1995=0.95) Vermilion snapper: overfished (static SPR = 21-27%) Red porgy: overfished (static SPR = 14-19%). Red snapper: overfished (static SPR = 24-32%) Gag: overfished (static SPR = 27%) Scamp: no longer overfished (static SPR = 35%) Speckled hind: overfished (static SPR = 8-13%) Warsaw grouper: overfished (static SPR = 6-14%) Snowy grouper: overfished (static SPR = 5-15%) White grunt: no longer overfished (static SPR = 29-39%) Golden tilefish: overfished (couldn't estimate static SPR) Nassau grouper: overfished (couldn't estimate static SPR) Goliath grouper: overfished (couldn't estimate static SPR) -overfishing level: goliath and Nassau grouper = F>F40% static SPR; all other species: = F>F30% static SPR Approved definitions for overfished and overfishing. MSST = [(1-M) or 0.5 whichever is greater]*B_{MSY}. MFMT = $F_{MSY.}$
Amendment #12 (2000a)	09/22/00	PR: 65 FR 35877 FR: 65 FR 51248	For Red porgy: -MSY=4.38 mp; OY=45% static SPR; MFMT=0.43; MSST=7.34 mp; rebuilding timeframe=18 years (1999=year 1); -no sale of red porgy during Jan-April; -1 fish bag limit; -50 lb. bycatch commercial trip limit May-December; -Modified management options and list of possible framework actions.
Regulatory Amendment #8 (2000b)	11/15/00	PR: 65 FR 41041 FR: 65 FR 61114	-Established 12 SMZs at artificial reefs off Georgia; revised boundaries of 7 existing SMZs off Georgia to meet CG permit specs; restricted fishing in new and revised SMZs.

Document	All Actions Effective By:	Proposed Rule Final Rule	Major Actions. Note that not all details are provided here. Please refer to Proposed and Final Rules for all impacts of listed documents.
Amendment #9 (1998b) resubmitted	10/13/00	PR: 63 FR 63276 FR: 65 FR 55203	-Commercial trip limit for greater amberjack.
Amendment #13A (2003)	04/26/04	PR: 68 FR 66069 FR: 69 FR 15731	-Extended for an indefinite period the regulation prohibiting fishing for and possessing snapper grouper species within the *Oculina* Experimental Closed Area.
Notice of Control Date	10/14/05	70 FR 60058	-Considered management measures to further limit participation or effort in the commercial fishery for snapper grouper species (excluding wreckfish).
Amendment #13C (2006)	10/23/06	PR: 71 FR 28841 FR: 71 FR 55096	-End overfishing of snowy grouper, vermilion snapper, black sea bass, and golden tilefish. Increase allowable catch of red porgy. Year 1 = 2006; 1. <u>Snowy Grouper</u> Commercial: -Quota = 151,000 lb gutted weight (gw) in year 1, 118,000 lb gw in year 2, and 84,000 lb gw in year 3 onwards. -Trip limit = 275 lb gw in year 1, 175 lb gw in year 2, and 100 lb gw in year 3 onwards; Recreational: -Limit possession to one snowy grouper in 5 grouper per person/day aggregate bag limit; 2. <u>Golden Tilefish</u> Commercial: Quota of 295,000 lb gw, 4,000 lb gw trip limit until 75% of the quota is taken when the trip limit is reduced to 300 lb gw. Do not adjust the trip limit downwards unless 75% is captured on or before September 1; Recreational: Limited possession to 1 golden tilefish in 5 grouper per person/day aggregate bag limit; 3. <u>Vermilion Snapper</u> Commercial: Quota of 1,100,000 lb gw; Recreational: 12" TL size limit. 4. <u>Black Sea Bass</u> Commercial: Quota of 477,000 lb gw in year 1, 423,000 lb gw in year 2, and 309,000 lb gw in year 3 onwards; -Required use of at least 2" mesh for the entire back panel of black sea bass pots effective 6 months after publication of the final rule; -Required black sea bass pots be removed from the water when the quota is met; -Changed fishing year from calendar year to June 1 – May 31; Recreational: Recreational allocation of 633,000 lb

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			gw in year 1, 560,000 lb gw in year 2, and 409,000 lb gw in year 3 onwards. Increase minimum size limit from 10" to 11" in year 1 and to 12" in year 2; -Reduced recreational bag limit from 20 to 15 per person per day; -Changed fishing year from the calendar year to June 1 through May 31. 5. Red Porgy Commercial and recreational: -Retained 14" TL size limit and seasonal closure (retention limited to the bag limit); -Specified a commercial quota of 127,000 lb gw and prohibit sale/purchase and prohibit harvest and/or possession beyond the bag limit when quota is taken and/or during January through April; -Increased commercial trip limit from 50 lb ww to 120 red porgy (210 lb gw) during May through December;--Increased recreational bag limit from one to three red porgy per person per day.
Notice of Control Date	3/8/07	72 FR 60794	-Considered measures to limit participation in the snapper grouper for-hire sector.
Amendment #14 (2007)	2/12/09	PR: 73 FR 32281 FR: 74 FR 1621	-Established eight deepwater Type II marine protected areas (MPAs) to protect a portion of the population and habitat of long-lived deepwater snapper grouper species.
Amendment #15A (2008a)	3/14/08	73 FR 14942	- Established rebuilding plans and status determination criteria for snowy grouper, black sea bass, and red porgy.
Notice of Control Date	12/4/08	74 FR 7849	-Established a control date for the golden tilefish portion of the snapper grouper fishery in the South Atlantic.
Notice of Control Date	12/4/08	74 FR 7849	-Established control date for black sea bass pot sector in the South Atlantic.
Amendment #15B (2008b)	2/15/10	PR: 74 FR 30569 FR: 74 FR 58902	-Prohibited the sale of snapper grouper harvested or possessed in the EEZ under the bag limits and prohibited the sale of snapper grouper harvested or possessed under the bag limits by vessels with a Federal charter vessel/headboat permit for South Atlantic snapper grouper were harvested; -Reduced the effects of incidental hooking on sea turtles and smalltooth sawfish; -Adjusted commercial permit renewal periods and transferability requirements; -Revised the management reference points for golden tilefish; -Implemented plan to monitor and assess bycatch; -Required a vessel that fished in the EEZ, if selected by NMFS, to carry an observer and install electronic logbook and/or video monitoring equipment provided by NMFS;

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			-Established reference points for golden tilefish; -Established allocations for snowy grouper (95% commercial & 5% recreational); -Established allocations for red porgy (50% commercial & 50% recreational).
Amendment #16 (2009a)	7/29/09	PR: 74 FR 6297 FR: 74 FR 30964	-Specified status determination criteria for gag and vermilion snapper; For gag: -Specified interim allocations 51% commercial & 49% recreational; -Recreational and commercial shallow water grouper spawning closure January through April; -Directed commercial quota= 352,940 lb gw; -Reduced 5-fish aggregate grouper bag limit, including tilefish species, to a 3-fish aggregate; -Captain and crew on for-hire trips cannot retain the bag limit of vermilion snapper and species within the 3-fish grouper aggregate; For vermilion snapper: -Specified interim allocations 68% commercial & 32% recreational; -Directed commercial quota split Jan-June=315,523 lb gw and 302,523 lb gw July-Dec; -Reduced bag limit from 10 to 4 and a recreational closed season November through March; -Required venting and dehooking tools when catching snapper grouper species to reduce recreational and commercial bycatch mortality.
Amendment #19 Comprehensive Ecosystem-Based Amendment 1 (CE-BA1) (2009b)	7/22/10	PR: 75 FR 14548 FR: 75 FR 35330	-Amended coral, coral reefs, and live/hardbottom habitat FMP to establish deepwater coral HAPCs; -Created a "shrimp fishery access area" (SFAA) within the Stetson-Miami Terrace CHAPC boundaries; -Created allowable "golden crab fishing areas" with the Stetson-Miami Terrace CHAPC and Pourtales Terrace CHAPC boundaries; -Amended the golden crab FMP to require vessel monitoring.
Amendment #17A (2010a)	12/3/10 red snapper closure; circle	PR: 75 FR 49447 FR: 75 FR 76874	-Required use of non-stainless steel circle hooks when fishing for snapper grouper species with hook-and-line gear north of 28 deg. N latitude in the South

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	hooks 3/3/2011		Atlantic EEZ; -Specified an annual catch limit (ACL) and an accountability measure (AM) for red snapper with management measures to reduce the probability that catches will exceed the stocks' ACL; -Specified a rebuilding plan for red snapper; -Specified status determination criteria for red snapper; -Specified a fishery-independent monitoring program for red snapper. -Implemented an area closure for snapper grouper species.
Emergency Rule	12/3/10	75 FR 76890	-Delayed the effective date of the area closure for snapper grouper species implemented through Amendment 17A.
Amendment #17B (2010b)	1/30/11	PR: 75 FR 62488 FR: 75 FR 82280	-Specify ACL of 0 and prohibit fishing for speckled hind and warsaw grouper; -Prohibited harvest of 6 deepwater species seaward of 240 feet to curb bycatch of speckled hind and warsaw grouper (snowy grouper, blueline tilefish, yellowedge grouper, misty grouper, queen snapper, silk snapper). -Specify allocations, ACLs and AMs for golden tilefish; -Modified management measures as needed to limit harvest to the ACL or ACT; -Updated the framework procedure for specification of total allowable catch; -Specified ACLs, ACTs, and AMs, where necessary, for 9 species undergoing overfishing (snowy grouper, black grouper, black sea bass, red grouper, vermilion snapper, gag, speckled hind, warsaw grouper, golden tilefish);
Regulatory Amendment #9 (2010a)	Bag limit: 6/22/11 Trip limits: 7/15/11	PR: 76 FR 23930 FR: 76 FR 34892	-Established trip limits for vermilion snapper and gag; -Increased trip limit for greater amberjack; -Harvest management measures for black sea bass (trip limit, split season quotas, carry-over of unused ACL, gear restrictions, bag limit modification, and a spawning season closure).
Regulatory Amendment #10 (2010b)	5/31/11	PR: 76 FR 9530 FR: 76 FR 23728	-Eliminated closed area for snapper grouper species approved in Amendment 17A.
Regulatory Amendment #11 (2011c)	5/10/12	PR: 76 FR 78879 FR: 77 FR 27374	-Eliminated 240 ft harvest prohibition for six deepwater species (snowy grouper, blueline tilefish, yellowedge grouper, queen snapper, silk snapper, misty grouper);

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Amendment # 25 Comprehensive Annual Catch Limit Amendment (2011d)	4/16/12	PR: 76 FR 74757 Amended PR: 76 FR 82264 FR: 77 FR 15916	-Reorganize FMUs to 6 complexes (deepwater, jacks, snappers, grunts, shallow-water groupers, porgies) (see final rule for species list); -Established acceptable biological catch (ABC) control rules and established ABCs, ACLs, and AMs for species not undergoing overfishing; -Removed some species from South Atlantic FMU (Tiger grouper, black margate, blue-striped grunt, French grunt, porkfish, smallmouth grunt, queen triggerfish, crevalle, yellow jack, grass porgy, sheepshead, puddingwife); -Designated species as ecosystem component species (schoolmaster, ocean triggerfish, bank triggerfish, rock triggerfish, longspine porgy); -Specified allocations between the commercial and, recreational sectors for species not undergoing overfishing; -Limited the total mortality for federally managed species in the South Atlantic to the ACLs.
Amendment #24 (2011e)	7/11/12	PR: 77 FR 19169 FR: 77 FR 34254	-Rebuilding plan (including MSY, ACLs, AMs, and OY, and allocations) for red grouper.
Amendment #23 Comprehensive Ecosystem-based Amendment 2 (CE-BA2) (2011f)	1/30/12	PR: 76 FR 69230 FR: 76 FR 82183	-Designated the Deepwater MPAs as EFH-HAPCs; -Modify management measures for Octocoral; -Limit harvest of snapper grouper species in SC SMZs to the bag limit; -Modify sea turtle release gear; -Designated new EFP for pelagic Sargassum habitat.
Amendment #18A (2012a)	7/1/12	PR: 77 FR 16991 FR: 77FR3 2408	-Limited participation and effort in the black sea bass sector; -Modifications to management of the black sea bass pot sector; -Improved data reporting (accuracy, timing, and quantity of fisheries statistics).
Amendment #20A (2012b)	10/26/12	PR: 77 FR 19165 FR: 77 FR 59129	- Individual transfer quota (ITQ) program for wreckfish: -Defined and reverted inactive shares; -Redistributed reverted shares; -Established a share cap; -Established an appeals process.
Regulatory Amendment #12 (2012c)	10/9/12	PR: 77 FR 42688 FR: 77 FR 61295	-Revised the ACL and OY for golden tilefish; -Revised recreational AMs for golden tilefish;

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Amendment #18B (2013a)	5/23/13	PR: 77 FR 75093 FR: 77 FR 23858	For Golden Tilefish: -Limited participation and effort in the commercial sector through establishment of a longline endorsement; -Established eligibility requirements and allowed transferability of longline endorsement; -Established an appeals process; -Modified trip limits; -Specified allocations ACLs for gear groups (longline and hook and line); -Adjusted the fishing year.
Amendment #28 (2013b)	8/23/13	PR: 78 FR 25047 FR: 78 FR 44461	-Established regulations to allow harvest of red snapper in the South Atlantic (formula used to compute ACLs, AMs, fishing seasons).
Regulatory Amendment #13 (2013c)	7/17/13	PR: 78 FR 17336 FR: 78 FR 36113	-Revised the ABCs, ACLs (including sector ACLs), and ACTs for 37 species implemented by the Comprehensive ACL Amendment (see final rule for list of species). The revisions may prevent a disjunction between the established ACLs and the landings used to determine if AMs are triggered.
Regulatory Amendment #15 (2013d)	9/12/13	PR: 78 FR 31511 FR: 78 FR 49183	-Modified ACLs and OY for yellowtail snapper; -Modified the commercial and recreational yellowtail snapper fishing years and commercial spawning season closure; -Modified the gag commercial ACL and AM to remove the requirement that all other shallow water groupers (black grouper, red grouper, scamp, red hind, rock hind, graysby, coney, yellowmouth grouper, and yellowfin grouper) are prohibited from harvest in the South Atlantic when the gag commercial ACL is met or projected to be met.
Regulatory Amendment #18 (2013e)	9/5/13	PR: 78 FR 26740 FR: 78 FR 47574	-Revised ACLs and OY for vermilion snapper; -Modified commercial trip limit for vermilion snapper; -Modified commercial fishing season and recreational closed season for vermilion snapper; -Revised ACLs and OY for red porgy.
Regulatory Amendment #19 (2013f)	ACL: 9/23/13 Pot closure: 10/23/13	PR: 78 FR 39700 FR: 78 FR 58249	-Specified ABC, and adjusted the ACL, recreational ACT and OY for black sea bass; -Implemented an annual closure on the use of black sea bass pots from November 1 to April 30.
Amendment #27 (2013g)	1/27/2014	PR:78 FR 78770 FR: 78 FR 57337	-Established the Council as the responsible entity for managing Nassau grouper throughout its range including federal waters of the Gulf of Mexico; -Modified the crew member limit on dual-permitted snapper grouper vessels; -Modified the restriction on retention of bag limit

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			quantities of some snapper grouper species by captain and crew of for-hire vessels; -Minimized regulatory delay when adjustments to snapper grouper species' ABC, ACLs, and ACTs are needed as a result of new stock assessments; -Removed blue runner from snapper grouper FMP; -Addressed harvest of blue runner by commercial fishermen who do not possess a South Atlantic Snapper Grouper Permit.
Amendment #31 Joint South Atlantic and Gulf of Mexico Generic Headboat Reporting Amendment (2013h)	1/27/2014	PR: 78 FR 59641 FR: 78 FR 78779	-Included under the Generic charter/headboat reporting amendment, that modified required logbook reporting for headboat vessels to require electronic reporting, regarding snapper grouper landings.
Amendment #?? (Revisions to Dealer Permitting and Reporting Requirements) (2013i)	8/7/2014	PR: 79 FR 81 FR: 79 FR 19490	- Modified permitting and reporting requirements for seafood dealers who first receive fish managed by the SA and Gulf through eight FMPs.
Regulatory Amendment #14 (2014a)	12/8/2014	PR: 79 FR 22936 FR: 79 FR 66316	-Modified the commercial and recreational fishing year for greater amberjack; -Modified the commercial and recreational sector fishing years for black sea bass; -Modified the recreational AM for black sea bass; -Modified the recreational AM for vermilion snapper; -Modify the commercial trip limit for gag.
Regulatory Amendment # 21 (2014b)	11/6/2014	PR: 79 FR 44735 FR: 79 FR 60379	-Modified the definition of the overfished threshold (MSST) for red snapper, blueline tilefish, gag, black grouper, yellowtail snapper, vermilion snapper, red porgy, and greater amberjack.
Amendment #29 (2014c)	7/1/2015	NOA: 79 FR 69819 PR: 79 FR 72567 FR: 80 FR 30947	-Updated the ABC control rule to incorporate methodology for determining the ABC of unassessed species; -Adjusted the ABCs for fourteen unassessed snapper grouper species (see final rule); -Adjusted the ACLs and ACTs for three species complexes and four snapper grouper species based on revised ABCs; -Established ACLs for unassessed species; -Modified gray triggerfish minimum size limits; -Established a commercial split season and commercial trip limits for gray triggerfish.

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Blueline Tilefish Emergency Rule	4/17/2014 through 10/10/2014 or 4/18/2015	PR: 79 FR 21636 FR:79 FR 61262	-Removed the blueline tilefish portion from the deep-water complex ACL; -Established separate commercial and recreational ACLs and AMs for blueline tilefish.
Regulatory Amendment #20 (2014d)	8/20/2015	PR: 80 FR 18797 FR: 80 FR 43033	-Adjusted the recreational and commercial ACLs for snowy grouper; -Adjusted the rebuilding strategy; -Modified the commercial trip limit; -Modified recreational bag limit; -Modified the recreational fishing season.
Amendment #32 (2014e)	3/30/2015	PR: 80 FR 3207 FR: 80 FR 16583	-End overfishing of blueline tilefish; -Removed blueline tilefish from the deepwater complex; -Specified AMs, ACLs, recreational ACLs, commercial trip limit, adjust recreational bag limit for blueline tilefish; -Specified ACLs and revised the AMs for the recreational section of the deepwater complex (yellowedge grouper, silk snapper, misty grouper, queen snapper, sand tilefish, black snapper, and blackfin snapper);
Regulatory Amendment #22 (2015a)	9/11/2015, except for the amendments to §§ 622.190(b) and 622.193(r)(1) which were effective 8/12/2015	PR: 80 FR 31880 FR: 80 FR 48277	-Adjusted ACLs and OY for gag and wreckfish;
Amendment # 33 Dolphin Wahoo Amendment 7 and Snapper Grouper Amendment 33 (2015b)	12/28/2015	NOA:80 FR 55819 PR:80 FR 60601 FR:80 FR 80686	-Allowed dolphin and wahoo fillets to enter the U.S. EEZ after lawful harvest in The Bahamas; -Specified the condition of any dolphin, wahoo, and snapper grouper fillets; -Described how the recreational bag limit is determined for any fillets; -Prohibited the sale or purchase of any dolphin, wahoo, or snapper grouper recreationally harvested in The Bahamas; -Specified the required documentation to be onboard any vessels that have these fillets; -Specified transit and stowage provisions for any vessels with fillets.
Amendment #34 Generic Accountability Measures and Dolphin	2/22/2016	NOA:80 FR 41472 PR:80 FR 58448 FR:81 FR 3731	-Modified AMs for snapper grouper species (golden tilefish, snowy grouper, gag, red grouper, black grouper, scamp, the shallow-water grouper complex (SASWG: red hind, rock hind, yellowmouth grouper, yellowfin grouper, coney, and graysby), greater amberjack, the jacks complex (lesser amberjack, almaco jack, and banded rudderfish), bar jack,

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Allocation Amendment (2015c)			yellowtail snapper, mutton snapper, the snappers complex (cubera snapper, gray snapper, lane snapper, dog snapper, and mahogany snapper), gray triggerfish, wreckfish (recreational sector), Atlantic spadefish, hogfish, red porgy, the porgies complex (jolthead porgy, knobbed porgy, whitebone porgy, scup, and saucereye porgy); -Modified the AM for commercial golden crab fishery; -Adjusted sector allocations for dolphin.
Amendment #35 (2015d)	6/22/2016	NOA:81 FR 6222 PR:81 FR 11502 FR:81 FR 32249	-Removed black snapper, dog snapper, mahogany snapper, and schoolmaster from the Snapper Grouper FMP; -Clarified regulations governing the use of Golden Tilefish Longline Endorsements.
Regulatory Amendment #16 (2016a)	12/29/2016 (closure) 1/30/2017 (gear markings)	NOI: 78 FR 72868 PR: 81 FR 53109 FR: 81 FR 95893	-Revise the area where fishing with black sea bass pots is prohibited from Nov.1-April 30. -Add additional gear marking requirements for black sea bass pot gear.
Regulatory Amendment #25 (2016b)	8/12/2016 except changes to blueline tilefish, effective 7/13/2016.	PR: 81 FR 34944 FR: 81 FR 45245	-Revised commercial and recreational ACL for blueline tilefish; -Revised the recreational bag limit for black sea bass; -Revised the commercial and recreational fishing year for yellowtail snapper.
Amendment #37 (2016c)	TBD	NOI: 80 FR 45641 NOA: 81 FR 69774 PR: 81 FR 91104	-Modify the hogfish fishery management unit; -Specify fishing levels for the two South Atlantic hogfish stocks; -Establish a rebuilding plan for the Florida Keys/East Florida stock; -Establish/revised management measures for both hogfish stocks in the South Atlantic Region, such as size limits, recreational bag limits, and commercial trip limits.
Amendment #26 (Bycatch Reporting Amendment)	TBD	TBD	-Modifies bycatch and discard reporting for commercial and for-hire vessels.
Amendment #36 (2016d)	TBD	NOI: 82 FR 810 PR: 82 FR 5512	-Establish SMZs to enhance protection for snapper grouper species in spawning condition including speckled hind and warsaw grouper.
Amendment #39 (Generic For-Hire Reporting Amendment) (2017b)	TBD		-Weekly electronic reporting for charter vessel operators with a federal for-hire permit; reduce the time allowed for headboat operators to complete electronic reports; and requires location reporting by charter vessels with the same detail currently

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			required for headboat vessels.
Amendment #41 (2017a)	TBD	TBD	-Update the MSY, ABC, ACL, OY, minimum stock size threshold, designate spawning months for regulatory purposes, and revise management measures for mutton snapper.

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Appendix D. Bycatch Practicability Analysis

1.1 Population Effects for the Bycatch Species

Background
In 2008, a stock assessment for red snapper indicated the red snapper stock was overfished and undergoing overfishing (Southeast Data, Assessment, and Review (SEDAR 15; 2008a). Consequently, an interim rule was published on December 4, 2009 (NOAA's National Marine Fisheries Service (NMFS) 2010), which prohibited harvest and possession of red snapper beginning on January 4, 2010. That rule was extended for 186 days. A new benchmark assessment completed in 2010, further confirmed that red snapper is experiencing overfishing and is overfished (SEDAR 24 2010b). Amendment 17A to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region (Snapper Grouper FMP) (Amendment 17A; SAFMC 2010a), effective December 3, 2010, continued the harvest and possession prohibition of red snapper to end overfishing and also implemented a rebuilding plan. Appendix R of Amendment 17A contains the BPA conducted for that amendment, and is incorporated herein by reference. At their June 2012 meeting, the South Atlantic Fishery Management Council (South Atlantic Council) reviewed red snapper discard mortality estimates and compared them to the 2012 acceptable biological catch (ABC) from the rebuilding projection, which were recommended by the South Atlantic Council's Scientific and Statistical Committee based on the results of SEDAR 24 (2010b). The estimated mortalities for 2012 were less than the ABC for 2012 suggesting some minimal level of harvest of red snapper could occur without negatively affecting the stock (Appendix B of Measures to Allow Limited Harvest of Red Snapper (*Lutjanus campechanus*) in the South Atlantic in 2012 (Temporary Measures through Emergency Action) (NMFS 2012)). As a result, the South Atlantic Council recommended reopening red snapper to a small amount of harvest in 2012.

With the exception of limited openings in 2012, 2013, and 2014, harvest of red snapper in federal waters has been prohibited since January 4, 2010. There have been very limited landings of red snapper in Florida state waters since Florida has not adopted compatible regulations (as of July 2017). Since 2010, dead discards have accounted for most of the total removals (92%) and resulted from incidental catch of red snapper while fishermen targeted co-occurring species. Amendment 17A indicated the top co-occurring species with red snapper are black sea bass, red grouper, gag, scamp, greater amberjack, vermilion snapper, and gray triggerfish. The Southeast Fisheries Science Center (SEFSC) provided a report on the level of landings and dead discards of red snapper in 2010 and 2011, which is contained in Appendix B of Measures to Allow Limited Harvest of Red Snapper (*Lutjanus campechanus*) in the South Atlantic in 2012 (Temporary Measures through Emergency Action) (NMFS 2012).

In 2012 Amendment 28 put forth a process to determine if a red snapper fishing season would occur each year and would specify annual catch limits for landings. Based on the annual catch limits, season lengths for the commercial and recreational sectors would be projected. Following the management measures of Amendment 28, an annual catch limit was set greater than zero and red snapper landings were allowed in 2012, 2013, and 2014. Landings were not allowed in 2015 and 2016.

SEDAR 41, a 2016 benchmark stock assessment for red snapper, indicated the red snapper stock was overfished and undergoing overfishing was still occurring (SEDAR 2017). During the review of the assessment, the Scientific and Statistical Committee of the South Atlantic Fishery Management Council (SSC) outlined several sources of uncertainty including: the stock-recruitment relationship, natural mortality at age, the age structure of the unfished population, the composition and magnitude of recreational discards, potential changes in CPUE catchability, and the selectivities for the different fishery fleets. Due to these uncertainties the SSC stated the stock was experiencing but the level of overfishing could not be determined and the population was rebuilding (SAFMC 2016).

The directed commercial snapper grouper fishery for most of the top co-occurring species with red snapper (red grouper, gag, scamp, greater amberjack, and gray triggerfish) is executed primarily with hook and line gear (Table 1). Black sea bass, another species that co-occurs with red snapper, are predominantly taken with pots. Red snapper were taken primarily (84%) with hook and line gear during the limited commercial openings in 2012, 2013, and 2014. This percentage is similar to the Amendment 17A BPA, which described red snapper primary gear as hook and line prior to the closure.

Table 1. Mean percentage of commercial landings by gear (2012-2014).

Species	Diving	Hook and Line	Longline	Pot	Other
Black sea bass	0.56%	41.12%	0.00%	54.62%	3.69%
Red grouper	6.04%	85.98%	7.28%	0.34%	0.36%
Gag	12.61%	85.85%	0.39%	0.27%	0.88%
Scamp	9.40%	89.07%	0.44%	0.16%	0.94%
Greater amberjack	5.02%	93.97%	0.05%	0.38%	0.57%
Vermilion snapper	0.53%	98.22%	0.31%	0.15%	0.78%
Gray triggerfish	2.51%	95.24%	0.32%	1.27%	0.66%

Between 2012 and 2014, the recreational sector dominated the landings of red grouper (>60% of landings) while black sea bass, greater amberjack, and gray triggerfish landings were evenly divided between the commercial and recreational sectors (Table 2). The commercial sector dominated landings of gag, vermilion snapper that commonly occur with red snapper. Appendix R from Amendment 17A indicates the recreational sector took approximately 83% of the red snapper landings during 2005-2008.

Table 2. Mean commercial and recreational landings (pounds whole weight) during 2012-2014. Commercial landings include all of Monroe County, Florida; MRFSS landings do not include Monroe County, Florida; Headboat landings include Monroe County, Florida for Atlantic-based vessels.

Species	Headboat	MRIP	Total Recreational	Commercial	Percent	Percent
					Recreational	Commercial
Black sea bass	385,656	117,050	502,706	446,078	53%	47%
Red grouper	231,018	12,937	243,954	137,478	64%	36%
Gag	176,023	15,646	191,669	415,611	32%	68%
Scamp	36,528	14,639	51,167	167,390	23%	77%
Greater amberjack	802,835	66,939	869,774	908,878	49%	51%
Vermilion snapper	135,838	150,565	286,403	965,649	23%	77%
Gray triggerfish	268,536	116,971	385,507	303,214	56%	44%

Source: SEFSC commercial annual catch limit (ACL) data (May 2017); Recreational ACL data (June 2017).

Commercial Sector

Based on the commercial logbook, the average number of trips per year between 2012 and 2014 was 13,130; and fishermen spent an average of 1.64 days at sea per trip (Table 3). Only trips that landed species under the SAFMC's snapper grouper fisheries management plan were used to calculate effort.

Table 3. Snapper grouper commercial fishery effort for South Atlantic.

Year	Trips	Days	Days per Trip
2012	12,737	20,899	1.64
2013	12,088	20,674	1.71
2014	14,564	23,019	1.58
Mean	13,130	21,531	1.64

Source: NMFS SEFSC coastal logbook program that records landings.

Among red snapper and co-occurring species during 2012-2014, the average percentage of trips that reported discards was greatest for red snapper and black sea bass (26.46% and 25.22%, respectively), followed by vermilion snapper (21.48%), gray triggerfish (14.13%), and gag (12.04%) (Table 4). Species with the greatest number of individuals discarded during 2012-2014 were black sea bass (41,821), vermilion snapper (21,944), and red snapper (18,734) (Table 4).

Since the discard logbook database represents a sample, data were expanded to estimate the number of discarded fish caught on vertical line and long line (Table 4). The formula used for expansion was: "discard per unit effort from discard logbook database * total effort from commercial logbook." Release mortality estimates for the commercial sector compiled from the most recent stock assessments (as available) using the SEDAR process are: 38% red snapper (SEDAR 41; 2017); 40% gag (SEDAR 10; 2006b); 7% for hook and line and 1% for pot caught black sea bass (SEDAR 25; 2011); 41% vermilion snapper (SEDAR 17 Update; 2012); 20% red grouper and 20% black grouper (SEDAR 19; 2010a); 20% greater amberjack (SEDAR 15; 2008); and 12.5% gray triggerfish (SEDAR 41; 2017) (Table 4). Dead discards were estimated by applying the release mortality rates to the total discards. Discard mortality was highest for vermilion snapper (8,997), followed by red snapper (7,119) (Table 4). See the "Finfish Bycatch Mortality" and "Practicability of Management Measures in Directed Fisheries Relative to their Impact on Bycatch and Bycatch Mortality" sections of this BPA for more details.

Table 4. Percentage of commercial trips that discarded species and expanded commercial discards of red snapper and co-occurring species from 2012-2014.

Species	Percentage of trips that discarded species	Total discards	Release mortality	Dead Discards
Black sea bass	25.22%	41,821	7%	2,927
Red grouper	5.56%	2,105	20%	421
Gag	12.04%	9,697	40%	3,879
Scamp	10.55%	1,268	Unknown	Unknown
Greater Amberjack	6.64%	2,029	20%	406
Red snapper	26.46%	18,734	38%	7,119
Vermilion snapper	21.48%	21,944	41%	8,997
Gray triggerfish	14.13%	12,918	12.50%	1,615

Note: Computed using mean discard rates (2012-2014) of vertical line and longline from commercial discard logbook applied to overall commercial effort reported to commercial logbook. Discard logbook and commercial logbook data provided by SEFSC April 2017.

Table 5. Percentage of commercial trips that discarded species and expanded commercial discards of red snapper and co-occurring species from 2015-2016.

Species	Percentage of trips that discarded species	Total discards	Release mortality	Dead Discards
Black sea bass	14.97%	48,380	7%	3,387
Red grouper	1.70%	818	20%	164
Gag	8.54%	5,918	40%	2,367
Scamp	8.10%	1,132	Unknown	Unknown
Greater Amberjack	8.13%	4,300	20%	860
Red snapper	33.82%	24,131	38%	9,170
Vermilion snapper	20.85%	24,527	41%	10,056
Gray triggerfish	12.97%	15,236	12.50%	1,905

Note: Computed using mean discard rates (2015-2016) of vertical line and longline from commercial discard logbook applied to overall commercial effort reported to commercial logbook. Discard logbook and commercial logbook data provided by SEFSC April 2017.

Recreational Sector

For the recreational sector, estimates of the number of recreational discards are available from Marine Recreational Information Program (MRIP) and the NMFS headboat survey. The MRIP system classifies recreational catch into three categories:
Type A - Fishes that were caught, landed whole, and available for identification and enumeration by the interviewers.
Type B - Fishes that were caught but were either not kept or not available for identification:
Type B1 - Fishes that were caught and filleted, released dead, given away, kept but not observed by interviewer, or disposed of in some way other than Types A or B2.
Type B2 - Fishes that were caught and released alive.

Recreational harvest of red snapper co-occurring species was greatest for black sea bass followed by vermilion snapper, gray triggerfish, and gag (Table 6). There were differences in the amount and variety of species harvested by the private recreational sector and the "for-hire" sectors (charter boats/headboats). During 2010 and 2011, 90% of black sea bass, 89% of red grouper, and 84% of gag were discarded in the private recreational sector (Table 6). During the same period, 87% of red grouper and 67% of black sea bass were released by fishermen on charter boats, versus 88% of red grouper, and 68% of black sea bass by fishermen on headboats (Table 6).

Release mortality estimates for the recreational sector compiled from the most recent stock assessments using data from SEDAR stock assessments (as available) are: 25% gag (SEDAR 10; 2006b); 7% black sea bass (SEDAR 25; 2011); 38% vermilion snapper (SEDAR 17; 2008b); 20% red grouper (SEDAR 19; 2010a); 20% greater amberjack (SEDAR 15; 2008a); and 12.5% gray triggerfish (SEDAR 41; 2017) (Table 6). Dead discards were estimated by applying the release mortality rates to the total discards. In 2010 and 2011, discard mortality was highest for black sea bass (207,156), vermilion snapper (19,425), and gag (19,136) for the private recreational sector (Table 6). For the "for-hire" sector (charter boats/headboats), discard mortality was highest for black sea bass (13,051/35,426), followed by vermilion snapper (6,464/35,228) and red grouper (1,381/2,099) (Table 6). Discard mortality was zero for gray triggerfish in 2010 and 2011, for both the private recreational and "for-hire" sectors (Table 6).

The SEFSC's May 2012 report (Appendix B of NMFS 2012) shows red snapper discard mortalities in the private recreational sector decreasing from 31,561 fish in 2010, to 16,156 fish in 2011. Conversely, the same report reveals red snapper discard mortalities in the "for-hire" sector (charter boats/headboats) increasing from 20,569 fish in 2010, to 22,131 fish in 2011. These estimates used the release mortality rates used in SEDAR 24 (2010b). If the new estimate for discard mortality for the private sector was used (28.5%), the mortalities would have been lower. The number of mortalities in the recreational sector has increased dramatically in 2014 from an average of 36,531 from 2012 and 2013 to 107,822 in 2014.

Table 6. Mean number (expanded) of fish based on harvest (A + B1) and discards (B2) from MRIP for private and charter boat trips and SHBS for headboat trips for the South Atlantic from 2012-2014.

Private							Charter boat						Headboat					
Species	Total	A+B1	B2	% B2	Release Mortality	Dead Discards	Total	A+B1	B2	% B2	Release Mortality	Dead Discards	Total	A+B1	B2	% B2	Release Mortality	Dead Discards
Black sea bass	3,868,459	234,732	3,633,727	94%	7%	254,361	412,777	53,573	359,204	87%	7%	25,144	822,707	91,929	730,778	89%	7%	51,154
Red grouper	123,088	30,611	92,477	75%	20%	18,495	18,059	3,479	14,580	81%	20%	2,916	9,780	1,484	8,297	85%	20%	1,659
Gag	93,529	9,745	83,784	90%	25%	20,946	21,914	2,700	19,214	88%	25%	4,803	3,855	1,508	2,347	61%	25%	587
Scamp	4,493	4,493	0	0%		-	1,479	1,154	325	22%			4,129	1,889	2,240	54%		
Greater amberjack	41,194	18,870	22,324	54%	20%	4,465	25,845	17,804	8,042	31%	20%	1,608	7,057	3,551	3,506	50%	20%	701
Vermilion snapper	140,761	70,674	70,087	50%	38%	26,633	49,030	38,945	10,085	21%	38%	3,832	189,572	122,253	67,319	36%	38%	25,581
Gray triggerfish	177,398	83,390	94,008	53%	12.5%	11,751	48,684	38,824	9,860	20%	12.5%	1,233	64,320	52,898	11,422	18%	12.5%	1,428

Source: SEFSC Recreational ACL Dataset (June 2017), Headboat CRNF files (expanded; Mar 2017).

Finfish Bycatch Mortality

SEDAR 41 used estimates release mortality rates of red snapper for the commercial sector (38%) and the recreational sector (28.5%). This stock assessment used a revised release mortality estimates from SEDAR 24 (2010b) which were 48% for the commercial sector, 41% for recreational for-hire sector (charter boats and headboats), and 39% for the private recreational sector, in the South Atlantic. SEDAR 15 (2008a) used the release mortality estimate of 90% for the commercial sector as reported in SEDAR 15 (2008a). There was no significant difference between the two stock assessments regarding the release mortality of red snapper in the recreational sector, which was 40%, as per the findings in SEDAR 15 (2008a). The most recent release mortality estimate was based on Sauls et al. (2015), which was a working paper submitted to SEDAR 41 (2017). In this paper, the researchers calculated the release mortality rate through a mark recapture study and relative risk of injury due to several factors. The estimate was revised due to suggestions at the workshop and recommended for use for the recreational sector in the assessment. The commercial sector used information from Burns et al. (2002), but the discard mortality was decreased due to use of circle hooks. Diamond and Campbell (2009) reported a delayed mortality rate of 64% off Texas. A study by Burns et al. (2004) conducted on headboats off Florida in the Atlantic and Gulf of Mexico found a release mortality of 64% for red snapper. The majority of acute mortalities in this study (capture depth of 9-42 m) were attributed to hooking (49%), whereas barotrauma accounted for 13.5%. An earlier study by Burns et al. (2002), also conducted in the Atlantic and Gulf of Mexico, had similar results, as J-hook mortality accounted for 56% of the acute mortalities of red snapper on headboats. Using tagging data and cage studies, Burns et al. (2002) determined the depth at which 50% of the released red snapper would die is 43.7 m (143 feet). SEDAR 15 (2008a) indicated red snapper were most often caught at depths of 141-190 feet by the recreational sector and 141-234 feet by the commercial sector. Rummer and Bennett (2005) reported over 70 different overexpansion injuries related to barotrauma in red snapper, and Wilde (2009) observed reduced survival of this species when vented.

SEDAR 17 (2008b) recommended a release mortality rate for vermilion snapper of 41% for the commercial sector and 38% for the recreational sector. The commercial sector has slightly higher discard mortality rate because that sector typically fishes in deeper water than the recreational sector. Ruderhshausen et al. (2007) estimated release mortality rate to be15% for undersized vermilion snapper. Immediate mortality of vermilion snapper was estimated to be 10% at depths of 25-50 m and delayed mortality was estimated to be 45% at the same depths. Rudershausen et al. (2007) indicated minimum size limits are moderately effective in shallower water for vermilion snapper. Previously, SEDAR 2 (2003) estimated a release mortality rate of 40% and 25% for vermilion snapper taken by commercial and recreational fishermen, respectively. Release mortality rates for vermilion snapper from SEDAR 2 (2003) were based on cage studies conducted by Collins (1996) and Collins et al. (1999). Burns et al. (2002) suggested that release mortality rates of vermilion snapper could be higher than those estimated from cage studies because cages protect the fish from predators. A higher release mortality rate is supported by low recapture rates of vermilion snapper in tagging studies. Burns et al. (2002) estimated a 0.7% recapture rate for 825 tagged vermilion snapper; whereas, recapture rates for red grouper, gag, and red snapper ranged from 3.8% to 6.0% (Burns et al. 2002). McGovern and Meister (1999) estimated a 1.6% recapture rate for 3,827 tagged vermilion snapper. Alternatively, recapture rates could be low if population size was very high or tagged fish were unavailable to fishing gear. Harris and Stephen (2005) indicated approximately 50% of released vermilion snapper caught by one commercial fisherman were unable to return to the bottom. Lower recapture rates were estimated for black sea bass (10.2%), gray triggerfish (4.9%), gag (11%), and greater amberjack (15.1%) (McGovern and Meister 1999; McGovern et al. 2005). Burns et al. (2002) suggested released vermilion snapper did not survive as well as other species due to predation. Vermilion snapper that do not have air removed from swim bladders are subjected to predation at the surface of the water. Individuals with a ruptured swim bladder or those that have air removed from the swim bladder are subject to bottom predators, since fish would not be able to join schools of other vermilion snapper hovering above the bottom (Burns et al. 2002). However, Wilde (2009) reports that venting appears to be increasingly harmful for fish captured from deep water.

SEDAR 10 (2006b) estimated release mortality rates of 40% and 25% for gag taken by commercial and recreational fishermen, respectively. A tagging study conducted by McGovern et al. (2005) indicated recapture rates of gag decreased with increasing depth. The decline in recapture rate was attributed to depth-related mortality. Assuming there was no depth-related mortality at 0 m, McGovern et al. (2005) estimated depth related mortality ranged from 14% at 11-20 m (36-65 feet) to 85% at 71-80 m (233-262 feet). Similar trends in depth related mortality were provided by a gag tagging study conducted by Burns et al. (2002). Overton et al. (2008) reported post-release mortality for gag as 13.3%. Release mortality rates are not known for other shallow water grouper species, but could be similar to gag since they have a similar depth distribution. Rudershausen et al. (2007) estimated release mortality rates of 33% for undersized gag taken with J-hooks in depths of 25-50 m off North Carolina. For other gag caught at depths of 25-50 m, no immediate mortality was observed but delayed mortality was estimated to be 49%. McGovern et al. (2005) estimated a release mortality rate of 50% at 50 m, which is similar to the findings of Rudershausen et al. (2007). Rudershausen et al. (2007) concluded minimum size limits are effective for gag in the shallower portions of their depth range.

Release mortality rates were estimated as 20% for red grouper taken by recreational and commercial fishermen in SEDAR 19 (2010a). There was limited information to estimate discard mortality for red grouper. Wilson and Burns (1996) reported potential mortality rates for released red grouper to be low (0 - 14%) as long as the fish were caught from waters shallower than 44 m. It was recommended to use a discard mortality of 20% based on gag discard mortality since some studies did not account for post release mortality. The 20% release mortality for red snapper was used a proxy for Nassau Grouper in the 2016 biological opinion (NMFS 2016). SEDAR 15 (2008a) estimated a 20% release mortality rate for greater amberjack. Although SEDAR 41 (2017) assessment was not approved as best science for assessing the gray triggerfish stock, a literature review was conducted on the release mortality. The report recommended using a release mortality of 12.5% for gray triggerfish.

Release mortality of black sea bass is considered to be low (7% for the recreational sector and 7% for hook and line fishery and 1% for pot fishery in the commercial sector) (SEDAR 25; 2011) indicating minimum size limits are probably an effective management tool for black sea bass. McGovern and Meister (1999) report a recapture rate of 10.2% for 10,462 that were tagged during 1993-1998 suggesting that survival of released black sea bass is high. Rudershausen et al. (2007) reported a sub-legal discard rate of 12% for black sea bass. Collins et al. (1999) reported venting of the swim bladder yielded reductions in release mortality of black sea bass, and the benefits of venting increased with capture depth. The same study was analyzed by Wilde (2009) to suggest that venting increased the survival of black sea bass, although this was an exception to the general findings of Wilde's (2009) study.

Practicability of Management Measures in Directed Fisheries Relative to their Impact on Bycatch and Bycatch Mortality

The snapper grouper fishery represents many species occupying the same location at the same time. For example, the top co-occurring species with red snapper are black sea bass, red grouper, gag, scamp, greater amberjack, vermilion snapper, and gray triggerfish. Fishermen could harvest one of these species and return a co-occurring species to the water as "regulatory discards" (e.g., if the fish is under the size limit) or if undesirable. A portion of the population would not survive. Species with the greatest average annual number of individuals discarded by the commercial sector during 2012 to 2014 were black sea bass (32,548), vermilion snapper (21,944), red snapper (18,734), and) (Table 4). During 2012 to 2014, 94% of black sea bass,, 90% of gag, and 75% of red grouper were discarded in the private recreational sector (Table 5). During the same period, 88% of gag, 87% of black sea bass, and 81% of red grouper were released by fishermen on charter boats, versus 89% of black sea bass and 85% of red grouper by fishermen on headboats (Table 5).

Although fishery management actions can adversely impact non-target species, the proposed action is not anticipated to significantly increase bycatch of snapper-grouper species. The red snapper open seasons in 2012, 2013, and 2014 were short in duration (total days open since 2010: 17 recreational and 122 commercial) and future seasons based on landings during this time period would also be small. Rather, the proposed action is likely to allow fishermen to retain incidentally caught red snapper when targeting co-occurring species. A portion of these red snapper might otherwise die when returned to the water.

Alternative 1 (no action) would retain the current process to determine the annual catch limit for red snapper. Under the current process, the annual catch limit has been zero due to exceeding the acceptable biological catch based on landings and discards in the previous year. The SSC has indicated there is a great deal of uncertainty in the catch and discards in the recreational sector and the catch statistic should not be used in management. Under Alternative 1 (No Action), if the season were to reopen, the minimum size limit would be effective. Alternative 4 would establish an annual catch limit of 42,510 red snapper. The commercial annual catch limit would be 124,815 pounds (whole weight) and recreational annual catch limit would be 29,656 fish. Both alternatives could have adverse effects on the stock due to discarding fish to the water of which a portion would not survive. Release mortality rates for red snapper range from 28.5 to 38% depending on the fishing sector (SEDAR 41; 2017). Fishermen may produce "regulatory discards" under both alternatives; but Alternative 4 could have a lower amount of discards because a portion of the red snapper would be retained as landings. If the red snapper fishery remains closed as has happened since 2014, then the bycatch would be higher under Alternative 1 (No Action).

Adverse effects (additional mortality) could be produced from both Alternative 1 (No Action) and Alternative 4 through "high-grading" behavior. High-grading is a practice of selectively landing fish so that only the best quality (usually largest) fish are brought ashore. For example, recreational fishermen may discard smaller size fish in order to retain a larger, more desirable red snapper. High-grading can result in many dead discards. Both Alternative 1 (No Action) and Alternative 4 could have similar impacts from additional mortality since fishermen would be restricted to 1 red snapper per person (if a season fishermen opens for Alternative 1 (No Action)).

Amendment 14 to the Snapper Grouper FMP (Amendment 14; SAFMC 2009a) established eight marine protected areas (MPAs) from North Carolina to Florida where harvest of snapper grouper species is prohibited. One of the objectives of Amendment 14 was to protect some areas where spawning of snapper grouper species (e.g., snowy grouper, golden tilefish, speckled hind, red porgy, vermilion snapper, gray triggerfish, red snapper, scamp, gag, red grouper, gray triggerfish, and others) was known to occur. As all harvest of snapper grouper species is prohibited in the MPAs, no bycatch of snapper grouper species in occurring in these areas.

Seasonal closures of shallow water grouper species (commercial and recreational sectors) and vermilion snapper (recreational sector) implemented through Amendment 16 to the Snapper Grouper FMP (Amendment 16; SAFMC 2009b) has likely reduced bycatch mortality of red snapper. Expected harvest reductions for red snapper from Amendment 16 in total kill was estimated to be 16.5% (commercial sector), 1.1 to 7.7% (headboat sector), and 2.3% (private/charter sector) (SERO 2009a; SERO 2009b; SERO 2009c; SERO 2009d). A longer spawning seasonal closure could enhance the reproductive potential of grouper stocks. For example, Amendment 16 established a January-April spawning season closure for gag, red grouper, black grouper, and shallow water grouper species. Gag are in spawning condition from December through April each year. There is some evidence spawning aggregations may be in place before and after a spawning season (Gilmore and Jones 1992). When aggregated, gag are extremely susceptible to fishing pressure since the locations are often well known by fishermen. Gilmore and Jones (1992) showed that the largest and oldest gag in aggregations are the most aggressive and first to be removed by fishing gear. Since gag change sex, larger and older males can be selectively removed. As a result, a situation could occur where there are not enough males in an aggregation to spawn with the remaining females. Furthermore, the largest, most fecund females could also be selectively removed by fishing gear. Therefore, a spawning season closure for all shallow water grouper species is expected to protect grouper species when they are most vulnerable to capture, reduce bycatch of co-occurring grouper species, increase the percentage of males in grouper populations, enhance reproductive success, and increase the magnitude of recruitment. Other actions in Amendment 16 that could reduce bycatch of snapper grouper species include a reduction in the recreational bag limit to 1 gag or black grouper (combined) per day within a grouper aggregate bag limit of 3 fish and the establishment of a commercial quota for gag. When the commercial quota is met, all fishing for or possession of shallow water grouper species will be prohibited.

Unobserved mortality due to predation or trauma associated with capture could be substantial (Burns et al. 2002; Rummer and Bennett 2005; St. John and Syers 2005; Parker et al. 2006; Rudershausen et al. 2007; Hannah et al. 2008; Diamond and Campbell 2009). Amendment 16 also included actions that required the use of dehooking devices, which could help reduce bycatch mortality of vermilion snapper, black sea bass, gag, red grouper, black grouper, and red snapper. Dehooking devices can allow fishermen to remove hooks with greater ease and more quickly from snapper grouper species without removing the fish from the water. If a fish does need to be removed from the water, dehookers could still reduce handling time in removing hooks, thus increasing survival (Cooke et al. 2001).

In addition to prohibiting the harvest of red snapper, Amendment 17A implemented regulations requiring the use of non-stainless circle hooks north of 28 degrees N. latitude, effective March 2, 2011. Circle hooks are generally thought to reduce the discard mortality rate for red snapper (SEDAR 7 2005; Rummer 2007); however, Burns et al. (2004) did not observe decreased discard mortality rate when comparing recapture rates of red snapper caught on circle and J-hooks. Rummer (2007), and Diamond and Campbell (2009) found that a greater differential between the surface and bottom temperature caused a higher discard mortality rate for red snapper. Amendment 17B to the Snapper Grouper FMP (Amendment 17B; SAFMC 2010b) established ACLs and accountability measures (AMs) and addressed overfishing for eight species in the snapper grouper management complex listed at that time as undergoing overfishing: snowy grouper; speckled hind; warsaw grouper; black sea bass; gag; and red grouper; in addition to black grouper, golden tilefish, and vermilion snapper.

The Comprehensive ACL Amendment (SAFMC 2011a) implemented ACLs and accountability measures (AMs) for species not undergoing overfishing in four fishery management plans, in addition to other actions such as allocations and establishing annual catch targets for the recreational sector. The Comprehensive ACL Amendment also established additional measures to reduce bycatch in the snapper grouper fishery with the establishment of species complexes based on biological, geographic, economic, taxonomic, technical, social, and ecological factors. ACLs were assigned to these species complexes, and when the ACL for the complex is met or projected to be met, fishing for species included in the entire species complex is prohibited for the fishing year. ACLs and AMs will likely reduce bycatch of target species and species complexes as well as incidentally caught species (i.e., red snapper).

Amendment 18A to the Snapper Grouper FMP (Amendment 18A; SAFMC 2011b) contains measures to limit participation and effort for black sea bass, and does not directly affect red snapper. Amendment 18A established an endorsement program than enables snapper grouper fishermen with a certain catch history to harvest black sea bass with pots. In addition, Amendment 18A included measures to reduce bycatch in the black sea bass pot fishery, modify the rebuilding strategy, and other necessary changes to management of black sea bass as a result of a 2011 stock assessment (SEDAR 25). Amendment 24 to the Snapper Grouper FMP (Amendment 24; SAFMC 2011c) established a rebuilding plan for red grouper which is overfished and undergoing overfishing. Amendment 24 also established ACLs and AMs for red grouper that could help to reduce bycatch of red grouper and co-occurring species such as red snapper.

NMFS must examine ways to reduce mortality of Nassau grouper. This includes, but is not limited to, examining possible modifications to fishing practices that can be adopted through changes in fishery management plan related regulations, as well as recommended best fishing practices. NMFS must assess:

> (a) the potential effectiveness of non-stainless steel circle hooks on reducing injury and mortality to Nassau grouper. If deemed an effective measure, NMFS shall consider revision of regulations to expand their current use to include areas south of 28° N. lat. for fishing activities that could incidentally capture Nassau grouper.

(b) the potential effectiveness of fishing practices after fish are captured that could reduce and minimize the effects of fishing. This includes, but is not limited to 1) de-hooking and 2) treatment for barotrauma, e.g., the possible use of "descender" devices. If deemed effective, NMFS shall consider revision of regulations to implement their use for incidentally caught Nassau grouper.

Ecological Effects Due to Changes in the Bycatch

The ecological effects of bycatch mortality are the same as fishing mortality from directed fishing efforts. If not properly managed and accounted for, either form of mortality could potentially reduce stock biomass to an unsustainable level.

Overall fishing effort could increase in the commercial and recreational sectors in response to the limited reopening(s) of red snapper, and therefore, increase the potential for bycatch. However, as stated in Chapter 2 and analyzed in detail in Chapter 4, the reopening(s) would be of short duration in the recreational sector and limited to an incidental catch limit (75 lbs) in the commercial sector (see Chapter 6 for details), and therefore, the ecological effects due to changes in the bycatch would likely be small (see Appendix C (SERO 2012)) for detailed analysis.

Changes in the Bycatch of Other Fish Species and Resulting Population and Ecosystem Effects

The action in the amendment could allow a limited harvest of red snapper beginning in 2018, and subsequent years. Thus, ecological changes could occur in the community structure of reef ecosystems through the proposed action, due to increased fishing pressure on co-occurring species that could be caught as bycatch. These ecological changes could affect the nature and magnitude of bycatch over time. However, as stated in Chapters 2 and 4, the allowed harvest of red snapper beginning in 2018 would likely be relatively limited in scope, and changes in the bycatch of other fish species and resulting population and ecosystem effects could be minimal in nature.

The commercial red snapper season would close when the commercial sector ACL is met or projected to be met. The end of the recreational red snapper season would be projected and announced before the start of the recreational season. The NMFS Regional Administrator has the authority to delay the opening of red snapper fishing seasons in the event of a tropical storm or hurricane affecting the South Atlantic Council's area of authority. The process would be repeated each year until modified.

Effects on Marine Mammals and Birds

Under Section 118 of the Marine Mammal Protection Act (MMPA), NMFS must publish, at least annually, a List of Fisheries (LOF) that places all U.S. commercial fisheries into one of three categories based on the level of incidental serious injury and mortality of marine mammals that occurs in each fishery. The southeast U.S. Atlantic black sea bass pot fishery is included in the grouping of the Atlantic mixed species trap/pot fisheries, which the 2017 LOF classified as a Category II (82 FR 3655; January 12, 20177). Gear types used in these fisheries are determined to have occasional incidental mortality and serious injury of marine mammals. The SEFSC Supplementary Discard Data Program (SDDP) initiated in July of 2001. The SDDP sub-samples 20% of the vessels with an active permit. Since August 2001, only three interactions with marine mammals have been documented; each was taken by handline gear and each released alive (McCarthy SEFSC database). The longline and hook-and-line gear components of the snapper grouper fishery in the South Atlantic are classified as Category III fisheries ().

Although the black sea bass pot fishery can pose an entanglement risk to large whales due to their distribution and occurrence, sperm, fin, sei, and blue whales are unlikely to overlap with the black sea bass pot fishery operated within the snapper grouper fishery since it is executed primarily off North Carolina and South Carolina (with some effort off Florida) in waters ranging from 70-120 feet deep (21.3-36.6 meters). North Atlantic right overlap both spatially and temporally with the black sea bass pot fishery. In 2007, revisions to the Atlantic Large Whale Take Reduction Plan folded the Atlantic mixed species trap/pot fisheries into the plan (72 FR 57104; October 5, 2007). In the 2016 biologocal opinion, NMFS estimated that the number of annual lethal takes for NARWs from black sea bass trap/pot gear ranged from an estimated minimum of 0.005 to a maximum of 0.08. This equates to 1 estimated lethal entanglement approximately every 25 to 42 years. Bermuda petrels are occasionally seen in the waters of the Gulf Stream off the coasts of North and South Carolina during the summer. Sightings are considered rare and only occurring in low numbers (Alsop 2001). Roseate terns occur widely along the Atlantic coast during the summer but in the southeast region, they are found mainly off the Florida Keys (unpublished U.S. Fish and Wildlife Service data). Interaction with fisheries has not been reported as a concern for either of these species.

These species are not commonly found and neither has been described as associating with vessels or having had interactions with fisheries, including the snapper grouper fishery. Thus, it is believed that the snapper grouper fishery has no effectaffect the Bermuda petrel and the roseate tern

Changes in Fishing, Processing, Disposal, and Marketing Costs

With the exception of a limited opening in 2012, 2013, and 2014, landing red snapper has been prohibited since January 4, 2010 for both the commercial and recreational sectors. The action in the amendment may allow a limited harvest of red snapper beginning in 2018. Since red snapper is a desirable species, it is highly likely that all opportunities to harvest this species would be entertained. Therefore, there could be changes to costs associated with the fishing, processing, disposal, and marketing of red snapper. It is likely that all four states (North Carolina, South Carolina, Georgia, and Florida) would be affected by the regulations associated with this action, since fishermen from all the states would be interested in participating in any reopening that allows landings of red snapper. Additionally, factors such as waterfront property values, availability of less expensive imports, etc. may affect economic decisions made by recreational and commercial fishermen.

The South Atlantic Council has discussed options to enhance current data collection programs in future amendments. This might provide more insight in calculating the changes in fishing, processing, disposal, and marketing costs. The states and the SEFSC would work together to collect as much biological information as possible during the limited commercial and recreational openings for red snapper. The life history information obtained through data collection efforts may help in assessing the status of the stock in the future.

Changes in Fishing Practices and Behavior of Fishermen

Allowing harvest of red snapper could result in a modification of fishing practices by commercial and recreational fishermen, thereby affecting the magnitude of discards. However, as the increase in the red snapper ACL as proposed by proposed alternatives in this amendment is likely to be very small and the seasons would be relatively short, none of the proposed actions are expected to substantially increase overall fishing effort or the spatial and/or temporal distribution of current fishing effort. With the exception of limited openings in 2012, 2013, and 2014, harvest of red snapper has been prohibited since January 4, 2010 for both the commercial and recreational sectors. Since red snapper is a desirable species, it is highly likely that all opportunities to harvest this species would be entertained. Predicting changes in angler behavior in response to a reopening is difficult. Many factors can influence fishing activity (see Chapter 3 for more details) including: fuel costs and trip expenses; weather; changes in regulations; changes in fishing behavior; and conflicting activities (e.g., family activities, sporting events on weekends).

Landings of red snapper have only been allowed for 17 days for the recreational sector and 122 days for the commercial sector since 2010. Additionally, landings of red snapper from federal waters has not been allowed since 2014. The limited information available for red snapper make it difficult to determine how fishermen will respond to a similar opening in 2018.

NMFS would announce the pre-determined commercial and recreational fishing year start dates. The commercial red snapper season would close when the commercial sector ACL is met or projected to be met. The end of the recreational red snapper season would be projected and announced before the start of the recreational season. The NMFS Regional Administrator has the authority to delay the opening of red snapper fishing seasons in the event of a tropical storm or hurricane affecting the South Atlantic Council's area of authority. The process would be repeated each year unless modified.

Changes in Research, Administration, and Enforcement Costs and Management Effectiveness

Research and monitoring is ongoing to understand the effectiveness of proposed management measures and their effect on bycatch. Efforts are underway by the states and the SEFSC to enhance data collection activities if a limited opening for red snapper were to occur. In 1990, the SEFSC initiated a logbook program for vessels with federal permits in the snapper grouper fishery from the Gulf of Mexico and South Atlantic. Approximately 20% of commercial fishermen are asked to fill out discard information in logbooks; however, a greater percentage of fishermen could be selected with emphasis on individuals that dominate landings. Recreational discards are obtained from the Marine Recreational Information Program (MRIP) and logbooks from the NMFS headboat program.

Additional data collection activities for the recreational sector are being considered by the South Atlantic Council that could allow for a better monitoring of snapper grouper bycatch in the future. The SEFSC is developing electronic logbooks, which could be used to enable fishery managers to obtain information on species composition, size distribution, geographic range, disposition, and depth of fishes that are released. Some observer information has been provided by Marine Fisheries Initiative and Cooperative Research Programs, but more is desired for the snapper grouper fishery. Electronic logbook reporting is in place for headboats in the southeast, which is expected to improve the quality of data in that sector. Further, the South Atlantic Council is developing an amendment that could require vessel monitoring systems for snapper grouper vessels, which would be expected to improve data quality.

Cooperative research projects between science and industry are being used to a limited extent to collect bycatch information on the snapper grouper fishery in the South Atlantic. For example, Harris and Stephen (2005) characterized the entire (retained and discarded) catch of reef fishes from a selected commercial fisherman in the South Atlantic including total catch composition and disposition of fishes that were released. The Gulf and South Atlantic Fisheries Foundation, Inc. conducted a fishery observer program within the snapper grouper vertical hook-and-line (bandit rig) fishery of the South Atlantic United States. Through contractors they randomly placed observers on cooperating vessels to collect a variety of data quantifying the participation, gear, effort, catch, and discards within the fishery.

In the spring 2010, Archipelago Marine Research Ltd. worked with North Carolina Sea Grant and several South Atlantic Unlimited Snapper Grouper Permit holders to test the effectiveness of electronic video monitoring to measure catch and bycatch. A total of 93 trips were monitored with video monitoring, 34 by self-reported fishing logbooks, and 5 by observers. Comparisons between electronic video monitoring data and observer data showed that video monitoring was a reliable source of catch and bycatch data for most species.

Research funds for observer programs, gear testing and testing of electronic devices or both are also available each year in the form of grants from the Marine Fisheries Initiative, Saltonstall-Kennedy program, and the CRP. Efforts are made to emphasize the need for observer and logbook data in requests for proposals issued by granting agencies. A condition of funding for these projects is that data are made available to the Councils and NMFS upon completion of a study.

Stranding networks for sea turtles and marine mammals are established in the Southeast Region. The NMFS SEFSC is the base for the Southeast United States Marine Mammal Stranding Program (http://sero.nmfs.noaa.gov/protected_resources/marine_mammal_health_and_stranding_response_program/index.html). NMFS authorizes organizations and volunteers under the MMPA to respond to marine mammal strandings throughout the United States. These organizations form the stranding network whose participants are trained to respond to, and collect samples from live and dead marine mammals that strand along southeastern United State beaches. The SEFSC is responsible for: coordinating stranding events; monitoring stranding rates; monitoring human caused mortalities; maintaining a stranding database for the southeast region; and conducting investigations to determine the cause of unusual stranding events including mass strandings and mass mortalities (http://www.sefsc.noaa.gov/species/mammals/strandings.htm). The Southeast Regional Office and the SEFSC participate in a wide range of training and outreach activities to communicate bycatch related issues. The NMFS Southeast Regional Office issues public announcements, Southeast Fishery Bulletins, or News Releases on different topics, including use of turtle exclusion devices, bycatch reduction devices, use of methods and devices to minimize harm to turtles and sawfish, information intended to reduce harm and interactions with marine mammals, and other methods to reduce bycatch for the convenience of constituents in the southern United States. These are mailed out to various organizations, government entities, commercial interests and recreational groups. This information is also included in newsletters and publications that are produced by NMFS and the various regional fishery management councils. Announcements and news released are also available on the internet and broadcasted over NOAA weather radio.

NMFS established the South East Fishery-Independent Survey in 2010 to strengthen fishery independent sampling efforts in southeast U.S. waters, addressing both immediate and long-term fishery-independent data needs, with an overarching goal of improving fishery-independent data utility for stock assessments. Meeting these data needs is critical to improving scientific advice to the management process, ensuring overfishing does not occur, and successfully rebuilding overfished stocks on schedule.

Changes in the Economic, Social, or Cultural Value of Fishing Activities and Non-Consumptive Uses of Fishery Resources

Preferred alternatives, including those that are likely to increase or decrease discards could result in social and/or economic impacts as discussed in Chapter 4 of the EA.

Changes in the Distribution of Benefits and Costs

The ACL for the commercial and recreational sectors was established in the Comprehensive ACL Amendment (SAFMC 2011). Management measures proposed in the amendment have the potential to reduce bycatch of red snapper during a limited opening of the recreational and commercial sectors. See earlier section titled, “Practicability of Management Measures in Directed Fisheries Relative to their Impact on Bycatch and Bycatch Mortality”, in this BPA for a list of amendments and a summary of actions within them that could help reduce bycatch and discard mortality in the snapper grouper fishery. The extent to which these management measures would increase or decrease the magnitudes of discards is unknown. However, this depends on the degree to which fishermen shift effort to other species, seasons, or fisheries and whether effort decreases in response to more restrictive management measures as well as changes in community structure and age/size structures that could result from ending overfishing.

Social Effects

The social effects of all the alternatives, including those most likely to reduce bycatch, are described in Chapter 4 of the EA.

Conclusion

This section evaluates the practicability of taking additional action to minimize bycatch and bycatch mortality using the ten factors provided at 50 CFR section 600.350(d)(3)(i). In summary, revising the process to determine annual catch limits for red snapper proposed in the amendment has the potential to reduce bycatch of red snapper during a limited opening of the recreational and commercial sectors as some bycatch is turned into retained catch. As summarized in Section 1.3 of this BPA, the action in the amendment is not expected to result in significant changes in bycatch of red snapper. In addition, the Council, NMFS, and the SEFSC have implemented and plan to implement numerous management measures and reporting requirements that have improved, or are likely to improve monitoring efforts of discards and discard mortality in the snapper grouper fishery. Therefore, no additional action is needed to minimize bycatch or bycatch mortality within the snapper grouper fishery.

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Appendix E. Regulatory Impact Review

Introduction

The National Marine Fisheries Service (NMFS) requires a Regulatory Impact Review (RIR) for all regulatory actions that are of public interest. The RIR does three things: 1) It provides a comprehensive review of the level and incidence of impacts associated with a regulatory action; 2) it provides a review of the problems and policy objectives prompting the regulatory proposals and an evaluation of the major alternatives which could be used to solve the problem; and 3) it ensures that the regulatory agency systematically and comprehensively considers all available alternatives so that the public welfare can be enhanced in the most efficient and cost effective way. The RIR also serves as the basis for determining whether any proposed regulations are a "significant regulatory action" under certain criteria provided in Executive Order 12866 (E.O. 12866) and whether the approved regulations will have a "significant economic impact on a substantial number of small business entities" in compliance with the Regulatory Flexibility Act of 1980.

Problems and Objectives

The purpose and need, issues, problems, and objectives of this action are presented in **Chapter 1** of this amendment and are incorporated herein by reference.

Description of Fisheries

A description of the red snapper portion of the snapper grouper fishery of the Atlantic region is provided in **Chapter 3** of this Amendment and is incorporated herein by reference.

Effects of Management Measures

A detailed analysis and discussion of the expected economic effects of each alternative for all proposed actions is included in **Chapter 4**. The following discussion summarizes the expected economic effects of the preferred alternatives for each action.

Action 1. Revise the process to determine the annual catch limits (ACLs) for red snapper

Cumulative Economic Effects Summary

Action 1

Public and Private Costs of Regulations

Determination of Significant Regulatory Action

Pursuant to E.O. 12866, a regulation is considered a "significant regulatory action" if it is likely to result in: 1) an annual effect of $100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local, or tribal governments or communities; 2) create a serious inconsistency or otherwise interfere with an action taken or planned by another agency; 3) materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights or obligations of recipients thereof; or 4) raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in this executive order.

Appendix F. Regulatory Flexibility Analysis

Introduction

The purpose of the Regulatory Flexibility Act (RFA) is to establish a principle of regulatory issuance that agencies shall endeavor, consistent with the objectives of the rule and applicable statutes, to fit regulatory and informational requirements to the scale of businesses, organizations, and governmental jurisdictions subject to regulation. To achieve this principle, agencies are required to solicit and consider flexible regulatory proposals and to explain the rationale for their actions to assure that such proposals are given serious consideration. The RFA does not contain any decision criteria; instead, the purpose of the RFA is to inform the agency, as well as the public, of the expected economic impacts of the alternatives contained in the FMP or amendment (including framework management measures and other regulatory actions) and to ensure that the agency considers alternatives that minimize the expected impacts while meeting the goals and objectives of the FMP and applicable statutes.

With certain exceptions, the RFA requires agencies to conduct a regulatory flexibility analysis for each proposed rule. The regulatory flexibility analysis is designed to assess the impacts various regulatory alternatives would have on small entities, including small businesses, and to determine ways to minimize those impacts. The following regulatory flexibility analysis was conducted to determine if the proposed rule would have a significant economic impact on a substantial number of small entities or not.

Statement of the need for, objective of, and legal basis for the proposed rule

The primary purpose and need, issues, problems, and objectives of the proposed action are presented in **Section 1.2** and are incorporated herein by reference.

Identification of federal rules which may duplicate, overlap or conflict with the proposed rule

No federal rules have been identified that duplicate, overlap or conflict with the proposed rule.

Description and estimate of the number of small entities to which the proposed action would apply

This rule concerns commercial and recreational fishing for red snapper in the South Atlantic EEZ. Anglers are not considered small entities as that term is defined in 5 U.S.C. 601(6), whether fishing from for-hire fishing, private or leased vessels. Therefore, an estimate of the number of anglers directly affected by the rule is not provided here.

The rule would directly apply to businesses that operate commercial fishing vessels that harvest red snapper in the South Atlantic EEZ. Any commercial fishing vessel that harvests red snapper or any other species or species group of the snapper grouper fishery in the South Atlantic EEZ must have a valid commercial snapper grouper permit that is specifically assigned to that vessel. The permit is a limited access permit for either an unlimited quantity of pounds (of most species within the fishery) per trip or no more than 225 pounds per trip.

As of September 12, 2016, there are 525 valid unlimited and 104 valid 225-lb permits. If all of the permits that are currently not valid but are renewable are included, there would be 551 unlimited and 114 225-lb permits representing a total of 665 commercial fishing vessels that may be directly affected by the rule. Approximately 71% of the permits (and vessels) are owned by Florida residents.

An estimated 557 businesses own the above snapper grouper permits and operate the 655 vessels. Approximately 91% (506) of these businesses operate only one of the 665 permitted vessels (**Table F-1**). Half of a percent of the businesses operate approximately 5% of the vessels. Of the businesses with one permitted vessel, 106 have 225-lb permits and 400 have unlimited pounds permits. Of the 51 businesses with multiple permitted vessels, 46 hold only unlimited pound permits. The other five businesses with multiple permitted vessels have at least one 225-lb permit.

Table F-1. Number of Businesses by Number of Vessels Owned/Operated with SA Snapper Grouper Permits.

Number			Percent of vessels	Percent of businesses
Permitted vessels	**Businesses**	**Combined vessels**		
1	506	506	76.1%	90.8%
2	31	62	9.3%	5.6%
3	8	24	3.6%	1.4%
4	6	24	3.6%	1.1%
5	3	15	2.3%	0.5%
6 and Over	3	34	5.1%	0.5%
Total	**557**	**665**	**100.0%**	**100.0%**

Source: NMFS SERO PIMS as of September 12, 2016.

Description and economic impacts of compliance requirements of the rule

Significance of economic impacts on a substantial number of small entities

Appendix G. Other Applicable Laws

1.1 Administrative Procedure Act (APA)

1.2 Information Quality Act (IQA)

1.3 Coastal Zone Management Act (CZMA)

1.4 Endangered Species Act (ESA)

1.5 Executive Order 12612: Federalism

1.6 Executive Order 12866: Regulatory Planning and Review

1.7 Executive Order 12898: Environmental Justice

1.8 Executive Order 12962: Recreational Fisheries

1.9 Executive Order 13089: Coral Reef Protection

1.10 Executive Order 13158: Marine Protected Areas (MPAs)

The alternatives considered in this document are consistent with the directives of E.O. 13158.

1.11 Marine Mammal Protection Act (MMPA)

1.12 National Environmental Policy Act (NEPA)

This document has been written and organized in a manner that meets NEPA requirements, and thus is a consolidated NEPA document, including an EA, as described in NOAA Administrative Order (NAO) 216- 6, Section 6.03a.2.

<u>Purpose and Need for Action</u>

The purpose and need for this action are described in **Chapter 1**.

Alternatives

The alternatives for this action are described in **Chapter 2**.

Affected Environment

The affected environment is described in **Chapter 3**.

Impacts of the Alternatives

The impacts of the alternatives on the environment are described in **Chapter 4**.

1.13 National Marine Sanctuaries Act (NMSA)

1.14 Paperwork Reduction Act (PRA)

1.15 Regulatory Flexibility Act (RFA)

1.16 Small Business Act (SBA)

1.17 Public Law 99-659: Vessel Safety

Appendix H. Essential Fish Habitat and Ecosystem-based Management

South Atlantic Fishery Management Council Habitat Conservation, Ecosystem Coordination and Collaboration

The South Atlantic Fishery Management Council (Council), using the Essential Fish Habitat Plan as the cornerstone, adopted a strategy to facilitate the move to an ecosystem-based approach to fisheries management in the region. This approach required a greater understanding of the South Atlantic ecosystem and the complex relationships among humans, marine life, and the environment including essential fish habitat. To accomplish this, a process was undertaken to facilitate the evolution of the Habitat Plan into a Fishery Ecosystem Plan (FEP), thereby providing a more comprehensive understanding of the biological, social, and economic impacts of management necessary to initiate the transition from single species management to ecosystem-based management in the region.

Moving to Ecosystem-Based Management

The Council adopted broad goals for Ecosystem-Based Management to include maintaining or improving ecosystem structure and function; maintaining or improving economic, social, and cultural benefits from resources; and maintaining or improving biological, economic, and cultural diversity. Development of a regional FEP (SAFMC 2009a) provided an opportunity to expand the scope of the original Council Habitat Plan and compile and review available habitat, biological, social, and economic fishery and resource information for fisheries in the South Atlantic ecosystem. The Council views habitat conservation as the core of the move to EBM in the region. Therefore, development of the FEP was a natural next step in the evolution and expands and significantly updates the SAFMC Habitat Plan (SAFMC 1998a) incorporating comprehensive details of all managed species (SAFMC, South Atlantic States, ASMFC, and NOAA Fisheries Highly Migratory Species and Protected Species) including their biology, food web dynamics, and economic and social characteristics of the fisheries and habitats essential to their survival. The FEP therefore serves as a source document and presents more complete and detailed information describing the South Atlantic ecosystem and the impact of fisheries on the environment. This FEP updated information on designated Essential Fish Habitat (EFH) and EFH-Habitat Areas of Particular Concern; expanded descriptions of biology and status of managed species; presented information that will support ecosystem considerations for managed species; and described the social and economic characteristics of the fisheries in the region. In addition, it expanded the discussion and description of existing research programs and needs to identify biological, social, and economic research needed to fully address ecosystem-based management in the region. It is anticipated that the FEP will provide a greater degree of guidance by fishery, habitat, or major ecosystem consideration of bycatch reduction, prey-predator interactions, maintaining biodiversity, and spatial management needs. This FEP serves as a living source document of biological, economic, and social information for all Fishery Management Plans (FMP). Future Environmental Assessments and Environmental Impact Statements associated with subsequent amendments to Council FMPs will draw from or cite by reference the FEP.

The Fishery Ecosystem Plan for the South Atlantic Region encompasses the following volume structure:
FEP Volume I - Introduction and Overview of FEP for the South Atlantic Region
FEP Volume II - South Atlantic Habitats and Species
FEP Volume III - South Atlantic Human and Institutional Environment
FEP Volume IV - Threats to South Atlantic Ecosystem and Recommendations
FEP Volume V - South Atlantic Research Programs and Data Needs
FEP Volume VI - References and Appendices

Comprehensive Ecosystem-Based Amendment (CE-BA) 1 (SAFMC 2009b) is supported by this FEP and updated EFH and EFH-HAPC information and addressed the Final EFH Rule (e.g., GIS presented for all EFH and EFH-HAPCs). Management actions implemented in CE-BA 1 established deepwater Coral HAPCs to protect what is thought to be the largest continuous distribution (>23,000 square miles) of pristine, deepwater coral ecosystems in the world.

The Fishery Ecosystem Plan, slated to be revised every 5 years, will again be the vehicle to update and refine information supporting designation and future review of EFH and EFH-HAPCs for managed species. Planning for the update is being conducted in cooperation with the Habitat Advisory Panel during the fall and winter of 2013 with initiation during 2014.

Ecosystem Approach to Deepwater Ecosystem Management

The Council manages coral, coral reefs and live/hard bottom habitat, including deepwater corals, through the Fishery Management Plan for Coral, Coral Reefs and Live/Hard Bottom Habitat of the South Atlantic Region (Coral FMP). Mechanisms exist in the FMP, as amended, to further protect deepwater coral and live/hard bottom habitats. The SAFMC's Habitat and Environmental Protection Advisory Panel and Coral Advisory Panel have supported proactive efforts to identify and protect deepwater coral ecosystems in the South Atlantic region. Management actions in Comprehensive Ecosystem-Based Amendment (CE-BA 1) (SAFMC 2009b) established deepwater coral HAPCs (C- HAPCs) to protect what is thought to be the largest continuous distribution (>23,000 square miles) of pristine deepwater coral ecosystems in the world. In addition, CE-BA 1 established areas within the CHAPC, which provide for traditional fishing in limited areas, which do not impact deepwater coral habitat. CE-BA 1, supported by the FEP, also addressed non-regulatory updates for existing EFH and EFH- HAPC information and addressed the spatial requirements of the Final EFH Rule (i.e., GIS presented for all EFH and EFH-HAPCs). Actions in this amendment included modifications in the management of the following: octocorals; special management zones (SMZs) off the coast of South Carolina; and sea turtle release gear requirements for snapper grouper fishermen. The amendment also designated essential fish habitat (EFH) and EFH-Habitat Areas of Particular Concern (EFH-HAPCs).

CE-BA 2 established annual catch limits (ACL) for octocorals in the South Atlantic as well as modifying the Fishery Management Unit (FMU) for octocorals to remove octocorals off the coast of Florida from the FMU (SAFMC 2011). The amendment also limited the possession of managed species in the SMZs off South Carolina to the recreational bag limit for snapper grouper and coastal migratory pelagic species; modified sea turtle release gear requirements for the snapper grouper fishery based upon freeboard height of vessels; amends Council fishery management plans (FMPs) to designate or modify EFH and EFH-HAPCs, including the FMP for Pelagic Sargassum Habitat; amended the Coral FMP to designate EFH for deepwater Coral HAPCs designated under CE-BA 1; and amended the Snapper Grouper FMP to designate EFH-HAPCs for golden and blueline tilefish and the deepwater Marine Protected Areas. The final rule was published in the federal register on December 30, 2011, and regulations became effective on January 30, 2012.

Building from a Habitat to an Ecosystem Network to Support the Evolution

Starting with our Habitat and Environmental Protection Advisory Panel, the Council expanded and fostered a comprehensive Habitat network in our region to develop the Habitat Plan of the South Atlantic Region completed in 1998 to support the EFH rule. Building on the core regional collaborations, the Council facilitated an expansion to a Habitat and Ecosystem network to support development of the FEP and CE-BA as well as coordinate with partners on other regional efforts.

Integrated Ocean Observing System (IOOS) and Southeast Coastal and Ocean Observing Regional Association (SECOORA)

The Integrated Ocean Observing System (IOOS®) is a partnership among federal, regional, academic, and private sector parties that works to provide new tools and forecasts to improve safety, enhance the economy, and protect our environment. IOOS supplies critical information about our Nation's oceans, coasts, and Great Lakes. Scientists working to understand climate change, governments adapting to changes in the Arctic, municipalities monitoring local water quality, and industries affected by coastal and marine spatial planning all have the same need: reliable, timely, and sustained access to data and information that inform decision making. Improving access to key marine data and information supports several purposes. IOOS data sustain national defense, marine commerce, and navigation safety. Scientists use these data to issue weather, climate, and marine forecasts. IOOS data are also used to make decisions for energy siting and production, economic development, and ecosystem-based resource management. Emergency managers and health officials need IOOS information to make decisions about public safety. Teachers and government officials rely on IOOS data for public outreach, training, and education.

SECOORA is one of 11 Regional Associations established nationwide through the US IOOS whose primary source of funding is through a 5-year cooperative agreement titled "Coordinated Monitoring, Prediction, and Assessment to Support Decision-Makers Needs for Coastal and Ocean Data and Tools". However, SECOORA was recently awarded funding via a NOAA Regional Ocean Partnership grant through the Governors' South Atlantic Alliance. SECOORA is the regional solution to integrating coastal and ocean observing data in the Southeast United States to inform decision makers and the general public. The SECOORA region encompasses 4 states, over 42 million people, and spans the coastal ocean from North Carolina to the west Coast of Florida and is creating customized products to address these thematic areas: Marine Operations; Coastal Hazards; Ecosystems, Water Quality, Living Marine Resources; and Climate Change. The Council is a voting member and Council staff was recently re-elected to serve on the

Board of Directors for the Southeast Coastal Regional Ocean Observing Association (SECOORA) to guide and direct priority needs for observation and modeling to support fisheries oceanography and integration into stock assessments through SEDAR. Cooperation through SECOORA is envisioned to facilitate the following:

- Refining current or water column designations of EFH and EFH-HAPCs (e.g., Gulf Stream and Florida Current).
- Providing oceanographic models linking benthic, pelagic habitats, and food webs.
- Providing oceanographic input parameters for ecosystem models.
- Integration of OOS information into Fish Stock Assessment process in the SA region.
- Facilitating OOS system collection of fish and fishery data and other research necessary to support the Council's use of area-based management tools in the SA Region including but not limited to EFH, EFH-HAPCs, Marine Protected Areas, Deepwater Coral Habitat Areas of Particular Concern, Special Management Zones, and Allowable Gear Areas.
- Integration of OOS program capabilities and research Needs into the South Atlantic Fishery Ecosystem Plan.
- Collaboration with SECOORA to integrate OOS products with information included in the Council's Habitat and Ecosystem Web Services and Atlas to facilitate model and tool development.
- Expanding Map Services and the Regional Habitat and Ecosystem Atlas in cooperation with SECOORAs Web Services that will provide researchers access to data or products including those collected/developed by SA OOS partners.

SECOORA researchers are developing a comprehensive data portal to provide discovery of, access to, and metadata about coastal ocean observations in the southeast US. Below are various ways to access the currently available data.

One project recently funded by SECOORA initiated development of species specific habitat models that integrate remotely sensed and in situ data to enhance stock assessments for species managed by the Council. The project during 2013/2014 was initiated to address red porgy, gray triggerfish, black seabass, and vermilion snapper. Gray triggerfish and red porgy are slated for assessment through SEDAR in 2014/15 and 2015/16 respectively.

National Fish Habitat Plan and Southeast Aquatic Resource Partnership (SARP)

In addition, the Council serves on the National Habitat Board and, as a member of the Southeast Aquatic Resource Partnership (SARP), has highlighted this collaboration by including the Southeast Aquatic Habitat Plan (SAHP) and associated watershed conservation restoration targets into the FEP. Many of the habitat, water quality, and water quantity conservation needs identified in the threats and recommendations Volume of the FEP are directly addressed by on-the-ground projects supported by SARP. This cooperation results in funding fish habitat restoration and conservation intended to increase the viability of fish populations and fishing opportunity, which also meets the needs to conserve and manage Essential Fish Habitat for Council managed species or habitat important to their prey. To date, SARP has funded 53 projects in the region through this program. This work supports conservation objectives identified in the SAHP to improve, establish, or maintain riparian zones, water quality, watershed connectivity, sediment flows, bottoms and shorelines, and fish passage, and addresses other key factors associated with the loss and degradation of fish habitats. SARP also developed the Southern Instream Flow Network (SIFN) to address the impacts of flow alterations in the Southeastern US aquatic ecosystems which leverages policy, technical experience, and scientific resources among partners based in 15 states. Maintaining appropriate flow into South Atlantic estuarine systems to support healthy inshore habitats essential to Council managed species is a major regional concern and efforts of SARP through SIFN are envisioned to enhance state and local partners ability to maintain appropriate flow rates.

Governor's South Atlantic Alliance (GSAA)

Initially discussed as a South Atlantic Eco-regional Compact, the Council has also cooperated with South Atlantic States in the formation of a Governor's South Atlantic Alliance (GSAA). This will also provide regional guidance and resources that will address State and Council broader habitat and ecosystem conservation goals. The GSAA was initiated in 2006. An Executive Planning Team (EPT), by the end of 2007, had created a framework for the Governors South Atlantic Alliance. The formal agreement between the four states (NC, SC, GA, and FL) was executed in May 2009. The Agreement specifies that the Alliance will prepare a "Governors South Atlantic Alliance Action Plan" which will be reviewed annually for progress and updated every five years for relevance of content. The Alliance's mission and purpose is to promote collaboration among the four states, and with the support and interaction of federal agencies, academe, regional organizations, non-governmental organizations, and the private sector, to sustain and enhance the region's coastal and marine resources. The Alliance proposes to regionally implement science-based actions and policies that balance coastal and marine ecosystems capacities to support both human and natural systems. The GSAA Action Plan was released in December 2010 and describes the four Priority Issue Areas that were identified by the Governors to be of mutual importance to the sustainability of the region's resources: Healthy Ecosystems; Working Waterfronts; Clean Coastal and Ocean Waters; and Disaster-Resilient Communities. The goals, objectives, actions, and implementation steps for each of these priorities were further described in the GSAA Implementation Plan released in July 2011. The final Action Plan was released on December 1, 2010 and marked the beginning of intensive work by the Alliance Issue Area Technical Teams (IATTs) to develop implementation steps for the actions and objectives. The GSAA Implementation Plan was published July 6, 2011, and the Alliance has been working to implement the Plan through the IATTs and two NOAA-funded Projects. The Alliance also partners with other federal agencies, academia, non-profits, private industry, regional organizations, and others. The Alliance supports both national and state-level ocean and coastal policy by coordinating federal, state, and local entities to ensure the sustainability of the region's economic, cultural, and natural resources. The Alliance has organized itself around the founding principles outlined in the GSAA Terms of Reference and detailed in the GSAA Business Plan. A team of natural resource managers, scientists, and information management system experts have partnered to develop a Regional Information Management System (RIMS) and recommend decision support tools that will support regional collaboration and decision-making. In addition to regional-level stakeholders, state and local coastal managers and decision makers will also be served by this project, which will enable ready access to new and existing data and information. The collection and synthesis of spatial data into a suite of visualization tools is a critical step for long-term collaborative planning in the South Atlantic region for a wide range of coastal uses. The Council's Atlas presents the spatial representations of Essential Fish Habitat, managed areas, regional fish and fish habitat distribution, and fishery operation information and it can be linked to or drawn on as a critical part of the collaboration with the RIMS.

South Atlantic Landscape Conservation Cooperative

One of the more recent collaborations is the Council's participation as Steering Committee member for the newly establish South Atlantic Landscape Conservation Cooperative (SALCC). Landscape Conservation Cooperatives (LCCs) are applied conservation science partnerships focused on a defined geographic area that informs on-the-ground strategic conservation efforts at landscape scales. LCC partners include DOI agencies, other federal agencies, states, tribes, non-governmental organizations, universities, and others. The newly formed Department of Interior Southeast Climate Services Center (CSC) has the LCCs in the region as their primary clients. One of the initial charges of the CSCs is to downscale climate models for use at finer scales.

The SALCC developed a Strategic Plan through an iterative process that began in December 2011. The plan provides a simple strategy for moving forward over the next few years. An operations plan was developed under direction from the SALCC Steering Committee to redouble efforts to develop version 1.0 of a shared conservation blueprint by spring-summer of 2014. The SALCC is developing the regional blueprint to address the rapid changes in the South Atlantic including but not limited to climate change, urban growth, and increasing human demands on resources which are reshaping the landscape. While these forces cut across political and jurisdictional boundaries, the conservation community does not have a consistent cross-boundary, cross-organization plan for how to respond. The South Atlantic Conservation Blueprint will be that plan. The blueprint is envisioned to be a spatially-explicit map depicting the places and actions need to sustain South Atlantic LCC objectives in the face of future change. The steps to creating the blueprint include development of: indicators and targets (shared metrics of success); the State of the South Atlantic (past, present, and future condition of indicators); and a Conservation Blueprint. Potential ways the blueprint could be used include: finding the best places for people and organizations to work together; raising new money to implement conservation actions; guiding infrastructure development (highways, wind, urban growth, etc.); creating incentives as an alternative to regulation; bringing a landscape perspective to local adaptation efforts; and locating places and actions to build resilience after major disasters (hurricanes, oil spills, etc.). Integration of connectivity, function, and threats to river, estuarine and marine systems supporting Council managed species is supported by the SALCC and enhanced by the Council being a voting member of its Steering Committee. In addition, the Council's Regional Atlas presents spatial representations of Essential Fish Habitat, managed areas, regional fish and fish habitat distribution, and fishery operation information and it be linked to or drawn on as a critical part of the collaboration with the recently developed SALCC Conservation Planning Atlas.

Building Tools to support EBM in the South Atlantic Region

The Council has developed a Habitat and Ecosystem Section of the website http://www.safmc.net/ecosystem/Home/EcosystemHome/tabid/435/Default.aspx and, in cooperation with the Florida Wildlife Research Institute (FWRI), developed a Habitat and Ecosystem Internet Map Server (IMS). The IMS was developed to support Council and regional partners' efforts in the transition to EBM. Other regional partners include NMFS Habitat Conservation, South Atlantic States, local management authorities, other Federal partners, universities, conservation organizations, and recreational and commercial fishermen. As technology and spatial information needs evolved, the distribution and use of GIS demands greater capabilities. The Council has continued its collaboration with FWRI in the now evolution to Web Services provided through the regional SAFMC Habitat and Ecosystem Atlas (http://ocean.floridamarine.org/safmc_atlas/) and the SAFMC Digital Dashboard (http://ocean.floridamarine.org/safmc_dashboard/). The Atlas integrates services for the following:

Species distribution and spatial presentation of regional fishery independent data from the SEAMAP-SA, MARMAP, and NOAA SEFIS systems; SAFMC Fisheries: (http://ocean.floridamarine.org/SA_Fisheries/)

Essential Fish Habitat and Essential Fish Habitat Areas of Particular Concern; SAFMC EFH: (http://ocean.floridamarine.org/sa_efh/)

Spatial presentation of managed areas in the region; SAFMC Managed Areas: (http://ocean.floridamarine.org/safmc_managedareas/)

An online life history and habitat information system supporting Council managed, State managed, and other regional species was developed in cooperation with FWRI. The Ecospecies system is considered dynamic and presents, as developed, detailed individual species life history reports and provides an interactive online query capability for all species included in the system: http://atoll.floridamarine.org/EcoSpecies

Web Services System Updates:
Essential Fish Habitat (EFH) – displays EFH and EFH-HAPCS for SAFMC managed species and NOAA Fisheries Highly Migratory Species.
Fisheries - displays Marine Resources Monitoring, Assessment, and Prediction (MARMAP) and Southeast Area Monitoring and Assessment Program South Atlantic (SEAMAP-SA) data.
Managed Areas - displays a variety of regulatory boundaries (SAFMC and Federal) or management boundaries within the SAFMC's jurisdiction.
Habitat – displays habitat data collected by SEADESC, Harbor Branch Oceanographic Institute (HBOI), and Ocean Exploration dives, as well as the SEAMAP shallow and ESDIM deepwater bottom mapping projects, multibeam imagery, and scientific cruise data.
Multibeam Bathymetry - displays a variety of multibeam data sources and scanned bathymetry charts.
Nautical Charts – displays coastal, general, and overview nautical charts for the SAFMC's jurisdictional area.

Ecosystem Based Action, Future Challenges and Needs

The Council has implemented ecosystem-based principles through several existing fishery management actions including establishment of deepwater Marine Protected Areas for the Snapper Grouper fishery, proactive harvest control rules on species (e.g., dolphin and wahoo) which are not overfished, implementing extensive gear area closures which in most cases eliminate the impact of fishing gear on Essential Fish Habitat, and use of other spatial management tools including Special Management Zones. Pursuant to development of the

Comprehensive Ecosystem-Based Amendment, the Council has taken an ecosystem approach to protect deepwater ecosystems while providing for traditional fisheries for the Golden Crab and Royal Red shrimp in areas where they do not impact deepwater coral habitat. The stakeholder based process taps in on an extensive regional Habitat and Ecosystem network. Support tools facilitate Council deliberations and with the help of regional partners, are being refined to address long-term ecosystem management needs.

One of the greatest challenges to the long-term move to EBM in the region is funding high priority research, including but not limited to, comprehensive benthic mapping and ecosystem model and management tool development. In addition, collecting detailed information on fishing fleet dynamics including defining fishing operation areas by species, species complex, and season, as well as catch relative to habitat is critical for assessment of fishery, community, and habitat impacts and for Council use in place based management measures. Additional resources need to be dedicated to expand regional coordination of modeling, mapping, characterization of species use of habitats, and full funding of regional fishery independent surveys (e.g., MARMAP, SEAMAP, and SEFIS) which are linking directly to addressing high priority management needs. Development of ecosystem information systems to support Council management should build on existing tools (e.g., Regional Habitat and Ecosystem GIS and Arc Services) and provide resources to regional cooperating partners for expansion to address long-term Council needs.

The FEP and CE-BA 1 complement, but do not replace, existing FMPs. In addition, the FEP serves as a source document to the CE-BAs. NOAA should support and build on the regional coordination efforts of the Council as it transitions to a broader management approach. Resources need to be provided to collect information necessary to update and refine our FEP and support future fishery actions including but not limited to completing one of the highest priority needs to support EBM, the completion of mapping of near-shore, mid-shelf, shelf edge, and deepwater habitats in the South Atlantic region. In developing future FEPs, the Council will draw on SAFEs (Stock Assessment and Fishery Evaluation reports) which NMFS is required to provide the Council for all FMPs implemented under the Magnuson-Stevens Act. The FEP, which has served as the source document for CE-BAs, could also meet some of the NMFS SAFE requirements if information is provided to the Council to update necessary sections.

EFH and EFH-HAPC Designations Translated to Cooperative Habitat Policy Development and Protection

The Council actively comments on non-fishing projects or policies that may impact fish habitat. Appendix A of the Comprehensive Amendment Addressing Essential Fish Habitat in Fishery Management Plans of the South Atlantic Region (SAFMC 1998b) outlines the Council's comment and policy development process and the establishment of a four-state Habitat Advisory Panel. Members of the Habitat Advisory Panel serve as the Council's habitat contacts and professionals in the field. AP members bring projects to the Council's attention, draft comment letters, and attend public meetings. With guidance from the Advisory Panel, the Council has developed and approved policies on:

1. Energy exploration, development, transportation, and hydropower re-licensing;
2. Beach dredging and filling and large-scale coastal engineering;
3. Protection and enhancement of submerged aquatic vegetation;

4. Alterations to riverine, estuarine, and nearshore flows;
5. Marine aquaculture;
6. Marine Ecosystems and Non-Native and Invasive Species: and
7. Estuarine Ecosystems and Non-Native and Invasive Species.

NOAA Fisheries, State and other Federal agencies apply EFH and EFH-HAPC designations and protection policies in the day-to-day permit review process. The revision and updating of existing habitat policies and the development of new policies is being coordinated with core agency representatives on the Habitat and Coral Advisory Panels. Existing policies are included at the end of this Appendix.

The Habitat and Environmental Protection Advisory Panel, as part of their role in providing continued policy guidance to the Council, is during 2013/14, reviewing and proposing revisions and updates to the existing policy statements and developing new ones for Council consideration. The effort is intended to enhance the value of the statements and support cooperation and collaboration with NOAA Fisheries Habitat Conservation Division and State and Federal partners in better addressing the Congressional mandates to the Council associated with designation and conservation of EFH in the region.

South Atlantic Bight Ecopath Model

The Council worked cooperatively with the University of British Columbia and the Sea Around Us project to develop a straw-man and preliminary food web models (Ecopath with Ecosim) to characterize the ecological relationships of South Atlantic species, including those managed by the Council. This effort was envisioned to help the Council and cooperators in identifying available information and data gaps while providing insight into ecosystem function. More importantly, the model development process provides a vehicle to identify research necessary to better define populations, fisheries, and their interrelationships. While individual efforts are still underway in the South Atlantic, only with significant investment of new resources through other programs will a comprehensive regional model be further developed.

The latest collaboration builds on the previous Ecopath model developed through the Sea Around Us project for the South Atlantic Bight with a focus on beginning a dialogue on the implications of potential changes in forage fish populations in the region that could be associated with environmental or climate change or changes in direct exploitation of those populations.

Essential Fish Habitat and Essential Fish Habitat Areas of Particular Concern

Following is a summary of the current Council's EFH and EFH-HAPCs. Information supporting their designation was updated (pursuant to the EFH Final Rule) in the Council's Fishery Ecosystem Plan and Comprehensive Ecosystem Amendment:

Snapper Grouper FMP

Essential fish habitat for snapper grouper species includes coral reefs, live/hard bottom, submerged aquatic vegetation, artificial reefs, and medium to high profile outcroppings on and around the shelf break zone from shore to at least 600 feet (but to at least 2,000 feet for wreckfish) where the annual water temperature range is sufficiently warm to maintain adult populations of members of this largely tropical complex. EFH includes the spawning area in the water column above the adult habitat and the additional pelagic environment, including *Sargassum*, required for larval survival and growth up to and including settlement. In addition the Gulf Stream is an essential fish habitat because it provides a mechanism to disperse snapper grouper larvae.

For specific life stages of estuarine dependent and nearshore snapper grouper species, essential fish habitat includes areas inshore of the 100-foot contour, such as attached macroalgae; submerged rooted vascular plants (seagrasses); estuarine emergent vegetated wetlands (saltmarshes, brackish marsh); tidal creeks; estuarine scrub/shrub (mangrove fringe); oyster reefs and shell banks; unconsolidated bottom (soft sediments); artificial reefs; and coral reefs and live/hard bottom.

Areas which meet the criteria for EFH-HAPCs for species in the snapper grouper management unit include medium to high profile offshore hard bottoms where spawning normally occurs; localities of known or likely periodic spawning aggregations; nearshore hard bottom areas; The Point, The Ten Fathom Ledge, and Big Rock (North Carolina); The Charleston Bump (South Carolina); mangrove habitat; seagrass habitat; oyster/shell habitat; all coastal inlets; all state-designated nursery habitats of particular importance to snapper grouper (e.g., Primary and Secondary Nursery Areas designated in North Carolina); pelagic and benthic *Sargassum*; Hoyt Hills for wreckfish; the *Oculina* Bank Habitat Area of Particular Concern; all hermatypic coral habitats and reefs; manganese outcroppings on the Blake Plateau; and Council-designated Artificial Reef Special Management Zones (SMZs). In addition, the Council through CEBA 2 (SAFMC 2011) designated the deepwater snapper grouper MPAs and golden tilefish and blueline tilefish habitat as EFH-HAPCs under the Snapper Grouper FMP as follows:

EFH-HAPCs for golden tilefish to include irregular bottom comprised of troughs and terraces inter-mingled with sand, mud, or shell hash bottom. Mud-clay bottoms in depths of 150-300 meters are HAPC. Golden tilefish are generally found in 80-540 meters, but most commonly found in 200-meter depths.

EFH-HAPC for blueline tilefish to include irregular bottom habitats along the shelf edge in 45-65 meters depth; shelf break or upper slope along the 100-fathom contour (150-225 meters); hardbottom habitats characterized as rock overhangs, rock outcrops, manganese-phosphorite rock slab formations, or rocky reefs in the South Atlantic Bight; and the Georgetown Hole (Charleston Lumps) off Georgetown, SC.

EFH-HAPCs for the snapper grouper complex to include the following deepwater Marine Protected Areas (MPAs) as designated in Snapper Grouper Amendment 14: Snowy Grouper Wreck MPA, Northern South Carolina MPA, Edisto MPA, Charleston Deep Artificial Reef MPA, Georgia MPA, North Florida MPA, St. Lucie Hump MPA, and East Hump MPA.

Deepwater Coral HAPCs designated in Comprehensive Ecosystem-Based Amendment 1 are designated as Snapper Grouper EFH-HAPCs: Cape Lookout Coral HAPC, Cape Fear Coral HAPC, Blake Ridge Diapir Coral HAPC, Stetson-Miami Terrace Coral HAPC, and Pourtalés Terrace Coral HAPC.

Shrimp FMP

For penaeid shrimp, Essential Fish Habitat includes inshore estuarine nursery areas, offshore marine habitats used for spawning and growth to maturity, and all interconnecting water bodies as described in the Habitat Plan. Inshore nursery areas include tidal freshwater (palustrine), estuarine, and marine emergent wetlands (e.g., intertidal marshes); tidal palustrine forested areas; mangroves; tidal freshwater, estuarine, and marine submerged aquatic vegetation (e.g., seagrass); and subtidal and intertidal non- vegetated flats. This applies from North Carolina through the Florida Keys.

For rock shrimp, essential fish habitat consists of offshore terrigenous and biogenic sand bottom habitats from 18 to 182 meters in depth with highest concentrations occurring between 34 and 55 meters. This applies for all areas from North Carolina through the Florida Keys. Essential fish habitat includes the shelf current systems near Cape Canaveral, Florida, which provide major transport mechanisms affecting planktonic larval rock shrimp. These currents keep larvae on the Florida Shelf and may transport them inshore in spring. In addition, the Gulf Stream is an essential fish habitat because it provides a mechanism to disperse rock shrimp larvae.

Essential fish habitat for royal red shrimp include the upper regions of the continental slope from 180 meters (590 feet) to about 730 meters (2,395 feet), with concentrations found at depths of between 250 meters (820 feet) and 475 meters (1,558 feet) over blue/black mud, sand, muddy sand, or white calcareous mud. In addition, the Gulf Stream is an essential fish habitat because it provides a mechanism to disperse royal red shrimp larvae.

Areas which meet the criteria for EFH-HAPCs for penaeid shrimp include all coastal inlets, all state-designated nursery habitats of particular importance to shrimp (for example, in North Carolina this would include all Primary Nursery Areas and all Secondary Nursery Areas), and state-identified overwintering areas.

Coastal Migratory Pelagics FMP

Essential fish habitat for coastal migratory pelagic species includes sandy shoals of capes and offshore bars, high profile rocky bottom, and barrier island ocean-side waters, from the surf to the shelf break zone, but from the Gulf Stream shoreward, including *Sargassum*. In addition, all coastal inlets and all state-designated nursery habitats of particular importance to coastal migratory pelagics (for example, in North Carolina this would include all Primary Nursery Areas and all Secondary Nursery Areas).

For Cobia essential fish habitat also includes high salinity bays, estuaries, and seagrass habitat. In addition, the Gulf Stream is an essential fish habitat because it provides a mechanism to disperse coastal migratory pelagic larvae.

For king and Spanish mackerel and cobia essential fish habitat occurs in the South Atlantic and Mid-Atlantic Bights.

Areas which meet the criteria for EFH-HAPCs include sandy shoals of Capes Lookout, Cape Fear, and Cape Hatteras from shore to the ends of the respective shoals, but shoreward of the Gulf stream; The Point, The Ten-Fathom Ledge, and Big Rock (North Carolina); The Charleston Bump and Hurl Rocks (South Carolina); The Point off Jupiter Inlet (Florida); *Phragmatopoma* (worm reefs) reefs off the central east coast of Florida; nearshore hard bottom south of Cape Canaveral; The Hump off Islamorada, Florida; The Marathon Hump off Marathon, Florida; The "Wall" off of the Florida Keys; Pelagic *Sargassum*; and Atlantic coast estuaries with high numbers of Spanish mackerel and cobia based on abundance data from the ELMR Program. Estuaries meeting these criteria for Spanish mackerel include Bogue Sound and New River, North Carolina; Bogue Sound, North Carolina (Adults May-September salinity >30 ppt); and New River, North Carolina (Adults May-October salinity >30 ppt). For Cobia they include Broad River, South Carolina; and Broad River, South Carolina (Adults & juveniles May-July salinity >25ppt).

Golden Crab FMP

Essential fish habitat for golden crab includes the U.S. Continental Shelf from Chesapeake Bay south through the Florida Straits (and into the Gulf of Mexico). In addition, the Gulf Stream is an essential fish habitat because it provides a mechanism to disperse golden crab larvae. The detailed description of seven essential fish habitat types (a flat foraminferan ooze habitat; distinct mounds, primarily of dead coral; ripple habitat; dunes; black pebble habitat; low outcrop; and soft-bioturbated habitat) for golden crab is provided in Wenner et al. (1987). There is insufficient knowledge of the biology of golden crabs to identify spawning and nursery areas and to identify HAPCs at this time. As information becomes available, the Council will evaluate such data and identify HAPCs as appropriate through the framework.

Spiny Lobster FMP

Essential fish habitat for spiny lobster includes nearshore shelf/oceanic waters; shallow subtidal bottom; seagrass habitat; unconsolidated bottom (soft sediments); coral and live/hard bottom habitat; sponges; algal communities (*Laurencia*); and mangrove habitat (prop roots). In addition, the Gulf Stream is an essential fish habitat because it provides a mechanism to disperse spiny lobster larvae.

Areas which meet the criteria for EFH-HAPCs for spiny lobster include Florida Bay, Biscayne Bay, Card Sound, and coral/hard bottom habitat from Jupiter Inlet, Florida through the Dry Tortugas, Florida.

Coral, Coral Reefs, and Live/Hard Bottom Habitats FMP

Essential fish habitat for corals (stony corals, octocorals, and black corals) incorporate habitat for over 200 species. EFH for corals include the following:

A. Essential fish habitat for hermatypic stony corals includes rough, hard, exposed, stable substrate from Palm Beach County south through the Florida reef tract in subtidal waters to 30 m depth; subtropical (15°-35° C), oligotrophic waters with high (30-35$^{o}/_{oo}$) salinity and turbidity levels sufficiently low enough to provide algal symbionts adequate sunlight penetration for photosynthesis. Ahermatypic stony corals are not light restricted and their essential fish habitat includes defined hard substrate in subtidal to outer shelf depths throughout the management area.

B. Essential fish habitat for *Antipatharia* (black corals) includes rough, hard, exposed, stable substrate, offshore in high (30-35$^{o}/_{oo}$) salinity waters in depths exceeding 18 meters (54 feet), not restricted by light penetration on the outer shelf throughout the management area.

C. Essential fish habitat for octocorals excepting the order Pennatulacea (sea pens and sea pansies) includes rough, hard, exposed, stable substrate in subtidal to outer shelf depths within a wide range of salinity and light penetration throughout the management area.

D. Essential fish habitat for Pennatulacea (sea pens and sea pansies) includes muddy, silty bottoms in subtidal to outer shelf depths within a wide range of salinity and light penetration.

Areas which meet the criteria for EFH-HAPCs for coral, coral reefs, and live/hard bottom include: The 10-Fathom Ledge, Big Rock, and The Point (North Carolina); Hurl Rocks and The Charleston Bump (South Carolina); Gray's Reef National Marine Sanctuary (Georgia); The *Phragmatopoma* (worm reefs) reefs off the central east coast of Florida; Oculina Banks off the east coast of Florida from Ft. Pierce to Cape Canaveral; nearshore (0-4 meters; 0-12 feet) hard bottom off the east coast of Florida from Cape Canaveral to Broward County); offshore (5-30 meter; 15-90 feet) hard bottom off the east coast of Florida from Palm Beach County to Fowey Rocks; Biscayne Bay, Florida; Biscayne National Park, Florida; and the Florida Keys National Marine Sanctuary. In addition, the Council through CEBA 2 (SAFMC 2011) designated the Deepwater Coral HAPCs as EFH-HAPCs under the Coral FMP as follows:

Deepwater Coral HAPCs designated in Comprehensive Ecosystem-Based Amendment 1 as Snapper Grouper EFH-HAPCs: Cape Lookout Coral HAPC, Cape Fear Coral HAPC, Blake Ridge Diapir Coral HAPC, Stetson-Miami Terrace Coral HAPC, and Pourtalés Terrace Coral HAPC.

Dolphin and Wahoo FMP

EFH for dolphin and wahoo is the Gulf Stream, Charleston Gyre, Florida Current, and pelagic *Sargassum*. This EFH definition for dolphin was approved by the Secretary of Commerce on June 3, 1999 as a part of the Council's Comprehensive Habitat Amendment (SAFMC 1998b) (dolphin was included within the Coastal Migratory Pelagics FMP at that time).

Areas which meet the criteria for EFH-HAPCs for dolphin and wahoo in the Atlantic include The Point, The Ten-Fathom Ledge, and Big Rock (North Carolina); The Charleston Bump and The Georgetown Hole (South Carolina); The Point off Jupiter Inlet (Florida); The Hump off Islamorada, Florida; The Marathon Hump off Marathon, Florida; The "Wall" off of the Florida Keys; and Pelagic *Sargassum*. This EFH-HAPC definition for dolphin was approved by the Secretary of Commerce on June 3, 1999 as a part of the Council's Comprehensive Habitat Amendment (dolphin was included within the Coastal Migratory Pelagics FMP at that time).

Pelagic *Sargassum* Habitat FMP

The Council through CEBA 2 (SAFMC 2011) designated the top 10 meters of the water column in the South Atlantic EEZ bounded by the Gulfstream, as EFH for pelagic Sargassum.

Actions Implemented That Protect EFH and EFH-HAPCs

Snapper Grouper FMP

- Prohibited the use of the following gears to protect habitat: bottom longlines in the EEZ inside of 50 fathoms or anywhere south of St. Lucie Inlet, Florida; bottom longlines in the wreckfish fishery; fish traps; bottom tending (roller- rig) trawls on live bottom habitat; and entanglement gear.
- Established the *Oculina* Experimental Closed Area where the harvest or possession of all species in the snapper grouper complex is prohibited.

Established deepwater Marine Protected Areas (MPAs) as designated in Snapper Grouper Amendment 14: Snowy Grouper Wreck MPA, Northern South Carolina MPA, Edisto MPA, Charleston Deep Artificial Reef MPA, Georgia MPA, North Florida MPA, St. Lucie Hump MPA, and East Hump MPA.

Shrimp FMP

- Prohibition of rock shrimp trawling in a designated area around the *Oculina* Bank,
- Mandatory use of bycatch reduction devices in the penaeid shrimp fishery,
- Mandatory Vessel Monitoring System (VMS) in the Rock Shrimp Fishery.
- A mechanism that provides for the concurrent closure of the EEZ to penaeid shrimping if environmental conditions in state waters are such that the overwintering spawning stock is severely depleted.

***Pelagic Sargassum* Habitat FMP**

- Prohibited all harvest and possession of *Sargassum* from the South Atlantic EEZ south of the latitude line representing the North Carolina/South Carolina border (34° North Latitude).
- Prohibited all harvest of *Sargassum* from the South Atlantic EEZ within 100 miles of shore between the 34° North Latitude line and the Latitude line representing the North Carolina/Virginia border.
- Harvest of *Sargassum* from the South Atlantic EEZ is limited to the months of November through June.
- Established an annual Total Allowable Catch (TAC) of 5,000 pounds landed wet weight.
- Required that an official observer be present on each *Sargassum* harvesting trip. Require that nets used to harvest *Sargassum* be constructed of four-inch stretch mesh or larger fitted to a frame no larger than 4 feet by 6 feet.

Coastal Migratory Pelagics FMP

- Prohibited of the use of drift gillnets in the coastal migratory pelagic fishery.

Golden Crab FMP

- In the northern zone, golden crab traps can only be deployed in waters deeper than 900 feet; in the middle and southern zones traps can only be deployed in waters deeper than 700 feet.

Northern zone - north of the 28°N. latitude to the North Carolina/Virginia border;
Middle zone - 28°N. latitude to 25° N. latitude; and
Southern zone - south of 25°N. latitude to the border between the South Atlantic and Gulf of Mexico Fishery Management Councils.

Coral, Coral Reefs and Live/Hard Bottom FMP

- Established an optimum yield of zero and prohibiting all harvest or possession of these resources which serve as essential fish habitat to many managed species.
- Designated the *Oculina* Bank Habitat Area of Particular Concern.
- Expanded the *Oculina* Bank Habitat Area of Particular Concern (HAPC) to an area bounded to the west by 80°W. longitude, to the north by 28°30' N. latitude, to the south by 27°30' N. latitude, and to the east by the 100 fathom (600 feet) depth contour.
- Established the following two Satellite *Oculina* HAPCs: (1) Satellite *Oculina* HAPC #1 is bounded on the north by 28°30'N. latitude, on the south by 28°29'N. latitude, on the east by 80°W. longitude, and on the west by 80°3'W. longitude; and (2) Satellite *Oculina* HAPC #2 is bounded on the north by 28°17'N. latitude, on the south by 28°16'N. latitude, on the east by 80°W. longitude, and on the west by 80°3'W. longitude.
- Prohibited the use of all bottom tending fishing gear and fishing vessels from anchoring or using grapples in the *Oculina* Bank HAPC.
- Established a framework procedure to modify or establish Coral HAPCs.
- Established the following five deepwater CHAPCs:

Cape Lookout Lophelia Banks CHAPC;
Cape Fear Lophelia Banks CHAPC;
Stetson Reefs, Savannah and East Florida Lithoherms, and Miami Terrace (Stetson- Miami Terrace) CHAPC;
Pourtales Terrace CHAPC; and
Blake Ridge Diapir Methane Seep CHAPC.

- Within the deepwater CHAPCs, the possession of coral species and the use of all bottom damaging gear are prohibited including bottom longline, trawl (bottom and mid-water), dredge, pot or trap, or the use of an anchor, anchor and chain, or grapple and chain by all fishing vessels.

Council Policies for Protection and Restoration of Essential Fish Habitat
SAFMC Habitat and Environmental Protection Policy

In recognizing that species are dependent on the quantity and quality of their essential habitats, it is the policy of the SAFMC to protect, restore, and develop habitats upon which fisheries species depend; to increase the extent of their distribution and abundance; and to improve their productive capacity for the benefit of present and future generations. For purposes of this policy, "habitat" is defined as the physical, chemical, and biological parameters that are necessary for continued productivity of the species that is being managed. The objectives of the SAFMC policy will be accomplished through the recommendation of no net loss or significant environmental degradation of existing habitat. A long-term objective is to support and promote a net-gain of fisheries habitat through the restoration and rehabilitation of the productive capacity of habitats that have been degraded, and the creation and development of productive habitats where increased fishery production is probable. The SAFMC will pursue these goals at state, Federal, and local levels. The Council shall assume an aggressive role in the protection and enhancement of habitats important to fishery species, and shall actively enter Federal, decision making processes where proposed actions may otherwise compromise the productivity of fishery resources of concern to the Council.

SAFMC EFH Policy Statements

In addition to implementing regulations to protect habitat from fishing related degradation, the Council in cooperation with NOAA Fisheries, actively comments on non-fishing projects or policies that may impact fish habitat. The Council adopted a habitat policy and procedure document that established a four-state Habitat Advisory Panel and adopted a comment and policy development process. Members of the Habitat Advisory Panel serve as the Council's habitat contacts and professionals in the field. With guidance from the Advisory Panel, the Council has developed and approved a number of habitat policy statements which are available on the Habitat and Ecosystem section of the Council website (http://www.safmc.net/ecosystem/Home/EcosystemHome/tabid/435/Default.aspx).

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Appendix I. Fishery Impact Statement

The Magnuson-Stevens Fishery Conservation and Management Act requires a FIS be prepared for all amendments to Fishery Management Plans (FMPs). The FIS contains an assessment of the likely biological, social, and economic effects of the conservation and management measures on: 1) fishery participants and their communities; 2) participants in the fisheries conducted in adjacent areas under the authority of another Council; and 3) the safety of human life at sea.

Actions Contained in Amendment 43 to the Snapper Grouper FMP (Amendment 43)

Assessment of Biological Effects

Assessment of Economic Effects

Assessment of Social Effects

Appendix J. NMFS Guidance on MRIP Usage in Red Snapper Management

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
75 Virginia Beach Drive
Miami, Florida 33149 U.S.A.
(305) 361-4204 Fax: (305) 361-4499

21 April, 2017

TO: Gregg Waugh, Executive Director, SAFMC
Michelle Duval, Ph.D., Chair, SAFMC

FROM: Bonnie J. Ponwith, Ph.D.,
Science and Research Director

SUBJECT: Red Snapper Guidance Request

The SEFSC concurs with the SEDAR Review Panel and SAFMC SSC's approval of SEDAR 41, the red snapper stock assessment. The SSC developed ABC recommendations based on the projection analysis that allowed the stock to reach a rebuilt status in the time allowed by the rebuilding plan (by 2044). The use of an ABC based primarily on fishery discards for monitoring the effectiveness of management action is likely ineffective due to the high level of uncertainty in measures of discards and the change in the effort estimation methodology that will be implemented in the MRIP survey.

Monitoring progress toward rebuilding will require a departure from the traditional techniques. SEFSC analysts are exploring an Index Projection Methodology as an alternative approach for monitoring stock response to management measures. They plan to discuss this with the SSC at their upcoming meeting to get input on the method. They will also discuss how these results may be used by the SSC to generate future catch level advice, given updated projections have not been provided. Information for the SSC regarding this is attached.

At the last SAFMC meeting we discussed holding a workshop to discuss ways to characterize the uncertainty of MRIP estimates (landings, discards) to provide guidance on: 1) at what point the uncertainty is sufficiently high to warrant alternative methods for accounting for catch; 2) what those alternative methods might be; 3) means to improve the precision of MRIP catch estimates; and 3) means to augment MRIP sampling to improve data quality. The SAFMC recognized this is a region-wide issue so a presentation was made to the GMFMC to request involvement of their SSC, and the GMFMC has agreed to participate. It has also been suggested that representation from the Mid-Atlantic Fishery Management Council may be advisable. We'll begin to stand up a steering committee to refine the workshop objectives, define the deliverables and begin work on the agenda. One deliverable from the workshop could evaluate the precision of red snapper discard estimates to help advise on their use for monitoring stock status when discards are the predominant contributor to fishing mortality. The target timeline for the workshop is this fall, however, we'll have more clarity on the timeline for delivery of advice to the SSC once the steering committee is stood up and begins their work on workshop planning.

Attachment

cc: Roy Crabtree, Jack McGovern, and Rick DeVictor
Monica Smit-Brunello
John Carmichael, Kari MacLauchlin, and Chip Collier
Theo Brainerd and Trika Gerard

SSC Input for April 2017 Meeting

The SAFMC SSC reviewed and approved the SEDAR 41 Red Snapper stock assessment in May 2016. The SSC developed ABC recommendations based on the projection analysis that allowed the stock to reach a rebuilt status in the time allowed by the rebuilding plan (by 2044). In our memo of February 15, 2017, the SEFSC indicated reasons why any further proposed projections would not be appropriate for management. These reasons revolve around the uncertainty and methodology changes for future estimates of discards from the MRIP survey. Non-traditional methods and data sources may need to be used to monitor management action effectiveness and progress toward rebuilding.

The SEFSC proposes creating and an Index Projection Methodology that uses trends in the fishery-independent survey to monitor rebuilding progress and serve as the basis for the SSC's future ABC advice to the Council.

The SEFSC would like to get feedback from the SSC on this proposed approach. Specifically:

1. The SEFSC is actively working on research into using SERFS video data to monitor future effectiveness of management actions, i.e. progress toward rebuilding. We ask the SSC to provide input on this proposed approach and its potential utility for determining management action effectiveness.
2. Discuss options for the appropriate baseline against which to compare the Index Projection.
3. Discuss how the index may be used by the SSC to develop ABC advice.

Dr. Erik Williams will be preparing a brief summary of the proposed approach and will be on hand to answer any questions the SSC may have at their next meeting.

We appreciate the SSC taking time to provide input on new methodology that has the potential to benefit management.

SOUTH ATLANTIC FISHERY MANAGEMENT COUNCIL
4055 Faber Place Drive, Suite 201, North Charleston SC 29405
Call: (843) 571-4366 | Toll-Free: (866) SAFMC-10 | Fax: (843) 769-4520 | Connect: www.safmc.net

Dr. Michelle Duval, Chair | Charlie Phillips, Vice Chair
Gregg T. Waugh, Executive Director

April 3, 2017

TO: Bonnie Ponwith

FROM: Gregg Waugh & Michelle Duval

SUBJECT: Red Snapper Guidance Request

At its March 2017 meeting, the South Atlantic Council requested that its SSC and the SEFSC work together to obtain an ABC for Red Snapper. This request was in response to two letters from NMFS addressing the status of Red Snapper. The first letter, from the SEFSC dated February 15, 2017 (**attached**), indicated that projections the Council requested in January 2017 could not be completed due to uncertainty in the assessment and the MRIP discard estimates. This letter also indicated that a complete evaluation of MRIP changes on the Red Snapper assessment (SEDAR 41) is necessary before it can be useful to management. The second letter, from SERO dated March 3, 2017 (**attached**), noted the SSC's concerns with uncertainty in the SEDAR 41 assessment and the resulting inability to reliably determine the degree of overfishing. In addition, NMFS noted that the assessment indicated overfishing was occurring during its terminal year of 2014 but the Council's actions to limit harvest since 2010, including harvest prohibitions in effect since 2015, have addressed overfishing and allowed the stock to continue rebuilding.

The SSC reviewed the SEDAR 41 Red Snapper assessment in May 2016 and considered it Best Scientific Information Available. However, because the Council has been informed in the past that SSC conclusions on BSIA are in fact recommendations, and that NMFS is actually responsible for the BSIA determinations, the Council requests the following:

1. The SEFSC concur with our determination that alternative methods are necessary to specify ABC and MSY for red snapper and that SEDAR 41 (original and revised) cannot be used to specify ABC or MSY for 2017 and beyond for the reasons outlined in your memo to Michelle Duval dated February 15, 2017. This is necessary to inform the SSC on the status of its existing ABC recommendation and to determine which sources of information used in the SEDAR 41 assessment can be considered for future ABC recommendations.
2. The SEFSC provide an evaluation of data limited techniques that can be considered by the SSC to develop an index-based ABC.
3. The SEFSC provide additional details on the proposed evaluation of the effect of MRIP changes on the Red Snapper assessment, particularly the types of evaluations to be considered and when they will be available for SSC review.

Given that the SEFSC will be providing the SSC a revised SEDAR 41 Red Snapper assessment to correct errors with some of the headboat input data, it is critical that a response to these issues

1

also be provided to the SSC. This will help inform the SSC on how to view the revised assessment.

Please provide this information needs to Council staff by noon on April 10, 2017 to be distributed to the SSC for review at their April 25-27, 2017 meeting. This is a complex matter and the SSC needs adequate time to review the revised assessment and responses prior to their meeting.

Please contact John Carmichael to address any questions concerning this request.

cc: Roy Crabtree, Jack McGovern, and Rick DeVictor
Monica Smit-Brunello
John Carmichael, Kari MacLauchlin, and Chip Collier
Theo Brainerd and Trika Gerard

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
75 Virginia Beach Drive
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15 February, 2017

MEMORANDUM FOR: Gregg Waugh, Executive Director
South Atlantic Fishery Management Council

FROM: Bonnie J. Ponwith, Ph.D.
Science and Research Director

SUJBECT: **Red Snapper Projections**

On January 18, 2017, you sent a memo requesting, "Provide projections to 2044 (the end of the rebuilding period) based on fixed fishing mortality rates at Fmax, F20%SPR, F27%SPR, F30%SPR, and F40%SPR under the assumptions that all fish caught at each F level are subsequently discarded and the scenario mortality level is the total mortality (i.e., there are no additional discard mortalities). For each scenario, provide the full suite of projection outputs as provided for SEDAR 41 projections."

In working on those projections, Southeast Fisheries Science Center staff have advised, and I concur, that the proposed projections are not appropriate for management use for the following reasons:

- The uncertainty in the assessment is already large, and will increase due to the MRIP discard data, especially for the interim period (2015-16), the upcoming changes to MRIP from the new effort survey. For some background: the uncertainty in projections is generally high after 3-5 years, and these projections would have 2-3 years of an interim period (depending on whether 2017 or 2018 was the effective year of regulations).
- The SAFMC SSC has indicated that overfishing for this stock is occurring, but cannot quantify by how much. Fishing mortality rates in the last few years of the assessment are very sensitive to 2014 data and retrospective analyses indicate fishing mortality rates are considerably lower if these data are excluded. This uncertainty in the stock assessment inhibits the ability to set an ABC that can be effectively monitored.
- Fishing mortality in the interim period is calculated using actual landings and discards in 2015, though the status was determined using fishing mortality when there was a fishery occurring during mini-seasons (2012-2014). There were no fishing seasons for red snapper in 2015 or 2016 and final 2016 MRIP data are not yet available.
- The MRIP telephone survey will end this year and be replaced by a new mail-based effort survey. The new effort survey will be calibrated with the old telephone survey and undergo peer-review this summer. Preliminary results from the calibration study will be available in late-2017 and final results incorporating all three years of side-by-

side surveys will be available in 2018. Projections timed to benefit from the completed calibration study would be stronger than if based on the preliminary results.

- We feel that a more complete evaluation of the effect of the upcoming changes to MRIP on the Red Snapper assessment is needed before it can be useful to management.
  - We further recommend a thorough investigation, possibly through a workshop, into the reliability and utility of mail survey based MRIP estimates of catch and discards for many of our offshore species, which are known to have low intercept rates relative to other species covered by MRIP.

cc: Roy Crabtree
Andy Strelcheck
Jack McGovern
Theo Brainerd
Trika Gerard
Erik Williams

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southeast Regional Office
263 13th Avenue South
St. Petersburg, Florida 33701-5505
http://sero.nmfs.noaa.gov

F/SER25:FH

Dr. Michelle Duval, Chair
South Atlantic Fishery Management Council
4055 Faber Place Drive, Suite 201
North Charleston, South Carolina 29405

MAR 03 2017

Dear Dr. Duval:

The most recent South Atlantic red snapper stock assessment (SEDAR 41) was completed in April 2016 and indicated that the stock is undergoing overfishing and is overfished, but is rebuilding. The South Atlantic Fishery Management Council's (Council) Scientific and Statistical Committee (SSC) reviewed the assessment and determined the assessment is based on the best scientific information available. However, the SSC noted there is considerable uncertainty in the exploitation status, and thus, the degree of overfishing is highly uncertain. The uncertainty in exploitation status inhibits the Council's ability to set an acceptable biological catch that can be effectively monitored. Additionally, in the February 15, 2017, response to a Council request for red snapper projections, Dr. Bonnie Ponwith, Director of the National Marine Fisheries Service (NMFS) Southeast Fisheries Science Center noted that the overfishing determination was based on fishing mortality levels during 2012-2014 when a limited amount of harvest was allowed. Landings during 2012-2014 represented a high fraction of the overall fishing mortality, but since that time, harvest has been prohibited. Dr. Ponwith also noted that the uncertainty in the assessment is large and is predicted to increase as catch and effort estimates are updated through the new Marine Recreational Information Program (MRIP) effort survey.

NMFS has determined that the latest assessment identified the South Atlantic red snapper stock as undergoing overfishing, and adequate management action has been taken to address overfishing and continue to rebuild the stock through a harvest prohibition in 2015 and 2016. Due to uncertainty in the level of overfishing associated with the assessment and the new MRIP effort survey, data poor assessment methods for the red snapper stock, such as use of fishery independent indices, may be appropriate in the future. I look forward to continuing work with the Council on Amendment 43 to the Fishery Management Plan for the Snapper-Grouper Fishery of the South Atlantic Region to reduce discards of red snapper in the South Atlantic and continue to rebuild the stock.

Sincerely,

Roy E. Crabtree, Ph.D.
Regional Administrator

cc:

F/SEC - Bonnie Ponwith
F/SER2 - Jack McGovern
F/SER25 - Rick DeVictor

Appendix K. Calculation of Red Snapper ACLs

Total Annual Catch Limit

The total annual catch limit (ACL) was calculated using two different base values. One value was based on the average landings during the mini-seasons from 2012 to 2014, and the other was based on the highest landings reported during the mini-seasons (2014). **Alternative 3** and **Alternative 5** ACLs were calculated by multiplying an adjustment factor by the average landings (**Alternative 2** ACL) or highest landings (**Alternative 4 ACL**), respectively. The adjustment factor was developed by comparing the average abundance index value from a scientific survey in 2012 to 2014 to the average abundance index from 2015 to 2016 (See **Appendix L** for information on the calculation of the abundance index). Over this time period, the average abundance index for red snapper increased by 1.88 times. Therefore the adjustment factor was 1.88.

Table K.1. Development of the ACL value for **Alternative 3** and **Alternative 5**. The landings were based on landings from 2012 to 2014 when mini-seasons for red snapper were open. The adjustment factor is based on the increase in the red snapper abundance index.

Landings Type	Landings (number)	Adjustment Factor	ACL (number)	Alternative
Average	23,623	1.88	44,411	**Alternative 3**
Maximum	42,510	1.88	79,919	**Alternative 5**

Sector ACL

The total ACL is developed in numbers of fish; however, the method to determine the allocations for each sector is based on pounds of fish. Therefore numbers of fish were converted to pounds of fish. The estimate of fish weight came from averaging four different values of projected red snapper weight in 2018 (SEDAR 2017).

The allocations were developed by using the allocations in Amendment 25 (SAFMC 2011). The allocation was developed using data from 1986 to 2008. The red snapper landings estimates for recreational (rec) and commercial (com) sectors came from SEDAR 41 (2017).

$$RecSum = \frac{1}{2} * Sum\ Rec\ Landings\ 1986\ to\ 2008 + \frac{1}{2} * Sum\ Rec\ Landings\ 2006\ to\ 2008$$

$$ComSum = \frac{1}{2} * Sum\ Com\ Landings\ 1986\ to\ 2008 + \frac{1}{2} * Sum\ Com\ Landings\ 2006\ to\ 2008$$

$$RecSector\% = RecSum/(RecSum + ComSum)$$

The allocation in Amendment 17A was 28.07% commercial and 71.93% recreational.

The commercial ACL in whole weight was calculated by multiplying the total weight of the ACL by the commercial allocation (28.07%) (**Table 2**). The commercial ACL in gutted weight was calculated by using the whole weight to gutted weight ratio developed in SEDAR 41 (2016), which was 1.1.

Table 2. Development of the red snapper commercial ACL for **Alternative 2** through **5** in Amendment 43. ww=whole weight, gw=gutted weight

Alt	ACL Num	Average Weight from SEDAR 41 Projections	Total ACL Weight (ww)	Commercial Allocation	Commercial ACL (ww)	Commercial ACL (gw)
Alt 2	23,623	10.46	247,097	28.07%	69,360	63,055
Alt 3	44,411	10.46	464,539	28.07%	130,396	118,542
Alt 4	42,510	10.46	444,655	28.07%	124,815	113,468
Alt 5	79,919	10.46	835,953	28.07%	234,652	213,320

The recreational ACL in numbers of fish was calculated by removing the commercial sector ACL converted to number of fish from the total ACL in number of fish. Since the commercial ACL is calculated in pounds of fish, pounds of fish were converted to number of fish based on average weight of red snapper caught in the commercial sector from 2012 to 2014 (9.71 lbs ww) (SEDAR 41 2016). The commercial number of fish is then subtracted from the total ACL to get the recreational ACL.

Table 3. Development of the red snapper recreational ACL for **Alternative 2** through **5** in Amendment 43.

Alt	ACL Num	Commercial ACL (lbs ww)	Commercial Avg Weight (lbs ww)	Commercial ACL Num	Recreational ACL Number
Alt 2	23,623	69,360	9.71	7,143	16,480
Alt 3	44,411	130,396	9.71	13,429	30,982
Alt 4	42,510	124,815	9.71	12,854	29,656
Alt 5	79,919	234,652	9.71	24,166	55,753

Appendix L. SERFS Chevron Trap Red Snapper Abundance Index Update

Red Snapper Fishery-Independent Index of Abundance in US South Atlantic Waters Based on a Chevron Trap Survey (1990-2016 & 2010-2016)

Joseph C. Ballenger

Marine Resources Research Institute
South Carolina Department of Natural Resources
P.O. Box 12259
Charleston, SC 29412

SAFMC Amendment Development Team Reference Document
Amendment 43
MARMAP Technical Report # 2017-008

*Report documents development of Red Snapper relative abundance index based on the SERFS chevron trap survey. The document details two versions of the abundance index, one using the full time series of the chevron trap index (1990-2016) and the other only using data derived during the years 2010-2016.

This work was completed under the Marine Resources Monitoring, Assessment, and Prediction (MARMAP, NA16NMF4540320) and the Southeast Monitoring and Assessment Program – South Atlantic (SEAMAP-SA, NA16NMF4350172) funded by the National Marine Fisheries Service (Southeast Fisheries Science Center) and the South Carolina Department of Natural Resources.

Objective

This report presents two standardized relative abundance indices of Red Snapper derived from the SERFS chevron trap survey: one spanning the years 1990-2016 and the other the years 2010-2016. The standardized index accounts for annual sampling distribution shifts with respect to covariates that affect catch of Red Snapper in chevron traps. This report uses the same methodology for index development as documented in Ballenger and Smart (2015) for the chevron trap index during SEDAR41:

http://sedarweb.org/docs/wpapers/SEDAR41_DW54_Ballenger%26Smart_RSChevron2010.2014_8.17.2015.pdf.

Methods

Survey Design and Gear
(see Smart et al. 2015 for full description)

Sampling area

- Cape Hatteras, NC, to St. Lucie Inlet, FL
  - General expansion of geographic coverage through time

Sampling season

- May through September
  - Limited earlier and later sampling in some years

Survey Design

- 1990-2014
  - Simple random sample survey design from a chevron trap universe of confirmed live-bottom and/or hard-bottom habitat stations
- 2015-2016
  - Stratified random sample survey design from a chevron trap universe of confirmed live-bottom and/or hard-bottom habitat stations
    - Depth and latitude strata
      - Depth strata: inner shelf (<30 m deep); mid-shelf (30-42 m deep); outer-shelf (43-63 m deep); slope (≥64 m deep)
      - Latitude strata: southern-latitudes (<29.71°N); mid-latitudes (29.71-32.60°N); northern-latitudes (≥32.61°N)
- In a given year, no two stations are selected for sampling that are closer than 200 m from each other
- Traps deployed on suspected live-bottom and/or hard-bottom in a given year (reconnaissance) are evaluated based on catch and/or video or photographic evidence of bottom type for inclusion in the universe in subsequent years
  - If added to the known habitat universe, data from the reconnaissance deployment is included in CPUE analysis

Sampling Gear – Chevron Traps

(see Collins 1990 and MARMAP 2009 for descriptions that are more complete)

Oceanographic and Environmental Data

- Latitude (°N) data collected via GPS
- Depth (m) data collected via fathometer
- Bottom temperature (°C) data collected via CTD

Data Filtering/Inclusion

(see Ballenger and Smart 2015 for more complete description)

Chevron trap data were limited to:

- Projects conducting monitoring efforts
- Reef fish monitoring samples
- Traps that fished properly
- Traps on live-bottom and/or hard-bottom habitat
- Traps with soak times between 45-150 minutes
    - SERFS targets a soak time of 90 minutes for all chevron trap deployments
- Traps deployed at depths between 15 and 75 m
    - Range of depth for which we have ever observed Red Snapper in our monitoring program
- Excluded any chevron trap samples missing covariate information (Table 1)

Standardized Index Model Formulation

Model Basics

- Response variable – Catch/Trap (Figures 1 and 2)
- Offset term – $\ln(\text{soak time})$
- Dependent variables
    - Year
    - Covariates
        - Depth (m), latitude (°N), bottom temperature (°C), and day of year
            - Annual summary of covariates available in Table 2
            - Distribution of covariates available in Figures 3 and 4
- Model structure – zero-inflated negative binomial GLM (ZINB)
- Annual year effect coefficients of variation (CVs) computed using bootstrapping

Zero-Inflated Model Background

(see Cameron & Trivedi 1998, Hardin and Hilbe 2007, Hilbe 2007, Zeileis et al. 2008, and Chapter 11 in Zuur et al. 2009)

Covariate Treatment

(see Ballenger and Smart 2015 for more complete description)

- Covariates modeled as continuous covariates using polynomials

- Pairs plots, variance inflation factors (Table 3), box plots and violin plots were used to investigate the possibility of collinearity between any of the considered variables
  - No indication of strong collinearity among any considered covariates
- Model selection based on Bayesian information criterion (BIC; Schwarz 1978)

Results

Sampling Summary

- 1990-2016
  - 14,306 chevron trap samples retained and used in the development of the relative abundance index (Table 1)
  - Proportion of traps positive for Red Snapper averaged 0.08 (range: 0.00 – 0.16)
  - Caught on average 148 (range: 5-1088) Red Snapper annually
- 2010-2016
  - 8,073 chevron trap samples retained and used in the development of the relative abundance index (Table 1)
  - Proportion of traps positive for Red Snapper averaged 0.12 (range: 0.09 – 0.16)
  - Caught on average 519 (range: 116-1088) Red Snapper annually

ZINB Index

Model Selection
(see Table 4 for model selection results)

- Both indices, covariate day of year is removed from the count sub-model
- Both indices, the covariates year and bottom temperature are removed from the zero-inflation sub-model
- Both indices, best fit model suggest little to no overdispersion remaining in the data

Covariate Effects
(see Figures 7 and 8)

- Relative effects of latitude and bottom temperature is larger than the effect of sampling depth or day of year
- Predicted covariate effects
  - Depth – catch is above average at depths of ~25-45 m
  - Latitude – catch is higher than average at latitudes 28-30°N
  - Bottom temperature – catch of Red Snapper increases exponentially as bottom temperature increases, over the range of bottom temperatures observed in the survey
  - Day of Year – linear decrease in catch of Red Snapper throughout the survey season

Final Index
(see Table 5 and Figure 8)

- 1990-2016 Index
  - General slight decreasing trend from index start through the mid-2000's
  - Increasing relative abundance from approximately 2006 through the terminal year
  - CV estimates generally decrease through time
    - 1990-2009 – avg. 0.54 (range: 0.35 – 0.98; SD: 0.14)
    - 2010-2016 – avg. 0.17 (range: 0.16 – 0.20; SD: 0.02)
- 2010-2016 Index
  - Increasing relative abundance throughout the time series
    - Rate of increase increases after 2013
  - CV estimates – avg. 0.14 (range: 0.10 – 0.19; SD: 0.03)
- Correlation between the indices was 0.99 for the period 2010-2016 (Table 6 and Figure 9)

Conclusions

Here I present two updated relative abundance indices derived from the SERFS chevron trap survey. Both of these indices were developed using the same methodology used for the development of the chevron trap index during SEDAR 41 (see Ballenger and Smart 2015). They differ only in the length of the time series, one using data from the full chevron trap index time series (1990-2016) and the other only using chevron trap data collected from 2010-2016. During SEDAR41 it was decided to use a reduced time series for the chevron trap index (2010-2014). The three primary reasons for this decision was the low proportion of traps positive for Red Snapper prior to 2010, the low absolute number of Red Snapper captured annually in the survey prior to 2010, and the lower level of sampling effort off the coasts of Georgia and Florida prior to 2010. The consequences of these three factors can be seen in the higher degree of uncertainty of the chevron trap index from 1990-2009 (Table 5), with the annual coefficient of variation being approximately three times higher during this period of time than it is from 2010-2016. However, during the overlapping period both indices depicted the same increase in relative abundance (Table 6 and Figure 9). Both suggest that Red Snapper relative abundance is more than three times higher in 2016 than it was in 2010 and is more than 1.5 times higher in 2016 than it was in 2014.

I also provide a quick comparison to the Red Snapper index of relative abundance presented in the 2016 SCDNR Reef Fish Survey annual trends report. SCDNR Reef Fish Survey staff presented the index as developed for the trends report to the SAFMC SSC in April 2017 and the SAFMC in June 2017. The trends report Red Snapper relative abundance index differs primarily in statistical framework (delta-lognormal versus the ZINB model used here), response variable (catch/(trap*hr) versus catch/trap), and treatment of covariates (discrete versus continuous). Despite these differences, the correlation of the trends report index with either index presented herein exceeds 0.91 (Table 6) and depicts a very similar pattern of increase since 2010. It suggests that Red Snapper relative abundance in 2016 is 3.3 times higher than it was in 2010 and is more than two times what it was in 2014.

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Tables

Table 1: Annual and total exclusion of chevron trap monitoring station collections from analysis due to missing covariate data (1 collection missing both latitude and water temperature information; 599 collections missing water temperature information). Pre-exclusion and post-exclusion refers to the sample size prior to or after exclusion of samples due to missing covariate data.

Year	Pre-exclusion	Post-exclusion	% Change
1990	343	308	10.20
1991	290	269	7.24
1992	315	288	8.57
1993	388	388	0.00
1994	404	379	6.19
1995	379	361	4.75
1996	357	347	2.80
1997	417	385	7.67
1998	425	414	2.59
1999	237	215	9.28
2000	299	293	2.01
2001	246	236	4.07
2002	238	238	0.00
2003	218	218	0.00
2004	275	275	0.00
2005	324	303	6.48
2006	302	291	3.64
2007	331	331	0.00
2008	297	297	0.00
2009	397	397	0.00
2010	726	697	3.99
2011	861	684	20.56
2012	1170	1114	4.79
2013	1353	1335	1.33
2014	1428	1428	0.00
2015	1440	1400	2.78
2016	1446	1415	2.14
1990-2016 Total	**14906**	**14306**	**4.03**
2010-2016 Total	**8424**	**8073**	**4.17**

Table 2: Number of chevron trap deployments on live/hard-bottom areas, proportion of traps positive for Red Snapper, total number of Red Snapper caught, and information regarding covariate distribution annually.

				Depth (m)				Latitude (°N)				Temperature (°C)				Day of Year			
					Range				Range				Range				Range		
Year	n	Prop. Pos.	# of Fish	Avg.	Min	Max	SE	Avg.	Min	Max	SE	Avg.	Min	Max	SE	Avg.	Min	Max	SE
1990	308	0.0227	23	33	17	62	0.60	32.52	30.42	33.82	0.037	22.1	18.4	27.8	0.14	149	114	222	1.6
1991	269	0.0223	17	33	17	57	0.64	32.64	30.75	34.61	0.049	25.0	20.6	27.5	0.10	216	163	268	2.1
1992	288	0.0278	20	34	17	62	0.59	32.77	30.42	34.32	0.041	21.3	15.3	24.5	0.16	155	92	227	2.5
1993	388	0.0309	31	34	16	60	0.62	32.41	30.44	34.32	0.040	22.8	17.7	28.5	0.14	176	131	226	1.5
1994	379	0.0501	45	38	16	64	0.61	32.37	30.74	33.82	0.031	22.8	18.1	26.9	0.10	173	130	300	1.8
1995	361	0.0194	13	34	16	60	0.71	32.14	29.78	33.75	0.042	24.6	20.1	28.3	0.13	198	124	299	2.6
1996	347	0.0173	6	36	15	62	0.63	32.38	27.92	34.33	0.052	22.2	14.2	27.0	0.16	190	121	261	2.4
1997	385	0.0156	24	38	15	74	0.69	32.00	27.87	34.59	0.080	22.9	17.8	28.0	0.12	194	126	273	1.5
1998	414	0.0193	25	39	15	75	0.71	32.03	27.44	34.59	0.071	21.4	9.5	28.6	0.22	178	126	231	1.9
1999	215	0.0186	22	37	15	75	0.88	31.88	27.27	34.41	0.123	22.9	17.9	28.8	0.14	202	154	272	1.8
2000	293	0.0273	17	35	15	75	0.75	32.29	28.95	34.28	0.064	24.0	18.0	28.5	0.13	202	138	294	2.7
2001	236	0.0297	9	37	15	67	0.82	32.36	27.87	34.28	0.074	23.6	16.0	29.2	0.17	203	144	298	2.2
2002	238	0.0546	33	37	15	70	0.84	31.87	27.86	33.95	0.087	24.3	15.2	28.3	0.20	207	169	268	1.9
2003	218	0.0046	7	38	16	62	0.79	32.07	27.43	34.33	0.112	18.9	13.4	25.1	0.15	203	155	266	2.2
2004	275	0.0145	5	40	15	75	0.92	32.26	29.00	33.97	0.064	20.9	16.7	25.8	0.17	176	127	303	2.2
2005	303	0.0231	12	38	15	69	0.74	32.08	27.33	34.32	0.084	23.0	18.0	28.5	0.17	191	124	273	2.8
2006	291	0.0172	6	37	15	69	0.76	32.29	27.27	34.39	0.088	22.6	15.0	26.7	0.17	203	158	272	2.0
2007	331	0.0242	29	37	15	73	0.75	32.17	27.33	34.33	0.079	23.4	15.3	28.9	0.16	200	142	268	2.1
2008	297	0.0236	19	37	15	70	0.70	32.16	27.27	34.59	0.086	21.8	15.2	27.2	0.14	193	127	274	2.6
2009	397	0.0202	10	36	15	73	0.69	32.23	27.27	34.6	0.082	22.6	15.4	27.2	0.13	202	127	282	2.4
2010	697	0.0875	148	38	15	72	0.51	31.41	27.34	34.59	0.063	22.1	12.3	29.4	0.16	219	125	301	2.0
2011	684	0.0950	116	40	15	75	0.53	30.86	27.23	34.54	0.070	21.7	14.8	28.8	0.15	210	140	300	1.8
2012	1114	0.1248	398	39	15	75	0.42	31.80	27.23	35.02	0.065	22.2	12.9	27.8	0.10	194	116	285	1.3
2013	1335	0.1049	367	37	15	75	0.36	31.24	27.23	35.01	0.054	22.1	12.4	28.1	0.08	197	115	278	1.3
2014	1428	0.1050	614	38	15	75	0.33	31.88	27.23	35.01	0.055	23.5	16.1	29.3	0.07	192	114	295	1.2
2015	1400	0.1129	903	37	16	75	0.35	31.84	27.26	35.02	0.055	22.7	13.6	28.5	0.07	186	112	296	1.2
2016	1415	0.1548	1088	38	17	75	0.35	32.06	27.23	35.01	0.055	24.1	15.5	29.3	0.06	217	126	302	1.2

Table 3: Variance inflation factor (VIF) estimates and degrees of freedom (df) for all considered covariates based on individual index time series.

	1990-2016		2010-2016	
Variable	**VIF**	**df**	**VIF**	**df**
Year	1.39	26	1.20	6
Depth (m)	1.28	1	1.29	1
Latitude (oN)	1.15	1	1.13	1
Bottom Temperature (oC)	1.80	1	1.69	1
Day of Year	1.41	1	1.33	1

Table 4: Results of BIC selection for the top 10 ranked ZINB models.

	Count Model					Zero-Inflation Model					
Rank	Latitude	Depth	Temperature	Day of Year	Year	Latitude	Depth	Temperature	Day of Year	BIC	Θ
					1990-2016 Index						
1	7	8	1	0	0	4	3	0	1	10565	1.100
2	7	8	1	0	0	4	4	0	1	10567	1.097
3	7	8	1	0	0	4	3	0	2	10567	1.107
4	7	8	1	0	0	5	3	0	1	10568	1.098
5	7	8	1	0	0	4	3	0	0	10568	1.124
6	7	8	1	0	0	4	4	0	2	10569	1.099
7	7	8	1	0	0	5	3	0	2	10569	1.105
8	7	8	1	0	0	5	4	0	1	10570	1.099
9	7	8	1	0	0	4	4	0	0	10570	1.122
10	7	8	1	0	0	5	4	0	2	10571	1.104
					2010-2016 Index						
1	8	3	1	0	0	4	3	0	1	8486	1.112
2	8	3	1	0	0	4	4	0	0	8486	1.121
3	8	3	1	0	0	8	4	0	0	8486	1.177
4	8	3	1	0	0	8	3	0	0	8487	1.117
5	8	3	1	0	0	4	4	0	1	8489	1.124
6	8	3	1	0	0	6	3	0	0	8489	1.064
7	8	3	1	0	0	4	3	1	0	8491	1.109
8	8	3	1	0	0	6	4	0	0	8491	1.058
9	8	3	1	0	0	8	4	0	1	8491	1.161
10	8	3	1	0	0	5	3	0	0	8491	1.106

Table 5: Red Snapper relative abundance index based on the SERFS chevron trap survey as standardized using a ZINB GLM. Index = relative abundance of Red Snapper, Bias = observed bias in bootstrap analysis, CV = coefficient of variation

	1990-2016 Index						2010-2016 Index					
					Confidence Interval						Confidence Interval	
Year	Index	Bias	SE	CV	Lower	Upper	Index	Bias	SE	CV	Lower	Upper
1990	1.1752	0.0030	0.8319	0.7079	0.1142	3.1460	–	–	–	–	–	–
1991	0.7657	0.0415	0.5712	0.7460	0.0797	2.1871	–	–	–	–	–	–
1992	1.8059	-0.0119	0.7724	0.4277	0.5011	3.4989	–	–	–	–	–	–
1993	1.1136	0.0027	0.4941	0.4437	0.3564	2.2705	–	–	–	–	–	–
1994	1.4820	0.0096	0.8147	0.5498	0.4279	3.4165	–	–	–	–	–	–
1995	0.3033	0.0013	0.1493	0.4923	0.0743	0.6456	–	–	–	–	–	–
1996	0.2011	0.0010	0.1010	0.5024	0.0482	0.4399	–	–	–	–	–	–
1997	0.4765	-0.0027	0.3072	0.6447	0.0422	1.1898	–	–	–	–	–	–
1998	0.7081	-0.0269	0.3771	0.5326	0.1238	1.5375	–	–	–	–	–	–
1999	1.0781	0.0464	0.6372	0.5910	0.0550	2.6007	–	–	–	–	–	–
2000	0.5232	-0.0004	0.2650	0.5066	0.1277	1.1317	–	–	–	–	–	–
2001	0.6394	0.0023	0.3179	0.4971	0.1553	1.3682	–	–	–	–	–	–
2002	1.2692	0.0263	0.5714	0.4502	0.3759	2.5989	–	–	–	–	–	–
2003	0.8969	-0.0207	0.8791	0.9801	0.0000	2.9783	–	–	–	–	–	–
2004	0.4063	-0.0030	0.2246	0.5527	0.0643	0.9236	–	–	–	–	–	–
2005	0.2797	-0.0034	0.1185	0.4237	0.0745	0.5352	–	–	–	–	–	–
2006	0.1955	-0.0017	0.0873	0.4464	0.0388	0.3852	–	–	–	–	–	–
2007	0.7004	-0.0367	0.3991	0.5698	0.1136	1.5524	–	–	–	–	–	–
2008	0.8762	-0.0167	0.3609	0.4119	0.2177	1.6263	–	–	–	–	–	–
2009	0.2318	-0.0034	0.0820	0.3538	0.0847	0.4057	–	–	–	–	–	–
2010	0.9839	-0.0126	0.1997	0.2029	0.6216	1.4206	0.5333	-0.0021	0.1023	0.1918	0.3498	0.7508
2011	0.9646	-0.0093	0.1740	0.1804	0.6449	1.3247	0.5490	0.0072	0.0948	0.1727	0.3893	0.7558
2012	1.3984	0.0011	0.2185	0.1563	1.0111	1.8683	0.8099	0.0017	0.0995	0.1229	0.6270	1.0136
2013	1.0847	0.0032	0.1754	0.1617	0.7832	1.4708	0.6657	-0.0054	0.0852	0.1280	0.5014	0.8362
2014	1.7807	0.0221	0.3052	0.1714	1.2763	2.4604	1.1501	-0.0132	0.1371	0.1192	0.8791	1.4210
2015	2.6890	-0.0291	0.4188	0.1558	1.8963	3.5523	1.5510	0.0027	0.1747	0.1127	1.2206	1.9063
2016	2.9708	0.0180	0.4737	0.1595	2.1387	3.9867	1.7409	0.0091	0.1794	0.1031	1.4045	2.1165

Table 6: Correlation table between the two indices provided in the current report and between those indices and the index provided in the 2016 SCDNR Reef Fish Survey trends report and presented to the SAFMC (June 2017) and SAFMC SSC (April 2017).

	1990-2016 ZINB	2010-2016 ZINB
2010-2016 ZINB	0.9949	
Trends Report	0.9155	0.9254

Figures

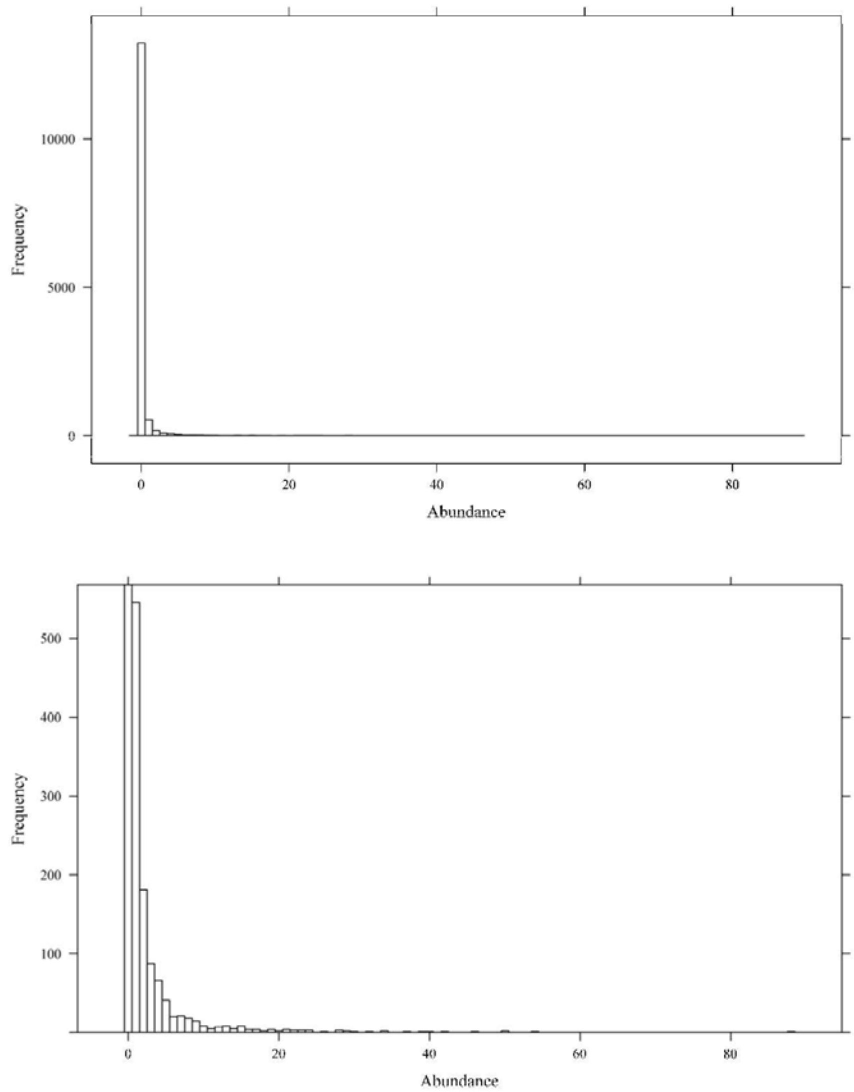

Figure 1: Frequency of occurrence of chevron traps (from 1990-2016) with a given catch of Red Snapper. Top panel – full distribution showing excess zeros; Bottom panel – restricted distribution better depicting frequency of traps with a given catch of Red Snapper.

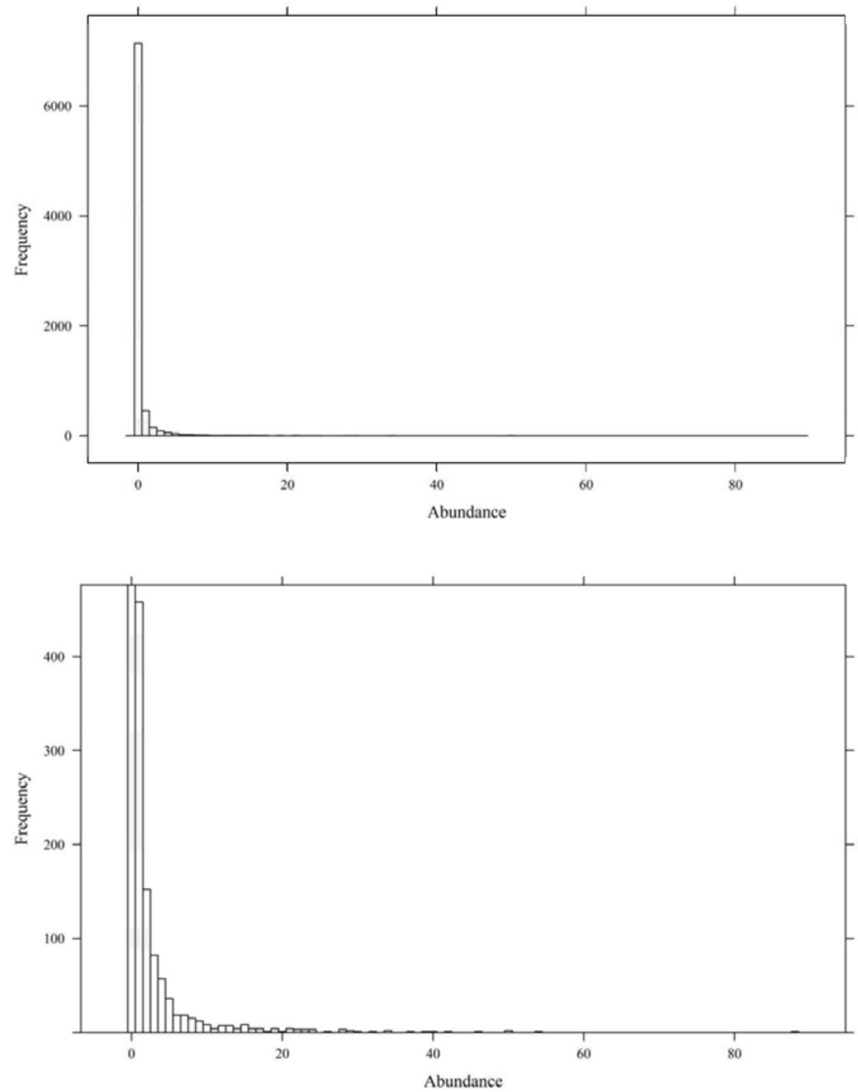

Figure 2: Frequency of occurrence of chevron traps (from 2010-2016) with a given catch of Red Snapper. Top panel – full distribution showing excess zeros; Bottom panel – restricted distribution better depicting frequency of traps with a given catch of Red Snapper.

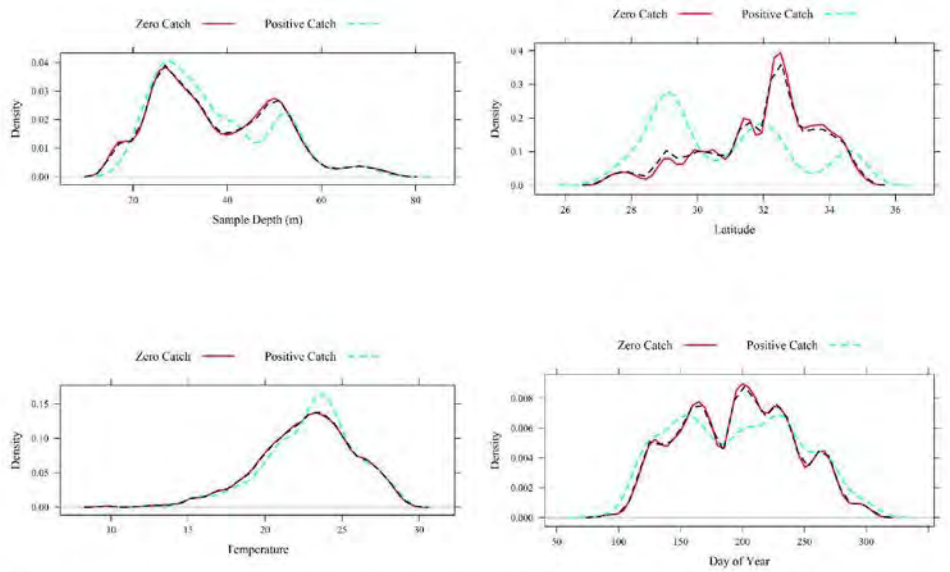

Figure 3: Density plots of all traps (1990-2016; dashed black line), negative (red line) and positive (dashed blue line) for Red Snapper with respect to each covariate considered in the model.

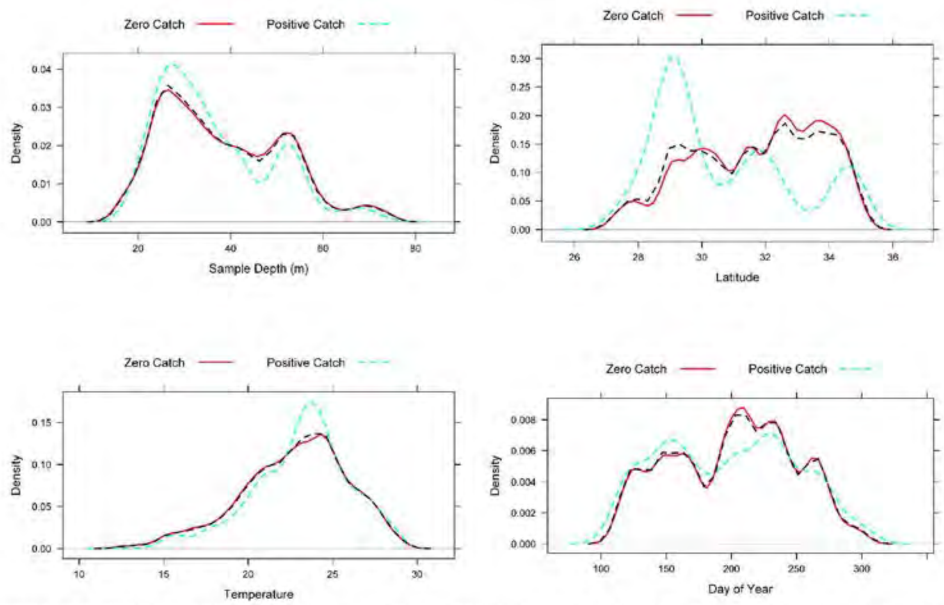

Figure 4: Density plots of all traps (2010-2016; dashed black line), negative (red line) and positive (dashed blue line) for Red Snapper with respect to each covariate considered in the model.

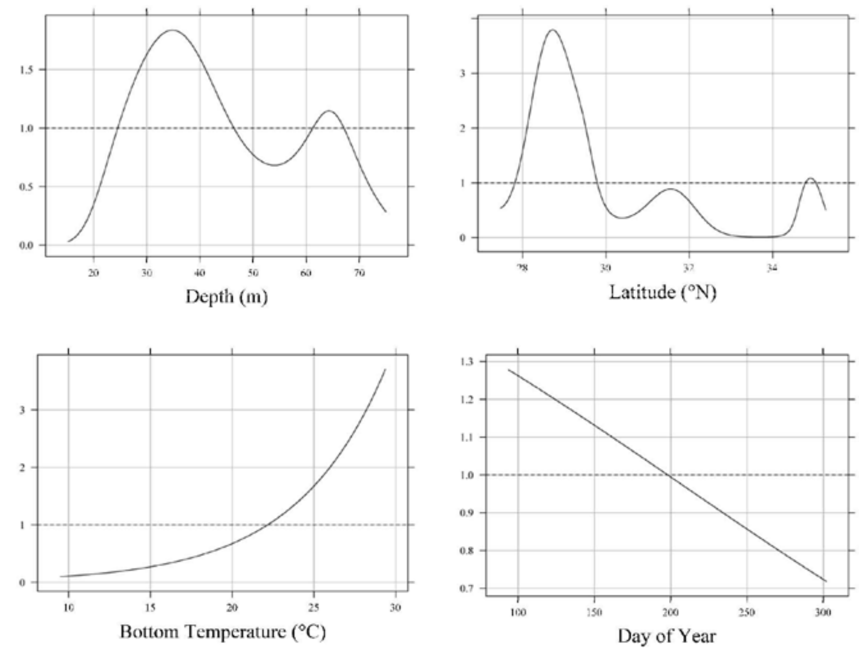

Figure 5: Predicted relative effect of each covariate on the catch of Red Snapper in chevron traps using the 1990-2016 data set. Note that the scale of the y-axis changes among panels, and hence y-axis scale can provide an indication of the magnitude of the effect of individual covariates.

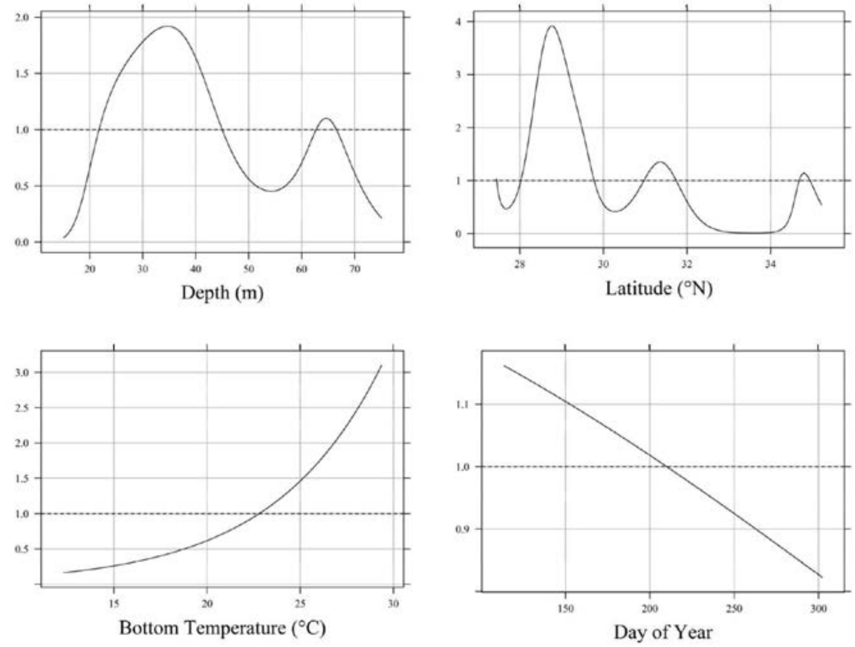

Figure 6: Predicted relative effect of each covariate on the catch of Red Snapper in chevron traps using the 2010-2016 data set. Note that the scale of the y-axis changes among panels, and hence y-axis scale can provide an indication of the magnitude of the effect of individual covariates.

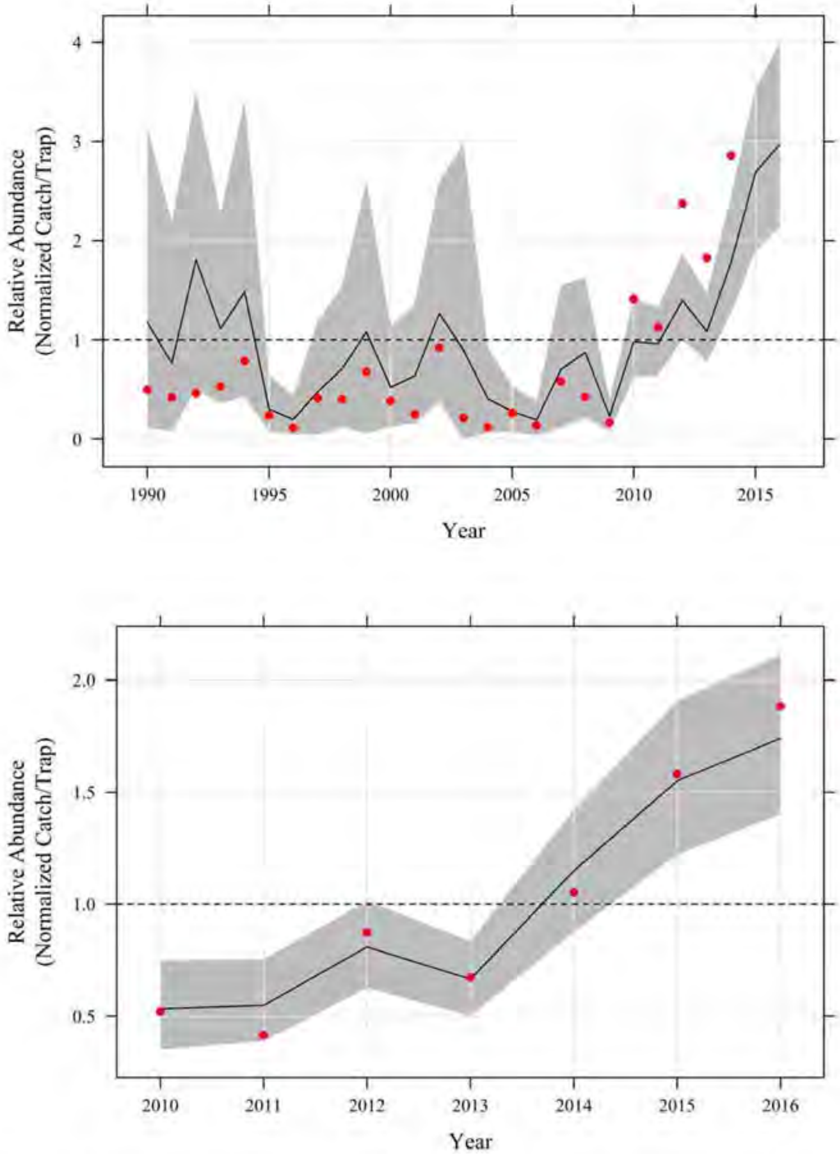

Figure 7: Red Snapper index of relative abundance based on the SERFS chevron trap survey. Top panel is the index based on the years 1990-2016. Bottom panel is the index based on the years 2010-2016. The ZINB standardized catch (solid black line) is normalized to the average relative abundance, as estimated by the model, during each surveys respective time series. Red dots represent normalized nominal annual relative abundance. Gray shaded region represents the 95% confidence interval of annual relative abundance based on 10,000 bootstraps.

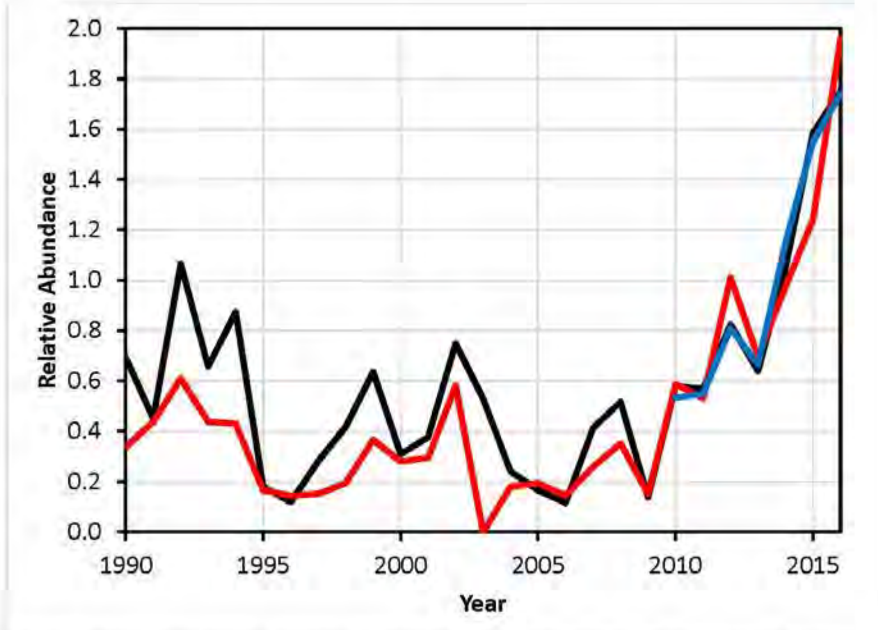

Figure 8: Red Snapper index of relative abundance based on the SERFS chevron trap survey, with annual relative abundance being normalized to the average relative abundance from 2010-2016. The different lines represent the relative abundance index developed using the full chevron trap time series and the methodology reported in Ballenger and Smart (2015; black line), the relative abundance index developed using the full chevron trap time series and the methodology reported in the SCDNR Reef Fish Survey 2016 trends report (red line), and the relative abundance index developed using only chevron trap data collected from 2010-2016 and the methodology reported in Ballenger and Smart (2015; blue line). The surveys are normalized to the average relative abundance from 2010-2016 here so that predicted changes in relative abundance in the overlapping period can be more easily compared.

Appendix M. Scientific and Statistical Committee October 2016 Final Report

SOUTH ATLANTIC FISHERY MANAGEMENT COUNCIL

SCIENTIFIC AND STATISTICAL COMMITTEE

SSC Meeting Report

Oct 18-20, 2016

Charleston Marriott Hotel
Charleston, SC

VERSION
Final Report
November 29, 2016

CONTENTS

revised NS1 Guidelines. Mr. Shepherd Grimes (NOAA General Council) clarified that the phase in needs to be part of the fisheries management plan and the ABC control rule. The requirement that Councils cannot exceed the ABC recommendations of the SSC is not overruled by the flexibility allowance. The FMP and control rule would specify the conditions under which the phase-in would occur and how the ABC is developed when a phase-in is considered.

- *A phase-in that reduces the buffer between the overfishing level and the allowable catch increases the risk of ending up in an overfished situation and a rebuilding plan, especially as overages have occurred in recent (3-4) years.*
- *If council chooses to phase-in the ACL, SSC recommends considering management uncertainty and recent overages. The SSC recommends that the ACL should not exceed 90% of the OFL in year one because the ACL was exceeded in recent years.*
- *In addition to revising the ABC control rule, new projection estimates will need to be provided if a phased-in approach is chosen.*

- Also consider providing a constant ABC for later years, specified in 3-year blocks.

Consistency in the ACL will make it easier for holders of the tilefish endorsements to adjust their business models. However, the economic analysis in Amendment 18B that led to the restriction of tilefish access rights to a limited number of endorsement holders noted that both the ACL and average trip costs would have to remain static in order for the remaining operations to maintain profitability. The IFQ system in the Wreckfish fishery was able to adjust to a much sharper reduction in its ACL through the sale of shares to the members of the fleet that utilized them most profitably.

7. SNAPPER GROUPER AMENDMENT 43 - RED SNAPPER

7.1. Documents

Attachment 19. SEDAR 41 SAR, Red Snapper
Attachment 20. SEDAR 41 Supplemental Projections Apr2016
Attachment 21. SEDAR 41 Proj Runs at F_{MAX} and $F_{20\%SPR}$ Aug 2016
Attachment 22. SEDAR 41 Projection Overview Presentation
Attachment 23. Amendment 43 Options Paper
Attachment 24a. MRIP Int Reliability RS

7.2. Presentation

Projections Overview: Dr. Kate Siegfried, SEFSC
Amendment 43 ACT alternative: Chip Collier, SAFMC

7.3. Overview

The Committee reviewed the Red Snapper Benchmark assessment prepared through SEDAR 41 and provided fishing level recommendations at their May 2016 meeting. The base assessment run suggested that in the terminal year of 2014 the stock remained overfished. The SSC did not have confidence in the terminal fishing mortality estimates; however they recommended that the assessment results suggested overfishing was likely occurring in the terminal years of the assessment (2012-2014). , although the degree to which overfishing was occurring at that time could not be reliably quantified from the assessment results. Status determination and catch level recommendations provided by the SSC in May 2016 were based on the current F_{MSY} proxy of $F_{30\%SPR}$.

SEDAR 41 estimated the long-term sustainable yield at MSY to be about 25% of what it was estimated to be in SEDAR 24, and projected catch levels from SEDAR 41 at $F_{Rebuild}$ were approximately 21% of the catch levels projected for 2017 based on SEDAR 24. Given the lack of an estimated stock recruitment relationship and the need to fix steepness in SEDAR 41 at a level different than that used for SEDAR 24, and considering the importance of the stock-recruit parameters to the reference point recommendations, the Council directed the SSC to recommend an appropriate F_{MSY} proxy for red snapper that reflects the most recent assessment results. The Council requested additional projection runs and reference point criteria at F_{MAX} and $F_{20\%SPR}$, for the SSC to consider.

There was also concern over the amount of uncertainty in the recreational landings and discard estimates used in SEDAR 41. Recent landings estimates have a high degree of error associated with them, which is partially due to the difficulties of generating estimates during the recent moratoriums and short mini-seasons. Discard estimates also exhibit high sampling error. Due to these recreational data uncertainties the Council requested that the SSC evaluate the current MRIP estimates (landings and discards) for Red Snapper to determine if they are reliable and adequate for management.

The Council has also begun work on Amendment 43 to address alternative management strategies for Red Snapper. Although the Amendment is still in the early stages, there are items the Council would like the SSC's feedback on, such as the MSY (Action 1 in Amendment 43), specifying ABC and Annual Catch Limit (ACL) in landings versus landings and discards (Action 3), and calculating the annual catch target (ACT; Action 4). Attachment 23 has the three actions highlighted here for SSC review copied to the front of the document after the purpose and need for the amendment for ease of SSC review. The full options paper is provided after the Actions 1, 3 and 4 to provide background information and all other proposed action and alternatives.

The Council requested the SSC discuss the risk associated with using different values of MSY (Action 1). The MSY alternatives in the options paper include F_{MAX}, $F_{20\%}$, $F_{26\%}$, $F_{30\%}$, and $F_{40\%}$. Projections are provided for F_{MAX}, $F_{20\%}$, $F_{27\%}$, and $F_{30\%}$ in Attachment 21.

There are slight differences between the alternatives and the projections because the alternatives in the amendment were developed after the request for projections was sent the SEFSC.

The Council requested the SSC comment on the risk of specifying the ABC and ACL in landings or landings + discards (Action 3). The current ABC is based on landings and dead discards and the ACL is based on landings only. The discards are not tracked for any other fish in the South Atlantic and compared to the ABC, which includes landings and dead discards. However, the largest component of fishing mortality for Red Snapper in the last five years came from the dead discards in the recreational fishery.

The calculation of the ACT (Action 5) includes a new method for review by the SSC (Alternative 4). The new method reduces the ACT from the ACL based on the average percentage the annual landings exceeded the ACL based on a selected timeframe. The timeframe for the ACT calculation was based on 2012 to 2014 when short seasons were opened for Red Snapper.

Table 3. Red Snapper Recommendations from the May 2016 SSC Meeting

Criteria			**Deterministic**	**Probabilistic**
Overfished evaluation ($SSB_{2014}/SSB_{30\%}$)			0.16	0.17
Overfishing evaluation			$F_{12\text{-}14}/F_{30\%} > 1$	$F_{12\text{-}14}/F_{30\%} > 1$
MFMT ($F_{30\%}$)			0.15	0.15
$SSB_{30\%}$ (Eggs 1E8)			328,552	294,166
MSST (Eggs 1E8)			246,414	220,624
MSY (1000 lb)			430	419
Y at 75% $F_{30\%}$ (1000 lb)			398	397
ABC Control Rule Adjustment			Under Rebuilding	
P-Star			Under Rebuilding	
M			0.134	
Management starting in 2017 (probabilistic projection results)				
OFL RECOMMENDATIONS				
Year	Landed LBS	Discard LBS	Landed Number	Discard Number
2017	174,000	189,000	18,000	35,000
2018	204,000	210,000	19,000	37,000
2019	230,000	227,000	21,000	39,000
ABC RECOMMENDATIONS				
Year	Landed LBS	Discard LBS	Landed Number	Discard Number
2017	165,000	179,000	17,000	33,000
2018	195,000	200,000	18,000	35,000
2019	220,000	218,000	20,000	37,000

7.4. Action

- Evaluate the MRIP estimates for Red Snapper

- Determine if they are reliable and adequate for management, including quota monitoring and discard information.

- Consider alternative reference points
  - Comment on the risk of using alternative SPR metrics in lieu of $F_{30\%SPR}$ in determining stock status and running projections.
  - Review the projections at F_{MAX} and $F_{20\%SPR}$.
  - Update or revise fishing level recommendations as appropriate.

- Amendment 43 ACT alternative (Action 4)
  - Discuss the pros and cons of the proposed alternative method for calculating the ACT.
  - What are the benefits to using the proposed methodology over the Council's current ACT rule of (1-PSE)*ACL?

SSC RECOMMENDATIONS:

- Evaluate the MRIP estimates for Red Snapper
  - Determine if they are reliable and adequate for management, including quota monitoring and discard information.
    - *The number of intercepts is relatively low and the expansion factors relatively high, with the highest number of intercepts in Florida.*
    - *The SSC realizes that these estimates are influential in assessments and management. By design, 90% of the effort is focused on "inshore" areas, while the remainder is focused "off-shore". Better data would be ideal, such as surveys focused on off-shore trips. The SSC realizes that while these estimates are influential in assessments and management, they are currently all there is. Uncertainties and use of data was discussed extensively at the SEDAR 41 Data Workshop and during the review.*
    - *The SSC agrees that all sources of mortality should be considered; therefore the ABC should be specified in total yield (landings + discards). Not accounting for dead discards in management increases the risk of overfishing ("a dead fish is a dead fish").*
    - *Discard mortality will remain one of the key issues. Assessment estimates and projections can be significantly improved if reliable estimates of discards and discard mortality are improved. As a result, efforts to better estimate and validate discards and discard mortality should be given a very high research and survey priority.*
    - *Similarly, the proportion of stock yield available for harvest can increase if discard mortality is reduced, e.g. by the use of descending devices or other descending techniques, or avoiding areas with high concentrations of red snapper. Release mortality*

studies could improve discard mortality estimates, and should be given a high research priority. Such studies could include evaluation of existing devices and release methods, and development of alternative methods. It will be important to evaluate acceptance of these techniques by fishers.

- *In addition, other data collection approaches should be studied, such as those in the GOM (stamp), as recommended in the new approach the Council put forth.*
- *The PSE could be informative in determining the adequacy of estimates. An ACCSP Workshop report (available on the ACCSP website) suggested PSEs higher than 40% to 60% may not be usable. However, higher levels were acceptable for short-lived species or those with low levels of recreational catch.*
- *Simulation evaluation could be used to determine the effect of differing PSE values on the resulting reference points.*
- *The incorporation of uncertainty in the catch data is dependent on the chosen method of assessment. We currently use catch-based assessments, which assume the catch is known with very little error. Moving to an effort-based assessment or a Bayesian framework would allow fitting to the catch and better incorporate the estimates of uncertainty (PSE) into the assessment.*

- Consider alternative reference points
  - Comment on the risk of using alternative SPR metrics in lieu of $F_{30\%SPR}$ in determining stock status and running projections.

    By definition F_{MAX} and $F_{20\%}$ have a higher risk of overfishing than $F_{30\%spr}$ or $F_{40\%spr}$. Furthermore, the analyses presented to the SSC indicated that the various alternatives ($F_{20\%}$, $F_{27\%}$, $F_{30\%}$, and F_{max}) showed very similar results and the changes in yield were minimal. It is the opinion of the SSC that there is no compelling reason to change the proxy based on the data presented, and even if a different metric is chosen (other than $F_{30\%}$), the status determination and yield will not change substantially. Scientific literature supports that longer lived species should have a higher percentage of SPR, which supports maintaining $F_{30\%}$ at a minimum.
  - Review the projections at F_{MAX}, $F_{20\%SPR}$, and $F_{27\%SPR}$.

    See above.
  - Update or revise fishing level recommendations as appropriate.
    - *Previous SSC discussions and the RW reports discussed the MSY proxy issues. No new data have become available to justify a revision of the fishing level recommendations.*

- ➢ *A retrospective analysis would be useful to investigate the "overfishing uncertainty" between the proposed F_{MSY} proxies.*

- Amendment 43 ACT alternative (Action 4)
  - Discuss the pros and cons of the proposed alternative method for calculating the ACT.
  - What are the benefits to using the proposed methodology over the Council's current ACT rule of (1-PSE)*ACL?
    - ➢ *The use of an ACT and chosen buffer is a management decision, but having an ACT is preferable over not having one because:*
      - *Provides buffer from the ACL. Using a percentage of the ACL recognizes that catches may not be known precisely.*
      - *Could be used for in-season monitoring, and can be adjusted as time progresses, management changes, and data collection improves.*
      - *It is consistent with Gulf methodology. ACT based on performance – evaluation of proportional overages over time, similar to alternative 6.*
    - ➢ *Does not consider uncertainty in the point estimates of the landings as Alt 2 does. Alt 2 accounts for the observed uncertainty in the catch estimates.*

8. ABC CONTROL RULE MODIFICATIONS

8.1. Documents

Attachment 25. ABC Control Rule Modifications DD
Attachment 26. ABC Control Rules from Other Jurisdictions
Attachment 27. ABC Control Rule Presentation
Attachment 28. ABC Control Rule Background Information

8.2. Presentation

Changes to the ABC Control Rule: John Carmichael, SAFMC

8.3. Overview

During the October 2014 ABC Workshop, several issues with the ABC Control Rule were identified, including the use of stock status, MRAG Productivity and Susceptibility Analysis scores and catch adequacy in determining the P* value for Tier 1 stocks . Other concerns include the overly prescriptive nature of Levels 2 and 3 that could be viewed as precluding consideration of newly developed data poor assessment methods and the lack of clarity on application of the ABC Control Rule in developing annual catch level recommendations for stocks in a rebuilding plan. The SSC created a sub-committee to develop recommendations for control rule revisions. At the May 2016 meeting, the SSC discussed the results of analyses that had been put together by the ABC Control Rule sub-

Appendix N. Commercial Sector Projected Seasons

Predicting Closure Dates for Amendment 43 Proposed Catch Limits for the South Atlantic Red Snapper Commercial Sector

LAPP/DM Branch
NOAA Fisheries Service
Southeast Regional Office

In 2016, a stock assessment was conducted for the South Atlantic red snapper (SEDAR 41). Results from the assessment showed the red snapper stock is overfished and experiencing overfishing. Amendment 43 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region (Amendment 43) is currently being drafted and its purpose is to establish new Annual Catch Limits (ACL) that will rebuild the stock.

Amendment 43 is currently being drafted and will likely be imposed on the 2018 fishing year. An estimate of future landings is required to determine potential closure dates for the alternative ACLs being considered. Frequently future landings are predicted from taking an average of the most recent years of complete data following the assumption that recent landings will likely reflect future landings. However, the South Atlantic red snapper fishery was closed in 2010, 2011, 2015 and 2016, and was only open for short periods of time (57 days or less) in 2012, 2013, and 2014. The short opening in 2012, 2013, and 2014 occurred over different months; therefore, landings from different months and years were combined to predict future landings. Commercial landings for South Atlantic red snapper came from the Southeast Fisheries Science Center's (SEFSC) updated commercial ACL dataset, which was provided on May 2, 2017. The commercial fishery will open on the second Monday of July and, if the ACL is not exceeded, close on December 31. Future landings were only predicted for July through December. Future landings were determined by calculating the daily catch rate for a month and then applying the catch rate to the total number of days in that month. Predicted landings for each month assumed a uniform distribution within a month, and were partitioned into a daily catch rate by dividing the landings for a month by the number of days in that month. The daily catch rates were projected forward and a closure date was determined when the landings exceeded the various ACLs proposed in Amendment 43. The projections start on July 9 because this is the second Monday of July in 2018, therefore landings were assumed to be zero before July 9.

- July 2014 was the most recent year when the commercial sector was open in July, and the commercial sector was open from July 14 through July 31. The July daily catch rate was applied for 22 days in July to match a potential opening in 2018.

- Future August landings were assumed to match the August 2014 landings because this was the most recent time period when the commercial sector was open for the entire month of August.
- Future September landings were assumed to match the September 2013 landings because this was the most recent year where the commercial sector was open for the entire month of September.
- October of 2013 was the most recent year when the commercial sector was open in October and the sector was open from October 1 through October 8 of 2013. Future October landings were determined from calculating the daily catch rate from October 2013 and then applying the catch rate to the total number of days in October (31 days).
- The most recent years where the commercial sector was open in November and December was in 2012 (8 days in November and 7 days for December). However, a reduced trip limit of 50 pounds gutted weight (lbs gw) was implemented in 2012 which is different than the trip limit of 75 lbs gw which was implemented in 2013 and continues today. A trip limit analysis was done for the red snapper temporary rule in 2012 (Red Snapper Rule 2012) and found that a change in the trip limit from 50 to 75 lbs gw resulted in a 51% increase in landings. Following the trip limit analysis done for the red snapper temporary rule, the landings in 2012 were increased by 51% to adjust for the increased trip limit from 50 to 75 lb gw. These modified landings were used to determine future November and December landings from calculating the daily catch rate within each month when they were open in 2012. The catch rate was applied to the total number of days in each month. Details of the landings used to create the predicted landings are shown in Table 1, and Figure 2 displays landings by month.

Table 1. Details of the commercial landings used to determine the predicted future commercial landings for red snapper.

Month	Most Recent Year	Days open	Method
July	2014	17 days	Determined July 2014 average daily catch rate; applied catch rate to open days in July
August	2014	31 days	Used August 2014 landings
September	2013	30 days	Used September 2013 landings
October	2013	8 days	Determined October 2013 average daily catch rate; applied to open days in October
November	2012	8 days	Landings adjusted for trip limit, then determined November 2012 average daily catch rate; applied to open days in November
December	2012	7 days	Landings adjusted for trip limit, then determined December 2012

			average daily catch rate; applied to open days in December

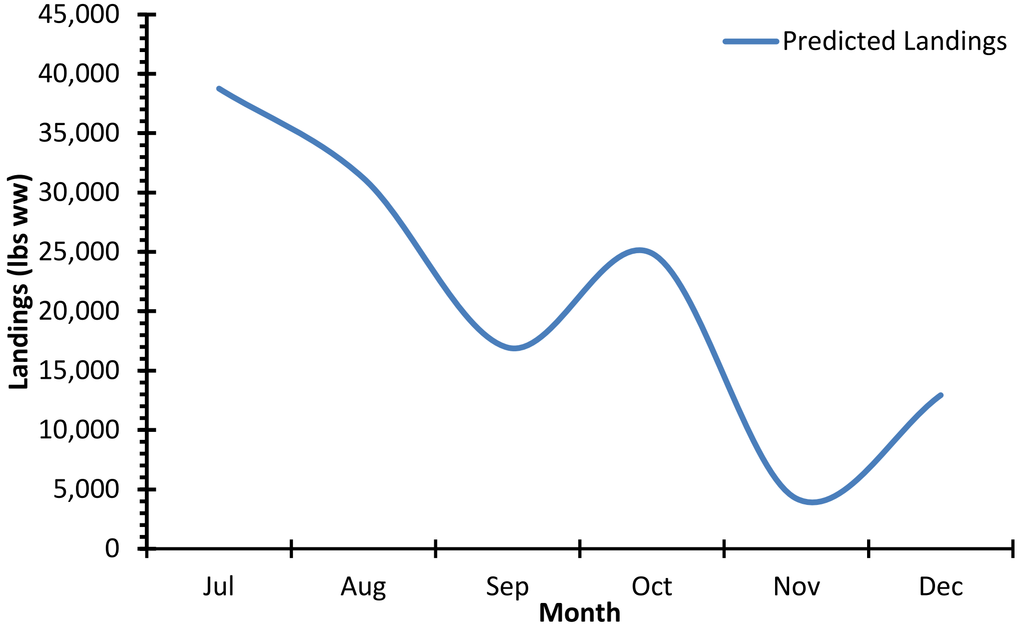

Figure 1. Predicted South Atlantic red snapper commercial landings by month. The commercial sector is expected to open on the second Monday in July and close at the end of December, therefore, landings were only predicted for July through December.

Amendment 43 includes different alternatives to develop ACLs. Some of the alternatives are increased by an adjustment factor due to an increase in red snapper abundance based on a fish trap index of abundance. The adjustment factor is 1.88 and is based on the change in the average index of abundance from 2012 to 2014 compared to the average abundance from 2015 to 2016. Opening the fishery to an increased stock size will likely cause changes in harvest. The question is how will the harvest change in the commercial sector? There likely won't be any new commercial fishermen harvesting red snapper because the number of commercial fishermen is capped because the permit is limited access. Also, the harvest per trip is capped by a 75 pound trip limit. The fishermen could do more trips for red snapper but it is not likely they will go fishing solely for red snapper because of the low trip limit (75 lbs gw). It's more likely that the increased stock size will cause more trips to meet the trip limit. This potential change in pounds per trip was analyzed by first examining the distribution of pounds per trip with the commercial logbook data (accessed April 17, 2017 from SEFSC). Figure 2 displays the pounds per trip distribution for the two most recent years that had the 75 lbs gw trip limit (2013 and 2014). Following the assumption that trips that did not meet the trip limit will now meet the trip limit the logbook landings were modified. For example, trips that harvested red snapper and had less than 60 pounds per trip were modified to meet the 75 lbs gw trip limit. Trips of 60 lbs gw or more were assumed to have been close to meeting the current trip limit and were not modified. This modification leads to an increase in landings of 34%. This percentage was applied to the predicted landings describer earlier to provide a "high landings" estimate. Table 2 provides the predicted closure dates for the proposed

ACL alternatives for Amendment 43 for both landings predictions. If the ACL is not met and there is no closure then the predicted commercial landings expected from July 9 to December 31 are 118,950 pounds whole weight (lbs ww) and the predicted high landings for the same time period are expected to be 159,393 lbs ww.

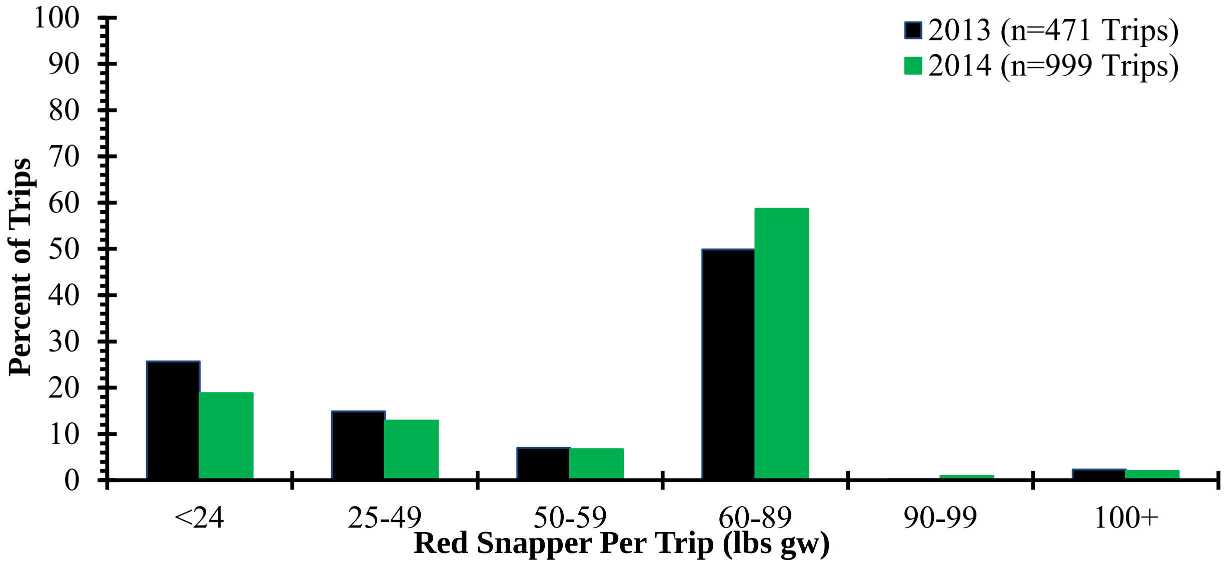

Figure 2. Distribution of the South Atlantic red snapper harvested per trip (lbs gw) in 2013 and 2014. Data comes from the commercial logbook dataset.

Table 2. South Atlantic predicted closure dates for the commercial sector for the different proposed ACL alternatives in Amendment 43. These closure dates assume the commercial sector start on the second Monday in July of 2018 (July 9, 2018). The "Predicted Landings" are a prediction of future landings, and the "High Landings" are the prediction of future landings with a 34% increase in landings following the assumption that more fishermen will meet the trip limit of 75 lbs gw due to an increased stock size. Alternative 1 states to be determined (TBT) because it's dependent on the total removals of 2017 which are not available at this time.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
ACL	TBT	69,360 lbs ww	130,396 lbs ww	124,815 lbs ww	234,652 lbs ww
Predicted Landings	TBT	17-Sep	No Closure	No Closure	No Closure
High Landings	TBT	23-Aug	26-Nov	21-Oct	No Closure

As with most projections, the reliability of the results is dependent upon the accuracy of the underlying data and input assumptions. This analysis attempted to create a baseline as a foundation for comparisons, under the assumption that projected past landings will accurately reflect actual future landings. Uncertainty exists in this projection, as economic conditions, weather events, changes in catch-per-unit effort, fisher response to management regulations, and a variety of other factors may cause departures from this assumption.

References

Red Snapper Rule. 2012. Measures to allow limited harvest of red snapper (*Lutjanus campechanus*) in the South Atlantic in 2012. Temporary measures through emergency action. 92 pages.

SEDAR 41. 2017. Stock assessment of red snapper off the Southeastern United States. Southeast Data, Assessment and Review. North Charleston, South Carolina. http://www.sefsc.noaa.gov/sedar/.

Appendix O. Recreational Sector Projected Seasons

Predicting Closure Dates for Amendment 43 Proposed Annual Catch Limits for the South Atlantic Red Snapper Recreational Sector

LAPP/DM Branch
NOAA Fisheries Service
Southeast Regional Office

In 2016, a stock assessment was conducted for the South Atlantic red snapper (SEDAR 41). Results from the assessment showed the red snapper stock is overfished and experiencing overfishing. Amendment 43 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region is currently being drafted and its purpose is to establish new Annual Catch Limits (ACL) that will rebuild the stock.
The recreational season for South Atlantic red snapper was closed in 2010 and 2011, then had a very short season in 2012, 2013, and 2014. The season varied each year and included two weekends (6 days) during September 2012, one weekend (3 days) in August 2013, and three weekends (8 days, with the third weekend only open on Friday and Saturday) during July 2014. Due to a short season and limitations of Marine Recreational Fisheries Statistics Survey (MRFSS) the South Atlantic states (North Carolina, South Carolina, Georgia, east Florida) conducted their own state specific red snapper surveys during the short red snapper recreational seasons in 2012, 2013, and 2014. A red snapper mini-season ad-hoc group call and webinar was held to review the MRFSS and individual state red snapper surveys to determine the best estimates to use to characterize the recreational catch. The ad-hoc group compared MRFSS against the specific state surveys for each state looking closely at estimates by wave and year. Then the ad-hoc group determined which survey best characterized the recreational catch. For example, in some years MRFSS was chosen as providing the best estimate of landings in Georgia but other years the Georgia state survey was chosen. Following the recommendations determined from the ad-hoc group the recreational red snapper landings were compiled. However, since the recent assessment (SEDAR 41) used Marine Recreational Information Program (MRIP) instead of MRFSS in any cases where the MRFSS landings were chosen as the best estimate of landings these MRFSS landings were replaced by MRIP landings. The recreational sector was closed in 2015 and 2016 and there were no state specific surveys during these years. Therefore, MRIP landings were used for 2015 and 2016 landings. Also, the Southeast Region headboat survery (SRHS) was conducted from 1972 to 2016 and was used to provide the red snapper landings from the headboat mode. Table 1 reveals which recreational survey was chosen by the ad-hoc group to estimate the recreational landings for each state by mode and year. Table 2 summarizes the South Atlantic red snapper recreational landings in numbers of fish by wave.

Table 1. The recreational survey that was chosen by the ad-hoc group to estimate the recreational landings for each state by mode and year.

Year	State	Charter	Private	Headboat
2012	NC	MRIP	No Landings	SRHS
	SC	SC Survey	No Landings	SRHS

	GA	MRIP	MRIP	SRHS
	FL	FL Survey	FL Survey	SRHS
2013	NC	No Landings	No Landings	SRHS
	SC	SC Survey	No Landings	SRHS
	GA	GA Survey	GA Survey	SRHS
	FL	FL Survey	FL Survey	SRHS
2014	NC	MRIP	NC Survey	SRHS
	SC	SC Survey	SC Survey	SRHS
	GA	GA Survey	MRIP	SRHS
	FL	FL Survey	FL Survey	SRHS
2015	NC	MRIP	MRIP	SRHS
	SC	MRIP	MRIP	SRHS
	GA	MRIP	MRIP	SRHS
	FL	MRIP	MRIP	SRHS
2016	NC	MRIP	MRIP	SRHS
	SC	MRIP	MRIP	SRHS
	GA	MRIP	MRIP	SRHS
	FL	MRIP	MRIP	SRHS

Table 2. South Atlantic red snapper recreational landings in numbers of fish by wave from 2012 to 2016.

	Jan/Feb	Mar/Apr	May/June	Jul/Aug	Sep/Oct	Nov/Dec	Total
2012	1	478	353	79	14,080	0	14,991
2013	0	2	403	2,050	4,160	14	6,629
2014	1,151	45	722	28,798	19	334	31,069
2015	0	847	467	486	56	14	1,870
2016	0	1	188	205	3	6	403

Amendment 43 is currently being drafted and will likely be implemented in the 2018 fishing year. An estimate of future landings is required to determine if the alternative ACLs being considered will lead to a closure. Frequently future landings are predicted from taking an average of the most recent years of complete data following the assumption that recent landings will likely reflect future landings. However, the South Atlantic red snapper recreational fishery was closed in 2010, 2011, 2015 and 2016, and was only open for short periods of time 2012 (6 days), 2013 (3 days), and 2014 (8 days). The short opening in 2012, 2013, and 2014 occurred over different months; therefore, landings from different months and years were combined to predict future landings. Recreational landings for South Atlantic red snapper came from the annual total removals reports provided by the Southeast Fisheries Science Center's (SEFSC) and then when MRFSS landings were used they were replaced with MRIP landings. MRIP landings were provided by the SEFSC on June 7, 2017. The recreational fishery will open on the second Friday of July and, if the ACL is not exceeded, close on December 31. Future landings were only predicted for July through September because the recreational ACLs proposed in Amendment 43 are relatively low and all of the proposed ACLs will likely be exceeded before the end of September. Future landings were determined by calculating the daily catch rate for a month and then applying the catch rate to the number of weekend days in that month (Friday, Saturday, and Sunday). Predicted landings for each month assumed a uniform distribution within a month, and were partitioned into a daily catch rate by dividing the landings for a month by the number of days in that month. The daily catch rates were projected forward and a closure date was determined when the landings exceeded the various ACLs proposed in Amendment 43. The projections start on July 13 because this is the second Friday of July in 2018, therefore landings were assumed to be zero before July 13. Additionally, the recreational season will only be open on Friday, Saturday, and Sunday. Therefore, landings were only predicted for each Friday, Saturday, and Sunday after July 13, 2018 and landings from Monday to Thursday were assumed to be zero.

- July 2014 was the most recent year when the recreational sector was open in July, and the recreational sector was open for 8 days. The July daily catch rate was applied to the open weekend days in July to match a potential opening in 2018.
- August 2013 was the most recent year when the recreational sector was open in August, and the recreational sector was open for 3 days. The August daily catch rate was applied to the open weekend days in August to match a potential opening in 2018.
- September 2012 was the most recent year when the recreational sector was open in September, and the recreational sector was open for 6 days. The September daily catch rate was applied to the open weekend days in September to match a potential opening in 2018.

Table 1. Details of the recreational landings used to determine the predicted future recreational landings for red snapper.

Month	Most Recent Year	Days open	Method
July	2014	8 days	Determined July 2014 average daily catch rate; applied catch rate to open days in July
August	2013	3 days	Determined August 2013 average daily catch rate; applied catch rate to open days in August
September	2012	6 days	Determined September 2012 average daily catch rate; applied catch rate to open days in September

Amendment 43 includes different alternatives to develop ACLs. Some of the alternatives are increased by an adjustment factor due to an increase in red snapper abundance based on a fish trap index of abundance. The adjustment factor is 1.88 and is based on the change in the average index of abundance from 2012 to 2014 compared to the average abundance from 2015 to 2016. Opening the fishery to an increased stock size will likely cause changes in harvest. The adjustment factor of 1.88 was applied to the landings to provide a “high landings” estimate to replicate what the future harvest will be with an increased stock size. The bag limit is restricted to one fish per person and the recreational ACL is in numbers of fish so the size of fish is irrelevant for monitoring the ACL. Therefore, the “high landings” assumes more recreational trips will harvest red snapper because of the increase in red snapper abundance. Table 2 provides the predicted closure dates and predicted number of open days for the proposed ACL alternatives for Amendment 43 for both landings predictions.

Table 2. South Atlantic predicted closure dates and predicted number of open days for the recreational sector for the different proposed ACL alternatives in Amendment 43. The predicted number of open days is provided in parenthesize after the closure dates. These closure dates assume the recreational sector start on the second Friday in July of 2018 (July 13, 2018). The “Predicted Landings” are a prediction of future landings, and the “High Landings” are the prediction of future landings with a 1.88 adjustment factor following the assumption of a larger stock size. Alternative 1 is stated as to be determined (TBT) because it’s dependent on the total removals of 2017 which are not available at this time.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
ACL	TBD	16,480 Fish	30,982 Fish	29,656 Fish	55,753 Fish
Predicted Landings	TBD	21-Jul (4)	28-Jul (7)	28-Jul (7)	15-Sep (28)
High Landings	TBD	15-Jul (2)	21-Jul (4)	21-Jul (4)	29-Jul (8)

As with most projections, the reliability of the results is dependent upon the accuracy of the underlying data and input assumptions. This analysis attempted to create a baseline as a foundation for comparisons, under the assumption that projected past landings will accurately reflect actual future landings. Uncertainty exists in this projection, as economic conditions, weather events, changes in catch-per-unit effort, fisher response to management regulations, and a variety of other factors may cause departures from this assumption.

References

SEDAR 41. 2017. Stock assessment of red snapper off the Southeastern United States. Southeast Data, Assessment and Review. North Charleston, South Carolina. http://www.sefsc.noaa.gov/sedar/.

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21 April, 2017

TO: Gregg Waugh, Executive Director, SAFMC
Michelle Duval, Ph.D., Chair, SAFMC

FROM: Bonnie J. Ponwith, Ph.D.,
Science and Research Director

SUBJECT: Red Snapper Guidance Request

The SEFSC concurs with the SEDAR Review Panel and SAFMC SSC's approval of SEDAR 41, the red snapper stock assessment. The SSC developed ABC recommendations based on the projection analysis that allowed the stock to reach a rebuilt status in the time allowed by the rebuilding plan (by 2044). The use of an ABC based primarily on fishery discards for monitoring the effectiveness of management action is likely ineffective due to the high level of uncertainty in measures of discards and the change in the effort estimation methodology that will be implemented in the MRIP survey.

Monitoring progress toward rebuilding will require a departure from the traditional techniques. SEFSC analysts are exploring an Index Projection Methodology as an alternative approach for monitoring stock response to management measures. They plan to discuss this with the SSC at their upcoming meeting to get input on the method. They will also discuss how these results may be used by the SSC to generate future catch level advice, given updated projections have not been provided. Information for the SSC regarding this is attached.

At the last SAFMC meeting we discussed holding a workshop to discuss ways to characterize the uncertainty of MRIP estimates (landings, discards) to provide guidance on: 1) at what point the uncertainty is sufficiently high to warrant alternative methods for accounting for catch; 2) what those alternative methods might be; 3) means to improve the precision of MRIP catch estimates; and 3) means to augment MRIP sampling to improve data quality. The SAFMC recognized this is a region-wide issue so a presentation was made to the GMFMC to request involvement of their SSC, and the GMFMC has agreed to participate. It has also been suggested that representation from the Mid-Atlantic Fishery Management Council may be advisable. We'll begin to stand up a steering committee to refine the workshop objectives, define the deliverables and begin work on the agenda. One deliverable from the workshop could evaluate the precision of red snapper discard estimates to help advise on their use for monitoring stock status when discards are the predominant contributor to fishing mortality. The target timeline for the workshop is this fall, however, we'll have more clarity on the timeline for delivery of advice to the SSC once the steering committee is stood up and begins their work on workshop planning.

Attachment

cc: Roy Crabtree, Jack McGovern, and Rick DeVictor
Monica Smit-Brunello
John Carmichael, Kari MacLauchlin, and Chip Collier
Theo Brainerd and Trika Gerard

SSC Input for April 2017 Meeting

The SAFMC SSC reviewed and approved the SEDAR 41 Red Snapper stock assessment in May 2016. The SSC developed ABC recommendations based on the projection analysis that allowed the stock to reach a rebuilt status in the time allowed by the rebuilding plan (by 2044). In our memo of February 15, 2017, the SEFSC indicated reasons why any further proposed projections would not be appropriate for management. These reasons revolve around the uncertainty and methodology changes for future estimates of discards from the MRIP survey. Non-traditional methods and data sources may need to be used to monitor management action effectiveness and progress toward rebuilding.

The SEFSC proposes creating and an Index Projection Methodology that uses trends in the fishery-independent survey to monitor rebuilding progress and serve as the basis for the SSC's future ABC advice to the Council.

The SEFSC would like to get feedback from the SSC on this proposed approach. Specifically:

1. The SEFSC is actively working on research into using SERFS video data to monitor future effectiveness of management actions, i.e. progress toward rebuilding. We ask the SSC to provide input on this proposed approach and its potential utility for determining management action effectiveness.
2. Discuss options for the appropriate baseline against which to compare the Index Projection.
3. Discuss how the index may be used by the SSC to develop ABC advice.

Dr. Erik Williams will be preparing a brief summary of the proposed approach and will be on hand to answer any questions the SSC may have at their next meeting.

We appreciate the SSC taking time to provide input on new methodology that has the potential to benefit management.

SOUTH ATLANTIC FISHERY MANAGEMENT COUNCIL

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Dr. Michelle Duval, Chair | Charlie Phillips, Vice Chair
Gregg T. Waugh, Executive Director

April 3, 2017

TO: Bonnie Ponwith

FROM: Gregg Waugh & Michelle Duval

SUBJECT: Red Snapper Guidance Request

At its March 2017 meeting, the South Atlantic Council requested that its SSC and the SEFSC work together to obtain an ABC for Red Snapper. This request was in response to two letters from NMFS addressing the status of Red Snapper. The first letter, from the SEFSC dated February 15, 2017 (**attached**), indicated that projections the Council requested in January 2017 could not be completed due to uncertainty in the assessment and the MRIP discard estimates. This letter also indicated that a complete evaluation of MRIP changes on the Red Snapper assessment (SEDAR 41) is necessary before it can be useful to management. The second letter, from SERO dated March 3, 2017 (**attached**), noted the SSC's concerns with uncertainty in the SEDAR 41 assessment and the resulting inability to reliably determine the degree of overfishing. In addition, NMFS noted that the assessment indicated overfishing was occurring during its terminal year of 2014 but the Council's actions to limit harvest since 2010, including harvest prohibitions in effect since 2015, have addressed overfishing and allowed the stock to continue rebuilding.

The SSC reviewed the SEDAR 41 Red Snapper assessment in May 2016 and considered it Best Scientific Information Available. However, because the Council has been informed in the past that SSC conclusions on BSIA are in fact recommendations, and that NMFS is actually responsible for the BSIA determinations, the Council requests the following:

1. The SEFSC concur with our determination that alternative methods are necessary to specify ABC and MSY for red snapper and that SEDAR 41 (original and revised) cannot be used to specify ABC or MSY for 2017 and beyond for the reasons outlined in your memo to Michelle Duval dated February 15, 2017. This is necessary to inform the SSC on the status of its existing ABC recommendation and to determine which sources of information used in the SEDAR 41 assessment can be considered for future ABC recommendations.

2. The SEFSC provide an evaluation of data limited techniques that can be considered by the SSC to develop an index-based ABC.

3. The SEFSC provide additional details on the proposed evaluation of the effect of MRIP changes on the Red Snapper assessment, particularly the types of evaluations to be considered and when they will be available for SSC review.

Given that the SEFSC will be providing the SSC a revised SEDAR 41 Red Snapper assessment to correct errors with some of the headboat input data, it is critical that a response to these issues also be provided to the SSC. This will help inform the SSC on how to view the revised assessment.

Please provide this information needs to Council staff by noon on April 10, 2017 to be distributed to the SSC for review at their April 25-27, 2017 meeting. This is a complex matter and the SSC needs adequate time to review the revised assessment and responses prior to their meeting.

Please contact John Carmichael to address any questions concerning this request.

cc: Roy Crabtree, Jack McGovern, and Rick DeVictor
Monica Smit-Brunello
John Carmichael, Kari MacLauchlin, and Chip Collier
Theo Brainerd and Trika Gerard

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
75 Virginia Beach Drive
Miami, Florida 33149 U.S.A.
(305) 361-4200 Fax: (305) 361-4499

15 February, 2017

MEMORANDUM FOR: Gregg Waugh, Executive Director
South Atlantic Fishery Management Council

FROM: Bonnie J. Ponwith, Ph.D.
Science and Research Director

SUJBECT: **Red Snapper Projections**

On January 18, 2017, you sent a memo requesting, "Provide projections to 2044 (the end of the rebuilding period) based on fixed fishing mortality rates at Fmax, F20%SPR, F27%SPR, F30%SPR, and F40%SPR under the assumptions that all fish caught at each F level are subsequently discarded and the scenario mortality level is the total mortality (i.e., there are no additional discard mortalities). For each scenario, provide the full suite of projection outputs as provided for SEDAR 41 projections."

In working on those projections, Southeast Fisheries Science Center staff have advised, and I concur, that the proposed projections are not appropriate for management use for the following reasons:

- The uncertainty in the assessment is already large, and will increase due to the MRIP discard data, especially for the interim period (2015-16), the upcoming changes to MRIP from the new effort survey. For some background: the uncertainty in projections is generally high after 3-5 years, and these projections would have 2-3 years of an interim period (depending on whether 2017 or 2018 was the effective year of regulations).
- The SAFMC SSC has indicated that overfishing for this stock is occurring, but cannot quantify by how much. Fishing mortality rates in the last few years of the assessment are very sensitive to 2014 data and retrospective analyses indicate fishing mortality rates are considerably lower if these data are excluded. This uncertainty in the stock assessment inhibits the ability to set an ABC that can be effectively monitored.
- Fishing mortality in the interim period is calculated using actual landings and discards in 2015, though the status was determined using fishing mortality when there was a fishery occurring during mini-seasons (2012-2014). There were no fishing seasons for red snapper in 2015 or 2016 and final 2016 MRIP data are not yet available.
- The MRIP telephone survey will end this year and be replaced by a new mail-based effort survey. The new effort survey will be calibrated with the old telephone survey and undergo peer-review this summer. Preliminary results from the calibration study will be available in late-2017 and final results incorporating all three years of side-by-

side surveys will be available in 2018. Projections timed to benefit from the completed calibration study would be stronger than if based on the preliminary results.

- We feel that a more complete evaluation of the effect of the upcoming changes to MRIP on the Red Snapper assessment is needed before it can be useful to management.
    - We further recommend a thorough investigation, possibly through a workshop, into the reliability and utility of mail survey based MRIP estimates of catch and discards for many of our offshore species, which are known to have low intercept rates relative to other species covered by MRIP.

cc: Roy Crabtree
Andy Strelcheck
Jack McGovern
Theo Brainerd
Trika Gerard
Erik Williams

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
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263 13th Avenue South
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F/SER25:FH

Dr. Michelle Duval, Chair
South Atlantic Fishery Management Council
4055 Faber Place Drive, Suite 201
North Charleston, South Carolina 29405

MAR 03 2017

Dear Dr. Duval:

The most recent South Atlantic red snapper stock assessment (SEDAR 41) was completed in April 2016 and indicated that the stock is undergoing overfishing and is overfished, but is rebuilding. The South Atlantic Fishery Management Council's (Council) Scientific and Statistical Committee (SSC) reviewed the assessment and determined the assessment is based on the best scientific information available. However, the SSC noted there is considerable uncertainty in the exploitation status, and thus, the degree of overfishing is highly uncertain. The uncertainty in exploitation status inhibits the Council's ability to set an acceptable biological catch that can be effectively monitored. Additionally, in the February 15, 2017, response to a Council request for red snapper projections, Dr. Bonnie Ponwith, Director of the National Marine Fisheries Service (NMFS) Southeast Fisheries Science Center noted that the overfishing determination was based on fishing mortality levels during 2012-2014 when a limited amount of harvest was allowed. Landings during 2012-2014 represented a high fraction of the overall fishing mortality, but since that time, harvest has been prohibited. Dr. Ponwith also noted that the uncertainty in the assessment is large and is predicted to increase as catch and effort estimates are updated through the new Marine Recreational Information Program (MRIP) effort survey.

NMFS has determined that the latest assessment identified the South Atlantic red snapper stock as undergoing overfishing, and adequate management action has been taken to address overfishing and continue to rebuild the stock through a harvest prohibition in 2015 and 2016. Due to uncertainty in the level of overfishing associated with the assessment and the new MRIP effort survey, data poor assessment methods for the red snapper stock, such as use of fishery independent indices, may be appropriate in the future. I look forward to continuing work with the Council on Amendment 43 to the Fishery Management Plan for the Snapper-Grouper Fishery of the South Atlantic Region to reduce discards of red snapper in the South Atlantic and continue to rebuild the stock.

Sincerely,

Roy E. Crabtree, Ph.D.
Regional Administrator

cc:

F/SEC - Bonnie Ponwith
F/SER2 - Jack McGovern
F/SER25 - Rick DeVictor