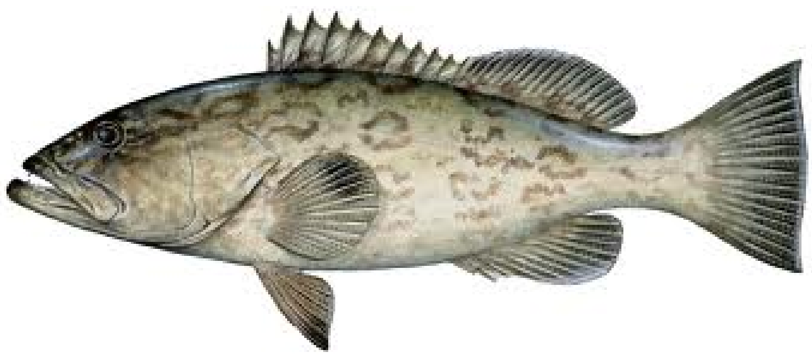
Stock Assessment of Gag off the Southeastern United States

SEDAR Update Assessment



Southeast Fisheries Science Center

National Marine Fisheries Service

Report issued: April 2014

Document History

April, 2014 Original release.

Contents

List of Tables

List of Figures

1 Executive Summary

This update assessment evaluated the stock of gag (*Mycteroperca microlepis*) off the southeastern United States[1]. The primary objectives were to update and improve the 2006 SEDAR-10 benchmark assessment of gag and to conduct new stock projections. Using data through 2004, SEDAR-10 had indicated that the stock was not overfished but was undergoing overfishing. For this assessment, data compilation and assessment methods were guided by methodology of SEDAR-10, as well as more recent SEDAR assessments. The assessment period is 1962–2012.

Available data on this stock include indices of abundance, landings, discards, and samples of annual length and age compositions from fishery dependent sources. Three indices of abundance were fitted by the model: one from the commercial handline fleet, one from the recreational headboat fleet, and one from the general recreational fleet. Data on landings and discards were available from commercial and recreational fleets. As in SEDAR-10, no fishery independent data were used in the assessment.

The primary model in SEDAR-10—and updated here—was the Beaufort Assessment Model (BAM), a statistical catch-age formulation. A base run of BAM was configured to provide estimates of key management quantities, such as stock and fishery status. Uncertainty in estimates from the base run was evaluated through a mixed Monte Carlo/Bootstrap (MCB) procedure. Median values from the uncertainty analysis are also provided. Stock status was evaluated by measuring the 2012 spawning biomass against the minimum stock size threshold (MSST). The current definition of MSST is $\mathrm{MSST} = (1 - M)\mathrm{SSB}_{\mathrm{MSY}}$, however the SAFMC is now considering in Regulatory Amendment 21 a revised definition of $\mathrm{MSST} = 75\%\mathrm{SSB}_{\mathrm{MSY}}$. In this report, both definitions are considered. Where only one is presented, the default is the current definition. The current MSST is the higher threshold, and thus if the stock is found to be not overfished by the current definition, the same would hold true of the revised definition.

Results suggest that spawning stock declined until the mid-1980s and has since been relatively stable, fluctuating around MSST, with an upturn in the last several years. The terminal (2012) base-run estimate of spawning stock is near $\mathrm{SSB}_{\mathrm{MSY}}$ ($\mathrm{SSB}_{2012}/\mathrm{SSB}_{\mathrm{MSY}}$ =0.97), as is the median estimate ($\mathrm{SSB}_{2012}/\mathrm{SSB}_{\mathrm{MSY}}$ =1.04), and this level is above the MSST (base: $\mathrm{SSB}_{2012}/\mathrm{MSST}$ =1.13; median: $\mathrm{SSB}_{2012}/\mathrm{MSST}$ =1.21). Projections suggest that spawning biomass will decline in the years immediately after 2012, primarily because of poor recruitment in 2010 and 2011. The estimated fishing rate has exceeded the MFMT (represented by F_{MSY}) for most of the last three decades, but has been decreasing in the last several years with the 2012 estimate below the MFMT. The current estimate of fishing rate, which is based on a three-year geometric mean, is above F_{MSY} in the case of the base run ($F_{2010-2012}/F_{\mathrm{MSY}} = 1.23$) and the median ($F_{2010-2012}/F_{\mathrm{MSY}} = 1.37$). Thus, this assessment finds that the stock is experiencing overfishing, but is not overfished.

The MCB analysis indicates that these estimates of stock and fishery status are robust, but also reveals some quantitative uncertainty in the results. Of all MCB runs, 97.5% are in qualitative agreement that the stock is not overfished ($\mathrm{SSB}_{2102}/\mathrm{MSST} > 1.0$), and 92.5% that the stock is experiencing overfishing ($F_{2010-2012}/F_{\mathrm{MSY}} > 1.0$).

The estimated trends and terminal status indicators of this SEDAR-10-Update assessment are similar to those from the SEDAR-10 benchmark. However, the two assessments did show some differences in results, which was not surprising given several modifications made to both the data and model (described throughout the report). Of those modifications, the initialization procedure and weighting of data components were likely the primary drivers of any differences in results. Compared to SEDAR-10, this assessment suggests lower values of $\mathrm{SSB}_{\mathrm{MSY}}$ and MSY, and a higher value of F_{MSY}.

[1]Abbreviations and acronyms used in this report are defined in Appendix A

2 Data Review and Update

In the SEDAR-10 benchmark, the assessment period was 1962–2004. In this update, the terminal year was extended to 2012. For some data sources, the data were simply updated with the additional eight years. However, for other sources, data prior to 2004 were updated as well using current methodologies. The input data for this assessment are summarized in Tables 1–7. and are described below, with focus on the data that required modification from SEDAR-10.

2.1 Data Review

In this update assessment, the Beaufort Assessment Model (BAM) was fitted to the same data sources as in SEDAR-10.

- Landings: commercial handline, commercial diving, headboat, and general recreational
- Discards: commercial handline, headboat, and general recreational
- Indices of abundance: commercial handline, headboat, and general recreational
- Length compositions of landings: commercial handline, commercial diving, and combined headboat and general recreational
- Age compositions of landings: commercial handline, commercial diving, and combined headboat and general recreational

2.2 Data Update

2.2.1 Life history

Life-history characteristics that were treated as input in SEDAR-10 remained the same in this assessment, including natural mortality at age, female maturity at age, and male maturity at age (all males assumed mature). The proportion female at age varied across time blocks, requiring new inputs for the additional years (2005–2012). Age-dependent natural mortality was based on Lorenzen (1996), scaled to an age-independent point estimate of $M = 0.14$. In SEDAR-10, the von Bertalanffy growth parameters were estimated within the assessment model, and that approach was repeated here: ($\widehat{L_\infty} = 905$ mm, $\widehat{K} = 0.354\ \mathrm{yr}^{-1}$, and $\widehat{t_0} = -0.395$ yr).

Other related inputs that remained the same as in SEDAR-10 were the length-weight relationship, the gutted weight to whole weight conversion (WW=1.059GW), and the release mortality rates. Release mortality rates were 0.4 for the commercial handline fleet, and 0.25 for the headboat and general recreational fleets.

Life-history information is summarized in Tables 1 and 2.

2.2.2 Commercial landings and discards

Estimates of commercial landings were developed for 1962-2012 using current methods as they were applied in SEDAR-36 (SEDAR36-WP11 2013). The two dominant commercial fleets for gag, handline and diving, were modeled in the assessment. Any landings from other commercial gears (e.g., longline or trawl) were combined with landings of the handline fleet; those other gears were relatively small contributors, typically much less than 1% of the total. Estimates of commercial diving landings were zero prior to 1976. Estimates of commercial handline discards were revised for their full time period 1999–2012. Commercial landings were supplied by the data providers (and therefore modeled) in units of 1000 lb gutted weight, and discards in units of 1000 fish (Table 3).

2.2.3 **Recreational landings and discards**

The landings and discards from the general recreational fleet were estimated from the Marine Recreational Information Program, MRIP (SEDAR-10 used estimates from MRIP's predecessor, the Marine Recreational Fisheries Statistics Survey, MRFSS). Direct estimates from MRIP were available for 2004–2012, and MRFSS estimates for 1981–2003 were converted for consistency with MRIP (SEDAR31-DW25 2012; SEDAR32-DW2 2013). In a few early years with estimated discards of zero, the arithmetic mean of positive discards (1981–1991) by mode (charter, private, or shore) was used to replace zero estimates.

The headboat landings were estimated from the South Atlantic Headboat Survey (SRHS) for 1972–2012. Information on live discards was added to the SRHS reported catch records in 2004, and thus these estimates were used for 2004–2012. For 1981–2003, the MRIP charter boat mode was used to derive headboat discards, by applying mean ratios of estimated released fish (b2) to estimated retained fish (a+b1) fish. The mean ratios were computed by primary regulation time periods (Table 4), and then applied to the headboat landings.

Recreational estimates prior to sampling programs were hind-casted in SEDAR-10 and were not revised for this update. Recreational landings and discards were fitted in units of 1000 fish, as these data are primarily recorded in numbers (Table 3).

2.2.4 **Indices of abundance**

The commercial and headboat indices of abundance were reevaluated with updated data, using computations similar to those in SEDAR-10. Because annual values of these indices are model-based (i.e., from delta-GLMs), years prior to 2004 were updated as well as any additional years. The general recreational index could not be reevaluated by data providers prior to the data deadline because of limitations in human resources. This index had very high annual CVs and was not considered critical in SEDAR-10.

Commercial handline index
For the commercial handline index, the Stephens and MacCall method (Stephens and MacCall 2004) for including trips (i.e., defining effective effort for gag) was modified to exclude species with prolonged management closures (red porgy and red snapper). The starting year for this index was changed from 1992 to 1993, because of changes in sampling procedures (more complete starting in 1993) and for consistency with more recent SEDAR assessments. The factor for region was aggregated over the latitude-level used in SEDAR-10 to three levels (North Carolina, South Carolina, and Georgia-North Florida). This change was made to accommodate smaller samples sizes associated with the spawning season closure.

Because this is a fishery dependent index, management measures must be considered because they can potentially hinder the ability of an index to track abundance. Since the benchmark assessment, several new management measures have been implemented. A commercial trip limit of 1000 lb gutted weighted was implemented in July of 2011. This trip limit was shown to be met infrequently and likely had little influence on the commercial index. Starting in 2010, commercial closures for gag were implemented during January–April for the spawning season, and in October 2012, for reaching the quota. Several options were explored for including or excluding data from the years and months affected by the closures. With the primary goal to include as many years as possible, and the secondary goal as many months, the index was extended through 2011 and includes May–December. The data were fit better using a lognormal distribution than a gamma distribution, and the uncertainty in the estimates were calculated from 1000 bootstrap iterations.

Headboat index
For the headboat index, the Stephens and MacCall method (Stephens and MacCall 2004) was applied after excluding species with prolonged management closures (red porgy and red snapper). In assessments since SEDAR-10, the Stephens

and MacCall method has been applied separately to two geographic areas split at Cape Canaveral, to account for regional differences in species assemblages (Shertzer et al. 2009).

As with the commercial index, the headboat index was also evaluated in light of new management measures since SEDAR-10. In July of 2009, a 3-fish aggregate bag limit was implemented, but was ignored here because headboat data showed the limit to be met only rarely. The months January-April were excluded from all years in the analysis, because of the shallow-water grouper spawning closure that started in 2010. The headboat index was extended to the terminal assessment year 2012.

The three indices used in this assessment are tabulated in Table 5 and plotted in Figure 1.

2.2.5 **Length and age compositions**

The SEDAR-10 data workshop developed commercial length compositions for handline, longline, trawl, and diving gear. The contribution of each length was weighted by the landings in number associated by state and year. The minimal longline and trawl compositions were combined with handline using sample size as a weighting factor.

This update assessment used a slightly modified approach. For each gear, state-specific length compositions were developed and then multiplied by the relative contribution of that state's landings to the total commercial landings. The weighting unit was in pounds instead of numbers to eliminate the need to convert using mean weights and to maintain the unit in which the data were collected. The 2010 spawning closure eliminated collections of lengths from all areas for January–April, and no adjustments could be made to account for this lack of length data. The nominal age compositions from commercial handlines were then weighted by the corresponding length compositions. Nominal age compositions from commercial diving were not weighted, because of relatively small sample sizes.

The headboat and MRIP length compositions were computed similarly to commercial handline with the exception of weighting by state-specific relative contribution by number instead of weight. Both length compositions were then combined (weighted by sample size) to form a general recreational length composition. The nominal recreational age composition was then weighted by this combined recreational length composition.

For inclusion in the update assessment, the SEDAR-10 sample size thresholds were applied to the composition data. Age compositions required a sample of $n \geq 47$ fish, and length compositions required $n \geq 100$ fish. New to this assessment were the number of trips from which fish were sampled. Unlike in SEDAR-10 but common practice now, the number of trips was used to represent the effective sample size when fitting the assessment model. The annual sample sizes of fish and trips by fleet are shown in Tables 6 and 7.

3 Stock Assessment Methods

This assessment updates the primary model applied during SEDAR-10 to South Atlantic gag. The methods are reviewed below, and modifications since SEDAR-10 are indicated.

3.1 Overview

The primary model in this assessment was the Beaufort Assessment Model (BAM), which applies a statistical catch-age formulation. The model was implemented with the AD Model Builder software (Fournier et al. 2012). In essence, the model simulates a population forward in time while including fishing processes (Quinn and Deriso 1999; Shertzer et al. 2008*a*). Parameters 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, greater amberjack, red grouper, snowy grouper, vermilion snapper, and red snapper, as well as in the previous SEDAR assessment of gag (SEDAR 2006).

3.2 Data Sources

The catch-age model included data from four fleets that caught gag in southeastern U.S. waters: commercial handlines (hook-and-line), commercial diving, recreational headboats, and general recreational. The model was fitted to data on annual landings (in gutted weight for commercial fleets, in numbers for recreational fleets); annual dead discards (in numbers) from all fleets but diving; annual length compositions of landings; annual age compositions of landings; and three fishery dependent indices of abundance (commercial handlines, headboat, and general recreational). As in SEDAR-10, discard mortality rates (proportions) of 0.4 for commercial handlines and 0.25 for recreational fleets were applied to the total discards. Ages used in composition data were $1-12^{+}$, a modification from SEDAR-10, which used ages $0-20^{+}$. The reason for this modification was that very few fish were observed at age 0 or older than age 12, and too many zeros in multinomial likelihoods can be problematic. Data used in the model are described further in §2 of this report.

3.3 Model Configuration and Equations

The assessment time period was 1962–2012. A general description of the assessment model follows.

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 $1-16^{+}$, where the oldest age class 16^{+} allowed for the accumulation of fish (i.e., plus group).

Initialization Initial (1962) abundance at age was computed in the model as the equilibrium age structure for ages 1–16. This equilibrium was based on natural and fishing mortality (F_{init}), where F_{init} was assumed $F_{\text{init}} = 0.03$ to be small given the relatively low volume of landings near the start of the assessment period. In addition, this value of F_{init} equals the SEDAR-10 estimate of full F in 1962. Sensitivity runs and uncertainty analyses considered other values of F_{init}. Deviations around that equilibrium age structure were not estimated, because information on age structure, as provided by composition data, did not become available until later in the assessment period. The first year of length composition data was 1972, and the first year of age composition data was 1978.

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 Lorenzen (1996). The Lorenzen (1996) approach inversely relates the natural mortality at age to mean weight at age W_a by the power function $\mathrm{M}_a{=}\alpha W_a^{\beta}$, where α is a scale parameter and β is a shape parameter. Lorenzen (1996) provided point estimates of $\hat{\alpha} = 3.69$ and $\hat{\beta} = -0.305$ for oceanic fishes, which were used for this assessment. As in SEDAR-10, the age-dependent estimates of M_a were rescaled to provide the same fraction of fish surviving from age 0 through the oldest observed age (30 yr) as would occur with constant $M = 0.14$. This approach using cumulative mortality allows that fraction at the oldest age to be consistent with the findings of Hoenig (1983) and Hewitt and Hoenig (2005). Sensitivity runs and uncertainty analyses considered other values of natural mortality.

Growth Mean total length (TL, in units of mm) at age of the population was modeled with the von Bertalanffy equation, and weight at age (whole weight, WW) was modeled as a function of total length (Table 1, Figure 2). The von Bertalanffy parameter estimates (base model) were $\widehat{L_\infty} = 905$ mm, $\widehat{K} = 0.354$ yr^{-1}, and $\widehat{t_0} = -0.395$ yr, and the CV of length at age was $\widehat{\mathrm{CV}} = 11\%$. These values were estimated within the assessment model, using normal prior distributions with means provided by the SEDAR-10 DW and CVs of 25%. The single CV of size at age was a modification from SEDAR-10, which estimated a CV for each age. The use of a single CV is more parsimonious, is more in line with current SEDAR assessments, and avoids the potential for unrealistic reductions in maximum size as fish age.

Conversions (TL-WW, WW-GW) were estimated external to the assessment model and were treated as input. Landings were converted to gutted weight using the conversion GW=WW/1.059.

Maturity and sex ratio Maturity at age of females was modeled as an increasing logistic function. The age at 50% female maturity was estimated to be just over 3 years. All males were considered mature.

Gag is a protogynous hermaphrodite. The proportion male at age was modeled with a Gompertz function and varied across years. Observations were not available in all years, but in blocks of years, including the early 1980s (extended back to 1962), 1994–1995, 2004–2005, and 2006–2012. Linear interpolation was applied between blocks. Estimates of transition were not modified from SEDAR-10, although values for the update's additional years were provided by SCDNR scientists. In the most recent time block, the age at 50% transition is near 8 years, younger than for any other block of observations.

Spawning stock Spawning biomass was modeled as total mature biomass (mt; males and females). As in SEDAR-10, spawning biomass was computed each year from number at age at the start of each year.

Recruitment Expected recruitment of age-1 fish was predicted from spawning stock using the Beverton–Holt spawner-recruit model. Annual variation in recruitment was assumed to occur with lognormal deviations starting in 1972, when composition data could provide information on year-class strength. Prior to 1972, recruitment was assumed to follow the spawner-recruit curve precisely. This approach is a modification from the benchmark assessment, which did attempt to estimate recruitment deviations prior to 1972; however, the benchmark acknowledged that those early recruitment deviations were not reliable, and it used only the deviations in 1972 and beyond for estimating the spawner-recruit curve from which benchmarks were derived. This update is consistent with that approach.

For modeling recruitment, this update assessment implemented one notable change to the SEDAR-10 model. The previous assessment attempted to estimate the steepness parameter of the spawner-recruit model, but the estimate was at the upper bound, indicating that steepness could not be estimated reliably (Conn et al. 2010). In this assessment, steepness remained non-estimable, but was fixed at $h = 0.84$, consistent with meta-analysis conducted since SEDAR-10 (Shertzer and Conn 2012). Sensitivity runs and uncertainty analyses considered other values of steepness.

Landings Time series of landings from four fleets were modeled: commercial handline (1962–2012), commercial diving (1976–2012), recreational headboat (1962–2012), and general recreational (1962–2012). Removals 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 gutted weight for commercial fleets, and 1000 fish for recreational).

Discards Commercial handline discard mortalities were modeled starting in 1999, and headboat and general recreational discard mortalities starting in 1981. 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 (described below) and release mortality rates. Headboat and recreational release mortality rates were both 0.25, and the commercial release mortality rate was 0.4. Sensitivity runs (described below) considered other values of discard mortality, based on Sauls (2014).

Fishing For each time series of removals, 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. In SEDAR-10, the across-fleet annual F was represented by the sum of fleet-specific full Fs. In this assessment, the across-fleet annual F was represented by apical F, computed as the maximum of F at age summed across fleets. The two approaches may differ under the presence of dome-shaped selectivities that peak at different ages. The change in approach was adopted in response to comments made by the SEDAR-17 review panel, and has been used in the BAM since.

Selectivities Selectivities were estimated using either a two-parameter logistic model (flat-topped) or a four-parameter logistic-exponential model (dome-shaped, described below). This parametric approach reduces the number of estimated parameters and imposes theoretical structure on the estimates. Critical to estimating selectivity parameters are age and size composition data.

In SEDAR-10, dome-shaped selectivities were estimated using a double logistic model. More recent assessments have found parameters of that model to lack identifiability, likely because it typically requires re-scaling to peak at one. Thus in this assessment, dome-shaped selectivity was modeled by 1) estimating logistic selectivity for ages prior to full selection (two estimated parameters, $\widehat{\eta}$ and $\widehat{\alpha}_{50}$), 2) assuming the age at full selection (fixed parameter, a_f), and 3) estimating the descending limb using a negative exponential model (one estimated parameter, $\widehat{\sigma}$):

$$\text{selex}_a = \begin{cases} \frac{1}{1+\exp[-\widehat{\eta}(a-\widehat{\alpha}_{50})]} & : \; a < a_f \\ 1.0 & : \; a = a_f \\ \exp\left(-\left(\frac{(a-a_f)}{\widehat{\sigma}}\right)^2\right) & : \; a > a_f \end{cases} \tag{1}$$

The commercial diving fleet was assumed to have dome-shaped selectivity, which was considered time-invariant. The age at full selection was fixed at $a_f = 6$, the value most consistent with the data (as indicated by likelihood values of model runs using various values of a_f). For consistency with age composition data, which used age 12 as the plus group, selectivity of ages 13^+ was assumed equal to that of age 12.

Consistent with SEDAR-10, the commercial handline and recreational selectivities were assumed to have flat-topped selectivities. The two recreational fleets, headboat and general, shared the same selectivity. The flat-topped selectivities were blocked into three time periods to reflect changes in regulations: 1962–1991 (no size limit), 1992–1998 (20-inch limit), and 1999–2012 (24-inch limit).

As in SEDAR-10, discard selectivities could not be freely estimated, because no relevant composition data exist to inform the estimation. Instead, the discard selectivities were computed as the difference between the estimated curve for landings and the same curve shifted two years younger. Because the landings selectivities were flat-topped, this approach imposes dome-shaped discard selectivity that peaks at an age younger than full selection of the landings.

The current configuration of BAM allows for priors to be placed on selectivity parameters. In this assessment, normal prior distributions were applied during estimation. These priors were loose ($CV = 0.5$), used primarily to avoid search space in the optimization with potentially no curvature in the likelihood surface.

Indices of abundance The model was fitted to three fishery dependent indices of abundance: commercial handline (1993–2011), headboat (1973–2012), and general recreational (1981-2004). No fishery independent indices were used. Predicted indices were computed from numbers at age at the midpoint of the year or, in the case of commercial handline, weight at age. Selectivities of indices equaled the relevant selectivities of landings. Catchability associated with each index was assumed constant through time.

Biological reference points Biological reference points (benchmarks) were calculated based on maximum sustainable yield (MSY) estimates from the Beverton–Holt spawner-recruit model with bias correction (expected values in arithmetic space). The bias correction was not considered in SEDAR-10. Computed benchmarks included MSY, fishing mortality rate at MSY (F_{MSY}), and spawning stock at MSY ($\mathrm{SSB}_{\mathrm{MSY}}$). In this assessment, spawning stock measures total biomass (mt) of mature males and females. 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.

Fitting criterion The fitting criterion was a likelihood approach in which observed landings and discards were fit closely, and observed composition data and abundance indices were fit to the degree that they were compatible. Landings, discards, 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 ($n \geq 47$ fish for age compositions and $n \geq 100$ fish for length compositions). For multinomial likelihoods, the number of trips sampled was used as the measure of effective sample size, reflecting the belief that the basic sampling unit occurs at the level of trip. This departs from SEDAR-10, which used the number of fish sampled, but it is consistent with current and recent SEDAR assessments, as well as recommendations from review panels.

SEDAR-10 also estimated the Beverton–Holt spawner-recruit parameters external to the assessment model, using a least-squares objective function for log deviations of annual recruitment. Instead, this current assessment applied the lognormal likelihood:

$$\Lambda_{\mathrm{SR}} = n \log(\widehat{\sigma}_R) + \sum_{y \geq 1972}^{2011} \frac{[(R_y + (\widehat{\sigma}_R^2/2)]^2}{2\widehat{\sigma}_R^2} \tag{2}$$

where Λ_{SR} is the spawner-recruit likelihood component, R_y are annual recruitment deviations in log space, n is the number of years of recruitment deviations (here starting in 1972), and $\widehat{\sigma}_R$ is the estimated standard deviation. Recruitment deviations are not estimated after 2011, because the data cannot inform such estimates. Instead, predicted recruitment events after 2011 (2012 and a projection to 2013) are taken as the expected values from the estimated spawner-recruit curve (mean unbiased in arithmetic space).

The influence of each dataset on the overall model fit was determined by the specification of the error terms in each likelihood component. In the case of lognormal likelihoods, error was quantified by the inverse of the annual coefficient of variation, and for the multinomial components, by the annual sample sizes. These terms determine the influence of each year of data relative to other years of the same data source. In SEDAR-10, the relative influence of different datasets and penalty terms was also influenced by external weights (ω_i) chosen by the AW. In this assessment, these weights were applied by either adjusting CVs (lognormal components) or adjusting effective sample sizes (multinomial components). The CVs of landings and discards (in arithmetic space) were assumed equal to 0.05 to achieve a close fit to these data while allowing for 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 and discards, while avoiding having to solve the Baranov equation iteratively (which is complex with multiple fleets). 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 data providers (Table 5). Effective sample sizes of the multinomial components were assumed equal to the number of trips sampled annually (Table 7). These initial weights were then adjusted until standard deviations of normalized residuals (SDNRs) were near 1.0, following the method of Francis (2011). However, this full iterative reweighting scheme resulted in degraded fits to the indices of abundance, which Francis (2011) cautions against. Thus for the base model, indices were not reweighted; only age and length composition data were reweighted. (A sensitivity run applied the full iteratively reweighted model, which is presented for comparison, not because that weighting scheme is considered equally plausible.)

For parameters defining selectivities, von Bertalanffy growth parameters, 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 (0.15) were based on Beddington and Cooke (1983) and Mertz and Myers (1996).

Configuration of 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).

Sensitivity analyses Sensitivity runs were chosen to investigate issues that arose specifically with this 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: Low natural mortality $M = 0.1$ used to scale the age-dependent vector of Lorenzen (1996)
- S2: High natural mortality $M = 0.18$ used to scale the age-dependent vector of Lorenzen (1996)
- S3: Steepness $h = 0.74$, lower than in the base run
- S4: Steepness $h = 0.94$, higher than in the base run
- S5: $F_{\text{init}} = 0.015$, 50% lower than in the base run
- S6: $F_{\text{init}} = 0.045$, 50% higher than in the base run
- S7: Discard mortality equal to 0.15 for all fleets, near the lower bound of Sauls (2014)
- S8: Discard mortality equal to 0.35 for all fleets, near the upper bound of Sauls (2014)
- S9: Estimates deviations in initial age structure and in 1962–1971 recruitment
- S10: Data weights, including those on indices, adjusted by iterative reweighting

3.4 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, annual recruitment deviations, von Bertalanffy growth parameters, and CV of size at age.

3.5 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 computation of MSY-related benchmarks (described in §3.6), 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 (2010–2012).

3.6 Benchmark/Reference Point Methods

In this assessment of gag, the quantities F_{MSY}, $\mathrm{SSB}_{\mathrm{MSY}}$, B_{MSY}, and MSY were estimated by the method of Shepherd (1982). In that method, the point of maximum yield is identified from the spawner-recruit curve and parameters describing growth, natural mortality, maturity, and selectivity. The value of F_{MSY} is the F that maximizes equilibrium removals.

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,

$$R_{eq} = \frac{R_0 \left[\varsigma 0.8 h \Phi_F - 0.2(1-h)\right]}{(h-0.2)\Phi_F} \tag{3}$$

where R_0 is virgin recruitment, h is steepness, 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). The R_{eq} and mortality schedule imply an equilibrium age structure and an average sustainable yield (ASY). The estimate of F_{MSY} is the F giving the highest ASY, and the estimate of MSY is that ASY. The estimate of $\mathrm{SSB}_{\mathrm{MSY}}$ follows from the corresponding equilibrium age structure, as does the estimate of discard mortalities (D_{MSY}), here separated from ASY (and consequently, MSY).

Estimates of MSY 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 (2010–2012). If the selectivities or relative fishing mortalities among fleets were to change, so would the estimates of MSY and related benchmarks.

The maximum fishing mortality threshold (MFMT) is defined by the SAFMC as F_{MSY}, and the minimum stock size threshold (MSST) as (1-M)$\mathrm{SSB}_{\mathrm{MSY}}$. An alternative definition, $\mathrm{MSST} = 75\%\mathrm{SSB}_{\mathrm{MSY}}$, is currently under consideration by the SAFMC, and so it is evaluated here as well. Overfishing is defined as $F > \mathrm{MFMT}$ and overfished as $\mathrm{SSB} < \mathrm{MSST}$. Current status of the stock is represented by SSB in the latest assessment year (2012), and current status of the fishery is represented by the geometric mean of F from the latest three years (2010–2012). Although SEDAR-10 used only the terminal-year F to gauge the fishing status, more recent SEDAR assessments have considered the mean over the terminal three years to be a more robust metric.

In addition to the MSY-related benchmarks, the assessment considered proxies based on per recruit analyses (e.g., $F_{40\%}$). The values of $F_{X\%}$ are defined as those Fs corresponding to X% spawning potential ratio, i.e., spawners (population fecundity) per recruit relative to that at the unfished level. These quantities may serve as proxies for F_{MSY}, if the spawner-recruit relationship cannot be estimated reliably. Mace (1994) recommended $F_{40\%}$ as a proxy, as did Legault and Brooks (2013). Other studies have found that $F_{40\%}$ is too high of a fishing rate across many life-history strategies (Williams and Shertzer 2003; Brooks et al. 2009) and can lead to undesirably low levels of biomass and recruitment (Clark 2002).

3.7 Uncertainty and Measures of Precision

The SEDAR-10 estimated uncertainty in benchmarks through a bootstrap procedure that repeatedly refit the spawner-recruit curve. This update assessment adopted the more thorough 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), and most South Atlantic SEDAR assessments since SEDAR (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 5.6% were discarded, because the model did not properly converge. This left $n = 3775$ 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. Furthermore, the results do not account for all sources of process error, nor for uncertainty in model structure.

3.7.1 **Bootstrap of observed data**

To include uncertainty in time series of observed removals and 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 ($\hat{O}_{s,y}$),

$$O_{s,y} = \hat{O}_{s,y}[\exp(x_{s,y} - \sigma^2_{s,y}/2)] \tag{4}$$

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 removals were assumed to be 0.05, and CVs of indices of abundance were those provided by, or modified from, the data providers (tabulated in Table 5 of this assessment report).

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.

3.7.2 **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.

Natural mortality A point estimate of natural mortality ($M = 0.14$) was given by the SEDAR-10 DW, but with some uncertainty. To carry forward this source of uncertainty, Monte Carlo sampling was used to generate deviations from the point estimate. A new M value was drawn for each MCB trial from a uniform distribution [0.1, 0.18]. Each realized value of M was used to scale the age-specific Lorenzen ogive, as in the base run.

Spawner-recruit parameters In initial trials of the assessment model, steepness approached its upper bound if freely estimated. This was more likely a result of poor estimation than an indication that steepness is near 1.0 (Conn et al. 2010). Consequently, steepness was fixed in the MCB analysis, drawn from a truncated beta distribution [0.32, 0.99], with parameters estimated by (Shertzer and Conn 2012). The lower bound (0.32) was the smallest observed value of steepness in the data analyzed by Shertzer and Conn (2012).

Initialization The initial abundance at age (in 1962) was estimated as the equilibrium age structure. That equilibrium was computed given the natural mortality rate and an initial fishing mortality rate, F_{init}. In the base run, $F_{\text{init}} = 0.03$. In MCB runs, F_{init} was drawn from a uniform distribution with bounds at $\pm 50\%$ of 0.03, [0.015, 0.045].

3.8 Projections

Projections were run to predict stock status in the 10 years after the assessment, 2013–2022.

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 selectivities, were fixed to the most recent values of the assessment period. A single selectivity curve was applied to calculate landings, averaged across fleets using geometric mean Fs from the last three years of the assessment period, similar to computation of MSY benchmarks (§3.6).

Expected values of SSB (start of year), F, recruits, landings, and discards were represented by deterministic projections using parameter estimates from the base run. These projections were built on the estimated spawner-recruit relationship with bias correction, and were thus consistent with estimated benchmarks in the sense that long-term fishing at F_{MSY} would yield MSY from a stock size at $\mathrm{SSB}_{\mathrm{MSY}}$. Uncertainty in future time series was quantified through stochastic projections that extended the Monte Carlo/Bootstrap (MCB) fits of the stock assessment model.

3.8.1 Initialization of projections

In the assessment, the terminal years of recruitment (2012 and start of year 2013) were computed without deviation from the spawner-recruit curve, but corrected to be unbiased in arithmetic space. This influenced the estimated abundances of ages 1 and 2 ($N_{1,2}$) in 2013 when projections begin. In the stochastic projections, lognormal stochasticity was applied to these abundances after adjusting them to be unbiased in log space, with variability based on the estimate of σ_R. Thus, the initial abundance in year one (2013) of projections included this variability in $N_{1,2}$. The deterministic projections were not adjusted in this manner, because deterministic recruitment follows the bias-corrected (arithmetic space) spawner-recruit curve precisely, consistent with the assessment's 2012 and 2013 predictions.

Fishing rates that define the projections were assumed to start in 2015, which is the earliest year management could react to this assessment. Because the assessment period ended in 2012, the projections required an interim period (2013–2014). Here, the interim period was modeled by applying F_{current}, the mean fishing rate from 2010–2012.

3.8.2 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 steepness, natural mortality, and F_{init}, as well as in all estimated quantities such as remaining spawner-recruit parameters, selectivity curves, and in initial (start of 2013) abundance at age.

Initial and subsequent recruitment values were generated with stochasticity using a Monte Carlo procedure, in which the estimated Beverton–Holt model 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,

$$R_y = \bar{R}_y \exp(\epsilon_y). \tag{5}$$

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.

Projection scenarios All of the projections scenarios applied constant fishing mortality rates (as opposed to constant catch). Two types of projections were considered: base-run projections and $P^{\star}$projections. The base-run projections were as described above, with expected values computed from deterministic projections of the base run, and with uncertainty described by the stochastic projections. The $P^{\star}$projections did not have a base-run component, only the stochastic component. The method considers uncertainty in F_{MSY}, computed through the MCB analysis (§3.7), and described by the probability density function, $\phi_{F_{\text{MSY}}}$. It also considers uncertainty in annual fishing mortality, described by the probability density function, ϕ_{F_t}. Here, ϕ_{F_t} is computed by scaling $\phi_{F_{\text{MSY}}}$ toward smaller values of F using a scalar multiplier $\psi \leq 1.0$. Given the distributions $\phi_{F_{\text{MSY}}}$ and ϕ_{F_t}, the probability of overfishing can be computed as,

$$\Pr(F_t > F_{\text{MSY}}) = \int_0^{\infty} \left[\int_F^{\infty} \phi_{F_t}(\theta) d\theta \right] \phi_{F_{\text{MSY}}}(F) dF \tag{6}$$

where θ is a dummy integration variable (Shertzer et al. 2008*b*). The value of ψ is computed by optimization such that the distribution of F_t is positioned to achieve $\Pr(F_t > F_{\text{MSY}}) = P^{\star}$. That value of ψ was then used in the projections, such that in each iteration, the applied fishing rate was $F = \psi F_{\text{MSY}}$, where F_{MSY} was specific to that particular run (i.e., MCB draw). This approach is similar to the $P^{\star}$calculations described by Shertzer et al. (2008*b*), but differs in that it is an F-based projection rather than a catch-based projection.

Five projection scenarios were considered.

- Scenario 1: $F = F_{\text{current}}$
- Scenario 2: $F = F_{\text{MSY}}$
- Scenario 3: $F = 75\% F_{\text{MSY}}$
- Scenario 4: $P^{\star} = 0.3$
- Scenario 5: $P^{\star} = 0.5$

Given the estimated distribution of F_{MSY}, $\psi = 0.835$ for $P^{\star} = 0.3$, and $\psi = 1.0$ for $P^{\star} = 0.5$.

4 Stock Assessment Results

4.1 Measures of Overall Model Fit

In general, the Beaufort Assessment Model (BAM) fit well to the available data. The fits were similar to those from SEDAR-10.

Predicted length compositions from each fishery were reasonably close to observed data in most years, as were predicted age compositions (Figure 3). The poorest fits of the age composition data were to the first three years of data; the lack of fit could be attributed 1) to the relatively small sample sizes in those years and 2) to inflexibility in the initialization procedure and early recruitment (examined further through Sensitivity Run 9). The model was configured to fit observed commercial and recreational landings closely (Figures 4–7), as well as observed discards (Figures 8–10). Fits to the commercial and headboat indices generally captured the observed trends but not all annual fluctuations, whereas the fit to the general recreational index was poor (Figures 11–13). This poor fit also occurred in SEDAR-10, and it could be attributed to inconsistency with the other indices and to the very high CVs on the general recreational index.

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, such as those of the spawner-recruit model, are reported in sections below.

4.3 Stock Abundance and Recruitment

In general, estimated abundance at age showed truncation of the older ages mostly through the 1980s, and more stable values since (Figure 14; Table 8). Annual number of recruits is shown in Table 8 (age-1 column) and in Figure 15. The strongest recruitment event (age-1 fish) was predicted to have occurred in 1982, a year class evidenced most notably in the headboat age composition data. In the most recent decade, the strongest year class was predicted to have occurred in 2009, followed by two years of poor recruitment in 2010 and 2011. These poor recruitment events appear to have empirical support in the headboat age composition data, the headboat index, and the general recreational discards in 2011.

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 throughout the assessment period, with relatively low but increasing values predicted near the end of the time series (Figure 17; Table 10). Spawning biomass was predicted to decline in the terminal year, a result of poor recent recruitment in 2010 and 2011.

4.5 Selectivity

Selectivities of landings from commercial and recreational fleets are shown in Figures 18–20. In the most recent years, full selection occurred near age-6 for commercial fleets and near age-4 for recreational fleets. By design, selectivities of discard mortalities were dome-shaped for all fleets (Figure 21).

Average selectivities of landings and of discard mortalities were computed from F-weighted selectivities in the most recent period of regulations (Figure 22). These average selectivities were used to compute point estimates of benchmarks. All selectivities from the most recent period, including average selectivities, are tabulated in Table 11.

4.6 Fishing Mortality, Landings, and Discards

The estimated fishing mortality rates (F) generally increased through the 1970s, peaked in the 1980s, and have shown a general pattern of decline since (Figure 23). In most years, the commercial handline fleet was the largest contributor to total F (Table 12).

Estimated landings have roughly been split equally between commercial and recreational sectors, although the majority have been commercial in the last three years (Figures 24, 25; Tables 13, 14). Estimated discard mortalities occurred on a smaller scale than landings, and the majority come from the general recreational fleet (Figures 26,27; Tables 15, 16).

4.7 Spawner-Recruitment Parameters

The estimated Beverton–Holt spawner-recruit curve is shown in Figure 28, along with the effect of density dependence on recruitment, depicted graphically by recruits per spawner as a function of spawning stock (mt). Values of recruitment-related parameters were as follows: steepness $h = 0.84$ (fixed), unfished age-1 recruitment $\widehat{R_0} = 228327$, unfished spawners (mt) per recruit $\phi_0 = 0.0131$, and standard deviation of recruitment residuals in log space $\widehat{\sigma}_R = 0.42$ (which resulted in bias correction of $\varsigma = 1.09$). Uncertainty in these quantities was estimated through the MCB analysis (Figure 29).

4.8 Per Recruit and Equilibrium Analyses

Yield per recruit and spawning potential ratio were computed as functions of F (Figure 30). As in computation of MSY-related benchmarks, per recruit analyses applied the most recent selectivity patterns averaged across fisheries, weighted by F from the last three years (2010–2012). The yield per recruit curve peaked near $F_{\max} = 0.31$. The F that provides 50% SPR is $F_{50\%} = 0.38$, $F_{40\%} = 0.54$, and $F_{30\%} = 0.78$. For comparison, F_{MSY} corresponds to about 57% SPR.

As in per recruit analyses, equilibrium landings and spawning biomass were computed as functions of F (Figure 31). By definition, the F that maximizes equilibrium landings is F_{MSY}, and the corresponding landings and spawning biomass are MSY and $\mathrm{SSB}_{\mathrm{MSY}}$. Equilibrium landings and discards could also be viewed as functions of biomass B, which itself is a function of F (Figure 32).

4.9 Benchmarks / Reference Points

As described in §3.6, biological reference points (benchmarks) were derived analytically assuming equilibrium dynamics, corresponding to the expected spawner-recruit curve (Figure 28). Reference points estimated were F_{MSY}, MSY, B_{MSY} and $\mathrm{SSB}_{\mathrm{MSY}}$. Based on F_{MSY}, three possible values of F at optimum yield (OY) were considered—$F_{\mathrm{OY}} = 65\% F_{\mathrm{MSY}}$, $F_{\mathrm{OY}} = 75\% F_{\mathrm{MSY}}$, and $F_{\mathrm{OY}} = 85\% F_{\mathrm{MSY}}$—and for each, the corresponding yield was computed. Standard errors of benchmarks were approximated as those from MCB analysis (§3.7).

Maximum likelihood estimates (base run) of benchmarks, as well as median values from MCB analysis, are summarized in Table 17. Point estimates of MSY-related quantities were $F_{\mathrm{MSY}} = 0.29$ (y^{-1}), $\mathrm{MSY} = 938.2$ (1000 lb gutted), $B_{\mathrm{MSY}} = 3449.3$ (mt), and $\mathrm{SSB}_{\mathrm{MSY}} = 1831.7$ (mt). Median estimates were $F_{\mathrm{MSY}} = 0.27$ (y^{-1}), $\mathrm{MSY} = 900.4$ (1000 lb gutted), $B_{\mathrm{MSY}} = 3409.4$ (mt), and $\mathrm{SSB}_{\mathrm{MSY}} = 1806.8$ (mt). Distributions of these benchmarks from the MCB analysis are shown in Figure 33.

4.10 Status of the Stock and Fishery

Estimated time series of stock status ($\mathrm{SSB}/\mathrm{MSST}$) showed general decline throughout the beginning of the assessment period, and modest increase in the last several years (Figure 34, Table 10). Base-run estimates of spawning biomass have generally been above the threshold (MSST), although not in all years. Current stock status was estimated in the base run to be $\mathrm{SSB}_{2012}/\mathrm{MSST} = 1.13$ (Table 17), indicating that the stock is not overfished in the terminal year. Median values from the MCB analysis indicated similar results ($\mathrm{SSB}_{2012}/\mathrm{MSST} = 1.21$). The uncertainty analysis suggested that the terminal estimate of stock status is robust (Figures 35, 36). Of the MCB runs, approximately 97.5% indicated that the stock was above MSST in 2012. Age structure estimated by the base run generally showed fewer older fish than the (equilibrium) age structure expected at MSY, but it also showed increases since 2000 (Figure 37).

The estimated time series of F/F_{MSY} suggests that overfishing has occurred throughout most of the assessment period (Table 10), but with some uncertainty demonstrated by the MCB analysis (Figure 34). Current fishery status in the terminal year, with current F represented by the geometric mean from the period 2010–2012, was estimated by the base run to be $F_{2010-2012}/F_{\mathrm{MSY}} = 1.23$, and the median value was $F_{2010-2012}/F_{\mathrm{MSY}} = 1.37$ (Table 17). As with stock status, the estimate of fishery status was robust (Figures 35, 36). Of the MCB runs, approximately 92.5% agreed with the base run that the stock is currently experiencing overfishing.

4.10.1 Comparison to previous assessment

Stock and fishery status estimated by this assessment show trends similar to those from the previous, SEDAR-10 assessment (Figure 38). However, this update assessment estimates higher levels of F/F_{MSY} since 1990 and higher levels of $\mathrm{SSB}/\mathrm{MSST}$ in the earliest years of the time series. Some of the difference in results, particularly in F/F_{MSY}, are due to improvements in the weighting of data components. The early-year differences in $\mathrm{SSB}/\mathrm{MSST}$ are due primarily to modifications in the initialization procedure. Given the advances in BAM and the additional years of data, estimates of stock and fishery status from this assessment are expected to be improvements over those from SEDAR-10.

4.11 Sensitivity 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_{MSY} and $\mathrm{SSB}/\mathrm{MSST}$ $[\mathrm{MSST} = (1-M)\mathrm{SSB}_{\mathrm{MSY}}]$ are plotted to demonstrate sensitivity to natural mortality (Figure 39), steepness (Figure 40), initialization fishing rate (Figure 41), discard mortality rate (Figure 42), initialization procedure (Figure 43), and data component weights (Figure 44). One of those runs suggested the stock to be overfished and undergoing overfishing, one suggested the stock not to be overfished but experiencing overfishing, and the rest agreed with the status indicated by the base run (Figure 45, Table 18). Results appeared to be most sensitive to natural mortality and to model component weights.

4.12 Projections

All projections showed an initial drop in spawning stock during 2013-2014. This drop was due in part to the current rate of overfishing, but could primarily be attributed to poor recruitment in 2010 and 2011. After that initial drop, projections based on $F = F_{\mathrm{current}}$ allowed the spawning stock to grow but to levels generally below $\mathrm{SSB}_{\mathrm{MSY}}$ (Figure 46, Table 19). Projections based on $F = F_{\mathrm{MSY}}$ showed similar increases with higher levels of spawning stock (Figure 47, Table 20), as did projections based on $F = 75\% F_{\mathrm{MSY}}$ (Figure 48, Table 21). The $P^{\star}$projections demonstrated similar trends (Figures 49, 49). Annual ABC (landings plus discard mortalities in 1000 lb gutted weight) are tabulated for $P^{\star} = 0.3$ in Table 22, and for $P^{\star} = 0.5$ in Table 23.

5 Discussion

5.1 Comments on the Assessment

Estimated benchmarks played a central role in this assessment. Values of $\mathrm{SSB}_{\mathrm{MSY}}$ and F_{MSY} were used to gauge the status of the stock and fishery. Computation of 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 is not overfished ($\mathrm{SSB}_{2012}/\mathrm{SSB}_{\mathrm{MSY}} = 0.97$), but that overfishing is occurring ($F_{2010-2012}/F_{\mathrm{MSY}} = 1.23$). Median values from the MCB analyses were in agreement with those results ($\mathrm{SSB}_{2012}/\mathrm{SSB}_{\mathrm{MSY}} = 1.04$ and $F_{2010-2012}/F_{\mathrm{MSY}} = 1.37$). These findings of stock and fishery status are qualitatively the same as terminal-year estimates (2004) from the SEDAR-10 benchmark assessment.

In addition to more years of data, this update assessment included several modifications to previous data, such as the use of MRIP (instead of MRFSS) and the re-evaluation (delta-GLM modeling) of commercial and headboat indices of abundance. Furthermore, 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.

One major methodological change in this update was the use of MCB analysis to quantify uncertainty. The SEDAR-10 assessment did not take this approach, but rather applied a simple bootstrap procedure toward estimation of the spawner-recruit curve and management benchmarks. That procedure was not nearly as comprehensive as the MCB analysis. This change was implemented because of the increased emphasis placed on quantifying uncertainty since SEDAR-10 (SEDAR Procedural Guidance 2010).

The SEDAR-10 assessment attempted to estimate the steepness parameter of the spawner-recruit model, but the estimate was at the upper bound. Initial runs of this update assessment obtained the same result, indicating that steepness could still not be estimated reliably (Conn et al. 2010). Thus, departing from the SEDAR-10 approach, the base run of this update assessment fixed steepness at the mode ($h = 0.84$) of the prior distribution of Shertzer and Conn (2012). Then, that prior distribution was incorporated into the uncertainty analysis.

The value of steepness affects MSY-based management quantities (Mangel et al. 2013). Thus, in some cases when steepness cannot be estimated reliably, benchmarks are approximated by using a proxy for F_{MSY}, most typically $F_{X\%}$ (such as $F_{30\%}$ or $F_{40\%}$). However, such proxies do not provide biomass-based benchmarks. If managers wish to gauge stock status, further assumptions about equilibrium recruitment levels would be necessary. Furthermore, choice of X% implies an underlying steepness, as described by Brooks et al. (2009). Thus, choosing a proxy equates to choosing steepness. Given the choice between choosing a proxy or fixing steepness, it seems preferable to focus on steepness, as its value is less arbitrary, coming from a prior distribution estimated through meta-analysis.

A primary weakness of this assessment is the lack of fishery independent information. 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, such as closures due to quota regulations. During a closure, CPUE goes to zero and hence provides no information on relative abundance. In months outside of the closure, fishing effort may become concentrated with changes in catchability, which would affect the relationship between CPUE and abundance. As such management measures become more common in the southeast U.S., the continued utility of fishery dependent indices in SEDAR stock assessments will be questionable. This situation amplifies the importance of fishery independent sampling.

The assessment accounted for the protogyny of gag implicitly by measuring spawning stock as the sum of male and female mature biomass, as recommended by Brooks et al. (2008). Accounting for protogynous sex change is important for stock assessments (Alonzo et al. 2008; Shepherd et al. 2013), and the approach taken here has the advantage of being tractable. However, it ignores possible dynamics of sexual transition, which may be quite complex (e.g., density dependent, mating-system dependent, occurring at local spatial scales). In addition, a protogynous life history accompanied by size- or age-selective harvest places disproportionate fishing pressure on males. This situation creates the possibility for population growth to become limited by the proportion of males. When this occurs, accounting for male (sperm) limitation may be important to the stock assessment (Alonzo and Mangel 2004; Brooks et al. 2008); however, in practice there is typically little or no information available to quantify sperm limitation. In this assessment, the proportion of adult fish that are male drops below 10% in most years, and is below 10% in recent years since the mid-1980s (Table 10). The equilibrium proportion of adult fish that are male at MSY is near 20% (in numbers), but again, this estimate does not explicitly account for the dynamics of sperm limitation.

Most 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).

5.2 Comments on the Projections

As usual, 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 projections assumed that the estimated spawner-recruit relationship applies in the future and that past residuals 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 trajectories 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 are in effect, introducing additional and unquantified uncertainty into the projection results.
- The gag projections showed an initial drop in spawning biomass. This was due in part to the F_{current} rate of fishing that exceeds F_{MSY}, but occurred primarily because of poor estimated recruitment in 2010 and 2011. Although recruitment events near the end of the time series are typically less informed than those that occur earlier, the data do support that recruitment in these years was poor, as evidenced by a well-defined minimum of a negative log likelihood profile on 2011 recruitment.

6 References

Alonzo, S. H., T. Ish, M. Key, A. D. MacCall, and M. Mangel. 2008. The importance of incorporating protogynous sex change into stock assessments. Bulletin of Marine Science **83**:163–179.

Alonzo, S. H., and M. Mangel. 2004. The effects of size-selective fisheries on the stock dynamics of and sperm limitation in sex-changing fish. Fishery Bulletin **102**:1–13.

Baranov, F. I. 1918. On the question of the biological basis of fisheries. Nauchnye Issledovaniya Ikhtiologicheskii Instituta Izvestiya **1**:81–128.

Beddington, J. R., and J. G. Cooke, 1983. The potential yield of fish stocks. FAO Fish. Tech. Pap. 242, 47 p.

Brooks, E. N., J. E. Powers, and E. Cortes. 2009. Analytical reference points for age-structured models: application to data-poor fisheries. ICES Journal of Marine Science **67**:165–175.

Brooks, E. N., K. W. Shertzer, T. Gedamke, and D. S. Vaughan. 2008. Stock assessment of protogynous fish: evaluating measures of spawning biomass used to estimate biological reference points. Fishery Bulletin **106**:12–23.

Clark, W. G. 2002. $F_{35\%}$ revisited ten years later. North American Journal of Fisheries Management **22**:251–257.

Conn, P. B., E. H. Williams, and K. W. Shertzer. 2010. When can we reliably estimate the productivity of fish stocks? Canadian Journal of Fisheries and Aquatic Sciences **67**:511–523.

Dunlop, E. S., K. Enberg, C. Jorgensen, and M. Heino. 2009. Toward Darwinian fisheries management. Evolutionary Applications **2**:245–259.

Efron, B., and R. Tibshirani. 1993. An Introduction to the Bootstrap. Chapman and Hall, London.

Enberg, K., C. Jorgensen, E. S. Dunlop, M. Heno, and U. Dieckmann. 2009. Implications of fisheries-induced evolution for stock rebuilding and recovery. Evolutionary Applications **2**:394–414.

Fournier, D. A., H. J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M. N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software **27**:233–249.

Francis, R. 2011. Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences **68**:1124–1138.

Hewitt, D. A., and J. M. Hoenig. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fishery Bulletin **103**:433–437.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin **81**:898–903.

Legault, C. M., and E. N. Brooks. 2013. Can stock–recruitment points determine which spawning potential ratio is the best proxy for maximum sustainable yield reference points? ICES Journal of Marine Science **70**:1075–1080.

Legault, C. M., J. E. Powers, and V. R. Restrepo. 2001. Mixed Monte Carlo/bootstrap approach to assessing king and Spanish mackerel in the Atlantic and Gulf of Mexico: Its evolution and impact. Amercian Fisheries Society Symposium **24**:1–8.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology **49**:627–642.

Mace, P. M. 1994. Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. Canadian Journal of Fisheries and Aquatic Sciences **51**:110–122.

Mangel, M., A. D. MacCall, J. Brodziak, E. J. Dick, R. E. Forrest, R. Pourzand, and S. Ralston. 2013. A perspective on steepness, reference points, and stock assessment. Canadian Journal of Fisheries and Aquatic Sciences **70**:930–940.

Manly, B. F. J. 1997. Randomization, Bootstrap and Monte Carlo Methods in Biolog, 2nd edition. Chapman and Hall, London.

Mertz, G., and R. Myers. 1996. Influence of fecundity on recruitment variability of marine fish. Canadian Journal of Fisheries and Aquatic Sciences **53**:1618–1625.

Methot, R. D. 1989. Synthetic estimates of historical abundance and mortality for northern anchovy. American Fisheries Society Symposium **6**:66–82.

Methot, R. D., 2009. User Manual for Stock Synthesis, Model Version 3.04. NOAA Fisheries, Seattle, WA.

Quinn, T. J., and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press, New York, New York.

Restrepo, V. R., J. M. Hoenig, J. E. Powers, J. W. Baird, and S. C. Turner. 1992. A simple simulation approach to risk and cost analysis, with applications to swordfish and cod fisheries. Fishery Bulletin **90**:736–748.

Sauls, B. 2014. Relative survivial 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.

SEDAR, 2006. SEDAR 10: South Atlantic Gag Grouper.

SEDAR, 2009. SEDAR 19: South Atlantic Red Grouper.

SEDAR Procedural Guidance, 2010. SEDAR Procedural Workshop IV: Characterizing and Presenting Assessment Uncertainty.

SEDAR31-DW25, 2012. Estimated conversion factors for adjusting MRFSS Gulf of Mexico red snapper catch estimates and variances in 1981–2003 to MRIP esimates and variances. SEDAR31-WP25. SEDAR, N. Charleston, SC.

SEDAR32-DW2, 2013. MRIP adjustment ratios, Excel doc. SEDAR32-DW2. SEDAR, N. Charleston, SC.

SEDAR36-WP11, 2013. Commercial Landings of Snowy Grouper in the U.S. Atlantic, 1950–2012. SEDAR36-WP11. SEDAR, N. Charleston, SC.

Shepherd, G., K. Shertzer, J. Coakley, and M. Caldwell, editors, 2013. Proceedings from a workshop on modeling protogynous hermaphrodite fishes, Avaliable from: Mid-Atlantic Fishery Management Council, www.mafmc.org.

Shepherd, J. G. 1982. A versatile new stock-recruitment relationship for fisheries, and the construction of sustainable yield curves. Journal du Conseil pour l'Exploration de la Mer **40**:67–75.

Shertzer, K. W., and P. B. Conn. 2012. Spawner-recruit relationships of demersal marine fishes: Prior distribution of steepness. Bulletin of Marine Science **88**:39–50.

Shertzer, K. W., M. H. Prager, D. S. Vaughan, and E. H. Williams, 2008*a*. Fishery models. Pages 1582–1593 *in* S. E. Jorgensen and F. Fath, editors. Population Dynamics. Vol. [2] of Encyclopedia of Ecology, 5 vols. Elsevier, Oxford.

Shertzer, K. W., M. H. Prager, and E. H. Williams. 2008*b*. A probability-based approach to setting annual catch levels. Fishery Bulletin **106**:225–232.

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. Fisheries Fisheries **100**:126–133.

Stephens, A., and A. MacCall. 2004. A multispecies approach to subsetting logbook data for purposes of estimating CPUE. Fisheries Research **70**:299–310.

Williams, E. H., and K. W. Shertzer. 2003. Implications of life-history invariants for biological reference points used in fishery management. Canadian Journal of Fisheries and Aquatic Science **60**:710–720.

7 Tables

Table 1. Life-history characteristics, including average body length and whole weight (mid-year), proportion females mature, and natural mortality at age. The von Bertalanffy growth parameters (length) and the CV of length were estimated by the assessment model; other values were treated as input.

Age	Total length (mm)	Total length (in)	CV length	Whole weight (kg)	Whole weight (lb)	Female maturity	Natural mortality
1	442.1	17.4	0.11	1.11	2.46	0.01	0.27
2	580.1	22.8	0.11	2.48	5.46	0.07	0.21
3	676.9	26.7	0.11	3.90	8.60	0.48	0.18
4	744.9	29.3	0.11	5.17	11.40	0.92	0.16
5	792.7	31.2	0.11	6.21	13.69	0.99	0.14
6	826.2	32.5	0.11	7.02	15.47	1.00	0.14
7	849.7	33.5	0.11	7.62	16.80	1.00	0.13
8	866.3	34.1	0.11	8.06	17.78	1.00	0.13
9	877.9	34.6	0.11	8.39	18.49	1.00	0.12
10	886.0	34.9	0.11	8.62	19.00	1.00	0.12
11	891.7	35.1	0.11	8.78	19.36	1.00	0.12
12	895.7	35.3	0.11	8.90	19.62	1.00	0.12
13	898.6	35.4	0.11	8.98	19.80	1.00	0.12
14	900.5	35.5	0.11	9.04	19.93	1.00	0.12
15	901.9	35.5	0.11	9.08	20.02	1.00	0.12
16	902.9	35.5	0.11	9.11	20.09	1.00	0.12

Table 2. Annual proportion female at age

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1962	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1963	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1964	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1965	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1966	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1967	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1968	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1969	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1970	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1971	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1972	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1973	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1974	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1975	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1976	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1977	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1978	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1979	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1980	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1981	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1982	0.999	0.997	0.994	0.987	0.974	0.950	0.913	0.859	0.784	0.691	0.584	0.471	0.359	0.258	0.175	0.111
1983	0.999	0.998	0.994	0.988	0.975	0.952	0.914	0.857	0.780	0.682	0.571	0.454	0.342	0.243	0.163	0.103
1984	0.999	0.998	0.995	0.988	0.976	0.953	0.915	0.856	0.775	0.673	0.557	0.437	0.325	0.228	0.151	0.094
1985	0.999	0.998	0.995	0.989	0.977	0.954	0.915	0.855	0.770	0.663	0.543	0.420	0.308	0.213	0.140	0.086
1986	0.999	0.998	0.996	0.990	0.978	0.956	0.916	0.854	0.765	0.654	0.529	0.404	0.291	0.198	0.128	0.078
1987	0.999	0.998	0.996	0.991	0.979	0.957	0.917	0.853	0.761	0.645	0.515	0.387	0.274	0.183	0.116	0.070
1988	0.999	0.999	0.996	0.991	0.980	0.958	0.918	0.851	0.756	0.635	0.501	0.370	0.257	0.168	0.104	0.062
1989	1.000	0.999	0.997	0.992	0.981	0.959	0.918	0.850	0.751	0.626	0.488	0.354	0.240	0.153	0.092	0.054
1990	1.000	0.999	0.997	0.993	0.983	0.961	0.919	0.849	0.747	0.617	0.474	0.337	0.223	0.138	0.081	0.045
1991	1.000	0.999	0.998	0.994	0.984	0.962	0.920	0.848	0.742	0.607	0.460	0.320	0.206	0.123	0.069	0.037
1992	1.000	0.999	0.998	0.994	0.985	0.963	0.920	0.847	0.737	0.598	0.446	0.304	0.188	0.107	0.057	0.029
1993	1.000	1.000	0.998	0.995	0.986	0.965	0.921	0.845	0.732	0.589	0.432	0.287	0.171	0.092	0.045	0.021
1994	1.000	1.000	0.999	0.996	0.987	0.966	0.922	0.844	0.728	0.579	0.418	0.270	0.154	0.077	0.034	0.013
1995	1.000	1.000	0.999	0.996	0.987	0.966	0.922	0.844	0.728	0.579	0.418	0.270	0.154	0.077	0.034	0.013
1996	1.000	1.000	0.999	0.996	0.987	0.965	0.919	0.838	0.717	0.564	0.402	0.256	0.144	0.071	0.031	0.011
1997	1.000	1.000	0.999	0.996	0.987	0.965	0.917	0.832	0.706	0.549	0.385	0.241	0.133	0.065	0.027	0.010
1998	1.000	1.000	0.999	0.996	0.987	0.964	0.915	0.826	0.695	0.534	0.369	0.226	0.123	0.058	0.024	0.009
1999	1.000	1.000	0.999	0.996	0.987	0.963	0.912	0.820	0.685	0.519	0.352	0.212	0.112	0.052	0.021	0.008
2000	1.000	1.000	0.999	0.996	0.987	0.963	0.910	0.814	0.674	0.504	0.336	0.197	0.101	0.046	0.018	0.006
2001	1.000	1.000	0.999	0.996	0.987	0.962	0.907	0.808	0.663	0.489	0.319	0.182	0.091	0.040	0.015	0.005
2002	1.000	1.000	0.999	0.996	0.987	0.962	0.905	0.802	0.652	0.474	0.303	0.168	0.080	0.033	0.012	0.004
2003	1.000	1.000	0.999	0.996	0.987	0.961	0.903	0.796	0.642	0.459	0.286	0.153	0.070	0.027	0.009	0.003
2004	1.000	1.000	0.999	0.997	0.987	0.960	0.900	0.790	0.631	0.444	0.270	0.138	0.059	0.021	0.006	0.001
2005	1.000	1.000	0.999	0.997	0.987	0.960	0.900	0.790	0.631	0.444	0.270	0.138	0.059	0.021	0.006	0.001
2006	1.000	1.000	0.999	0.986	0.929	0.808	0.643	0.474	0.330	0.221	0.144	0.092	0.059	0.037	0.023	0.014
2007	1.000	1.000	0.999	0.986	0.929	0.808	0.643	0.474	0.330	0.221	0.144	0.092	0.059	0.037	0.023	0.014
2008	1.000	1.000	0.999	0.986	0.929	0.808	0.643	0.474	0.330	0.221	0.144	0.092	0.059	0.037	0.023	0.014
2009	1.000	1.000	0.999	0.986	0.929	0.808	0.643	0.474	0.330	0.221	0.144	0.092	0.059	0.037	0.023	0.014
2010	1.000	1.000	0.999	0.986	0.929	0.808	0.643	0.474	0.330	0.221	0.144	0.092	0.059	0.037	0.023	0.014
2011	1.000	1.000	0.999	0.986	0.929	0.808	0.643	0.474	0.330	0.221	0.144	0.092	0.059	0.037	0.023	0.014
2012	1.000	1.000	0.999	0.986	0.929	0.808	0.643	0.474	0.330	0.221	0.144	0.092	0.059	0.037	0.023	0.014

Table 3. Observed time series of landings (L) and discards (D) for commercial handlines (L.cH.ob), commercial diving (L.cD.ob), recreational headboat (L.HB.ob), and general recreational (L.GR.ob). Commercial landings are in units of 1000 lb gutted weight. Recreational landings and all discards are in units of 1000 fish. Discards include all released fish, live or dead.

Year	L.cH.ob	L.cD.ob	L.HB.ob	L.GR.ob	D.cH.ob	D.HB.ob	D.GR.ob
1962	150.34	.	8.41	6.32	.	.	.
1963	136.98	.	7.66	5.75	.	.	.
1964	128.39	.	7.18	5.40	.	.	.
1965	130.40	.	7.41	5.57	.	.	.
1966	99.11	.	5.58	4.19	.	.	.
1967	210.93	.	11.77	8.83	.	.	.
1968	309.92	.	17.72	13.29	.	.	.
1969	217.17	.	12.13	9.10	.	.	.
1970	299.03	.	16.66	12.49	.	.	.
1971	306.72	.	17.18	12.89	.	.	.
1972	204.48	.	13.44	8.57	.	.	.
1973	290.49	.	17.99	12.44	.	.	.
1974	372.77	.	13.92	16.05	.	.	.
1975	421.77	.	8.57	17.90	.	.	.
1976	565.04	3.75	7.56	24.34	.	.	.
1977	627.57	8.81	8.48	22.46	.	.	.
1978	967.40	13.87	6.01	38.43	.	.	.
1979	907.55	18.92	9.55	36.55	.	.	.
1980	846.15	16.40	6.96	36.23	.	.	.
1981	983.99	13.88	13.86	51.19	.	0.002	10.485
1982	1027.43	15.85	11.84	18.28	.	0.002	1.775
1983	1101.10	9.08	16.46	133.60	.	0.002	25.295
1984	1108.19	18.75	18.69	191.54	.	0.002	5.388
1985	865.72	11.62	16.13	52.56	.	1.742	3.865
1986	819.84	6.34	17.35	42.77	.	1.875	8.435
1987	857.78	21.93	24.09	87.80	.	2.602	6.067
1988	672.39	12.96	24.21	63.19	.	2.615	5.430
1989	967.01	22.26	22.42	81.92	.	2.420	19.047
1990	784.30	19.07	17.59	65.09	.	1.900	8.310
1991	656.43	85.01	13.55	39.74	.	1.462	8.697
1992	691.66	106.76	13.94	54.87	.	2.565	11.915
1993	756.63	78.15	11.80	59.59	.	2.170	9.908
1994	800.03	97.50	9.81	56.42	.	1.805	22.460
1995	840.43	83.77	10.54	49.38	.	1.940	29.465
1996	751.90	118.56	7.50	47.06	.	1.380	19.180
1997	608.22	98.71	6.85	36.43	.	1.260	25.350
1998	654.46	138.79	8.67	39.29	.	1.595	15.043
1999	538.08	113.49	5.34	50.64	3.048	1.173	17.565
2000	438.23	63.02	5.98	29.79	3.228	1.315	34.875
2001	450.08	82.30	5.12	42.57	5.464	1.125	20.782
2002	448.33	84.52	4.58	25.75	4.944	1.008	33.475
2003	443.90	117.41	3.27	51.78	2.100	0.720	47.657
2004	476.39	74.97	6.66	50.91	3.052	1.548	28.525
2005	573.44	53.60	8.05	33.26	3.316	1.638	38.110
2006	486.70	57.84	4.60	43.11	1.232	0.910	30.212
2007	560.80	73.02	6.70	43.13	1.228	0.845	56.102
2008	425.89	57.36	3.06	46.33	1.492	1.135	52.350
2009	396.19	64.64	3.00	34.62	1.384	2.062	27.185
2010	340.25	95.30	3.28	16.30	1.124	1.198	26.330
2011	361.84	70.68	2.63	12.80	1.360	0.958	14.203
2012	291.69	70.81	2.10	13.44	1.564	1.280	37.825

Table 4. Mean MRIP charter boat discard ratios for primary regulation time periods (prior to 2004).

Regulation Period	b2/ab1
1981-1984	0.000703
1985-1991	0.432004
1992-1998	0.735857
1999-2003	0.879432

Table 5. Observed indices of abundance and CVs from commercial handlines (U.cH.ob), headboat (U.HB.ob), and general recreational (U.GR.ob).

Year	U.cH.ob	cv.U.cH	U.HB.ob	cv.U.HB	U.GR.ob	cv.U.GR
1973	.	.	2.96	0.13	.	.
1974	.	.	1.92	0.12	.	.
1975	.	.	1.09	0.16	.	.
1976	.	.	0.77	0.20	.	.
1977	.	.	0.75	0.19	.	.
1978	.	.	0.79	0.16	.	.
1979	.	.	1.28	0.12	.	.
1980	.	.	1.41	0.12	.	.
1981	.	.	1.18	0.17	0.59	1.28
1982	.	.	1.30	0.11	0.49	1.23
1983	.	.	1.30	0.10	0.45	0.99
1984	.	.	1.06	0.16	0.58	0.88
1985	.	.	1.14	0.12	1.29	0.76
1986	.	.	1.04	0.14	1.26	0.66
1987	.	.	1.22	0.12	1.01	0.67
1988	.	.	1.34	0.12	0.62	0.70
1989	.	.	1.52	0.12	1.98	0.62
1990	.	.	1.42	0.13	0.78	0.70
1991	.	.	1.20	0.13	1.02	0.64
1992	.	.	1.16	0.14	1.10	0.64
1993	0.86	0.04	0.88	0.17	1.11	0.64
1994	0.89	0.04	0.94	0.16	1.04	0.64
1995	0.85	0.04	0.84	0.17	1.54	0.63
1996	0.97	0.04	0.77	0.18	0.84	0.65
1997	0.74	0.04	0.87	0.20	0.88	0.70
1998	0.93	0.04	0.92	0.16	0.34	0.74
1999	0.95	0.04	0.68	0.20	1.74	0.64
2000	0.75	0.04	0.69	0.20	0.89	0.65
2001	0.73	0.04	0.58	0.20	0.70	0.65
2002	0.86	0.04	0.56	0.23	1.20	0.63
2003	1.21	0.04	0.48	0.25	0.99	0.65
2004	1.37	0.04	0.70	0.18	1.56	0.62
2005	1.66	0.04	0.88	0.16	.	.
2006	1.26	0.04	0.51	0.22	.	.
2007	1.10	0.04	0.66	0.20	.	.
2008	0.76	0.04	0.44	0.24	.	.
2009	0.90	0.05	0.45	0.25	.	.
2010	1.05	0.05	0.65	0.20	.	.
2011	1.16	0.05	1.09	0.15	.	.
2012	.	.	0.57	0.21	.	.

Table 6. Sample sizes (number fish) of length compositions (lcomp) or age compositions (acomp) by survey or fleet. Data sources are commercial handlines (cH), commercial diving (cD), and combined headboat and general recreational (HB).

Year	lcomp.cH.nfish	lcomp.cD.nfish	lcomp.HB.nfish	acomp.cH.nfish	acomp.cD.nfish	acomp.HB.nfish
1972	.	.	153	.	.	.
1973	.	.	247	.	.	.
1974	.	.	152	.	.	.
1975	.	.	262	.	.	.
1976	.	.	278	.	.	.
1977	.	.	380	.	.	.
1978	.	.	339	.	.	48
1979	.	.	290	144	.	56
1980	.	.	341	80	.	80
1981	.	.	474	161	.	179
1982	.	.	605	.	.	70
1983	116	.	910	.	.	283
1984	3270	.	1292	.	.	336
1985	3628	.	988	.	.	178
1986	2298	.	688	.	.	140
1987	3376	.	768	.	.	.
1988	1932	.	627	.	.	.
1989	1752	.	573	.	.	.
1990	1305	.	454	.	.	.
1991	1496	.	248	.	.	.
1992	2197	.	390	66	.	.
1993	2528	.	362	98	.	.
1994	1898	122	472	344	.	.
1995	3209	126	2661	821	63	.
1996	2415	122	363	69	.	.
1997	1981	121	318	115	54	.
1998	2235	.	467	.	.	.
1999	2481	348	376	88	.	.
2000	2433	224	302	70	.	.
2001	2212	147	306	182	.	.
2002	1514	.	211	114	.	69
2003	1922	497	229	183	.	102
2004	2177	.	212	552	.	90
2005	2241	.	190	1755	.	80
2006	1864	.	204	873	.	84
2007	1914	.	220	1414	.	81
2008	1586	.	159	1112	.	26
2009	1358	.	180	936	.	80
2010	985	146	199	967	148	93
2011	1098	.	138	1012	111	.
2012	1050	.	163	709	.	62

Table 7. Sample sizes (number trips) of length compositions (lcomp) or age compositions (acomp) by fleet. Data sources are commercial handlines (cH), commercial diving (cD), and combined headboat and general recreational (HB).

Year	lcomp.cH.n	lcomp.cD.n	lcomp.HB.n	acomp.cH.n	acomp.cD.n	acomp.HB.n
1972	.	.	95	.	.	.
1973	.	.	115	.	.	.
1974	.	.	86	.	.	.
1975	.	.	130	.	.	.
1976	.	.	151	.	.	.
1977	.	.	166	.	.	.
1978	.	.	172	.	.	29
1979	.	.	151	19	.	47
1980	.	.	150	13	.	46
1981	.	.	239	28	.	106
1982	.	.	263	.	.	45
1983	16	.	387	.	.	146
1984	159	.	440	.	.	147
1985	199	.	398	.	.	106
1986	139	.	324	.	.	95
1987	182	.	359	.	.	.
1988	164	.	285	.	.	.
1989	138	.	243	.	.	.
1990	125	.	200	.	.	.
1991	179	.	131	.	.	.
1992	211	.	171	18	.	.
1993	241	.	194	29	.	.
1994	184	15	179	59	.	.
1995	290	14	316	131	17	.
1996	234	6	168	17	.	.
1997	192	8	179	19	8	.
1998	207	.	263	.	.	.
1999	228	18	209	25	.	.
2000	254	21	168	24	.	.
2001	250	16	178	40	.	.
2002	172	.	137	37	.	46
2003	196	25	154	46	.	59
2004	246	.	130	77	.	54
2005	255	.	126	182	.	51
2006	336	.	108	219	.	57
2007	399	.	135	345	.	46
2008	337	.	107	319	.	22
2009	310	.	121	282	.	64
2010	237	18	114	234	19	73
2011	277	.	88	262	20	.
2012	225	.	101	150	.	45

Table 8. 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	Total
1962	254.99	193.94	155.93	128.93	108.35	91.59	77.69	66.15	56.60	48.57	41.76	35.98	31.03	26.79	23.15	148.35	1489.78
1963	254.99	194.00	156.15	129.17	108.60	91.87	77.97	66.40	56.81	48.75	41.92	36.12	31.15	26.89	23.24	148.92	1492.93
1964	255.01	194.05	156.34	129.51	108.96	92.25	78.39	66.80	57.16	49.06	42.18	36.34	31.34	27.06	23.38	149.85	1497.69
1965	255.05	194.09	156.47	129.78	109.35	92.68	78.84	67.27	57.60	49.44	42.51	36.63	31.59	27.27	23.57	151.02	1503.15
1966	255.09	194.11	156.47	129.84	109.54	92.98	79.17	67.63	57.98	49.80	42.83	36.90	31.82	27.47	23.74	152.15	1507.52
1967	255.12	194.24	156.82	130.22	109.97	93.56	79.86	68.29	58.62	50.41	43.38	37.38	32.24	27.83	24.05	154.14	1516.14
1968	255.19	193.94	155.82	129.27	109.05	92.51	78.91	67.60	58.08	50.00	43.08	37.15	32.05	27.67	23.91	153.23	1507.46
1969	255.12	193.65	154.48	127.22	107.04	90.38	76.66	65.59	56.44	48.64	41.96	36.23	31.27	27.00	23.33	149.53	1484.54
1970	254.93	193.89	155.22	127.20	106.40	89.89	76.06	64.75	55.66	48.04	41.48	35.85	30.99	26.77	23.14	148.31	1478.59
1971	254.87	193.49	154.56	126.86	105.44	88.27	74.57	63.28	54.12	46.66	40.35	34.92	30.21	26.13	22.60	144.89	1461.24
1972	57.82	193.41	154.09	126.15	104.99	87.29	73.04	61.88	52.76	45.25	39.09	33.88	29.34	25.41	22.00	141.17	1247.58
1973	59.10	43.93	154.80	126.64	105.30	87.99	73.32	61.57	52.41	44.82	38.52	33.34	28.92	25.07	21.74	139.72	1097.18
1974	87.02	44.81	34.86	125.76	104.32	86.78	72.50	60.59	51.11	43.63	37.39	32.20	27.90	24.22	21.02	135.50	989.61
1975	158.64	65.93	35.45	28.19	102.97	85.14	70.61	59.12	49.63	41.99	35.92	30.84	26.58	23.05	20.04	129.61	963.70
1976	175.70	120.20	52.17	28.68	23.07	83.72	68.86	57.20	48.10	40.49	34.33	29.42	25.29	21.82	18.94	123.09	951.07
1977	153.89	132.88	94.37	41.74	23.11	18.30	65.62	53.96	45.01	37.96	32.02	27.20	23.34	20.08	17.34	113.01	899.85
1978	214.80	116.36	104.23	75.37	33.47	18.08	14.05	50.28	41.51	34.73	29.35	24.81	21.10	18.12	15.60	101.40	913.24
1979	325.23	161.63	89.46	80.88	57.92	24.27	12.55	9.67	34.71	28.74	24.09	20.40	17.27	14.70	12.64	81.69	995.84
1980	268.16	244.49	123.77	68.99	61.45	41.00	16.28	8.33	6.44	23.18	19.23	16.16	13.70	11.61	9.89	63.55	996.24
1981	281.12	201.87	188.31	96.11	52.57	43.17	27.08	10.62	5.45	4.22	15.23	12.67	10.66	9.05	7.67	48.59	1014.40
1982	628.94	205.84	147.62	139.73	69.30	33.59	25.19	15.49	6.08	3.13	2.43	8.79	7.32	6.16	5.24	32.60	1337.44
1983	185.33	474.46	160.92	116.64	105.64	45.07	19.52	14.27	8.78	3.46	1.78	1.39	5.02	4.19	3.53	21.69	1171.67
1984	112.32	130.92	315.04	106.96	73.75	55.59	20.69	8.68	6.34	3.91	1.54	0.80	0.62	2.25	1.88	11.33	852.62
1985	310.25	78.33	77.57	174.87	54.22	28.76	17.83	6.34	2.65	1.94	1.20	0.47	0.25	0.19	0.70	4.08	759.64
1986	587.29	225.43	54.49	52.95	109.03	25.73	11.14	6.58	2.33	0.98	0.72	0.44	0.18	0.09	0.07	1.78	1079.22
1987	371.52	430.61	162.08	38.80	34.59	54.73	10.62	4.39	2.59	0.92	0.39	0.28	0.18	0.07	0.04	0.73	1112.54
1988	336.72	269.88	295.36	107.16	22.40	13.60	16.13	2.93	1.20	0.71	0.25	0.11	0.08	0.05	0.02	0.21	1066.80
1989	199.72	246.61	192.32	205.56	64.86	9.09	4.09	4.52	0.81	0.33	0.20	0.07	0.03	0.02	0.01	0.07	928.33
1990	411.88	140.20	163.40	126.27	115.73	23.07	2.29	0.95	1.04	0.19	0.08	0.05	0.02	0.01	0.01	0.02	985.18
1991	255.06	298.66	97.80	112.42	79.38	55.29	8.97	0.85	0.35	0.39	0.07	0.03	0.02	0.01	0.00	0.01	909.31
1992	441.48	187.23	219.01	72.05	77.61	44.58	26.27	4.13	0.39	0.16	0.18	0.03	0.01	0.01	0.00	0.01	1073.15
1993	74.75	325.91	138.43	155.98	49.05	39.32	17.69	10.24	1.62	0.15	0.06	0.07	0.01	0.01	0.00	0.00	813.30
1994	480.62	54.90	239.38	98.24	104.76	22.41	13.18	5.78	3.36	0.53	0.05	0.02	0.02	0.00	0.00	0.00	1023.28
1995	166.17	346.84	39.55	169.27	65.89	47.39	7.36	4.22	1.86	1.09	0.17	0.02	0.01	0.01	0.00	0.00	849.82
1996	177.34	117.85	245.39	27.97	113.87	29.07	14.89	2.25	1.29	0.57	0.34	0.05	0.01	0.00	0.00	0.00	730.89
1997	217.74	126.02	83.82	174.91	19.07	54.06	10.21	5.11	0.78	0.45	0.20	0.12	0.02	0.00	0.00	0.00	692.49
1998	210.06	152.01	88.23	60.19	121.28	9.25	19.54	3.61	1.82	0.28	0.16	0.07	0.04	0.01	0.00	0.00	666.56
1999	316.26	151.30	109.03	61.92	40.15	57.58	3.28	6.80	1.26	0.64	0.10	0.06	0.03	0.02	0.00	0.00	748.41
2000	316.86	230.56	112.34	69.40	33.25	16.69	20.90	1.18	2.46	0.46	0.24	0.04	0.02	0.01	0.01	0.00	804.42
2001	303.00	225.06	168.07	77.06	41.57	15.50	6.88	8.54	0.49	1.02	0.19	0.10	0.02	0.01	0.00	0.00	847.50
2002	320.21	221.01	168.44	113.49	44.49	18.44	6.00	2.64	3.29	0.19	0.40	0.08	0.04	0.01	0.00	0.00	898.72
2003	195.96	228.53	163.14	122.23	74.06	23.34	8.62	2.79	1.23	1.55	0.09	0.19	0.04	0.02	0.00	0.00	821.78
2004	197.63	133.23	158.77	111.85	77.04	39.19	11.16	4.11	1.34	0.60	0.76	0.04	0.09	0.02	0.01	0.00	735.83
2005	208.63	137.66	95.06	108.95	70.82	42.04	19.85	5.63	2.08	0.68	0.31	0.39	0.02	0.05	0.01	0.01	692.18
2006	267.78	140.88	94.99	65.95	70.23	38.66	21.27	9.99	2.85	1.06	0.35	0.16	0.20	0.01	0.03	0.01	714.41
2007	229.23	188.24	101.55	64.71	41.07	37.39	19.12	10.48	4.95	1.42	0.53	0.17	0.08	0.10	0.01	0.02	699.06
2008	284.80	150.99	125.30	65.68	37.36	18.88	15.41	7.82	4.31	2.04	0.59	0.22	0.07	0.03	0.04	0.01	713.57
2009	435.36	190.41	102.23	81.39	38.19	17.57	8.01	6.49	3.31	1.84	0.88	0.25	0.10	0.03	0.01	0.02	886.10
2010	136.74	315.34	142.34	71.21	50.28	19.12	7.91	3.58	2.92	1.50	0.84	0.40	0.12	0.04	0.01	0.02	752.36
2011	85.64	98.23	236.21	107.54	49.86	29.61	10.18	4.20	1.91	1.57	0.81	0.46	0.22	0.06	0.02	0.02	626.56
2012	239.26	61.21	73.48	183.83	79.91	32.45	17.98	6.17	2.56	1.17	0.97	0.50	0.29	0.14	0.04	0.03	699.99
2013	242.84	158.33	41.89	56.08	141.56	57.66	22.56	12.52	4.32	1.80	0.83	0.69	0.36	0.20	0.10	0.05	741.76

Table 9. Estimated biomass at age (1000 lb, whole weight) at start of year

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
1962	626.11	1059.32	1341.73	1470.26	1483.49	1416.69	1305.14	1176.17	1046.54	922.86	808.66	705.92	614.43	533.96	463.41	2979.77	17954.23
1963	626.11	1059.54	1343.50	1473.13	1487.02	1420.88	1309.77	1180.58	1050.50	926.16	811.74	708.57	616.85	535.94	465.18	2991.01	18006.70
1964	626.33	1059.76	1345.26	1477.10	1491.87	1426.83	1316.82	1187.63	1056.90	932.12	816.81	712.98	620.60	539.25	468.04	3009.75	18088.27
1965	626.33	1059.98	1346.36	1479.96	1497.38	1433.67	1324.54	1196.01	1065.05	939.39	823.21	718.71	625.45	543.44	471.79	3033.34	18184.39
1966	626.33	1060.20	1346.36	1480.85	1499.81	1438.08	1330.05	1202.40	1072.11	946.00	829.16	724.00	630.08	547.63	475.32	3055.83	18264.42
1967	626.55	1060.87	1349.23	1485.03	1505.76	1447.12	1341.51	1214.31	1083.79	957.69	839.96	733.48	638.46	554.68	481.49	3095.95	18416.10
1968	626.55	1059.32	1340.63	1474.23	1493.19	1430.80	1325.86	1201.74	1073.87	949.97	834.23	728.85	634.71	551.38	478.62	3077.65	18282.06
1969	626.55	1057.78	1329.17	1450.86	1465.63	1397.95	1287.94	1166.25	1043.67	924.18	812.40	710.77	619.28	538.15	467.16	3003.36	17900.66
1970	626.11	1059.10	1335.56	1450.64	1456.82	1390.23	1277.80	1151.25	1029.12	912.71	803.14	703.50	613.55	533.74	463.41	2978.89	17785.35
1971	625.89	1056.90	1329.83	1446.89	1443.81	1365.32	1252.67	1125.24	1000.68	886.48	781.32	684.98	598.11	520.95	452.61	2910.10	17481.56
1972	141.98	1056.23	1325.86	1438.74	1437.63	1350.11	1227.09	1100.11	975.55	859.80	756.85	664.69	580.92	506.40	440.48	2835.37	16698.26
1973	145.06	239.86	1331.81	1444.25	1441.82	1361.13	1231.94	1094.82	968.93	851.42	745.82	654.11	572.76	499.79	435.19	2806.26	15824.78
1974	213.63	244.71	300.05	1434.11	1428.38	1342.39	1218.05	1077.18	945.12	828.94	724.00	631.62	552.48	482.81	420.86	2721.61	14565.72
1975	389.56	360.01	304.90	321.43	1409.86	1316.82	1186.31	1051.16	917.56	797.63	695.34	604.95	526.46	459.44	401.24	2603.22	13346.35
1976	431.44	656.54	448.86	327.17	315.92	1295.00	1156.77	1016.99	889.35	769.41	664.69	577.17	500.67	434.97	379.19	2472.26	12336.19
1977	377.87	725.76	811.96	475.98	316.58	283.07	1102.31	959.45	832.25	721.13	619.94	533.74	462.09	400.14	347.23	2269.88	11239.83
1978	527.57	635.59	896.84	859.58	458.34	279.77	236.12	893.98	767.43	659.84	568.13	486.78	417.78	361.12	312.39	2036.63	10397.44
1979	798.74	882.73	769.63	922.41	793.00	375.23	210.76	171.96	641.77	546.09	466.50	400.36	341.94	292.99	253.09	1640.90	9508.10
1980	658.52	1335.34	1064.83	786.83	841.50	634.27	273.59	148.15	119.05	440.26	372.36	317.02	271.39	231.49	198.20	1276.48	8969.07
1981	690.27	1102.53	1620.40	1096.14	719.81	667.78	454.81	188.94	100.75	80.25	294.98	248.46	210.98	180.34	153.66	975.99	8786.08
1982	1544.56	1124.36	1270.08	1593.50	948.87	519.63	423.07	275.58	112.44	59.52	46.96	172.40	144.84	122.80	104.94	654.77	9118.10
1983	455.03	2591.31	1384.50	1330.27	1446.45	697.10	327.83	253.75	162.26	65.70	34.39	27.12	99.43	83.33	70.77	435.63	9465.33
1984	275.80	714.96	2710.58	1219.82	1009.94	859.80	347.67	154.32	117.29	74.30	29.76	15.65	12.35	44.97	37.70	227.52	7852.43
1985	761.92	427.70	667.34	1994.30	742.52	444.89	299.39	112.66	48.94	36.82	23.15	9.26	4.85	3.75	13.89	82.01	5673.82
1986	1442.26	1231.28	468.92	603.85	1492.75	397.93	187.17	117.06	43.21	18.52	13.89	8.82	3.53	1.76	1.32	35.72	6067.78
1987	912.27	2351.89	1394.64	442.47	473.55	846.36	178.57	78.04	47.84	17.42	7.50	5.51	3.53	1.32	0.66	14.77	6776.79
1988	826.95	1474.01	2541.27	1222.02	306.66	210.32	270.95	52.03	22.27	13.45	4.85	1.98	1.54	0.88	0.44	4.19	6954.04
1989	490.53	1347.03	1654.79	2344.40	888.02	140.66	68.78	80.47	14.99	6.39	3.75	1.32	0.66	0.44	0.22	1.32	7043.55
1990	1011.48	765.67	1405.89	1440.06	1584.46	356.71	38.58	16.98	19.18	3.53	1.54	0.88	0.22	0.22	0.00	0.44	6646.06
1991	626.33	1631.20	841.50	1281.99	1086.88	855.17	150.80	15.21	6.39	7.28	1.32	0.66	0.44	0.22	0.00	0.22	6505.62
1992	1084.23	1022.50	1884.51	821.66	1062.63	689.61	441.37	73.41	7.28	3.09	3.53	0.66	0.22	0.22	0.00	0.00	7094.92
1993	183.65	1780.01	1191.16	1778.91	671.75	608.25	297.18	181.88	29.98	2.87	1.32	1.32	0.22	0.00	0.00	0.00	6728.51
1994	1180.36	299.83	2059.78	1120.39	1434.33	346.57	221.56	102.73	62.17	10.14	0.88	0.44	0.44	0.00	0.00	0.00	6839.84
1995	408.08	1894.43	340.39	1930.37	902.13	733.04	123.68	74.96	34.39	20.72	3.31	0.22	0.22	0.22	0.00	0.00	6465.94
1996	435.41	643.75	2111.37	319.01	1559.11	449.52	250.22	39.90	23.81	10.80	6.61	1.10	0.00	0.00	0.00	0.00	5851.07
1997	534.62	688.28	721.13	1994.74	261.03	835.99	171.52	90.83	14.33	8.60	3.97	2.42	0.44	0.00	0.00	0.00	5327.91
1998	515.88	830.26	759.27	686.52	1660.52	143.08	328.27	64.16	33.51	5.29	3.09	1.32	0.88	0.22	0.00	0.00	5032.27
1999	776.69	826.29	938.07	706.14	549.61	890.45	55.12	120.81	23.37	12.12	1.98	1.10	0.44	0.22	0.00	0.00	4902.86
2000	778.01	1259.28	966.51	791.46	455.25	258.16	350.98	20.94	45.41	8.82	4.63	0.66	0.44	0.22	0.22	0.00	4941.44
2001	744.06	1229.30	1446.01	878.76	569.23	239.86	115.52	151.90	9.04	19.40	3.75	1.98	0.22	0.22	0.00	0.00	5409.26
2002	786.39	1207.03	1449.32	1294.33	609.14	285.06	100.75	46.96	60.85	3.53	7.72	1.54	0.88	0.22	0.00	0.00	5853.72
2003	481.27	1248.26	1403.68	1393.98	1013.91	360.90	144.84	49.60	22.71	29.54	1.76	3.75	0.66	0.44	0.00	0.00	6155.31
2004	485.24	727.75	1366.20	1275.60	1054.91	606.05	187.39	72.97	24.69	11.24	14.55	0.88	1.76	0.44	0.22	0.00	5830.13
2005	512.35	751.78	817.91	1242.53	969.59	650.36	333.34	100.09	38.58	13.01	5.95	7.72	0.44	0.88	0.22	0.22	5444.98
2006	657.64	769.41	817.25	752.22	961.66	597.89	357.37	177.69	52.69	20.06	6.83	3.09	3.97	0.22	0.44	0.22	5178.66
2007	562.84	1028.02	873.69	737.89	562.40	578.27	321.21	186.29	91.49	26.90	10.14	3.53	1.54	1.98	0.22	0.44	4987.08
2008	699.31	824.75	1078.06	749.13	511.47	292.11	258.82	139.11	79.59	38.80	11.46	4.41	1.54	0.66	0.88	0.22	4690.11
2009	1069.02	1039.92	879.64	928.15	522.94	271.83	134.70	115.52	61.29	34.83	16.98	5.07	1.98	0.66	0.22	0.44	5083.20
2010	335.76	1722.25	1224.67	812.18	688.50	295.64	132.94	63.71	54.01	28.44	16.09	7.94	2.42	0.88	0.22	0.44	5385.89
2011	210.32	536.61	2032.44	1226.43	682.77	457.90	171.08	74.74	35.49	29.76	15.65	9.04	4.41	1.32	0.44	0.44	5488.63
2012	587.53	334.44	632.29	2096.38	1094.15	501.99	302.03	109.79	47.40	22.27	18.74	9.92	5.73	2.87	0.88	0.44	5766.41
2013	596.35	864.87	360.46	639.56	1938.31	891.77	378.98	222.45	79.81	34.17	16.09	13.45	7.05	3.97	1.98	0.88	6050.15

Table 10. Estimated time series of status indicators, fishing mortality, and biomass. Fishing mortality rate is apical F. Total biomass (B, mt) and spawning biomass (SSB, mt) are at the start of the year. The MSST *is defined by* $(1 - M)\mathrm{SSB}_{\mathrm{MSY}}$*, with constant* $M = 0.14$*, and MSST.75 as 75%*$\mathrm{SSB}_{\mathrm{MSY}}$*. Prop.fem is the estimated proportion of mature fish that are female.*

Year	F	F/F_{MSY}	B	B/B_{unfished}	SSB	$\mathrm{SSB}/\mathrm{SSB}_{\mathrm{MSY}}$	SSB/MSST	SSB/MSST.75	Prop.fem
1962	0.0262	0.0917	8144	0.818	4564	2.491	2.897	3.322	0.678
1963	0.0238	0.0831	8168	0.820	4577	2.499	2.906	3.332	0.678
1964	0.0222	0.0775	8205	0.824	4598	2.510	2.919	3.347	0.677
1965	0.0226	0.0790	8248	0.828	4622	2.523	2.934	3.365	0.677
1966	0.0170	0.0593	8285	0.832	4641	2.533	2.946	3.378	0.676
1967	0.0360	0.1257	8353	0.839	4676	2.553	2.969	3.404	0.676
1968	0.0544	0.1902	8293	0.833	4635	2.531	2.943	3.374	0.676
1969	0.0382	0.1336	8120	0.815	4530	2.473	2.876	3.298	0.676
1970	0.0533	0.1865	8067	0.810	4499	2.456	2.856	3.275	0.677
1971	0.0560	0.1958	7930	0.796	4422	2.414	2.807	3.219	0.678
1972	0.0402	0.1404	7574	0.761	4350	2.375	2.761	3.166	0.680
1973	0.0602	0.2106	7178	0.721	4320	2.359	2.743	3.145	0.679
1974	0.0736	0.2575	6607	0.664	4031	2.201	2.559	2.935	0.666
1975	0.0804	0.2811	6054	0.608	3489	1.905	2.215	2.539	0.644
1976	0.1137	0.3975	5596	0.562	2968	1.620	1.884	2.160	0.627
1977	0.1365	0.4771	5098	0.512	2549	1.392	1.618	1.856	0.627
1978	0.2447	0.8557	4716	0.474	2307	1.260	1.465	1.679	0.644
1979	0.2809	0.9823	4313	0.433	2040	1.114	1.295	1.485	0.673
1980	0.2990	1.0456	4068	0.409	1907	1.041	1.211	1.388	0.713
1981	0.4318	1.5097	3985	0.400	2010	1.097	1.276	1.463	0.766
1982	0.4425	1.5473	4136	0.415	2078	1.134	1.319	1.513	0.816
1983	0.6859	2.3983	4293	0.431	2240	1.223	1.422	1.631	0.854
1984	1.0611	3.7102	3562	0.358	2222	1.213	1.411	1.617	0.890
1985	0.8750	3.0596	2574	0.258	1710	0.933	1.085	1.245	0.911
1986	0.8096	2.8308	2752	0.276	1373	0.749	0.871	0.999	0.905
1987	1.1715	4.0962	3074	0.309	1264	0.690	0.803	0.920	0.914
1988	1.1541	4.0352	3154	0.317	1474	0.805	0.935	1.073	0.954
1989	1.3437	4.6984	3195	0.321	1892	1.033	1.201	1.377	0.964
1990	0.8704	3.0435	3015	0.303	1814	0.990	1.151	1.320	0.954
1991	0.6503	2.2739	2951	0.296	1693	0.924	1.075	1.233	0.934
1992	0.8115	2.8375	3218	0.323	1771	0.967	1.124	1.289	0.925
1993	0.9880	3.4544	3052	0.307	1820	0.994	1.156	1.325	0.930
1994	1.0089	3.5276	3102	0.312	1868	1.020	1.186	1.360	0.938
1995	1.0559	3.6918	2933	0.295	1755	0.958	1.114	1.278	0.933
1996	0.9385	3.2816	2654	0.267	1631	0.890	1.035	1.187	0.933
1997	0.9093	3.1795	2417	0.243	1603	0.875	1.017	1.167	0.932
1998	0.9253	3.2352	2283	0.229	1450	0.792	0.920	1.055	0.924
1999	0.8907	3.1145	2224	0.223	1235	0.674	0.784	0.899	0.916
2000	0.7637	2.6704	2241	0.225	1063	0.580	0.675	0.774	0.925
2001	0.8275	2.8935	2454	0.246	1186	0.648	0.753	0.863	0.940
2002	0.6359	2.2235	2655	0.267	1364	0.745	0.866	0.993	0.949
2003	0.6104	2.1342	2792	0.280	1621	0.885	1.029	1.180	0.945
2004	0.5526	1.9322	2645	0.266	1696	0.926	1.077	1.235	0.933
2005	0.5554	1.9419	2470	0.248	1619	0.884	1.028	1.179	0.916
2006	0.5770	2.0176	2349	0.236	1286	0.702	0.816	0.936	0.898
2007	0.7633	2.6688	2262	0.227	1124	0.614	0.713	0.818	0.892
2008	0.7329	2.5626	2127	0.214	1012	0.552	0.642	0.736	0.908
2009	0.6741	2.3568	2306	0.232	1004	0.548	0.637	0.730	0.921
2010	0.5023	1.7562	2443	0.245	1114	0.608	0.707	0.811	0.933
2011	0.3699	1.2933	2490	0.250	1490	0.814	0.946	1.085	0.939
2012	0.2315	0.8096	2616	0.263	1776	0.969	1.127	1.293	0.925
2013	.	.	2744	0.276	1683	0.919	1.068	1.225	0.884

Table 11. Selectivity at age for commercial handlines (cH), commercial diving (cD), headboat (HB), commercial discard mortalities (D.cH), headboat discard mortalities (D.HB), selectivity of landings averaged across fisheries (L.avg), and selectivity of discard mortalities averaged across fisheries (D.avg). The selectivity of landings from the headboat and general recreational fleets were assumed equal, as was the selectivity of discards from the headboat and general recreational fleets. TL is total length. For time-varying selectivities, values shown are from the terminal assessment year.

Age	TL(mm)	TL(in)	cH	cD	HB	D.cH	D.HB	L.avg	D.avg	L.avg+D.avg
1	442.1	17.4	0.001	0.009	0.005	0.061	0.863	0.003	0.231	0.234
2	580.1	22.8	0.006	0.029	0.110	0.385	1.000	0.026	0.272	0.298
3	676.9	26.7	0.045	0.092	0.763	1.000	0.269	0.166	0.084	0.251
4	744.9	29.3	0.286	0.255	0.988	0.936	0.013	0.392	0.015	0.407
5	792.7	31.2	0.772	0.534	1.000	0.307	0.001	0.770	0.004	0.774
6	826.2	32.5	0.966	1.000	1.000	0.045	0.000	0.982	0.001	0.982
7	849.7	33.5	0.996	0.990	1.000	0.006	0.000	1.000	0.000	1.000
8	866.3	34.1	1.000	0.962	1.000	0.001	0.000	0.997	0.000	0.997
9	877.9	34.6	1.000	0.915	1.000	0.000	0.000	0.990	0.000	0.990
10	886.0	34.9	1.000	0.855	1.000	0.000	0.000	0.979	0.000	0.979
11	891.7	35.1	1.000	0.782	1.000	0.000	0.000	0.967	0.000	0.967
12	895.7	35.3	1.000	0.702	1.000	0.000	0.000	0.953	0.000	0.953
13	898.6	35.4	1.000	0.702	1.000	0.000	0.000	0.953	0.000	0.953
14	900.5	35.5	1.000	0.702	1.000	0.000	0.000	0.953	0.000	0.953
15	901.9	35.5	1.000	0.702	1.000	0.000	0.000	0.953	0.000	0.953
16	902.9	35.5	1.000	0.702	1.000	0.000	0.000	0.953	0.000	0.953

Table 12. Estimated time series of fully selected fishing mortality rates for commercial handlines (F.cH), commercial diving (F.cD), headboat (F.HB), general recreational (F.GR), commercial discard mortalities (F.cH.D), headboat discard mortalities (F.HB.D), and general recreational discard mortalities (F.GR.D). Also shown is apical 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	F.cD	F.HB	F.GR	F.cH.D	F.HB.D	F.GR.D	Apical F
1962	0.013	0.000	0.007	0.006	0.000	0.000	0.000	0.026
1963	0.012	0.000	0.007	0.005	0.000	0.000	0.000	0.024
1964	0.011	0.000	0.006	0.005	0.000	0.000	0.000	0.022
1965	0.011	0.000	0.007	0.005	0.000	0.000	0.000	0.023
1966	0.008	0.000	0.005	0.004	0.000	0.000	0.000	0.017
1967	0.018	0.000	0.010	0.008	0.000	0.000	0.000	0.036
1968	0.027	0.000	0.016	0.012	0.000	0.000	0.000	0.054
1969	0.019	0.000	0.011	0.008	0.000	0.000	0.000	0.038
1970	0.027	0.000	0.015	0.011	0.000	0.000	0.000	0.053
1971	0.028	0.000	0.016	0.012	0.000	0.000	0.000	0.056
1972	0.019	0.000	0.013	0.008	0.000	0.000	0.000	0.040
1973	0.028	0.000	0.019	0.013	0.000	0.000	0.000	0.060
1974	0.037	0.000	0.017	0.020	0.000	0.000	0.000	0.074
1975	0.044	0.000	0.012	0.025	0.000	0.000	0.000	0.080
1976	0.067	0.001	0.011	0.036	0.000	0.000	0.000	0.114
1977	0.087	0.001	0.013	0.035	0.000	0.000	0.000	0.136
1978	0.168	0.003	0.010	0.064	0.000	0.000	0.000	0.245
1979	0.197	0.005	0.016	0.063	0.000	0.000	0.000	0.281
1980	0.223	0.005	0.011	0.060	0.000	0.000	0.000	0.299
1981	0.320	0.005	0.023	0.085	0.000	0.000	0.025	0.432
1982	0.391	0.006	0.018	0.028	0.000	0.000	0.003	0.443
1983	0.473	0.004	0.023	0.186	0.000	0.000	0.045	0.686
1984	0.658	0.011	0.036	0.357	0.000	0.000	0.022	1.061
1985	0.686	0.009	0.043	0.138	0.000	0.006	0.012	0.875
1986	0.666	0.005	0.040	0.099	0.000	0.003	0.013	0.810
1987	0.948	0.021	0.044	0.160	0.000	0.004	0.009	1.172
1988	0.991	0.015	0.042	0.108	0.000	0.005	0.010	1.154
1989	1.131	0.022	0.042	0.151	0.000	0.006	0.049	1.344
1990	0.685	0.015	0.036	0.135	0.000	0.004	0.018	0.870
1991	0.492	0.058	0.027	0.078	0.000	0.003	0.018	0.650
1992	0.575	0.073	0.034	0.133	0.000	0.005	0.022	0.812
1993	0.763	0.058	0.028	0.141	0.000	0.006	0.027	0.988
1994	0.772	0.075	0.025	0.141	0.000	0.004	0.049	1.009
1995	0.835	0.064	0.028	0.132	0.000	0.005	0.069	1.056
1996	0.697	0.095	0.021	0.128	0.000	0.005	0.067	0.939
1997	0.696	0.080	0.022	0.114	0.000	0.004	0.089	0.909
1998	0.637	0.122	0.031	0.139	0.000	0.005	0.049	0.925
1999	0.502	0.108	0.027	0.257	0.015	0.003	0.045	0.891
2000	0.511	0.075	0.030	0.150	0.013	0.003	0.076	0.764
2001	0.530	0.100	0.022	0.179	0.019	0.002	0.045	0.828
2002	0.441	0.089	0.016	0.092	0.015	0.002	0.072	0.636
2003	0.335	0.099	0.011	0.168	0.006	0.002	0.128	0.610
2004	0.311	0.054	0.022	0.167	0.011	0.005	0.097	0.553
2005	0.364	0.037	0.030	0.126	0.014	0.006	0.133	0.555
2006	0.328	0.041	0.020	0.189	0.006	0.003	0.089	0.577
2007	0.463	0.062	0.032	0.208	0.006	0.002	0.164	0.763
2008	0.432	0.062	0.015	0.226	0.007	0.003	0.147	0.733
2009	0.419	0.074	0.015	0.168	0.006	0.004	0.053	0.674
2010	0.329	0.097	0.013	0.065	0.004	0.003	0.064	0.502
2011	0.271	0.055	0.008	0.038	0.004	0.005	0.069	0.370
2012	0.146	0.040	0.006	0.040	0.006	0.005	0.158	0.232

Table 13. Estimated time series of landings in numbers (1000 fish) for commercial handlines (L.cH), commercial diving (L.cD), headboat (L.HB), and general recreational (L.GR).

Year	L.cH	L.cD	L.HB	L.GR	Total
1962	8.96	0.00	8.42	6.33	23.71
1963	8.16	0.00	7.67	5.76	21.59
1964	7.65	0.00	7.19	5.41	20.25
1965	7.78	0.00	7.42	5.58	20.77
1966	5.91	0.00	5.59	4.19	15.69
1967	12.59	0.00	11.80	8.85	33.23
1968	18.52	0.00	17.79	13.33	49.65
1969	12.97	0.00	12.17	9.12	34.26
1970	17.90	0.00	16.74	12.54	47.18
1971	18.39	0.00	17.28	12.95	48.62
1972	12.25	0.00	13.51	8.60	34.36
1973	17.47	0.00	18.14	12.51	48.13
1974	22.48	0.00	14.02	16.19	52.69
1975	25.29	0.00	8.61	18.07	51.96
1976	33.48	0.22	7.58	24.60	65.89
1977	36.81	0.52	8.50	22.62	68.46
1978	57.44	0.83	6.02	38.71	103.01
1979	54.61	1.18	9.56	36.67	102.01
1980	52.00	1.07	6.96	36.25	96.28
1981	62.37	0.95	13.85	51.05	128.22
1982	67.71	1.15	11.83	18.25	98.93
1983	74.87	0.68	16.42	130.96	222.93
1984	77.26	1.45	18.62	184.46	281.78
1985	63.44	0.92	16.09	52.18	132.63
1986	60.33	0.51	17.33	42.67	120.84
1987	63.13	1.85	24.06	87.45	176.50
1988	54.73	1.21	24.17	62.95	143.07
1989	81.10	2.04	22.39	81.57	187.11
1990	62.81	1.64	17.59	65.06	147.10
1991	50.29	6.93	13.55	39.74	110.51
1992	49.46	8.70	13.94	54.86	126.96
1993	54.31	6.46	11.80	59.48	132.05
1994	58.39	8.20	9.80	56.12	132.51
1995	60.57	6.94	10.53	49.06	127.09
1996	54.59	9.70	7.49	46.83	118.62
1997	43.57	8.01	6.84	36.24	94.67
1998	47.65	11.16	8.66	39.15	106.61
1999	40.82	9.06	5.34	51.01	106.24
2000	33.93	5.29	5.98	29.88	75.08
2001	35.60	7.20	5.12	42.42	90.35
2002	35.65	7.42	4.57	25.58	73.23
2003	34.74	9.89	3.27	51.17	99.08
2004	36.57	6.04	6.65	50.57	99.83
2005	44.03	4.17	8.07	33.56	89.82
2006	36.83	4.43	4.61	43.83	89.70
2007	41.36	5.62	6.70	43.17	96.84
2008	31.50	4.59	3.06	45.72	84.86
2009	29.72	5.41	3.00	34.19	72.33
2010	26.65	8.08	3.28	16.33	54.35
2011	28.64	5.82	2.63	12.82	49.91
2012	22.43	5.54	2.10	13.45	43.51

Table 14. Estimated time series of landings in gutted weight (1000 lb) for commercial handlines (L.cH), commercial diving (L.cD), headboat (L.HB), and general recreational (L.GR).

Year	L.cH	L.cD	L.HB	L.GR	Total
1962	150.38	0.00	111.82	84.00	346.20
1963	137.02	0.00	101.91	76.47	315.41
1964	128.44	0.00	95.62	71.89	295.95
1965	130.57	0.00	98.77	74.22	303.56
1966	99.22	0.00	74.46	55.90	229.59
1967	211.50	0.00	157.41	118.02	486.94
1968	311.29	0.00	237.01	177.58	725.88
1969	217.92	0.00	161.66	121.18	500.76
1970	300.63	0.00	221.83	166.10	688.56
1971	308.63	0.00	228.06	170.86	707.55
1972	205.46	0.00	182.00	115.83	503.30
1973	292.91	0.00	259.46	178.95	731.32
1974	377.55	0.00	209.83	242.21	829.59
1975	428.32	0.00	129.20	271.18	828.70
1976	576.71	3.75	109.34	354.63	1044.43
1977	641.22	8.81	116.83	310.83	1077.69
1978	995.78	13.88	78.26	503.56	1591.48
1979	925.54	18.93	112.09	430.01	1486.57
1980	855.71	16.40	73.54	382.99	1328.64
1981	989.57	13.88	139.21	513.11	1655.77
1982	1019.77	15.85	107.49	165.85	1308.96
1983	1079.50	9.08	141.73	1130.42	2360.73
1984	1076.92	18.74	174.43	1728.07	2998.16
1985	848.27	11.62	150.02	486.36	1496.27
1986	810.94	6.34	132.70	326.64	1276.62
1987	848.90	21.92	167.93	610.30	1649.07
1988	668.46	12.96	181.64	472.96	1336.01
1989	961.76	22.26	184.80	673.16	1841.99
1990	783.82	19.07	148.76	550.28	1501.92
1991	657.65	85.03	111.73	327.66	1182.07
1992	693.84	106.80	129.15	508.32	1438.10
1993	758.54	78.16	108.58	547.52	1492.80
1994	793.97	97.41	93.92	537.79	1523.09
1995	825.83	83.64	98.23	457.91	1465.61
1996	746.77	118.42	71.11	444.39	1380.69
1997	607.62	98.64	68.00	360.10	1134.36
1998	647.87	138.52	85.70	387.26	1259.35
1999	544.35	113.76	56.87	542.81	1257.78
2000	442.58	63.10	60.30	301.08	867.05
2001	449.58	82.27	49.80	412.82	994.48
2002	441.36	84.28	45.22	252.90	823.76
2003	437.28	116.96	33.50	524.66	1112.40
2004	473.43	74.89	70.91	538.94	1158.18
2005	584.68	53.70	90.23	375.31	1103.92
2006	501.73	58.05	52.05	495.16	1107.00
2007	567.52	73.13	73.09	470.82	1184.56
2008	422.21	57.30	31.91	477.25	988.67
2009	387.21	64.40	30.85	352.03	834.48
2010	343.23	95.47	32.63	162.39	633.71
2011	367.06	70.87	26.72	130.23	594.88
2012	292.28	70.85	24.03	153.88	541.04

Table 15. Estimated time series of discard mortalities in numbers (1000 fish) for commercial handlines (D.cH), headboat (D.HB), and general recreational (D.GR).

Year	D.cH	D.HB	D.GR	Total
1981	.	0.00	10.47	10.48
1982	.	0.00	1.77	1.78
1983	.	0.00	25.23	25.23
1984	.	0.00	5.39	5.39
1985	.	1.74	3.86	5.61
1986	.	1.87	8.43	10.31
1987	.	2.60	6.07	8.67
1988	.	2.61	5.43	8.04
1989	.	2.42	19.03	21.45
1990	.	1.90	8.31	10.21
1991	.	1.46	8.69	10.16
1992	.	2.56	11.91	14.47
1993	.	2.17	9.90	12.07
1994	.	1.80	22.43	24.24
1995	.	1.94	29.39	31.33
1996	.	1.38	19.15	20.53
1997	.	1.26	25.30	26.56
1998	.	1.59	15.03	16.62
1999	3.05	1.17	17.54	21.76
2000	3.23	1.31	34.78	39.32
2001	5.46	1.12	20.75	27.33
2002	4.94	1.01	33.38	39.33
2003	2.10	0.72	47.47	50.29
2004	3.05	1.55	28.47	33.06
2005	3.32	1.64	38.01	42.97
2006	1.23	0.91	30.13	32.27
2007	1.23	0.84	55.80	57.87
2008	1.49	1.13	52.09	54.72
2009	1.38	2.06	27.13	30.58
2010	1.12	1.20	26.28	28.60
2011	1.36	0.96	14.19	16.51
2012	1.56	1.28	37.82	40.66

Table 16. Estimated time series of discard mortalities in gutted weight (1000 lb) for commercial handlines (D.cH), headboat (D.HB), and general recreational (D.GR).

Year	D.cH	D.HB	D.GR	Total
1981	.	0.01	42.85	42.86
1982	.	0.01	6.01	6.02
1983	.	0.01	117.99	118.00
1984	.	0.01	27.03	27.04
1985	.	5.72	12.70	18.42
1986	.	6.17	27.76	33.93
1987	.	10.82	25.22	36.03
1988	.	11.07	22.99	34.06
1989	.	10.78	84.82	95.60
1990	.	6.72	29.37	36.09
1991	.	6.10	36.29	42.39
1992	.	9.53	44.26	53.79
1993	.	10.88	49.63	60.51
1994	.	6.00	74.57	80.57
1995	.	8.61	130.42	139.03
1996	.	6.15	85.39	91.54
1997	.	4.82	96.78	101.60
1998	.	6.26	59.00	65.27
1999	23.58	4.27	63.87	91.72
2000	24.28	5.11	135.21	164.60
2001	42.10	4.52	83.41	130.04
2002	39.66	4.02	133.19	176.87
2003	17.40	3.16	208.66	229.22
2004	26.15	6.43	118.32	150.90
2005	28.57	6.43	149.36	184.36
2006	10.00	3.38	111.98	125.37
2007	9.57	3.39	223.79	236.74
2008	11.73	4.29	197.02	213.05
2009	10.58	7.25	95.40	113.23
2010	8.61	5.65	123.92	138.17
2011	11.74	4.92	72.93	89.58
2012	14.93	4.38	129.36	148.67

Table 17. 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 total (males and females) mature biomass. The two definitions of* MSST *considered in this assessment are indicated as M for* $\mathrm{MSST} = (1-M)\mathrm{SSB}_{\mathrm{MSY}}$ *and as 75% for* $\mathrm{MSST} = 75\%\mathrm{SSB}_{\mathrm{MSY}}$.

Quantity	Units	Estimate	Median	SE
F_{MSY}	y^{-1}	0.29	0.27	0.06
$85\%F_{\mathrm{MSY}}$	y^{-1}	0.24	0.23	0.05
$75\%F_{\mathrm{MSY}}$	y^{-1}	0.21	0.20	0.05
$65\%F_{\mathrm{MSY}}$	y^{-1}	0.19	0.18	0.04
$F_{30\%}$	y^{-1}	0.78	0.79	0.13
$F_{40\%}$	y^{-1}	0.54	0.55	0.09
$F_{50\%}$	y^{-1}	0.38	0.38	0.06
B_{MSY}	mt whole	3449.3	3409.4	253.5
$\mathrm{SSB}_{\mathrm{MSY}}$	mt whole	1831.7	1806.8	165.9
MSST (M)	mt whole	1575.3	1546.3	120.9
MSST (75%)	mt whole	1373.8	1546.3	124.4
MSY	1000 lb gutted	938.2	900.4	131.8
D_{MSY}	1000 fish	28.6	26.4	4.2
R_{MSY}	1000 age-1 fish	243	232	53
Y at $85\%F_{\mathrm{MSY}}$	1000 lb gutted	932.7	894.9	131.5
Y at $75\%F_{\mathrm{MSY}}$	1000 lb gutted	921.1	883.6	130.7
Y at $65\%F_{\mathrm{MSY}}$	1000 lb gutted	900.8	863.8	129.3
$F_{2010-2012}/F_{\mathrm{MSY}}$	—	1.23	1.37	0.57
SSB_{2012}/MSST (M)	—	1.13	1.21	0.13
SSB_{2012}/MSST (75%)	—	1.29	1.38	0.15
$\mathrm{SSB}_{2012}/\mathrm{SSB}_{\mathrm{MSY}}$	—	0.97	1.04	0.11

Table 18. 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_{MSY}	$\mathrm{SSB}_{\mathrm{MSY}}$ (mt whole)	MSY(1000 lb gutted)	$\mathrm{F}_{\mathrm{current}}/F_{\mathrm{MSY}}$	SSB_{2012}/MSST	steep	R0(1000)
Base	—	0.286	1832	938	1.23	1.13	0.84	229
S1	M=0.1	0.226	1503	695	2.44	1.22	0.84	111
S2	M=0.18	0.357	1841	993	0.94	1.28	0.84	308
S3	h=0.74	0.259	1857	901	1.34	1.11	0.74	230
S4	h=0.94	0.257	1875	960	1.42	1.1	0.94	209
S5	Finit=0.015	0.285	1809	923	1.23	1.14	0.84	227
S6	Finit=0.045	0.287	1847	949	1.23	1.12	0.84	231
S7	Dmort=0.15	0.35	1729	982	1.01	1.18	0.84	220
S8	Dmort=0.35	0.247	1857	877	1.45	1.11	0.84	232
S9	Flexible IC	0.287	2039	1095	1.28	1.05	0.84	235
S10	Iter reweight	0.325	1865	1001	1.88	0.74	0.84	235

Table 19. Projection results with fishing mortality rate fixed at $F = F_{\text{current}}$ starting in 2013. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (mt), L = landings expressed in numbers (n, in 1000s) or gutted weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or gutted weight (w, in 1000* lb*), pr.M = proportion of stochastic projection replicates with* SSB $\geq$ MSST *using the 1-M definition of MSST, and pr.75=proportion of stochastic projection replicates with* SSB $\geq$ MSST *using the 75% definition of MSST. 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(mt)	S.med(mt)	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.M	pr.75
2013	243	205	0.35	0.38	1680	1700	69	73	930	985	31	29	119	111	0.845	0.990
2014	242	203	0.35	0.38	1419	1359	63	65	875	910	34	32	137	132	0.260	0.525
2015	238	198	0.35	0.38	1374	1258	58	56	791	773	34	32	141	136	0.214	0.385
2016	237	193	0.35	0.38	1450	1304	59	55	793	742	34	31	140	134	0.280	0.452
2017	238	194	0.35	0.38	1531	1373	63	57	833	769	34	31	140	131	0.350	0.519
2018	240	195	0.35	0.38	1578	1410	65	59	864	790	34	31	141	131	0.381	0.554
2019	240	196	0.35	0.38	1601	1422	66	60	883	803	34	31	141	132	0.391	0.566
2020	241	195	0.35	0.38	1613	1424	67	60	895	809	34	31	142	132	0.397	0.569
2021	241	195	0.35	0.38	1622	1432	67	60	904	814	34	31	142	131	0.402	0.570
2022	241	194	0.35	0.38	1628	1433	68	60	911	817	34	31	142	131	0.402	0.570

Table 20. Projection results with fishing mortality rate fixed at $F = F_{\mathrm{MSY}}$ starting in 2015. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (mt), L = landings expressed in numbers (n, in 1000s) or gutted weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or gutted weight (w, in 1000* lb*), pr.M = proportion of stochastic projection replicates with* SSB $\geq$ MSST *using the 1-M definition of MSST, and pr.75=proportion of stochastic projection replicates with* SSB $\geq$ MSST *using the 75% definition of MSST. 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(mt)	S.med(mt)	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.M	pr.75
2013	243	205	0.35	0.38	1680	1700	69	73	930	985	31	29	119	111	0.845	0.990
2014	242	203	0.35	0.38	1419	1359	63	65	875	910	34	32	137	132	0.260	0.525
2015	238	198	0.29	0.27	1374	1258	48	42	661	582	28	24	116	101	0.214	0.385
2016	237	193	0.29	0.27	1496	1362	52	44	692	602	28	24	117	101	0.322	0.516
2017	239	196	0.29	0.27	1616	1482	56	48	750	658	28	24	117	101	0.444	0.644
2018	241	198	0.29	0.27	1698	1565	59	52	800	706	28	24	118	102	0.532	0.724
2019	242	200	0.29	0.27	1746	1608	62	54	837	743	28	24	118	103	0.580	0.764
2020	242	200	0.29	0.27	1774	1639	63	56	863	770	28	24	119	103	0.608	0.790
2021	243	200	0.29	0.27	1792	1657	64	57	883	790	28	24	119	104	0.626	0.805
2022	243	200	0.29	0.27	1805	1671	65	58	897	805	29	24	119	104	0.639	0.820

Table 21. Projection results with fishing mortality rate fixed at $F = 75\% F_{\mathrm{MSY}}$ starting in 2015. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (mt), L = landings expressed in numbers (n, in 1000s) or gutted weight (w, in 1000 lb), and D = dead discards expressed in numbers (n, in 1000s) or gutted weight (w, in 1000 lb), pr.M = proportion of stochastic projection replicates with SSB ≥ MSST using the 1-M definition of MSST, and pr.75=proportion of stochastic projection replicates with SSB ≥ MSST using the 75% definition of MSST. 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(mt)	S.med(mt)	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.M	pr.75
2013	243	205	0.35	0.38	1680	1700	69	73	930	985	31	29	119	111	0.845	0.990
2014	242	203	0.35	0.38	1419	1359	63	65	875	910	34	32	137	132	0.260	0.525
2015	238	198	0.21	0.20	1374	1258	37	32	510	448	21	18	88	76	0.214	0.385
2016	237	193	0.21	0.20	1548	1409	41	36	560	486	21	18	90	78	0.370	0.565
2017	240	197	0.21	0.20	1717	1570	46	40	630	551	21	18	90	78	0.527	0.718
2018	242	199	0.21	0.20	1843	1694	51	44	694	610	22	18	91	79	0.643	0.806
2019	243	202	0.21	0.20	1925	1767	54	47	746	659	22	18	92	80	0.712	0.852
2020	244	202	0.21	0.20	1977	1820	56	50	786	698	22	19	92	80	0.750	0.876
2021	245	203	0.21	0.20	2011	1854	58	52	818	730	22	19	93	81	0.776	0.893
2022	245	203	0.21	0.20	2034	1878	60	53	842	754	22	19	93	81	0.798	0.905

Table 22. Projection results with fishing mortality rate such that $P^{\star} = 0.3$ starting in 2015. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (mt), L = landings expressed in numbers (n, in 1000s) or gutted weight (w, in 1000 lb*), D = dead discards expressed in numbers (n, in 1000s) or gutted weight (w, in 1000* lb*), ABC=Acceptable Biological Catch (total removals) expressed in numbers (n, in 1000s) or gutted weight (w, in 1000* lb*), pr.M = proportion of stochastic projection replicates with* SSB $\geq$ MSST *using the 1-M definition of MSST, and pr.75=proportion of stochastic projection replicates with* SSB $\geq$ MSST *using the 75% definition of MSST. All values except year and probabilities are medians from the stochastic projections.*

Year	R	F	S(mt)	L(n)	L(w)	D(n)	D(w)	ABC(n)	ABC(w)	pr.M	pr.75
2013	205	0.38	1700	73	985	29	111	102	1105	0.845	0.990
2014	203	0.38	1359	65	910	32	132	98	1054	0.260	0.525
2015	198	0.23	1258	36	494	20	85	57	587	0.214	0.385
2016	193	0.23	1392	39	528	20	86	60	621	0.354	0.549
2017	196	0.23	1539	43	591	20	86	64	682	0.501	0.694
2018	199	0.23	1649	47	647	20	87	69	740	0.607	0.781
2019	201	0.23	1710	50	692	20	88	72	788	0.672	0.826
2020	202	0.23	1754	52	728	21	88	74	824	0.705	0.849
2021	202	0.23	1784	54	756	21	89	76	851	0.730	0.868
2022	202	0.23	1803	55	777	21	89	77	873	0.749	0.882

Table 23. Projection results with fishing mortality rate such that $P^{\star} = 0.5$ starting in 2015. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (mt), L = landings expressed in numbers (n, in 1000s) or gutted weight (w, in 1000 lb*), D = dead discards expressed in numbers (n, in 1000s) or gutted weight (w, in 1000* lb*), ABC=Acceptable Biological Catch (total removals) expressed in numbers (n, in 1000s) or gutted weight (w, in 1000* lb*), pr.M = proportion of stochastic projection replicates with* SSB $\geq$ MSST *using the 1-M definition of MSST, and pr.75=proportion of stochastic projection replicates with* SSB $\geq$ MSST *using the 75% definition of MSST. All values except year and probabilities are medians from the stochastic projections.*

Year	R	F	S(mt)	L(n)	L(w)	D(n)	D(w)	ABC(n)	ABC(w)	pr.M	pr.75
2013	205	0.38	1700	73	985	29	111	102	1105	0.845	0.990
2014	203	0.38	1359	65	910	32	132	98	1054	0.260	0.525
2015	198	0.27	1258	42	582	24	101	67	692	0.214	0.385
2016	193	0.27	1362	44	602	24	101	70	712	0.322	0.516
2017	196	0.27	1482	48	658	24	101	74	766	0.444	0.644
2018	198	0.27	1565	52	706	24	102	77	815	0.532	0.724
2019	200	0.27	1608	54	743	24	103	80	854	0.580	0.764
2020	200	0.27	1639	56	770	24	103	81	881	0.608	0.790
2021	200	0.27	1657	57	790	24	104	83	902	0.626	0.805
2022	200	0.27	1671	58	805	24	104	84	918	0.639	0.820

8 Figures

Figure 1. Observed indices of abundance from commercial handline, headboat, and general recreational fleets.

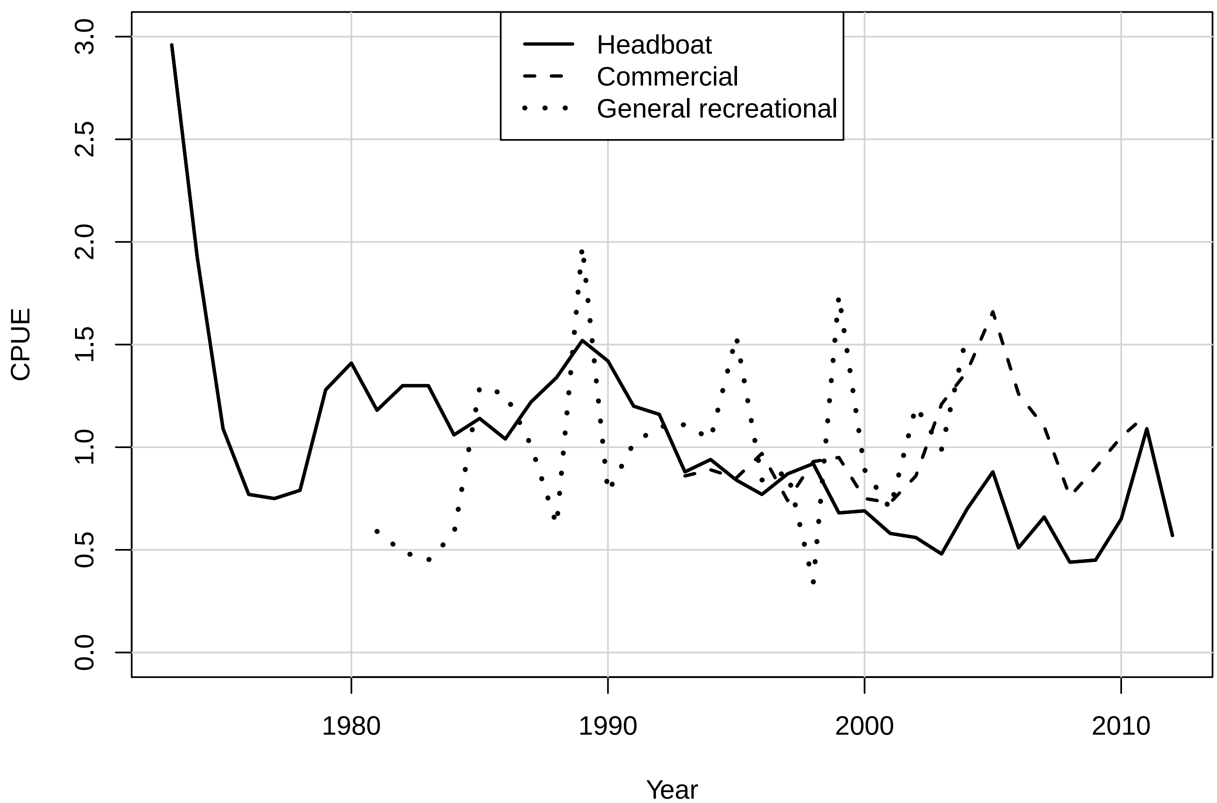


Figure 2. Mean length at age (mm) and estimated upper and lower 95% confidence intervals of the population.

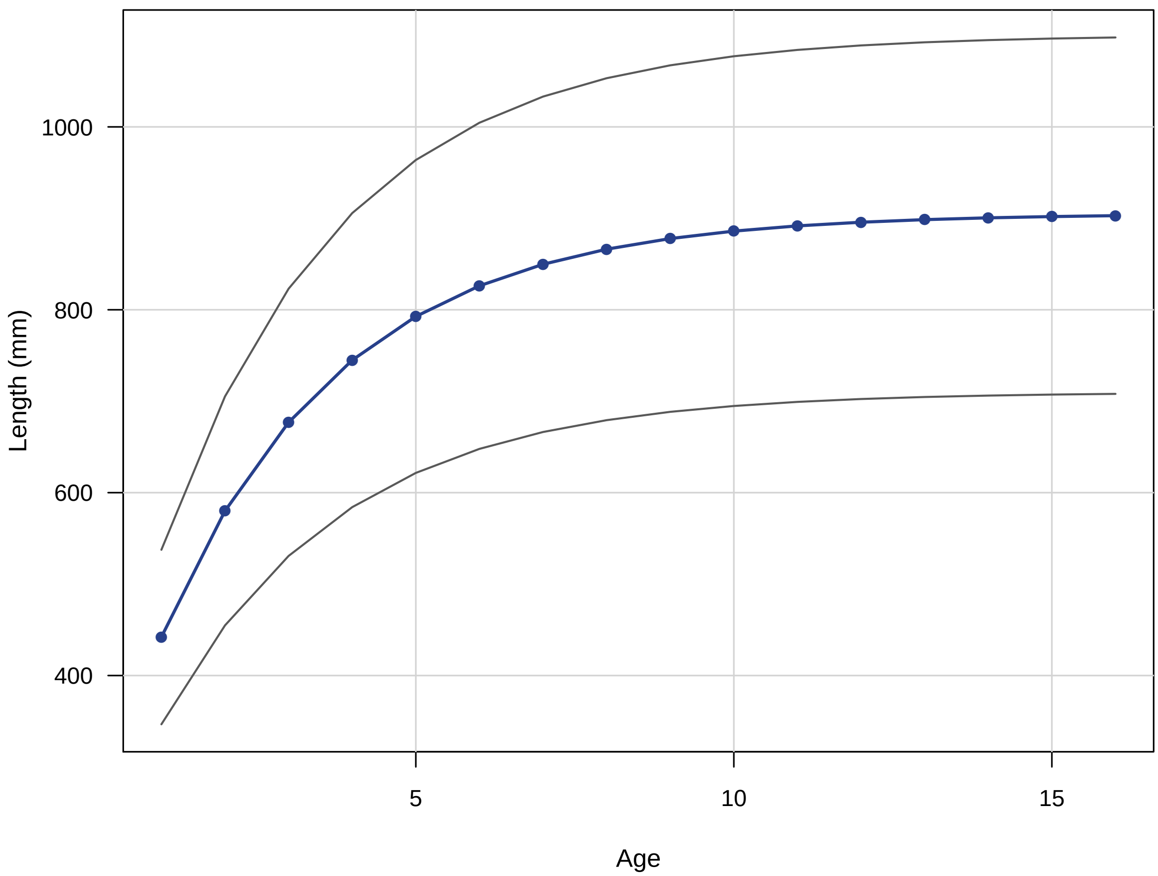


Figure 3. Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cH to commercial handline, cD to commercial diving, and HB to combined headboat and general recreational. $N = -99999$ indicates that the composition was not used for fitting, in most cases because the sample size was below the cutoff.

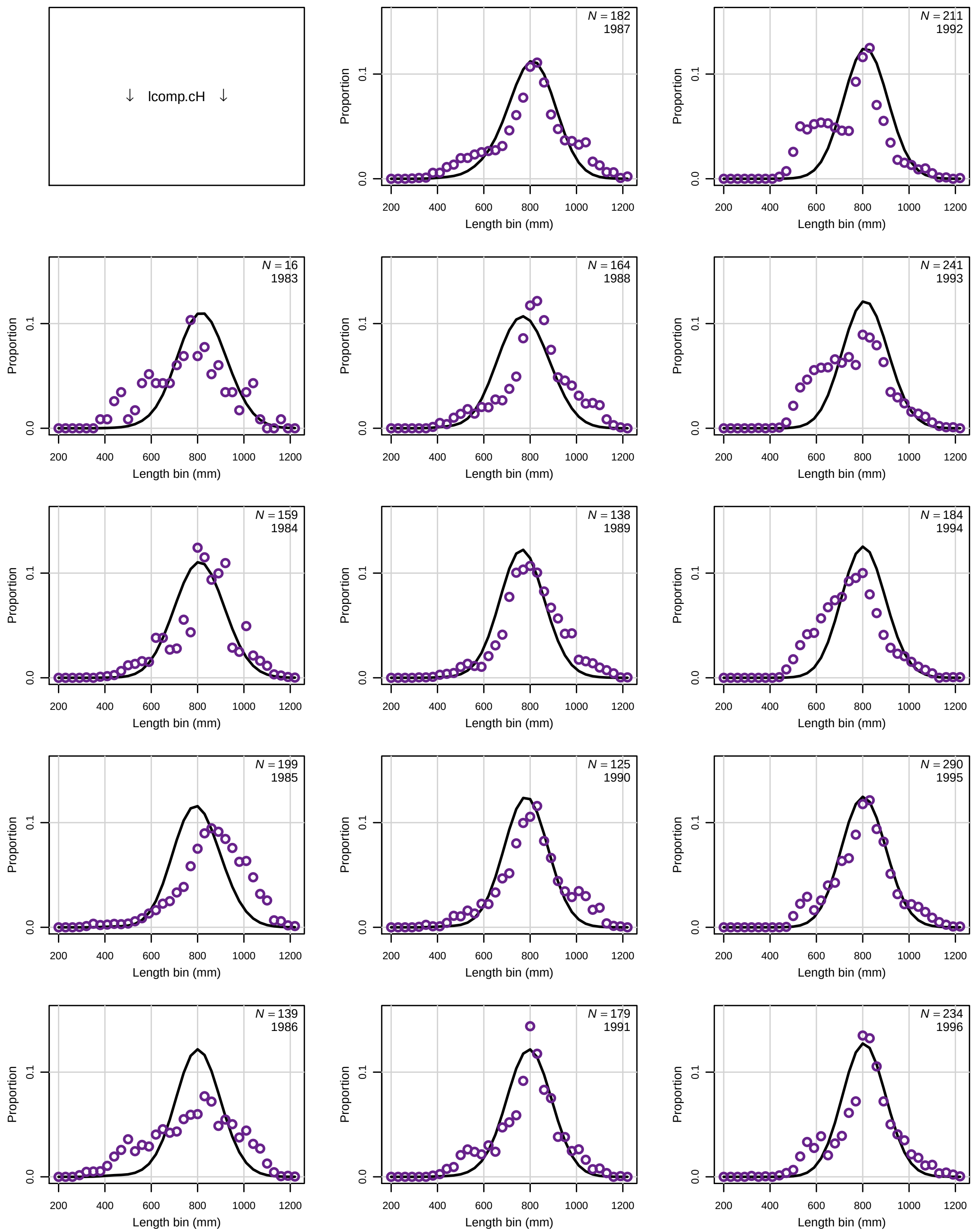


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

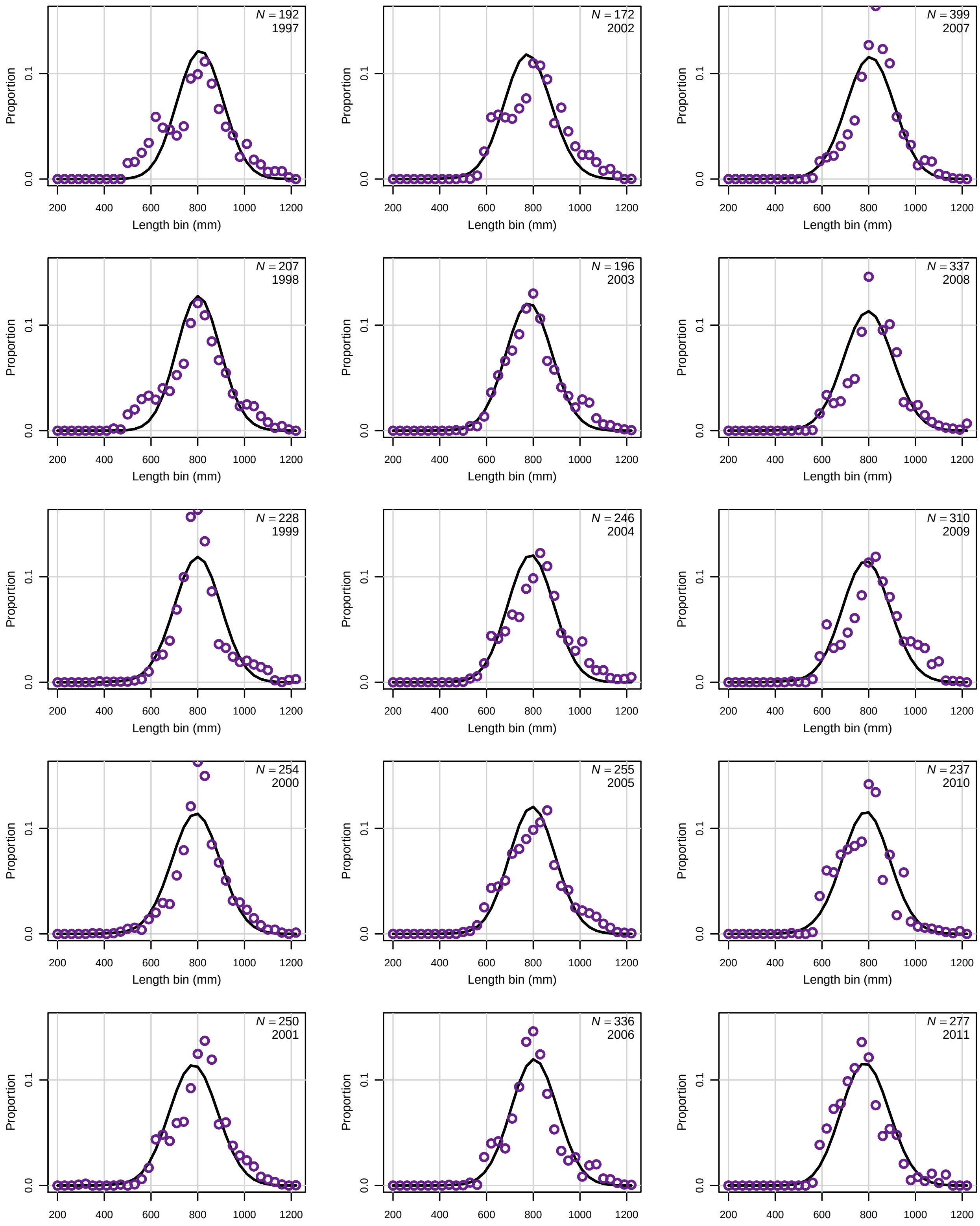


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

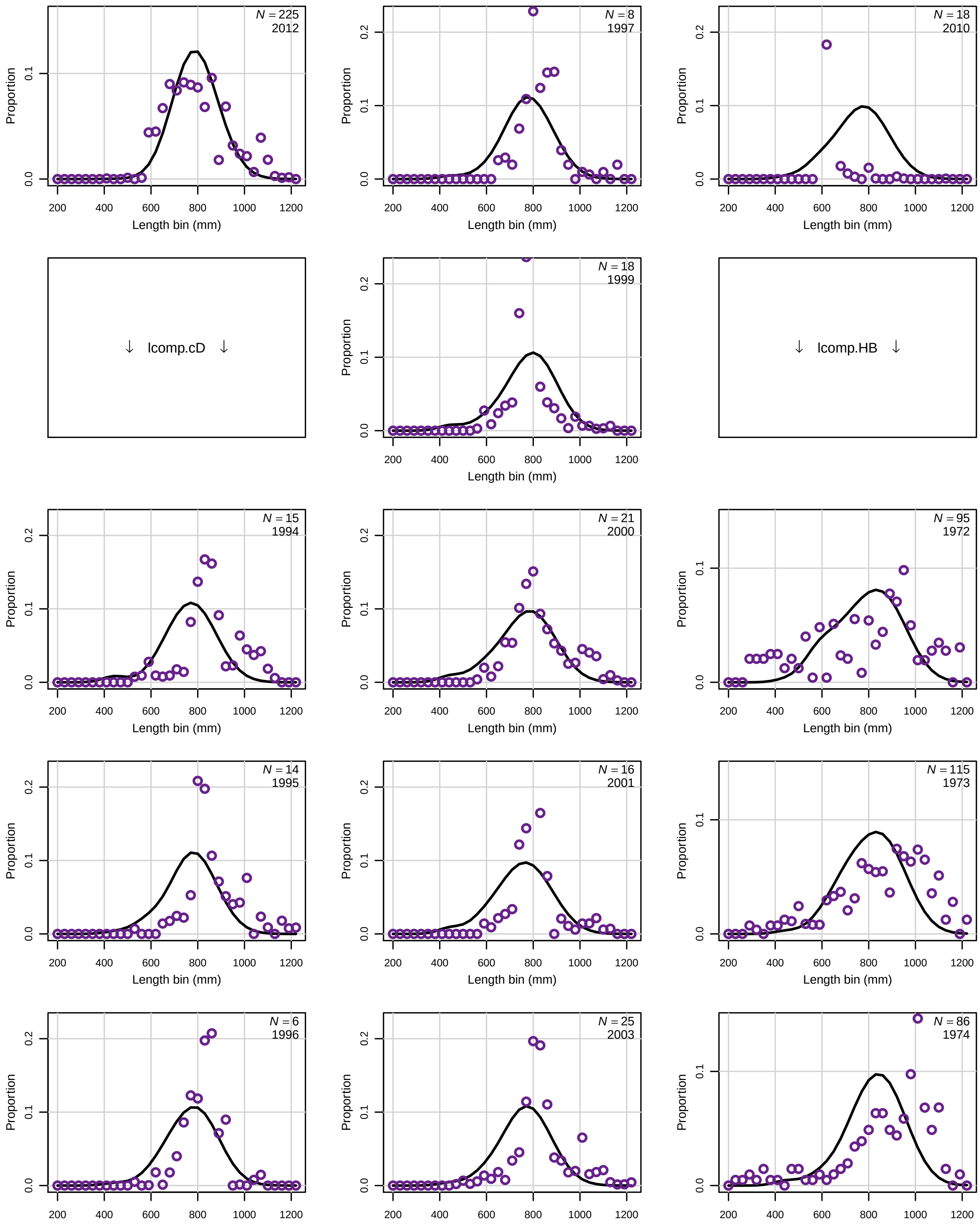


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

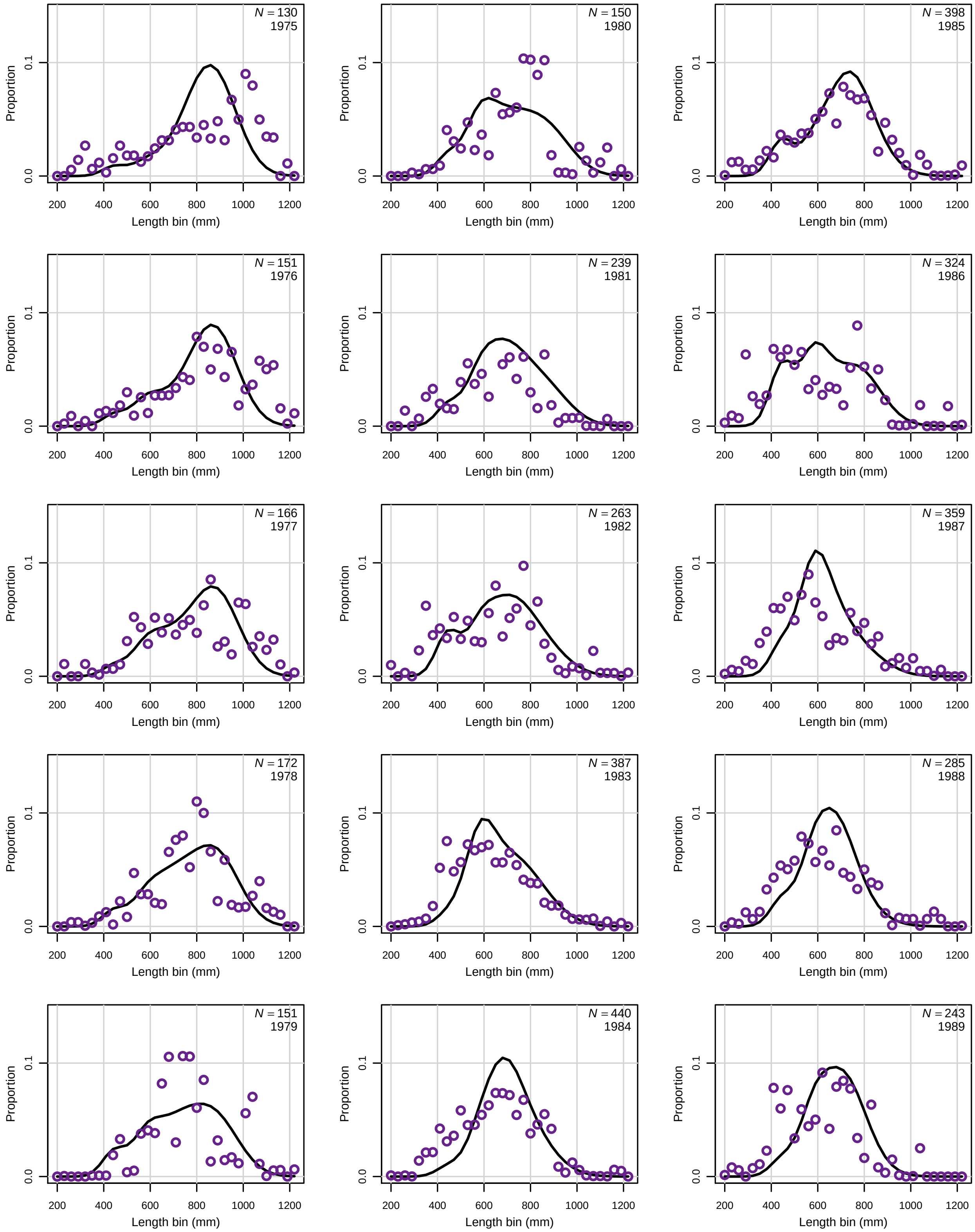


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

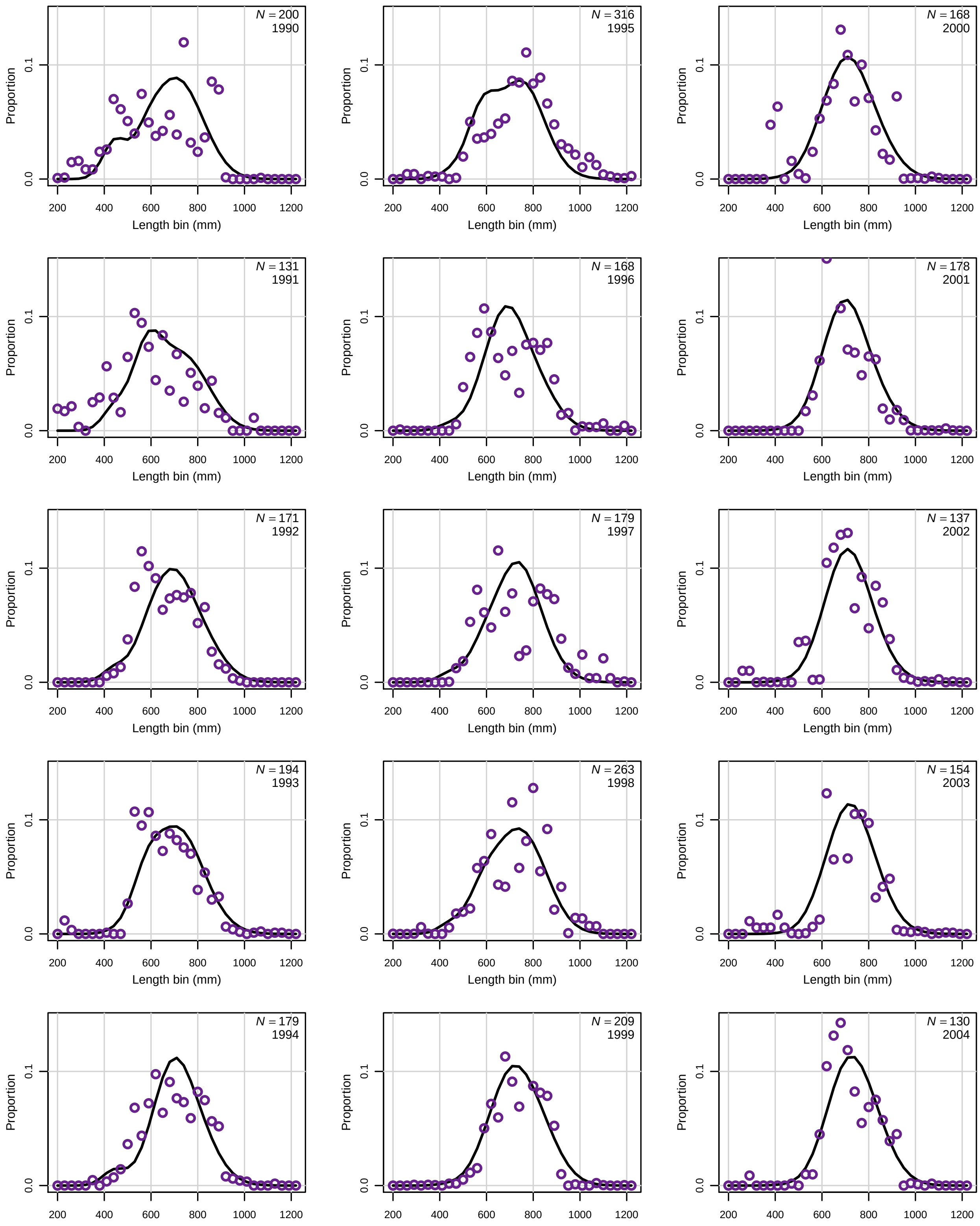


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

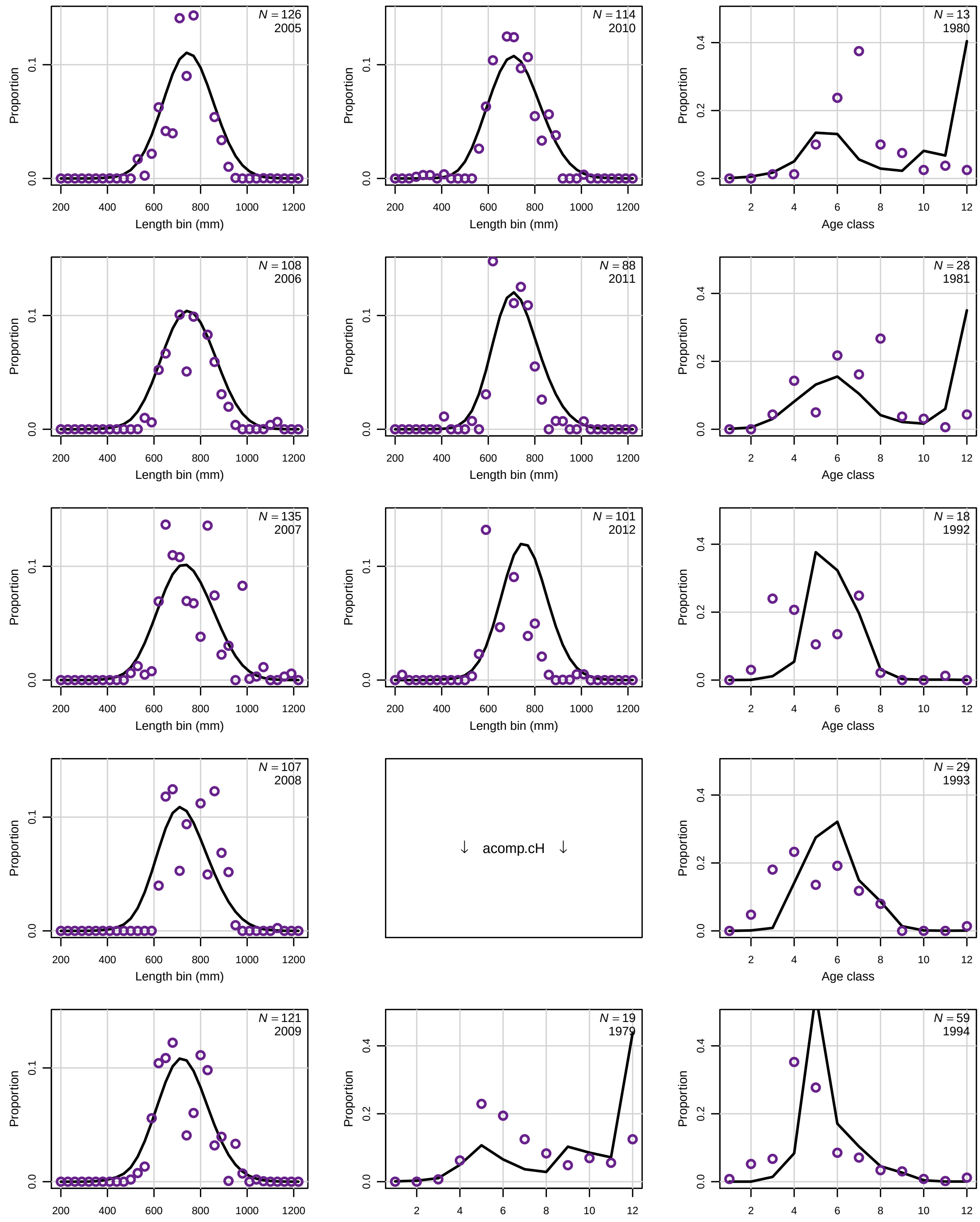


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

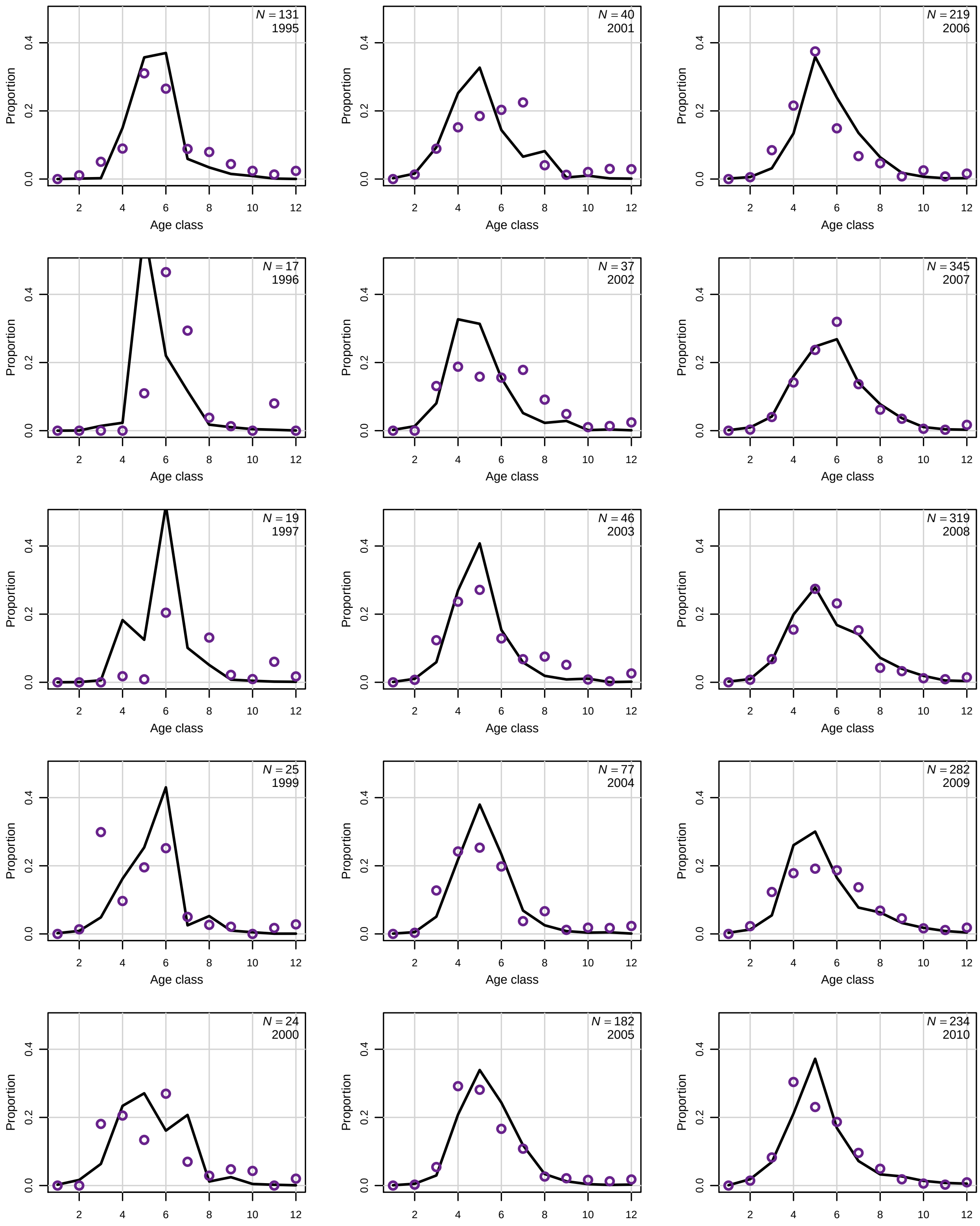


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

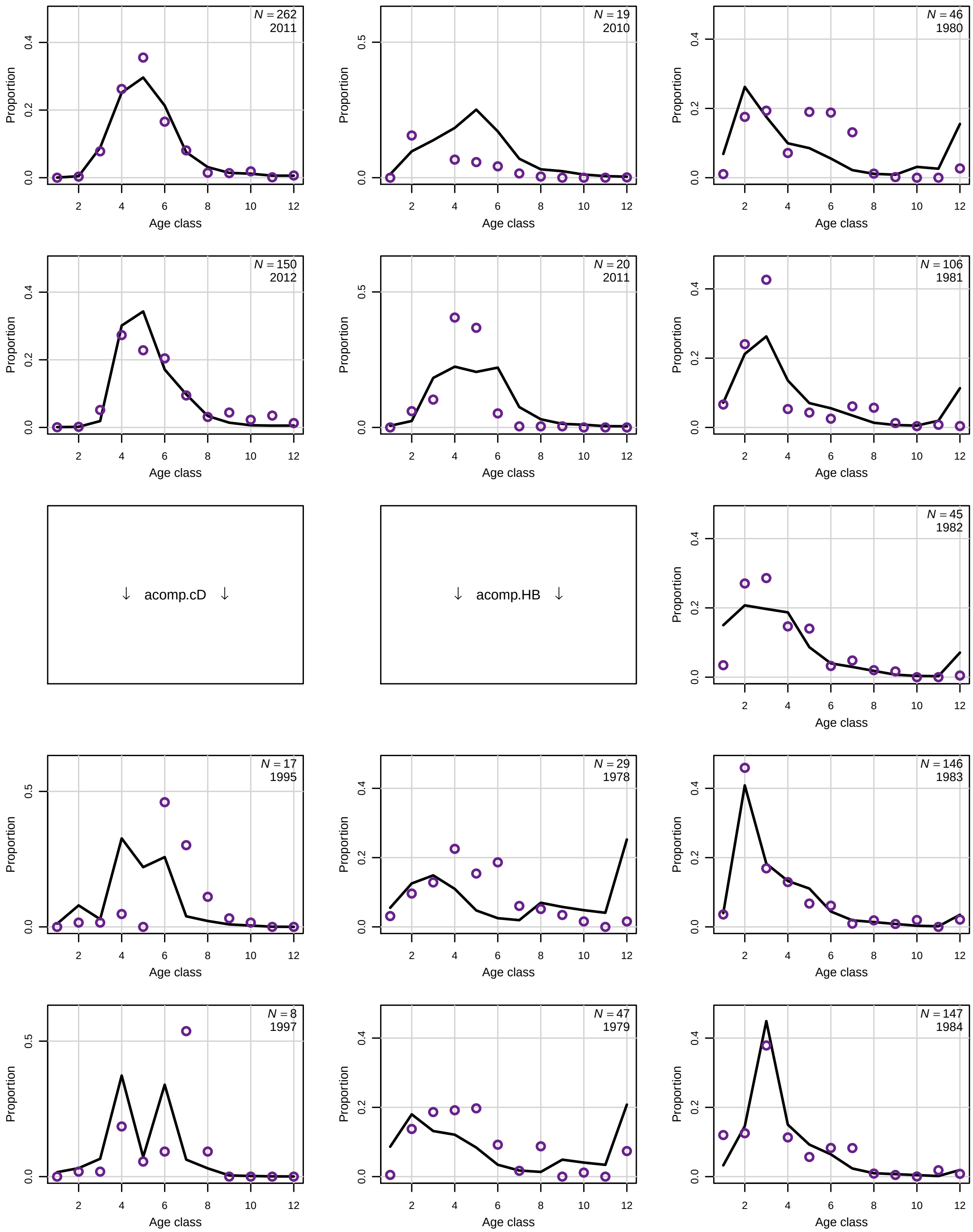


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

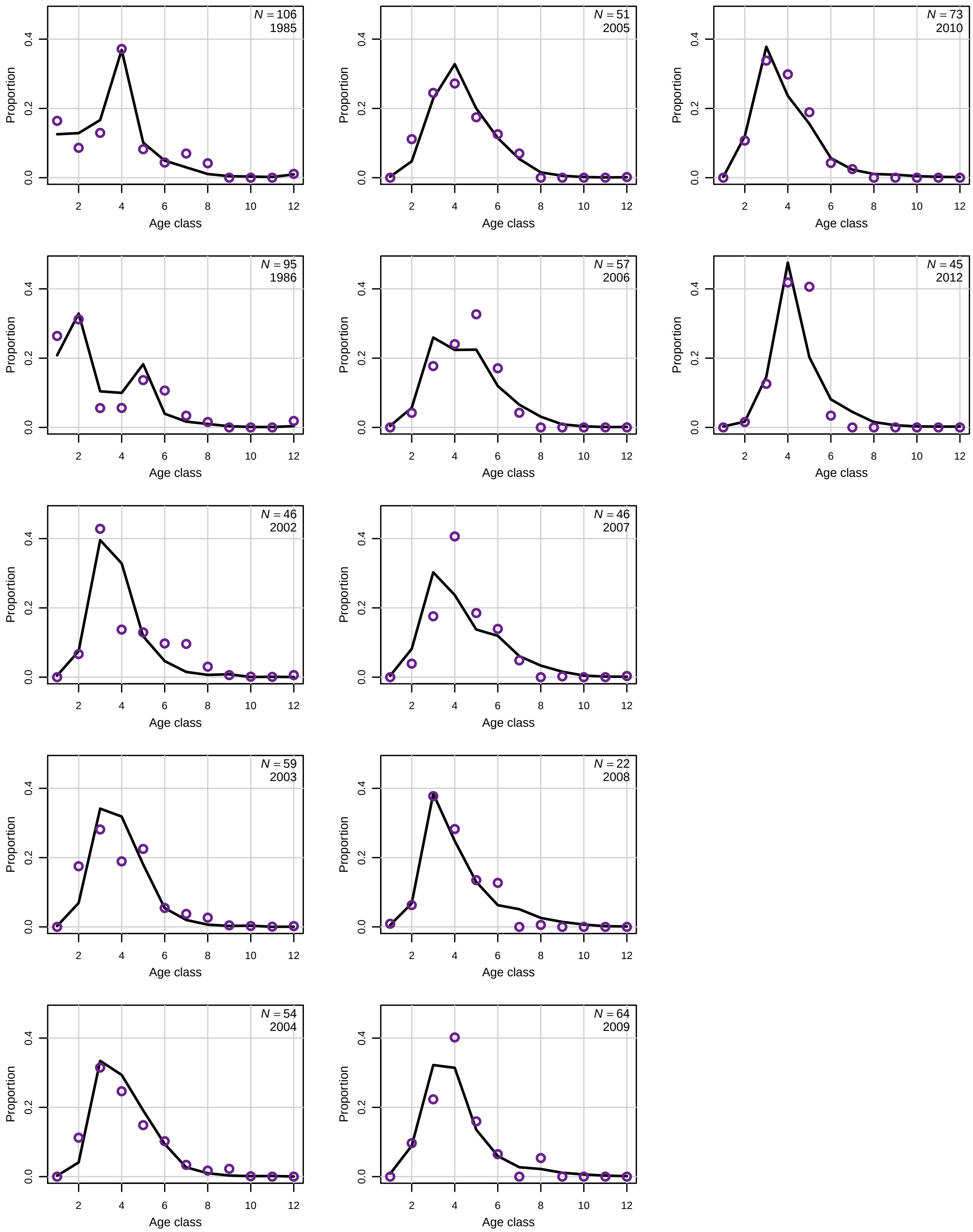


Figure 4. Observed (open circles) and estimated (solid line, circles) commercial handline landings (1000 lb gutted weight). Open and solid circles may be indistinguishable in years with very close fits.

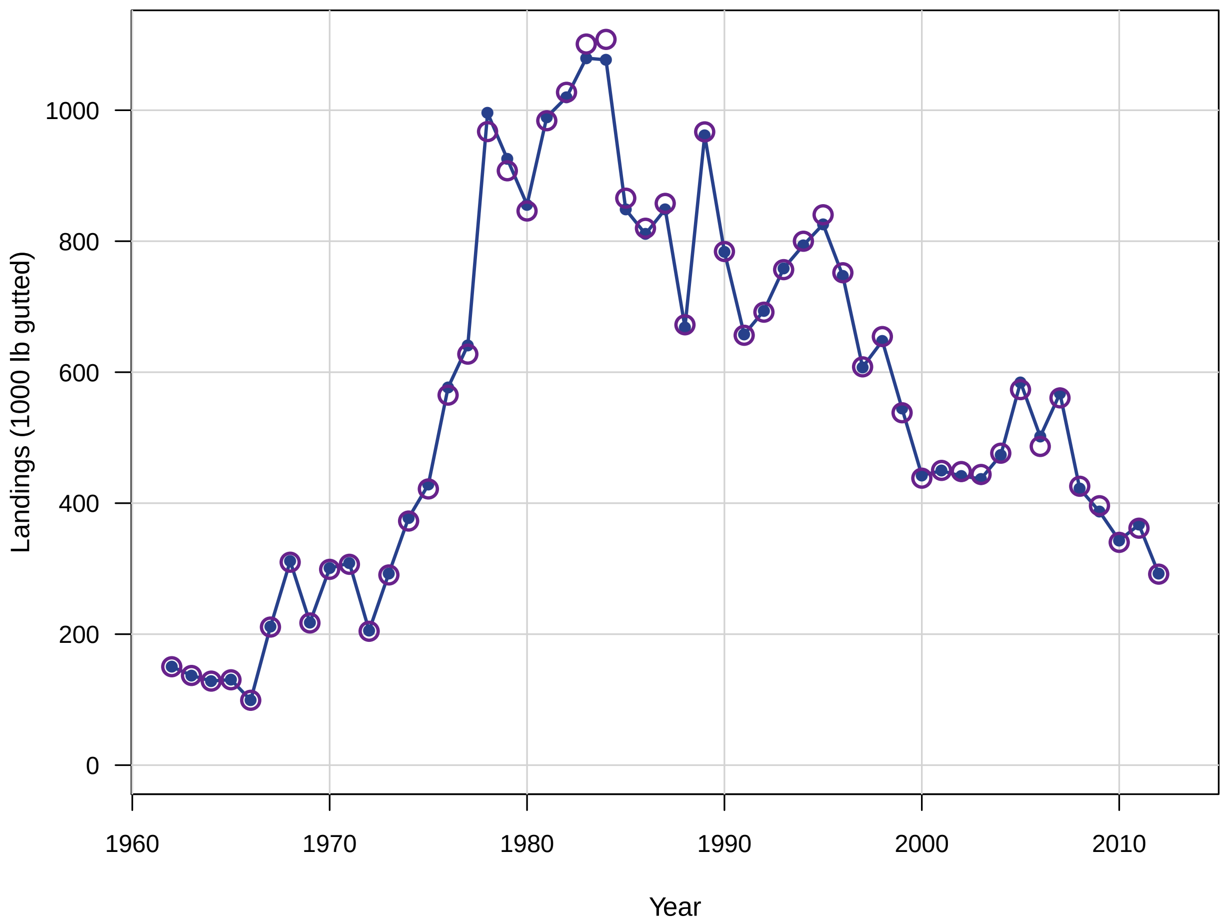


Figure 5. Observed (open circles) and estimated (solid line, circles) commercial diving (1000 lb gutted weight). Open and solid circles may be indistinguishable in years with very close fits.

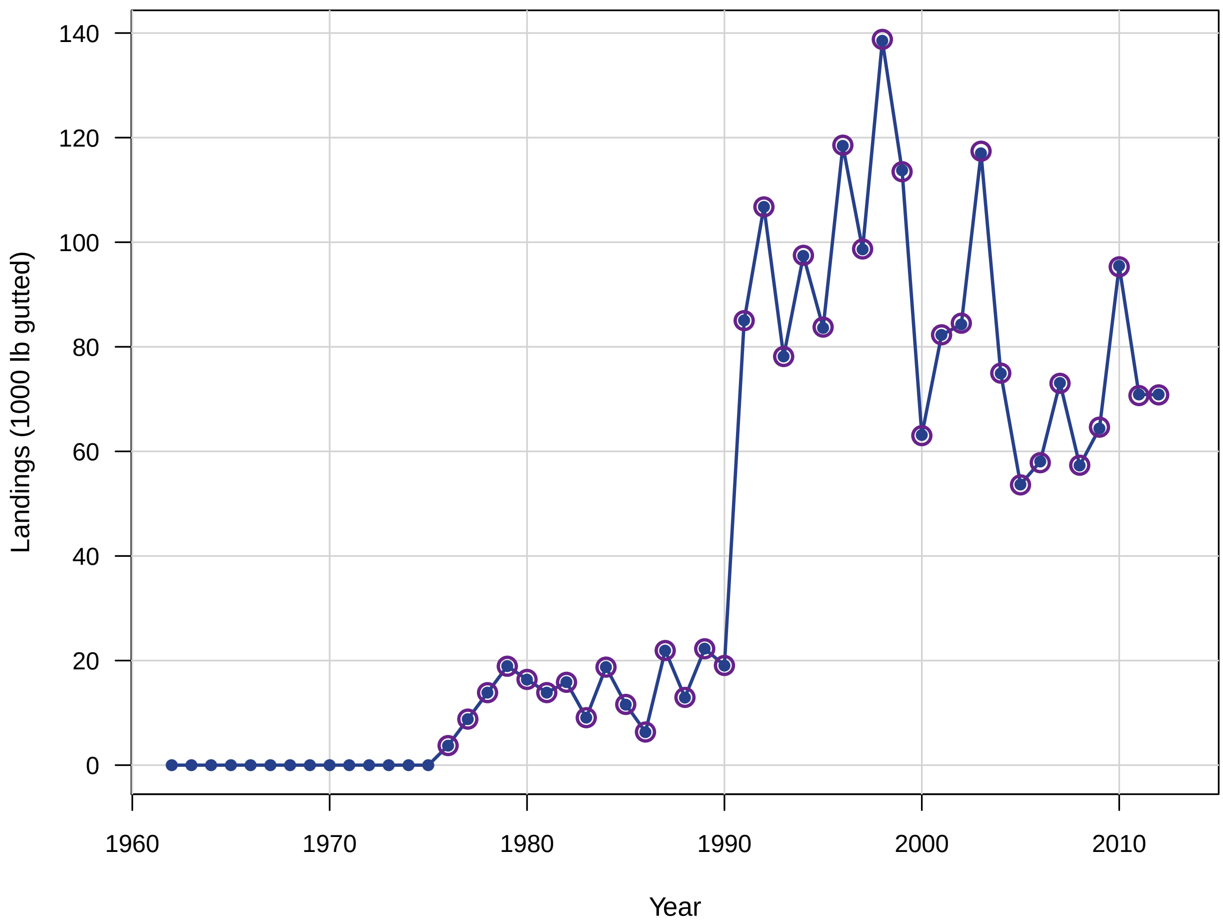


Figure 6. Observed (open circles) and estimated (solid line, circles) headboat landings (1000 fish). Open and solid circles may be indistinguishable in years with very close fits.

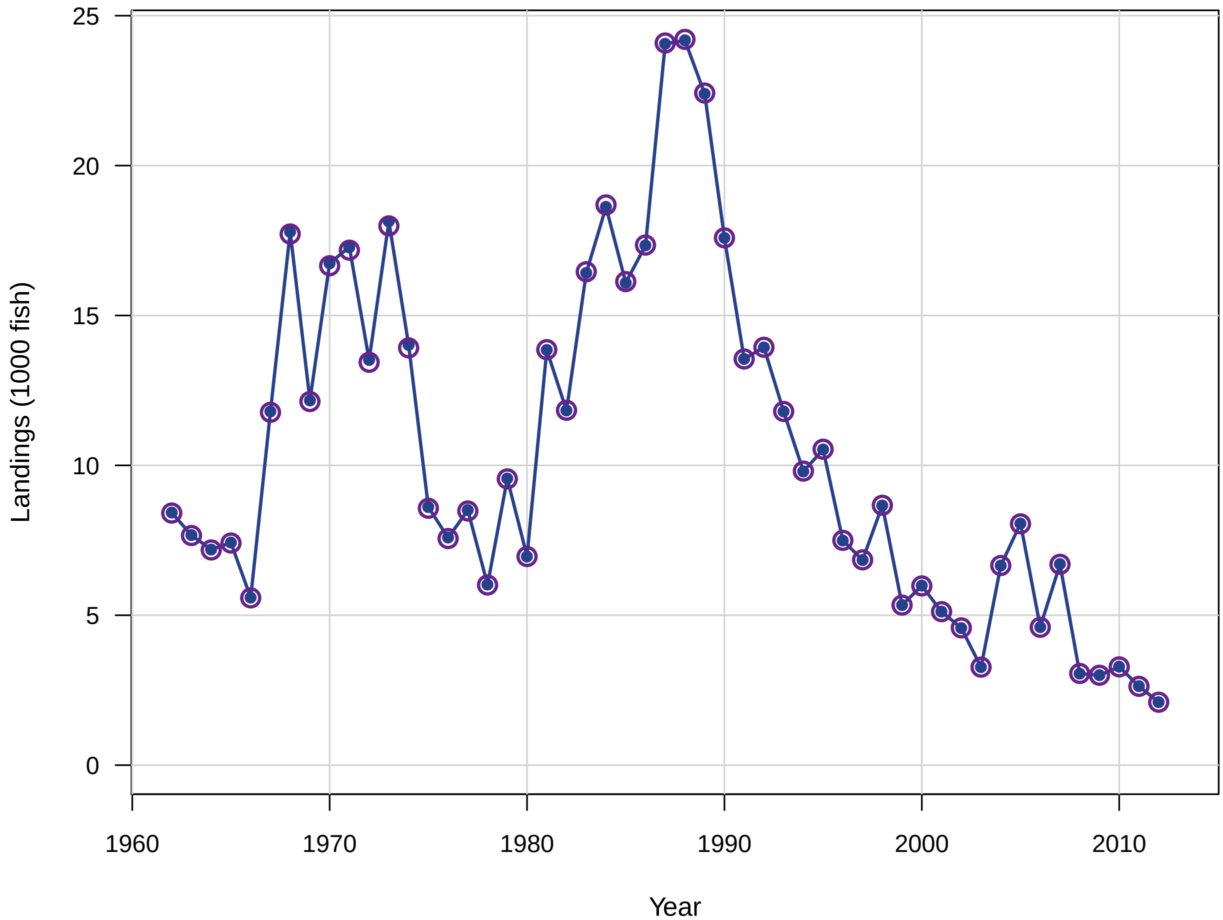


Figure 7. Observed (open circles) and estimated (solid line, circles) general recreational landings (1000 fish). Open and solid circles may be indistinguishable in years with very close fits.

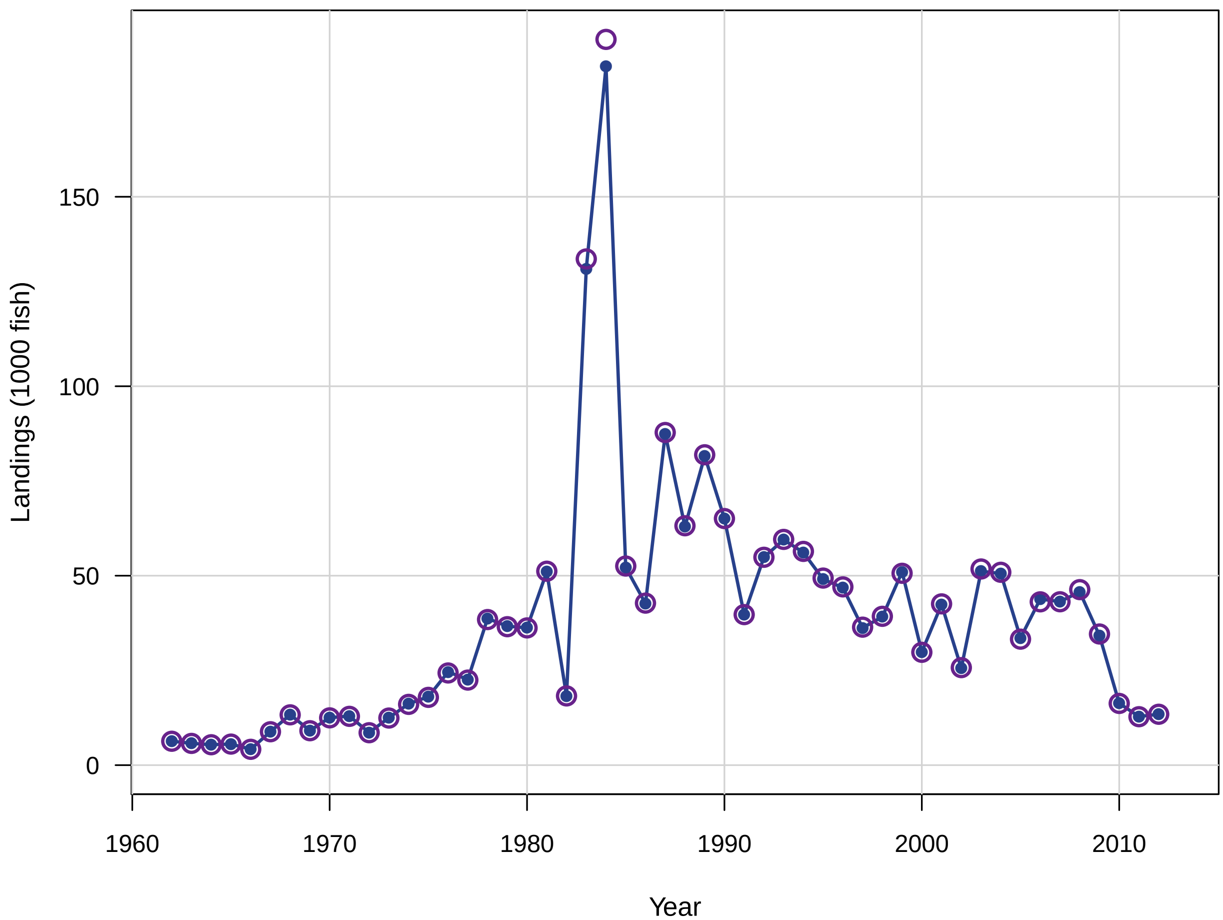


Figure 8. Observed (open circles) and estimated (solid line, circles) commercial handline discard mortalities (1000 dead fish). Open and solid circles may be indistinguishable in years with very close fits.

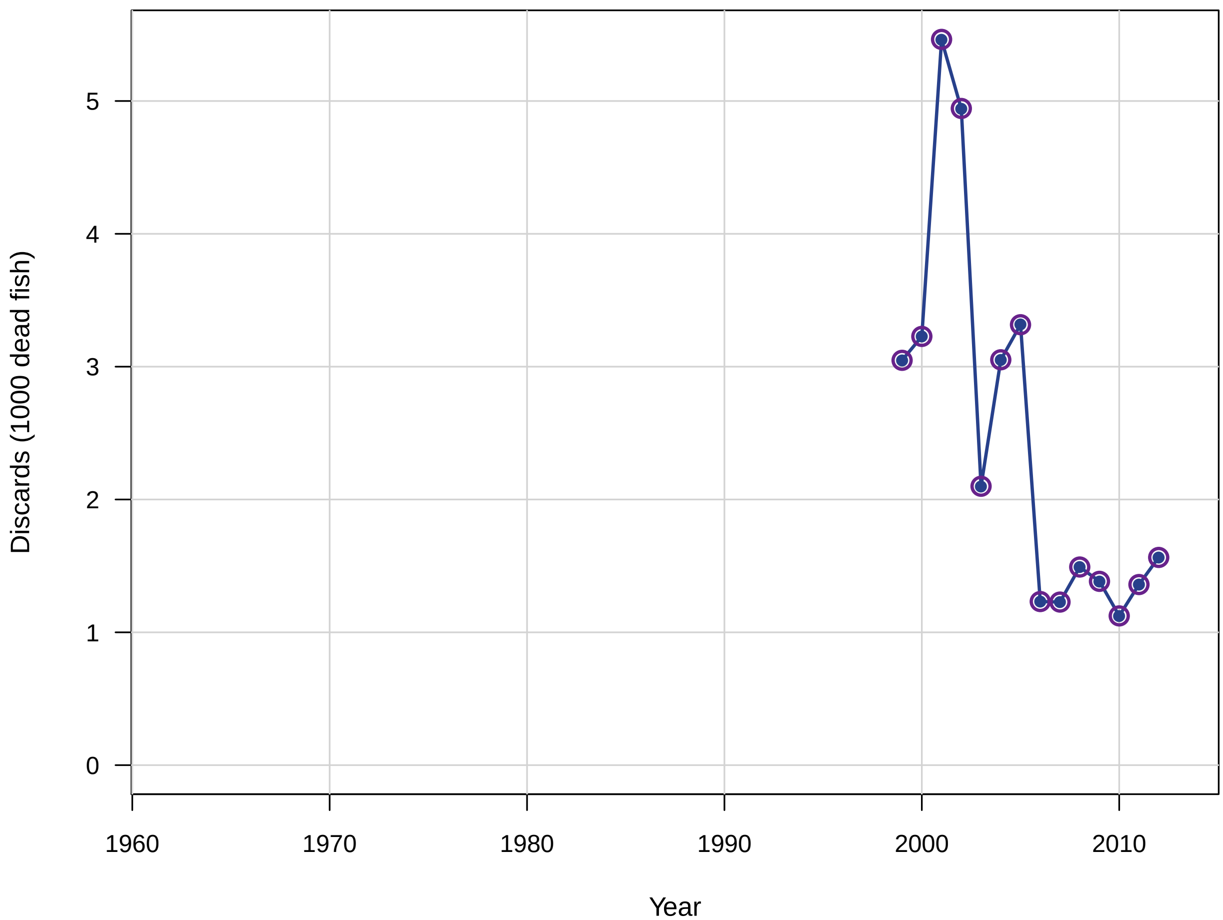


Figure 9. Observed (open circles) and estimated (solid line, circles) headboat discard mortalities (1000 dead fish). Open and solid circles may be indistinguishable in years with very close fits.

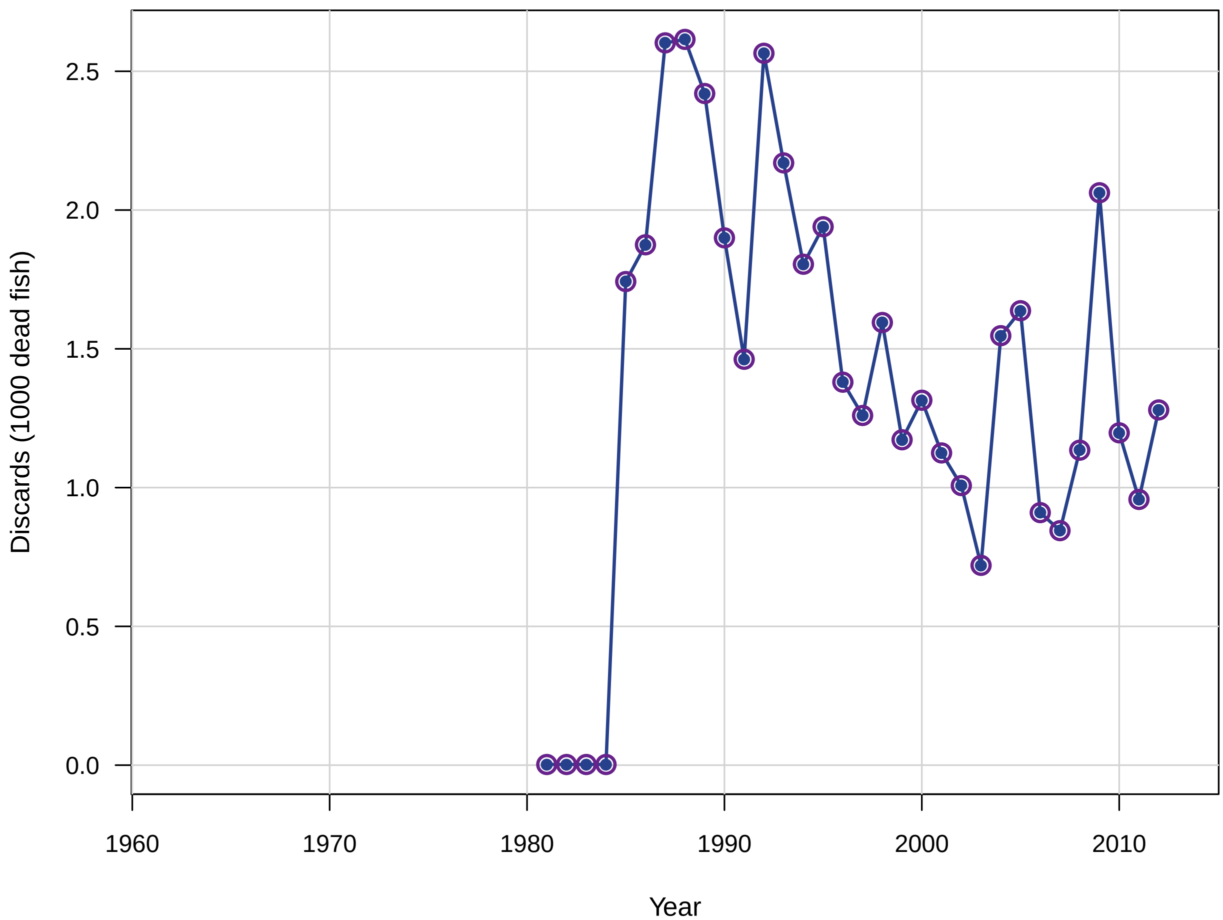


Figure 10. Observed (open circles) and estimated (solid line, circles) general recreational discard mortalities (1000 dead fish). Open and solid circles may be indistinguishable in years with very close fits.

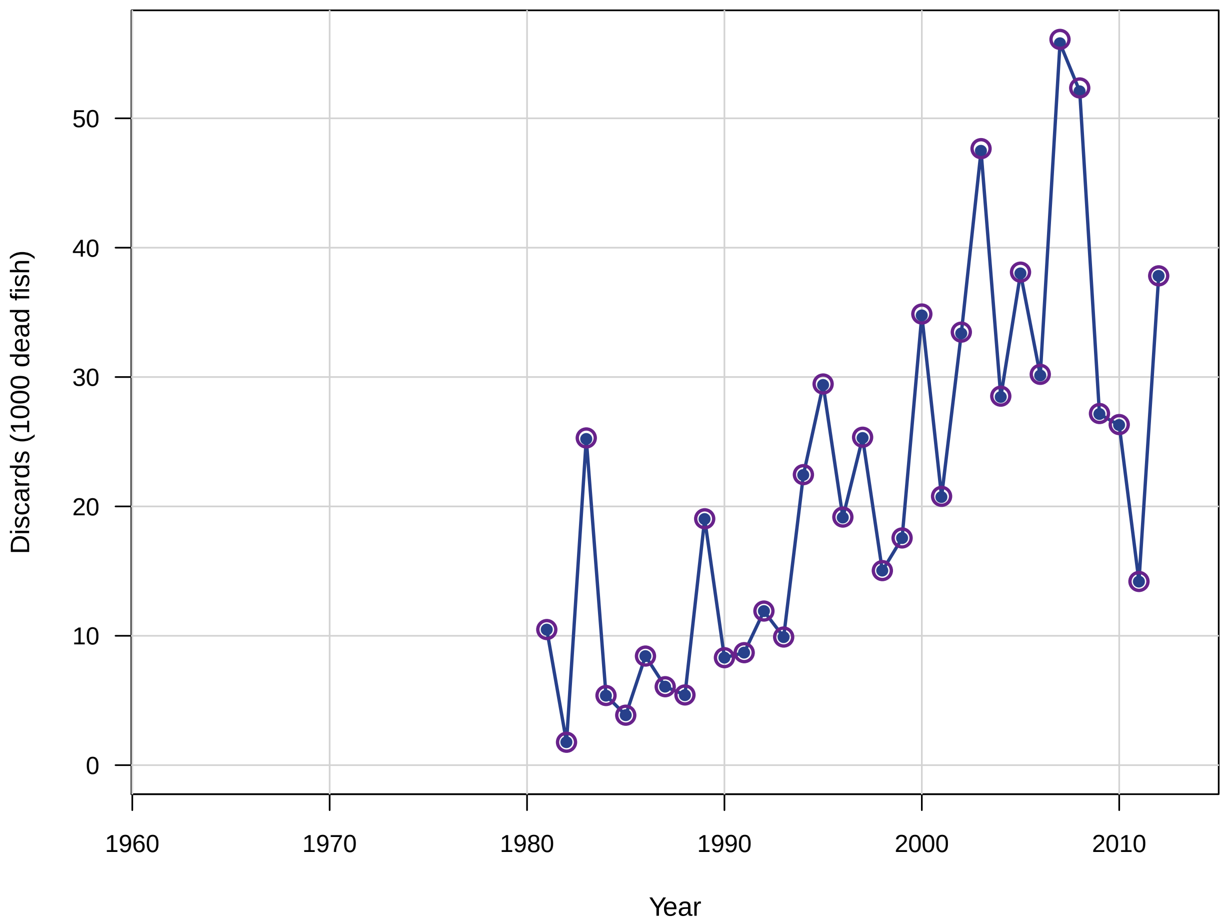


Figure 11. Observed (open circles) and estimated (solid line, circles) index of abundance from commercial handline.

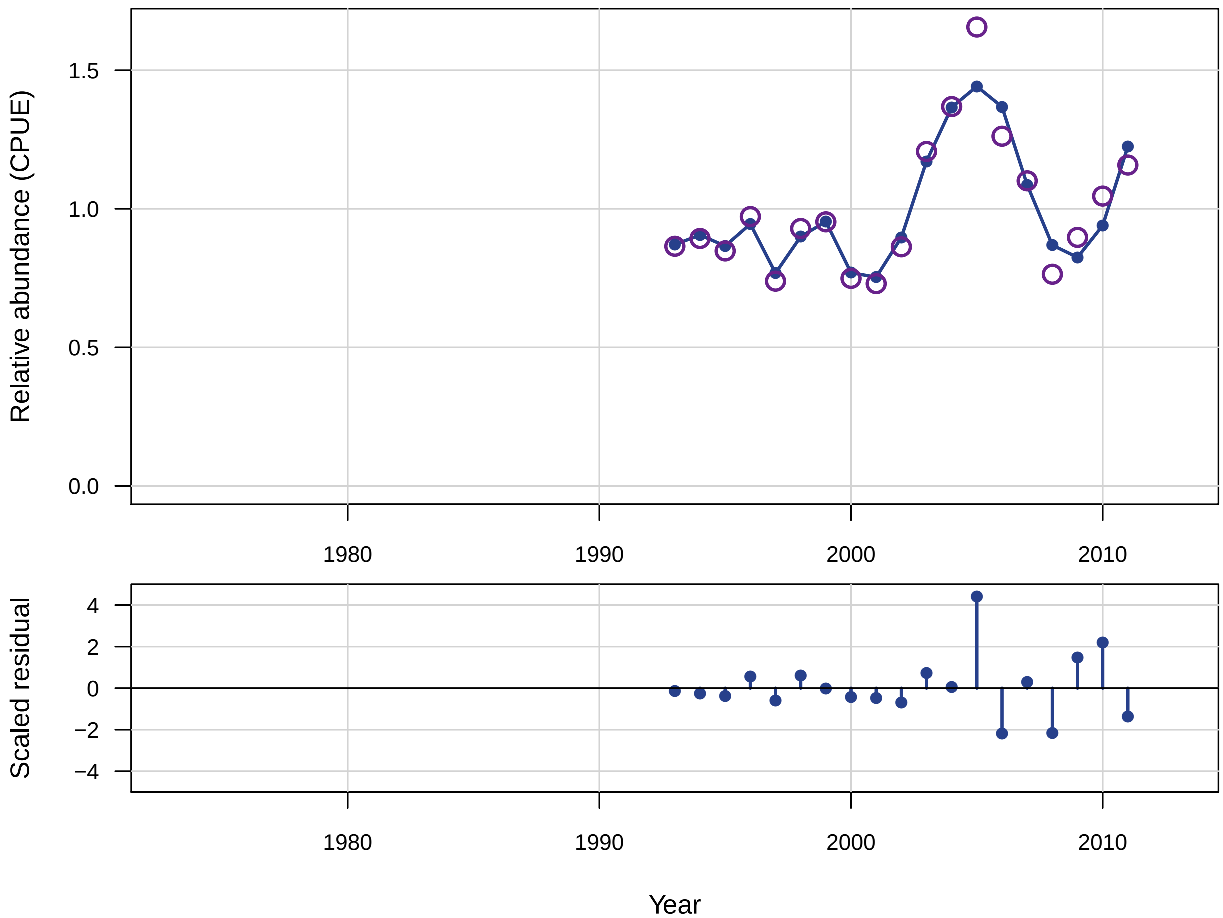


Figure 12. Observed (open circles) and estimated (solid line, circles) index of abundance from headboat.

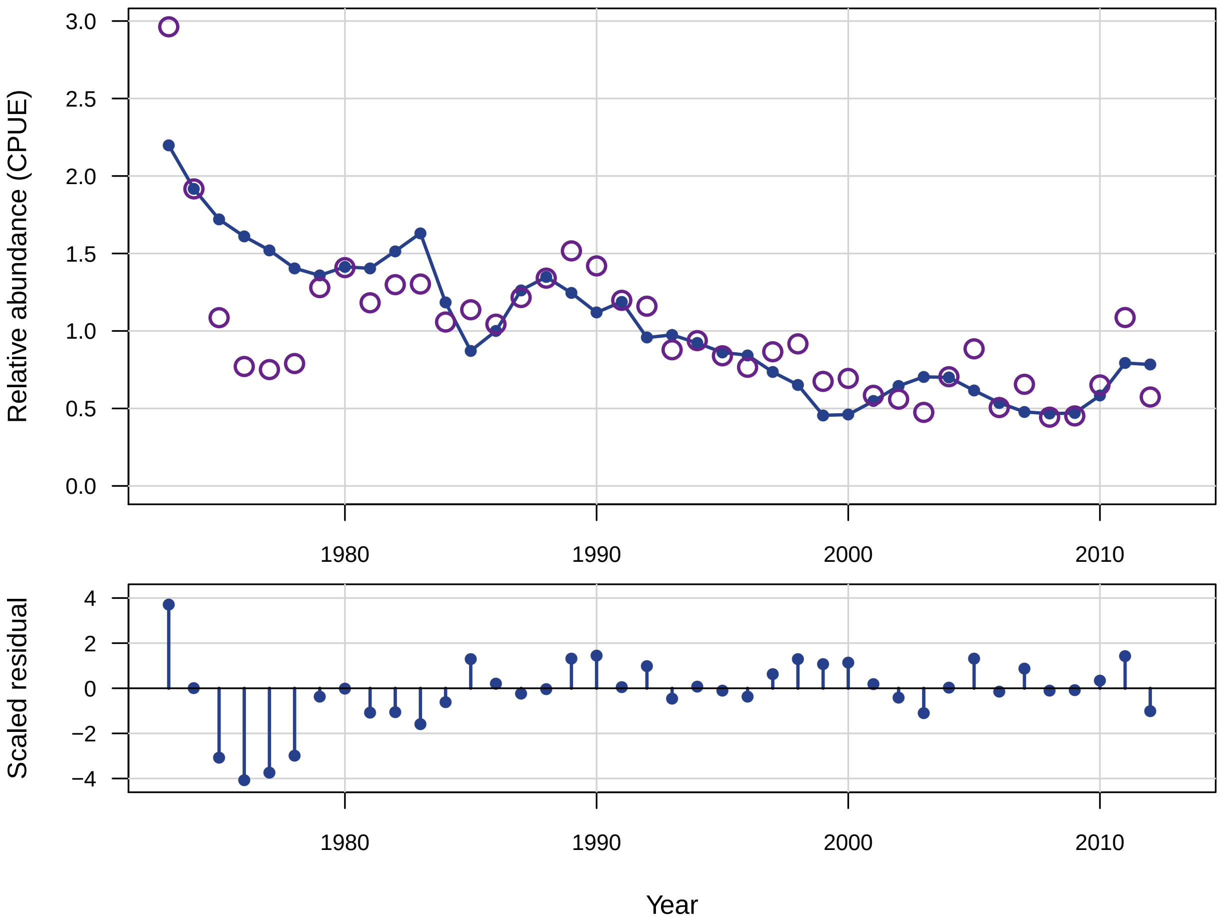


Figure 13. Observed (open circles) and estimated (solid line, circles) index of abundance from general recreational.

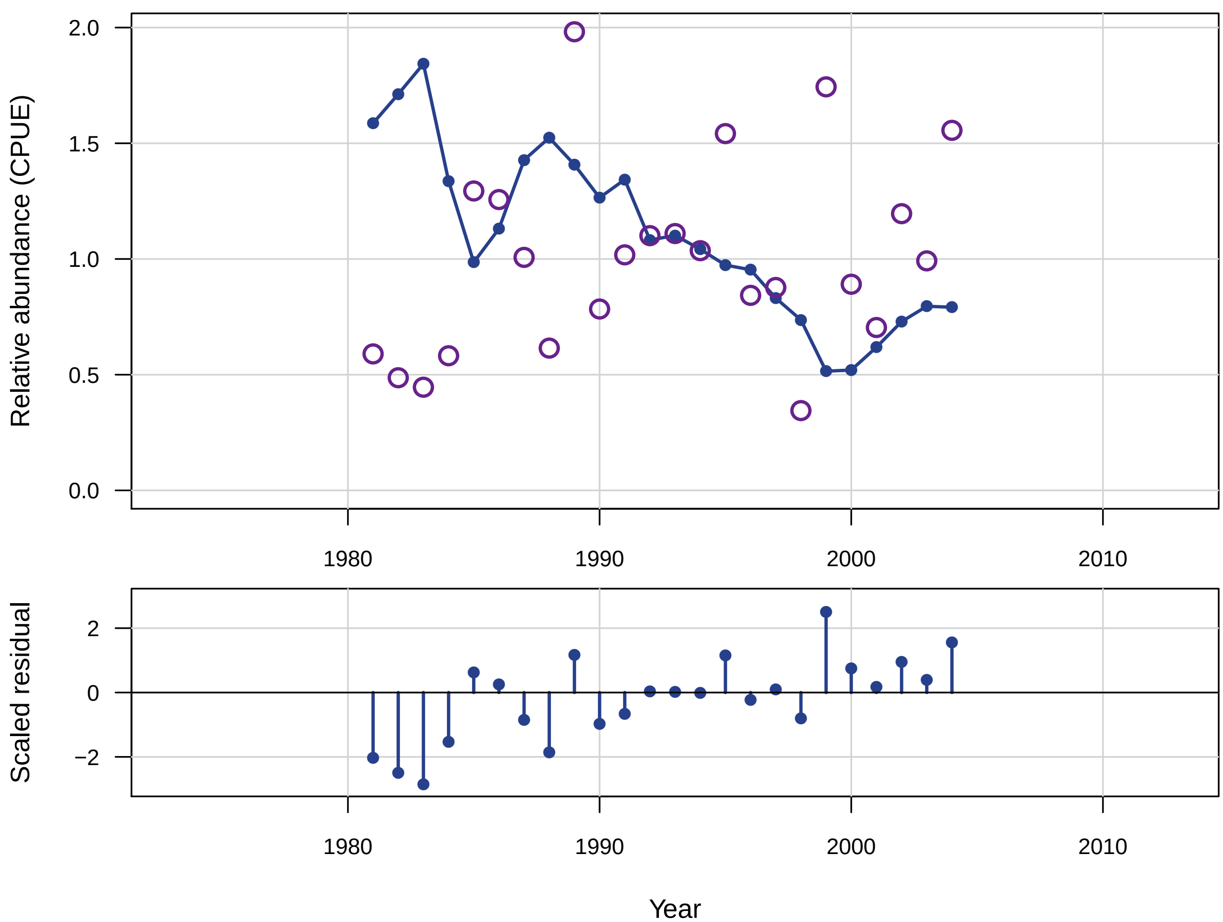


Figure 14. Estimated abundance at age at start of year.

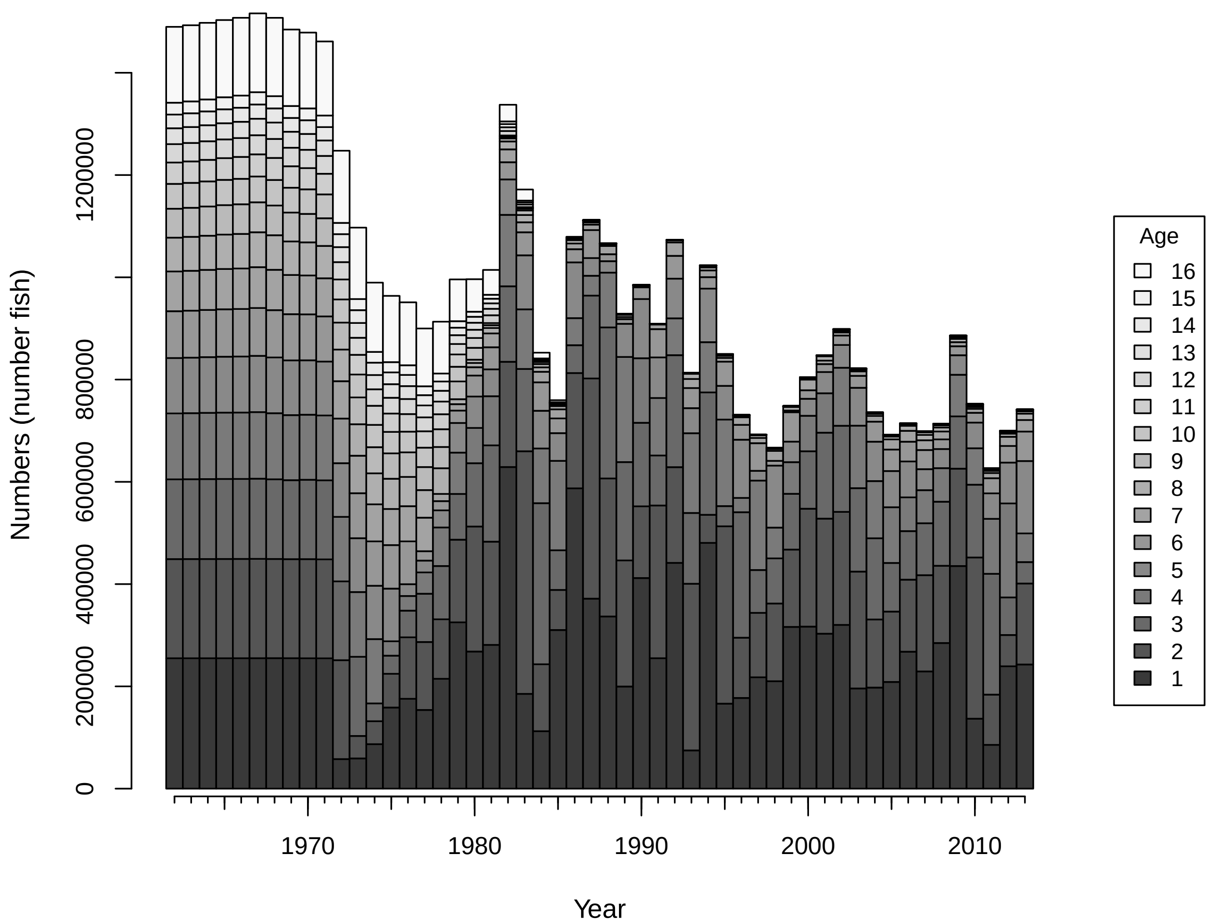


Figure 15. Top panel: Estimated recruitment of age-1 fish. Horizontal dashed line indicates R_{MSY}. Bottom panel: log recruitment deviations (residuals).

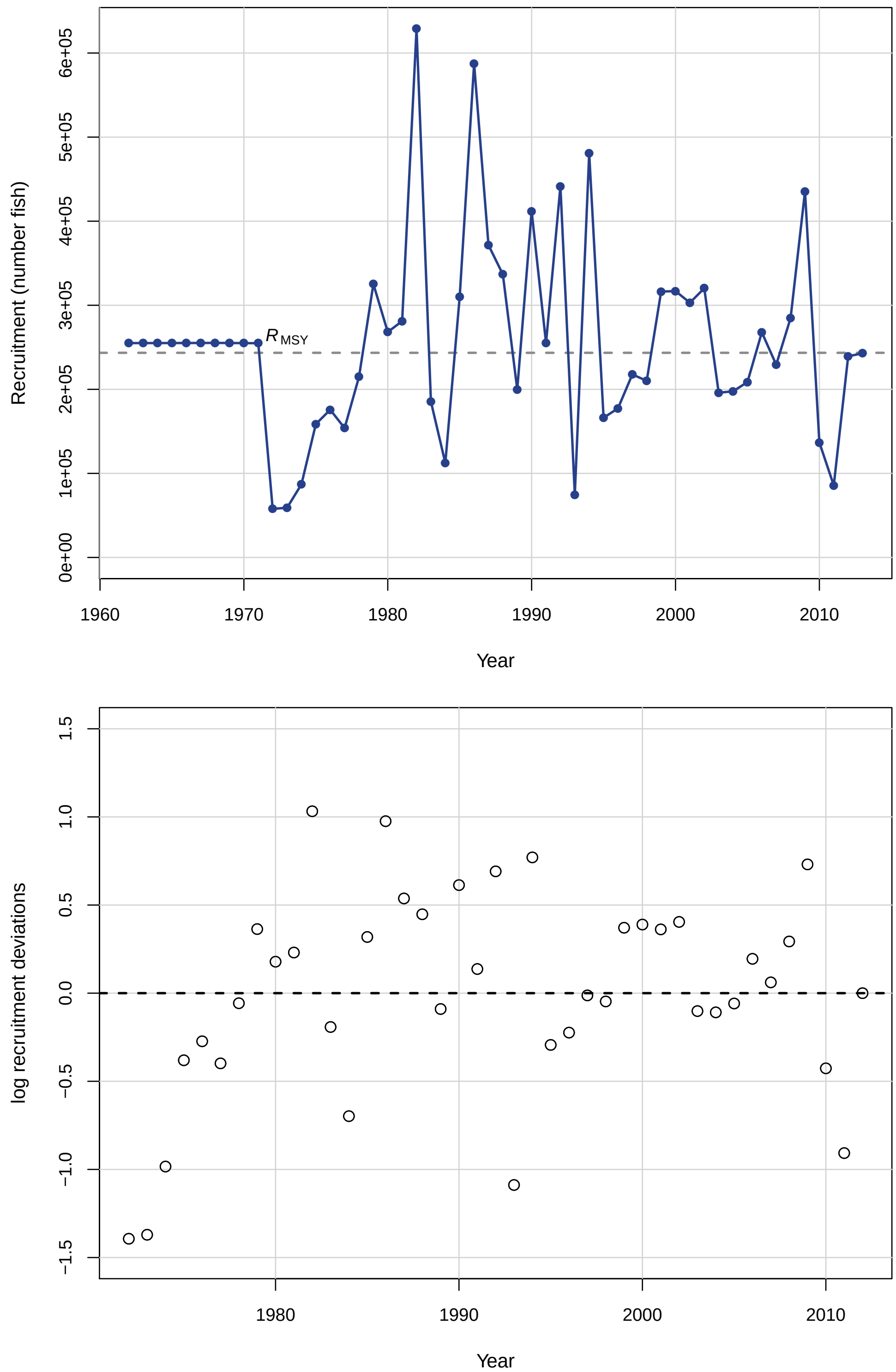


Figure 16. Estimated biomass at age at start of year.

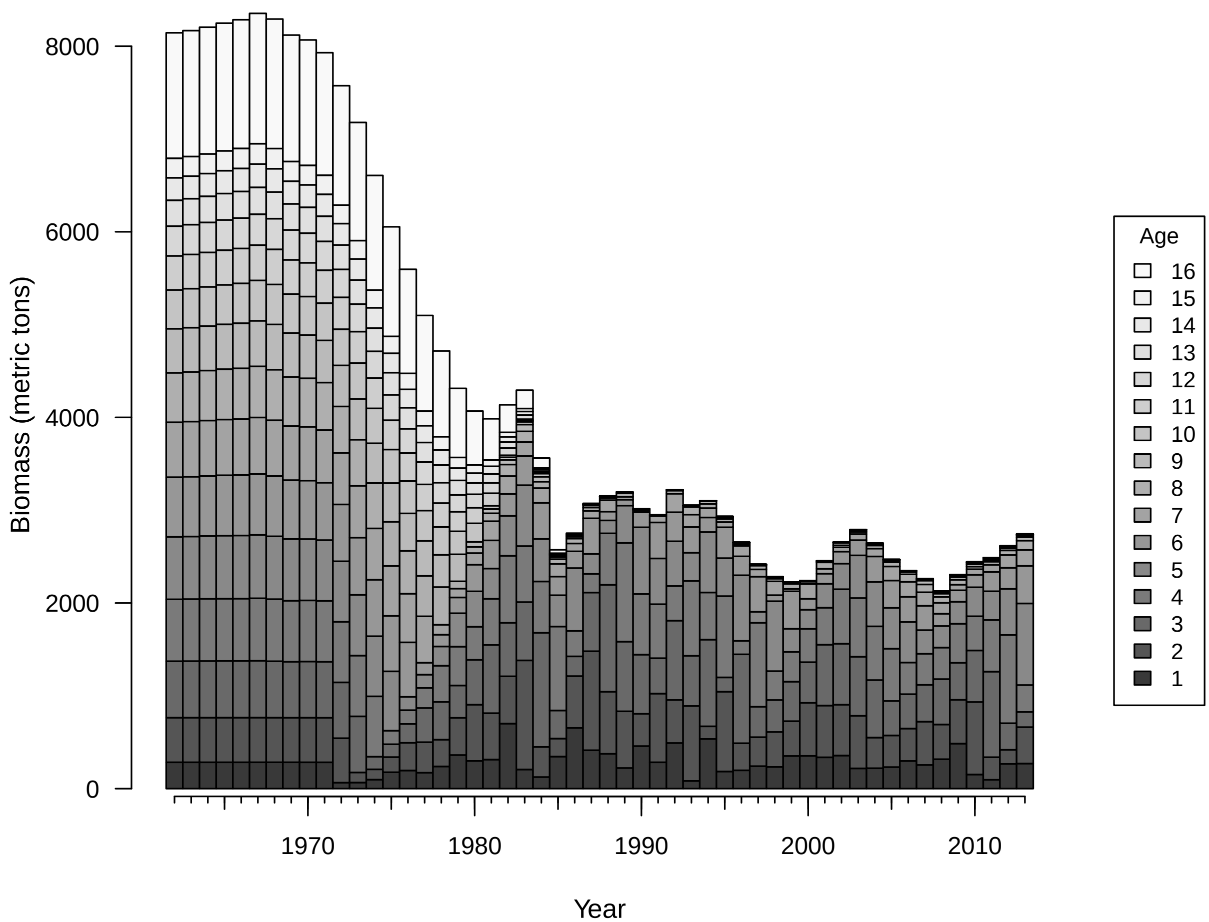


Figure 17. Top panel: Estimated total biomass (mt) at start of year. Horizontal dashed line indicates B_{MSY}*. Bottom panel: Estimated spawning stock (total mature biomass, mt) at start of year, with the horizontal* MSST *line defined as* MSST $=(1\text{-}M)\mathrm{SSB}_{\mathrm{MSY}}$.

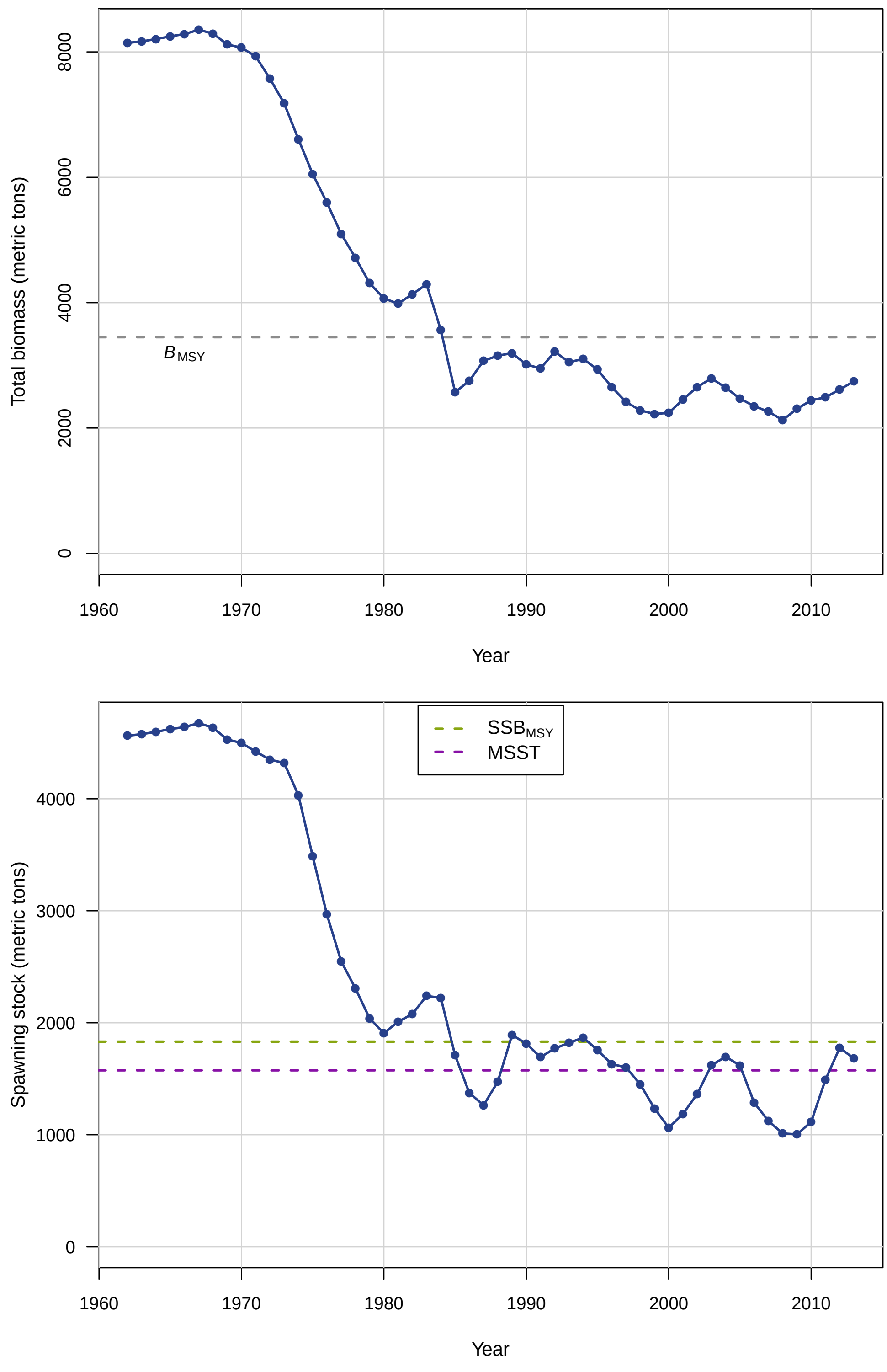


Figure 18. Estimated selectivities of commercial handline. Top panel: period 1 (prior to 1992, no size limit). Middle panel: period 2 (1992–1998, 20-inch limit). Bottom panel: period 3 (1999–2012, 24-inch limit).

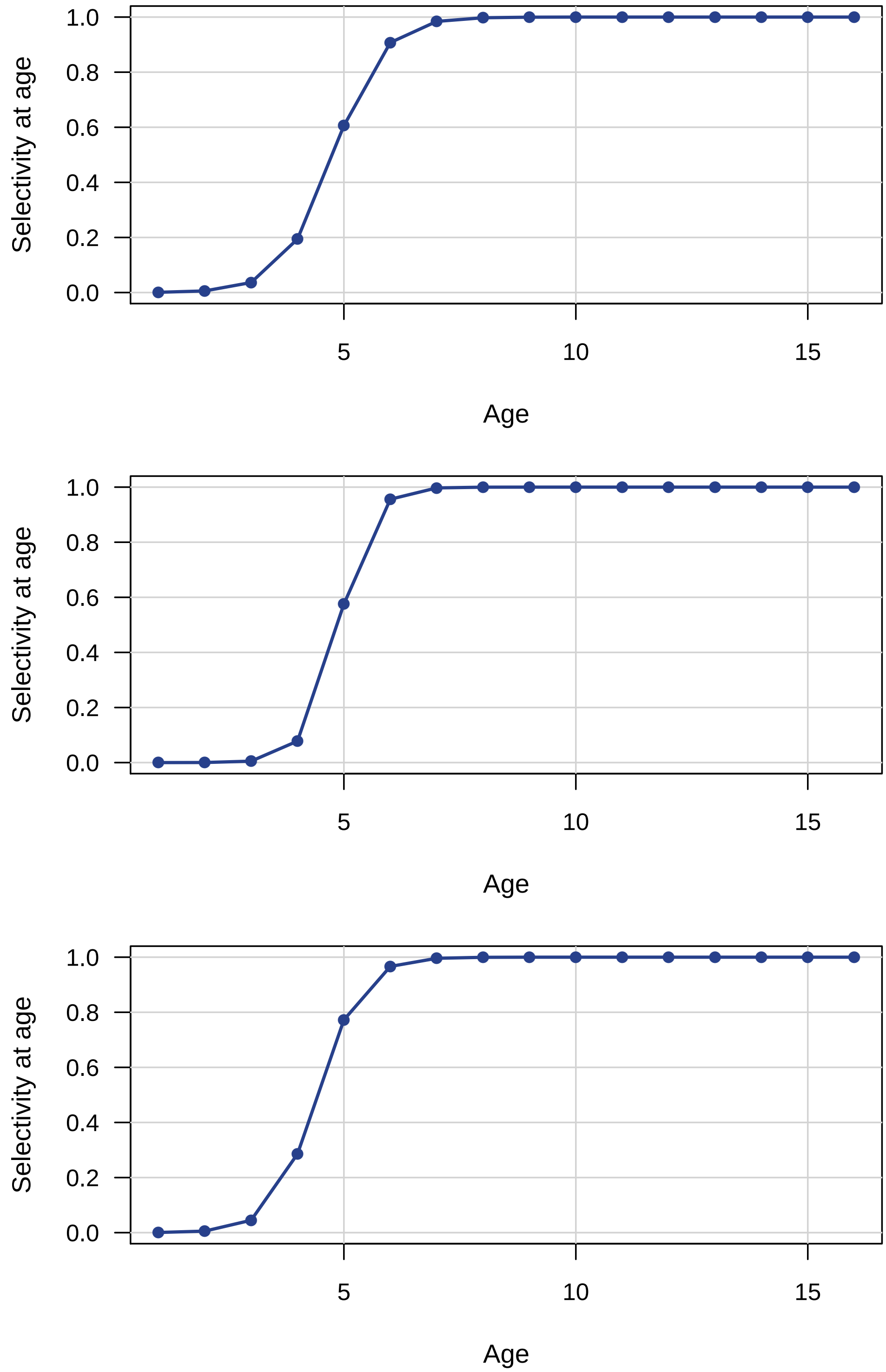


Figure 19. Selectivity of commercial diving.

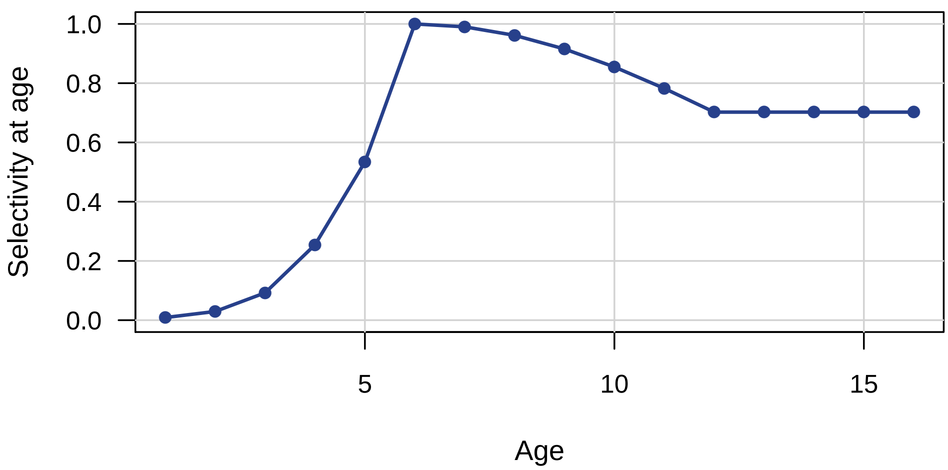


Figure 20. Estimated selectivities of the headboat and general recreational fleets. Top panel: period 1 (prior to 1992, no size limit). Middle panel: period 2 (1992–1998, 20-inch limit). Bottom panel: period 3 (1999–2012, 24-inch limit).

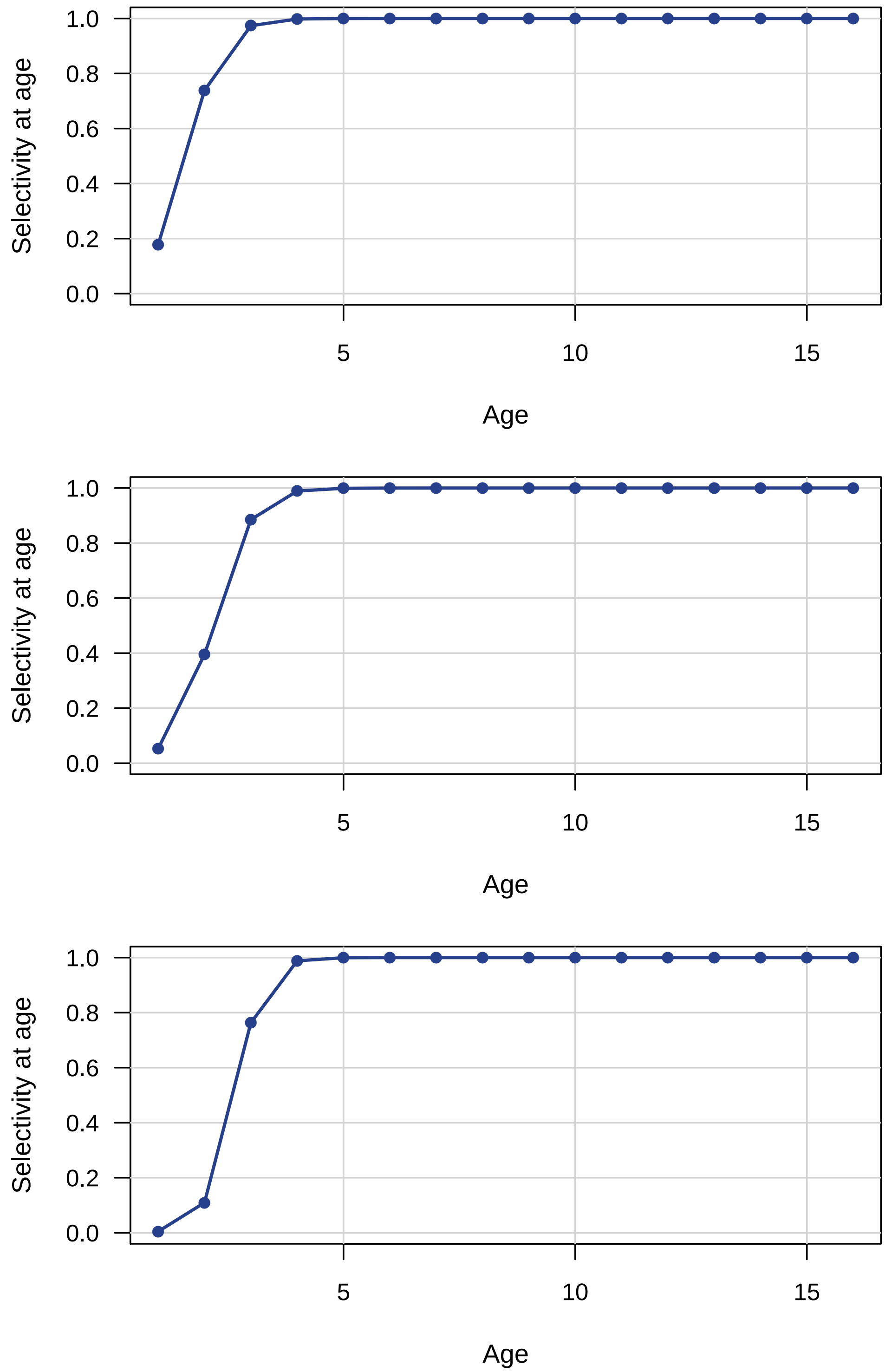


Figure 21. Selectivity of discard mortalities. Top panel: commercial handline. Bottom panel: headboat and general recreational.

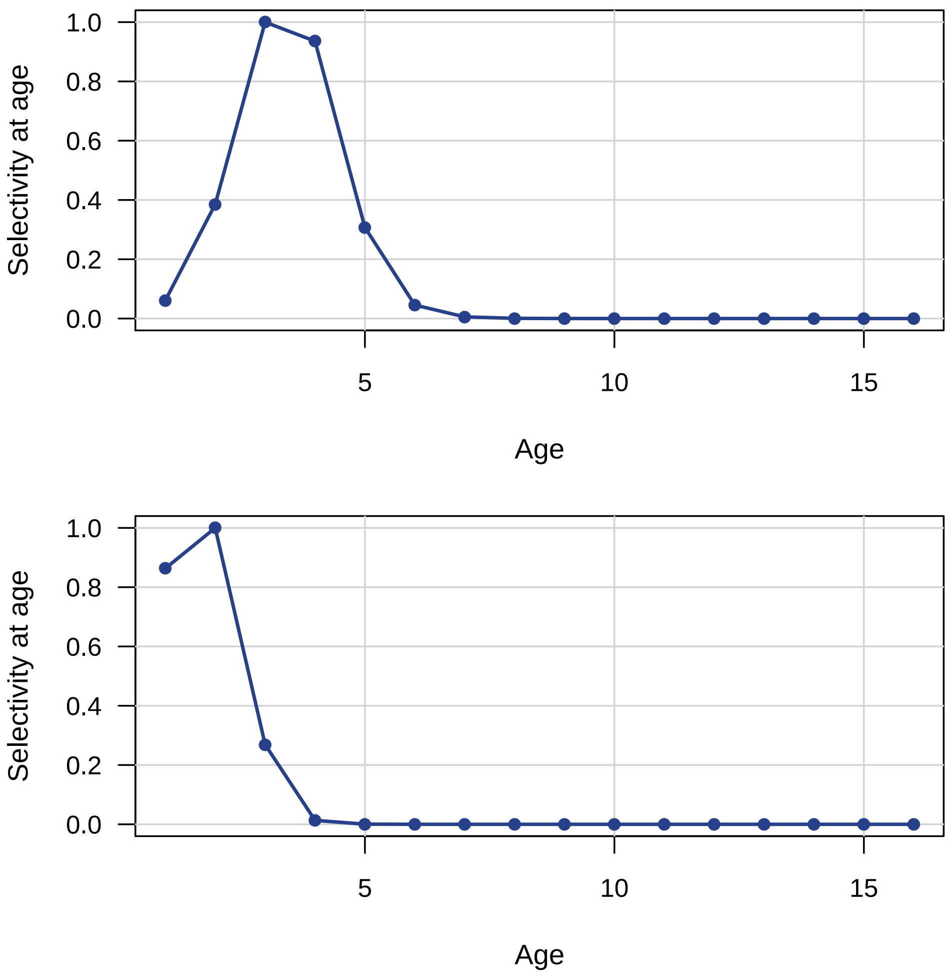


Figure 22. Average selectivities from the terminal assessment years, weighted by geometric mean Fs from the last three assessment years, and used in computation of benchmarks and projections. Top panel: average selectivity applied to landings. Middle panel: average selectivity applied to discard mortalities. Bottom panel: total average selectivity.

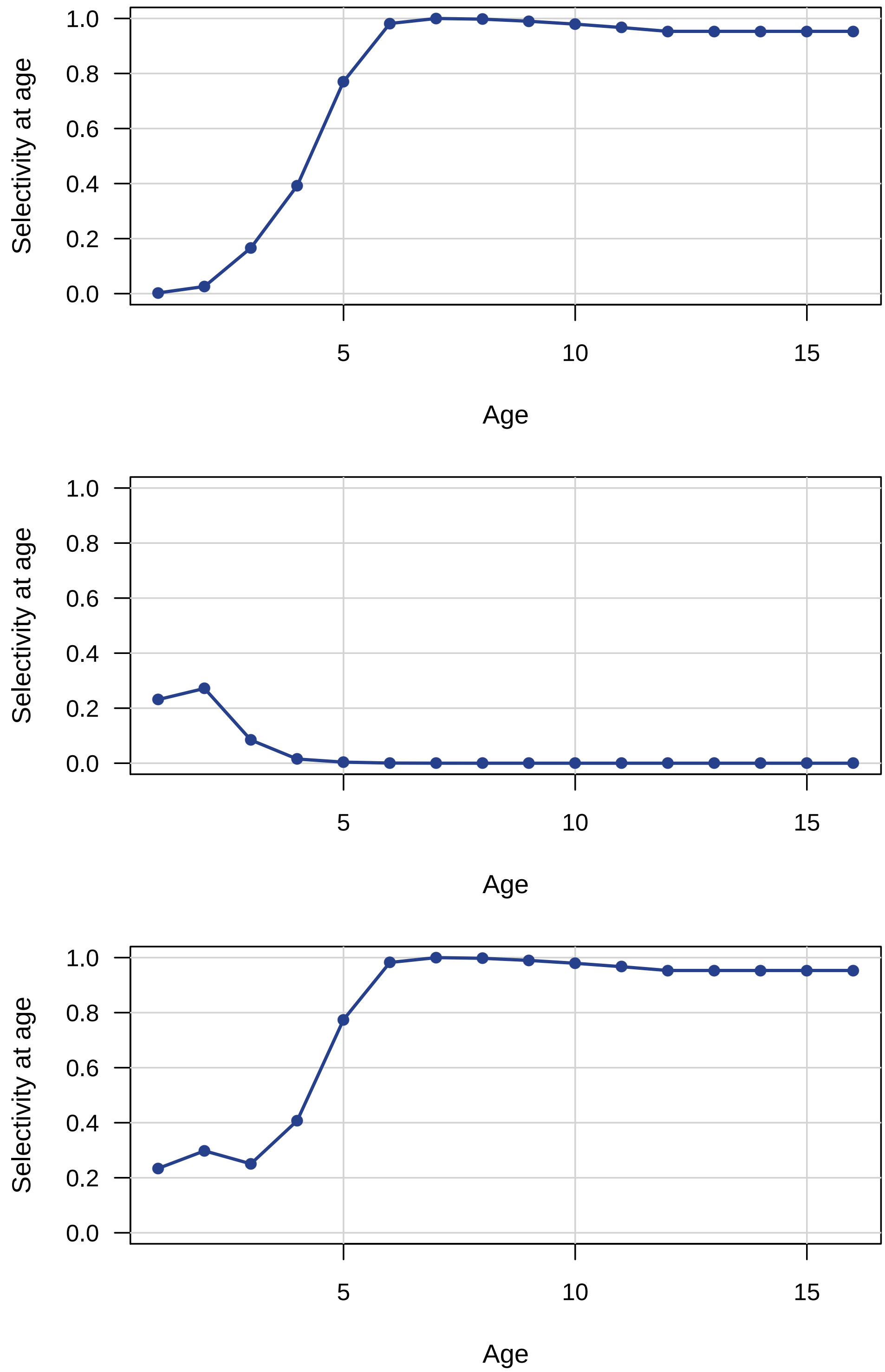


Figure 23. Estimated fully selected fishing mortality rate (per year) by fleet. cH refers to commercial handlines, cD to commercial diving, HB to headboat, GR to general recreational, cH.D to commercial discard mortalities, HB.D to headboat discard mortalities, and GR.D to general recreational discard mortalities.

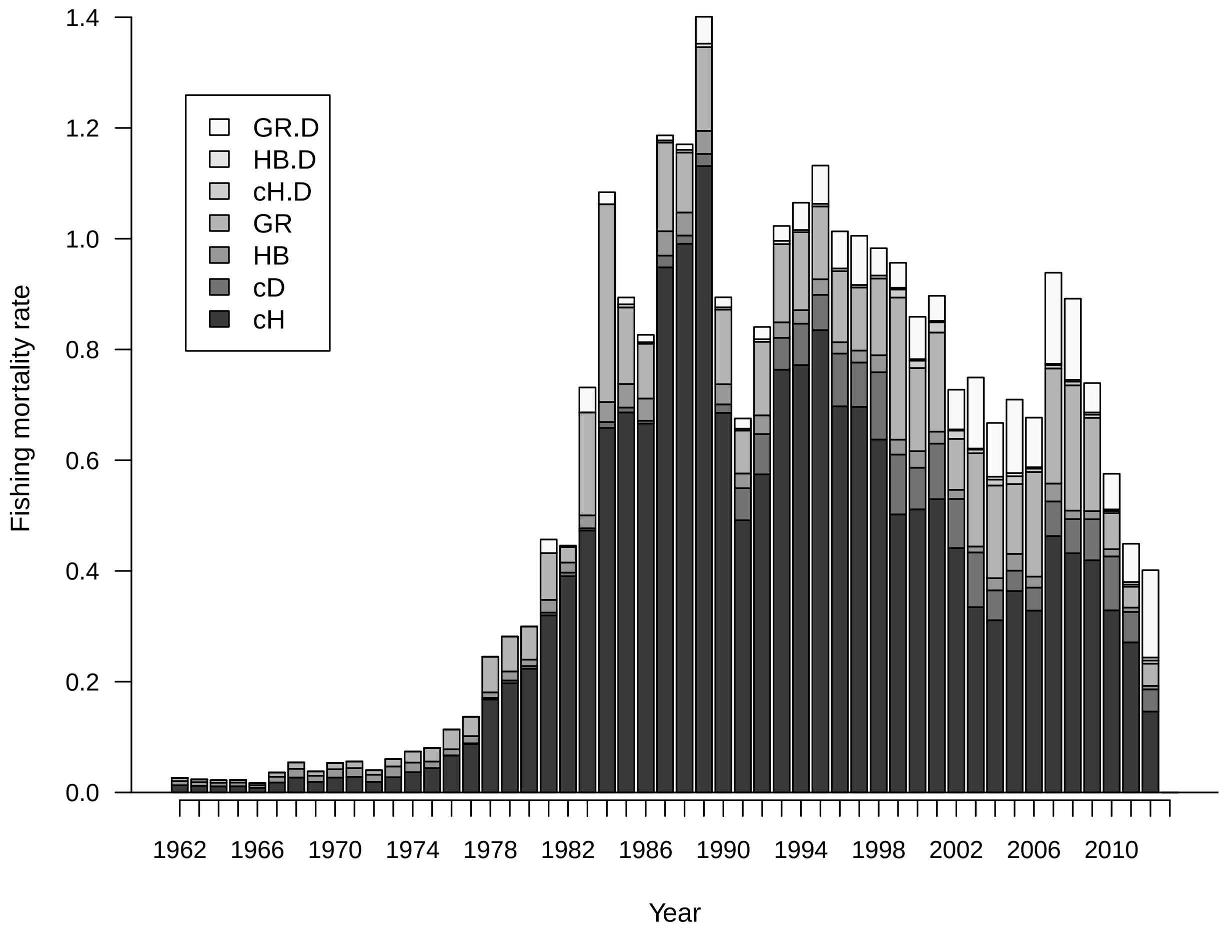


Figure 24. Estimated landings in numbers by fleet from the catch-age model. cH refers to commercial handlines, cD to commercial diving, HB to headboat, GR to general recreational.

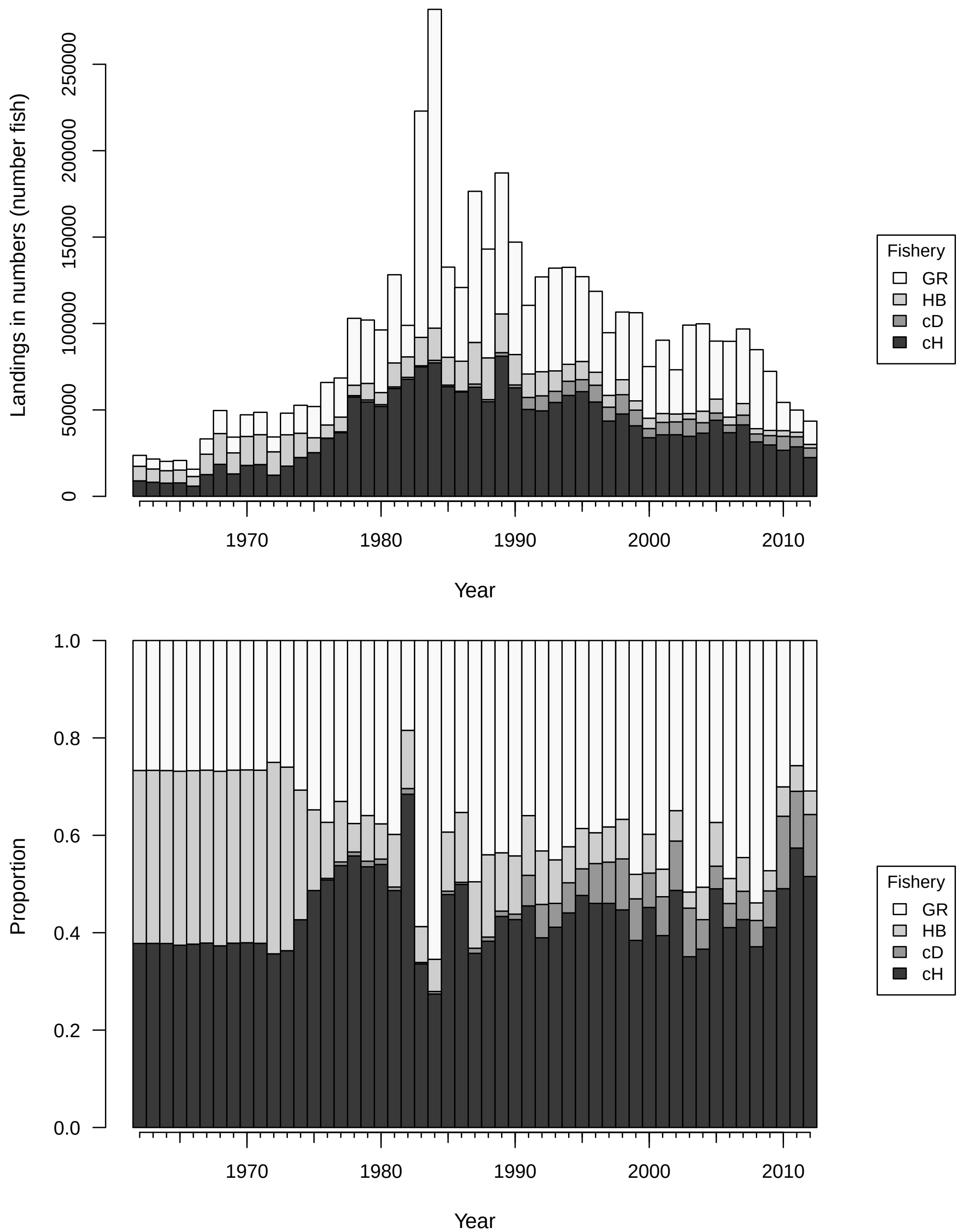


Figure 25. Estimated landings in gutted weight by fleet from the catch-age model. cH refers to commercial handlines, cD to commercial diving, HB to headboat, GR to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of MSY.

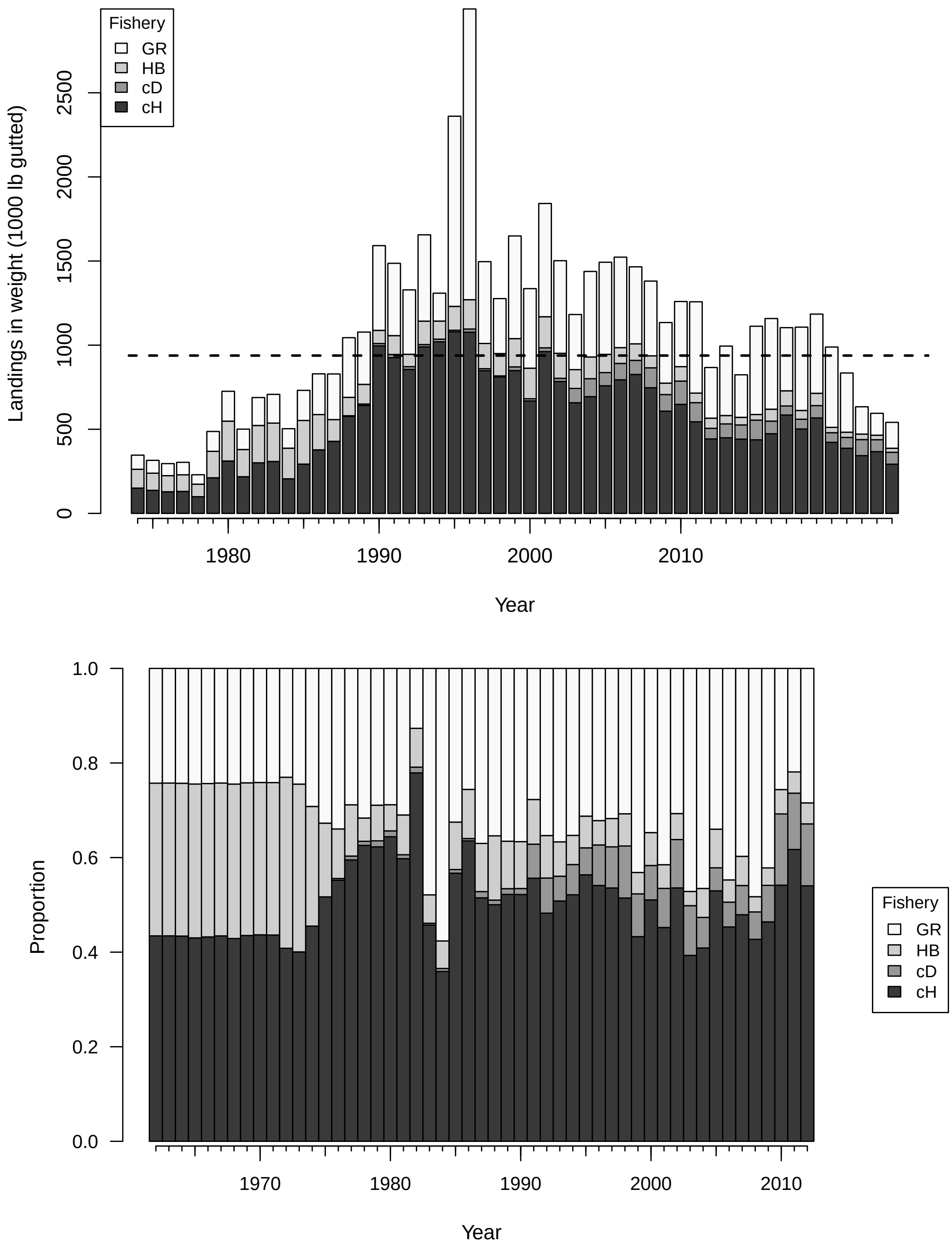


Figure 26. Estimated discard mortalities in numbers by fleet from the catch-age model. cH refers to commercial handlines, HB to headboat, GR to general recreational.

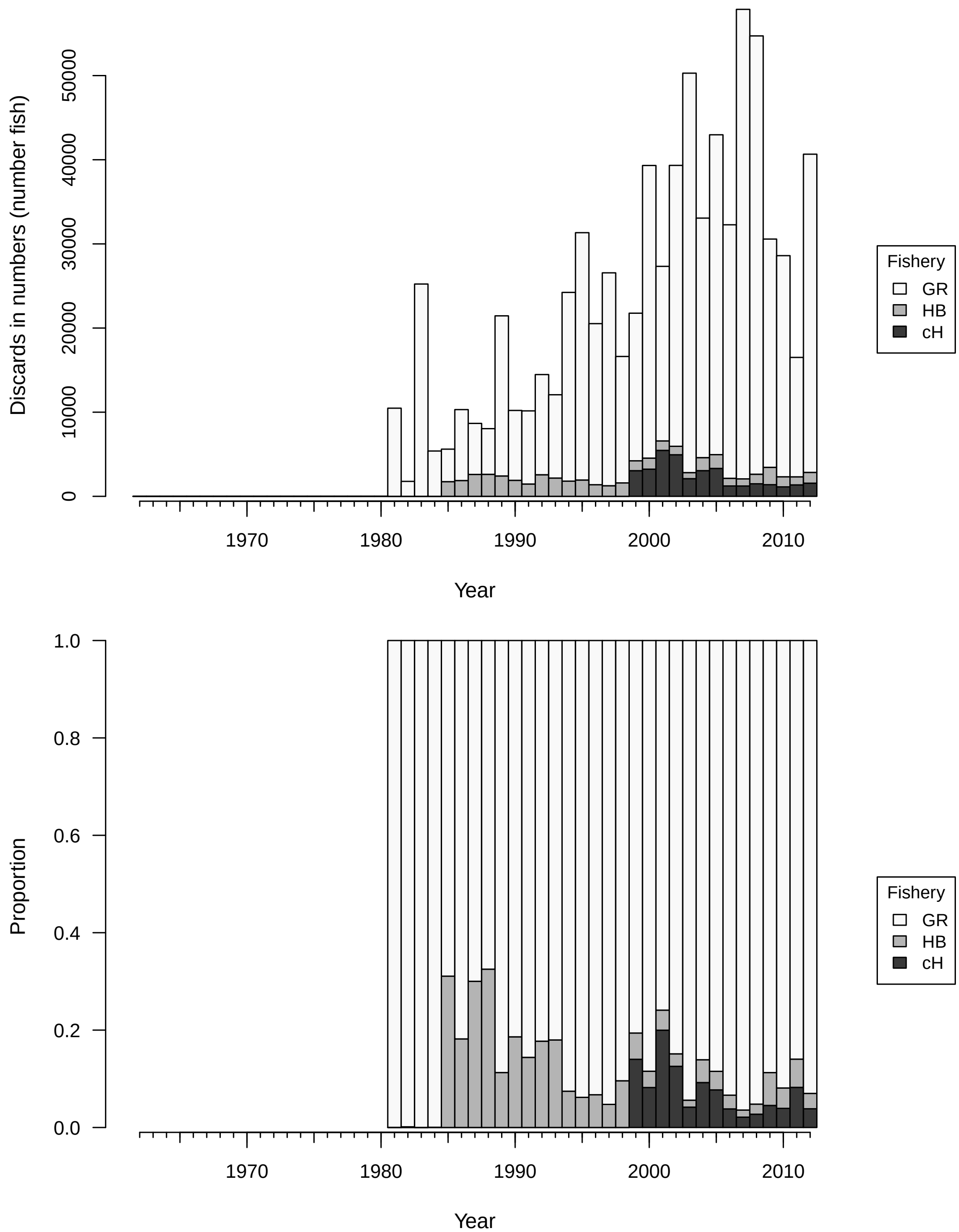
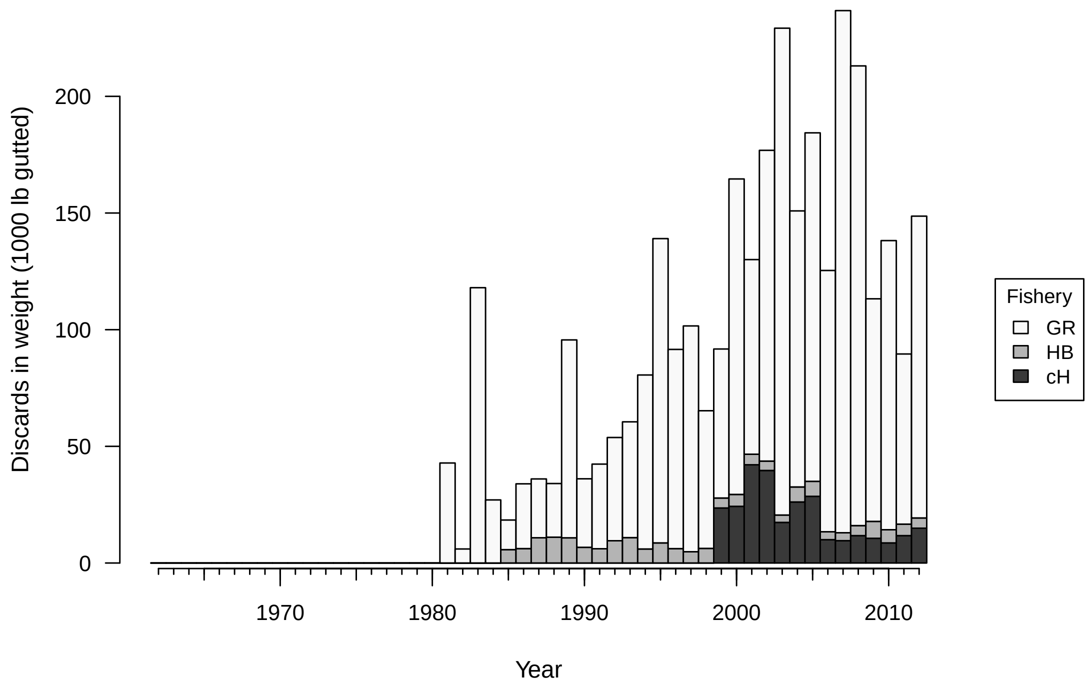


Figure 27. Estimated discard mortalities in gutted weight by fleet from the catch-age model. cH refers to commercial handlines, HB to headboat, GR to general recreational.



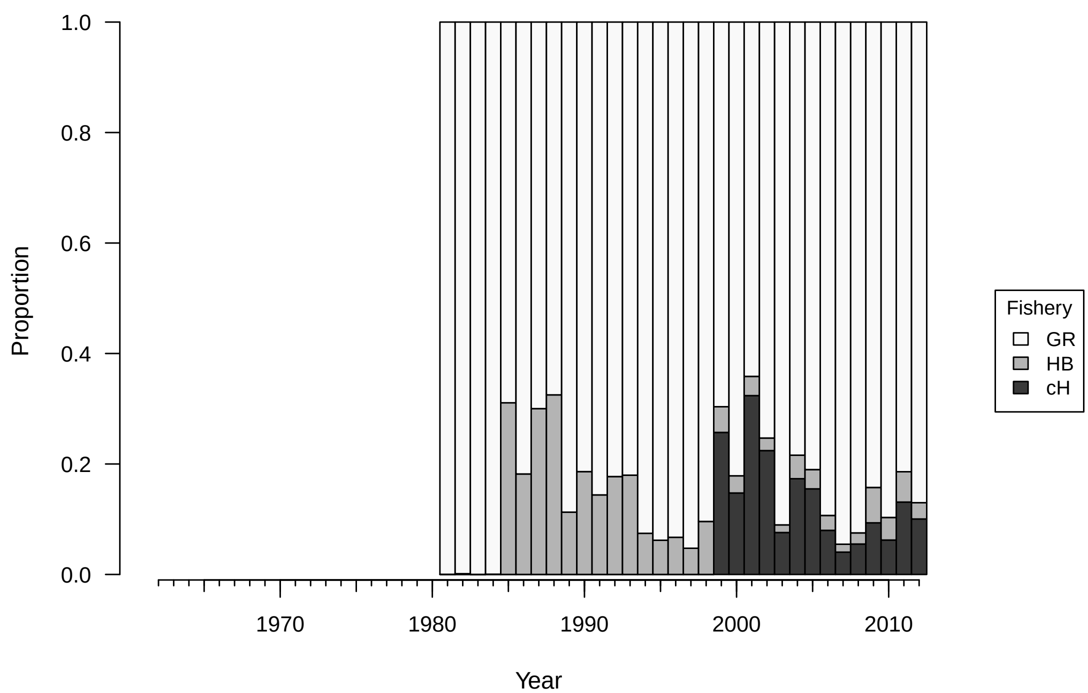
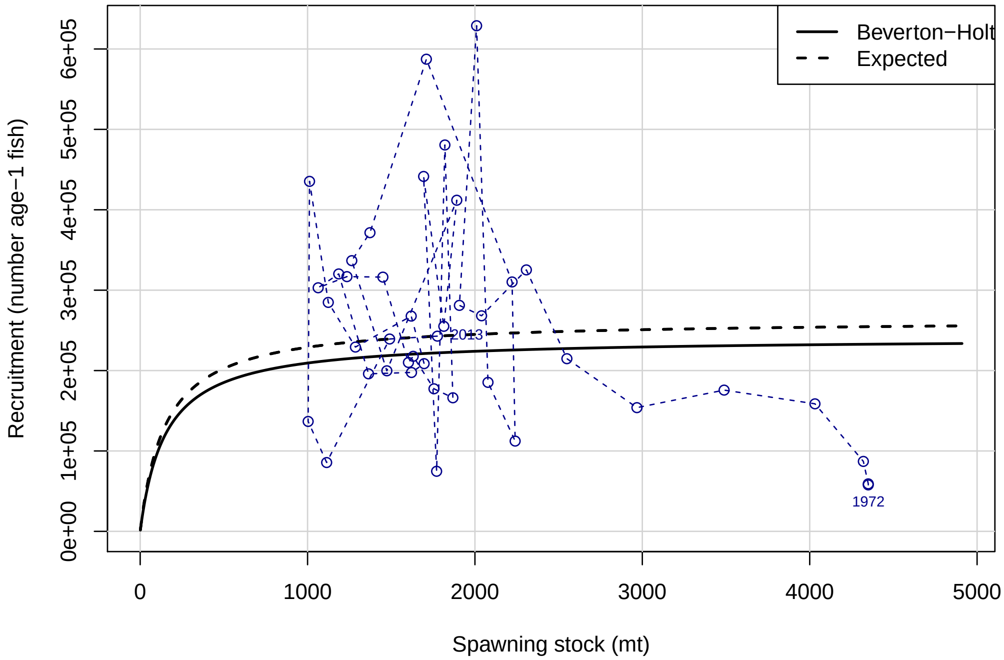


Figure 28. Top panel: Beverton–Holt spawner-recruit curves, with and without lognormal bias correction. The expected (upper) curve was used for computing management benchmarks. Bottom panel: log of recruits (number age-1 fish) per spawner as a function of spawners.



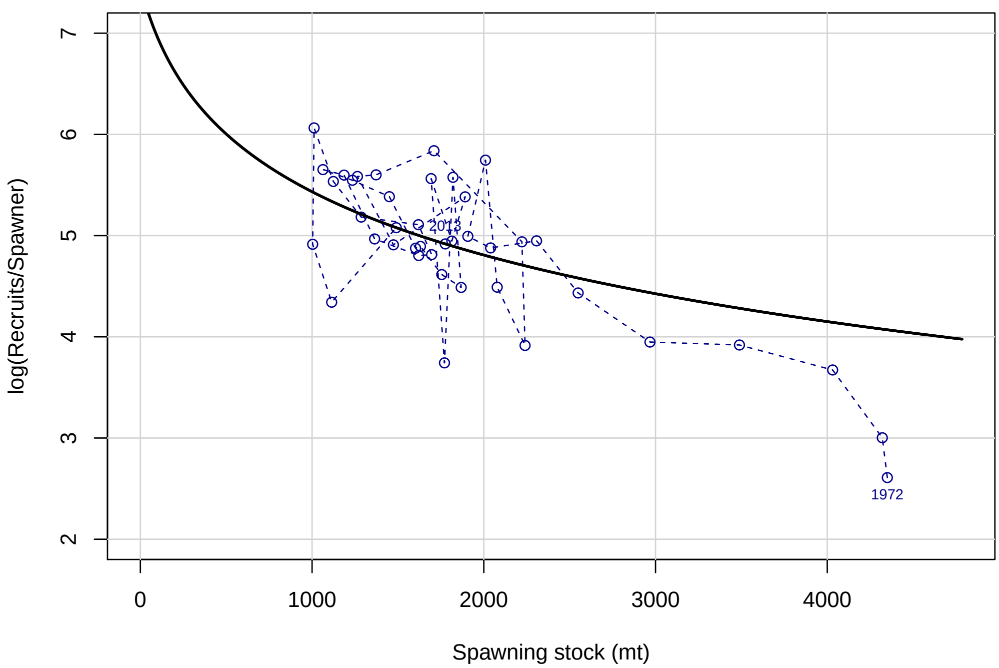


Figure 29. Probability densities of spawner-recruit quantities R0 (unfished recruitment of age-1 fish), steepness, unfished spawners per recruit, and standard deviation of recruitment residuals in log space. Solid vertical lines represent point estimates or values from the base run of the Beaufort Assessment Model; dashed vertical lines represent medians from the MCB runs.

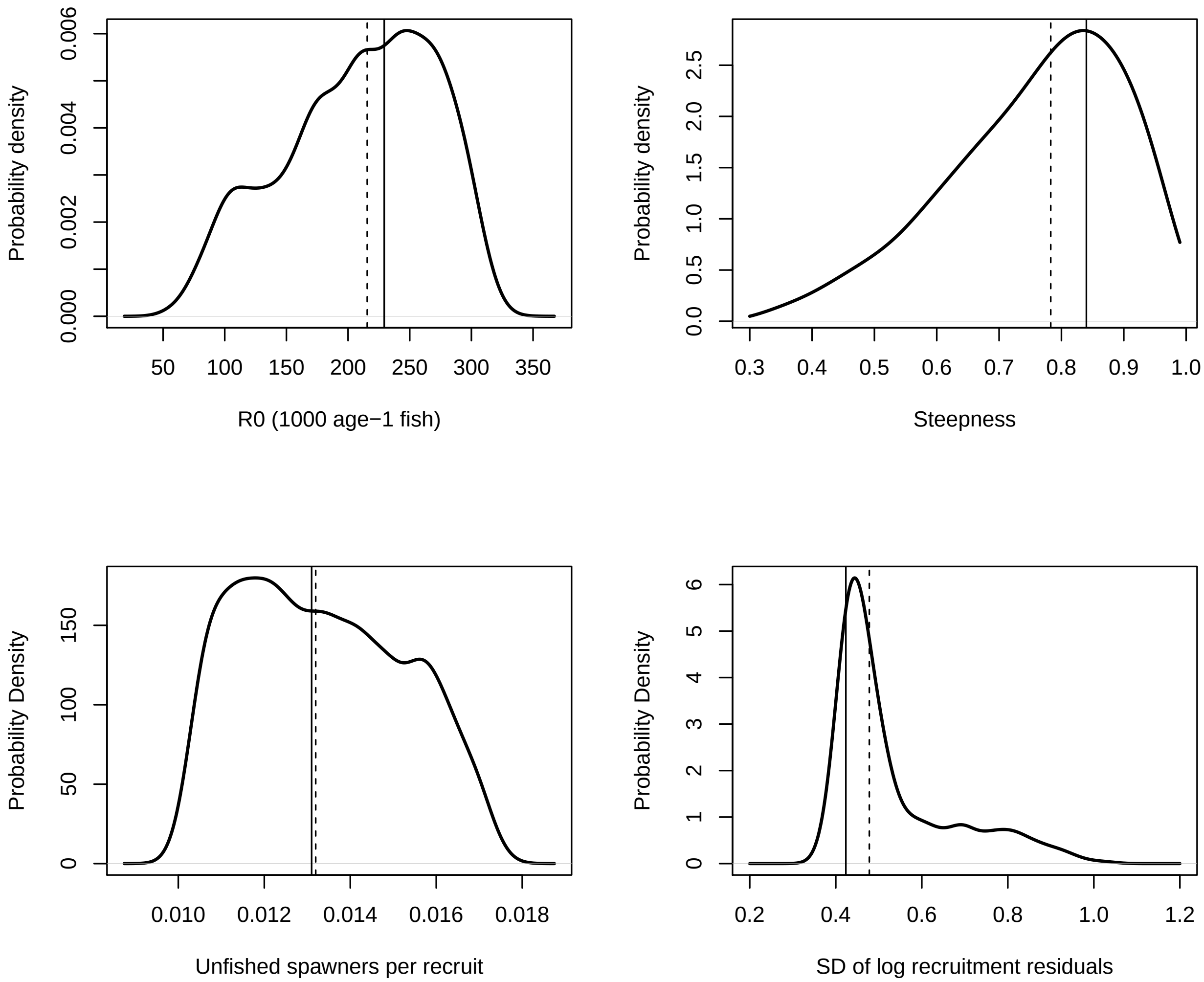


Figure 30. Top panel: yield per recruit. Bottom panel: spawning potential ratio (spawning biomass per recruit relative to that at the unfished level), from which the X% level of SPR provides $F_{X\%}$. Both curves are based on average selectivity from the end of the assessment period.

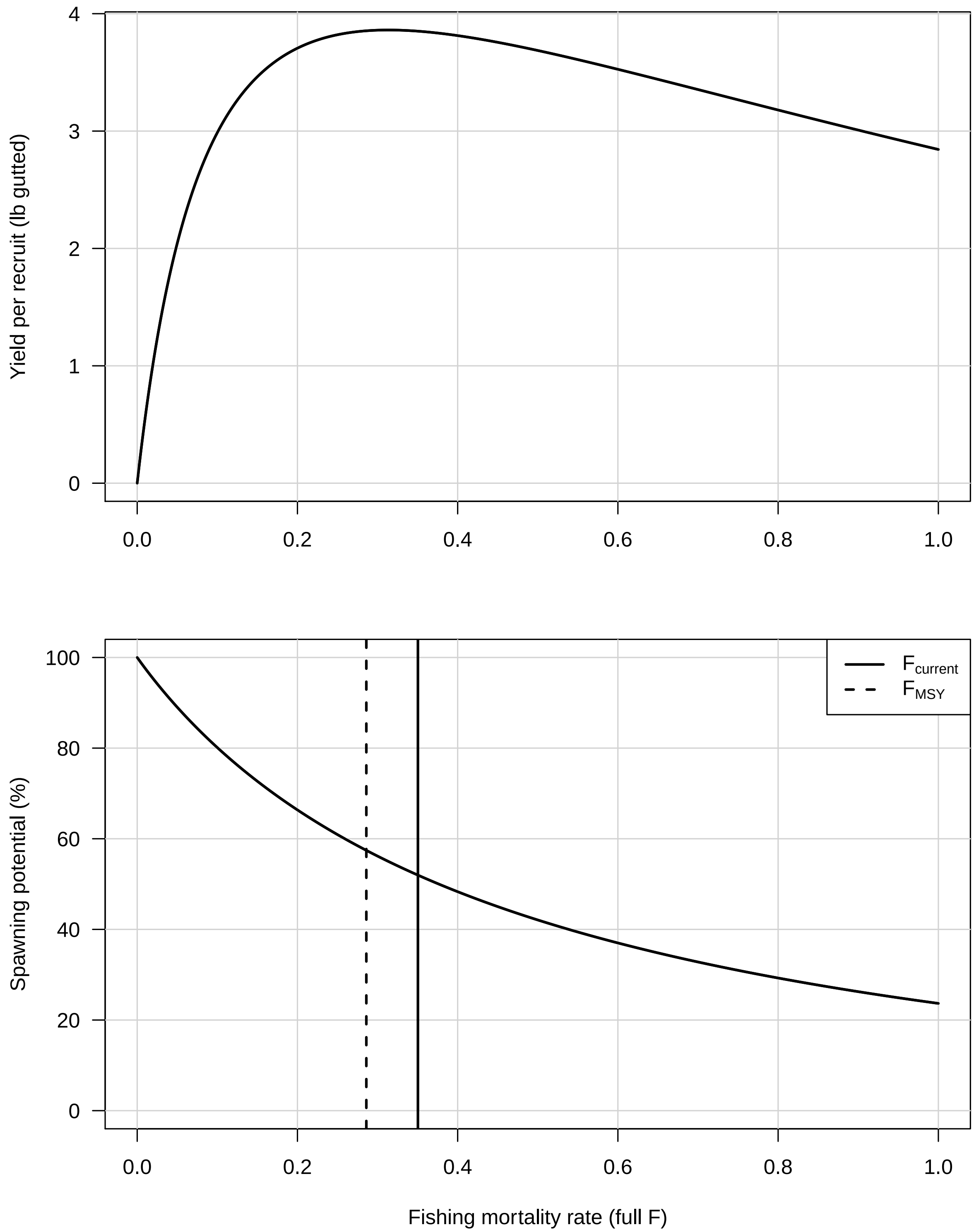


Figure 31. Top panel: equilibrium landings. The peak occurs where fishing rate is $F_{\mathrm{MSY}} = 0.29$ *and equilibrium landings are* $\mathrm{MSY} = 938.2$ *(1000 lb gutted). Bottom panel: equilibrium spawning biomass. Both curves are based on average selectivity from the end of the assessment period.*

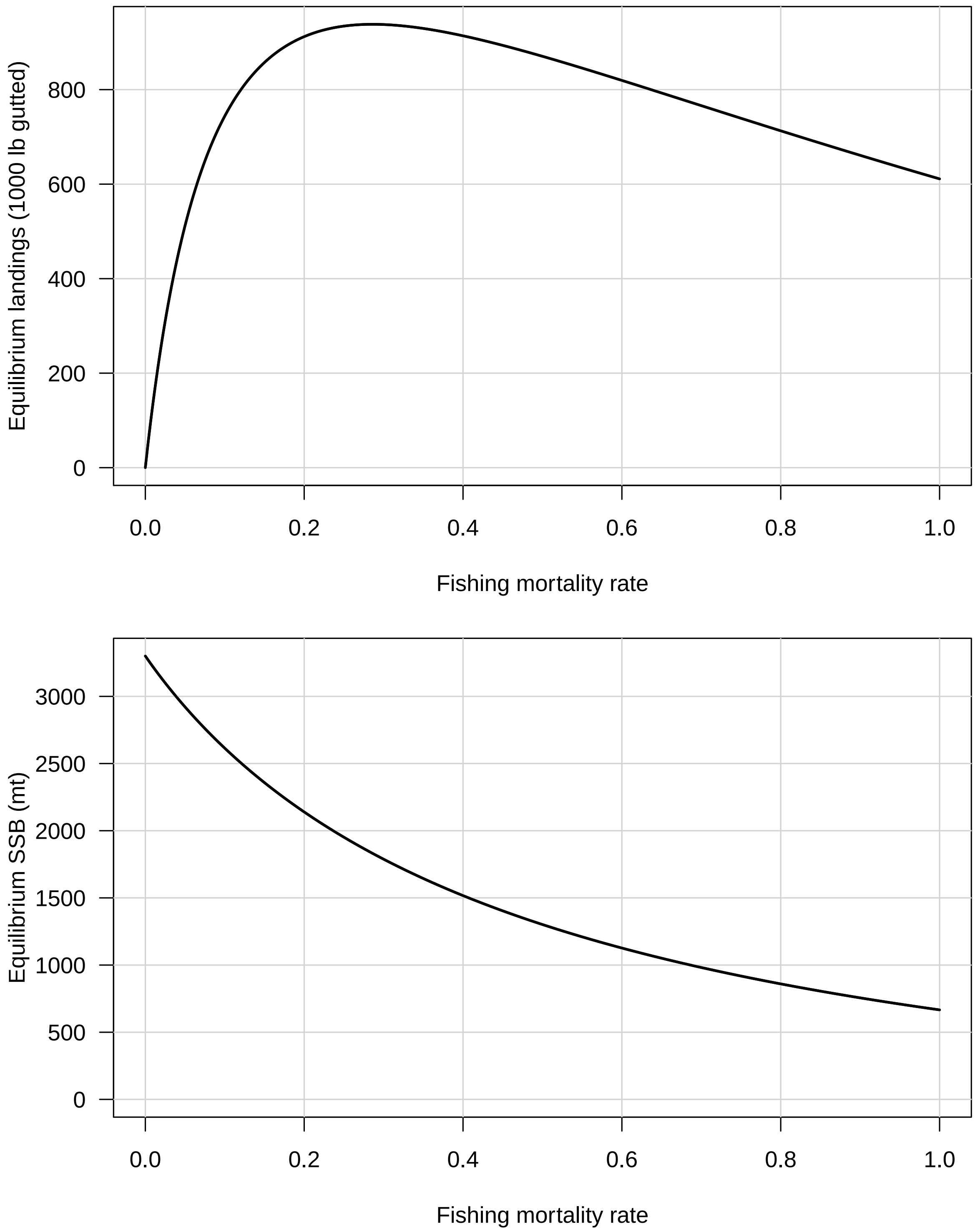


Figure 32. Top panel: equilibrium landings as a function of equilibrium biomass, which itself is a function of fishing mortality rate. The peak occurs where equilibrium biomass is $B_{\mathrm{MSY}} = 3449.3$ *mt and equilibrium landings are* $\mathrm{MSY} = 938.2$ *(1000 lb gutted). Bottom panel: equilibrium discard mortality as a function of equilibrium biomass.*

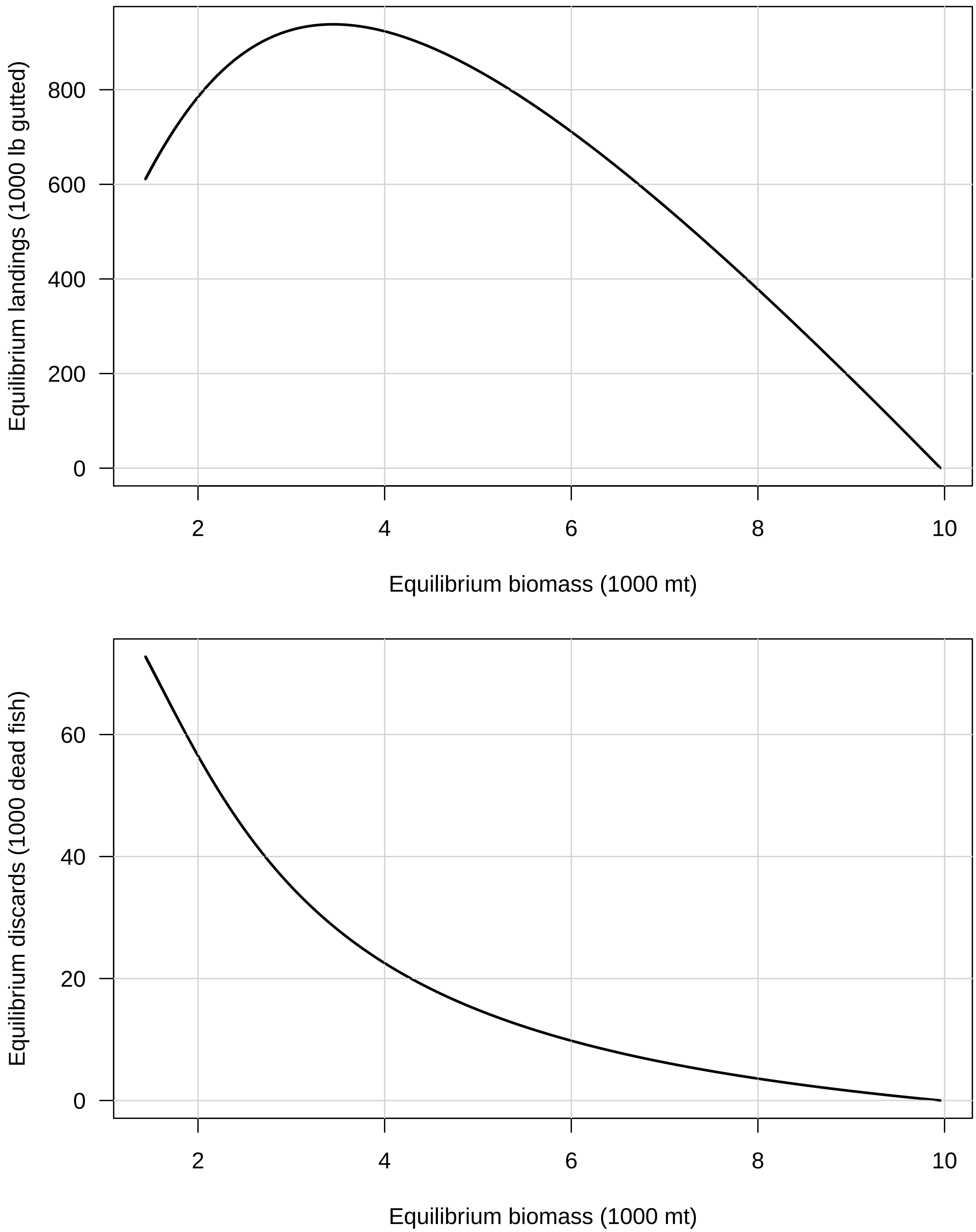


Figure 33. Probability densities of MSY*-related benchmarks from MCB analysis of the Beaufort Assessment Model. Solid vertical lines represent point estimates from the base run; dashed vertical lines represent median values.*

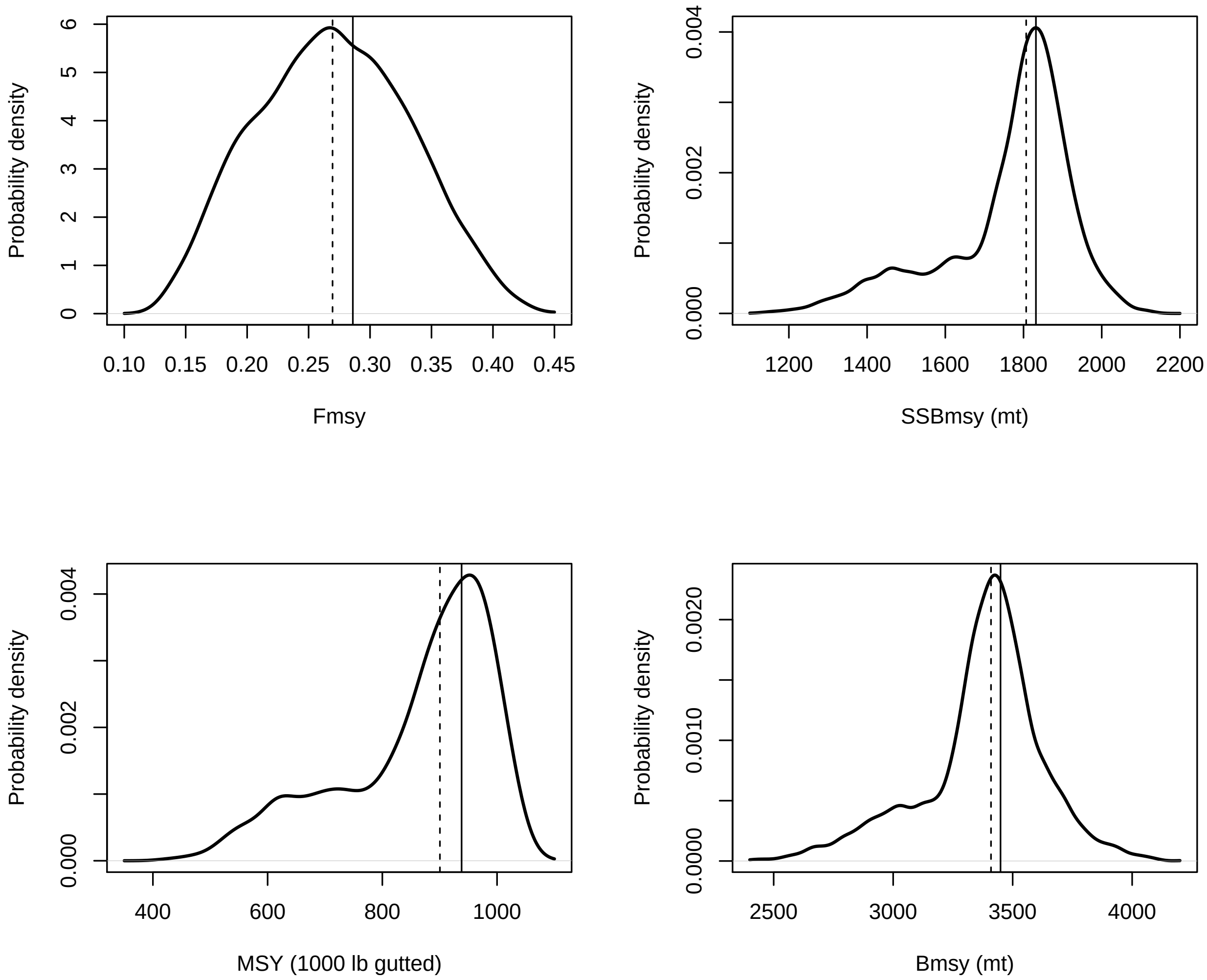


Figure 34. Estimated time series relative to benchmarks. Solid line indicates estimates from base run of the Beaufort Assessment Model; dashed lines represent median values; gray error bands indicate 5^{th} and 95^{th} percentiles of the MCB trials. Top panel: spawning biomass relative to the minimum stock size threshold, $\mathrm{MSST} = (1 - M)\mathrm{SSB}_{\mathrm{MSY}}$. *Middle panel: spawning biomass relative to the minimum stock size threshold,* $\mathrm{MSST} = 75\%\mathrm{SSB}_{\mathrm{MSY}}$. *Bottom panel: F relative to F_{MSY}.*

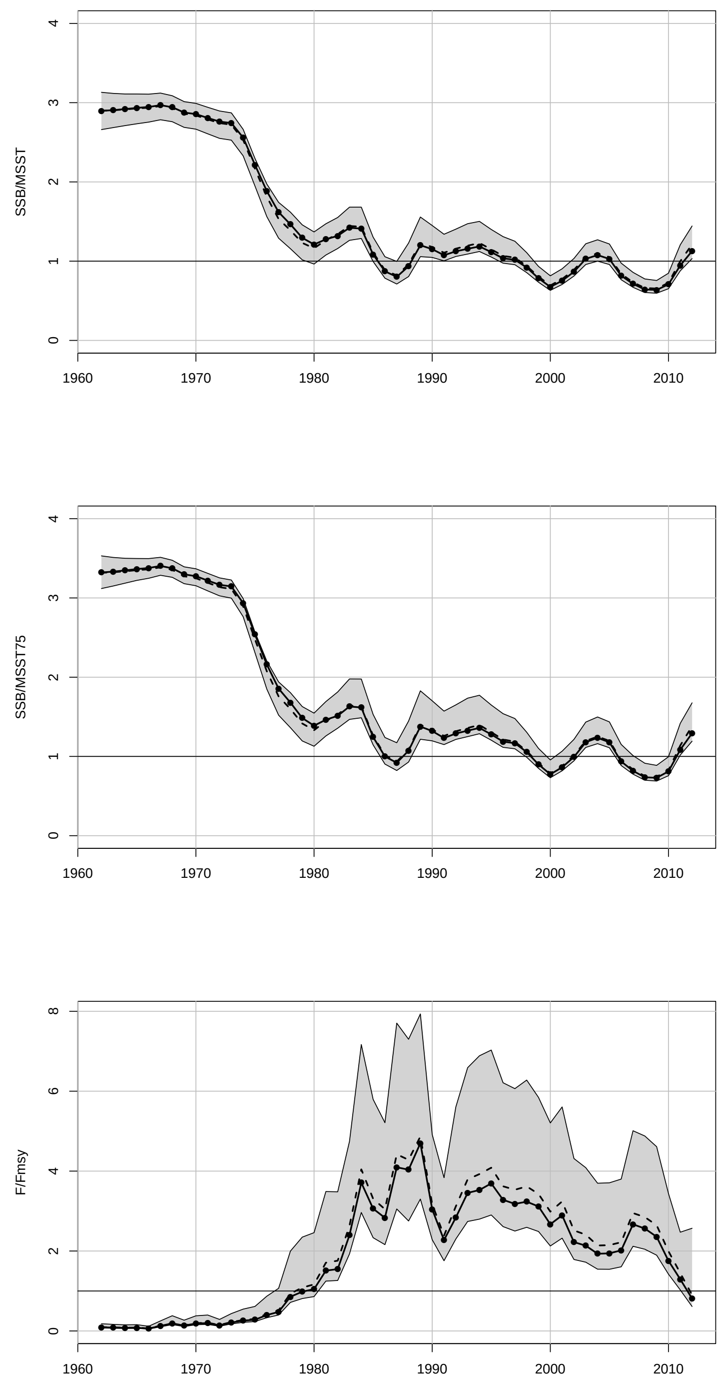


Figure 35. Probability densities of terminal status estimates from MCB analysis of the Beaufort Assessment Model. MSST indicates MSST $= (1 - M)\mathrm{SSB}_{\mathrm{MSY}}$*, and MSST75 indicates* MSST $= 75\%\mathrm{SSB}_{\mathrm{MSY}}$*. Solid vertical lines represent point estimates from the base run; dashed vertical lines represent median values.*

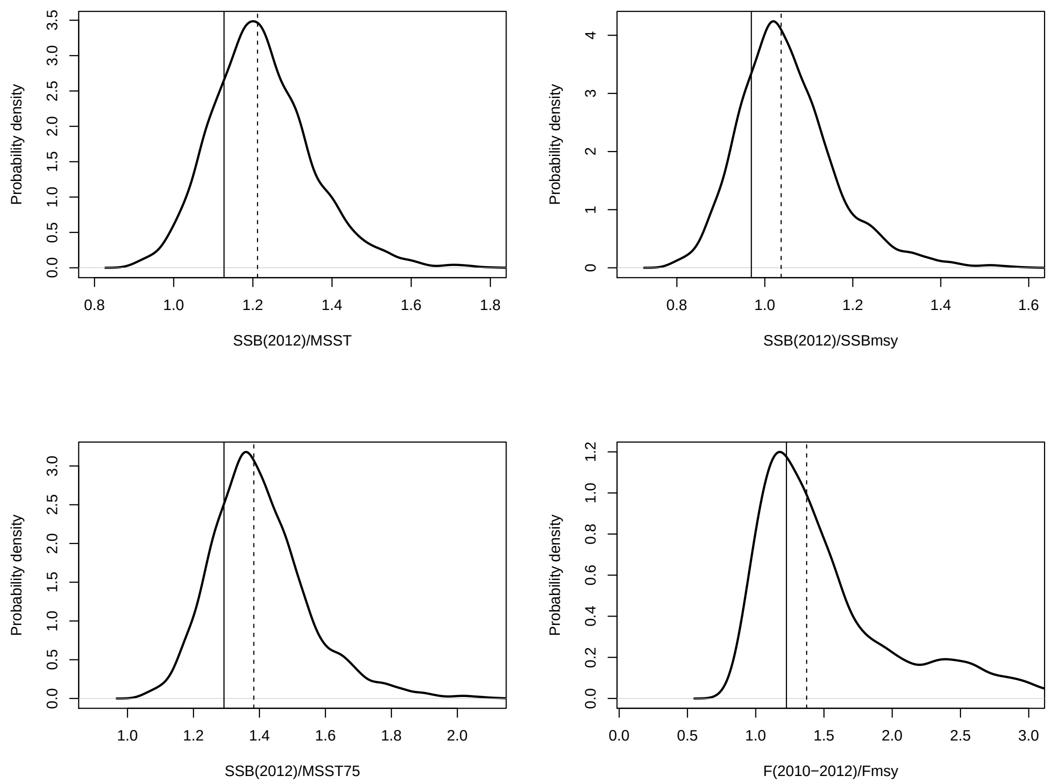
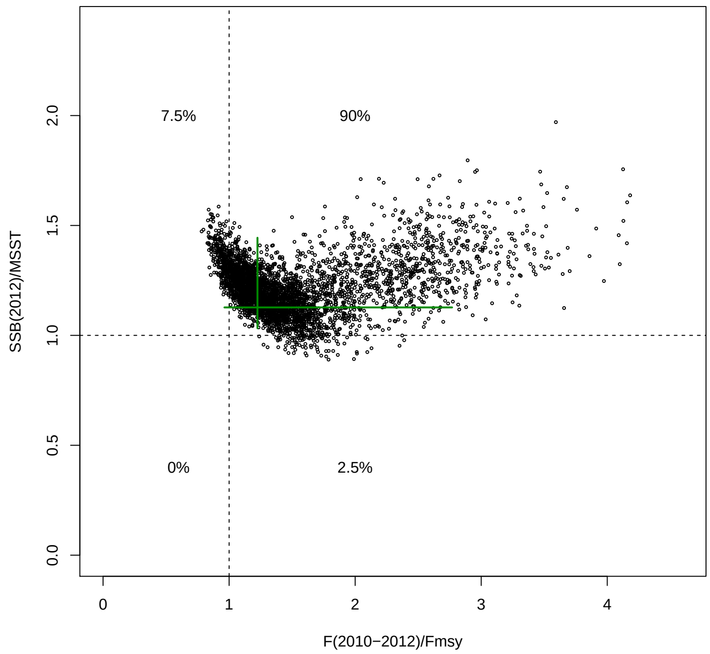


Figure 36. Phase plots of terminal status estimates from MCB analysis of the Beaufort Assessment Model. The intersection of crosshairs indicates estimates from the base run; lengths of crosshairs defined by 5^{th} and 95^{th} percentiles. Proportion of runs falling in each quadrant indicated. Top panel: spawning biomass relative to the minimum stock size threshold, $\mathrm{MSST} = (1 - M)\mathrm{SSB}_{\mathrm{MSY}}$. *Bottom panel: spawning biomass relative to the minimum stock size threshold,* $\mathrm{MSST} = 75\%\mathrm{SSB}_{\mathrm{MSY}}$.



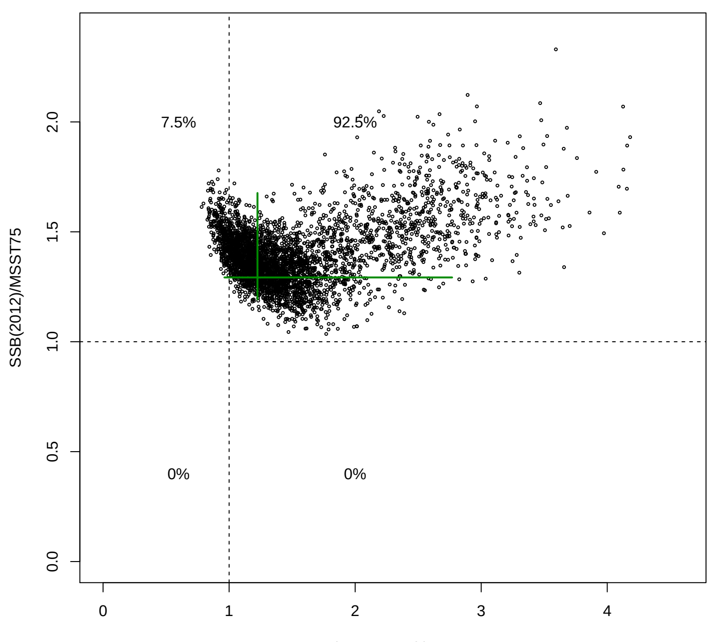


Figure 37. Age structure relative to the equilibrium expected at MSY*.*

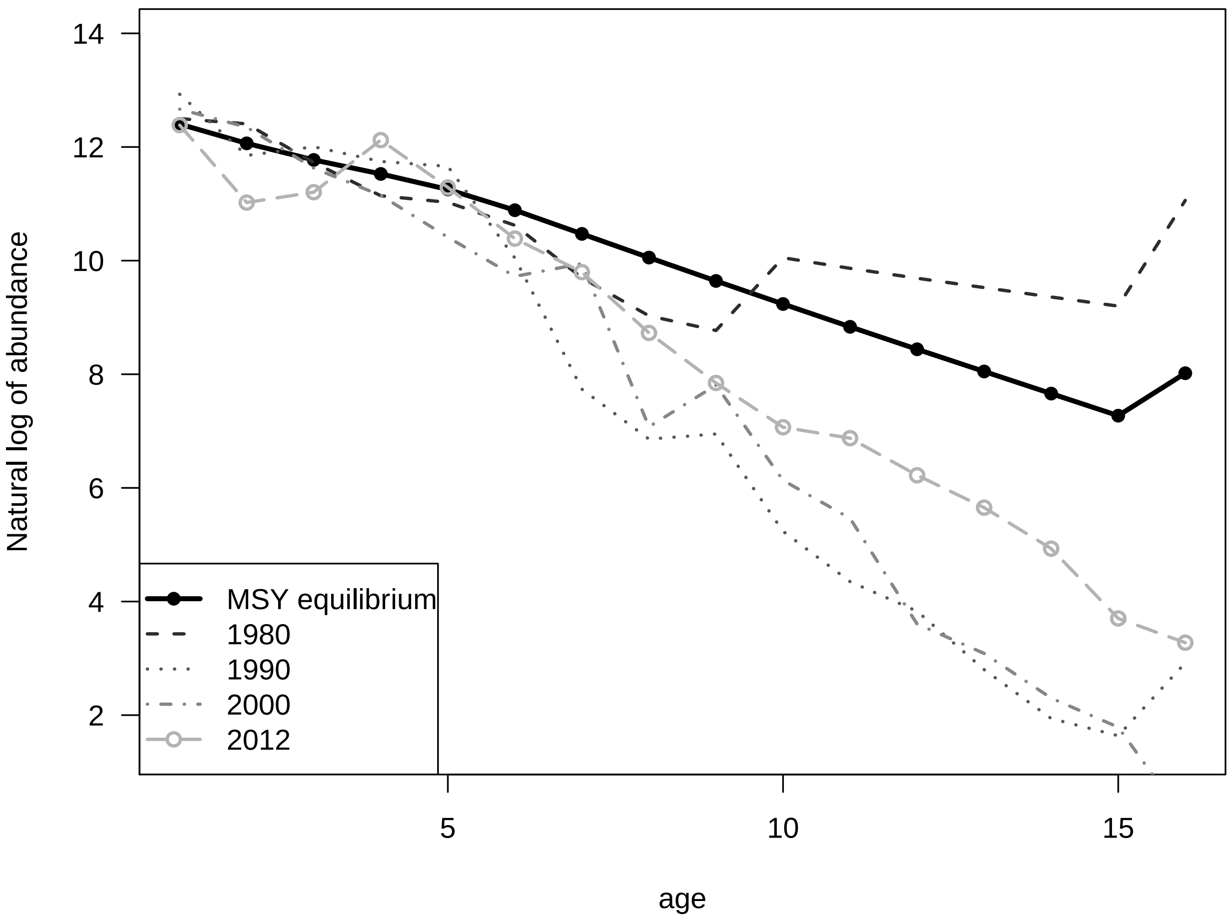


Figure 38. Comparison of results from this update assessment and from the previous, SEDAR-10 benchmark assessment. Top panel: F relative to F_{MSY}. Bottom panel: spawning biomass relative to the minimum stock size threshold ($\mathrm{MSST} = (1 - M)\mathrm{SSB}_{\mathrm{MSY}}$*).*

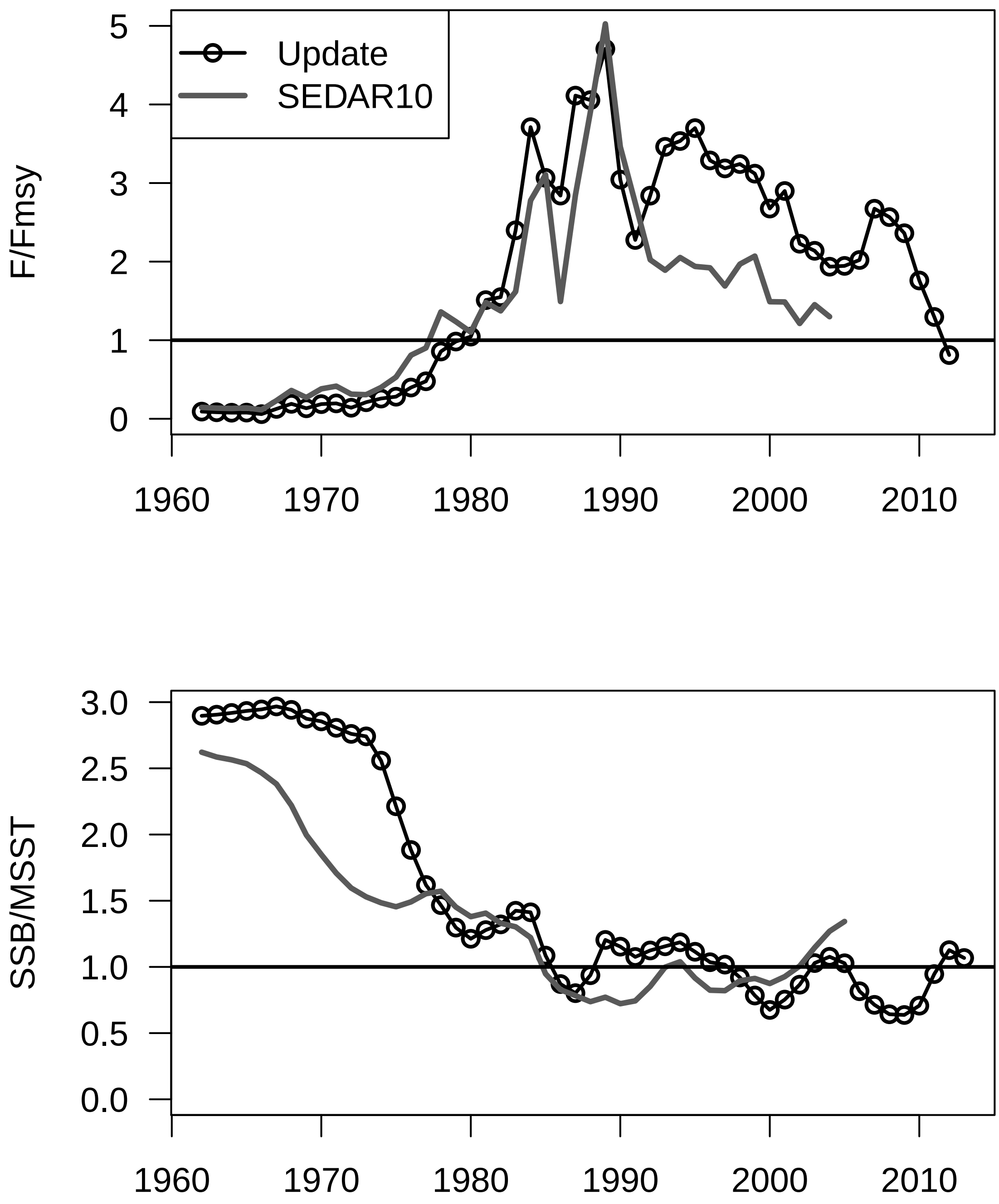
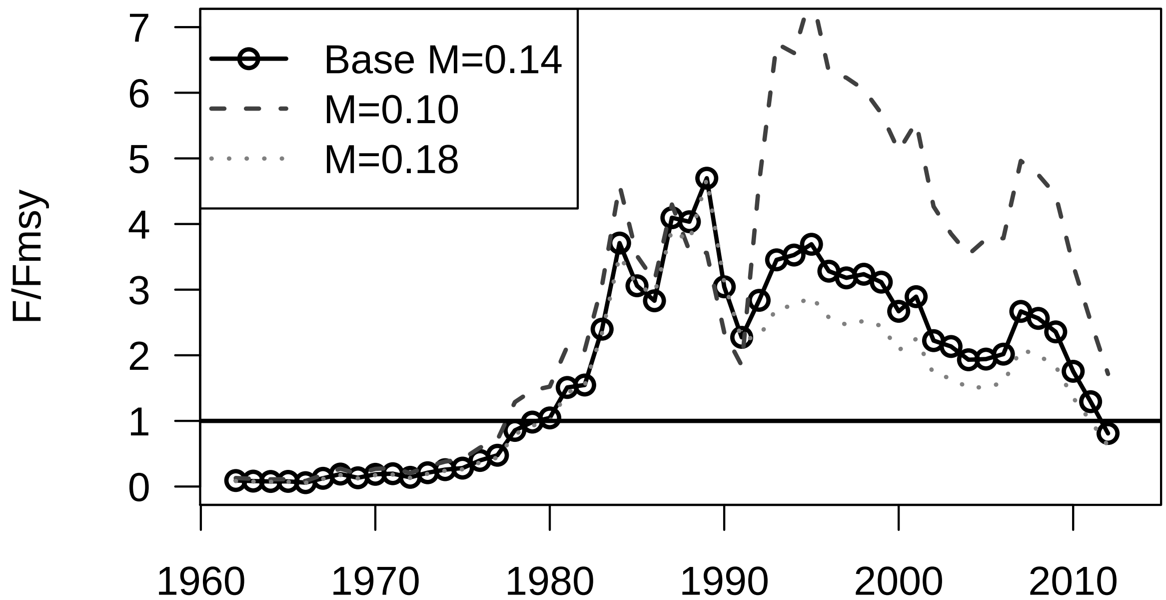


Figure 39. Sensitivity to changes in natural mortality (sensitivity runs S1–S2). Top panel: Ratio of F to F_{MSY}. Bottom panel: Ratio of SSB *to* MSST*.*



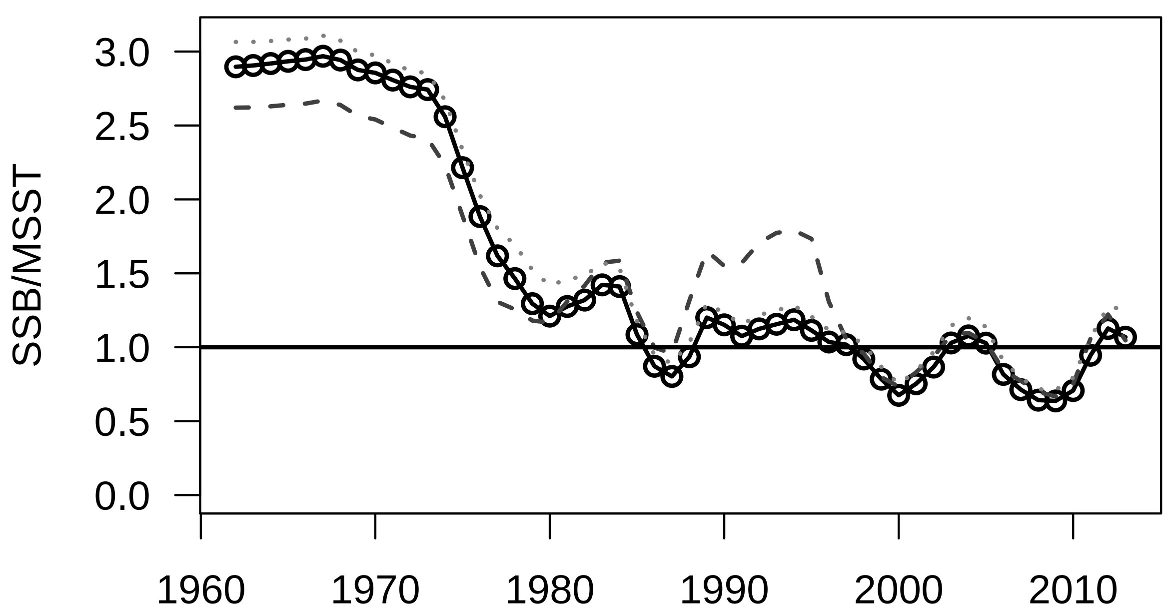
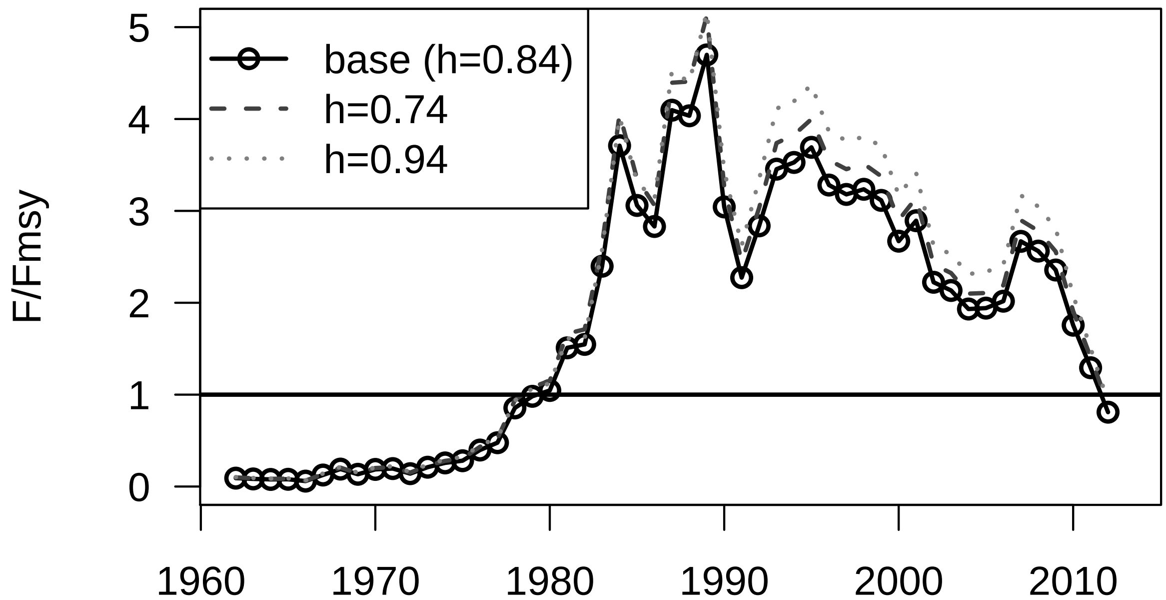


Figure 40. Sensitivity to steepness (sensitivity runs S3–S4). Top panel: Ratio of F to F_{MSY}. Bottom panel: Ratio of SSB to MSST.



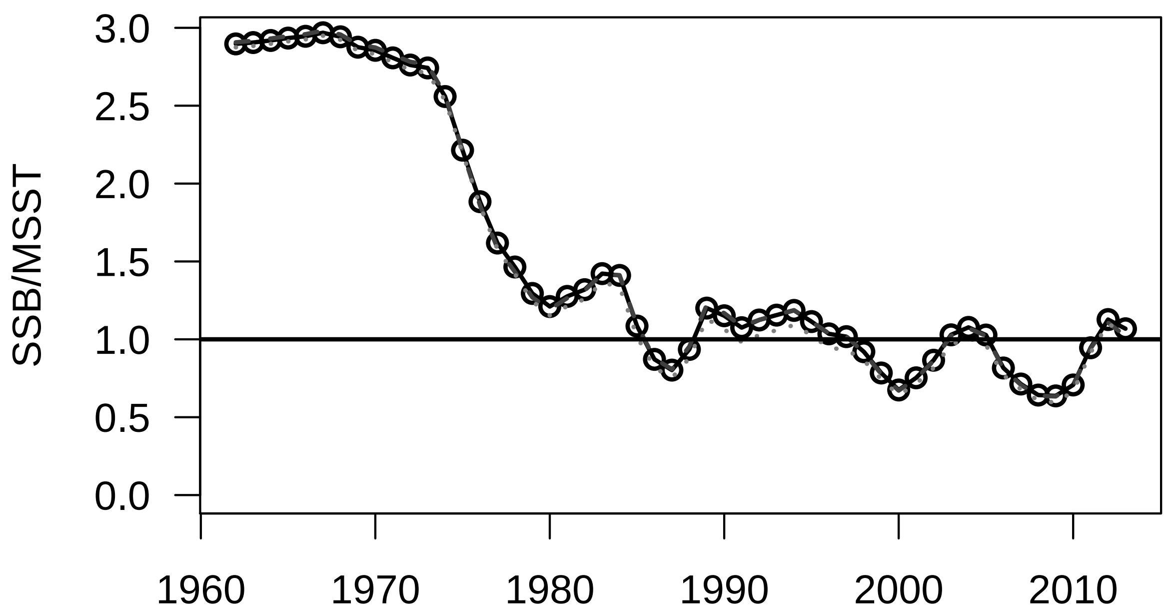


Figure 41. Sensitivity to initialization (1962) fishing mortality rate (sensitivity runs S5–S6). Top panel: Ratio of F to F_{MSY}*. Bottom panel: Ratio of* SSB *to* MSST.

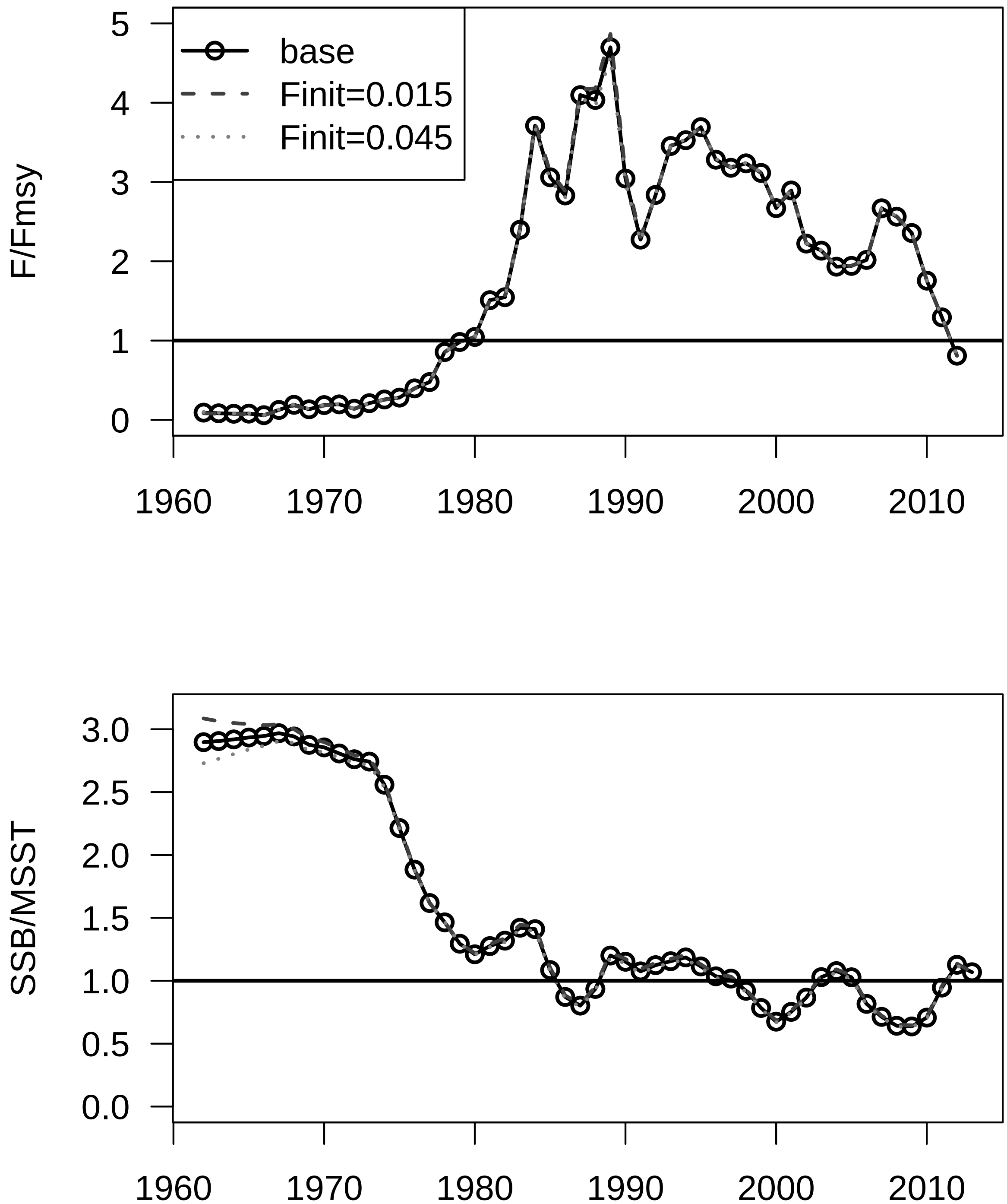


Figure 42. Sensitivity to the discard mortality rate (sensitivity runs S7 and S8). Top panel: Ratio of F to F_{MSY}. Bottom panel: Ratio of SSB *to* MSST*.*

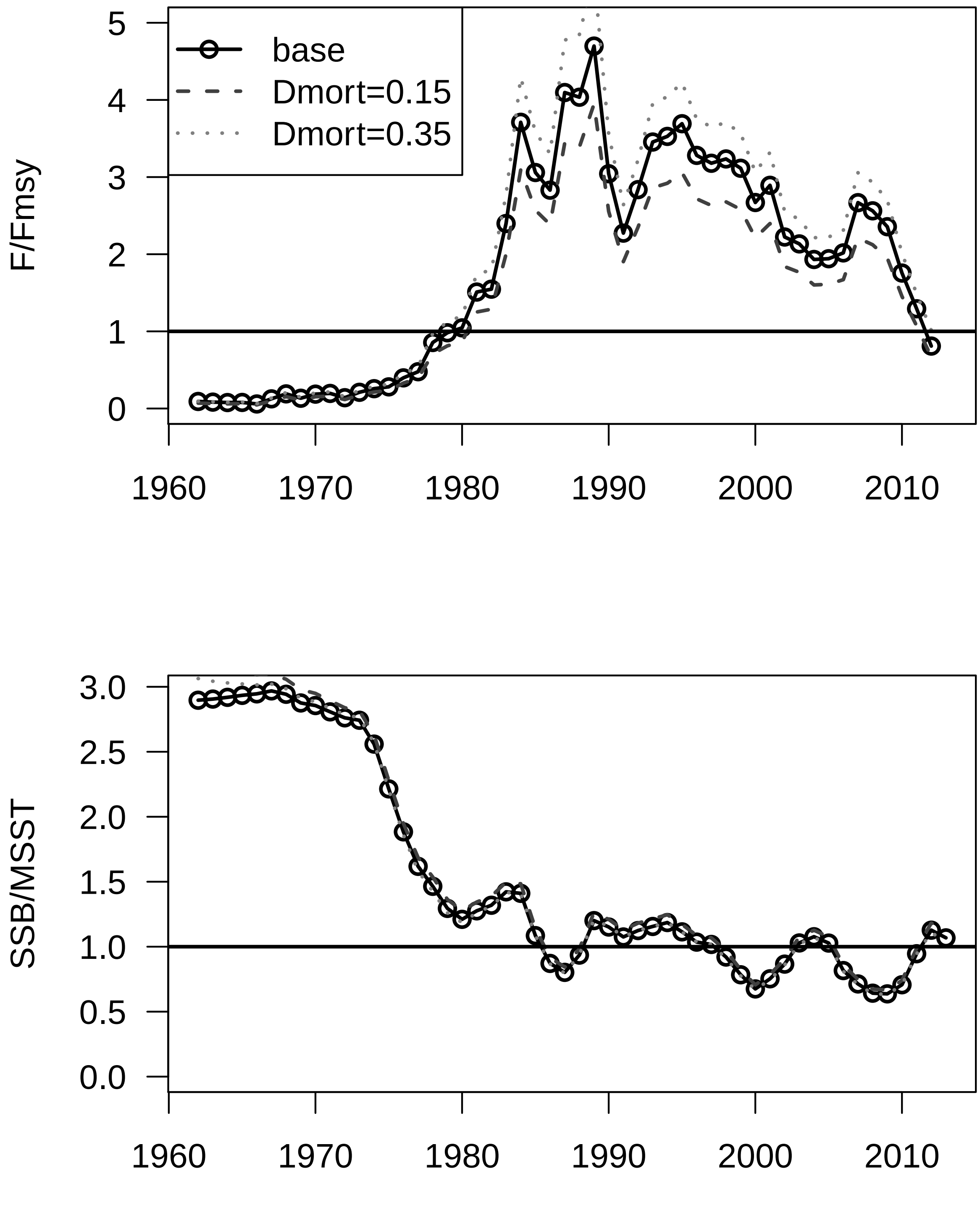


Figure 43. Sensitivity to flexibility in the initialization (1962) age structure and in early (1962–1971) recruitment deviations (sensitivity run S9). Top panel: Ratio of F to F_{MSY}. Bottom panel: Ratio of SSB *to* MSST.

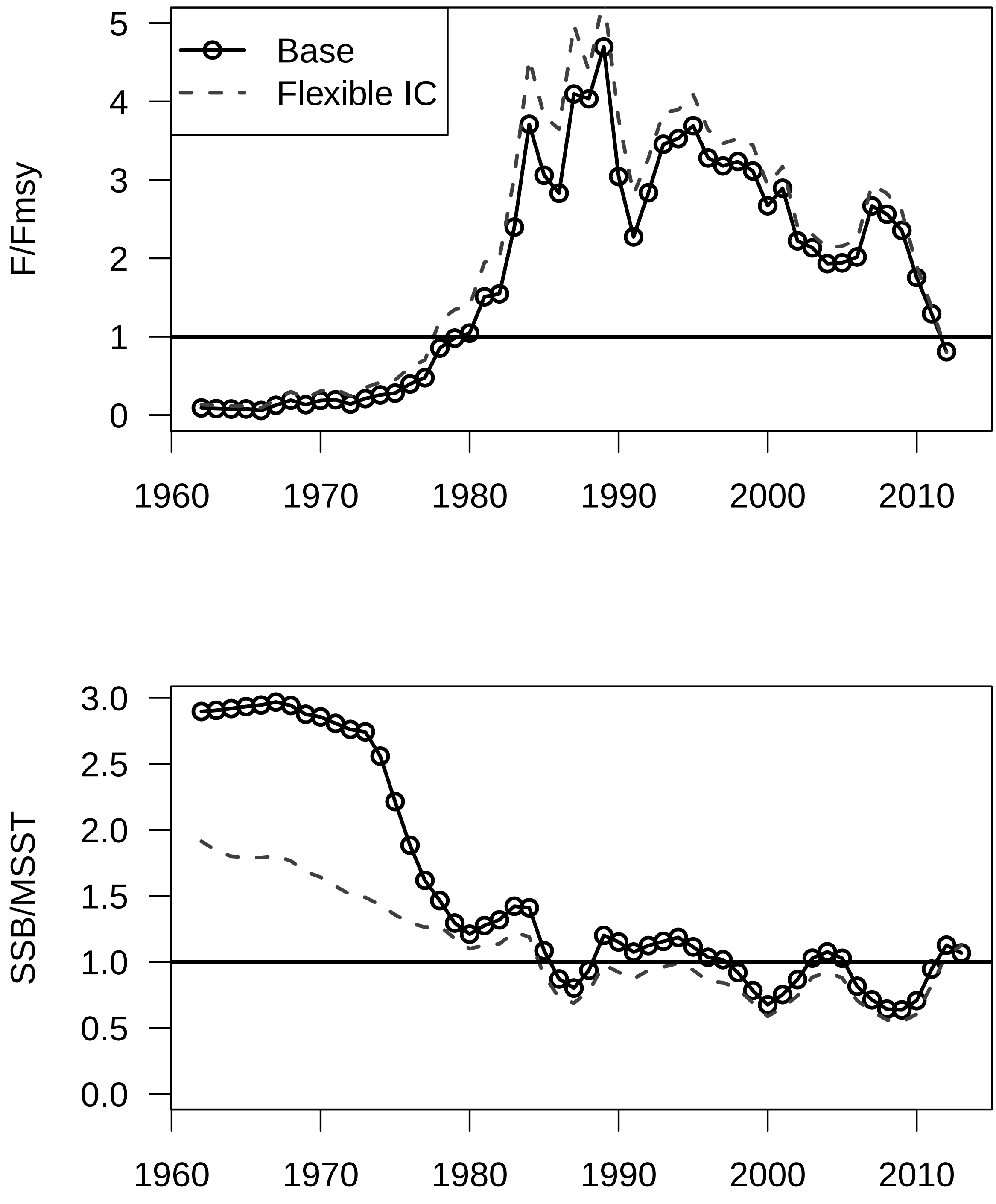


Figure 44. Sensitivity to data component weights (sensitivity run S10). Top panel: Ratio of F to F_{MSY}. Bottom panel: Ratio of SSB *to* MSST.

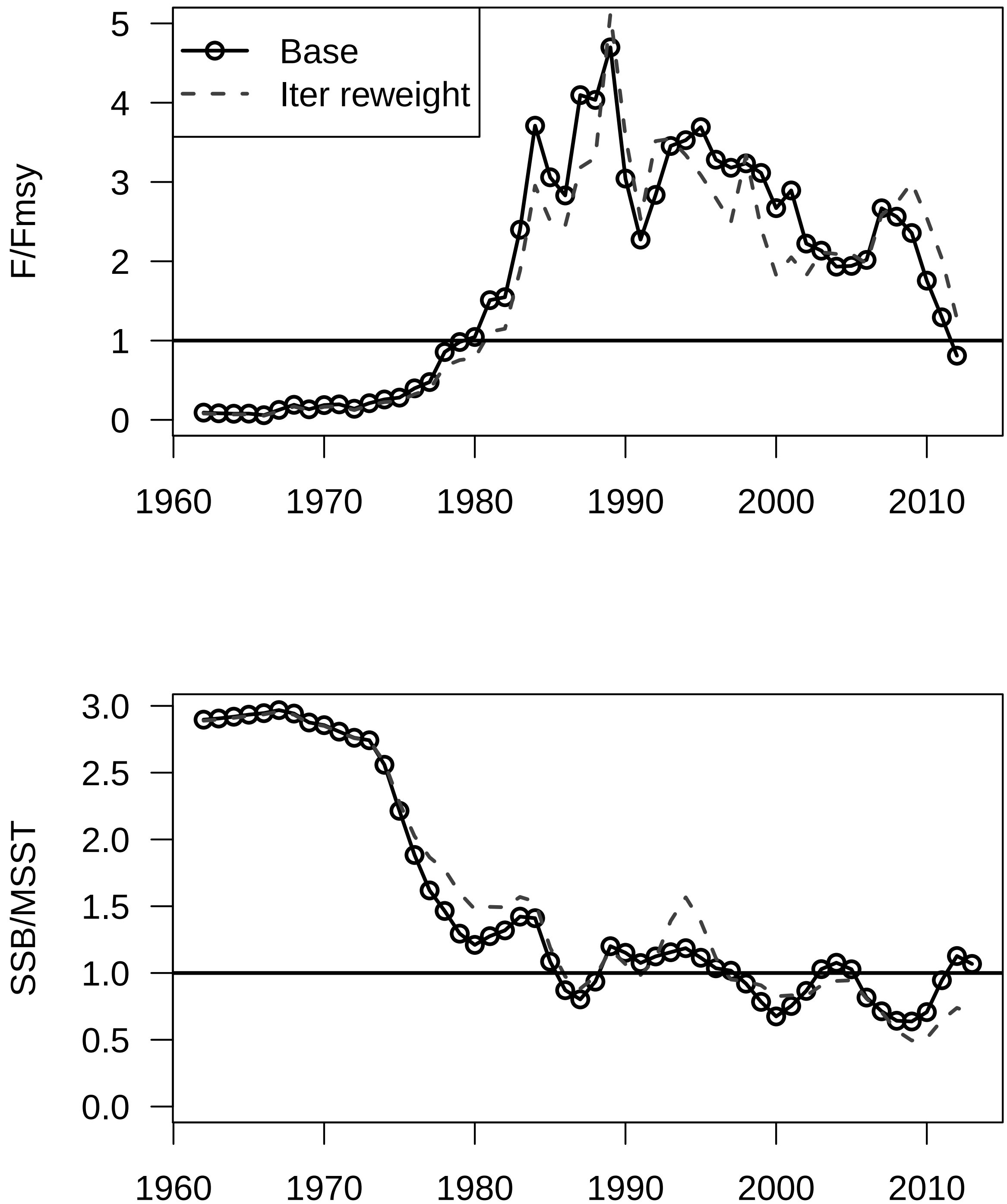


Figure 45. Phase plot of terminal status indicators from sensitivity runs of the Beaufort Assessment Model.

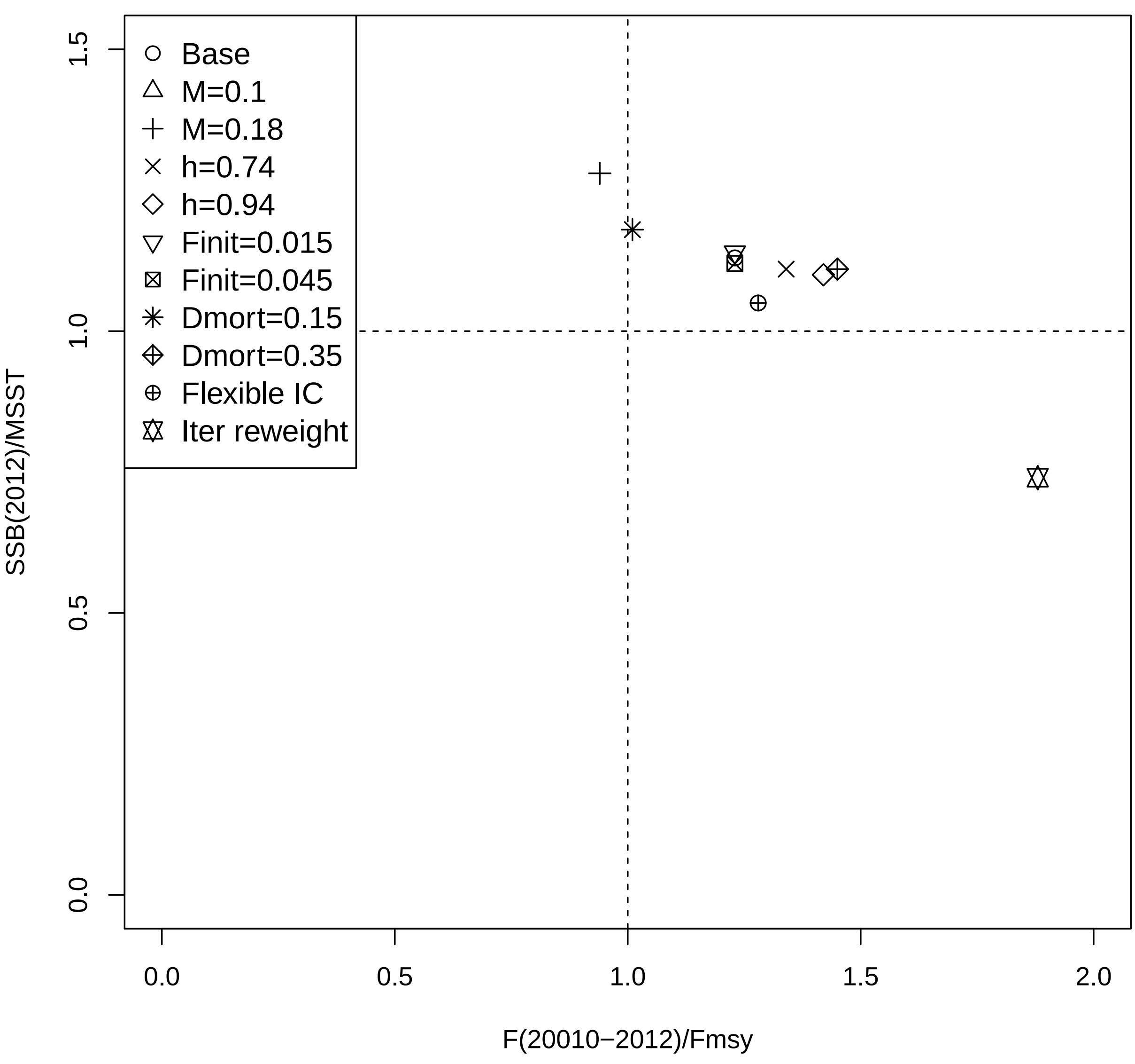


Figure 46. Projection results under scenario 1—fishing mortality rate at $F = F_{\text{current}}$. In the top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark MSY-related quantities; dashed horizontal lines represent corresponding medians. In the bottom two panels, the curves represents the proportion of projection replicates for which SSB exceeds the replicate-specific MSST. The bottom left panel uses $\text{MSST} = (1 - M)\text{SSB}_{\text{MSY}}$, and the bottom right panel uses $\text{MSST} = 75\%\text{SSB}_{\text{MSY}}$. Horizontal lines drawn at 0.5 and 0.7 for reference.

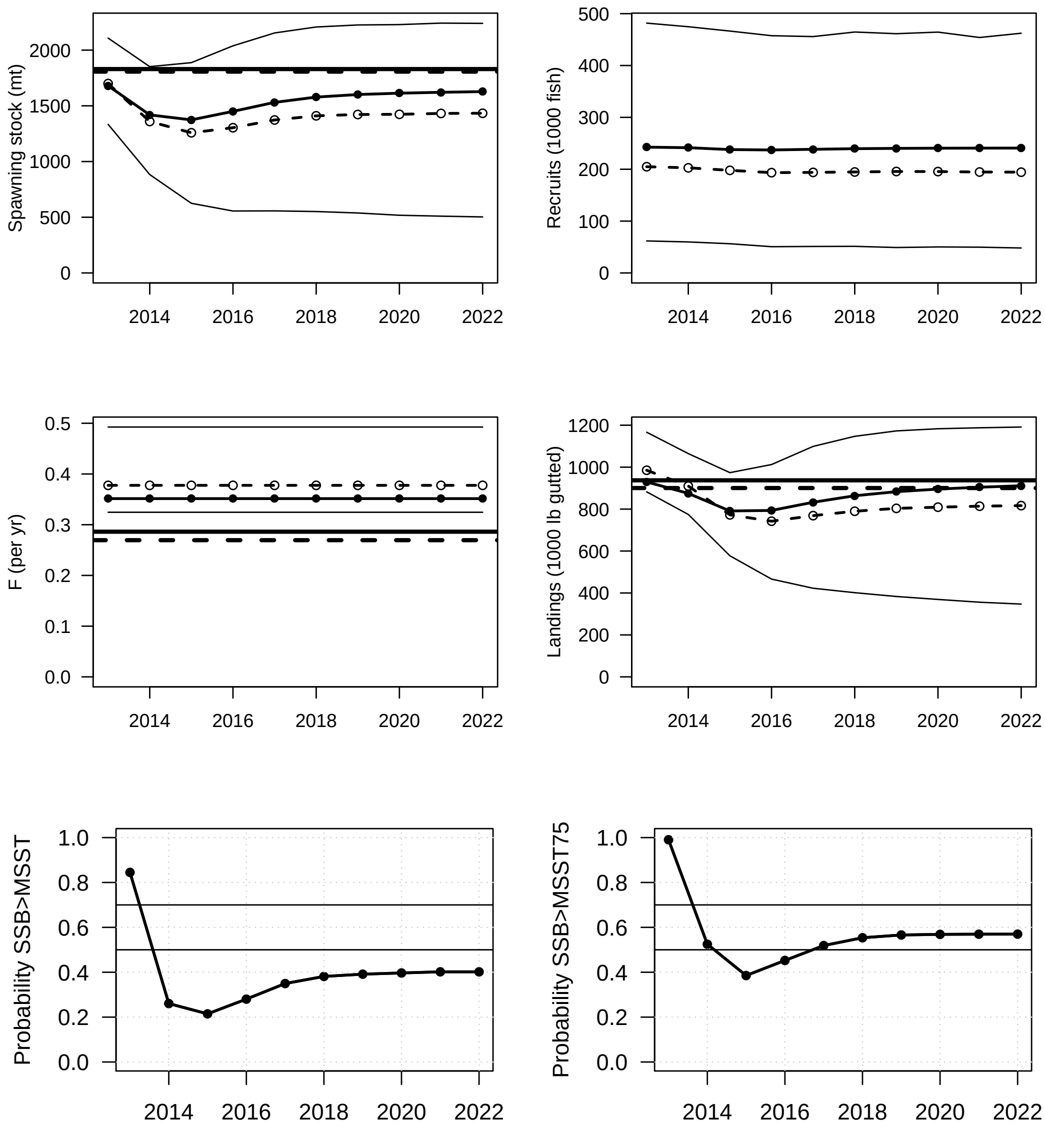


Figure 47. Projection results under scenario 2—fishing mortality rate at $F = F_{\mathrm{MSY}}$. In the top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark MSY*-related quantities; dashed horizontal lines represent corresponding medians. In the bottom two panels, the curves represents the proportion of projection replicates for which SSB exceeds the replicate-specific* MSST*. The bottom left panel uses* $\mathrm{MSST} = (1 - M)\mathrm{SSB}_{\mathrm{MSY}}$*, and the bottom right panel uses* $\mathrm{MSST} = 75\%\mathrm{SSB}_{\mathrm{MSY}}$*. Horizontal lines drawn at 0.5 and 0.7 for reference.*

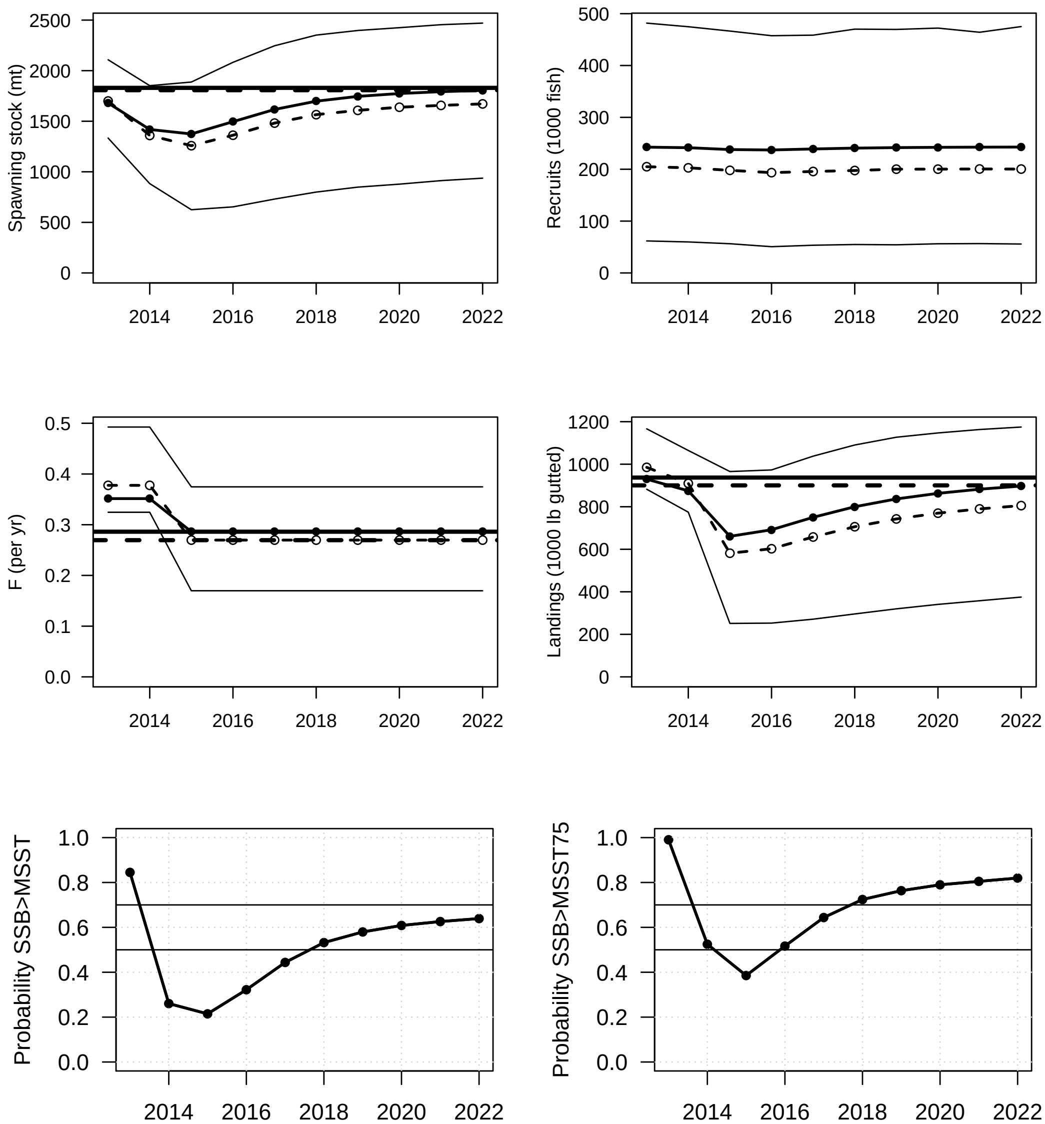


Figure 48. Projection results under scenario 3—fishing mortality rate at $F = 75\%F_{\mathrm{MSY}}$. In the top four panels, expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark MSY*-related quantities; dashed horizontal lines represent corresponding medians. In the bottom two panels, the curves represents the proportion of projection replicates for which SSB exceeds the replicate-specific* MSST. *The bottom left panel uses* $\mathrm{MSST} = (1 - M)\mathrm{SSB}_{\mathrm{MSY}}$, *and the bottom right panel uses* $\mathrm{MSST} = 75\%\mathrm{SSB}_{\mathrm{MSY}}$. *Horizontal lines drawn at 0.5 and 0.7 for reference.*

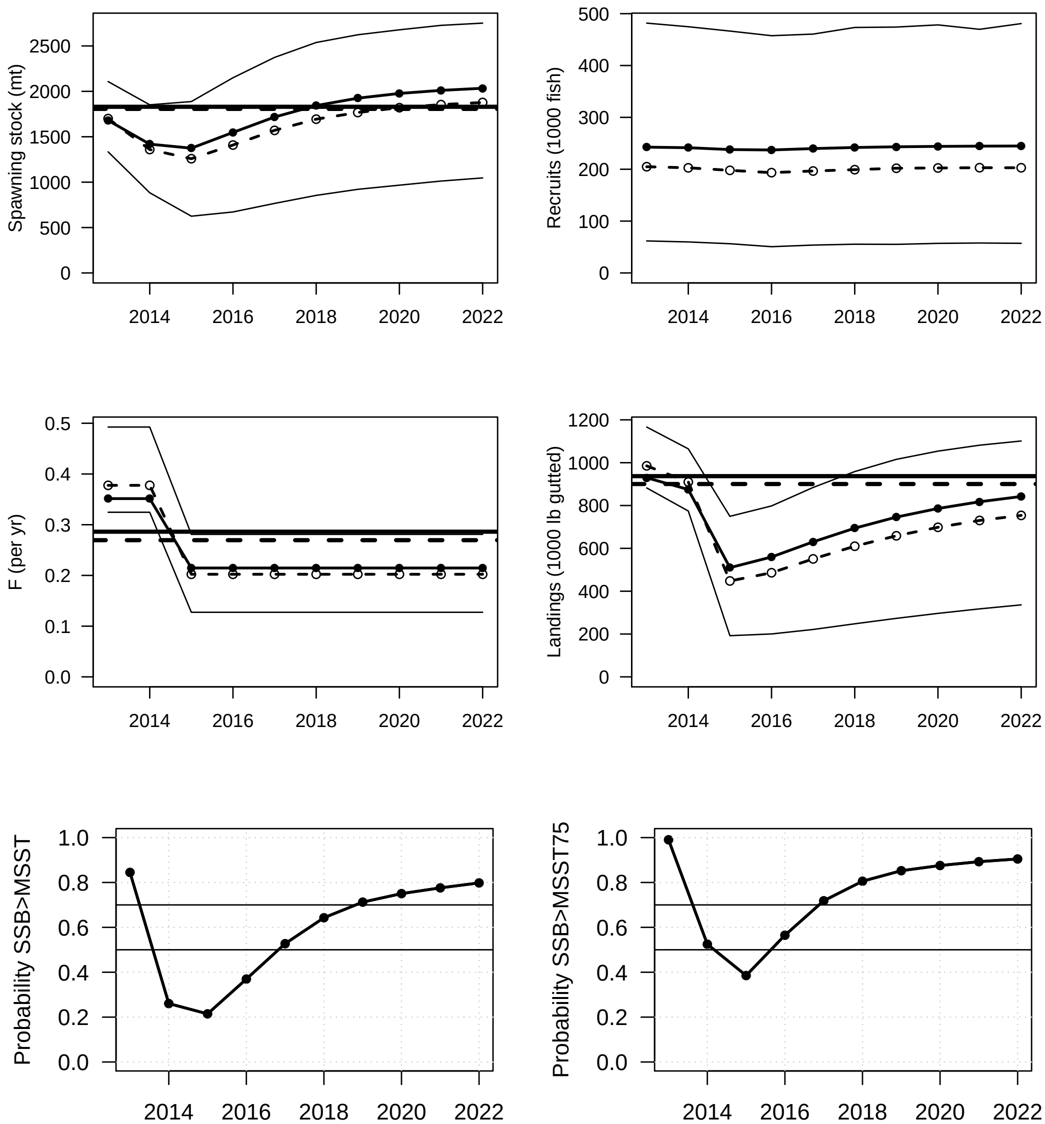


Figure 49. Projection results under scenario 4—fishing mortality rate defined such that $P^{\star} = 0.3$. *In the top four panels, medians represented by dashed lines with open circles and uncertainty represented by thin lines corresponding to* 5^{th} *and* 95^{th} *percentiles of replicate projections. Solid horizontal lines mark* MSY*-related quantities; dashed horizontal lines represent corresponding medians. In the bottom two panels, the curves represents the proportion of projection replicates for which SSB exceeds the replicate-specific* MSST. *The bottom left panel uses* $\mathrm{MSST} = (1 - M)\mathrm{SSB}_{\mathrm{MSY}}$, *and the bottom right panel uses* $\mathrm{MSST} = 75\%\mathrm{SSB}_{\mathrm{MSY}}$. *Horizontal lines drawn at 0.5 and 0.7 for reference.*

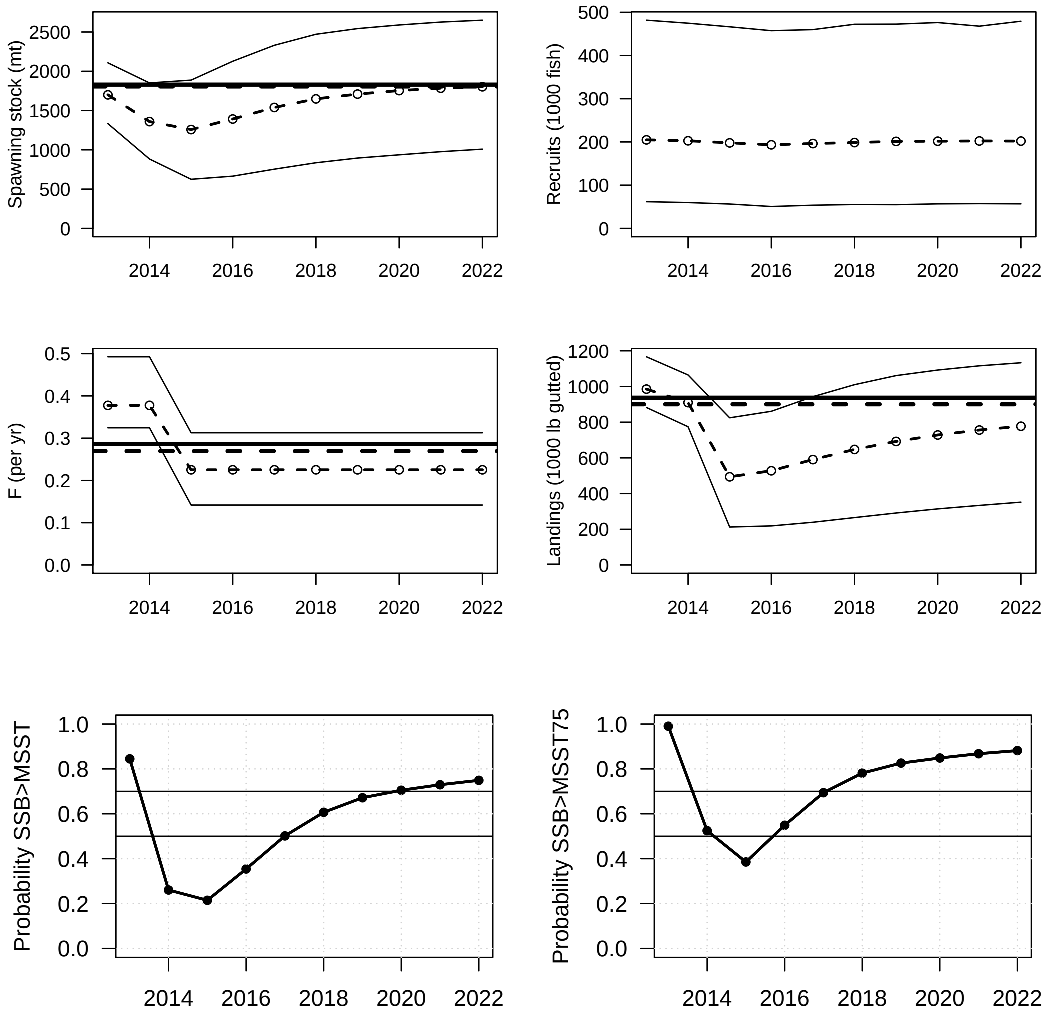
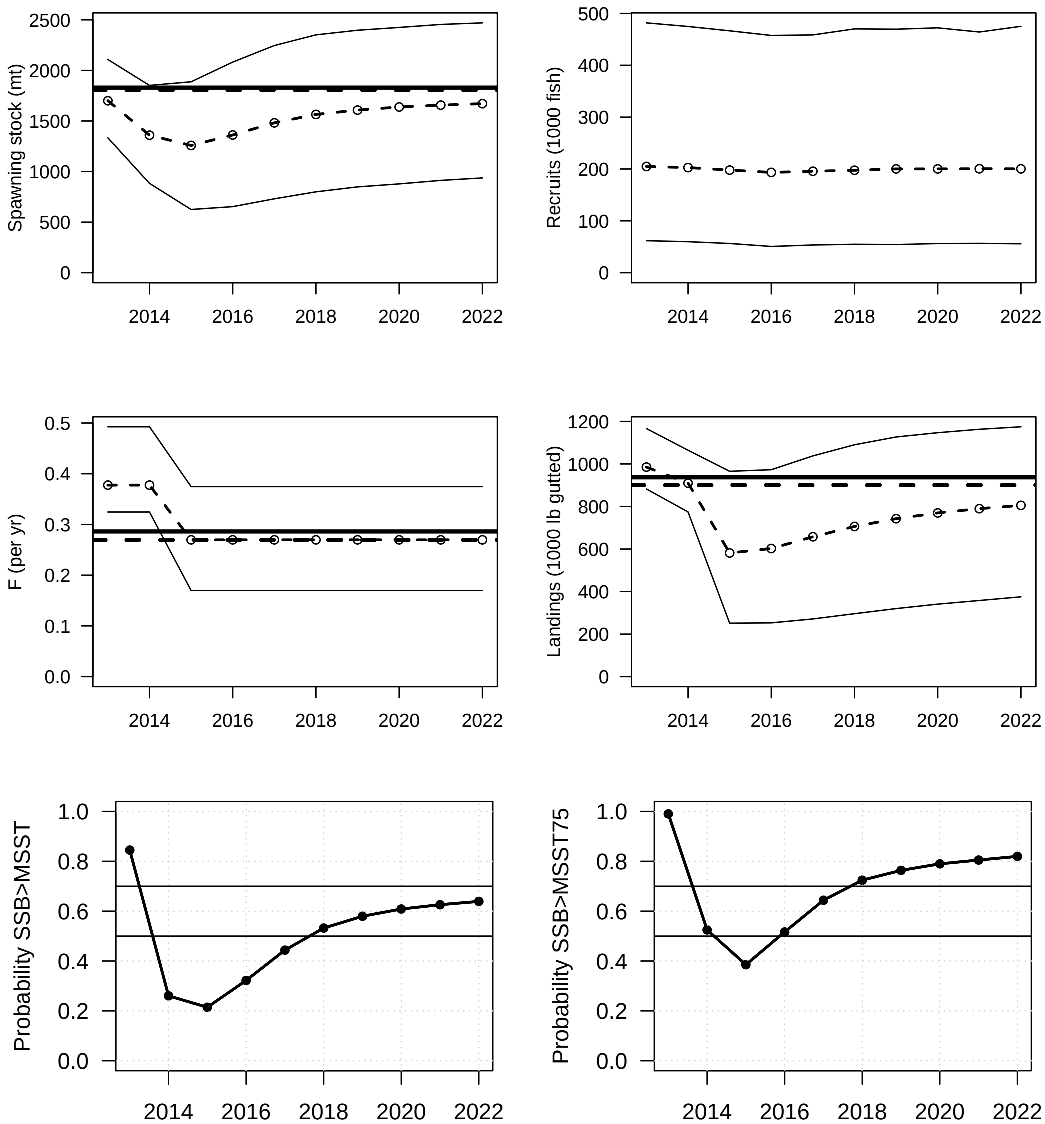


Figure 50. Projection results under scenario 5—fishing mortality rate defined such that $P^{\star} = 0.5$. In the top four panels, medians represented by dashed lines with open circles and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Solid horizontal lines mark MSY*-related quantities; dashed horizontal lines represent corresponding medians. In the bottom two panels, the curves represents the proportion of projection replicates for which SSB exceeds the replicate-specific* MSST*. The bottom left panel uses* $\mathrm{MSST} = (1 - M)\mathrm{SSB}_{\mathrm{MSY}}$*, and the bottom right panel uses* $\mathrm{MSST} = 75\%\mathrm{SSB}_{\mathrm{MSY}}$*. Horizontal lines drawn at 0.5 and 0.7 for reference.*



Appendix A Abbreviations and symbols

Table 24. Acronyms and abbreviations used in this report

Symbol	Meaning
ABC	Acceptable Biological Catch
AW	Assessment Workshop (here, for gag)
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
DW	Data Workshop (here, for gag)
F	Instantaneous rate of fishing mortality
F_{MSY}	Fishing mortality rate at which MSY can be attained
FL	State of Florida
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 gag 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
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
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 = 339  Objective function value = -6411.39  Maximum gradient component = 0.000134074
# Linf:
905.221452321
# K:
0.353719006095
# t0:
-0.394255778064
# len_cv_val:
0.110142598402
# log_Nage_dev:
 0.000000000000 0.000000000000 0.000000000000 0.000000000000 0.000000000000 0.000000000000 0.000000000000 0.000000000000 0.000000000000
 0.000000000000 0.000000000000 0.000000000000 0.000000000000 0.000000000000 0.000000000000
# log_R0:
12.3418991610
# steep:
0.840000000000
# rec_sigma:
0.423132153167
# R_autocorr:
0.000000000000
# log_rec_dev:
 -1.39394237922 -1.37113529191 -0.979225303943 -0.371272408816 -0.270981553691 -0.397734432925 -0.0567206259442 0.366122412030
 0.180861102959 0.235871171411 1.03848638952 -0.187186439871 -0.697893995278 0.318124834670 0.977497276642 0.524832208578
 0.438029099628 -0.0957714988604 0.612892578836 0.134894328565 0.688601670583 -1.08985593229 0.772354854472 -0.294655101667
 -0.225751568751 -0.0171471219595 -0.0495048537086 0.368473715475 0.388776595478 0.362358066321 0.407264424537 -0.0983415616013
 -0.106812899305 -0.0576840031021 0.196377273414 0.0607087078268 0.295147065217 0.730549973970 -0.427246185419 -0.909360591866
# selpar_L50_cH1:
4.77343860591
# selpar_slope_cH1:
1.84898594041
# selpar_L50_cH2:
4.89183456775
# selpar_slope_cH2:
2.77294536582
# selpar_L50_cH3:
4.43131304937
# selpar_slope_cH3:
2.13563887426
# selpar_L50_cD:
4.89164939631
# selpar_slope_cD:
1.20950067464
# selpar_afull_cD:
6.00000000000
# selpar_sigma_cD:
10.0940673569
# selpar_L50_HB1:
1.59651822575
# selpar_slope_HB1:
2.57578474584
# selpar_L50_HB2:
2.17251742016
# selpar_slope_HB2:
2.46600547164
# selpar_L50_HB3:
2.64172608329
# selpar_slope_HB3:
3.26429687154
# log_q_cH:
-7.05419520448
# log_q_HB:
-12.9639887214
# log_q_GR:
-12.8414714538
# M_constant:
0.140000000000
# log_avg_F_cH:
-1.70020602861
# log_F_dev_cH:
 -2.63128477852 -2.72897722695 -2.80003478120 -2.79006984581 -3.07314865080 -2.31780563219 -1.91441731674 -2.25323963742
 -1.91523475281 -1.86535287618 -2.25679485094 -1.88629430825 -1.59950906596 -1.41805141379 -1.00734691124 -0.735001271460
 -0.0814472562079 0.0790208162329 0.202724369062 0.561783256142 0.761894134869 0.953525240416 1.28355737090 1.32669504290
 1.29850591035 1.65289720435 1.69730927381 1.82647331914 1.32321314827 0.992077606755 1.14775132492 1.43320455814
 1.44440622408 1.52288399901 1.34280813280 1.34141216761 1.25268839511 1.01444622943 1.03274084440 1.06783554278
 0.885466586371 0.608962519212 0.535523149444 0.692477656870 0.589901283348 0.933569220304 0.864160255106 0.834435828529
 0.591691247461 0.398133339792 -0.220164621436
# log_avg_F_cD:
-3.66331121441
# log_F_dev_cD:
 -3.92226949540 -2.88151740164 -2.20599612432 -1.66628614470 -1.63953932067 -1.64488686730 -1.38915499534 -1.85294860078
 -0.865076901573 -1.07389637910 -1.60318020370 -0.189069606390 -0.537470985223 -0.157166802606 -0.506909090647 0.814774126308
 1.04428561115 0.813769090194 1.07227386886 0.912499037136 1.31466782165 1.14244906493 1.56023497933 1.44061301359
 1.07705980404 1.36545982022 1.24276656778 1.35121512829 0.747173369391 0.359298618550 0.484168138718 0.892596524442
 0.880336986683 1.06433184235 1.33758283728 0.767063209567 0.450749458948
# log_avg_F_HB:
-4.03395889312
# log_F_dev_HB:
 -0.861019425187 -0.957864792112 -1.02697446863 -0.999984029730 -1.28946117600 -0.541451923925 -0.116680317901
 -0.484089529937 -0.154406082633 -0.107471479658 -0.316522403188 0.0876485226272 -0.0332016620517 -0.413239341910
```

```
 -0.475007005375 -0.304702035165 -0.572461510968 -0.0762408406207 -0.433712720525 0.259157384968 0.0263439048221
 0.274638683074 0.711495389740 0.882588664235 0.821407853908 0.912101176782 0.856070667082 0.854801250742 0.722795626957
 0.404854074220 0.646135345968 0.459877676295 0.328770115907 0.467246254146 0.149653962979 0.197719256072 0.551554447142
 0.419024977870 0.529573610739 0.200077650138 -0.0721150211939 -0.497439724595 0.219150945091 0.539440501536 0.115963508928
 0.601263616392 -0.155912392952 -0.181770455044 -0.300797100897 -0.827279616613 -1.03955001155
# log_avg_F_GR:
-2.90075814795
# log_F_dev_GR:
 -2.28028201795 -2.37824310972 -2.44545182859 -2.41892142200 -2.70940429777 -1.96265371182 -1.53858656444 -1.90549885129
 -1.57694814539 -1.52943296885 -1.90159403757 -1.41704358160 -1.02286588744 -0.804948693468 -0.431543456677 -0.459334819666
 0.155994483330 0.135060340523 0.0831965830682 0.430448297080 -0.673172292606 1.21780713866 1.87136902846 0.925564007641
 0.589001930955 1.06930432422 0.679884681252 1.01430031318 0.897724442647 0.347589224124 0.883061141919 0.944624051196
 0.940550014494 0.873336201409 0.848877993099 0.731396188118 0.926630162891 1.54182641816 1.00443501129 1.18182141138
 0.516019439085 1.12050585248 1.11411336686 0.831636754289 1.23534975992 1.33083501187 1.41586038614 1.11950466823
 0.170886327827 -0.376527181002 -0.316062087933
# log_avg_F_cH_D:
-4.80884624562
# log_F_dev_cH_D:
 0.587078524730 0.480768853643 0.820629298887 0.603394865050 -0.245489451895 0.257097304816 0.548219100249 -0.308918540855
 -0.332996732683 -0.186832996824 -0.353526723902 -0.795668099981 -0.732394342638 -0.341361058594
# log_avg_F_HB_D:
-6.07902644336
# log_F_dev_HB_D:
 -0.947281657801 0.360358800343 0.0939239630420 0.933133451425 0.572174400118 -0.737994632931 -1.73385918818 -1.19162914370
 -4.26903314752 0.742571968396 -0.612925551682 0.551970809920 0.368040663856 0.410733763705 0.951136556466 0.410184412788
 0.0585315345215 -0.476129336734 -0.762778871318 0.0388951528441 -0.301929520764 0.0261839137234 0.652170214450 0.839473995447
 0.933405995418 0.191763368509 0.127963530881 0.351882725405 0.579044680726 0.258063975737 0.719874357872 0.862078815041
# log_avg_F_GR_D:
-3.15772056109
# log_F_dev_GR_D:
 -0.552056200252 -2.81238137157 0.0535915559583 -0.672441729747 -1.23816988850 -1.17395588402 -1.54307691519 -1.44711684979
 0.137712187380 -0.854499226279 -0.831201686045 -0.656430527062 -0.459378009419 0.144177259632 0.485536359366 0.456129770187
 0.739226171295 0.150645097530 0.0600759896753 0.587381183134 0.0640646900083 0.522235199686 1.10405658824 0.825502663987
 1.13730072692 0.743240001392 1.35348287543 1.23737331210 0.223777249105 0.415100744496 0.486982197713 1.31311646463
# F_init:
0.0300000000000
```