January 18, 2014

Chairman Ben Hartig
South Atlantic Fishery Management Council
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

Dear Chairman Hartig,

Thank you for the opportunity to provide input on a number of proposed fishery management plan amendments that are up for either scoping or public hearings this month

Below are our comments for council consideration.

Snapper Grouper Regulatory Amendment 16 (Scoping):

Black sea bass pot fishery closure November 1 through April 30 -

We believe the actions the fishery council took in Snapper-Grouper Amendment 18A in 2012, such as capping the number of vessels utilizing pot gear at 32, limiting vessel to 35 pots, requiring that pots be brought back to shore after each trip and establishing a commercial trip limit of 1,000 lb., reduced the potential for any interactions with right whales, even though there never have been any documented interactions between whales and pot gear.

The CFSF supports allowing a black sea bass pot fishery November 1 through April 30, even if it is restricted to areas outside the defined right whale critical habitat, such as considered in new Alternative 6 of the proposed Amendment.

Snapper Grouper Amendment 29 (Public Hearing):

Only Reliable Catch Stocks (ORCS) Approach -

We support amending the fishery council's ABC Control Rule proposed in Action 1, Alternative 2, to adopt the SSC's recommended approach to determine ABC values for Only Reliable Catch Stocks.

Action 2: We support the application of the revised ABC Control Rule to the selected unassessed snapper-grouper species in the low, moderate and high risk categories using the Risk Tolerance scalars in Sub-alternatives 2b, 3b and 4b.

Fishermen would benefit for the higher ACLs that would result from the amended ABC control rule and the application of the higher Risk Tolerance scalars.

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Gray Triggerfish –

Action 3: We support Alternative 4, which would specify a minimum size limit for gray triggerfish of 14 inches fork length in federal waters off North Carolina, South Carolina, Georgia, and east Florida.

From the standpoint of yield from a 12 inch or smaller triggerfish, it is not large enough to benefit commercial markets and is small even for personal consumption. We think the fishery would benefit from a minimum size limit of 14 inches.

Action 4: We support Alternative 2, which would change the allocation of the commercial ACL to 50 percent from January 1 through June 30 and the other 50 percent from July 1 through December 31 each year. The gray triggerfish seasons would then mirror the seasons for vermilion snapper and since these are co-occurring species that are caught together, this Alternative would reduce bycatch of both species.

Action 5: We support the use of trip limits to manage commercial fisheries, however this action needs more alternatives for analysis.

Consideration should be given to establishing a trip limit for gray triggerfish that is combined with a step-down trip limit when 75 percent of the commercial ACL is met or is projected to be met. A range of step-down trip limits such as 50 lb., 75 lb., 100 lb., and 150 lb. should be considered.

Coastal Migratory Pelagics Amendment 24 (Scoping):

Modifying sector allocations for Atlantic migratory group Spanish mackerel and Gulf migratory group king mackerel -

The CFSF supports optimization of fishery ACLs. It's clear that in both fisheries, the total ACLs have never been landed in the 10 year time series within Tables S-1 and S-2 in the scoping document, and that the commercial sector has exceeded its ACL while the recreational sector has landed decreasingly lower proportions of its ACL.

The fishery council should consider reallocation alternatives in both fisheries.

Coastal Migratory Pelagics (Mackerel) Framework Amendment 1 (Public Hearing):

Modify the Annual Catch Limit (ACL) for Atlantic and Gulf Spanish mackerel migratory groups -

The CFSF supports the alternatives that would increase the ACLs for these fishery groups.

Consideration of our comments is appreciated.

Respectfully,

Wayne Mershon
President

my name is jeff emery, I hold a snapper grouper unlimited permit and have been commercial diving/fishing offshore Daytona Beach since 1980. I believe the triggerfish population is healthy. in my opinion the quota should be raised, a commercial trip limit should be used to insure the fishery stays open year round. decrease the rec limit to 3 per person, keep the 12 inch limit in effect. thank you...

F/V HULL'S SEA LOVER

Mr. Bob Mahood, Executive Director
South Atlantic Fishery Management Council
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

SGAmend29Comments@safmc.net

Date: Saturday February 01, 2014

Re: Snapper Grouper Fishery Management Plan Amendment 29

Mr. Mahood,

I would like to submit this written comment about Amendment 29 to the Fishery Management Plan for the Snapper Grouper (SG) Fishery of the South Atlantic Council Region which proposes actions to:

(1) update the South Atlantic Council's Acceptable Biological Catch (ABC) Control Rule to incorporate methodology for determining the ABC of "Only Reliable Catch Species" (ORCS)

(2) adjust ABCs for the affected species

(3) establish management measures for gray triggerfish in federal waters of the South Atlantic Council region.

Action 1. Amend the South Atlantic Council's ABC Control Rule

Preferred Alternative 2. Adopt the SSC's recommended approach to determine ABC values for Only Reliable Catch Stocks (ORCS). This approach will become Level 4 of the ABC Control Rule and the existing Level 4 will be renumbered as Level 5.

Action 2. Apply the Revised ABC Control Rule to select unassessed snapper grouper species

Alternative 2. Assign a Risk Tolerance scalar to stocks deemed by the SSC to be under Low Risk of Overexploitation:

Preferred Sub-alternative 2b. Apply a Risk Tolerance scalar of 0.90

Alternative 3. Assign a Risk Tolerance scalar to stocks deemed by the SSC to be under Moderate Risk of Overexploitation:

Preferred Sub-alternative 3b. Apply a Risk Tolerance scalar of 0.80

Alternative 4. Assign a Risk Tolerance scalar to stocks deemed by the SSC to be under Moderately High Risk of Overexploitation:

Preferred Sub-alternative 4a. Apply a Risk Tolerance scalar of 0.70

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Action 3. Modify the measurement method for gray triggerfish and establish a size limit

Alternative 1 (No Action). There is no good reason to raise the size limit of triggerfish causing more discards. All of the triggerfish harvested should be utilized.

Action 4. Establish a commercial split season for gray triggerfish

Alternative 1 (No Action). Presently, the commercial fishing season is from January 1st through December 31st of each year. The Commercial ACL is allocated for the entire year.

Action 5. Establish a commercial trip limit for gray triggerfish

Alternative 1 (No Action). There is no commercial trip limit for gray triggerfish in the South Atlantic region.

Captain Jimmy Hull

Hull's Seafood, Inc.
F/V Hull's Sea Lover
Black Sea bass (BSB) Pot Endorsement Holder
Snapper Grouper Advisory Panel Member
Bottlenose Dolphin Take Reduction Team Member
SouthEast Data, Assessment and Review (SEDAR 25) BSB Data Workshop Panelist and Assessment Workshop Observer

Mr. Mahood, I am submitting this written comment about Amendment 29 to the Fishery Management Plan.

On Action 1. I will go with alternitive 2 the SSC's recommendation.

On Action 2. I like alternitive 2. And sub- alternative 2b Apply a risk tolerance scalar of 0.90

Sub -alternative 3b. apply a risk tolerance of 0.80
Sub - alternative 4a apply a risk tolerance of 0.70

On Action 3. I like Alternative 1

On Action 4 I like the Split season

On Action 5 I would like a trip limit of a 1000 pound but can live with 500.

Thank you,
Capt. Paul Nelson (Bloodline Fishing)

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Ocean Conservancy

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February 3, 2014

Robert Mahood, Executive Director, SAFMC
4055 Faber Place Drive, Suite 201
N. Charleston, SC 29405

RE: Amendment 29 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region Decision Document – Amendment to the ABC Control Rule, ABC Adjustments to Unassessed Species, and Management Measures for Gray Triggerfish[1]

Dear Mr. Mahood:

Ocean Conservancy[2] appreciates the opportunity offered by the South Atlantic Fishery Management Council Staff to give comment as Snapper Grouper Amendment 29 is advanced through the scoping process. Among other provisions, **Amendment 29** proposes to utilize the Only Reliable Catch Stocks ('ORCS') methodology in setting the Acceptable Biological Catch ('ABC') for species that remain unassessed by the council within the snapper grouper fishery. The Ocean Conservancy cautions the Council that the selected interpretation of the ORCS methodology deviates from the version developed by the original ORCS working group and as such does not adequately protect the majority of unassessed snapper grouper species from overfishing and would likely lead to biomass reductions and overfished statuses for those species.

The ORCS Working Group Methodology

The original ORCS approach as developed and presented in *Berkson, et al* (2011)[3] consists of three basic steps:

1) A stock is assigned to an exploitation category with the help of a pre-determined attribute table that reflects regional circumstances. The stock status categories that the ORCS group recommended were *lightly*, *moderately*, and *heavily* exploited.

2) An appropriate catch statistic over the relevant time period is chosen, commonly the mean or median landings, and this catch statistic is then multiplied by a scalar to obtain the

[1] South Atlantic Fishery Management Council, *Amendment 29 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region Decision Document*, http://safmc.net/sites/default/files/meetings/pdf/Council/12-2013/SG/Attach8_Am29DD_Dec2013.pdf (accessed February 3, 2014).

[2] Ocean Conservancy, a non-profit organization with over 120,000 members, educates and empowers citizens to take action on behalf of the ocean. From the Arctic to the Gulf of Mexico to the halls of Congress, Ocean Conservancy brings people together to find solutions for our water planet. Informed by science, our work guides policy and engages people in protecting the ocean and its wildlife for future generations.

[3] Department of Commerce, *NOAA Technical Memorandum NMFS-SEFSC-616 (May, 2011)*, https://grunt.sefsc.noaa.gov/P_QryLDS/download/TM616_tm_616.pdf?id=LDS (accessed February 3, 2014).

Overfishing Level ('OFL'). The ORCS group performed some simple evaluations of appropriate scalars using a production model approach, the results of which were then used as the basis of recommending a multiplier of 0.5 for *heavily* exploited species (biomass is assumed to be below 20% of unfished levels), 1.0 for *moderately* exploited species (biomass is assumed to be around biomass at MSY), and 2.0 for *lightly* exploited species (biomass is assumed to be above 65% of unfished levels). It is important to note that these scalar recommendations were based on the assumption that they would be applied the catch statistic "average catch". If a catch statistic vastly different from mean or median catch was chosen, the recommended range of scalars might not be applicable.

3) ABC is calculated as a proportion of the OFL, reflecting Council risk tolerance.

The ORCS working group intended this methodology to be a structured approach that could improve upon existing methods for determining ABCs for data-poor species (which in the southeast were nil), recognizing the challenges involved in the heavy reliance on expert judgment and assumptions. It was also intended that each region modify the approach to suit their needs. Importantly, the working group recommended that evaluation tools such as Management Strategy Evaluation ('MSE') be used to test the performance of decision rules.

The Amendment 29 ORCS Methodology Currently Under Pre-Scoping by Council Staff

The version of the ORCS approach that is currently proposed in Amendment 29 is far removed from the original method proposed by the ORCS working group as discussed above. The key distinctions are:

1) No ORCS species was assigned to the "high" exploitation tier, implying that the council does not believe that any of its currently unassessed species are overfished, which is unlikely given the high proportion of assessed species that are overfished or are undergoing overfishing.

2) The catch metric proposed for use is "highest landings," which is combined with a scalar between 1.25 and 2, meaning that the resulting quantity (which is deliberately not referred to as an OFL) will be higher than the highest observed catches in the time series. This quantity is then multiplied by a risk tolerance scalar between 0.7 for species deemed to be at a moderately high risk of overexploitation to 0.9 for species taken to be at low risk of overexploitation.

The consequence of applying this approach would be that five species would have the ABC (and therefore the ACL) set at a level slightly lower than the highest catch during the time series, ten species would have it set slightly above the highest landings, and one species would have the ABC set at about twice the highest landings.

Under the system proposed in Amendment 29 even those species that are determined to have a *moderately high* risk of overexploitation already have Annual Catch Limits that would rarely be exceeded under the status quo. No evaluation of the expected performance of the proposed measures is provided and no rationale is given in support of the notion that ABCs resulting from applying the proposed approach would prevent overfishing. In fact, the opposite can be expected based on the risk-prone decisions regarding catch metrics and scalars that have been made and based on the large proportion of assessed snappers and groupers undergoing overfishing.

While the council did not conduct an evaluation of this proposed method, an independent group of scientists did—this evaluation, which has been presented to the scientific and statistical committee ('SSC') confirms that the proposed approach to setting ABCs cannot be expected to meet the spirit of National Standard One. This independent group conducted a simulation analysis of several data-poor approaches to setting catch limits, including a method previously proposed by the council, using the third highest catch.[4] This method is more conservative than the currently considered highest catch approach. Scientists in this independent study evaluated methods across several generic species' life histories, including the types of life histories those species within the council's snapper grouper complex would be likely to exhibit, and at various biomass levels. The results show that the third-highest catch method performs poorly in terms of probability of overfishing and long-term yield, especially in low biomass scenarios. Out of all the methods evaluated, some of which could easily be applied to species under the purview of the council, the third highest catch method had the poorest performance.

Based on this analysis it can be expected that the council's currently proposed highest catch method to setting ABCs would not prevent overfishing for the majority of unassessed species and would likely lead to biomass reductions and overfished status.

Conclusion

The ORCS methodology proposed in Amendment 29 significantly deviates from the original ORCS approach developed by the working group and will likely result in deleterious effects to unassessed species managed by the council. Accordingly, Ocean Conservancy recommends that the council does not use the proposed method of selecting ABCs for unassessed species, and instead employs a methodology that would offer greater protections against the threat of overfishing and the potential for overfished status for these fish, and that incorporates feedback from the fishery (such as catch-per-unit-effort time series or indices of average fish length over time) to modify future catch levels.

We thank council staff for the opportunity to provide input as it goes about developing Amendment 29 and we look forward to continued work with the council on ensuring effective fisheries management in the South Atlantic.

Sincerely,

s/ Jon Paul S. Brooker, JD
Policy Analyst
Ocean Conservancy
727.369.6613

[4] Fisheries Centre (Dr. Thomas J Carruthers), *Evaluating Methods for Setting Catch Limits in Data-Limited Fisheries*, http://safmc.net/sites/default/files/meetings/pdf/SSC/SSC-102013/A19_DataPoorAssessmentsCarruthers.pdf (accessed February 3, 2014).

February 3, 2014

Mr. Bob Mahood
Executive Director
South Atlantic Fishery Management Council
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

RE: Amendment 29 to the Snapper Grouper Fishery Management Plan

Dear Mr. Mahood,

On behalf of The Pew Charitable Trusts, please accept these comments for consideration by the South Atlantic Fishery Management Council regarding Amendment 29 (Am29) to the Snapper Grouper Fishery Management Plan (FMP) for data-limited stocks in the South Atlantic.[1] We urge the Council to delay action on Am29 until the Science and Statistical Committee (SSC) has had another opportunity to review the proposed application of the Only Reliable Catch Stocks (ORCS) approach for specifying allowable biological catch (ABC) in the ABC control rule.

We commend the Council on achieving significant progress toward ending and preventing overfishing of its managed species. Staying on the path to long-term sustainability is critically important but as currently drafted, Am29 could undermine that progress. Although we support efforts to refine and improve the methods used to calculate and assign catch levels, any revisions to the ABC control rule should be scientifically justified and adequately safeguard fish populations from overfishing. As proposed, the applied ORCS methodology would greatly increase the ABCs - and the risk of overfishing - for most of the managed species addressed by this action without strong scientific justification and assurance. **Specifically, Am29 would result in ABCs that are 20-80% <u>above</u> the highest reported landings for each species**. While we do not necessarily oppose increasing catch limits, particularly moderate increases over time, major changes should have strong justification supported by scientific analysis.

<u>Application of ORCS Approach in Amendment 29 Could Undermine its Basic Objectives</u>

As described by technical experts in a report to the NOAA Fisheries Service ("ORCS report"),[2] the ORCS approach is designed to specify the legally required Overfishing Limit (OFL) and ABC in data-limited situations where managed species cannot be assessed with traditional stock assessment methods and reliable catch data are the only information available. Because

[1] SAFMC (2013), Amendment 29 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region: Decision Document, 44pp. Available at: http://safmc.net/sites/default/files/meetings/pdf/Council/12-2013/SG/Attach8_Am29DD_Dec2013.pdf.
[2] NOAA Fisheries Service (2011), Calculating Acceptable Biological Catch for Stocks that have Reliable Catch Data Only, NOAA Technical Memorandum NMFS-SEFSC-616, 44pp.

uncertainty and the risk of overfishing are greater in these situations, methods for specifying OFL and ABC should generally be more conservative than those applied to data-rich stocks. As currently proposed, Am29 consistently chooses the least conservative catch statistics and numerical risk multipliers (scalars) among a range of values suggested in the ORCS report.

As such, the method for managing data-limited stocks proposed by Am29 does not provide adequate assurance that the resulting ABCs and ACLs will meet the requirement of National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) to "prevent overfishing while achieving, on a continuing basis, the optimum yield (OY) from each fishery for the U.S. fishing industry."[3]

The ORCS method outlines a structured, step-wise approach for obtaining an OFL and ABC when reliable catch data are the only information available:

1. Assign stocks to one of three exploitation categories (i.e. Lightly, Moderately, Heavily Exploited) using an evidence-based scoring procedure;
2. Obtain an OFL by multiplying a statistical measure of historical catch by a scalar that depends upon the exploitation category; and
3. Obtain an ABC as a proportion (<1) of the OFL to reflect a policy decision on acceptable risk, which may depend on productivity of the stock.[4]

The intent of this approach is to maintain stable catches at current levels for moderately exploited species and reduce catches on heavily exploited species whose populations may be categorized as overfished, while allowing for limited increases in catch for lightly exploited species.[5] By contrast, the risky approach proposed in Am29 sidelines caution and stability in favor of large increases in ABCs for most species. With the possible exception of the one species classified in the lightly exploited category (bar jack), the catch statistic used by the SAFMC at each exploitation level is higher than recommended in the ORCS report (Table 1). Likewise, the scalar used to calculate an OFL based on the selected catch statistic is also less conservative in most cases (Table 2).

Although Am29's proposed risk level scalar (used to calculate ABC from the OFL level) is within the range suggested in the ORCS framework, the Council's preferred risk levels are the least conservative for species in the lightly and moderately exploited categories and the second least conservative for species in the high-moderate categories (Table 3). In addition, the Council's preferred choice of maximum catch statistics, OFL risk scalars, and ABC risk scalars in Am29 differs substantially from the approach NOAA recommends for obtaining OFLs and ABCs in the ORCS report (Table 4). The net effect of Am29's preferred choice of maximum catch statistics, OFL risk scalars, and ABC risk scalars is much higher and much less conservative ABCs compared to the current ABCs (Table 5). **The Council's approach in Am29 is sufficiently different from the approach recommended in NOAA's ORCS report to warrant revisions to be more consistent with the report's recommendations.**

[3] Magnuson-Stevens Fishery Conservation and Management Act, 16 U.S.C. 1851(a)(1).
[4] NOAA Fisheries Service (2011), NOAA Technical Memorandum NMFS-SEFSC-616, p.19.
[5] Berkson et al. (2011), Table 3, p. 36.

Application of ORCS in Amendment 29 Yields Unjustifiably High Catch Limits

With the exception of lightly exploited/low-risk stocks, each of the new ABC outcomes is less precautionary under Am29, and in the case of "moderate risk stocks," increases the proposed ABC from the current ABC for any determined catch statistic by 20%.[6] However, the Council also has also chosen to use the highest reported catch in the selected time series and when this catch statistic is multiplied by the Council's preferred risk scalars, the resulting ABCs are skewed even higher, producing increases of ABCs from 31% to 329% in the "moderate" risk category and 8% to 14% in the "moderately high" risk category, although ABCs for two stocks (rock hind and the northern stock of white grunt) would decrease slightly (1-4%).

The resulting large increases in ABCs conflict with NOAA recommendations in the ORCS report to set the management objective for moderately exploited stocks at "*maintaining current catch levels*."[7] The choice of catch statistic based on the highest reported landings from 1999-2007 in Am29[8] undermines this objective, and the Council does not provide sufficient justification for its choice. Indeed, in the case of Atlantic spadefish, the highest reported catch in the time series (1999-2007) greatly exceeds any reported catch since NOAA Fisheries began keeping modern catch records (Fig. 1).

The rationale for choosing the highest reported landings from the time series as the relevant catch statistic (rather than average or median) is not clearly documented in the SSC's reports to the Council or justified in the public documentation for Am29. Choosing a less risky catch statistic, such as mean or median catch, would be more consistent with the objective of maintaining stable catches at or near the current levels for species categorized at moderate level, as intended in the ORCS report. **The ORCS Report cautions that use of "*the maximum catch statistic should only be considered for non-target species with compelling evidence that they are lightly exploited*."**[9] Only one species in the list of species proposed to receive new ABCs under Am29 has been determined to be "lightly exploited," and the council has not analyzed the other species proposed to receive new ABC to determine whether they are targeted in the fishery. **We calculate that the end result for Low and Medium Risk stocks in Am29 would be to set ABCs that are 20-80% <u>above</u> the highest reported landings for each species.**

As proposed, Am29 threatens to reverse the significant progress made in ending and preventing overfishing in the South Atlantic. We strongly urge the Council to delay action on this amendment until the SSC has had an opportunity to re-examine the rationale for using the highest reported catch from 1999-2007 as the appropriate catch statistic for all species under consideration, as well as the adequacy of the proposed risk scalars in preventing unintended overfishing in these poorly monitored fisheries. This review should include consideration of other data-limited approaches that may be more suitable for use in the ABC control rule as well

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[6] See SAFMC (2014), Overview of Snapper Grouper Amendment 29, Slide 15: Summary of Preferred Alternative 3b under Action 2. Available at: http://www.safmc.net/sites/default/files/meetings/pdf/Public%20Hearings%20&%20Scoping/Jan%202014/SGAm29Presentation.pdf. 20% is derived by multiplying the Risk of Overexploitation scalar (1.5) x the Risk Tolerance scalar (0.80): 1.5 x 0.8 = 1.20.

[7] *Berkson et al. (2011)*, pp. 20, 36.

[8] SAFMC (2013), p.1.

[9] *Ibid*., p. 24.

as more recent evaluations of data-limited methods for setting catch limits such as the simulation analyses by Carruthers *et al*. (in press). This analysis indicates that use of catch-based, ORCS-like methods do not appear to provide a better basis for management than maintaining current catch or effort levels, and often perform even worse than the status quo methods of current catch or current effort if stock biomass is below B_{MSY}.[10]

In addition, the SSC and the Council should give careful consideration to the long-term effects on the stability and sustainability of the fishery by authorizing large increases in catches for these stocks. Finally, we encourage the Council to continue improving data collection, catch monitoring and reporting systems at every opportunity, in order to provide better information on the sustainability of data-limited catch limits.[11] We thank you for providing this opportunity to comment and look forward to working with the Council to ensure that healthy fisheries are sustained in the South Atlantic.

Sincerely,

Leda A. Dunmire
Manager, U.S. Oceans, Southeast
The Pew Charitable Trusts
ldunmire@pewtrusts.org

[10] For instance, see: T. Carruthers, C.J. Walters, and M.K. McAllister (2013), Evaluating methods for setting catch limits in data-limited fisheries. In press.
[11] Berkson et al. (2011), pp. 30-21.

Table 1. Comparison of management objectives and catch statistics used to calculate OFLs as suggested by NOAA (ORCS Report) and as proposed by the Council in Am29.

Stock Status	Management Objectives (ORCS Report)	Suggested Catch Statistic for Setting 'OFL' (ORCS Report)	Proposed by SAFMC in Am29
Light/Low	Maintain current catch levels or allow for limited increases in catch	• 75% of highest catch • Highest catch only for lightly exploited, non-targeted species • 2 standard deviations above average catch	Maximum catch
Low Moderate			Maximum catch
Moderate	Maintain current catch levels	Average catch	Maximum catch
High Moderate			Maximum catch
Heavy / High	Reduce catches to end overfishing	Below average catch	Maximum catch

Table 2. Comparison of the "scalars" used to calculate OFL

Exploitation Level	Recommended in ORCS Report	Proposed by SAFMC in Am29
Light/Low	2.0 x catch statistic	2.0 x catch statistic
Low Moderate	NA	1.75 x catch statistic
Moderate	1.0 x catch statistic	1.5 x catch statistic
High Moderate	NA	1.25 x catch statistic
Heavy/High	0.50 x catch statistic	NA

In Amendment 29, scalar is the catch level associated with the risk of overexploitation.

Table 3. NOAA ORCS Recommended options for risk levels

Risk Level	ORCS Alt A	ORCS Alt B	ORCS Alt C	ORCS Alt D	Am29
Light/Low	0.75 x OFL	0.75 x OFL	0.90 x OFL	0.90 x OFL	0.90 x OFL
Low Moderate					0.80 x OFL
Moderate	0.75 x OFL	0.75 x OFL	0.75 x OFL	0.80 x OFL	0.80 x OFL
High Moderate					0.70 x OFL
Heavy/High	0.75 x OFL	0.50 x OFL	0.50 x OFL	0.70 x OFL	NA

Please note that NOAA's ORCS Report uses three exploitation levels whereas the SAFMC uses five exploitation levels as determined by the SSC.

Table 4. Comparing ABC calculations: NOAA's ORCS report vs. Am29.

Exploitation Level	Catch Statistic ORCS	Catch Statistic Am29	OFL Scalar ORCS	OFL Scalar Am29	Risk Level	ABC Calc. ORCS	ABC Calc. Am29
Light/Low	Max Catch	Max Catch	2.0	2.0	0.90	1.8 x Max Catch	1.8 x Max Catch
Moderate	Average Catch	Max Catch	1.0	1.5	0.80	0.8 x Avg Catch	1.2 x Max Catch
Heavy/ Moderate High	Below Avg Catch	Max Catch	0.75[1]	1.25	0.70	0. 525 x Below Avg Catch	0.875 x Max Catch

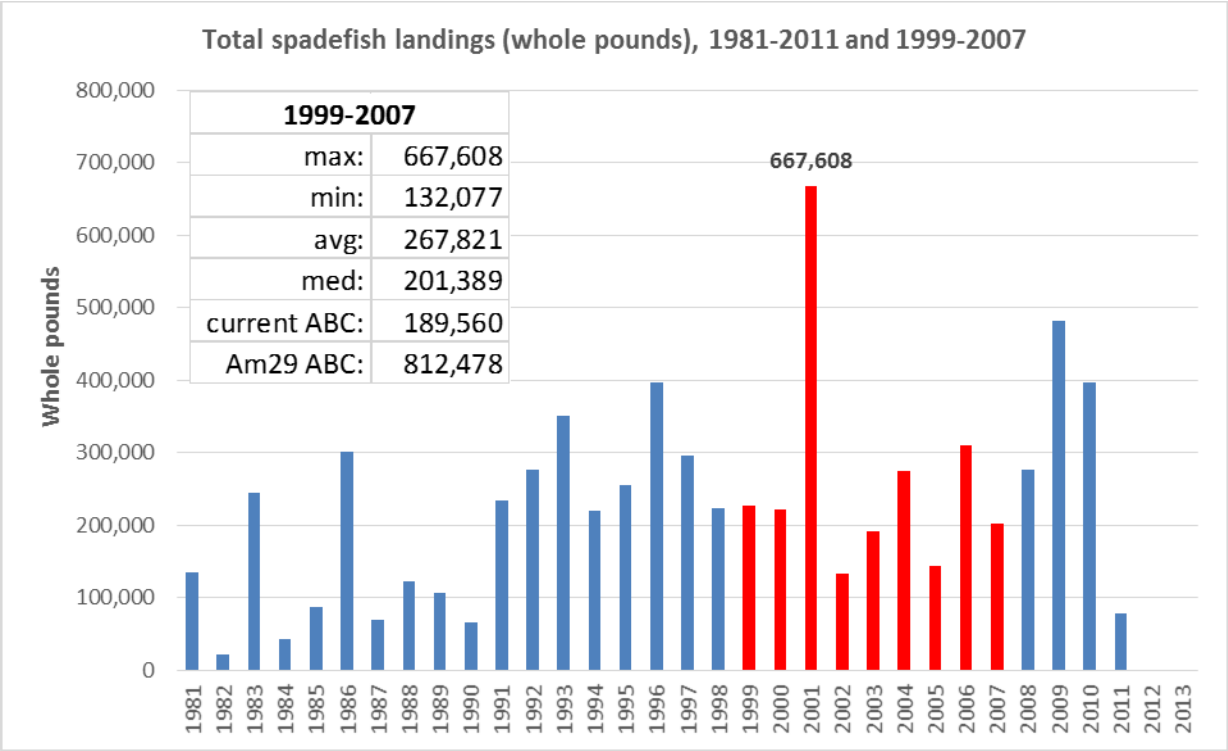
[1] NOAA's ORCS report did not use the 'moderately high' exploitation category as proposed in Am29, thus the OFL scalar shown is interpolated between the ORCS 'moderate' and 'heavy' exploitation levels. Additionally, the ORCS report recommendations did not have a risk level associated with a 'moderately high' category but instead recommended a risk level range of 0.5 to 0.75 for heavily exploited species.

Table 5. Summary of proposed new ABCs in Am 29

Species	Exploitation Status	Current ABC	Highest Catch (1999-2007)	New ABC Am29	Diff. in Am29 ABCs
Bar Jack	Low	24,780	34,583	62,250	151%
Margate	Moderate	29,889	63,993	76,792	157%
Red Hind	Moderate	24,867	27,570	33,084	33%
Cubera Snapper	Moderate	24,680	52,721	63,265	156%
Yellowedge Grouper	Moderate	30,221	46,330	55,596	84%
Silk Snapper	Moderate	25,104	75,269	90,323	260%
White Grunt (South)	Moderate	674,033	735,873	883,048	31%
Atlantic Spadefish	Moderate	189,460	677,065	812,478	329%
Gray Snapper	Moderate	795,743	1,039,277	1,247,133	57%
Lane Snapper	Moderate	119,984	169,572	203,486	70%
Rock Hind	Mod High	37,953	42,849	37,493	-1%
Tomtate	Mod High	80,056	105,909	92,670	16%
White Grunt (North)	Mod High	674,033	735,873	643,889	-4%
Scamp	Mod High	509,788	596,879	552,269	8%
Gray Triggerfish	Mod High	626,518	819,428	717,000	14%

These are based on the selected catch statistic (max catch), scalars and risk levels for each exploitation category compared to current ABCs. ABCs and catch statistics are all in pounds (whole weight).

Fig. 1 – Combined recreational and commercial landings of Atlantic spadefish, 1981-2011. The highest reported catch (landings) from the years 1999-2007 (red bars) was selected as the ORCS catch statistic in Am29. This reported catch (667,608 whole pounds in 2001) is far higher than any recorded catch in the past three decades.[2]



[2] Catch (landings) data were obtained by request from NOAA Fisheries, Fishery Monitoring Branch-Southeast Fisheries Science Center.

Mr. Bob Mahood, Executive Director
South Atlantic Fishery Management Council
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

SGAmend29Comments@safmc.net

Date: Tuesday January 28, 2014

Re: Snapper Grouper Fishery Management Plan Amendment 29

Mr. Mahood,

The SFA ECFS Board is submitting this written comment about Amendment 29 to the Fishery Management Plan (FMP) for the Snapper Grouper (SG) Fishery of the South Atlantic Council Region which proposes actions to:

(1) update the South Atlantic Council's Acceptable Biological Catch (ABC) Control Rule to incorporate methodology for determining the ABC of "Only Reliable Catch Species" (ORCS)

(2) adjust ABCs for the affected species

(3) establish management measures for gray triggerfish in federal waters of the South Atlantic Council region.

Action 1. Amend the South Atlantic Council's ABC Control Rule

SFA ECFS Preferred Alternative 2. Adopt the SSC's recommended approach to determine ABC values for Only Reliable Catch Stocks (ORCS). This approach will become Level 4 of the ABC Control Rule and the existing Level 4 will be renumbered as Level 5.

Action 2. Apply the Revised ABC Control Rule to select unassessed snapper grouper species

Alternative 2. Assign a Risk Tolerance scalar to stocks deemed by the SSC to be under Low Risk of Overexploitation:

SFA ECFS Preferred Sub-alternative 2b. Apply a Risk Tolerance scalar of 0.90

Stock	Catch Statistic (Highest landings 1999-2007)	Risk of Overexploitation Scalar	Risk Tolerance Scalar	New ABC (lbs ww)	Current ABC (lbs ww)	Difference in ABC
Bar Jack	34,583	2	0.90	62,249	24,780	+37,469

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Alternative 3. Assign a Risk Tolerance scalar to stocks deemed by the SSC to be under Moderate Risk of Overexploitation:

SFA ECFS Preferred Sub-alternative 3b. Apply a Risk Tolerance scalar of 0.80

Stock	Catch Statistic (Highest landings 1999-2007)	Risk of Overexploitation Scalar	Risk Tolerance Scalar	New ABC (lbs ww)	Current ABC (lbs ww)	Difference in ABC
Margate	63,993	1.5	0.80	76,792	29,889	+46,903
Red Hind	27,570	1.5	0.80	33,084	24,867	+8,217
Cubera Snapper	52,721	1.5	0.80	63,265	24,680	+38,585
Blue Runner*	1,328,272	1.5	0.80	1,593,926	1,125,729	+468,197
Yellowedge Grouper	46,330	1.5	0.80	55,596	30,221	+25,375
Silk Snapper	75,269	1.5	0.80	90,323	25,104	+65,219
White Grunt (South)	735,873	1.5	0.80	883,048	674,033	+209,015
Atlantic Spadefish	677,065	1.5	0.80	812,478	189,460	+623,018
Gray Snapper	1,039,277	1.5	0.80	1,247,132	795,743	+451,389
Lane Snapper	169,572	1.5	0.80	203,486	119,984	+83,502

* Blue runner will no longer be managed under the federal Snapper Grouper Fishery Management Plan as of January 27, 2014.

Alternative 4. Assign a Risk Tolerance scalar to stocks deemed by the SSC to be under Moderately High Risk of Overexploitation:

SFA ECFS Preferred Sub-alternative 4a. Apply a Risk Tolerance scalar of 0.70

Stock	Catch Statistic (Highest landings 1999-2007)	Risk of Overexploitation Scalar	Risk Tolerance Scalar	New ABC (lbs ww)	Current ABC (lbs ww)	Difference in ABC
Rock Hind	42,849	1.25	0.70	37,493	37,953	-460
Tomtate	105,909	1.25	0.70	92,670	80,056	+12,614
White Grunt (North)	735,873	1.25	0.70	643,889	674,033	-30,144
Scamp	596,879	1.25	0.70	522,269	509,788	+12,481
Gray Triggerfish	819,428	1.25	0.70	717,000	626,518	+90,482

Action 3. Modify the measurement method for gray triggerfish and establish a size limit

Alternative 1 (No Action). Currently, the minimum size limit for gray triggerfish is specified in inches total length (TL) in federal waters off east Florida only. In Florida state waters, the minimum size for gray triggerfish is specified in inches fork length (FL). The minimum size limit is 12 inches TL in federal waters off east Florida and 12 inches FL in east Florida state waters.

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SFA ECFS Preferred Alternative Note: <u>No Alternative was offered with a 12-inch TL (10.46-inch FL) for the entire Council region, versus No Action, Alternative 1</u>.

Action 4. Establish a commercial split season for gray triggerfish

SFA ECFS Alternative 1 (No Action). Presently, the commercial fishing season is from January 1st through December 31st of each year. The Commercial ACL is allocated for the entire year.

Action 5. Establish a commercial trip limit for gray triggerfish

Alternative 2. Establish a commercial trip limit for gray triggerfish in the South Atlantic region.

SFA ECFS Preferred Sub-alternative 2b. 1,000 lbs with no step-downs

Jimmy Hull, Chairman
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January 31, 2014

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Re: Snapper-Grouper Amendment 29 Scoping Comments

Dear Mr. Mahood,

Please accept the following comments on Amendment 29 to the Snapper-Grouper Fishery Management Plan. Chronic overfishing in the South Atlantic and other regions led Congress to require science-based annual catch limits and accountability measures for all stocks in the fishery, with some limited exceptions. We appreciate the time and effort that has gone toward adopting ACLs, including for the large number of unassessed stocks in the region. We are concerned, however, that the proposed approaches for ACL-setting contained in Amendment 29 have a high probability of allowing severe overfishing and do not reflect the best scientific information and methods available for the management of data-limited stocks. As discussed below, the proposed approach lacks support in the scientific literature for the way in which the chosen method is being applied, specifically in light of the conclusions of a peer-reviewed management strategy evaluation conducted by experts from academia and NMFS. As a result, we believe the changes being proposed in Amendment 29 are indefensible under the Magnuson-Stevens Act, the National Environmental Policy Act, and the Administrative Procedure Act.

We understand the time constraints under which the Council and NMFS were operating when establishing the first ACLs for these stocks but believe the Council and NMFS must now engage in a more fully-informed process for adopting the best scientific approaches for assessing and setting ACLs for unassessed stocks. The state of fisheries science has progressed significantly over the past several years. There is now clear evidence that the use of non-precautionary catch scalars like the 3rd highest catch are generally inappropriate, as they have high probabilities of overfishing and stock depletion. Fortunately, new data-limited methods and assessment tools have been developed, many of which are being applied in other fishery

management regions. The continued reliance on disproven ACL-setting methods, especially when more effective alternatives exist, not only fails to fulfill National Standard 2's requirement for use of the best scientific information available, but also does a disservice to fishermen and the resource on which they depend by failing to prevent overfishing and stock depletion. We urge the Council to abandon the proposed changes contained in Action 1 of Amendment 29 and, as described below, work in coordination with NMFS, the States, and other partners on a comprehensive and systematic process for applying the best assessment and ACL-setting methods available.

1. Amendment 29 Misconstrues and Misapplies the ORCS Methodology

As the Council is aware, Amendment 29 contains a proposed application of the "Only Reliable Catch Stock" (ORCS) Method that was developed by the South Atlantic Fishery Management Council's (SAFMC) Scientific and Statistical Committee (SSC). Unfortunately, the documentation of the process to date – including the SSC's two ORCS Workshop Reports, previous and current drafts of Amendment 29, and associated briefings provided to the Council – has failed to provide an adequate scientific rationale for the proposed approach, failed to consider a reasonable range of alternative approaches, and failed to sufficiently analyze the potential environmental harm that might come from implementation. For the Council to effectively evaluate the proposed approach, it needs to consider how the approach diverges from the recommended approaches contained within the ORCS Technical Memorandum and the previous NMFS technical guidance on which the ORCS method relies.

The ORCS control rule approach is in part derived from Restrepo *et al.* (1998) and the Conceptual Framework recommended by Rick Methot as described in the ORCS Technical Memorandum.[1] The former recommends a "default limit control rule be implemented by multiplying the average catch from a time period when there is no quantitative or qualitative evidence of declining abundance ('Recent Catch') by a factor depending on a qualitative estimate of relative stock size."[2] A limit of 1.0 times recent catch is recommended where qualitative evidence and expert judgment indicates that biomass may be above biomass at maximum sustainable yield (B_{MSY}), 0.67 times recent catch if biomass is thought to be greater than the minimum stock size threshold (the MSST, or overfished level), and 0.33 times recent catch if biomass is believed to be below the MSST (i.e., the stock is overfished). Restrepo further recommends that a target be set at 75% of the limits to account for uncertainties.

The Methot Conceptual Framework is less specific than the Restrepo approach, but essentially considers the impact that the fishery may be having on the stock. If there is no impact, then it may qualify for ecosystem component status. If the impact is small, then the catch limit may be

[1] V.R. Restrepo *et al.*, "Technical Guidance On the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act," NOAA Technical Memorandum (July 17, 1998) (attached as Exhibit 1); Jim Berkson *et al.*, "Calculating Acceptable Biological Catch for Stocks That Have Reliable Catch Data Only (Only Reliable Catch Stocks – ORCS)", NOAA Technical Memorandum NMFS-SEFSC-616, at 16-19 (May 2011).
[2] Restrepo *et al.*, at 26.

set above the average catch level over a period of time exhibiting no decrease in abundance, but a catch target should be set no higher than recent catch levels unless evidence suggests an increase above recent catch will not harm the stock. If the fishing impact is deemed moderate, then catch should be limited to average catch, and if the fishing impact is considered moderate to high, then the limit should be set below recent average catch to allow rebuilding. While not as precautionary as the approach recommended by Restrepo, the Methot Framework stands for the proposition that catch should be limited at or below average catch levels from a stable period unless evidence can be presented that fishing is having a small impact and any increase is not likely to deplete the stock to unhealthy levels.

The approach recommended by the ORCS Working Group uses similar exploitation categories as Restrepo and Methot but prescribes a specific scoring system of attributes about the life history, vulnerability, and catch/landings trends to approximate a stock's current exploitation level. The ORCS approach multiplies a catch scalar based on exploitation level by a statistical measure of historic catch, and then adds an Acceptable Biological Catch (ABC) adjustment factor to calculate an ABC for each stock. The recommended catch scalar is 2.0 times the catch statistic for stocks considered lightly exploited, 1.0 times the catch statistic for moderately exploited stocks, and 0.5 times the catch statistic for heavily exploited stocks. While the ORCS Technical Memorandum provides a list of possible catch statistics – including: the mean, median, maximum, minimum, and a percentile of historic catch – it states that the mean is the appropriate catch statistic in many cases.[3] Importantly, the report states that the use of a *maximum* catch statistic, which is the approach adopted by the SSC for Amendment 29, *"should only be considered for non-target species with compelling evidence that they are lightly exploited."*[4]

Table 1: Recommended Catch Statistics and Catch Scalars by Method

		Low Exploitation		**Moderate Exploitation**		**Moderate-Heavy Exploitation**[+]	
Method	**Catch Statistic**	**Catch Scalar (OFL)**	**Risk Tolerance (ABC)**	**Catch Scalar (OFL)**	**Risk Tolerance (ABC)**	**Catch Scalar (OFL)**	**Risk Tolerance (ABC)**
Restrepo	Mean	1.0 (Limit)	0.75 (Target)	0.67 (Limit)	0.5 (Target)	0.5 (Limit)	0.375 (Target)
Methot	Mean	>1.0	1.0	1.0	unspecified	<1.0	Unspecified
ORCS	Mean*	2.0	1.5-1.8	1.0	0.75-0.8	0.75	0.50-0.587
Am. 29	Max.	2.0	1.8	1.5	1.2	1.25	0.875

*Generally recommended. [+]Restrepo et al. and ORCS do not specify the moderate-high exploitation category used in Amendment 29, so the values provided for these methods are equal to the average of the recommended catch scalars and risk adjustments for the "moderate" and "heavy/high" exploitation categories for each method.

The proposed approach contained in Amendment 29 diverges significantly from these previous recommendations, including from the ORCS Technical Memorandum on which it is based. The use of the maximum historical catch statistic is particularly troubling, as it conflicts with the specific recommendation contained in the ORCS Technical Memorandum against using maximum catch for any stock that may be targeted or moderately- to heavily-exploited. Of the 17 stocks for which the maximum catch statistic is being proposed for use in Amendment 29,

[3] ORCS, at 24.
[4] *Id.* (emphasis added).

every one is considered targeted, according to the evaluation conducted as part of the Comprehensive ACL Amendment.[5] And, all but one of the 17 stocks – bar jack – are listed as having a moderate or moderate-high risk of overexploitation. Thus, none of the stocks for which the maximum catch statistic is being proposed in Amendment 29 satisfy the criteria contained in the ORCS Technical Memorandum for deviating from a mean or median catch statistic.

Not only is the proposed catch statistic significantly higher than recommended by the best available scientific information, but the catch scalars and ABC risk tolerance adjustments proposed in Amendment 29 are also significantly higher, and thus less precautionary, than recommended. For example, for moderately exploited stocks, Amendment 29 provides an Overfishing Limit (OFL) that is 150% of the *maximum* historical catch, compared with a limit of 67% of the *mean* catch under Restrepo and 100% of the *mean* catch under the ORCS approach. After the risk policy is factored in, Amendment 29 would set the ABC for stocks at moderate risk of overexploitation at 120% of the *maximum* catch compared with 50% of the *mean* catch under Restrepo and 75-80% of the *mean* catch under the ORCS approach recommended in the Technical Memorandum.

The rationale behind the SSC's decision to diverge from the technical guidance by endorsing a catch statistic based on maximum catch is clear – the mean or median catch may actually limit future catch, while setting the ABC at or above maximum catch would make it highly unlikely that any type of accountability measures would ever be triggered. This approach renders meaningless the MSA's annual catch limit requirement. Here is how the SSC explained its reasoning:

> "The group had an extensive discussion regarding the difficulties associated with choosing a catch statistic that would be appropriate for the full suite of stocks being considered for application of the ORCS method. Initial suggestions focused on using the median landings over a set time period. However, after further inspection the median was considered inadequate to represent the high fluctuation in landings—i.e., to appropriately capture the range of occasional high landings—and the group reached consensus on using the maximum catch over the period 1999-2007."[6]

If the goal is to set the ACL above any historical catch, even a year with occasionally high landings, so that any future fluctuations in landings never actually reaches the ACL, then there is no actual limit on future catch. The purpose of an approach like ORCS is to use limited data and expert judgment to determine whether the historic catch represents a period of light, moderate, or heavy exploitation, and then adjust accordingly. The ORCS Technical Memorandum provides more reasonable and scientifically-justifiable ways of dealing with the

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[5] SAFMC, "Comprehensive Annual Catch Limit (ACL) Amendment for the South Atlantic Region," at 339-342 (Oct. 2011).
[6] SAFMC SSC, "ORCS Workshop Report" (April 8-9, 2013).

issue of high fluctuations than simply choosing a catch statistic and scalar well above any potential outlier. These alternative approaches include using a trimmed mean or a Winsorized mean.[7] To our knowledge, neither the SSC nor the Council has even considered these recommended approaches. A more fundamental question is why the SSC and the Council feel the need to significantly increase the ABCs for all but two of the stocks when the existing "ACLs (commercial or recreational) for most of the species other than blue runner, scamp, and gray triggerfish have not recently been met…"[8]

2. Amendment 29 Would Lead to Extremely High Probabilities of Overfishing and Low Long-Term Yields

A recent management strategy evaluation (MSE) of data-limited methods by a group of fisheries scientists from academia and NMFS provides a comprehensive analysis of the performance of current and proposed approaches for ACL-setting for data-limited stocks.[9] The MSE, which has been accepted for publication (the final corrected proof of the manuscript is attached as Exhibit 2), analyzed the probability of overfishing and long-term yield for a number of data-limited methods applied to six distinct fish stock life histories over a minimum of 30 years. The results of this analysis were presented to the SAFMC SSC in October, 2013 by two of the paper's lead authors. That presentation (attached as Exhibit 3) included additional simulation evaluation of the proposed approaches contained in Amendment 29 using the same peer-reviewed operating model as was used for the paper. The results are summarized in Charts 1 and 2 below, which show the performance of different methods based on initial biomass when applied to snapper and porgy life history types, with the probability of overfishing on the X axis and relative long-term yield on the Y axis.

Methods that set the ABC to average historical catch or a percentile of recent catch (3rd highest catch over the previous 10 years was specifically tested) led to some of the worst results of any method in terms of very high probabilities of overfishing, high levels of stock depletion, and low long-term yield. The paper describes the results as follows:

> "Methods that set the ABC to average historical catches or a percentile of recent catch…led to the worst performance of the methods tested by a large margin. When starting below 50% B_{MSY}, the probability of overfishing was high – typically above 80% ("POF", Table 4)…These static catch-based methods failed to rebuild stocks initially below 50% B_{MSY} to above 50% B_{MSY} in the majority of simulations (between 60% and 95%; on most occasions the failure rate was over 85% ("P<10", Table App.C.2). The static catch-based methods could lead to very high probabilities of dropping below 10% of B_{MSY} (generally 40–60%) when applied to stocks starting below B_{MSY} (Table App.C.3)…This was particularly the case for

[7] ORCS, at 24.
[8] Amendment 29, "Public Hearing Summary," at 11 (January 2014).
[9] Carruthers, T.R., *et al.*, "Evaluating methods for setting catch limits in data-limited fisheries," Fish. Res. (forthcoming, 2014). (Manuscript attached as Exhibit 2).

> method M3 (ABC set at the third highest historical catch) which drove 19 out of 20 stocks that were already below 50% of B_{MSY} at the start of the projection to below 10% of B_{MSY} by the end of the projection (Table 4). This was only somewhat reduced to 7 out of 10 stocks in those simulations starting between 50% and 100% of B_{MSY} (Table 5)."[10]

The performance of the maximum catch scalars being proposed in Amendment 29 was even worse than 3rd highest catch. In cases where the initial biomass was less than 100% of B_{MSY} (indicated in red and purple in the Charts), all three ABC scalars led to probabilities of overfishing nearing 100% and long-term yields of less than 10% of the perfect knowledge F_{MSY} reference case. Even in cases where the starting biomass is above 100% of B_{MSY}, the probabilities of overfishing were about 80% or higher.

It is very important to note that these results represent the potential consequences, in very real terms, of the specific application of the ORCS method being proposed in Amendment 29 (using multiples of maximum catch). The results are not representative of how different ORCS applications might perform. Carruthers *et al.* found it impossible to simulation test a generic version of the ORCS method due to the subjective nature of the attributes scoring and other variables that may change depending on who is applying it.[11] However, the authors did test a related method, named "Depletion-Adjusted Catch Scalar" ("DACS"), which simulated a scalar of mean catch as recommended in the ORCS Technical Memorandum and described above. The control rule tested in the simulation adjusted the ABC every third year according to the prescribed upward and downward scalars (*i.e.*, 2.0 times mean historical catch when the stock has low exploitation, 1.0 times when the stock is moderately exploited, and 0.5 times when the stock is highly exploited). The determination as to exploitation rate was based on a biased and imprecise estimate of depletion from the operating model, intending to mimic real-world bias and imprecision. As depicted in Charts 1 and 2, the basic concept of the ORCS scalar, tested as DACS, performed fairly well, assuming some estimate of current stock status can be determined, even one that is quite imprecise. In fact, sensitivity analysis of the data inputs demonstrated that the DACS method was not at all sensitive to quite imprecise estimates of depletion, as long as they were not significantly biased. This was true of all of the methods tested that rely on a measure of current abundance or depletion.

[10] Carruthers *et al.*, at 9.
[11] Id., at 2.

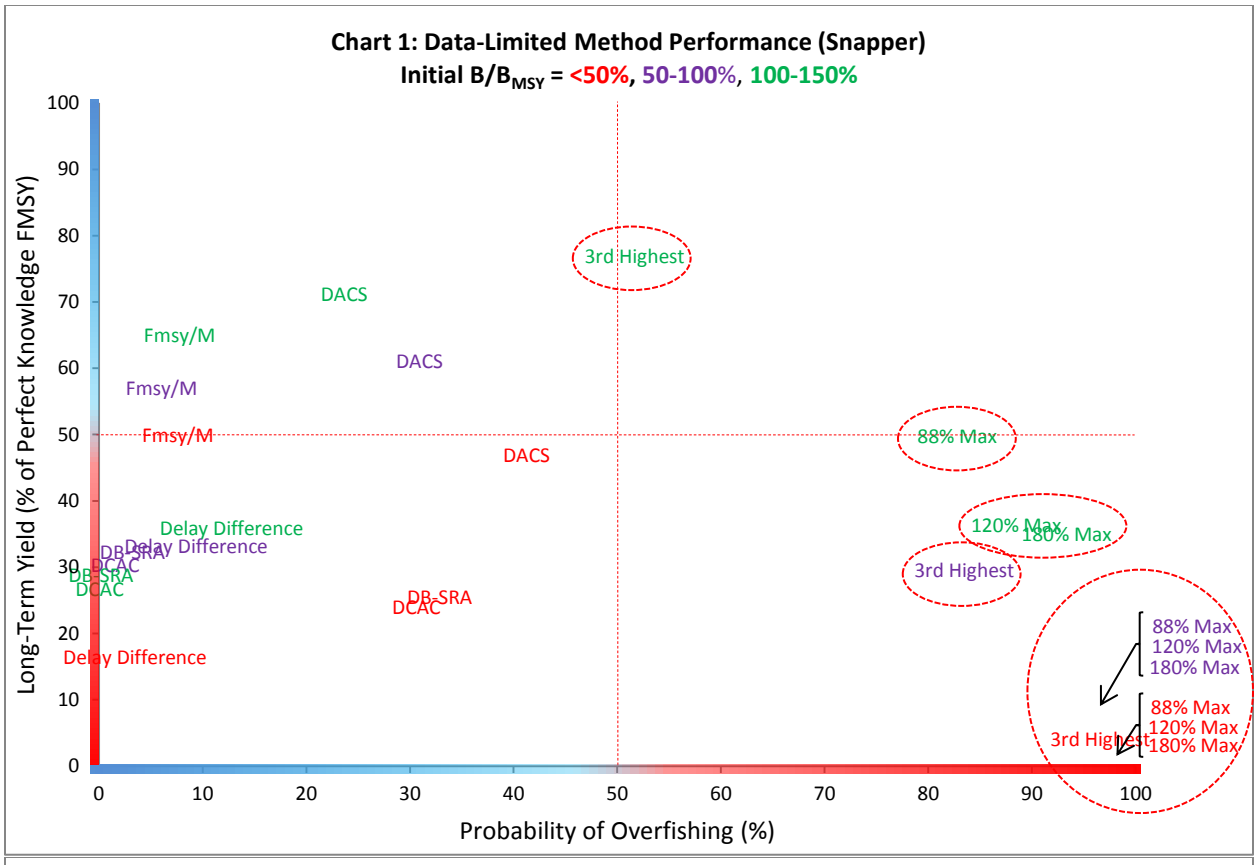
Chart 1: Data-Limited Method Performance (Snapper)
Initial B/B$_{MSY}$ = <50%, 50-100%, 100-150%
Long-Term Yield (% of Perfect Knowledge FMSY)
Probability of Overfishing (%)
3rd Highest
DACS
Fmsy/M
DACS
Fmsy/M
Fmsy/M
DACS
88% Max
Delay Difference
Delay Difference
DB-SRA
DCAC
DB-SRA
DCAC
120% Max
180% Max
3rd Highest
DB-SRA
DCAC
Delay Difference
88% Max
120% Max
180% Max
88% Max
120% Max
3rd Highest
180% Max

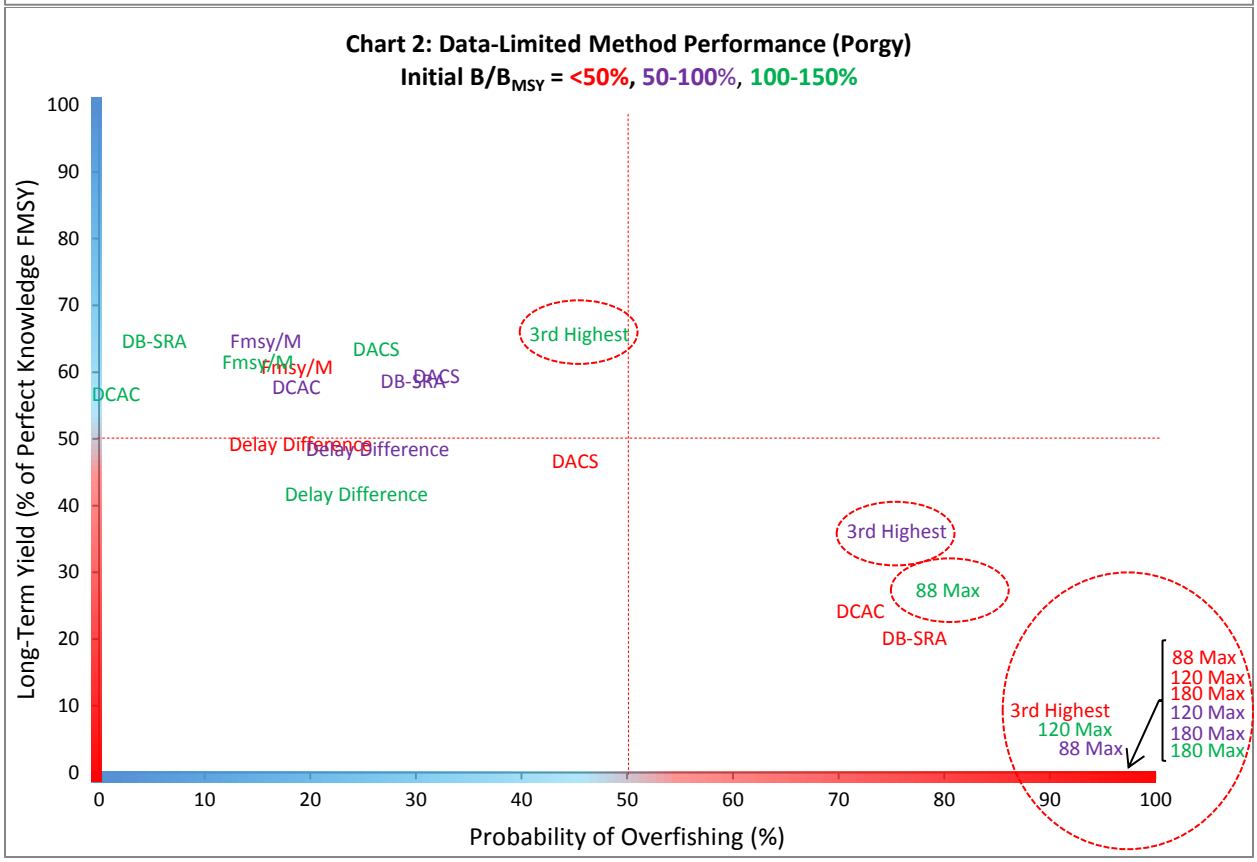
Chart 2: Data-Limited Method Performance (Porgy)
Initial B/B$_{MSY}$ = <50%, 50-100%, 100-150%
Long-Term Yield (% of Perfect Knowledge FMSY)
Probability of Overfishing (%)
DB-SRA
Fmsy/M
Fmsy/M
Fmsy/M
DACS
3rd Highest
DCAC
DCAC
DB-SRA
DACS
Delay Difference
Delay Difference
DACS
Delay Difference
3rd Highest
88 Max
DCAC
DB-SRA
88 Max
120 Max
180 Max
120 Max
180 Max
180 Max
3rd Highest
120 Max
88 Max

Not surprisingly, the key to the success of the ORCS approach, assuming adherence to the catch scalars and mean catch statistic recommended by the ORCS Technical Memorandum, is to rely heavily on any information related to current stock status (*e.g.*, catch per unit effort trends, fishery-independent abundance estimates, length and age data, etc.) in determining current stock status for purposes of adjusting the scalar on a regular, pre-defined interval (*e.g.*, every three years). Fortunately, for many of the stocks that have been labeled "only reliable catch" or "data-poor," a substantial amount of data exists, although such data are currently going unused. Examples of potentially valuable data include: unused MARMAP indices, unprocessed catch and effort data, and length and age samples.

3. Developing a Roadmap for Data-Limited Stocks in the South Atlantic

Over the past several years, the Pacific fishery management region has applied several data-limited methods to 90 groundfish stocks using similar quality data, including: Depletion-Based Stock Reduction Analysis (DB-SRA), Extended DB-SRA, Depletion-Corrected Average Catch (DCAC), F_{MSY}/M, and Extended Simple Stock Synthesis (exSSS). DB-SRA and DCAC are already prescribed for use in the current South Atlantic ABC Control Rule and could be applied immediately to many stocks in the region similarly to the approach taken in the Pacific region. The SAFMC and SSC should set aside disproven, ad-hoc methods, like those being proposed in Amendment 29, and begin working on a roadmap for implementing best practices with the Science Center, Regional Office, relevant state agencies, and data providers like MARMAP and ACCSP, academic partners and knowledgeable stakeholders.

Fortunately, the process of developing and implementing such a roadmap has already started. Just a few weeks ago, nearly three-dozen leading fisheries scientists from across the country convened for a workshop on data-limited methods co-hosted by Alec MacCall, formerly of the Southwest Fisheries Science Center, and Clay Porch, the head of Sustainable Fisheries at the Southeast Fisheries Science Center. The workshop reviewed a number of existing and emerging data-limited methods, unveiled a new Data-Limited Assessment Toolkit that enables assessment scientists to efficiently apply a number of data-limited assessment methods, and developed a proposed roadmap for improving the assessment and ACL-setting of data-limited stocks in the Southeast region. The roadmap discussions focused on three key tasks: (1) conducting an inventory of all available data for each unassessed stock in the region, (2) conducting rapid assessments of large numbers of unassessed stocks using methodologies and tools that have been peer-reviewed and approved for use in management, and (3) streamlining the data collection and stock assessment process to accommodate a data-limited track and improve throughput of all current assessments. The details of the proposed roadmap will be published within the next several months, and we would appreciate the opportunity to present the results to the Council, SSC and other regional stakeholders.

We appreciate the opportunity to comment on this important process and look forward to discussing it further at the March 2014 Council meeting.

Very Truly Yours,

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Exhibit 1

Technical Guidance On the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act

Prepared for the
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NOAA Technical Memorandum NMFS-F/SPO-##
July 17, 1998

U.S. Department of Commerce
William M. Daley, Secretary

National Oceanic and Atmospheric Administration
D. James Baker, Under Secretary for Oceans and Atmosphere

National Marine Fisheries Service
Rolland E. Schmitten, Assistant Administrator for Fisheries

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PREFACE

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) contains a set of ten National Standards for fishery conservation and management. National Standard 1 states,

> "*Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry*."

The MSFCMA requires the Secretary of Commerce to "*establish advisory guidelines (which shall not have the force and effect of law), based on the national standards, to assist in the development of fishery management plans*." These advisory guidelines, known as the National Standard Guidelines (NSGs), were first published in the *Federal Register* as a proposed rule on August 4, 1997, and revised in the final rule published on May 1, 1998. Section 600.310 of the guidelines contains the text pertaining to National Standard 1. Because the NSGs were written for a non-technical audience, they do not provide detailed guidance for the stock assessment scientists who will ultimately be requested to develop many of the conservation and management measures called for, particularly in the Section relating to National Standard 1, and particularly in light of the widely perceived need to adopt a precautionary approach to the management of marine fisheries. The main purpose of this paper is therefore to provide technical guidance on the use of precautionary approaches to implementing National Standard 1 of the MSFCMA in accordance with the NSGs.

This paper was prepared by a team of scientists from the National Marine Fisheries Service (NMFS) with experience in conducting stock assessments, providing scientific advice for fishery management, and developing precautionary approaches to managing fisheries. The technical guidance provided below is partly the product of their combined expertise. In addition, this guidance also reflects the work and group discussions of over 80 scientists who participated in the Fifth NMFS National Stock Assessment Workshop (February 24-26, 1998, Key Largo, Florida), which focused on the theme "Providing Scientific Advice to Implement the Precautionary Approach under the MSFCMA." Proceedings from that workshop will be published in a complementary NOAA Technical Memorandum.

This technical guidance is provided essentially for those aspects of scientific fishery management advice that have biological underpinnings, such as the response of fish populations to exploitation. The drafting team recognizes that there are many other important aspects to managing fisheries, such as socioeconomic factors, which are key to defining optimum yield, and which Fishery Management Councils must consider. Unfortunately, no formal operational protocol is routinely used to incorporate socioeconomic benchmarks into management advice. As such, the implementation of the MSFCMA would benefit greatly from complementary guidelines that address non-biological aspects of fisheries management in a quantitative framework.

EXECUTIVE SUMMARY

The 1998 Guidelines for National Standard 1 (Optimum Yield) of the Magnuson-Stevens Fishery Conservation and Management Act, 50 CFR Part 600, state: *"In general, Councils should adopt a precautionary approach to specification of OY."* Because of the technical nature of the task, NMFS convened a panel of scientists to provide technical guidance on specifying OY that is consistent with the Guidelines (NSGs). The technical guidance is contained in this document.

The precautionary approach implements conservation measures even in the absence of scientific certainty that fish stocks are being overexploited. In a fisheries context, the precautionary approach is receiving considerable attention throughout the world primarily because the collapse of many fishery resources is perceived to be due to the inability to implement timely conservation measures without scientific proof of overfishing. Thus, the precautionary approach is essentially a reversal of the "burden of proof".

The precautionary approach in fisheries is multi-faceted and broad in scope. The discussions in this document are not so broad in scope, and are limited to providing guidance to managers and scientists for specifying OY and for developing reference points to guide management decisions.

A common element in the application of the precautionary approach to fisheries management worldwide is the definition of "limits" intended to safeguard the long-term productivity of a stock. Several international agreements and documents that deal with the precautionary approach identify maximum sustainable yield (MSY) levels as a minimum standard for defining management limits. The Magnuson-Stevens Act encompasses this concept in that it constrains OY to be no greater than MSY.

The NSGs identify two limits for fishery management (referred to as "thresholds") that are necessary to maintain a stock within safe levels, capable of producing MSY: A maximum fishing mortality threshold (MFMT) and a minimum stock size threshold (MSST). The MFMT and MSST are intended for use as benchmarks to decide if a stock or stock complex is being overfished or is in an overfished state. In the NSGs, these two limits are intrinsically linked through an "MSY Control Rule" that specifies how fishing mortality or catches could vary as a function of stock biomass in order to achieve yields close to MSY. If the maximum fishing mortality limit is reduced as biomass decreases, then the minimum stock size limit decreases (although the MSST cannot become lower than ½ of the equilibrium biomass under a constant-fishing mortality MSY control rule). Thus, the shape of the MSY control rule is an important consideration for developing status determination criteria for overfishing.

A default MSY control rule is recommended in Section 2 of this document. Noting that Councils have considerable flexibility in defining the shape of the MSY control rule for each stock under their jurisdiction, and that different control rule shapes pertain to different management objectives, the recommended default could be used in the absence of more specific analyses. The default makes use of estimates of the constant fishing mortality rate resulting in MSY, F_{MSY}, and of the corresponding average spawning

biomass, B_{MSY}. The limit F, MFMT, is set equal to F_{MSY} at higher stock sizes; if the stock decreases much below B_{MSY}, the limit F is reduced proportionately (the reduction starts at a fraction of B_{MSY} related to the level of natural mortality). It is anticipated that estimates of F_{MSY} and B_{MSY} will be either unavailable or unreliable for many stocks. For this reason, Section 2 also presents a discussion of useful proxies.

Another common element in the application of the precautionary approach to fisheries management worldwide is the specification of "targets" that are safely below limits. Setting OY at its limit (MSY in the Magnuson-Stevens Act) would not normally be precautionary because there could be a high probability of exceeding the limit year after year. Under the precautionary approach, the target should be set below the limit taking uncertainty and other management objectives into consideration. Development of control rules requires communication between fisheries managers, scientists, industry and the public. If performance criteria for target control rules can be defined, then a range of alternative control rules can be developed and evaluated in terms of precautionary behavior and other desirable economic or operational characteristics for management, once precautionary constraints have been met.

Control rules are pre-agreed plans for making management decisions based on stock size. The pre-agreed nature of the measures ensures that management actions are implemented without delay, and it is possible to respond rapidly to changing conditions. As with MSY control rules, Councils have considerable flexibility in defining targets. Section 3 presents a recommended default target control rule that could be used in the absence of more specific analyses. The default sets the target fishing mortality rate 25% below the default limit proposed in Section 2. The 25% reduction constitutes a safety margin that may not perform well for all stocks in terms of preventing overfishing. The performance of the default target can only be evaluated on a case-by-case basis and will depend on (a) the accuracy and precision of stock size, B_{MSY} and F_{MSY} estimates, (b) natural variability in population dynamics, and (c) errors in the implementation of management regulations. Age-structured deterministic models suggest that, for a large combination of life history parameters, the recommended default can result in high stock sizes (around 130% of B_{MSY}) at the expense of relatively small foregone yields (achieving around 95% of MSY). It is recognized that no single policy can fully address all of the considerations to be encountered in the wide variety of fisheries subject to the Magnuson-Stevens Act. Nevertheless, the default target will be useful in a variety of situations and should at least serve to encourage development of more suitable policies for individual fisheries.

The default target control rule may not be applicable for many stocks that are already below the MSST (i.e., that are already overfished). In such cases, the NSGs require that special plans be implemented to rebuild the stocks up to the B_{MSY} level within a time period that is related to the stock's productivity. This document does not propose a default rebuilding plan, because the time to rebuilding may depend on each stock's current level of depletion. Instead, the document presents the four key elements that should be considered in rebuilding plans: An estimate of B_{MSY}, a rebuilding time period, a rebuilding trajectory, and a transition from rebuilding to more optimal management. The default target control rule may be adapted into a rebuilding plan for each overfished stock, for

example, by allowing only a very low fishing mortality when the stock is below the MSST in order to rebuild the stock within the rebuilding time period.

This document also discusses a number of special considerations, such as changes in the selectivity of fishing gear, mixed-stock situations, changes in productivity due to the environment, and the appropriateness of various proxies for MSY-related parameters. One consideration of particular importance relates to setting limits and targets for data-poor stocks, i.e., those having very limited information. While the document provides defaults for these cases as well, it is imperative to improve the ability to make informed decisions through enhanced data collection and analyses.

Specification of MSY control rules, status determination criteria, and precautionary target control rules is a challenging exercise. Key to this process is communication between managers, scientists, users and the public. In the face of conflicting objectives (avoiding overfishing while achieving high long-term yields), it is essential to understand the tradeoffs associated with alternative control rules and the importance of the weights assigned to the different objectives or performance criteria. Simulation frameworks can facilitate the necessary interaction. In addition, simulation tools should be used to examine the performance of management systems as a whole, including data collection, assessments, control rules, and implementation of management tactics.

1. INTRODUCTION

1.1 The MSFCMA and the National Standard Guidelines

1.1.1 The MSY[1] Control Rule and Status Determination Criteria

A brief recap of key points from §600.310 of the NSGs will help to focus the task at hand. In discussing the concept of maximum sustainable yield (MSY), the NSGs include the following definitions in paragraph (c)(1):

> "*MSY is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions*."
>
> "*MSY control rule means a harvest strategy which, if implemented, would be expected to result in a long-term average catch approximating MSY*."
>
> "*MSY stock size means the long-term average size of the stock or stock complex, measured in terms of spawning biomass or other appropriate units, that would be achieved under an MSY control rule in which the fishing mortality rate is constant*."

Paragraph (c)(2) expands upon the meaning and importance of the MSY control rule, providing considerable flexibility in the process:

> "Because MSY is a theoretical concept, its estimation in practice is conditional on the choice of an MSY control rule. In choosing an MSY control rule, Councils should be guided by the characteristics of the fishery, the FMP's objectives, and the best scientific information available. The simplest MSY control rule is to remove a constant catch in each year that the estimated stock size exceeds an appropriate lower bound, where this catch is chosen so as to maximize the resulting long-term average yield. Other examples include the following: Remove a constant fraction of the biomass in each year, where this fraction is chosen so as to maximize the resulting long-term average yield; allow a constant level of escapement in each year, where this level is chosen so as to maximize the resulting long-term average yield; vary the fishing mortality rate as a continuous function of stock size, where the parameters of this function are constant and chosen so as to maximize the resulting long-term average yield. In any MSY control rule, a given stock size is associated with a given level of fishing mortality and a given level of potential harvest, where the long-term average of these potential harvests provides an estimate of MSY."

Although the MSFCMA mandates use of MSY, paragraph (c)(3) of the NSGs allows for cases in which MSY cannot be estimated directly:

> "When data are insufficient to estimate MSY directly, Councils should adopt other measures of productive capacity that can serve as reasonable proxies for MSY, to the extent possible. Examples include various reference points defined in terms of

[1] MSY and other terms that appear throughout this document are defined in the Glossary (Appendix B).

relative spawning per recruit. For instance, the fishing mortality rate that reduces the long-term average level of spawning per recruit to 30-40 percent of the long-term average that would be expected in the absence of fishing may be a reasonable proxy for the MSY fishing mortality rate. The long-term average stock size obtained by fishing year after year at this rate under average recruitment may be a reasonable proxy for the MSY stock size, and the long-term average catch so obtained may be a reasonable proxy for MSY. The natural mortality rate may also be a reasonable proxy for the MSY fishing mortality rate. If a reliable estimate of pristine stock size (i.e., the long-term average stock size that would be expected in the absence of fishing) is available, a stock size approximately 40 percent of this value may be a reasonable proxy for the MSY stock size, and the product of this stock size and the natural mortality rate may be a reasonable proxy for MSY."

In discussing the concept of overfishing, the NSGs use the MSY control rule to define a pair of "status determination criteria" (SDC) in paragraph (d)(2):

"Each FMP must specify, to the extent possible, objective and measurable status determination criteria for each stock or stock complex covered by that FMP and provide an analysis of how the status determination criteria were chosen and how they relate to reproductive potential. Status determination criteria must be expressed in a way that enables the Council and the Secretary to monitor the stock or stock complex and determine annually whether overfishing is occurring and whether the stock or stock complex is overfished. In all cases, status determination criteria must specify both of the following:

"(i) <u>A maximum fishing mortality threshold or reasonable proxy thereof</u>. The fishing mortality threshold may be expressed either as a single number or as a function of spawning biomass or other measure of productive capacity. The fishing mortality threshold must not exceed the fishing mortality rate or level associated with the relevant MSY control rule. Exceeding the fishing mortality threshold for a period of 1 year or more constitutes overfishing.

"(ii) <u>A minimum stock size threshold or reasonable proxy thereof</u>. The stock size threshold should be expressed in terms of spawning biomass or other measure of productive capacity. To the extent possible, the stock size threshold should equal whichever of the following is greater: One-half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock or stock complex were exploited at the maximum fishing mortality threshold specified under paragraph (d)(2)(i) of this section. Should the actual size of the stock or stock complex in a given year fall below this threshold, the stock or stock complex is considered overfished."

Section 2 of this document focuses on technical guidance for establishing MSY and limit control rules and the associated minimum stock size and maximum fishing mortality thresholds.

1.1.2 The Precautionary Approach in Specifying Management Targets

The MSFCMA does not use the term "precautionary approach" *per se*. However, in discussing the concept of optimum yield (OY), the NSGs call for the use of a precautionary approach in paragraph (f)(5):

> "In general, Councils should adopt a precautionary approach to specification of OY. A precautionary approach is characterized by three features:
>
> > "(i) Target reference points, such as OY, should be set safely below limit reference points, such as the catch level associated with the fishing mortality rate or level defined by the status determination criteria. Because it is a target reference point, OY does not constitute an absolute ceiling, but rather a desired result. An FMP must contain conservation and management measures to achieve OY, and provisions for information collection that are designed to determine the degree to which OY is achieved on a continuing basis--that is, to result in a long-term average catch equal to the long-term average OY, while meeting the status determination criteria. These measures should allow for practical and effective implementation and enforcement of the management regime, so that the harvest is allowed to reach OY, but not to exceed OY by a substantial amount. The Secretary has an obligation to implement and enforce the FMP so that OY is achieved. If management measures prove unenforceable--or too restrictive, or not rigorous enough to realize OY--they should be modified; an alternative is to reexamine the adequacy of the OY specification. Exceeding OY does not necessarily constitute overfishing. However, even if no overfishing resulted from exceeding OY, continual harvest at a level above OY would violate national standard 1, because OY was not achieved on a continuing basis.
> >
> > "(ii) A stock or stock complex that is below the size that would produce MSY should be harvested at a lower rate or level of fishing mortality than if the stock or stock complex were above the size that would produce MSY.
> >
> > "(iii) Criteria used to set target catch levels should be explicitly risk averse, so that greater uncertainty regarding the status or productive capacity of a stock or stock complex corresponds to greater caution in setting target catch levels. Part of the OY may be held as a reserve to allow for factors such as uncertainties in estimates of stock size and DAH. If an OY reserve is established, an adequate mechanism should be included in the FMP to permit timely release of the reserve to domestic or foreign fishermen, if necessary."

Section 3 of this document focuses on technical guidance for specifying

precautionary targets that would be consistent with the NSGs. The subsection below provides more comprehensive information on the precautionary approach as it has been and is being considered in different fisheries fora, and discusses elements of the approach that are not identified in the National Standard 1 Guidelines.

1.2 The Precautionary Approach in Fisheries Management

1.2.1 Evolution: International Agreements

The United Nations Convention on the Law of the Sea (1982) provided several mechanisms to promote responsible management of marine fisheries; however, it was not until the 1990s that work began on developing a precautionary approach to fisheries management. In 1991, the Committee on Fisheries (COFI) of the Food and Agriculture Organization (FAO) requested FAO to develop an International Code of Conduct for Fisheries. Subsequently, FAO and the government of Mexico sponsored an International Conference on Responsible Fishing, held in Cancun in May 1992. Resolutions formulated in Cancun were presented at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992. The Rio meeting highlighted the importance of the precautionary approach in the Rio Declaration and Agenda 21. For example, Principle 15 of the Rio Declaration states that "*in order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*."

Several binding and non-binding agreements embodying the precautionary approach were developed and concluded over the period 1991-1996. The most comprehensive of these is the FAO Code of Conduct for Responsible Fisheries, concluded in late 1995 (FAO 1995a). The Code of Conduct addresses six key themes: Fisheries management, fishing operations, aquaculture development, integration of fisheries into coastal area management, post-harvest practices and trade, and fisheries research. In total, there are 19 general principles and 210 standards in the Code. While a precautionary approach is integral to all themes, it is applied particularly to fisheries management, as detailed in Article 7.5. Paragraph 7.5.1 includes a statement to the effect that:

> "*States should apply the precautionary approach widely to conservation, management, and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment*."

The same paragraph also emphasizes that the absence of adequate scientific information is not a reason for postponing or failing to take conservation and management measures. The remaining paragraphs include similar provisions to those in Article 6 of the UN Straddling Stocks Agreement (see below); for example, determination of stock-specific target and limit reference points (Caddy and Mahon 1995), the need to take action if they are exceeded, and the need to take account of uncertainties and impacts on non-target and associated or dependent species. In addition, guidelines are given for adopting a cautious approach in the case of new or exploratory fisheries, and for implementing

emergency management measures when resources are seriously threatened due to environmental factors or fishing activity.

The Code of Conduct is a voluntary, non-binding agreement. However, it contains sections that are similar to those in two binding agreements: The Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas (the Compliance Agreement), and the Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (the Straddling Stocks Agreement; UN 1995).

The Compliance Agreement was adopted at the FAO Conference at the 27th session in November 1993. The agreement specifies the obligations of Parties whose fishing vessels fish on the high seas, including the obligation to ensure that such vessels do not undermine international fishery conservation and management measures. The Compliance Agreement is considered to be an integral part of the Code of Conduct. The United States implemented the Compliance Agreement through the High Seas Fishing Vessel Compliance Act of 1995.

The Straddling Stocks Agreement was negotiated over a similar period to the Code of Conduct and the content and wording on many issues, including those related to the precautionary approach and General Principles, is similar to that in the Code of Conduct. Although the Straddling Stocks Agreement is strictly applicable to straddling fish stocks and highly migratory fish stocks, much of it is also relevant to fishing within national exclusive economic zones.

Annex II of the Straddling Stocks Agreement (UN 1995) provides guidelines for the application of precautionary reference points. Paragraph 2 states, "Two types of precautionary reference points should be used: conservation, or limit, reference points and management, or target, reference points." Paragraph 5 stipulates, "Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low," and imposes the further constraint that target reference points should not be exceeded on average. Paragraph 7 states that "The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points." This combination of requirements implies that fishing mortality should always be well below the level associated with maximum sustainable yield (F_{MSY}).

More detailed treatments of the historical development of the precautionary approach are contained in ICES (1997a), Serchuk *et. al.* (1997), Thompson and Mace (1997), and Mace and Gabriel (in prep.).

1.2.2 The Overall Scope of the Precautionary Approach

According to the Code of Conduct (FAO 1995a), precaution is required in development planning, management, research, technology development and transfer, legal and institutional frameworks, fish capture and processing, fisheries enhancement, and aquaculture. Thus the precautionary approach is multi-faceted and broad in scope.

The 1995 FAO Technical Guidelines on the Precautionary Approach (FAO 1995b)

groups guidelines on the precautionary approach into three primary subject areas of relevance to capture fisheries: Fisheries management, fisheries research, and fisheries technology. The next three subsections summarize the main issues covered under each area and, while they do not include every aspect of the guidelines, they highlight the large number and diversity of issues involved.

Fisheries Management

The precautionary approach to fisheries management requires:

- prudent foresight;
- taking into account unknown uncertainty by being more conservative;
- establishment of legal or social frameworks for all fisheries, including rules to control access, data reporting requirements, and management planning processes;
- implementation of interim measures that safeguard resources until management plans are finalized;
- avoidance of undesirable or unacceptable outcomes such as overexploitation of resources, overdevelopment of harvesting capacity, loss of biodiversity, major physical disturbances of sensitive biotopes, and social or economic dislocations;
- explicit specification of management objectives including operational targets and constraints;
- prospective evaluation; and
- sound procedures for implementation, monitoring and enforcement.

Fisheries Research

Research needed to implement precautionary management should strive to:

- provide data and analyses of relevance to fisheries management;
- emphasize the roles that fisheries scientists and others must play in helping managers develop objectives;
- provide scientific evaluation of consequences of management actions;
- develop operational targets, constraints and criteria that are both scientifically usable and managerially relevant;
- incorporate both biological and socio-economic elements;
- ensure that data are accurate and complete;
- monitor fisheries;
- conduct research on which management processes and decision structures work best;
- incorporate uncertainty into assessments and management;
- address reversibility and irreversibility in ecosystems;
- formulate implementation guidelines;
- be multi-disciplinary in nature, including social, economic, and environmental sciences, and addressing management institutions and decision-making processes; and
- investigate environmentally-friendly fishing gears.

Fisheries Technology

A precautionary approach to fisheries technology would:

- not use technology to cause capacity to increase further in already overcapitalized fisheries;
- use technology to improve sustainability, prevent damage to the environment, improve economic and social benefits, and improve safety;
- evaluate the effects of new technologies and gears;
- educate fishers and consumers towards responsible practices;
- consider impacts on non-target species and ecosystems;
- evaluate fishing gears with respect to selectivity by size and species, survival of escapees, ghost fishing, effects on habitat, contamination, pollution, generation of debris, safety and occupational hazards, user conflicts, employment, monitoring and enforcement costs, techno-economic factors (infrastructure and service requirements, product quality), and legal factors (existing legislation, international agreements, civil liberties);
- consider proper procedures for introducing new technology or changes to existing technology;
- promote research to encourage improvement of existing technologies and to encourage development of appropriate new technologies, and;
- encourage research into responsible fisheries technology.

From these three lists, it is obvious that biological reference points and control rules are but one part in the overall framework of the precautionary approach. Although in some respects they can be considered a primary focus of any precautionary management strategy, they need to be put in proper perspective. Other needs may be just as important; for example, development of access control systems to ensure that fishing capacity is commensurate with resource productivity, evaluation of alternative management systems and institutions, improvements in the quality and reliability of data, improved monitoring and enforcement, design of "environmentally-friendly" fishing gear, and education of fishers and consumers.

Regarding research in support of management decisions, it is important that decisions made in stock assessments regarding model choice, estimation techniques and selection of parameters be transparent. Care should be taken when using the term “precautionary” in relation to the science underpinning advice to managers. The scientists’ primary role is to provide scientifically-based options that managers can use to achieve management goals. It is perfectly reasonable for managers to select a "precautionary" management target (e.g., F = lower 80% CI of the probability distribution for F_{MSY}) based on advice from scientists that this choice will achieve the management objectives, but it is not reasonable for scientists to add non-transparent conservatism or precaution into the estimation process (e.g., by claiming that the lower 80% CI of the distribution of F_{MSY} is the best estimate of F_{MSY}).

1.3 Control Rules and Reference Points in the Context of the Precautionary Approach

According to the Code of Conduct for Responsible Fisheries (FAO 1995a),

"*States and subregional or regional fisheries management organizations and arrangements should, on the basis of the best scientific evidence available, inter alia, determine:*

"*stock specific target reference points, and, at the same time, the action to be taken if they are exceeded; and*

"*stock-specific limit reference points, and, at the same time, the action to be taken if they are exceeded; when a limit reference point is approached, measures should be taken to ensure that it will not be exceeded.*"

Thus, two critical components of precautionary management are the specification of limit and target reference points, and pre-agreed management measures to be implemented as a function of stock conditions relative to those reference points. The pre-agreed nature of the measures ensures that management actions are implemented without delay, and it is possible to respond rapidly to changing conditions. Otherwise, management actions could be dependent on the achievement of consensus while stock conditions continue to deteriorate. The MSFCMA makes it clear that effective management actions must be implemented promptly.

Limit reference points are intended to constrain harvests so that the stock remains within safe biological limits, and is capable of producing maximum sustainable yield. Management should proceed so that the risk of exceeding the limit reference points is very low. The minimum standard for limit reference points should be the fishing mortality rate that generates MSY, according to Annex II of the Straddling Stocks Agreement. This is consistent with the revised MSFCMA, which states that the terms "overfishing" and "overfished" mean a rate or level of fishing mortality that jeopardizes the stocks's capacity to produce MSY. Thus, the MSFCMA definition of overfishing and the Annex II standards for precautionary limit reference points both imply that F_{MSY} should be an upper bound on fishing mortality, although the MSFCMA does not define F_{MSY} as an undesirable outcome to be avoided.

[NOTE: Nomenclature within the National Standard Guidelines differs somewhat from that in various FAO documents. *Limit* reference points in the FAO text correspond to *threshold* levels in the National Standard Guidelines and in some literature, such as the review of overfishing definitions by Rosenberg *et. al.* (1994). In the FAO text and much of the international literature, the word threshold is used in the context of establishing "buffers", to trigger action before limit reference points are reached. Such buffers are not equivalent to the thresholds defined in the NSGs, but are analogous to the "interim thresholds" referred to in the preamble to the final rule issuing the NSGs. This document uses the word limit in the same sense as the FAO text. However, in order to maintain consistency with the language of the NSGs, "threshold" is used when referring specifically to the limit reference points that define the act overfishing and an overfished state in the NSGs --the Maximum Fishing Mortality Threshold, MFMT, and the Minimum Stock Size Threshold, MSST--]

Target reference points are intended to achieve management objectives, and represent desirable outcomes to be attained. Target reference points should not be exceeded more than 50% of the time, nor on average. A target biomass level for stocks that require rebuilding could be the biomass that would produce MSY. The FAO guidelines on the precautionary approach (FAO 1995b) indicate that the constraints of limit reference points have precedence over targets, and target reference points may require adjustment so that the probability of violating the constraints while meeting the target would be small. The idea that limits have precedence over targets is consistent with the revised MSFCMA, in which OY corresponds to a target level, but is constrained to be less than or equal to MSY.

A control rule describes a variable over which management has some direct control as a function of some other variable(s) related to the status of the stock. In many discussions of the topic, a control rule describes a reference fishing mortality rate as a function of stock size, and such is the main focus of Sections 2 and 3 of this paper. In general, however, control rules do not have to be cast in terms of fishing mortality rates or biomass levels. Simply put, a control rule seeks to identify measures of "good" and "bad" stock condition (by comparing perceived stock status with biological reference points), as well as the actions that will make the stock condition change from "bad" to "good." There are two types of precautionary elements that can be considered in implementing a control rule for management targets: The reference points to be used, and the type of management reaction to be implemented. The degree of precaution achieved in implementing such a control rule is determined by a combination of the probability of going from a "good" stock condition to a "bad" one (overfishing), and the action to be taken when the stock is overfished. Naturally, the current stock condition affects the probability of overfishing, and hence the degree of precaution.

Development of control rules requires interaction between fisheries managers and scientists. In addition, public participation is important because the public and fishing industry are more inclined to support management measures on which they have been consulted and which they understand clearly (FAO 1995b). If managers can define acceptable performance criteria for target control rules, then a range of alternative control rules can be developed and evaluated in terms of precautionary behavior and other desirable economic or operational characteristics for management, once precautionary constraints have been met (this approach is explained in Section 3.2). For example, performance criteria could be formulated as the application of a target control rule with "probability of less than X% of reducing the resource below Y% of K within a period of Z years" (Butterworth and Bergh 1993). The effects of other criteria, e.g., "no more than W% change in catch from year to year" could also be evaluated once precautionary constraints were met. An alternative to maximizing performance, constrained by the degree of precaution defined by managers, is to define performance itself in terms of precaution (i.e., the approach in Section 3.1) so that precaution is built directly into optimizing the management objective. With either approach, it is clear that the nature of tradeoffs between the various performance criteria of interest requires substantial interaction between managers and scientists, and open consultation with the public.

Target control rules will vary depending on the quality and quantity of available

data, as well. Thus, it is unreasonable to expect that target control rules will be perfectly uniform over all stocks. Specification of objectives and performance criteria will enable the development of control rules that will have more acceptable operational implications and still meet precautionary criteria.

Rebuilding plans are special forms of target control rules, to be implemented when stocks have fallen below limit biomass levels. Rebuilding plans should include quantifiable milestones to measure progress toward recovery during the plan's implementation. The precautionary approach counsels that rebuilding action be undertaken immediately, rather than deferred to the end of the proposed rebuilding period.

2. LIMIT CONTROL RULES AND STATUS DETERMINATION CRITERIA

This section provides technical guidance for specifying what the National Standard Guidelines refer to as “MSY control rules” (Section 1.1.1), which are used to set the criteria for determining whether a stock is being overfished or the stock is in an overfished state. Also included are recommended defaults for cases lacking detailed analyses, and guidance on the use of proxies. In presenting these defaults, our intention is not to inhibit the use of other control rules, but rather to suggest a useful starting point or a “fall-back” position.

2.1 General Approach

2.1.1 Control Rules

A control rule describes a variable over which management has some direct control as a function of some other variable(s) related to the status of the stock. That is, the control rule represents a pre-agreed plan for adjusting management actions depending on the condition of the stock. In broad terms, the management actions may be designed as strategies to achieve (a) a fixed exploitation rate (to harvest a constant fraction of the stock each year), (b) constant escapement (e.g., to maintain a constant spawning stock size), or (c) constant catch. However, control rules do not have to adhere strictly to any of these three strategies, and managers may prefer control rules that achieve different results depending on the condition of the stock.

In many discussions of the topic, a control rule describes a reference fishing mortality rate F as a function of stock size B, although it is also possible to use catch as the dependent variable. In fact, either option can be expressed in terms of the other, and it is useful to present both. Figure 1 illustrates three possible functional forms for target control rules in terms of both fishing mortality and catch: The two-parameter "logarithmic" form

$$F(B) = a + b\ln(B),$$

the three-parameter "linear-linear" form

$$F(B) = a + b\min(0, B - c),$$

and the three-parameter "linear-hyperbolic" form

$$F(B) = \frac{ac}{\max(B, c)} + b\min(0, B - c),$$

where a, b and c are parameters that determine the magnitude of F depending on the value of B.

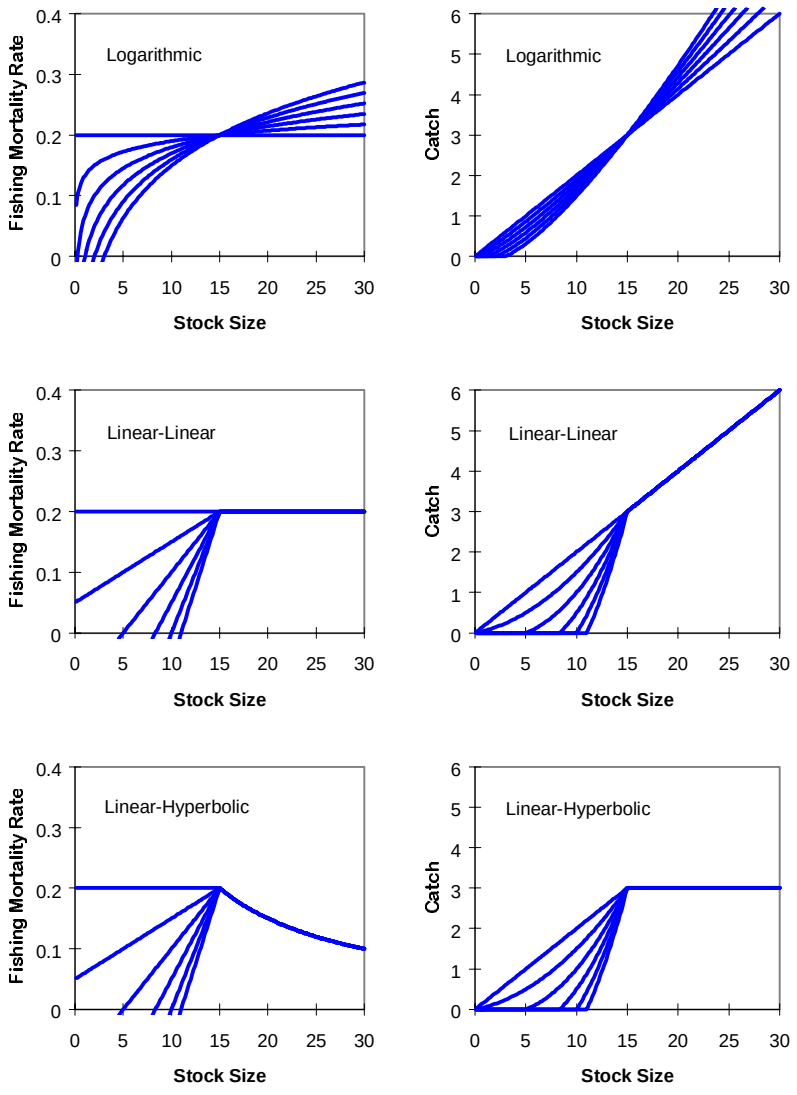

Figure 1. Some families of control rules. Each panel shows a family of control rules conforming to a particular functional form and passing through a common (arbitrary) point.

The logarithmic form forces the fishing mortality rate to vary smoothly with stock size. The linear-linear form forces the fishing mortality rate to be constant when the stock exceeds a specified size. The linear-hyperbolic form forces the catch to be constant when the stock exceeds a specified size (for the special case where catch is computed as the product of stock size and the fishing mortality rate). Figure 1 shows six examples for each form of control rule, where the six examples of the linear-linear form (middle panels of Figure 1) are indistinguishable from one another at values of $B>c$, as are the six examples of the linear-hyperbolic form (lower panels of Figure 1).

The control rules shown in Figure 1 are only a subset of the many shapes possible that could be specified. For instance, an asymptotic (mono-molecular) equation would be

an alternative to the smooth logarithmic control rule in which *F* would be capped at high levels of biomass.

2.1.2 MSY Control Rules and the Status Determination Criteria

A special case of control rule is the MSY control rule. Referring to control rules of the type described above and illustrated in the left half of Figure 1, NMFS' guidelines for National Standard 1 state that such an MSY control rule gives

> "*...fishing mortality rate as a continuous function of stock size, where the parameters of this function are constant and chosen so as to maximize the resulting long-term average yield.*"

For example, any of the control rules listed above could be transformed into an MSY control rule by fixing the value of one or perhaps two of the control parameters (say, *b* in the case of the logarithmic control rule or *b* and *c* in the case of the linear-linear or linear-hyperbolic control rules) independently and setting the remaining control parameter (say, *a*) at the value that maximizes long-term average yield, conditional on the value of the independent control parameter(s) (see Section 3.1). For example, in either the logarithmic or linear-linear forms, setting b=0 gives a control rule in which the fishing mortality rate is equal to the constant *a* (i.e., a control rule in which fishing mortality is independent of stock size). Setting *a* at the value that maximizes long-term average yield for this special case results in a very simple form of MSY control rule. However, substituting the same value of *a* into a control rule where b>0 would generally *not* result in an MSY control rule, because the yield-maximizing value of one control parameter will typically be dependent on the value of the other(s) (Thompson in prep.).

Under the guidelines for National Standard 1, the MSY control rule serves two important purposes: (1) It constitutes the maximum fishing mortality threshold (MFMT), above which overfishing is considered to be occurring; and (2) it determines the minimum stock size threshold (MSST), below which the stock is considered overfished. Thus, the MSY control rule is key to defining limit reference points. The role of the MSY control rule in determining the MSST can be seen in the following definition:

> "*To the extent possible, the stock size threshold should equal whichever of the following is greater: One-half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock or stock complex were exploited at the maximum fishing mortality threshold ...*"

For example, all of the logarithmic control rules shown in the upper-left panel of Figure 1 happen to constitute MSY control rules under a particular model (Thompson in prep.). These control rules are reproduced in Figure 2 together with a set of vertical dotted lines, each of which indicates the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock were consistently exploited according to the corresponding MSY control rule. The vertical dotted line labeled "A" corresponds to the control rule labeled "A," the vertical dotted line labeled "B" corresponds to the control rule labeled "B," and so forth. The more the control rule departs from the horizontal (control rule "F"), the lower the stock can fall and still be

expected to recover within 10 years. This result conforms with intuition, because curves with greater departure from the horizontal exert less fishing pressure at low stock sizes, thus increasing the rate of rebuilding at those stock sizes.

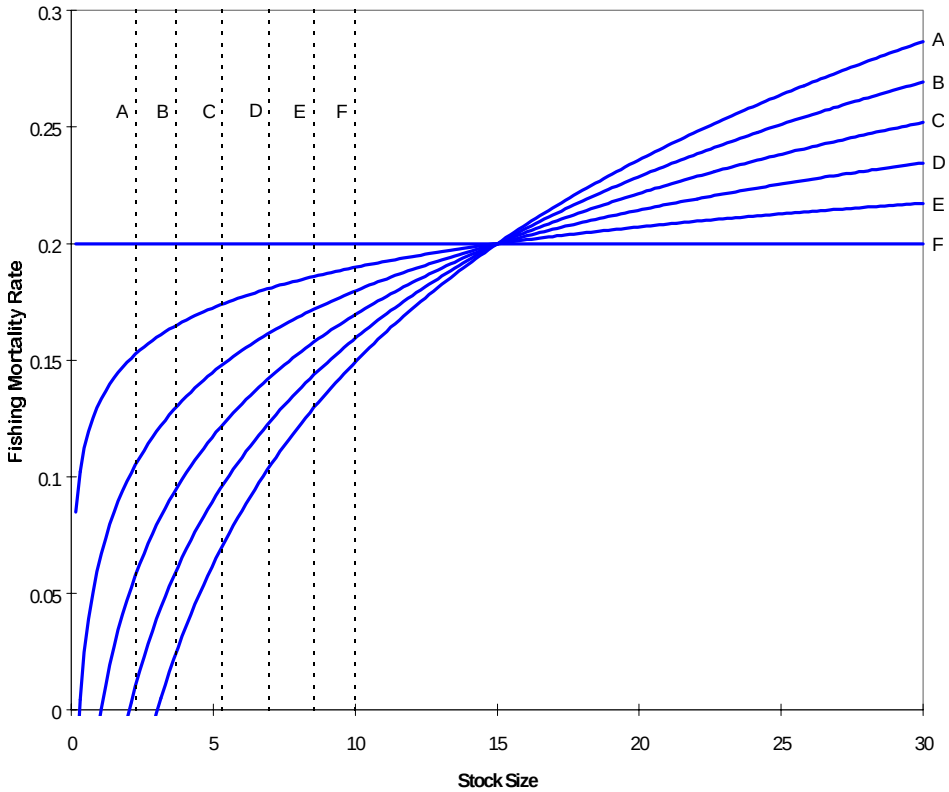

Figure 2. Example MSY control rules (solid curves) and associated stock sizes at which rebuilding would be expected within 10 years (dotted lines). The curve labeled "A" is associated with the line labeled "A," etc.

The dependence of the MSST on the MSY control rule is also illustrated in Figure 3 for a linear-linear type of control rule. Here, the MSY control rule sets MFMT constant for biomass levels above B_{MSY} and decreases it linearly with biomass below B_{MSY}. The solid lines labeled a, b and c represent three such MSY control rules and the dashed lines indicate the corresponding MSST levels (shown in relative units), i.e., the values of biomass at which rebuilding to B_{MSY} would take 10 years when fishing at the MFMT (in reality, the actual position of these levels will vary with the life-history characteristics of the species in question). The ascending parts of these example control rules can be interpreted as built-in plans for rebuilding from the MSST to B_{MSY} — for a fixed rebuilding time period (e.g., 10 years), the stronger reductions in limit fishing mortality at low biomass allow for rebuilding from lower biomass limits.

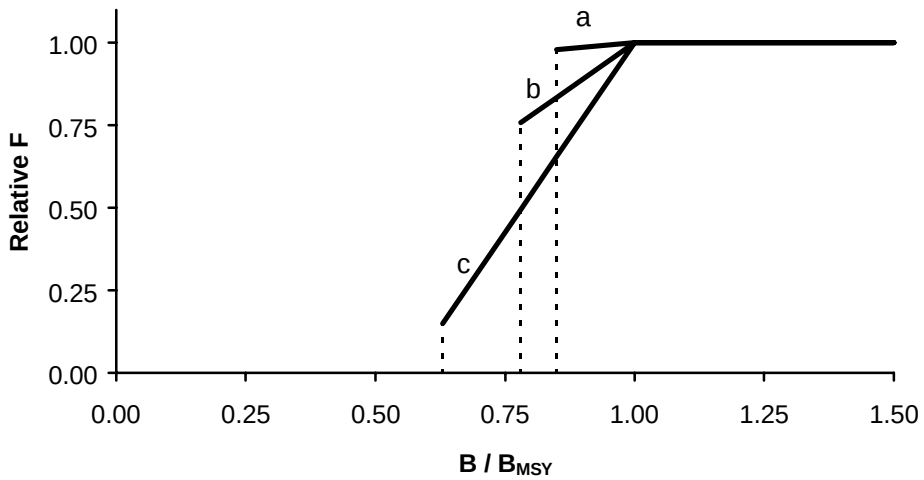

Figure 3 Hypothetical example illustrating the relationship between Minimum Stock Size Threshold (intersection of the dashed lines with the X-axis) and a linear-linear MSY control rule (solid lines, which define the Maximum Fishing Mortality Threshold). Each of the three rules labeled a, b and c, is scaled relative to its own maximum.

2.1.3 Choosing an MSY Control Rule

One factor that might go into choosing an MSY control rule is the resulting location of the MSST. For example, if a Council wished to minimize the range of stock sizes within which special rebuilding plans would be required, it would probably opt for an MSY control rule that afforded a good deal of "built-in" rebuilding, that is, an MSY control rule in which fishing mortality was greatly decreased at low stock sizes. Of course, in no case could the MSST fall below one-half of the MSY level.

Another factor that might go into choosing an MSY control rule is the tradeoff between magnitude of yield and constancy of yield. In general, a horizontal MSY control rule (e.g., control rule "F" in Figure 2) would be expected to result in a lower long-term average yield but a less variable yield than an MSY control rule in which fishing mortality was strongly related to stock size (e.g., control rule "A" Figure 2). Councils have considerable flexibility in choosing how to weight their preferences for these and other performance criteria. NMFS' guidelines for National Standard 1 give the following advice:

> "*In choosing an MSY control rule, Councils should be guided by the characteristics of the fishery, the FMP's objectives, and the best scientific information available.*"

2.1.4 Recommended Default MSY Control Rule

As implied above, specifying an MSY control rule is a flexible process that should involve a great deal of communication between scientists and managers so that the tradeoffs between the relevant performance criteria are understood. Due to the demands

imposed by the timetable of required FMP amendments or other factors, it is desirable to propose a limit control rule that can be used as a default for defining SDC in the absence of more detailed analyses.

We recommend a default MSY control rule of the form (see Figure 4):

$$F(B) = \frac{F_{MSY}\, B}{c\, B_{MSY}} \quad \text{for all } B \le c\, B_{MSY}$$

$$F(B) = F_{MSY} \quad \text{for all } B \ge c\, B_{MSY},$$

where c=max(1-M, 1/2), F_{MSY} is the fishing mortality rate that maximizes long-term yield under a constant-F policy, and B_{MSY} is the equilibrium biomass expected when fishing constantly at F_{MSY}. Setting c=max(1-M, 1/2), where M is the natural mortality rate of the exploited age classes, seems reasonable insofar as one would expect a stock fished at F_{MSY} to fluctuate around B_{MSY} on a scale related to M (small fluctuations for low M and large fluctuations for high M).

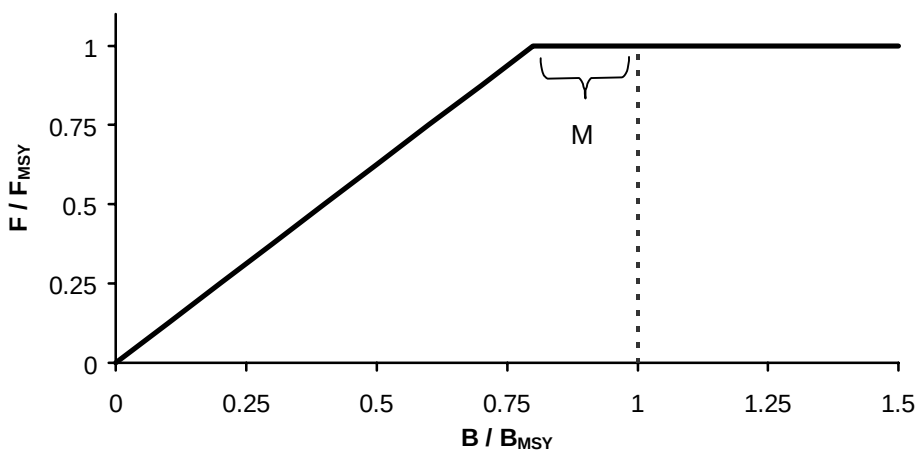

Figure 4. Recommended default MSY control rule.

Note that a control rule of this shape, and parameterized as suggested, may not exactly achieve the maximum long-term yield. The reason for this is that, in an MSY control rule of this form, $F(B)$ would be somewhat larger than F_{MSY} in the flat part of the function (the degree of departure from F_{MSY} is likely to be small in many cases, but is unknown *a priori* in the absence of detailed analyses). Nevertheless, $F(B)$ can be used to define an approximate MFMT.

As noted in Section 2.1.2, the MSST is determined in part by the MSY control rule and is constrained to be greater than ½B_{MSY}. However, for a given MSY control rule, the precise location of the MSST with respect to B_{MSY} may depend on the dynamics of the

particular stock. Estimating the location of the MSST with respect to the MSY stock size can be fairly difficult in some situations and may require the use of simulation tools. If needed, we recommend that the point cB_{MSY} in the default MSY control rule be used as a default proxy for the MSST.

2.1.5 The Role of Selectivity

A fact often overlooked is that the enumeration of MSY depends on partial recruitment patterns. In theory, assuming no variability in life-history parameters, there could be a "global" MSY that can be achieved by totally avoiding fishing until each cohort reaches the age (size) at which losses due to natural mortality exceed contributions from growth and reproduction, and then harvesting all fish of that age (size) instantaneously. However, such knife-edge selection and deterministic life-history parameters are unrealistic, such that the “global” MSY referred to by the NSGs should be treated as a purely theoretical concept.

Calculations of MSY are generally based on the current partial recruitment pattern exhibited by the fishery. "Partial recruitment" patterns reflect both the relative *availability* of fish of different ages or sizes (i.e., their distribution in time and space relative to that of the fishery) and of the relative *selectivity* of fish of different ages or sizes exhibited by the mix of gears used in the fishery. For any particular partial recruitment pattern, there is a unique estimate of MSY (all other things being constant). What this means is that estimates of MSY will change if management actions or environmental factors alter the partial recruitment of the fishery in any way. Management actions that can affect MSY include reallocation of quotas between sectors, increases or decreases in size limits, gear modifications and seasonal changes in the fishery. Environmental factors that can alter MSY include those that influence growth rates and other life history characteristics, and those that influence fish movements and distribution, and therefore availability. Estimates of MSY can vary over a large range due to these factors. It is often possible to substantially increase sustainable yields by changing the selectivity pattern to improve yield per recruit. Similarly, potential sustainable yield is dissipated when the fishery is managed in such a way that yield per recruit is reduced, even though management may still be based on “MSY.”

Clearly, the magnitude of MSY is an important management issue, as is the exploitation pattern, since it affects the magnitude of MSY. Indeed, these are important issues in developing rebuilding plans for overfished stocks. However, initial specification of control rules should be based upon existing partial recruitment patterns, i.e., the existing mix of gears, allocation decisions and management regulations. If the partial recruitment pattern used for defining the MFMT is substantially different from that in the fishery, then the Councils and the Secretary will be unable to monitor and evaluate the condition of the stock relative to the definition of overfishing.

2.2 Situations Requiring the Use of Proxies

As noted in Section 1.1, the MSFCMA allows for the use of proxies in situations where there is insufficient knowledge to implement approaches such as that in Section 2.1. In general, proxies will be needed when MSY-related parameters cannot be estimated from available data, or when their estimated values are deemed to be unreliable for various

reasons (e.g., extremely low precision, insufficient contrast in the data, or inadequate models). This documents refers to "data-moderate" and "data-poor" situations as those that require the use of proxies.

There are no standards for measuring the level of data richness for a stock. This document offers the following guidance to categorize stocks (note that cases involving a stock complex are likely to be of mixed data richness):

> Data-rich cases: Reliable estimates of MSY-related quantities and current stock size are available. Control rules typically involve parameters such as F_{MSY}, B_{MSY}, etc. Stock assessments may be sophisticated, and provide a reasonably complete accounting of uncertainty.
>
> Data-moderate cases: Reliable estimates of MSY-related quantities are either unavailable or of limited use due to peculiar life history, poor data contrast, or high recruitment variability, but reliable estimates of current stock size and all critical life history (e.g., growth) and fishery (e.g., selectivity) parameters are available. Control rules typically involve parameters such as $F_{35\%}$, $B_{35\%}$, etc., or other proxies for MSY-related benchmarks. Stock assessments may range from simple to sophisticated and uncertainty can be reasonably characterized and quantified. (It should be noted that there may be cases when proxies would be useful in "data-rich" situations, i.e., when the proxies are believed to be more robust or reliable than the estimates of MSY parameters. Thus, the term "data-moderate" might be better interpreted as meaning "information-moderate").
>
> Data-poor cases: Reliable estimates of MSY-related quantities are unavailable, as are reliable estimates of either current stock size or certain critical life history or fishery parameters. Control rules typically involve parameters such as M, historical average catch, etc. Stock assessments are minimal, and measurements of uncertainty may be qualitative rather than quantitative.

The list of proxies presented in the following sections is not all-inclusive and scientists are encouraged to develop and examine alternatives.

2.2.1 Data-Moderate Situations

The most widely used biological reference points are those derived from age-structured stock-recruitment models or surplus production models (MSY, F_{MSY}, f_{MSY}), yield per recruit analysis ($F_{0.1}$ and F_{max}), spawning per recruit analysis (various percentages of maximum SPR and associated fishing mortality rates such as $F_{20\%}$, $F_{30\%}$, $F_{35\%}$, and $F_{40\%}$), and stock-recruitment relationships (slope at the origin, or the spawning biomass below which recruitment markedly drops) (Caddy and Mahon 1995). In general, reference points from YPR and SPR analyses are the simplest to calculate because they require fewer inputs (stock recruitment data in particular). For this reason, YPR and SPR reference points are often used as proxies for other reference points that do require stock and recruitment data.

Proxies for F_{MSY}

F_{max} was one of the earliest measures used as a proxy for F_{MSY}. However, it was often believed to be an overestimate of F_{MSY}, because it does not account for the fact that recruitment must decline at some point for low spawning stock sizes, and because F_{max} is unreasonably large (or even infinite) for some sets of growth and mortality parameters. Computer models have also demonstrated that F_{max} typically overestimates F_{MSY} if a Beverton-Holt (1957) stock-recruitment relationship applies, although F_{MSY} can sometimes exceed F_{max} with a Ricker (1958) curve. $F_{0.1}$ (Gulland and Boerema 1973) was developed as an alternative to F_{max} which could result in nearly the same yield per recruit but with lower levels of exploitation. Today, $F_{0.1}$ is commonly interpreted as a conservative or cautious proxy for F_{MSY}, although this is not always the case (Mace 1994; Mace and Sissenwine 1993).

Another class of reference points that has gained prominence are those based on $F_{\%SPR}$. In particular, values in the range $F_{20\%}$ to $F_{30\%}$ have frequently been used to characterize recruitment overfishing thresholds (Rosenberg *et. al.* 1994), while values in the range $F_{30\%}$ to $F_{40\%}$ have been used as proxies for F_{MSY}. These uses are supported by Goodyear (1993); by Mace and Sissenwine (1993), who advocated $F_{20\%}$ as a recruitment overfishing threshold for well-known stocks with at least average resilience and $F_{30\%}$ as a recruitment overfishing threshold for less well-known stocks or those believed to have low resilience; and by Clark (1991; 1993), who advocated $F_{35\%}$ as a robust estimator of F_{MSY} applicable over a wide range of life histories, or $F_{40\%}$ if there is strong serial correlation in recruitment. Note, however, that much of the work on $F_{\%SPR}$ has presupposed a moderate amount of resilience to fishing pressure. Moderate resilience may not be a viable assumption for long-lived species and those with low reproductive output. For example, recent analyses of west coast rockfish (*Sebastes* spp.) stocks are showing the high SPR levels in the range of 50% to 60% are needed to sustain these fisheries (A. MacCall, personal communication). Similar high SPR levels may be necessary to protect many species of sharks and other species that have low productivity.

F_{med} (Sissenwine and Shepherd 1987) may be a useful proxy for different biological reference points, depending on the level of exploitation of the stock from which the stock-recruitment data were estimated. If the stock has been maintained near B_{MSY}, then F_{med} may be considered a reasonable proxy for F_{MSY}.

Proxies for B_{MSY}

The equilibrium biomasses corresponding to the above-mentioned fishing mortality reference points can be used as proxies for B_{MSY}. In addition, B_{MSY} has been approximated by various percentages of the unfished biomass, B_0, usually in the range 30-60% B_0 (higher percentages being used for less resilient species, and lower percentages for more resilient species). Referring (in the preamble) to estimates based on two shapes of production models, the NSGs recommend $0.4B_0$ as a reasonable proxy for B_{MSY}. However, this value may be too low for species with low fecundity such as many species of sharks.

B_{MSY} can also be approximated by the mean recruitment (R_{mean}) multiplied by either (a) the level of spawning per recruit at F_{MSY} — namely SPR(F_{MSY}), or some proxy thereof; or (b) 30-60% $SPR_{F=0}$ (the percentage being determined by the stock's resilience to fishing). The danger with using the first approach to develop an MSY control rule of the

type in Section 2.1.4 is that, if F_{MSY} is overestimated, then SPR(F_{MSY}) and B_{MSY} will both be underestimated. Thus, the MFMT could be too high and the MSST too low.

If catch and CPUE data are available, production models may provide useful proxies, such as CPUE_{MSY}, which can be used as a relative index of B_{MSY} (in addition, the nominal effort (e.g., in boat-months) corresponding to F_{MSY} can be used as a relative index of F_{MSY}).

Proxies for B_0

Where B_0 is unknown, it can be approximated by the product of average recruitment and $\text{SPR}_{F=0}$ (Myers *et al.* 1994). However, this approximation may be unrealistic because it assumes that there have been no density-dependent changes in growth, survival, or age at maturity during the "fishing down" period.

Proxies for MSY

The equilibrium yield corresponding to the above-mentioned *F* and/or *B* reference points can be used as a proxy for MSY.

Inadequate proxies for F_{MSY} and B_{MSY}

The literature offers a number of estimators of, or approximations to, the "ultimate" limit reference point at which a stock is likely to collapse (variously called $F_{extinction}$, F_{ext}, F_{τ} (Mace 1994), F_{crash} (ICES 1997a)). In terms of fishing mortality, these estimators include F_{med} (if calculated from data collected during a period when the stock was overexploited), F_{high} (the fishing mortality corresponding to the 90th percentile of survival ratios), $F_{20\%}$, and F_{loss} (the fishing mortality corresponding to the lowest observed spawning stock — Cook in press). In terms of biomass, these estimators include some definitions of MBAL (the minimum biologically acceptable level of spawning biomass; Serchuk and Grainger 1992), $B_{50\%R}$ (the spawning biomass corresponding to 50% of the maximum recruitment in a stock recruitment relationship; Mace 1994; Myers *et al.* 1994), $B_{90\%R,90\%R/S}$ (the biomass corresponding to the intersection of the 90th percentile of observed recruitment and the 90th percentile of survival; Serebryakov 1991; Shepherd 1991), and B_{loss} (the biomass corresponding to the lowest observed spawning stock; ICES 1997a). In the absence of a reasonable basis for it, the use of these estimators as proxies for F_{MSY} or B_{MSY} should be avoided because they are likely to be poor approximations.

Recommended data-moderate defaults

The recommended data-moderate default MSY control rule is that of Section 2.1.4, using proxies for F_{MSY} and B_{MSY} as described below.

It is recommended that fishing mortality rates in the range $F_{30\%}$ to $F_{60\%}$ be used as general default proxies for F_{MSY}, when the latter cannot be reliably estimated. In the absence of data and analyses that can be used to justify alternative approaches, it is recommended that $F_{30\%}$ be used for stocks believed to have relatively high resilience, $F_{40\%}$ for stocks believed to have low to moderate resilience, and $F_{35\%}$ for stocks with "average" resilience (Mace and Sissenwine 1993). For stocks with very low productivity (such as rockfish and most elasmobranchs), fishing mortality rates in the range $F_{50\%}$ to $F_{60\%}$ are recommended as proxies for F_{MSY}. Less-preferred alternatives (in order of preference) are

to use $F_{0.1}$, M, F_{max}, or F_{med} (however, if F_{med} is calculated from data collected when the stock was fluctuating around B_{MSY}, then it would be a good proxy for F_{MSY}). The equilibrium or average biomass levels corresponding to these fishing mortality rates should then be used as proxies for B_{MSY}, in the same order of preference. The default limit control rule would then be defined with fishing mortality set to this default level when biomass exceeds $(1\text{-}M)*B_{MSY}$ or ½ B_{MSY}, whichever is greater, and would decline linearly to zero for biomass levels below this level (see Figure 4). The recommended default MSST corresponds to ½ B_{MSY} (the absolute lowest limit triggering the need for a rebuilding plan) for species with $M \geq 0.5$; but occurs at a larger biomass for species with smaller M.

2.2.2 Data-Poor Situations

If there are insufficient or inadequate data to conduct YPR and SPR analyses, or if estimates of F and B cannot be obtained for comparison with YPR and SPR reference points, there are few options for defining meaningful targets and limits. Priority should be given to bringing the knowledge base at least up to "data-moderate" standards.

Proxies for F_{MSY}

The natural mortality rate M has often been considered to be a conservative estimate of F_{MSY}; however, it is becoming more and more frequently advocated as a target or limit for fisheries with a modest amount of information. In fact, in several fisheries, F=0.8*M and F=0.75*M have been suggested as default limits for data-poor cases (Thompson 1993, NMFS 1996).

Proxies for B_{MSY}

The equilibrium biomass corresponding to F=M or F=0.8*M can be used as a proxy for B_{MSY}. However, in most data-poor situations, it will not be possible to calculate this quantity.

Proxies for B_0

Some function of CPUE might conceivably be used as a relative index of initial biomass. If information (perhaps anecdotal) exists on resource conditions prior to or shortly after the onset of fishing, some inferences of initial biomass (B_0) may be possible. Because the geographic area occupied by a stock may contract with declines in abundance, the contrast between present and early geographic distributions of the resource may be used to obtain a rough approximation of pre-fishery abundance. Early sport fishing records may provide useful information on resource conditions prior to intense exploitation (MacCall 1996). Estimates of early CPUE may relate to B_0, but care must be taken to correct for the general tendency for CPUE to underestimate declines in resource abundance. For example, this may require geographic stratification, correction for temporal changes in fleet composition (e.g., loss of less efficient vessels as catch rate declines) and a variety of behavioral and biological interactions (see Section 3.5.5). Nonequilibrium production modeling (Hilborn and Walters 1992; Prager 1994) also may provide an inference of initial CPUE for the fishery.

Proxies for MSY

If there is no reliable information available to estimate fishing mortality or biomass

reference points, it may be reasonable to use the historical average catch as a proxy for MSY, taking care to select a period when there is no evidence that abundance was declining.

Recommended data-poor defaults

In data-poor cases it is recommended that the default limit control rule be implemented by multiplying the average catch from a time period when there is no quantitative or qualitative evidence of declining abundance ("Recent Catch") by a factor depending on a qualitative estimate of relative stock size:

Above B_{MSY}:	Limit catch = 1.00*(Recent catch).
Above MSST but below B_{MSY}:	Limit catch = 0.67*(Recent catch).
Below MSST (i.e., overfished):	Limit catch = 0.33*(Recent catch).

The multipliers 1.0, 0.67 and 0.33 were derived by dividing the default precautionary target multipliers in Section 3.3.1 by 0.75, in order to maintain the 0.75 ratio recommended as the default distance between the limit and target reference points for stocks above $(1\text{-}M)*B_{MSY}$. Since it probably will not be possible to determine stock status relative to B_{MSY} analytically, an approach based on "informed judgement" (e.g., a Delphi approach) may be necessary.

2.3 Multispecies Considerations in Implementing MSY Control Rules

Under the National Standard Guidelines, MSY is to be specified for each stock in a mixed-stock fishery, and if this is not possible, then "*MSY may be specified on the basis of one or more species as an indicator for the mixed stock as a whole or for the fishery as a whole.*"

Because productivity (growth, recruitment and mortality) of each species in a stock complex is likely to be different, there will be no single value of F_{MSY} that applies to all species within the assemblage. Likewise, catchability (vulnerability) of each co-occurring species by the gear is likely to be different. Thus, fishing rates for co-occurring species are not going to be reduced by equal amounts if effort within the fishery is reduced. Consequently, it will be difficult if not impossible to obtain F_{MSY} and B_{MSY} for several species simultaneously. Depending on which stock (or stocks) within the mixed-stock complex serve as indicators for the complex as a whole, remaining stocks within the complex may be variously over- or under-exploited with respect to their individual MSY levels. If the indicator stock is more productive than other species within the mixed-stock complex, some stocks within the complex may not be able to withstand the same level of fishing effort associated with the MSY control rule for the indicator species, and a precautionary approach becomes warranted in the face of uncertainty about productivity of non-indicator stocks (Section 3.5.1). Those stocks may be potentially at risk for protection under the Endangered Species Act (ESA) if the fishery continues to overfish those stocks, while maintaining productive indicator stocks at MSY levels.

The National Standard Guidelines allow exceptions to the requirement to prevent overfishing in the case of a mixed-stock complex. If one species in the complex is harvested at OY, overfishing of other components in the complex may occur if (1) long-term net benefits to the Nation will be obtained *and* (2) similar long-term net benefits

cannot be obtained by modification of fleet behavior or gear characteristics or other operational characteristics to prevent overfishing *and* (3) the resulting fishing mortality rate will not cause any stock or ecologically significant unit to require protection under the ESA.

3. TARGET CONTROL RULES

NMFS' guidelines for National Standard 1 state,

"*Target reference points, such as OY, should be set safely below limit reference points, such as the catch level associated with the fishing mortality rate or level defined by the status determination criteria.*"

They also state,

"*...target harvest levels may be prescribed on the basis of an OY control rule similar to the MSY control rule ... but designed to achieve OY on average, rather than MSY. The annual harvest level obtained under an OY control rule must always be less than or equal to the harvest level that would be obtained under the MSY control rule.*"

The words “safely below” in the first quotation have a clear precautionary connotation as elaborated in the National Standard 1 text cited in Section 1.1.2. This section provides technical guidance for developing target control rules. As noted in the Preface, this technical guidance for defining management targets does not incorporate socioeconomic considerations other than aversion to the risk of overfishing.

In terms of accounting for uncertainty, two main approaches have been proposed for establishing a target control rule. Both employ probabilistic treatments of uncertainty, but differ in how probability is used. The first approach can be viewed as "decision-theoretic" because it uses the principles of decision theory to establish a target, given a specified level of relative risk aversion. The greater the level of relative risk aversion, the more conservative the precautionary target control rule will be. For example, if a substantial over-estimate of allowable harvest is perceived to be much more undesirable than an under-estimate of equal magnitude, the implied level of relative risk aversion is higher, and the resulting target fishing mortality will be lower, than if the two mis-estimates were perceived to be equally undesirable. In this approach, risk is defined as "expected loss" and is viewed as an objective function to be minimized. A risk-averse target control rule established under a decision-theoretic approach will also necessarily imply some probability of exceeding the limit, but this probability will generally vary on a case-by-case basis, even under a fixed level of relative risk aversion.

The second approach can be considered as "frequentist" because it uses the frequency of violating the limit to establish a target, given a specified time frame and a critical frequency level. The lower the critical frequency level, the more conservative the target control rule will be. For example, if it is unacceptable to have more than a 5% chance of violating the limit at any time within a 20-year period, the resulting target control rule will be more conservative than if it were acceptable to have a 10% chance of violating the limit within the same time period. In this approach, risk is defined as "frequency of violation" and is viewed as a constraint to be satisfied. A target control rule established under a frequentist approach will also necessarily imply some level of relative risk aversion, but this level will generally vary on a case-by-case basis, even under a fixed critical frequency level.

In Section 3.1 below, an example of a precautionary target control rule developed under the decision-theoretic approach is given. In Section 3.2, a general simulation framework, applicable to both the decision-theoretic and frequentist approaches, is presented.

3.1 A Decision-Theoretic Approach

The distinction between limit and target control rules can be thought of as a distinction between levels of relative risk aversion, and development of both limit and target control rules considered as an optimization problem in a decision-theoretic context. For example, a limit control rule might be defined by the optimum derived under a risk-neutral attitude, while a target control rule might be defined by the optimum derived under a risk-averse attitude. A simple and intuitive way to characterize this difference is in terms of stationary (i.e., long-term) yield: A risk-neutral solution maximizes the expectation of stationary yield (MESY) while a risk-averse solution maximizes the expectation of log stationary yield (MELSY; Thompson 1992 and 1996). When computing these expectations, uncertainty in parameter values should be considered along with uncertainty due to recruitment variability and other natural processes.

In the absence of fishing, stock size B at time t can theoretically range anywhere from zero to infinity, with some stock sizes being more probable than others. Stock size can be modeled as a probability density function (pdf) with parameter vector θ and an initial condition B_0 (in this section, B_0 is not used to denote pristine stock size, but rather the stock size at the start of a population projection). Thus, given an initial condition $B=B_0$, the probability that stock size falls between B_1 and B_2 at time t may be written in terms of the "transition distribution" $g_B(B|\theta;B_0;t)$ as follows:

$$Pr(B_1 \le B(t) \le B_2) = \int_{B_1}^{B_2} g_B(B|\theta;B_0;t)\,\mathrm{d}B\,.$$

As t approaches infinity, g_B describes the "stationary distribution" of stock size, which can be written as $g_B(B|\theta)$.

Next, consider a function which uses a parameter vector to map stock size B into a fishing mortality rate F. Such a function constitutes a control rule. A simple but useful control rule may be specified by two parameters, c and d (for example, the logarithmic form $F(B) = c + d\ln(B)$). For any control rule, yield Y will be a function of stock size conditional on the parameters of the control rule. The stationary distribution of stock size will also be conditional on the same control rule parameters. In the case of the two-parameter control rule, yield can be written as $Y(B|c,d)$, the transition distribution of stock size as $g_B(B|c,d;\theta;B_0;t)$, and the stationary distribution of stock size as $g_B(B|c,d;\theta)$.

Risk-neutral Optimization

A risk-neutral approach can be useful in defining a limit control rule. A risk-neutral solution maximizes the expectation of stationary yield (MESY) for one of the

parameters of the control rule (for example c), conditional on the other parameters (for example d) being fixed, while simultaneously accounting for parameter uncertainty. The solution can be denoted by $c_{MESY}(d)$, meaning the optimum value of parameter c of the control rule that maximizes long-term yield conditional on parameter d. Mathematically, the solution is found by maximizing the marginal arithmetic mean long-term yield, $A_Y(c,d)$ with respect to c. This is achieved by differentiating the marginal arithmetic mean yield with respect to c, setting the resulting expression equal to zero, and solving with respect to c. The arithmetic mean yield can generally be computed by projecting the population over a long time horizon. Analytical expressions for arithmetic mean yield can also be obtained for some simple models; in many cases, the solution for $c_{MESY}(d)$ will need to be found numerically.

Risk-averse Optimization

A risk-averse approach can be useful for defining a target control rule. A risk-averse solution maximizes the expectation of log stationary yield (MELSY) for one of the parameters of the control rule conditional on the other parameters being fixed, while also accounting for parameter uncertainty.

Continuing with the example of optimizing c in a two-parameter control rule, the solution can be denoted by $c_{MELSY}(d)$, and is found by maximizing the marginal geometric mean yield, $G_Y(c,d)$ with respect to c. As with $A_Y(c,d)$, the geometric mean yield can be computed by means of simulation, or, in some simple cases, analytically.

An Example

Thompson (in prep.) provides a detailed example of using the decision-theoretic approach to define limit and target control rules based on maximizing the expected stationary yield or expected log stationary yield. In the deterministic case of that example, the population dynamics of the stock are regulated by a Gompertz-Fox model. The control rule is the two-parameter logarithmic form, giving the expression for change in population size as

$$\frac{\mathrm{d}B}{\mathrm{d}t} = aB\left(1 - \ln\left(\frac{B}{b}\right)\right) - (c + d\ln(B))\,B,$$

where a is a growth rate and b is a scale parameter.

By recasting the model as a stochastic differential equation that incorporates natural variability, analytical expressions can be derived for the risk-neutral and risk-averse solutions presented above (note, however, that the decision-theoretic approach is not limited to cases where an analytical solution is available, as the same approach can be followed using simulation tools such as those of Section 3.2). Figure 5 presents examples of limit and target control rules developed with the decision-theoretic approach for two levels of parameter uncertainty. The control rules shown in Figure 5 have the desirable precautionary property that the buffer between the limit and the target fishing mortality increases as the level of uncertainty surrounding parameter estimates increases.

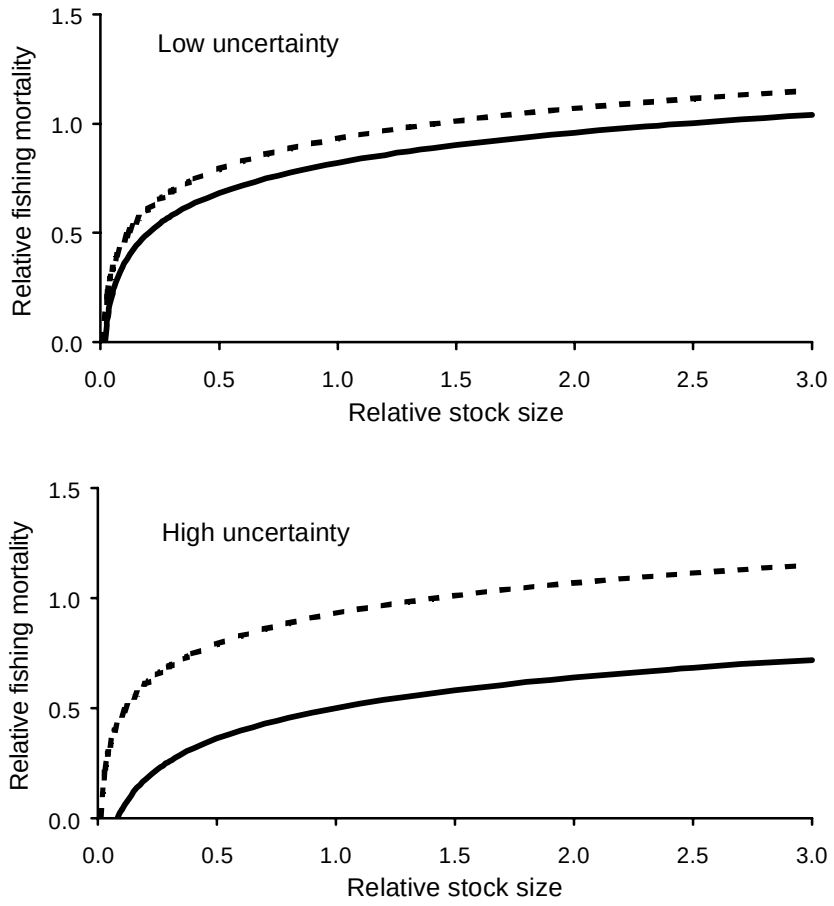

Figure 5. Example limit (dashed lines) and target (solid lines) control rules in a particular model derived with a decision-theoretic approach. The size of the buffer between the limit and target control rules is dictated by the amount of parameter uncertainty (compare upper and lower panels).

3.2 A General Simulation Framework

A fishery management strategy is the combination of data collection, stock assessment, control rules, and technical measures for implementing the harvest controls. Considerable work has been undertaken to develop simulation methods to evaluate the performance of management strategies (e.g.,de la Mare 1986; see Kirkwood and Smith 1996), with much attention often given to the way the various components of a strategy may interact with each other over time. For example, in a recent review of stock assessment methods, the National Research Council stated that "*Both harvesting strategies and decision rules for regulatory actions have to be evaluated simultaneously to determine their combined ability to sustain stocks*" (NRC 1998).

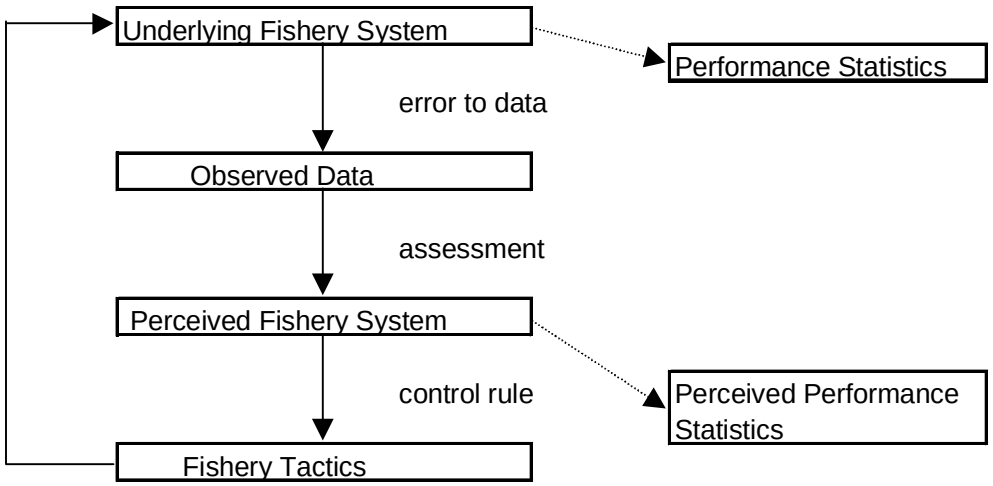

Figure 6. Schematic representation of a simulation framework for evaluating management strategies. Modified, with permission, from Section 4 of ICES (1997b).

The conceptual framework depicted in Figure 6 (taken from ICES 1997b), illustrates a flexible simulation approach for evaluating management strategies. The general technique is to simulate a "true" underlying fishery system of known characteristics, including natural variability. Monte Carlo simulation is used to sample observations with measurement error from the underlying system, and the sample observations are then used in a stock assessment. This allows repeated realizations of the "perceived" system, which may or may not differ substantially from the "true" system (depending partly on the degree of similarity between the true population dynamics and those assumed in the assessment procedure). Using a pre-specified target control rule (e.g., to set the Total Allowable Catch equal to the catch obtained by harvesting the perceived population at the F_{MSY} rate), a regulatory strategy can then be translated into specific fishery tactics (e.g., catch allocations for different fishing sectors). These tactics in turn affect the real underlying system in the next iteration, and so on.

A key step in the evaluation process is to identify the performance criteria that will be examined (see also Section 1.3). In the case of rebuilding an overfished stock, an important performance criterion might be the probability that $B \geq B_{MSY}$ after X years (e.g., 10 years) of implementing a target control rule (a similar approach was used in the guidelines for estimating "potential biological removals" [PBR] for the implementation of the 1996 amendments to the Marine Mammal Protection Act; Wade and Angliss 1997). In most applications, multiple criteria will probably need to be examined, such as the probability that the stock remains above MSST, the average annual yield, and the interannual variability in yield. Inclusion of multiple criteria is particularly useful when there are conflicting goals, such as preventing the stock from falling below B_{MSY} while at the same time achieving yields as close to MSY as possible. Figure 7 depicts an example from ICES (1997b), in which simulation starts with a stock at an equilibrium biomass equal to $\frac{1}{2}B_{MSY}$, the limit F is set to F_{MSY}, and the precautionary target F is set below F_{MSY}

by a given percentage. The figure illustrates the tradeoffs between increasing the chances of rebuilding in a 10-year period and sacrificing average yield.

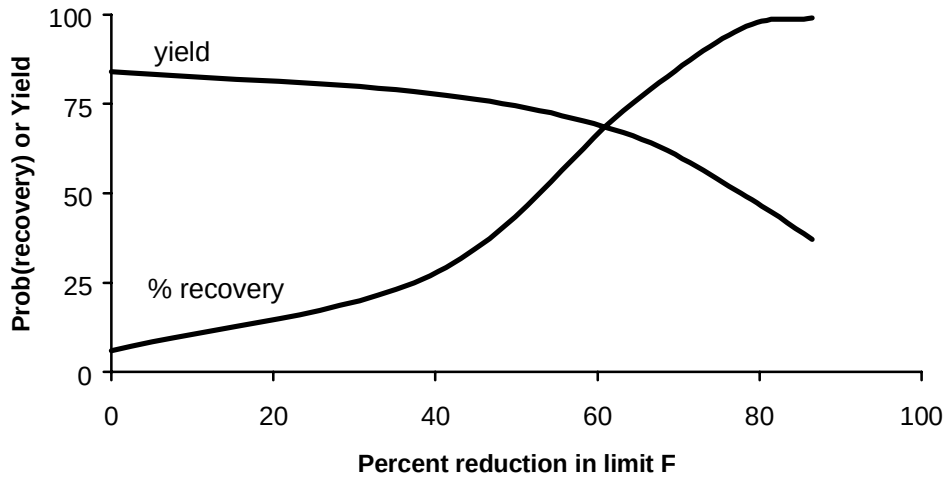

Figure 7 Tradeoffs between two conflicting performance criteria: Rebuilding an overfished stock and maximizing average yield during a 10-year period. Hypothetical example taken from ICES (1997b), data set 7, with limit $F = F_{MSY}$.

Simulation results such as those depicted in Figure 7 can be used to infer the degree of precaution required to achieve a desired outcome. In the example above, if at least a 50% probability of rebuilding to B_{MSY} was desired, then the rebuilding target F should be set at about $\frac{1}{2}F_{MSY}$. Thus, the simulation approach can help determine how far apart (or how "safely below") targets have to be from limits to achieve management goals. In general, simulations should be conducted on a case-by-case basis to account for:

- Growth, reproductive and recruitment dynamics of the stock, including variability (process error);
- Initial conditions, including age-structure;
- Selectivity of the fishing gear(s);
- Types of observations sampled (e.g., age-structure data) and their variability;
- Stock assessment method used;
- Estimation of biological reference points (e.g., limit F) and their uncertainty; and
- Potential biases in the implementation of regulations determined by the control rule.

The simulation approach can also be used to evaluate the benefits to management from reduced uncertainty (Powers and Restrepo 1993). Figure 8 shows that the probability-of-rebuilding curve (from the previous example) is shifted upwards when there is increased in precision regarding current stock status and F_{MSY}.

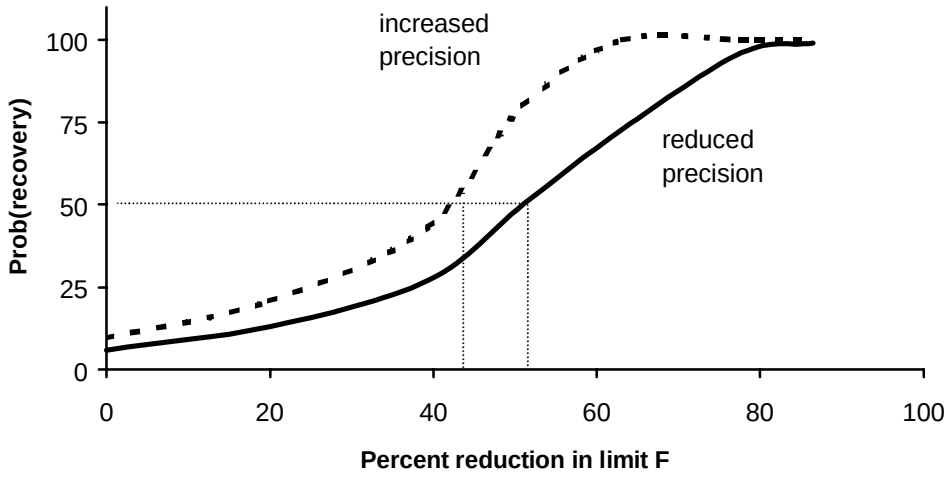

Figure 8 The effect of increased precision on the rebuilding example of Figure 7.

3.3 Recommended Default Target

Ideally, target control rules should be developed using approaches such as those in Sections 3.1 or 3.2. In setting a precautionary target control rule by means of the "frequentist" approach (Sections 3 and 3.2), we recommend that the probability of exceeding the MFMT be not greater than 20%-30%, and certainly smaller than 50%. Absent such analyses or a risk-averse solution as explained in Section 3.1, the following default target control rule is recommended.

The recommended target control rule (Figure 9) sets the target fishing mortality rate 25 percent below the limit fishing mortality (MFMT) recommended in Section 2.1.4. In equation form, the recommended default target is:

$$F(B) = \frac{0.75\ F_{MSY}\ B}{c\ B_{MSY}} \quad \text{for all } B \le c\ B_{MSY}$$

$$F(B) = 0.75\ F_{MSY} \quad \text{for all } B \ge c\ B_{MSY},$$

where c, F_{MSY} and B_{MSY} are as defined in Section 2.1.4.

The default provides a safety margin (or buffer) to ensure that the realized F does not exceed MFMT. The default target control rule also facilitates rebuilding of stocks by reducing F proportionately at stock sizes below $(1\text{-}M)B_{MSY}$. In some cases, however, the rebuilding rate from the default target will be insufficient to rebuild an overfished stock to B_{MSY} within the time period allowed by the NSGs (depending on the life history characteristics of the stock and the level of depletion). In such cases, stronger conservation measures will be required, as explained in Section 3.4.

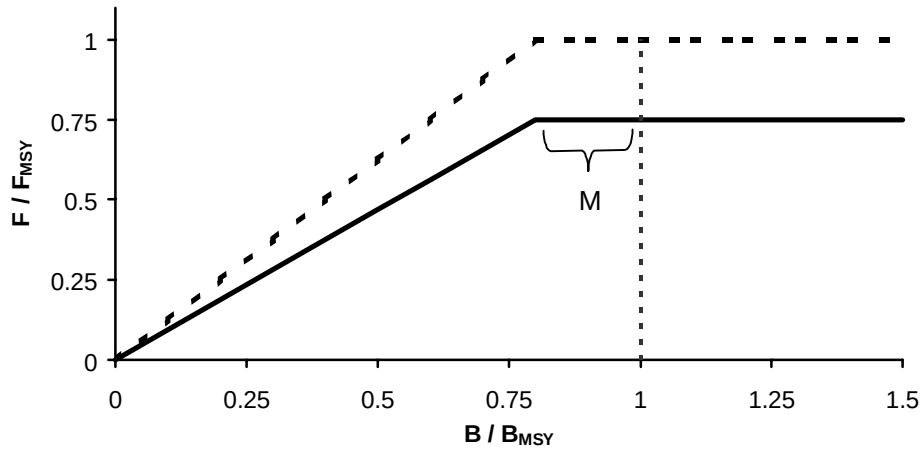

Figure 9. Recommended target (solid line) and limit (dashed line) control rules. The target may only be applicable for biomass levels at or above the minimum stock size threshold because it may not allow for sufficient rebuilding for stocks that are already overfished. Such stocks may require a more conservative target control rule for rebuilding (Section 3.4).

The equilibrium consequences of fishing at the default 75% F_{MSY} were evaluated using the deterministic model of Mace (1994) (see Appendix A). The results of this exercise indicate that fishing at 75% F_{MSY} would result in equilibrium yields of 94% MSY or higher, and equilibrium biomass levels between 125% and 131% B_{MSY} -- a relatively small sacrifice in yield for a relatively large gain in biomass (Table A1). Although it is likely that results would diverge for more complex models (e.g., those in which the ages of maturity and recruitment differed substantially, or those incorporating stochasticity), the calculations indicate that relatively small sacrifices in yields will result in relatively much larger gains in stock biomass. Increased biomass should in turn result in a number of benefits to the fishery, including increased CPUE, decreased costs of fishing, and decreased risk to the stock. Relative to fishing at F_{MSY}, fishing at 75% F_{MSY} will reduce the probability that a stock will decline to ½ B_{MSY}.

The deterministic simulation results presented in Appendix A should not be taken as being strictly applicable to every situation. Variability in the population dynamics parameters of a stock will affect the performance of fishing at 75% F_{MSY}. As well, the evaluation only pertains to cases where F_{MSY} can be reliably estimated. As such, the performance of the default target will depend on the robustness with which F_{MSY} can be estimated or approximated. Simulation tools such as those discussed in Section 3.2 could be used to investigate these issues.

It is recognized that no single policy can fully address all of the considerations to be encountered in the wide variety of fisheries subject to the MSFCMA. To the extent that this default target control rule may be inappropriate, it should at least serve to encourage development of more suitable policies for individual fisheries.

3.3.1 Data-Moderate and Data-Poor Situations

In data-moderate cases, the default target control rule may require the use of appropriate proxies for reference points such as those presented in Section 2.2.

In data-poor cases, the default policy may be interpreted qualitatively as follows:

Above B_{MSY}	Target catch = 0.75*(Recent catch).
Above MSST but below B_{MSY}	Target catch = 0.50*(Recent catch).
Below MSST (i.e., overfished)	Target catch = 0.25*(Recent catch).

Determination of the status of biomass relative to B_{MSY} preferably involves quantitative analysis, but in data-poor cases, applicable analytic methods may not be particularly sophisticated and include a variety of stock assessment methods developed in the 1960s and 1970s (e.g., Gulland 1983). In cases of severe data limitations, qualitative approaches may be necessary, including expert opinion and consensus-building methods (see also Section 2.2.2).

3.4. Rebuilding from Overfished Status

The National Standard 1 guidelines indicate that once biomass falls below the minimum stock size threshold (MSST), then remedial action is required "*to rebuild the stock or stock complex to the MSY level within an appropriate time frame*." Therefore, recommendations are presented here for determining the adequacy and efficacy of rebuilding plans.

A rebuilding plan is a strategy of selecting fishing mortality rates or equivalent catches that are expected to increase the stock size to the MSY level within a specified period of time. Components for a rebuilding plan typically include: (a) an estimate of B_{MSY}, (b) a rebuilding period, (c) a rebuilding trajectory, and (d) a transition from rebuilding to more "optimal" management (Powers 1996). Specifying a control rule in terms of fishing mortality rate and biomass incorporates these components.

Species life history characteristics will affect rebuilding plans in several ways. Some stocks may possess low productivity and will be incapable of recovering within 10 years[2], even in the absence of fishing mortality. Alternatively, a stock may be highly productive, in which case a rebuilding plan of 10 years will not be precautionary, i.e. the stock has the capability of reaching B_{MSY} well before 10 years.

Often productivity is correlated with the mean generation time of a stock (defined below), which is why the final rule issuing the NSGs link the maximum rebuilding time period to generation time when rebuilding cannot be achieved in 10 years. The minimum possible rebuilding period is constrained by a stock's status relative to B_{MSY} and its biological productivity. Linking the rebuilding period with generation time is important because it highlights the time span in the future during which recruitment will begin to depend primarily upon fish that have yet to be born, as opposed to spawners that already

[2] The MSFCMA requires that the rebuilding time period be as short as possible and not to exceed 10 years with a few exceptions, including cases where the biology of the stock or other environmental conditions dictate otherwise.

exist.

Rebuilding rates will also be affected by the partial recruitment pattern. Generally, greater rebuilding rates are possible by reducing mortality rates on juveniles than by equal mortality rate reductions on adult fish. However, this depends upon the relative growth and natural mortality between the age groups.

For all overfished resources, the overarching principle is that initial actions must provide a very high probability of preventing further stock declines and have a high probability of immediate improvement. Delaying action is not precautionary.

Generation time

Although the NSGs do not provide a definition of generation time, various definitions exist in the scientific literature (Caswell 1989). In the context of stock rebuilding time horizons, the definition of generation time used could refer to an unfished state. We recommend that the default definition of generation time, G, be (Goodyear 1995):

$$G = \frac{\sum_{a=1}^{A} a E_a N_a}{\sum_{a=1}^{A} E_a N_a},$$

where a denotes age, A is the oldest age expected in a pristine (unfished) condition, E_a is the mean fecundity at age of females, and N_a is the average number of females per recruit alive at age a in the absence of fishing, i.e.,

$$N_a = N_1 \exp(-\sum_{j=1}^{a-1} M_j),$$

where M is the natural mortality rate. These expressions should be computed on an equilibrium per-recruit basis, i.e., setting $N_1 = 1$. When fecundity data are not available, G can be computed by replacing E_a with an age-specific vector of maturity ratios times body weight (as commonly used to compute spawning biomass).

The rebuilding plan

In the absence of data and analyses that can be used to justify alternative approaches, we recommend that a default rebuilding plan for stocks below the MSST be based upon the precautionary target control rule of Section 3.3 with the following extensions:

1) The maximum rebuilding period, T_{max}, should be 10 years, unless T_{min} (the expected time to rebuilding under zero fishing mortality) is greater than 10 years, when T_{max} should be equal to T_{min} plus one mean generation time.

2) The target rebuilding time period, T_{target}, should be as short as possible and lower than T_{max} (although it could be adjusted up to T_{max} under the circumstances described in §600.310(e)(4) of the NSGs). We suggest that T_{target} not exceed the midpoint between T_{min} and T_{max}; and,

3) If the stock is well below the MSST (e.g., $B \leq$ ½MSST), it may be necessary to set the fishing mortality rate as close to zero as possible (i.e., to that associated with unavoidable levels of bycatch) for a number of years.

Figure 10 illustrates what a rebuilding plan might look like for a severely-overfished stock. In region a, the rebuilding plan's F is set to zero. In region b, between ½MSST and B_{MSY}, the rebuilding F is set to 75% of the target F in the control rule of Section 3.3. In region c, the stock is rebuilt and the F is set again to the target of Section 3.3. Whether or not a zero F in region a and a 75% reduction in region b satisfy the requirement for rebuilding within the target time period largely depends on the initial level of stock depletion and the stock's productivity.

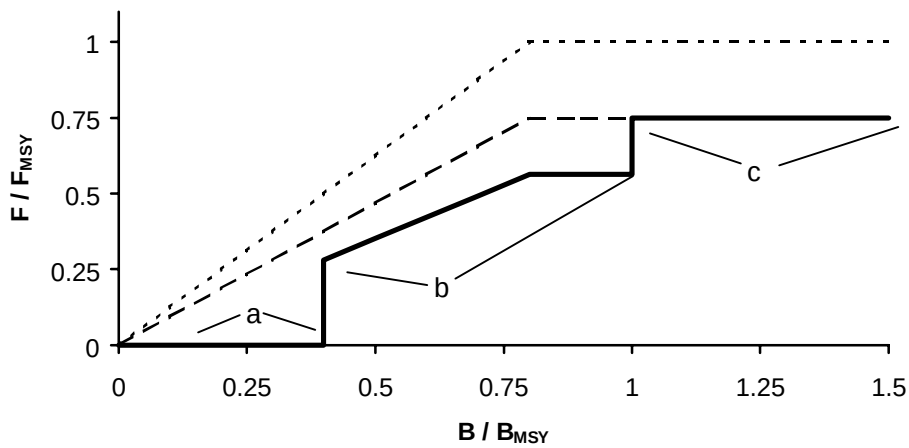

Figure 10. Example of a rebuilding plan (solid line) for a severely-overfished stock. The dotted and dashed lines represent the recommended default limit and target control rules of Sections 2.1.4 and 3.3, respectively. The regions a, b and c represent three phases in the rebuilding plan: part a is designed to initiate rebuilding with high probability; part b is designed to accelerate rebuilding compared to the rate of rebuilding that is built into the target control rule of Section 3.3; part c represents a transition to more "optimal" management.

The role of uncertainty

Accounting for uncertainty in stock dynamics, current stock status and recruitment variability is important in developing rebuilding plans (Rosenberg and Restrepo 1994). As such, we suggest that the rebuilding plan should be designed to possess a 50% — or higher — chance of achieving B_{MSY} within T_{target} years, and a 90% — or higher — chance of achieving B_{MSY} within T_{max} years.

The intent of the MSFCMA is that overfished stocks be rebuilt quickly. For this

reason, stock rebuilding should be monitored closely so that adjustments can be made when rebuilding milestones are not being met for whatever reason. For example, if target rebuilding *F*s are exceeded due to quota over-runs, subsequent target *F*s should typically be adjusted downwards to put the stock back on the rebuilding time table.

The magnitude and variability of future recruitment will affect the realized rebuilding trajectory. In cases when one or more very large year classes appear, it may be tempting to utilize them to increase short-term yield at the expense of slower stock rebuilding, hoping that subsequent year classes will be of similar — or at least average — magnitude. Such action would not be precautionary. Furthermore, the resulting change in fishing mortality would depart from the pre-agreed nature of the rebuilding control rule and therefore be inconsistent with the rebuilding plan.

3.5 Special Considerations

3.5.1 Mixed-Stock Complexes

The National Standard Guidelines provide for specification of a fishery-wide OY for a mixed-stock fishery, where management measures for separate target harvest levels for individual stocks may be specified, but are not required. Although the guidelines recommend that the sum of individual target levels be less than the fishery-wide OY, if individual OY levels are not specified, the entire OY could be removed from one or a few unproductive stock components and overfishing of these components would occur. Clearly, a precautionary approach should be used to minimize the risk of removing the least productive components in the mixed-stock fishery.

Biological reference points (or proxies) and precautionary target control rules for each stock in a mixed-stock complex should be developed whenever possible, even though information may be limited. At a minimum, fishing mortality should not exceed the limit (MFMT) for any individual stock in a mixed-stock complex, except as provided under the very stringent criteria specified in §600.310(d)(6) of the NSGs. The relevant target control rule should be implemented, regardless of the level of information from which the rule was developed. This should lessen the possibility of reducing less-productive stocks to levels at which they would require protection under the ESA, especially if relatively little were known about those stocks.

3.5.2 Environmental Fluctuations

Fish stocks undergo natural fluctuations in abundance. These fluctuations are principally due to year-to-year changes in recruitment which are often environmentally induced. Environmental influences can be inter-decadal in nature, with a low level of predictability. Harvest policies should prepare for these natural swings in abundance, which may be greater than half to double the target level of abundance.

It is convenient to classify the impacts of recruitment variability (independent of stock size) on implementation of target control rules into one of three types:

A. Short-term (year-to-year) fluctuations in recruitment are frequently difficult to measure until the fish have been in the population for several years. This causes uncertainty in the estimation of current stock abundance, thus introducing some random

error in the implementation of the control rule.

B. Medium-term (3-10 year; Francis and Hare 1994, Jacobson and MacCall 1995) fluctuations in recruitment can impact rebuilding time frames. While the expected time to rebuilding may be calculated to be, say, less than 10 years, the actual time to rebuilding will be shorter or longer depending on the actual sequence of recruitments over the 10-year period. When recruitment is highly variable, the actual time to rebuilding will usually also be highly variable. This is one of the reasons why it is important to account for future recruitment uncertainty in developing rebuilding plans.

C. Longer-term (decadal) climate conditions appear to impact recruitment dynamics (Alheit and Hagen 1997, MacCall 1996), producing prolonged periods with above-average (or below-average) recruitment. In an evolutionary sense, fish stocks have adapted to this pattern, and harvest policies should attempt to preserve this adaptation. It may be therefore necessary to design control rules that conserve spawning stock abundance during prolonged periods of poor recruitment to preserve a stock's capability to produce higher recruitment when environmental conditions improve. In some cases, environmental effects may be directly integrated into the stock assessment and the control rule. However, one should be cautious in interpreting a long run of good or poor recruitments as indicative of an environmentally-driven change in stock productivity. In particular, for a period of declining abundance, the "burden of proof" should initially rest on demonstrating that the environment (as opposed to fishing) caused the decline, and that, therefore, the target control rule should be modified. However, if productivity has in fact declined, more conservative limit and target reference points will be needed .

3.5.3 Stock Definition Issues

A "stock" or "stock complex" is a management unit in the sense of the Magnuson-Stevens Act's first definition of the term "fishery": *"One or more stocks of fish that can be treated as a unit for purposes of conservation and management and that are identified on the basis of geographic, scientific, technical, recreational, or economic characteristics."*

Defining a "stock" on a scientific basis is a very difficult task. Many types of information are used to identify stocks: Distribution and movements, population trends, morphological differences, genetic differences, contaminants and natural isotope loads, parasite differences, and oceanographic habitat differences. Evidence of morphological or genetic differences in animals from different geographic regions normally indicates that the populations are reproductively isolated. Separate management is usually appropriate when such differences are found. Failure to detect differences experimentally, however, does not mean the opposite. Dispersal rates, though sufficiently high to homogenize morphological or genetic differences detectable experimentally between putative populations, may still be insufficient to deliver enough recruits from an unexploited population (source) to an adjacent exploited population (sink) to prevent local extinctions leading to contraction or fragmentation of range.

When the distribution of fishing effort corresponds spatially with the density of the target species, management errors caused by improper stock definition are likely to be

small. However, for multispecies fisheries and particularly for by-caught species, fishing effort may be concentrated in only a portion of a species' range. The risk of local depletion leading to range contraction or fragmentation is particularly high for long-lived species with high site fidelity.

Careful consideration needs to be given to how stocks are defined scientifically. In the absence of adequate information on stock structure, a species' range within an ocean should be divided into stocks that represent useful management units. Examples of such management units include distinct oceanographic regions, semi-isolated habitat areas, and areas of higher density of the species that are separated by relatively lower density areas.

3.5.4 Special Life Histories

Delayed maturity, where fish become vulnerable to fishing before they are reproductively mature, can pose a risk of recruitment overfishing. Proxy policies such as $F_{0.1}$ and $F=M$ may be too high in such cases. SPR-based policies such as $F_{35\%}$ account for impacts on spawning potential and tend to provide more precaution in this respect (Clark 1991; Goodyear 1993). Protandric hermaphrodites may be considered as cases of late sexual maturity, and an SPR approach based on female maturity schedules should be adequate.

Species with life stages or behaviors that are highly vulnerable to fishing merit precautionary management. Groupers may be protogynous hermaphrodites, and form very large and predictable spawning aggregations that render them highly vulnerable to fishing, risking both depletion and disturbed population structure due to targeting on large males (Bannerot *et. al.* 1987). Precaution might require severe reductions in fishing pressure, and perhaps a ban on fishing during these vulnerable time periods. No-fishing areas (a.k.a. Marine Protected Areas) could also be appropriate for these species.

Fishes with low frequency variability in recruitment or with rare large recruitments may also require a precautionary reduction in fishing. Clark (1993) showed that an $F_{40\%}$ SPR-based fishing rate is preferable to his generally recommended $F_{35\%}$ policy if there is high serial correlation in annual recruitment. Management of rarely-recruiting species should adopt a very high SPR so that sufficient biomass survives the intervals between major recruitment events. Similarly, certain taxa (e.g., elasmobranchs) that are highly vulnerable to fishing due to their low productivity should be managed to ensure very high SPR.

3.5.5 Data Issues

The precautionary approach dictates that greater caution be used in the face of greater uncertainty. Thus, improved knowledge of stock dynamics and of the effects of fishing should result in higher benefits to the Nation through higher yields and lower risks of stock depletion (the relative benefits and costs of enhanced research can be evaluated with the methods presented in Sections 3.1 and 3.2).

As noted by FAO (1995b, section 4.2), a precautionary approach *"requires explicit specification of the information needed to achieve the management objectives, taking account of the management structure, as well as of the processes required to*

ensure that these needs are met." Data should be collected to improve data quality from a lower tier to a higher tier level of data richness. Logbooks from commercial fishing operations may be useful, whereby daily fishing logs would record target catch and bycatch amount, by species, by fishing statistical area, by gear type, and by units of fishing effort. Any self-report information, such as that contained in logbooks, should be verifiable. Improved data collection systems should also be implemented for recreational fisheries. Scientific observer coverage should also be encouraged, whenever feasible, for independent scientific sampling of commercial and recreational catches.

Scientific (fishery-independent) surveys should also be conducted to estimate the distribution, relative or absolute abundance, age/length frequency, and other relevant biological characteristics of the stocks to improve data quality to a higher data quality tier. An important aspect of fishery-independent monitoring is that it can form the basis for addressing issues and questions that are not necessarily of immediate concern but may become important in the future.

Another important data issue is that of the appropriateness of certain types of data for use in assessment models. Although catch per unit of effort (CPUE) has a long history of use as a fishery-based index of abundance, it also has often proved insensitive to changes in true abundance, particularly when not properly standardized, and its uncritical use has contributed to the collapse of major world fisheries, including the northern cod (Hutchings 1996). Walters and Ludwig (1994) go so far as to say "We flatly recommend that catch/effort data never be used as a direct abundance index (assumed proportional to stock size)." Given the dangers of unvalidated CPUE, the precautionary approach would call for the burden of proof to be placed on demonstrating that CPUE is linearly related to abundance. Patterns such as that shown in Hutchings (1996) and other studies suggest that CPUE often varies approximately in proportion to the square root of abundance. Thus, in cases where a nonlinear relationship between catchability and stock biomass is suspected, it may be necessary to transform CPUE (e.g., by squaring it) before using it as an index of abundance (MacCall in prep.). In addition, standardization of CPUE series may fail to account for increases in fishing power due to the unavailability of appropriate data on gear/vessel configuration and fishing tactics for use in the analyses. In such cases, it is risky to assume that catchability remains constant over time and it may be necessary to adjust CPUE (e.g., by assuming a 3%-5% increase in fishing power per year) before using it as an index of abundance. Such adjustments to CPUE data, while difficult to justify in the absence of direct evidence, may be necessary to reduce the chances of overly-optimistic perceptions of stock status. These risks should be clearly communicated to managers and the public so that they understand that the CPUE adjustments may be necessary in order to avoid serious biases in the assessment. Of course, the preferred remedial action to take is to develop accurate fishery-independent indices of stock abundance.

3.5.6 New Fisheries

New fisheries should be viewed as data-poor cases. Initially, fishing should be largely exploratory in nature, and aimed at gathering sufficient information to bring the level of information content up to at least data-moderate standards. New fisheries present

opportunities to estimate life history parameters such as natural mortality, which should be considered when planning for data collection. It is precautionary to develop new fisheries gradually from an unexploited state to a fully-exploited state over a period of more than one generation time in order to obtain information from intermediate stock sizes that may be vital to determining B_{MSY}. FAO (1995b, section 3.5) contains other recommendations for a precautionary approach to managing new fisheries.

3.5.7 Other Precautionary Tactics

A number of fishery management tools (or tactics) possess precautionary properties and may be useful mechanisms to ensure that limit reference points are not exceeded. For example, allowing fish to spawn at least once before becoming vulnerable to the fishing gear adds a measure of protection against biased estimates of stock status (Myers and Mertz 1998).

Marine Protected Areas (MPAs), wherein all fishing is prohibited, are an extension of area closures, and include precautionary properties (Bohnsack 1996). MPAs may allow a segment of the resource to preserve its unexploited life history, age structure, ecological relationships, etc., in the presence of exploitation. MPAs have limited benefit for highly mobile resources such as pelagic fishes. Somewhat analogous to an MPA is a “biomass reserve”, where a fixed amount of the resource is set aside before applying a target management measure such as $F_{35\%}$. This alternative approach may reduce the need for precise specification of SPR in $F_{\%\mathrm{SPR}}$ policies, offsets imprecision in stock assessments, and may be especially useful in managing rarely recruiting species that are easily subject to depletion.

Other tactics that may have precautionary properties include: (a) Use of "clean" gear types to minimize impacts of fisheries on the stocks, (b) restrictions on the physical characteristics of gear (such as mesh size, hook size, and other physical characteristics) to minimize impacts of fisheries on the stocks and damage to the habitat, (c) modifying fishing characteristics to minimize impacts of fisheries on the stocks and damage to the habitat, and (d) modifying fishing seasons to achieve conservation goals.

Adoption of any of the above or similar conservative tactics into an FMP does not guarantee that the NSGs’ recommendations for achieving National Standard 1 will be satisfied. Nevertheless, it is important to consider these as management options that possess desirable conservation properties.

CONCLUDING REMARKS

Specification of status determination criteria and target control rules is a challenging exercise. Key to this process is communication among managers, scientists, industry and the public. In the face of conflicting objectives, it is essential to understand the tradeoffs associated with alternative control rules and the importance of the weights assigned to the different objectives or performance criteria. Simulation frameworks of the type highlighted in Section 3.2 can facilitate these interactions. Simulation tools should also be used to examine the performance of management systems as a whole, including data collection, assessments, control rules, and implementation of management tactics.

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APPENDIX A

Equilibrium Implications of Fishing at 75% F_{MSY}

The simple, deterministic model described in Mace (1994) was used to evaluate the consequences of fishing at the default target of 75% F_{MSY}. Since the calculations were deterministic and the equilibrium biomass associated with a fishing mortality rate below F_{MSY} will always exceed B_{MSY}, it was not necessary to take explicit account of the behavior of the default target at biomass levels below B_{MSY}. This model is age-structured with natural mortality constant over all ages, knife-edge recruitment and maturity, growth rates represented by a von Bertalanffy growth function, and recruitment represented by either a Beverton-Holt relationship or a Ricker relationship. The procedures used to run the model were the same as those described in Mace (1994), except that the outputs of primary interest were the equilibrium yield at 75% F_{MSY} (abbreviated Y75), the equilibrium biomass at 75% F_{MSY} (B75), the ratio Y75/MSY, and the ratio B75/B_{MSY}. Since the biomass is calculated as the average level present during the course of the fishing year, the ratio B75/B_{MSY} is equivalent to 1.333*(Y75/MSY). These calculations were performed for all combinations of natural mortality (M) = 0.1, 0.2, and 0.3; Brody growth coefficient in von-Bertalanffy equation (K) = 0.1, 0.2, and 0.3; age of recruitment (t_r) equal to age of maturity (t_m), both knife-edged at ages 3, 5, 7, and 9 years; and extinction parameter (τ) = 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50 (where 100*τ represents the level of %SPR corresponding to the slope at the origin of a stock-recruitment relationship) with a Beverton-Holt stock-recruitment relationship for which maximum (asymptotic) recruitment was fixed at 10^8 recruits for all parameter combinations. Additional runs combining M and/or K = 0.4 with the other parameter values were also conducted.

Even though some of these parameter combinations resulted in rather unlikely sets of life history characteristics, the ratios calculated were remarkably consistent across parameter combinations: Y75/MSY ranged between 0.949 and 0.983 and B75/B_{MSY} ranged between 1.265 and 1.311. Selected results for these and other variables are shown in Table A1.

Similar calculations were conducted for a Ricker stock-recruitment function with maximum recruitment fixed at 10^8. Parameter values and combinations were the same as those used with the Beverton Holt stock-recruitment function, except that only one age of recruitment was used (t_r = 5). For this formulation, Y75/MSY ranged between 0.940 and 0.963, and B75/B_{MSY} ranged between 1.253 and 1.284 (Table A1).

Table A1. Equilibrium yield and biomass levels corresponding to F_{MSY} and 0.75 F_{MSY} (selected results from 600 parameter and model combinations). SRR: stock-recruitment relationship (B-H = Beverton-Holt, R = Ricker).

SRR	M	K	τ	t_r	FMSY	0.75* FMSY	MSY	BMSY	Y75	Y75/ MSY	B75/ BMSY
B-H	0.1	0.1	0.05	5	0.091	0.068	12096	133565	11770	0.973	1.298
B-H	0.1	0.1	0.20	5	0.051	0.038	7223	141068	6941	0.961	1.281
B-H	0.1	0.1	0.50	5	0.022	0.016	2279	105381	2175	0.955	1.273
B-H	0.1	0.2	0.05	5	0.147	0.110	30719	209012	30007	0.977	1.302
B-H	0.1	0.2	0.20	5	0.074	0.056	17594	237692	16946	0.963	1.284
B-H	0.1	0.3	0.05	5	0.200	0.150	45966	229351	45008	0.979	1.306
B-H	0.1	0.3	0.20	5	0.091	0.068	25388	278511	24494	0.965	1.286
B-H	0.2	0.1	0.05	5	0.189	0.141	7042	37333	6873	0.976	1.301
B-H	0.2	0.1	0.20	5	0.099	0.075	4120	41422	3964	0.962	1.283
B-H	0.2	0.2	0.05	9	0.501	0.375	45113	90125	44315	0.982	1.310
B-H	0.2	0.2	0.05	5	0.300	0.225	23231	77558	22744	0.979	1.306
B-H	0.2	0.2	0.05	3	0.194	0.145	13215	68123	12873	0.974	1.299
B-H	0.2	0.2	0.20	9	0.195	0.146	23811	122170	23012	0.967	1.289
B-H	0.2	0.2	0.20	5	0.141	0.106	13090	92667	12619	0.964	1.285
B-H	0.2	0.2	0.20	3	0.107	0.080	7831	73125	7529	0.961	1.282
B-H	0.2	0.2	0.50	9	0.069	0.052	6897	99668	6568	0.952	1.270
B-H	0.2	0.2	0.50	5	0.055	0.041	3961	72352	3764	0.950	1.267
B-H	0.2	0.2	0.50	3	0.045	0.034	2456	54969	2331	0.949	1.266
B-H	0.2	0.3	0.05	5	0.405	0.304	39200	96819	38446	0.981	1.308
B-H	0.2	0.3	0.20	5	0.175	0.131	21411	122555	20667	0.965	1.287
B-H	0.3	0.1	0.05	5	0.329	0.246	5447	16579	5331	0.979	1.305
B-H	0.3	0.1	0.20	5	0.159	0.119	3105	19555	2992	0.964	1.285
B-H	0.3	0.2	0.05	5	0.499	0.374	20371	40864	19984	0.981	1.308
B-H	0.3	0.2	0.20	5	0.217	0.163	11226	51639	10833	0.965	1.287
B-H	0.3	0.3	0.05	9	0.926	0.695	61113	65962	60059	0.983	1.310
B-H	0.3	0.3	0.05	5	0.651	0.489	36410	55889	35756	0.982	1.309
B-H	0.3	0.3	0.05	3	0.395	0.297	19438	49150	19011	0.978	1.304
B-H	0.3	0.3	0.20	9	0.337	0.253	31391	93032	30363	0.967	1.290
B-H	0.3	0.3	0.20	5	0.264	0.198	19555	73941	18888	0.966	1.288
B-H	0.3	0.3	0.20	3	0.195	0.146	11114	57070	10707	0.963	1.285
B-H	0.3	0.3	0.50	9	0.115	0.087	8917	77240	8492	0.952	1.270
B-H	0.3	0.3	0.50	5	0.096	0.072	5738	59609	5458	0.951	1.268
B-H	0.3	0.3	0.50	3	0.077	0.058	3399	44086	3228	0.950	1.267
R	0.2	0.2	0.05	5	0.669	0.502	30262	45243	29096	0.962	1.282
R	0.2	0.2	0.20	5	0.190	0.142	23630	124380	22459	0.950	1.267
R	0.2	0.2	0.50	5	0.061	0.045	9037	149062	8522	0.943	1.257
R	0.3	0.3	0.05	5	1.458	1.094	50728	34784	48840	0.963	1.284
R	0.3	0.3	0.20	5	0.358	0.268	35826	100105	34121	0.952	1.270
R	0.3	0.3	0.50	5	0.107	0.080	13120	122951	12385	0.944	1.259

APPENDIX B

Glossary

Availability. Refers to the distribution of fish of different ages or sizes relative to that of the fishery.

B. Biomass, measured in terms of spawning capacity (in weight) or other appropriate units of production.

B_0. Virgin stock biomass, i.e. the long-term average biomass value expected in the absence of fishing mortality. In Section 3.1, B_0 is used as the biomass at the start of a population projection.

B_{MSY}. Long-term average biomass that would be achieved if fishing at a constant fishing mortality rate equal to F_{MSY}.

BRP (Biological Reference Point). Benchmarks against which the abundance of the stock or the fishing mortality rate can be measured, in order to determine its status. BRPs can be categorized as limits or targets, depending on their intended use (see also Reference Points). There are also socio-economic reference points, but those are not treated in any detail in this document.

Catchability. Proportion of the stock removed by one unit of effective fishing effort (typically age-specific due to differences in selectivity and availability by age).

Control Rule. Describes a plan for pre-agreed management actions as a function of variables related to the status of the stock. For example, a control rule can specify how *F* or yield should vary with biomass. In the NSGs, the "MSY control rule" is used to determine the limit fishing mortality, MFMT. Control rules are also known as "decision rules" or "harvest control laws" in some of the scientific literature.

CPUE (Catch per Unit of Effort). Measures the relative success of fishing operations, but is also sometimes used a proxy for relative abundance based on the assumption that CPUE is linearly related to stock size. The use of CPUE that has not been properly standardized for temporal-spatial changes in catchability is highly undesirable.

DAH (Domestic Annual Harvest).

ESA (Endangered Species Act).

F. Instantaneous fishing mortality rate. Measures the effective fishing intensity for a given partial recruitment pattern.

$F_{0.1}$. Fishing mortality at which the slope of equilibrium yield per recruit (YPR) is reduced to 10% of the slope when F=0.

F_{high}. Fishing mortality rate corresponding to an equilibrium SPR equal to the inverse of the 90th percentile observed survival ratio.

F_{low}. Fishing mortality rate corresponding to an equilibrium SPR equal to the inverse of the 10th percentile observed survival ratio.

F_{max}. Fishing mortality at which the slope of equilibrium yield per recruit (YPR) is zero (may be undefined in some cases where the YPR-*F* curve is asymptotic).

F_{med}. Fishing mortality rate corresponding to an equilibrium SPR equal to the inverse of the median observed survival ratio.

f_{MSY}. Effective fishing effort corresponding to F_{MSY}.

$\boldsymbol{F_{MSY}}$. Fishing mortality rate which, if applied constantly, would result in MSY.

$\boldsymbol{F_{\blacktriangle}}$ (also $F_{extinction}$, F_{crash}). Fishing mortality rate corresponding to an equilibrium SPR equal to the inverse of the survival ratio at the origin of the stock-recruitment relationship. A stock fished at or above this level for a prolonged period of time is expected to collapse.

$\boldsymbol{F_{x\%}}$. Fishing mortality rate that results in x% equilibrium spawning potential ratio.

FMP (Fishery Management Plan). A plan containing conservation and management measures for fishery resources, and other provisions required by the MSFCMA, developed by the Fishery Management Councils or the Secretary of Commerce.

Generation Time. In the context of the NSGs, generation time is a measure of the time required for a female to produce a reproductively-active female offspring for use in setting maximum allowable rebuilding time periods. Several estimators of generation time are available in the literature, and one is presented in Section 3.4.

Limit Reference Points. Benchmarks used to indicate when harvests should be constrained substantially so that the stock remains within safe biological limits. The probability of exceeding limits should be low. In much of the NSGs, limits are referred to as thresholds. In much of the international literature (e.g., FAO documents), "thresholds" are used as buffer points that signal when a limit is being approached.

$\boldsymbol{M}$. Instantaneous natural mortality rate.

MESY (Maximum expected stationary yield). Maximum statistical expectation of long-term yield, considering uncertainties in parameter values and natural (process) variability.

MELSY (Maximum expected log stationary yield). Maximum statistical expectation of the logarithm of long-term yield, considering uncertainties in parameter values and natural (process) variability.

MFMT (Maximum Fishing Mortality Threshold). SDC for determining if overfishing is occurring. It will usually be equivalent to the F corresponding to the MSY Control Rule.

MSFCMA (Magnuson-Stevens Fishery Conservation and Management Act). U.S. Public Law 94-265, as amended through October 11, 1996. Available as NOAA Technical Memorandum NMFS-F/SPO-23, 1996.

MSST (Minimum Stock Size Threshold). The greater of (a) $\frac{1}{2}B_{MSY}$, or (b) the minimum stock size at which rebuilding to B_{MSY} will occur within 10 years of fishing at the MFMT. MSST should be measured in terms of spawning biomass or other appropriate measures of productive capacity.

MSY (Maximum Sustainable Yield). Largest long-term average yield (catch) that can be taken from a stock (or stock complex) under prevailing ecological and environmental conditions. Any estimate of MSY depends on the population dynamics of the stock, the characteristics of the fisheries (e.g. gear selectivity), and the control rule used. In much of the traditional fisheries literature, MSY is estimated with a control rule in which F is independent of stock size. In the language of the NSGs, estimates of MSY will change depending on the shape of the control rule, but B_{MSY} and F_{MSY} pertain only to a constant-F control rule.

NSGs (National Standard Guidelines). Advisory guidelines developed by NMFS, based on the National Standards of the MSFCMA, intended to assist in the development of FMPs.

Published in the Federal Register[3] first as proposed rule on August 4, 1997, and then revised as final rule on May 1, 1998.

Overfished. According to the NSGs, an overfished stock or stock complex is one "whose size is sufficiently small that a change in management practices is required in order to achieve an appropriate level and rate of rebuilding." A stock or stock complex is considered overfished when its size falls below the MSST. A rebuilding plan is required for stocks that are overfished.

Overfishing. According to the NSGs, "overfishing occurs whenever a stock or stock complex is subjected to a rate or level of fishing mortality that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis." Overfishing is occurring if the MFMT is exceeded for 1 year or more.

OY (Optimum Yield). The amount of fish that will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities and taking into account the protection of marine ecosystems. MSY constitutes a "ceiling" for OY. OY may be lower than MSY, depending on relevant economic, social, or ecological factors. In the case of an overfished fishery, OY should provide for rebuilding to B_{MSY}.

Partial Recruitment. Patterns of relative vulnerability of fish of different sizes or ages due to the combined effects of selectivity and availability.

Rebuilding Plan. A plan that must be designed to recover stocks to the B_{MSY} level within 10 years when they are overfished (i.e. when B < MSST). Normally, the 10 years would refer to an expected time to rebuilding in a probabilistic sense.

Recent Catch. In the context of this document, this term should be interpreted as the average catch during a time period (e.g., 5 years) for which there is evidence of stable abundance. As this type of information is unlikely to be available in many data-poor cases, scientists could carefully consider defining Recent Catch as the median catch during the last 5, 10 or 15 years.

Reference Points. Values of parameters (e.g. B_{MSY}, F_{MSY}, $F_{0.1}$) that are useful benchmarks for guiding management decisions. Biological reference points are typically limits that should not be exceeded with significant probability (e.g. MSST) or targets for management (e.g. OY).

Risk. The probability of an event times the cost associated with the event (loss function). Sometimes "risk" is simply used to denote the probability of an undesirable result (e.g. the risk of biomass falling below MSST).

SDC (Status Determination Criteria). Objective and measurable criteria used to determine if a stock is being overfished or is in an overfished state according to NSGs.

Selectivity. Measures the relative vulnerability of different age (size) classes to the fishing gears(s).

SPR (1). Spawning output Per Recruit: Amount of per-capita spawning biomass (or other appropriate measure of reproductive output) obtained at a given value of F, conditional on values of partial recruitment, growth, maturity (and/or fecundity) and natural mortality. (2). Spawning Potential Ratio: The expected lifetime spawning output per recruit relative to the spawning output that would be realized in the absence of fishing, often expressed as

[3] Copies of the NSGs and other relevant documents that have appeared in the Federal Register can be obtained in the Web at http://www.nmfs.gov/sfa.

a percentage. Throughout this document, references to the second definition are associated with a percentage (%) sign.

Survival Ratios. Ratios of recruits to spawners (or spawning biomass) in a stock-recruitment analysis.

Target Reference Points. Benchmarks used to guide management objectives for achieving a desirable outcome (e.g. OY). Target reference points should not be exceeded on average.

Uncertainty. Uncertainty results from a lack of perfect knowledge of many factors that affect stock assessments, estimation of reference points, and management. Rosenberg and Restrepo (1994) identify 5 types: Measurement error (in observed quantities), process error (or natural population variability), model error (mis-specification of assumed values or model structure), estimation error (in population parameters or reference points, due to any of the preceding types of errors), and implementation error (or the inability to achieve targets exactly for whatever reason).

YPR (Yield per Recruit). Amount of per-capita yield obtained at a given value of *F*, conditional on values of partial recruitment, growth and natural mortality.

Exhibit 2

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Evaluating methods for setting catch limits in data-limited fisheries☆

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ABSTRACT

The majority of global fish stocks lack adequate data to evaluate stock status using conventional stock assessment methods. This poses a challenge for the sustainable management of these stocks. Recent requirements to set scientifically based catch limits in several countries, and growing consumer demand for sustainably managed fish have spurred an emerging field of methods for estimating overfishing thresholds and setting catch limits for stocks with limited data. Using a management strategy evaluation framework we quantified the performance of a number of data-limited methods. For most life-histories, we found that methods that made use of only historical catches often performed worse than maintaining current fishing levels. Only those methods that dynamically accounted for changes in abundance and/or depletion performed well at low stock sizes. Stock assessments that make use of historical catch and effort data did not necessarily out-perform simpler data-limited methods that made use of fewer data. There is a high value of additional information regarding stock depletion, historical fishing effort and current abundance when only catch data are available. We discuss the implications of our results for other data-limited methods and identify future research priorities.

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1. Introduction

The majority of global fish stocks lack adequate catch, survey, and other biological data to calculate current abundance and productivity using conventional stock assessment methods. In developed countries, the fraction of fish stocks that are assessed ranges between 10 and 50%. This fraction is generally lower in developing countries where it ranges between 5 and 20% (Costello et al., 2012). This poses a significant challenge for the sustainable management of these stocks. Recent requirements to set scientifically based catch limits in countries such as Australia, New Zealand, and the United States, along with growing consumer demand for sustainably managed fish, have spurred an emerging field of methods for estimating overfishing thresholds and setting catch limits for stocks with limited data.

In 2006, the U.S. Magnuson-Stevens Fishery Conservation and Management Act was amended to require annual catch limits (ACLs) to prevent overfishing for most federally managed fish stocks, including many data-limited stocks. According to the National Marine Fisheries Service's (NMFS's) National Standard 1 Guidelines (2009), setting ACLs is a three-step process that begins by identifying an overfishing limit (OFL). The OFL is the annual catch when fishing the stock's current abundance at the maximum sustainable fishing mortality rate (F_{MSY}). In the second step, a harvest control rule is used to determine the acceptable biological catch (ABC). The ABC is a catch level equal to or less than the OFL that accounts for the scientific uncertainty in the estimate of the OFL. Finally, fisheries managers use the ABC to establish an ACL. The ACL is set to a level equal to or below the ABC and accounts for various ecological, social and economic factors in addition to uncertainty in management controls.

The most established basis for estimating an OFL is by a conventional stock assessment, which typically uses fishery time series data to estimate current stock size and productivity. However, many populations have insufficient fishery catch data, survey data, or information about life-history characteristics to support a conventional stock assessment, requiring the use of alternative, data-limited methods. Most data-limited methods are designed to operate on a single time series of annual catches (generally no fishing effort or survey data are available) with additional

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user-specified inputs for fisheries characteristics, demographic parameters, exploitation rate and/or stock status. Many of these methods are now being used in management, although they have not been thoroughly tested. Management strategy evaluation (MSE) is an appropriate tool to evaluate and compare the performance of existing methods across various types of fish stocks and relative population levels (see Section 2.2 for a detailed description of MSE). We use MSE in this research to test the performance of data-limited methods for various stock types and depletion levels (depletion is defined here as current biomass divided by unfished biomass).

It may be possible to make reasonable qualitative statements about the performance of various data-limited methods without undertaking an MSE. However detailed simulation evaluation enables the relative performance of methods to be quantified to support strategic decisions regarding data collection and selection of methods. Previous simulation evaluations of data-limited OFL-setting methods and ABC control rules have been conducted by Wetzel and Punt (2011) and Wilberg et al. (2011). Wetzel and Punt (2011) evaluated the performance of two methods (DB-SRA and DCAC) over a range of population and fishery dynamics. Limitations of their approach include the simulation of a relatively narrow range of fishery dynamics without simultaneously considering a realistic level of uncertainty and bias in all of the inputs to the methods under examination (e.g., natural mortality rate, M). Wilberg et al. (2011) simulation tested a more comprehensive range of data-limited methods. However, not all data-limited methods were applied to all stock types preventing a complete performance comparison (Vaughan et al., 2012). Their approach was also criticized on the basis of a relatively narrow range of simulated life-histories and discrete simulation of error and bias. We aim to address these criticisms by (1) simulating a wide range of fishery and population dynamics and (2) assigning probability distributions for bias and imprecision to more of the inputs to data-limited methods (e.g., depletion, M). Such an approach may better reveal the trade-offs among management objectives and provide a more detailed account of the performance characteristics of data-limited methods.

2. Materials and methods

This research is aimed at evaluating methods that determine an ABC as a basis for setting annual catch limits. Twenty-five methods for determining OFLs and modifying them using ABC control rules are evaluated, including nine that have been used in the management of U.S. fisheries (M1–M9), 12 alternative methods (A1–A12), and four reference methods that can be used to comparatively assess the performance of the other methods (R1–R4).

The methods are classified as follows: (1) those that rely on a time series of recent catch ("catch-based methods"); (2) those that adjust historical catches using assumptions about historical depletion and life history characteristics ("depletion-based methods"), and (3) those that rely on current estimates of absolute abundance ("abundance-based methods"). Methods within these classes can be further distinguished into those methods that dynamically update with current information on depletion and those that remain static. The following section describes the specific methods selected for evaluation (see Table 1 for a list of all methods). The data requirements of each method tested are summarized in Table 2, and their detailed description can be found in Appendix B.

These methods are subject to modification by two types of ABC control rule. The first is no downward adjustment. For example, methods M1–M3 are catch methods for which ABC equals the OFL. The second type of ABC control rule uses a simple scalar approach in which a point value produced by a method (e.g., the median outcome of DB-SRA or DCAC) is multiplied by a factor. These scalar factors differ depending on a broadly defined characterization of scientific uncertainty for different groups of stocks (e.g., alternative methods A1, A2 and A7–A12 make use of 75% and 100% scalars).

2.1. Methods evaluated in this study

2.1.1. Catch-based methods

Catch-based methods have generally been employed where insufficient data exist for determining an OFL using more sophisticated methods. For example, the U.S. Southeast and Mid-Atlantic Fishery Management Councils currently apply catch-based methods to dozens of stocks. The South Atlantic Fishery Management Council (SAFMC) has adopted two quantitative approaches to ACL-setting that are simulation tested: the OFL is set to the third highest landings over the last ten years or to the median landings over the last ten years (SAFMC, 2011). The Mid-Atlantic Fishery Management Council has adopted an OFL for Atlantic Mackerel that is the median catch from the last three years (MAFMC, 2010; NMFS, 2011). These approaches stem from the work of Restrepo et al. (1998) who suggested the use of average catches with a downward adjustment based on uncertainty about stock status, although these implementations do not include a downward adjustment. All three of these methods are tested: the median catch over the most recent three years (M1), the median catch over the most recent 10 years (M2), and the third-highest catch over the most recent 10 years (M3).

Other catch-based methods that have been proposed attempt to introduce dynamic updates of simple catch-based control rules based on generally subjective scoring systems, such as the Only Reliable Catch Stocks (ORCS, Berkson et al., 2011) method and Productivity–Susceptibility Analysis (PSA, Patrick et al., 2009). Both of these approaches use biological and fishery characteristics to calculate a single catch value. Berkson et al. (2011) identify a possible means of using the outcome from ORCS to categorize stocks into exploitation levels. Each level leads to a different multiplication of interquartile mean catch (the average of all catches greater than the 25th percentile and less than the 75th percentile) that is selected as a proxy for the OFL or ABC. PSA has been suggested as a basis for an ABC control rule that increases the precautionary buffer with increasing vulnerability of the stock (Berkson et al., 2011). Unfortunately, it proved difficult to test these approaches due to an inability to simulate the subjective scoring systems in a defensible way. The success of the methods is likely to be determined by how they are implemented, so we decided to omit them from the comparative performance analysis.

Instead of simulating these subjective methods we tested a control rule similar to that proposed by Berkson et al. (2011). This control rule dynamically scales a catch-based OFL according to periodic estimates of depletion. The OFL is set to half, equal or twice the interquartile mean catch when current biomass is considered to be less than 20% of unfished, greater than 20% and less than 65% of unfished, and greater than 65% of unfished levels, respectively. In lieu of a subjective scoring system to estimate depletion, we test the performance of the catch scalar methods using imperfect knowledge of simulated current depletion. An imperfect estimate of depletion was simulated by calculating the current level of stock depletion (current biomass divided by unfished biomass) and then adding error according to specified levels of bias and imprecision. This method (referred to as "Depletion Adjusted Catch Scalar", DACS) represents a very simple approach to modifying an OFL using coarse subjective information about current stock levels. We test the DACS method with two ABC control rules: 75% and 100% scalars (methods A1 and A2).

Table 1
A summary table of the methods tested in this management strategy evaluation, including nine methods currently in use in the management of stocks in U.S. fishery management plans (M1–M9), 12 alternative methods described in the peer-reviewed literature (A1–A12) and four reference methods (R1–R4).

Type	Code	Name	OFL setting	ABC control rule	Source
Static methods					
Catch-based (static)	M1	Median catch – 3 years	Median catch over last 3 years	None	MAFMC
	M2	Median catch – 10 years	Median catch over last 10 years	None	SAFMC
	M3	3rd highest catch	3rd highest catch over last 10 years	None	SAFMC
Depletion-based (static)	M4	DB-SRA (depletion fixed @ 40% B_0) – 69.4% scalar	Median of OFL distribution	69.4% scalar	PFMC (Dick and MacCall, 2011)
	M5	DB-SRA (depletion fixed @ 40% B_0) – 83.4% scalar	Median of OFL distribution	83.4% scalar	PFMC (Dick and MacCall, 2011)
	M6	DB-SRA (depletion fixed @ 40% B_0) – 91.3% scalar	Median of OFL distribution	91.3% scalar	PFMC (Dick and MacCall, 2011)
	M7	DCAC (depletion fixed @ 40% B_0) – 69.4% scalar	Median of OFL distribution	69.4% scalar	PFMC (Dick and MacCall, 2010)
	M8	DCAC (depletion fixed @ 40% B_0) – 83.4% scalar	Median of OFL distribution	83.4% scalar	PFMC (Dick and MacCall, 2010)
	M9	DCAC (depletion fixed @ 40% B_0) – 91.3% scalar	Median of OFL distribution	91.3% scalar	PFMC (Dick and MacCall, 2010)
Dynamic methods					
Catch-based (dynamic)	A1	Depletion adjusted catch scalar – 75% scalar	0.5, 1.0, or 2.0 × mean landings	75% scalar	Berkson et al. (2011)
	A2	Depletion adjusted catch scalar – 100% scalar	0.5, 1.0, or 2.0 × mean landings	100% scalar	Berkson et al. (2011)
Depletion-based (dynamic)	A3	DB-SRA (depletion adjusted) – 25% P*	Stochastic model output	25% P^*	Dick and MacCall (2011)
	A4	DB-SRA (depletion adjusted) – 50% P^*	Stochastic model output	50% P^*	Dick and MacCall (2011)
	A5	DCAC (depletion adjusted) – 25% P^*	Stochastic model output	25% P^*	Dick and MacCall (2011)
	A6	DCAC (depletion adjusted) – 50% P^*	Stochastic model output	50% P^*	Dick and MacCall (2011)
Abundance-based (dynamic)	A7	Life history analysis – 75% scalar	F_{MSY} × abundance	75% scalar	Beddington and Kirkwood (2005)
	A8	Life history analysis – 100% scalar	F_{MSY} × abundance	100% scalar	Beddington and Kirkwood (2005)
	A9	F_{MSY}/M (low) – 75% scalar	F_{MSY} @ 0.5 M × abundance	75% scalar	Gulland (1971) and Walters and Martell (2002)
	A10	F_{MSY}/M (low) – 100% scalar	F_{MSY} @ 0.5 M × abundance	100% scalar	Gulland (1971) and Walters and Martell (2002)
	A11	F_{MSY}/M (hi) – 75% scalar	F_{MSY} @ 0.8 M × abundance	75% scalar	Gulland (1971) and Walters and Martell (2002)
	A12	F_{MSY}/M (hi) – 100% scalar	F_{MSY} @ 0.8 M × abundance	100% scalar	Gulland (1971) and Walters and Martell (2002)
Reference cases					
Stock assessment (dynamic)	R1	Delay-difference – 75% scalar	Delay-difference assessment	75% scalar	Deriso (1980) and Schnute (1985)
	R2	Delay-difference – 100% scalar	Delay-difference assessment	100% scalar	Deriso (1980) and Schnute (1985)
Status quo (static)	R3	Current catch	Catch in last simulated year	None	N/A
	R4	Current effort	Effort in last simulated year	None	N/A

Table 2
The data requirements or inputs of the data-limited methods tested in this evaluation. These include a time series of historical catches (Catch), current stock size relative to unfished condition (Depltn), the ratio of fishing mortality rate at maximum sustainable yield to the natural mortality rate (F_{MSY}/M), biomass at maximum sustainable yield relative to unfished biomass (B_{MSY}/B_0), natural mortality rate (M), median age at maturity, current biomass, the rate parameter K of the von Bertalanffy growth equation (Von Bert. K) and the mean length at first capture.

Type	Code	Name	Catch	Depltn.	F_{MSY}/M	B_{MSY}/B_0	M	Age at 50% Maturity	Current biomass	Von Bert. K	Length-at-first capture
Static Methods											
Catch-Based (Static)	M1	Mean Catch - 3 Years	■								
	M2	Median Catch - 10 Years	■								
	M3	3rd Highest Catch	■								
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B_0) - 69.4% scalar	■		■	■	■	■			
	M5	DB-SRA (Depletion Fixed @ 40%B_0) - 83.4% scalar	■		■	■	■	■			
	M6	DB-SRA (Depletion Fixed @ 40%B_0) - 91.3% scalar	■		■	■	■	■			
	M7	DCAC (Depletion Fixed @ 40%B_0) - 69.4% scalar	■		■	■	■				
	M8	DCAC (Depletion Fixed @ 40%B_0) - 83.4% scalar	■		■	■	■				
	M9	DCAC (Fixed Depletion @ 40%B_0) - 91.3% scalar	■		■	■	■				
Dynamic Methods											
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	■	■							
	A2	Depletion Adjusted Catch Scalar - 100% scalar	■	■							
Depletion-Based (Dynamic)	A3	DB-SRA (Depletion Adjusted) - 25% P*	■	■	■	■	■	■			
	A4	DB-SRA (Depletion Adjusted) - 50% P*	■	■	■	■	■	■			
	A5	DCAC (Depletion Adjusted) - 25% P*	■	■	■	■	■				
	A6	DCAC (Depletion Adjusted) - 50% P*	■	■	■	■	■				
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar							■	■	■
	A8	Life History Analysis - 100% scalar							■	■	■
	A9	F_{MSY}/M (Low) - 75% scalar					■		■		
	A10	F_{MSY}/M (Low) - 100% scalar					■		■		
	A11	F_{MSY}/M (Hi) - 75% scalar					■		■		
	A12	F_{MSY}/M (Hi) - 100% scalar					■		■		
Reference Cases											
Stock Assessment (Dynamic)	R1	Delay-Difference - 75% scalar	■					■		■	■
	R2	Delay-Difference - 100% scalar	■					■		■	■
Status Quo (Static)	R3	Current Catch	■					■		■	■
	R4	Current Effort	■					■		■	■

2.1.2. Depletion-based methods

These data-limited methods rely on estimates of depletion relative to an unfished population, combined with other inputs to estimate an OFL directly or to adjust historical catch with historical depletion to derive a catch level recommendation. Depletion-Based Stock Reduction Analysis (DB-SRA, Dick and MacCall, 2011) is a method for estimating an OFL based on a complete time series of historical catches and four key inputs: (1) the level of current depletion, (2) the ratio of F_{MSY} to the natural mortality rate (F_{MSY}/M), (3) the natural mortality rate (M) and (4) the most productive stock size relative to unfished (B_{MSY}/B_0). Given input values for M, F_{MSY}/M and B_{MSY}/B_0, DB-SRA finds a stock reconstruction that matches the input level of depletion and historical catch. DB-SRA then calculates the OFL by multiplying together F_{MSY}, depletion, and the reconstructed unfished biomass. The process is stochastic, and samples many values for all four inputs, each sample leading to an estimate of unfished biomass and therefore an OFL recommendation (see Appendix B.1 for details). DB-SRA also requires an estimate of the age at which fish become recruited to the fishery since it assumes delay-difference stock dynamics.

Depletion-Corrected Average Catch (DCAC, MacCall, 2009) provides an estimate of "sustainable catch" based on an estimate of average annual catch and the same four key inputs as DB-SRA (depletion, F_{MSY}/M, M and B_{MSY}/B_0). In essence, DCAC calculates average catches accounting for the removal of the "windfall harvest" of less productive biomass that may have occurred as the stock became depleted (the equations are included in the Appendix B.1). DCAC requires the same inputs as DB-SRA and is also stochastic, sampling many input values to produce numerous estimates of "sustainable catch."

Both DB-SRA and DCAC are currently being used to set OFLs and ABCs for data-limited stocks by the Pacific Fishery Management Council (PFMC, 2010). Different ABC control rules are applied depending on the degree of scientific uncertainty for different stocks. The Pacific Fishery Management Council's implementation of DB-SRA and DCAC assumes that current depletion is, on average,

40% of unfished biomass – for many stocks this may be considered a productive and healthy stock size (Dick and MacCall, 2010). These methods also do not make direct use of the stochastic OFL output of DB-SRA and DCAC. Instead, a downward adjustment is achieved by superimposing a distribution (with a pre-specified variance) over the median OFL estimate from DB-SRA and DCAC. It is a percentile of this superimposed distribution that is used as the ABC. Three versions of DB-SRA and DCAC are tested that rely on distributions for depletion which are centered on 40% of unfished biomass. The OFL for each method is then adjusted according to the same ABC control rules applied to different categories of data-limited stocks by the PFMC (M4–M9, Appendix B.1).

Two generic implementations of DB-SRA and DCAC were tested (A3–A6) that include dynamic updates in depletion (they are linked to the actual simulated level of stock depletion and do not rely on a fixed assumption of 40% unfished biomass). These implementations also make direct use of the stochastic output of DB-SRA and DCAC to derive the ABC based on pre-specified percentiles (25% and 50%).

2.1.3. Abundance-based methods

As an alternative to data-limited methods that rely solely or primarily on catch data and/or depletion estimates we tested a class of methods that rely on estimates of current abundance and F_{MSY}. While methods such as DB-SRA attempt to reconstruct historical stock levels, abundance-based methods rely only on current data. The methods that use current biomass are also not reliant on historical catch data and there is no positive feedback from previous management recommendations (the catch prescribed in one year does not directly inform the next catch recommendation). These methods also rely on weaker assumptions of stationary population and fishery dynamics.

We examine two methods of quantifying F_{MSY} based on growth and natural mortality rate. Beddington and Kirkwood (2005) describe a method for calculating F_{MSY} using length at first capture and information about maximum growth rate of individuals. Simpler still are methods that assume a fixed value for F_{MSY}/M. The originator of this concept, Gulland (1971), assumed $F_{MSY} = M$. Subsequent publications have recommended lower ratios of 0.8 (Thompson, 1993) and 0.5 (Walters and Martell, 2002). An estimate of current biomass is required to apply these approaches. The North Pacific Fishery Management Council (NPFMC) currently uses an F_{MSY}/M ratio method for managing stocks for which typical stock assessment reference points are not available ('Tier 5' stocks NPFMC, 2012,2013, referred to as 'data poor' by DiCosimo et al., 2010). Six variants of the abundance-based method are considered (A7–A12) depending on the assumed ratio of F_{MSY} to M, and the assumed ratio of the ABC to the OFL.

2.1.4. Reference cases

Four reference cases are included to provide a yardstick for the performance of the methods described above (R1–R4). We test a stock assessment method based on a delay-difference model (Deriso, 1980; Schnute, 1985) (R1–R2), which may be applied in instances where catch age- and length-composition data are not available (similar population dynamics are assumed by DB-SRA). The delay-difference assessment also requires auxiliary information regarding the form of the stock-recruit function, the fraction of mature fish-at-age, body growth rate, natural mortality rate, and the vulnerability-at-age curve. It calculates the OFL directly from estimates of current biomass and F_{MSY}. The performance of 100% and 75% scalar ABC control rules is evaluated. Similar to the data-limited methods, the delay-difference stock assessment method has inputs that are subject to imperfect information regarding historical catches. The delay-difference reference cases may be expected to perform better than the data-limited methods that only make use of catch data. Two "status quo" reference cases are simulated to frame the results of the data-limited methods in terms of two non-adaptive methods: (R3) a constant current catch scenario and (R4) a constant current effort scenario.

2.2. Management strategy evaluation

Experimental evaluation of methods for setting OFLs and ABCs through manipulation and monitoring of wild populations is impractical. Previous research has sought to compare the outputs of data-limited methods with those of data-rich assessments given the same data (e.g., Dick and MacCall, 2011). The principal limitation of this approach is the difficulty in assessing risks, and the inability to quantify bias. For example, relatively large differences in predicted fishing mortality rate (F) between an assessment and a data-limited method may not translate to commensurate differences in the risks of certain events occurring (e.g., the probability of reduction in biomass below B_{MSY}). Stock assessment models typically make use of common assumptions that may bias their results in similar ways (e.g., not accounting for habitat degradation, spatial expansion of fishing, or increases in fishing efficiency), and may therefore provide a limited basis for comparative performance evaluation. Equally, the stocks that are subject to assessment may not be representative of those with limited data; perhaps due to economic value they are heavily exploited or conversely subject to stringent management. Fundamentally, it is not possible to evaluate the accuracy of a data-limited method without knowledge of the quantity which is to be estimated (e.g., actual abundance or simulated abundance). For these reasons simulation evaluation is recommended as an important first step in testing data-limited methods (Butterworth et al., 2010).

Management Strategy Evaluation (MSE, Cochrane et al., 1998; Butterworth and Punt, 1999) is a simulation approach which generates many realizations of a real fishery system encompassing a credible range of population and exploitation scenarios. The simulated reality, commonly referred to as the "operating model," is then projected forward in time and updated according to the ACL recommendations generated by a particular management method (the ACL is assumed to be the ABC in this study). The relative performance of each management strategy can then be evaluated relative to defined management objectives. MSE also provides an opportunity to better understand the trade-offs among management objectives for any given management method and to quantify the value of various types of information and data. The core requirements of the MSE approach are the operating model that describes the "true" simulated population (Section 2.3), a range of candidate management methods (Section 2.1), and criteria for evaluating the performance of management methods (Section 2.7). Fig. 1 describes the components of the MSE design as it related to this research.

2.3. Operating model

The operating model is parameterized for six life-history types (also referred to as "stocks" or "simulated stocks"): mackerel (*Scombridae*), butterfish (*Stromateidae*), snapper (*Lutjanidae*), porgy (*Sparidae*), sole (*Pleuronectidae*) and rockfish (*Sebastidae*).[4] In addition to providing diversity in life-history, these stocks also represent generic versions of real-world stocks that appear in various geographic regions. Populations were first simulated for 50 years using random selections for various parameters. This duration was sufficiently long to develop a range of exploitation patterns over a length of time similar to industrial fishing in US waters. Management reference points such as maximum sustainable yield (MSY),

[4] The results of this research should not be interpreted as empirical support for the status of real-world fish stocks.

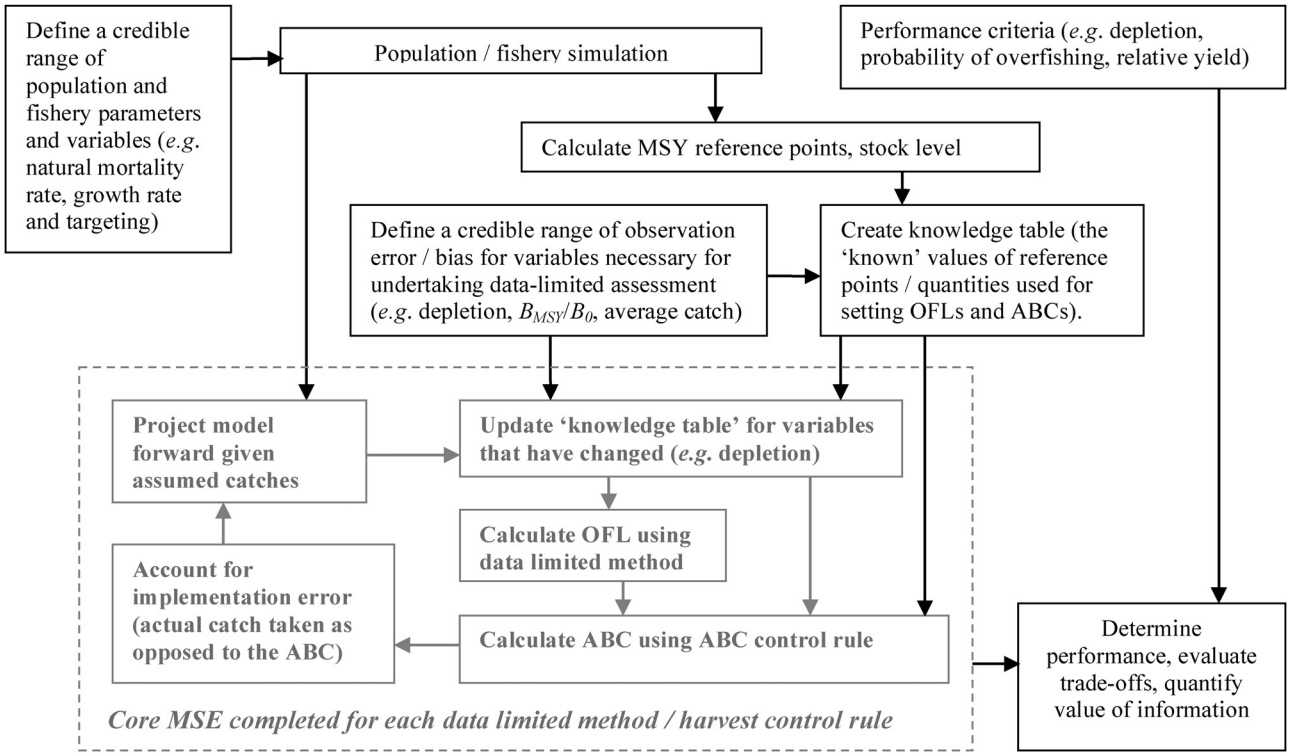

Fig. 1. A flow diagram of the components of the MSE for any given stock. The dashed box represents the projection of the model and update according to a particular combination of data-limited OFL setting method (e.g., DB-SRA) and ABC control rule (e.g., the P^* approach).

B_{MSY}, and F_{MSY} were then calculated for each simulation. Bias and imprecision in the knowledge of the simulated system were generated for all variables and parameters used by the management methods (e.g., M, current biomass, etc.). Each simulation was then projected forward subject to the ABC recommendations from each of the management methods. This update of information and setting of a new ABC was simulated every three years of the projection period to approximate a typical assessment cycle. To provide meaningful advice over a time-scale relevant to each stock, generation time was used as a basis for setting the number of projected years. Simulations were projected for a maximum of either 30 years or twice the mean generation time. The rockfish stock, with a generation time of 25 years, was projected for 50 years.

For each of the six stock types we carried out 10,000 simulations for each data-limited method. A much lower level of replication was required to obtain stability in aggregate performance metrics (the difference was less than 2% between 2000 and 3000 simulations for such metrics). However a larger degree of replication was required to provide plots of trends in performance with changing simulation parameters. The simulation evaluation framework was programmed in the statistical environment R (2.15.0 64bit, R Development Core Team, 2012) using the "Snowfall" package for parallel computing.

The "branched" form of experimental design (Fig. 2) allows management methods to be compared side-by-side because projections are made from the same set of historical simulations and the same future recruitment patterns. An additional benefit of this design is that the performance of any management method can be phrased in terms of a "best case" reference method based on identical conditions. For example, we standardized the predicted yield of a particular management method for any given simulation by dividing it by the "best case" yield that could be obtained with perfect knowledge of F_{MSY}.

The operating model was an age-structured, spatial model (a detailed description can be found in Appendix A). Simulating

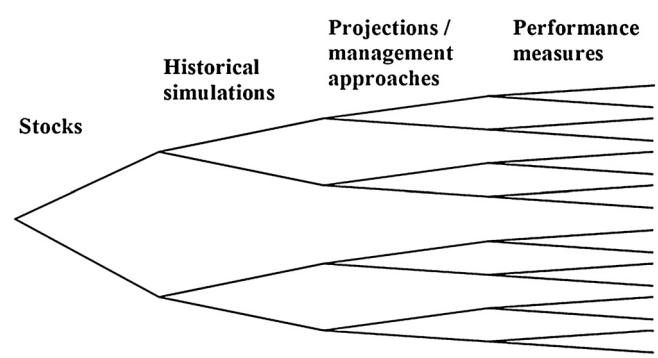

Fig. 2. The "branched" design of the simulation evaluation including six stock types, 50 historical years, 30–50 projected years, 25 data-limited and reference methods, and 7 performance measures.

spatial dynamics provided the basis to account for differences among life-history types that may be considered important, such as low mixing among areas and refuges from fishing. All stocks are assumed to have density-dependent recruitment that does not decrease with increasing stock size, and maximum surplus recruitment is achieved when spawning output is less than half of unfished (Beverton and Holt, 1957). For the purposes of simulation, variability among simulations and where applicable, inter-annual variability within simulations, were generated in a number of biological parameters such as M, stock-recruitment parameters and recruitment deviations. Auto-correlation in recruitment was not simulated. The location and slope of the age-at-maturity curve, weight-at-length curve and scale parameters such as unfished stock size and maximum length did not vary among simulations for the same stock.

Five discrete areas were modeled for each population. The operating model generated both directed and diffusive movement among areas by adjusting regional gravity parameters and a stock

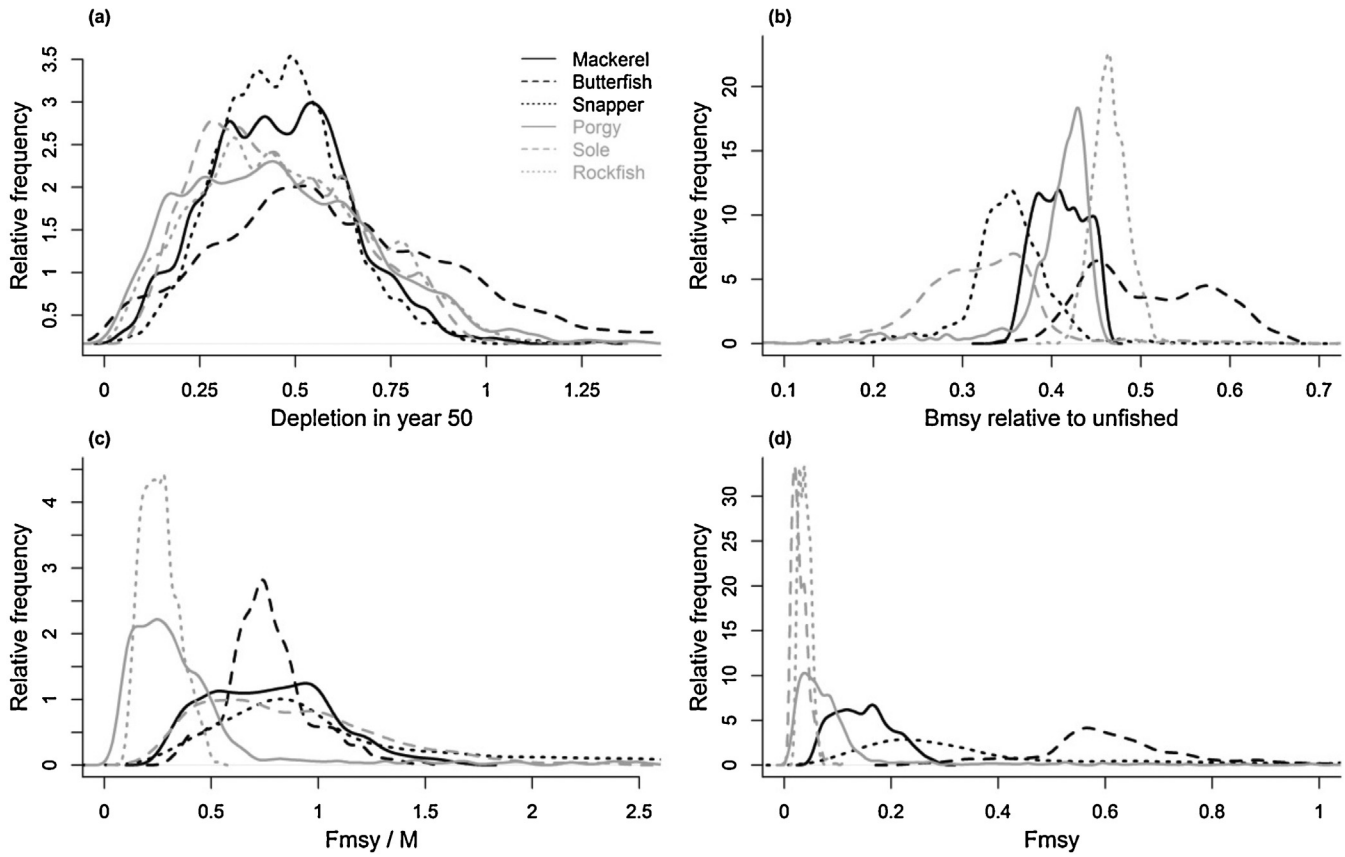

Fig. 3. The historical simulation conditions (10,000 simulations). Plotted in panel a are the relative frequencies of sampled depletion (the biomass in year 50, the final historical year, divided by unfished biomass). Panel b describes the sampled ratio of B_{MSY}/B_0. Plotted in panel c are the relative frequencies of the sampled ratio of F_{MSY}/M. Panel d describes the sampled distribution of F_{MSY}.

mixing ("viscosity") parameter (Eqs. (App.A.27) and (App.A.28)). With the exception of recruitment deviations, all population dynamics parameters were assumed to be time-invariant. Simulations were also conducted without spatial structure to evaluate the sensitivity of results to spatial dynamics.

For each simulation a single trend in fishing effort was generated. This time series represents the total effort on the stock from all sources of fishing. Among simulations both the mean trend and inter-annual variability in effort was allowed to vary (see Appendix App.A.2 for full details). For all simulations mean trends always increased during the first 25 years. Subsequently fishing effort could range from a strong decline to a steep increase over the last 25 historical years. The same inter-annual variation in fishing effort was simulated for each stock with a coefficient of variation (*CV*) ranging from 0.2 and 0.4. For all stocks, catch observation error was sampled over a range for the *CV* of 0.1–0.5. Some species-specific fishery characteristics were specified, including vulnerability-at-age, spatial targeting (or avoidance) and spatial refuges from fishing. While fishing effort, targeting and fishing efficiency could change temporally, all other fishery characteristics were assumed to remain constant over time.

2.4. Defining simulations for specific stocks

The operating model inputs for each stock are summarized in Table App.A.1. Some of these inputs describe a range from which a value is sampled (e.g., *M* uniformly sampled between 0.2 and 0.4 yr^{-1}). The number of areas (5), historical simulation years (50), the level of unfished recruitment, the rate of catch observation error and the variability in the simulated trend in effort are the same for each stock.

Fifty years of historical projection prior to first application of the management methods (Fig. 3) led to a wide range of depletions that were nevertheless comparable among stocks so that conclusions were not confounded by stock-specific depletion levels. All stocks had mean depletion values close to 45% at the end of the historical simulation period (Fig. 3). The exception is butterfish which, due to a short life-span and high recruitment variability, could not be made comparable to the depletion distributions of the other stocks. The six life-history types span a reasonably wide range of values for B_{MSY}/B_0 (mean simulated values in the range of 0.33 for sole to 0.52 for butterfish). The range for F_{MSY}/M among stocks was greater, with mean values between 0.27 (rockfish) and 1.4 (snapper). F_{MSY} varied widely among stocks, with mean rates of 0.05 for sole and 0.6 for butterfish.

2.5. Calculating MSY reference points

B_{MSY} and F_{MSY} are required to evaluate the performance of data-limited methods (Section 2.7). These quantities were computed for each simulation by projecting the operating model forward for 100 years, numerically optimizing for the fishing effort that provided the maximum yield. Optimizations were undertaken assuming that future recruitment is deterministically related to the stock-recruit relationship, and that there are no changes in fisheries targeting and catchability. Optimizations to find F_{MSY} were conducted via successive parabolic interpolation using the function 'optimize' of the R stats package.

2.6. Simulating imperfect knowledge

There may be considerable uncertainty regarding the inputs to the management methods. Imperfect knowledge of these quantities was simulated by adding error to the "true" simulated values of the operating model. Since these inputs are likely to control the relative performance of the methods they are assigned ranges that are considered to be representative of the magnitude of uncertainty in a data-limited setting. An additional purpose for generating imperfect information is to determine the effect of the misspecification of inputs on the performance of a particular management method. A related objective is quantifying the value of more precise and/or accurate information regarding population variables (e.g., current stock depletion) and parameters (e.g., M).

Table 3 describes how bias (and in some cases imprecision) was introduced to operating model parameters that are used by the management methods. All such variables have the subscript "*obs*" to denote an observed quantity. For example, M_{obs} is the simulated value of M, subject to variable bias determined by a coefficient of variation parameter CV_M. In each simulation the same biased level of M_{obs} is used by the methods throughout the projection to determine OFLs and ABCs. In some cases, data-limited methods require inputs that are updated annually as the population is projected (e.g., current biomass $Bcur_{obs}$, current depletion, and current fishing mortality rate). Both bias and imprecision are simulated in such instances. For example, $Bcur_{obs}$ is the simulated "true" current biomass ($Bcur$), subject to error sampled in each projected year according to a bias (μ_{Bcur}) and imprecision (σ_{Bcur}) that are perpetuated over the whole projection (on average, inputs were allowed to be positively or negatively biased and precise or imprecise over the whole projection). The rationale for the values of these inputs is explained further in Appendix A.5.

2.7. Evaluating performance

Performance of the data-limited and reference methods were evaluated against the legal standards implied by the Magnuson-Stevens Fishery Conservation and Management Act ("MSA"): preventing overfishing, avoiding becoming overfished, and producing maximum sustainable yield. The MSA's National Standard 1 (NSG, 2009) requires that "[c]onservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery." 16 U.S.C. § 1851(a)(1). The National Standard 1 Guidelines (50 C.F.R. § 600.310(f)(4)) specify that the probability of overfishing cannot exceed 50%, but should be lower based on the degree of scientific uncertainty in the estimate of the OFL. The MSA requires that overfished stocks, which are often defined as $Bcur/B_{MSY} < 50\%$, be rebuilt as fast as possible.

Performance was measured in terms of preventing overfishing, avoiding becoming overfished, and producing long-term yield in light of these management objectives. The probability of overfishing is recorded for each simulation by calculating the fraction of projected years in which $F > F_{MSY}$. This was averaged over multiple simulations to create a probability of overfishing metric (POF) that is the expected probability of overfishing in a projected year using a particular management method. We use B_{MSY} as a management reference point for overfished stock status. Similarly to the POF metric, the future stock biomass relative to B_{MSY} (B/B_{MSY}) was averaged over projected years and simulations to provide the expectation of stock status using a particular management method. Absolute yield of any projection is difficult to interpret because it depends on the specific conditions of each projection (i.e., starting depletion, future productivity, etc.). A standardized measure of yield was calculated by dividing the total projected yield for each simulation by the catch under F_{ref}, the constant F that maximizes catch over the projected time period with perfect knowledge of future recruitment deviations. In this way, yields are standardized as a percentage of an "upper bound." In some cases it is possible for a method to obtain relatively high total yields over the whole projection by depleting the stock (a "mining" strategy). The yield metric was therefore calculated based on the last five years of each projection (e.g., the yield from a method in projected years 26–30 divided by the yield of the F_{ref} strategy in projected years 26–30) since it is of more interest to identify methods that can achieve sustainable long-term yields. This was averaged over multiple simulations of each stock to provide the expected relative yield (herein referred to as 'Yield') of a management method.

The metrics POF, B/B_{MSY} and Yield relate to the central reference points for overfishing, overfished status and sustainable yield, but cannot be readily interpreted in terms of the average trajectory of biomass using a particular management method. To address this, we derive four additional metrics that relate to stock status in the final three years of the projections. The probability of biomass increasing, P_{inc}, is the fraction of projected simulations for which average biomass in the last three years of the projection is larger than average biomass for the last three years of the historical simulation. B_{end} is the mean biomass over the final three years of the projection divided by B_{MSY} averaged over simulations. The probability of ending below 50% B_{MSY}, $P_{<50}$ is the fraction of simulations for which the mean biomass of the last three projected years is below 50% B_{MSY}. Similarly, $P_{<10}$ is the fraction of simulations ending below 10% B_{MSY}.

Each performance metric was calculated for each simulation allowing performance to be averaged over various subsets of the simulations. For example, of the 10,000 simulations that were conducted for mackerel, approximately 1700 corresponded to stocks that were below 50% B_{MSY} levels at the end of the historical projection. The mean performance metrics were calculated for this subset of 1700 simulations to reveal how the expected performance when starting from low population levels. We used a similar approach to quantify the value of different sources of information (Section 2.8 below).

2.8. Quantifying value of information

We evaluated how long-term yield can be expected to vary with the uncertainty in each input. This was used to assess the value of various sources of information for each method. To do this we took each input variable/parameter in turn and subdivided the simulations into ten equally sized blocks relating to the 10th percentiles of the sampled input. For example, less than the 10th percentile of sampled bias in depletion, greater than or equal to the 10th percentile but less than the 20th percentile of bias in depletion, and so on. Since the 10,000 simulations of each stock type were subdivided according to percentiles in the input parameters, these subsets were approximately equal in size at around 1000 simulations. The mean relative yield for each of the ten subdivisions was calculated for each method. The standard deviation of these relative yield scores can be interpreted as the marginal effect of an input variable on expected yield. These results are unit-less because they are standardized according to the level of simulated uncertainty for each of the input parameters/variables.

3. Results

3.1. Performance

The general results statements below refer to the mackerel, snapper, porgy, sole and rockfish simulations. The results for butterfish are discussed in Section 3.2 because the simulations for butterfish behaved very differently from those for the other stocks.

Table 3
Summary of the bias/error parameters and related distributions that control the accuracy and imprecision of knowledge of the simulated system that is subsequently used by the data-limited methods and harvest control rules. The log-normal distribution described in the table below ($\sim$LN(μ,CV)) is the exponent of the normal distribution with mean and standard deviation ($sd = CV \times$ mean) parameters: $N(-0.5\ \log(1+sd^2/\mu^2),\ \sqrt{\log(1+sd^2/\mu^2)})$.

Variable	Symbol	Related functions	All stocks
The coefficient of variation of the log-normally distributed bias in natural mortality rate M	CV_M	$M_{obs} = M \times \mu_M$ $\mu_M \sim dlnorm(\mu = 1, CV_M)$	0.5
The coefficient of variation of the log-normally distributed bias in von Bertalanffy growth rate parameter K	CV_K	$K_{obs} = K \times \mu_K$ $\mu_K \sim dlnorm(\mu = 1, CV_K)$	0.2
The coefficient of variation of the log-normally distributed bias in length at first capture, L_c	CV_{Lc}	$Lc_{obs} = Lc \times \mu_{Lc}$ $\mu_{Lc} \sim dlnorm(\mu = 1, CV_{Lc})$	0.5
The coefficient of variation of the log-normally distributed bias in biomass at maximum sustainable yield relative to unfished B_{peak} (B_{MSY}/B_0)	CV_{Bpeak}	$B_{peak_{obs}} = B_{peak} \times \mu_{Bpeak}$ $\mu_{B_{peak}} \sim dlnorm\ \ (\mu = 1, CV_{B_{peak}})$	0.2
The coefficient of variation of the log-normally distributed bias in the ratio of maximum sustainable fishing mortality rate to natural mortality rate c	CV_c	$c_{obs} = c \times \mu_c$ $\mu_c \sim dlnorm(\mu = 1, CV_c)$	0.2
The coefficient of variation of the log-normally distributed bias in the age at first maturity Am	CV_{Am}	$Am_{obs} = Am \times \mu_{Am}$ $\mu_{Am} \sim dlnorm(\mu = 1, CV_{Am})$	0.2
The coefficient of variation of the log-normally distributed bias in the intrinsic rate of increase parameter r	CV_r	$r_{obs} = r \times \mu_r$ $\mu_r \sim dlnorm(\mu = 1, CV_r)$	0.5
The coefficient of variation of the log-normally distributed bias in the current level of stock depletion D ($Bcur/B_0$)	CV_D	$D_{obs} = D \times j_D$ $j_D \sim dlnorm(\mu_D, \sigma_D)$ $\mu_D \sim dlnorm(\mu = 1, CV_D)$	1
The maximum coefficient of variation for log-normal error around bias in current stock depletion μ_D for projected years	σ_{maxD}	$D_{obs} = D \times j_D$ $j_D \sim dlnorm(\mu_D, \sigma_D)$ $\sigma_D \sim U(0, \sigma_{maxD})$	2
The coefficient of variation of the log-normally distributed bias in the current stock level $Bcur$	CV_{Bcur}	$Bcur_{obs} = Bcur \times j_{Bcur}$ $j_{Bcur} \sim dlnorm(\mu_{Bcur}, \sigma_{Bcur})$ $\mu_{Bcur} \sim dlnorm(\mu = 1, CV_{Bcur})$	1
The maximum coefficient of variation for log-normal error around bias μ_{Bcur} for projected years	$\sigma_{maxBcur}$	$Bcur_{obs} = Bcur \times j_{Bcur}$ $j_{Bcur} \sim dlnorm(\mu_{Bcur}, \sigma_{Bcur})$ $\sigma_{Bcur} \sim U(0, \sigma_{maxBcur})$	2

It was instructive to separate the simulations according to the depletion at the start of the projection. Four categories were chosen relating to projections starting (1) below 50% of B_{MSY}, (2) between 50% and 100% B_{MSY}, (3) between 100% and 150% of B_{MSY} and (4) above 150% B_{MSY}. The largest discrepancies in performance were found among the first three categories and for the benefit of brevity the table for projections starting above 150% B_{MSY} is included in the Appendix (Table App.C.1)

3.1.1. Catch-based methods

Methods that set the ABC to average historical catches or a percentile of recent catch (M1–M3) led to the worst performance of the methods tested by a large margin. When starting below 50% B_{MSY}, the probability of overfishing was high – typically above 80% ("P_{OF}", Table 4). While some catch-based methods performed better at moderate levels of depletion (above 50% of B_{MSY}) particularly in regard to yield, they still led to relatively high probabilities of overfishing-in most cases exceeding 60% of the simulations (Tables 5 and 6). These static catch-based methods failed to rebuild stocks initially below 50% B_{MSY} to above 50% B_{MSY} in the majority of simulations (between 60% and 95%; on most occasions the failure rate was over 85% ("$P_{<10}$", Table App.C.2). The static catch based methods could lead to very high probabilities of dropping below 10% of B_{MSY} (generally 40–60%) when applied to stocks starting below B_{MSY} (Table App.C.3). Relative to other methods, $P_{<10}$ remained high even when stock levels were above B_{MSY} (between 12% and 26% for M1–M3 compared with less than 2% for M4–M9, Table App.C.4). Methods M1–M3 also led to amongst the lowest yields in simulations starting below B_{MSY} (Figs. 4 and 5). The performance of these methods was poor for all stocks except butterfish (see Section 3.2), and was not as strongly related to life-history type compared to the other methods. Methods M1–M3 performed worse than the "status quo" current catch and effort scenarios (R3–R4) in several instances. This was particularly the case for method M3 (ABC set at the third highest historical catch) which drove 19 out of 20 stocks that were already below 50% of B_{MSY} at the start of the projection to below 10% of B_{MSY} by the end of the projection (Table 4). This was only somewhat reduced to 7 out of 10 stocks in those simulations starting between 50% and 100% of B_{MSY} (Table 5).

The dynamic catch-based methods A1 and A2 led to intermediate performance at low stock sizes (i.e., less than 50% B_{MSY}) in terms of the probability of overfishing and yield relative to the other methods. At moderate stock sizes they performed much better, leading to reasonably high yields (approximately 50–80% of those corresponding to F_{ref}), with moderate probabilities of overfishing (approximately 30–40%) (Tables 4 and 5, Figs. 5 and App.C.6). Methods A1 and A2 reduced catches by multiplying historical mean catch by 50% when the stock declines below 20% of unfished levels. This does not appear to be sufficiently responsive to prevent these methods from frequently depleting the stock below the overfished threshold of 50% B_{MSY}, even in simulations that start above 50% B_{MSY} (Tables App.C.3 and App.C.4).

3.1.2. Depletion-based methods

The static implementation of DB-SRA that assumes that stock depletion is, on average, 40% of unfished levels (equivalent to $\sim$100% of B_{MSY}) performed well when this assumption was reasonably close to actual depletion (e.g., 50–150% of B_{MSY}, Tables 5 and 6). At these stock levels, the probability of overfishing, projected stock status (B/B_{MSY}) and yield were among the best of any method. The probabilities of stocks falling below 50% B_{MSY} were also relatively small, with the majority of cases exhibiting an increasing biomass trend on average ("P_{inc}", Table App.C.3). However, these methods prescribed OFLs that were too high and stocks suffered from high probabilities of overfishing, depletion and consequently reduced yields when starting biomass was much below that assumed (Table 4). Since the PFMC DB-SRA methods do not introduce feedback between stock status and the OFL recommendation, these methods suffer from a similar, but less pronounced phenomenon as the average catch methods. DB-SRA performed relatively poorly,

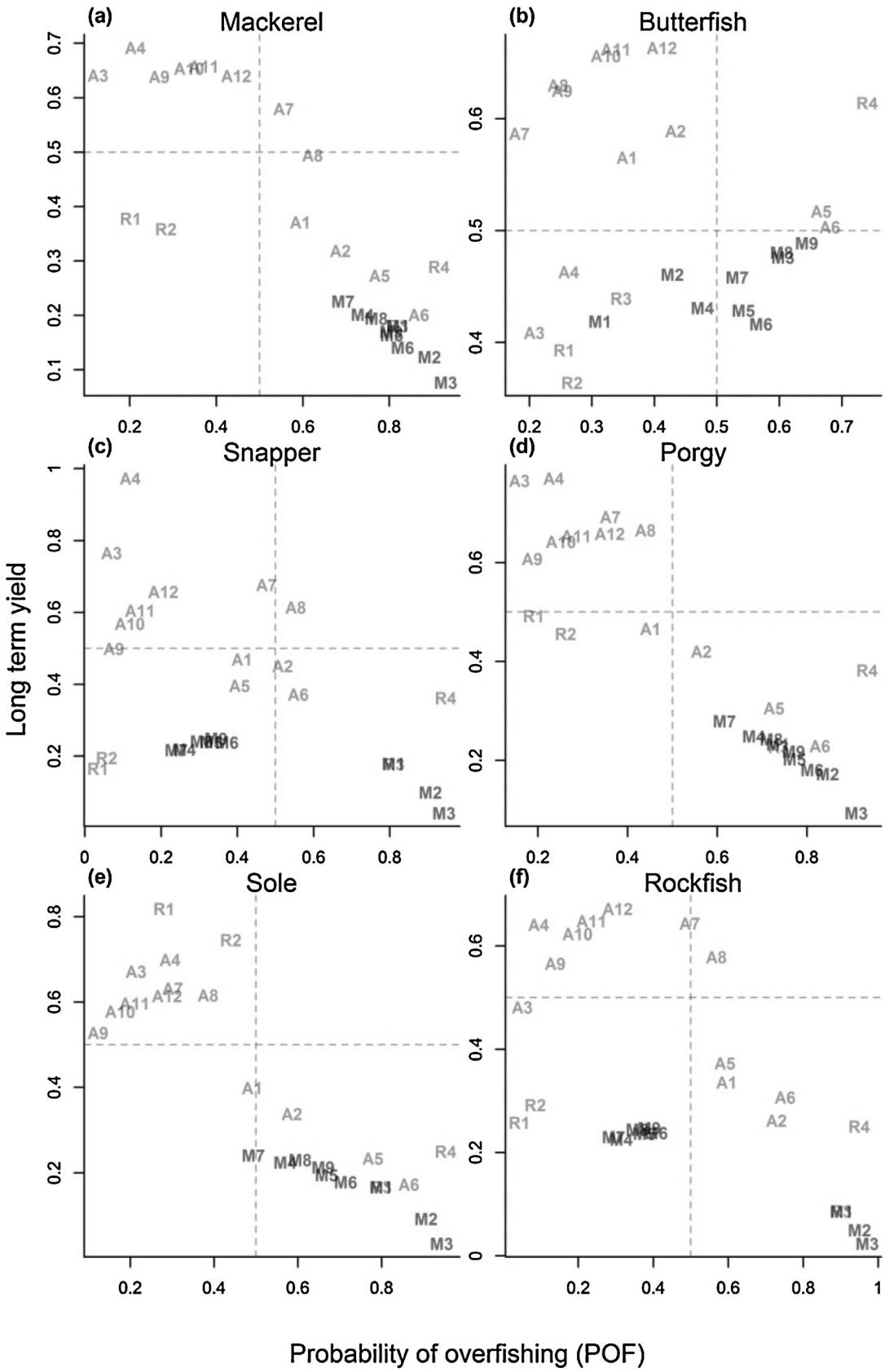

Fig. 4. The trade-off between of long term yield (yield over last 5 projected years divided by that of the F_{ref} strategy) and the probability of overfishing (fraction of projected years for which fishing mortality rate exceeded F_{MSY}) for projections starting below 50% B_{MSY}.

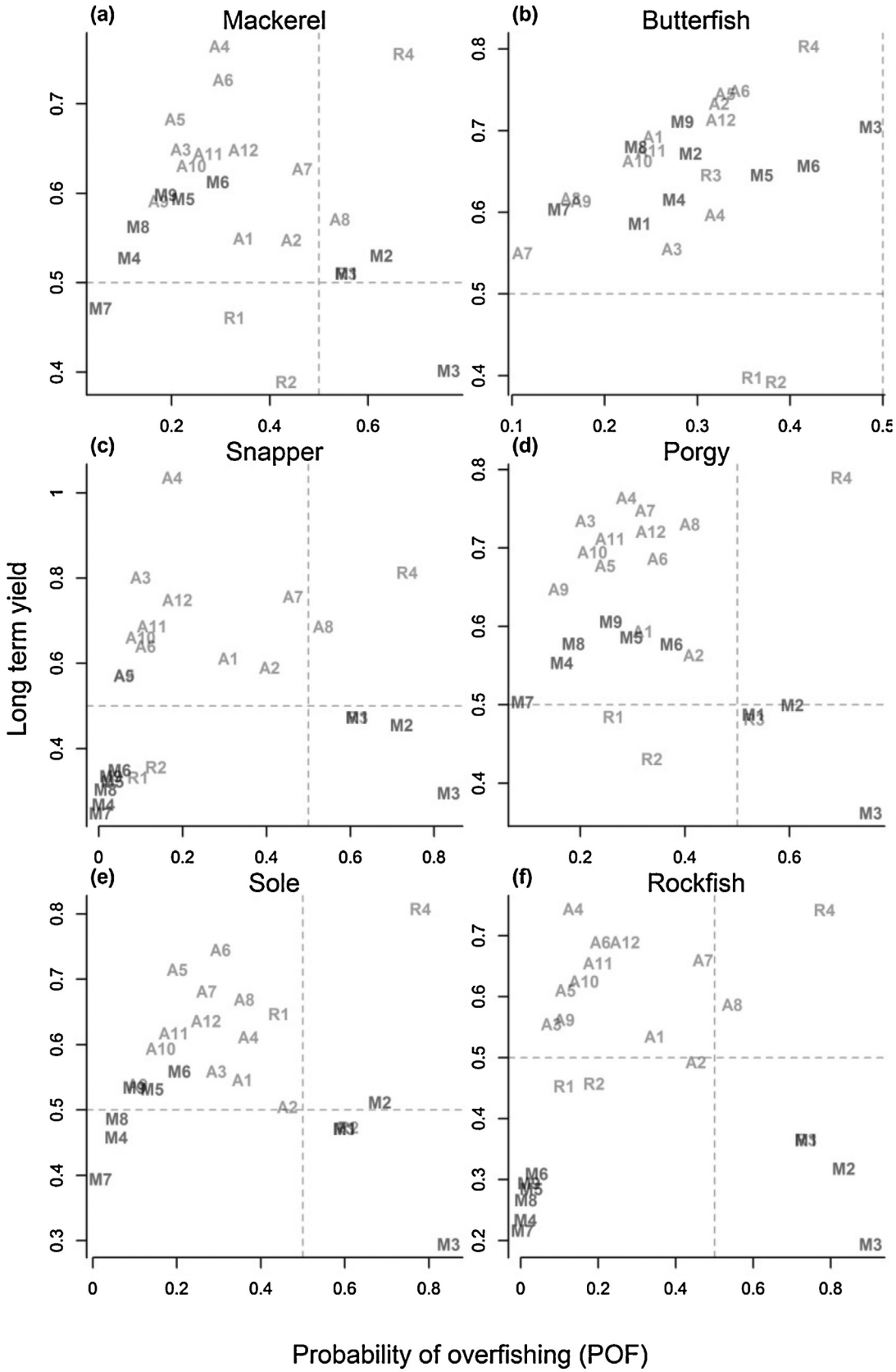

Fig. 5. The trade-off between of long term yield (yield over last 5 projected years divided by that of the F_{ref} strategy) and the probability of overfishing (fraction of projected years for which fishing mortality rate exceeded F_{MSY}) for projections starting between 50% and 100% B_{MSY}.

Table 4
Overfishing, stock status and yield performance metrics for simulations starting below 50% of *BMSY*. All of the numbers represent a percentage. The probability of overfishing (P_{OF}) is the fraction of years (across all simulations and all of their projection years) for which fishing mortality rate exceeds F_{MSY}. 'B/B_{MSY}' is the mean biomass (across all simulations and all of their projection years) divided by biomass at maximum sustainable yield. 'Yield' is the mean relative yield over the last five years of the projection (the yield of a simulation over the last five years of the projection divided by that of the F_{ref} policy). Dark gray shading reflects poor scores (P_{OF} greater than 50%, B/B_{MSY} less than 50%, yield less than 25%). Light gray shading reflects intermediate scores (P_{OF} greater than 25%, B/B_{MSY} less than 100%, yield less than 50%).

Type	Code	Name	Mackerel			Butterfish			Snapper			Porgy			Sole			Rockfish		
			P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield
Catch-Based	M1	Median Catch - 3 Years	82	22	18	31	103	42	81	29	18	74	39	23	80	31	17	90	14	9
(Static)	M2	Median Catch - 10 Years	89	14	12	43	88	46	91	16	10	85	26	17	91	17	9	95	8	5
	M3	3rd Highest Catch	93	10	8	61	67	48	94	9	4	91	16	9	94	9	3	97	5	2
Depletion-	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	74	32	20	48	78	43	26	98	22	68	47	25	57	63	22	31	69	23
Based (Static)	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	81	25	16	54	71	43	33	88	24	77	35	20	67	49	20	38	63	24
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	83	22	14	57	67	42	37	83	24	81	30	18	71	42	18	41	60	24
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	69	38	23	53	75	46	24	102	22	62	55	28	49	73	24	29	71	23
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	77	29	19	60	66	48	31	92	24	72	42	24	61	58	23	36	65	24
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	80	26	17	64	61	49	34	86	25	77	36	22	66	50	21	39	62	25
Catch-Based	A1	Depletion Adjusted Catch Scalar - 75% scalar	59	39	37	36	92	57	41	67	47	45	61	47	49	64	40	60	36	34
(Dynamic)	A2	Depletion Adjusted Catch Scalar - 100% scalar	69	32	32	43	83	59	52	55	45	56	50	42	59	52	34	73	27	26
Depletion-	A3	DB-SRA (Depletion Adjusted) - 25% P*	13	67	64	21	105	41	7	122	77	16	90	77	21	99	67	5	85	48
Based	A4	DB-SRA (Depletion Adjusted) - 50% P*	21	60	69	26	98	46	12	110	97	24	81	77	29	88	70	9	75	64
(Dynamic)	A5	DCAC (Depletion Adjusted) - 25% P*	78	26	27	67	58	52	41	74	40	73	40	31	78	34	23	59	42	37
	A6	DCAC (Depletion Adjusted) - 50% P*	87	18	20	68	57	50	56	56	37	83	29	23	86	23	17	75	30	31
Abundance-	A7	Life History Analysis - 75% scalar	56	38	58	18	110	59	48	59	68	36	74	69	30	89	63	50	43	64
Based	A8	Life History Analysis - 100% scalar	62	31	49	25	102	63	55	49	61	44	64	67	39	76	62	57	36	58
(Dynamic)	A9	FMSY/M (Low) - 75% scalar	27	64	64	25	102	63	8	120	50	19	96	61	12	117	53	14	77	57
	A10	FMSY/M (Low) - 100% scalar	34	58	65	32	94	66	12	112	57	25	87	64	18	107	58	20	71	62
	A11	FMSY/M (Hi) - 75% scalar	37	55	66	34	92	66	14	107	61	29	83	65	21	102	60	24	68	65
	A12	FMSY/M (Hi) - 100% scalar	45	48	64	41	84	66	21	97	66	36	73	66	29	91	61	31	61	67
Stock	R1	Delay-Difference - 75% scalar	20	69	38	26	100	39	3	142	17	19	100	49	28	99	82	4	92	26
Assessment	R2	Delay-Difference - 100% scalar	28	63	36	27	97	36	6	138	20	26	92	46	44	81	75	8	88	29
Status Quo	R3	Current Catch	82	22	18	35	99	44	81	29	18	74	39	23	80	31	17	90	14	9
(Static)	R4	Current Effort	91	16	29	74	54	61	95	19	36	93	23	38	95	17	25	95	14	25

leading to a low probability of recovery from biomass below 50% B_{MSY} regardless of the ABC control rule (scalar multipliers between 69% and 91%) ('$P_{<50}$', Table App.C.2). This was particularly the case for the mackerel and porgy stocks, where the probability of projections ending below half of B_{MSY} was between 50% and 80% when starting below half of B_{MSY} (Table App.C.2).

DB-SRA and DCAC performed somewhat better for long-lived life history types such as snapper and rockfish compared with other methods. This result is a product of the greater "windfall" biomass of older age classes, that is deliberately accounted for by DCAC and is approximated by the delay-difference stock dynamics of DB-SRA.

Performance of DB-SRA is improved for stocks starting below 50% B_{MSY} when stock depletion is updated dynamically (methods A3 and A4), leading to less than 20% probability of overfishing on average. Methods A3 and A4 lead to increasing biomass from low levels in over 70% of simulations regardless of life-history type (Table App.C.2). Rebuilding performance was considerably worse for the mackerel, and while these methods managed better performance than any other method, between 36% and 42% of stocks did not rebuild above 50% B_{MSY}. The performance of methods A3 and A4 became much worse at higher stock levels in comparison to the other data-limited methods largely due to the high level

Table 5
As for Table 4, except the simulations start between 50% and 100% of B_{MSY}.

Type	Code	Name	Mackerel			Butterfish			Snapper			Porgy			Sole			Rockfish		
			P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield
Catch-Based	M1	Median Catch - 3 Years	56	76	51	24	126	59	62	72	47	53	84	49	60	76	47	74	54	37
(Static)	M2	Median Catch - 10 Years	63	68	53	29	119	67	72	60	46	61	75	50	68	67	51	83	43	32
	M3	3rd Highest Catch	76	51	40	49	97	70	83	43	30	76	54	36	85	45	29	90	31	19
Depletion-	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	11	128	53	27	122	62	1	174	27	16	132	55	6	152	46	1	150	23
Based (Static)	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	22	115	59	37	111	65	3	167	32	30	115	59	14	137	53	3	145	28
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	29	107	61	42	105	66	5	162	35	37	105	58	21	128	56	4	143	31
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	6	135	47	15	135	60	0	177	25	9	143	50	2	161	39	0	152	22
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	13	125	56	23	124	68	2	170	30	19	128	58	6	149	49	1	148	27
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	19	118	60	28	118	71	3	166	34	26	119	61	10	142	53	2	145	29
Catch-Based	A1	Depletion Adjusted Catch Scalar - 75% scalar	35	92	55	25	125	69	31	106	61	32	106	59	36	102	55	35	82	53
(Dynamic)	A2	Depletion Adjusted Catch Scalar - 100% scalar	44	78	55	32	115	73	41	89	59	42	91	56	46	84	50	45	68	49
Depletion-	A3	DB-SRA (Depletion Adjusted) - 25% P*	22	108	65	27	124	56	10	155	80	21	122	73	29	117	56	8	134	56
Based	A4	DB-SRA (Depletion Adjusted) - 50% P*	30	98	76	32	117	60	18	138	104	29	111	76	37	105	61	14	114	74
(Dynamic)	A5	DCAC (Depletion Adjusted) - 25% P*	21	110	68	33	113	75	6	146	57	25	117	68	20	118	72	12	117	61
	A6	DCAC (Depletion Adjusted) - 50% P*	30	100	73	35	111	75	11	133	64	35	104	69	30	107	75	21	105	69
Abundance-	A7	Life History Analysis - 75% scalar	47	80	63	11	143	55	46	84	76	32	111	75	27	121	68	47	73	66
Based	A8	Life History Analysis - 100% scalar	54	67	57	16	135	62	54	70	69	41	97	73	36	106	67	55	61	59
(Dynamic)	A9	FMSY/M (Low) - 75% scalar	17	128	59	17	134	61	6	165	57	16	141	65	11	156	54	11	131	56
	A10	FMSY/M (Low) - 100% scalar	24	117	63	24	125	66	10	155	66	22	129	69	16	144	59	16	121	63
	A11	FMSY/M (Hi) - 75% scalar	27	111	64	25	123	68	13	149	69	26	123	71	19	137	62	20	116	66
	A12	FMSY/M (Hi) - 100% scalar	35	99	65	33	114	71	19	136	75	34	109	72	27	123	64	27	105	69
Stock	R1	Delay-Difference - 75% scalar	33	104	46	36	115	40	9	166	33	26	127	49	44	98	65	11	131	45
Assessment	R2	Delay-Difference - 100% scalar	43	91	39	38	111	39	14	158	36	34	114	43	61	77	47	19	121	46
Status Quo	R3	Current Catch	56	76	51	31	118	65	62	72	47	53	84	48	60	76	47	74	54	37
(Static)	R4	Current Effort	67	70	76	42	101	80	74	68	81	70	72	79	78	69	81	78	61	74

Table 6
As for Table 4, except the simulations start between 100% and 150% of B_{MSY}.

Type	Code	Name	Mackerel			Butterfish			Snapper			Porgy			Sole			Rockfish		
			P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield
Catch-Based	M1	Median Catch - 3 Years	26	130	65	26	129	61	34	122	77	29	130	63	26	130	70	43	109	67
(Static)	M2	Median Catch - 10 Years	25	128	76	27	127	69	34	116	86	29	127	73	22	128	85	47	103	76
	M3	3rd Highest Catch	41	109	72	46	104	72	52	96	77	45	104	66	44	104	78	62	85	63
Depletion-	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	1	176	43	22	135	64	0	209	24	2	178	54	0	190	41	0	193	17
Based (Static)	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	2	168	53	31	124	67	0	204	29	5	166	65	0	180	51	0	190	21
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	4	163	58	36	118	68	0	201	32	9	159	70	1	174	57	0	188	23
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	0	181	37	12	146	61	0	211	22	0	186	46	0	196	35	0	195	16
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	1	174	46	19	137	69	0	206	27	2	176	57	0	187	44	0	192	20
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	1	170	51	23	131	73	0	204	30	3	169	63	0	182	49	0	190	22
Catch-Based	A1	Depletion Adjusted Catch Scalar - 75% scalar	28	128	61	21	134	68	24	139	71	26	136	64	28	135	64	27	116	63
(Dynamic)	A2	Depletion Adjusted Catch Scalar - 100% scalar	36	110	60	30	123	74	30	123	73	34	119	62	35	116	62	38	99	59
Depletion-	A3	DB-SRA (Depletion Adjusted) - 25% P*	26	120	54	25	132	56	11	174	66	22	133	63	33	126	53	9	159	55
Based	A4	DB-SRA (Depletion Adjusted) - 50% P*	35	107	58	29	125	62	18	152	89	30	121	61	40	115	59	14	132	73
(Dynamic)	A5	DCAC (Depletion Adjusted) - 25% P*	3	158	65	27	126	77	1	182	57	5	163	70	1	162	69	3	162	55
	A6	DCAC (Depletion Adjusted) - 50% P*	4	152	71	28	124	77	1	174	65	7	155	76	2	156	74	4	154	64
Abundance-	A7	Life History Analysis - 75% scalar	46	97	59	9	151	52	48	97	81	30	131	72	28	134	64	47	91	69
Based	A8	Life History Analysis - 100% scalar	53	83	53	15	143	59	55	83	76	38	115	71	36	117	62	55	76	61
(Dynamic)	A9	FMSY/M (Low) - 75% scalar	15	155	57	17	141	59	8	185	65	15	163	62	11	172	53	11	160	56
	A10	FMSY/M (Low) - 100% scalar	22	142	61	23	132	65	12	174	73	21	150	66	17	159	57	16	149	63
	A11	FMSY/M (Hi) - 75% scalar	25	136	62	25	130	66	15	167	76	24	143	67	20	152	59	19	142	67
	A12	FMSY/M (Hi) - 100% scalar	33	122	63	32	121	71	20	154	82	31	128	68	28	136	60	26	129	71
Stock	R1	Delay-Difference - 75% scalar	32	121	39	37	118	44	13	169	36	24	140	42	38	110	50	19	145	37
Assessment	R2	Delay-Difference - 100% scalar	40	107	38	41	114	41	15	158	36	30	128	43	49	91	47	27	129	39
Status Quo	R3	Current Catch	26	130	65	37	118	69	34	122	78	29	130	63	26	130	70	43	109	67
(Static)	R4	Current Effort	22	130	81	33	117	75	27	122	96	27	127	86	21	128	89	34	118	85

of uncertainty regarding depletion. This led to many occasions of inflated OFL recommendations and therefore stock declines when depletion was assumed to be too high.

MacCall (2009) notes that DCAC is "not directly suitable for specifying catches in a stock-rebuilding program." This is because it returns an estimate of an MSY proxy ("sustainable catch" which is particular to a productive stock size) and not an estimate of the OFL (which changes with depletion level). It is not surprising, therefore, that DCAC performs relatively poorly at low starting levels (below 50% B_{MSY}, Tables 4 and App.C.2) regardless of whether or not depletion is dynamically updated. The static DCAC provides yields and probabilities of overfishing comparable to the best performing methods at intermediate levels of depletion when the stock is closer to MSY levels (Tables 5 and App.C.3). As is the case with the dynamic update in DB-SRA, the high level of uncertainty in current depletion that was simulated led to relatively poor performance at moderate depletion levels (50–150% depletion).

3.1.3. Abundance-based methods

The method of Beddington and Kirkwood (2005; A7 and A8) that estimates F_{MSY} based on size at first recapture and age at 50% maturity appears to offer intermediate performance overall. Often providing relatively high yields, the method tended to overfish more than the best performing approaches (see trade-off plots, Figs. 4 and 5). The propensity to overfish was not reduced substantially for simulations at intermediate depletion levels (between 50% and 150% B_{MSY}, Table 5) unlike other methods that make use of current information regarding stock level. Methods A7 and A8 appeared to perform particularly poorly for mackerel, snapper and rockfish in terms of the probability of ending below the 50% B_{MSY} threshold, even when biomass is initially above this threshold (Table App.C.3).

In general, F_{MSY}/M methods A9–A12 were among the best performers regardless of life-history and initial depletion level. Along with methods A3 and A4, methods A9 and A10 were unique in their ability to rebuild stocks in a substantial number of simulations while achieving relatively high yields. Overall, F_{MSY}/M method A9 performed somewhat worse than DB-SRA method A3 at low stock sizes, with the exception of higher yields for rockfish and a lower probability of overfishing for porgy. At intermediate stock depletion levels, method A9 compared favorably with method A3 and led to similar yields with lower probabilities of overfishing for all stocks, with the exception of rockfish (Tables 5 and 6).

3.1.4. Reference case methods

The delay-difference assessment had mixed performance despite having unbiased information regarding vulnerability at age, median age at maturity, growth rate and natural mortality rate. The probability of overfishing was generally low, but yields were unremarkable compared with the other methods, particularly when starting from moderate stock sizes (i.e., between 50% and 150% B_{MSY}). Projected biomass increased from low stock sizes in most cases, but the probability of remaining below the overfished threshold was still high for mackerel. As expected, the current catch and effort methods performed poorly due to their lack of feedback between the OFL and stock depletion. It follows that simulations that did not lead to stock collapses coincided with those for which the final historical fishing mortality rate happened to be sustainable.

3.1.5. Trade-offs among ABC control rules

ABC control rules, incorporating varying downward adjustments, were considered for each OFL-setting method. As expected, the reduction in the ABC led to a reduced probability of overfishing and increases in expected population size (e.g., B/B_{MSY}, Figs. 6, 7 and App.C.4). The pattern in long-term yield was less clear, with the largest downward adjustments leading to relatively small reductions in yield. For example: a 75% scalar applied to method A9 led to a 27% probability of overfishing and 64% yield for mackerel starting below 50% B_{MSY} compared with the unmodified rule (method A10) that achieved a 34% probability of overfishing and 65% yield. In methods where the probability of overfishing is generally higher, greater downward adjustment increases the long term expectation of yield. For example, a 75% scalar for methods A7 and A8 leads a lower probability of overfishing, higher expected biomass and higher long-term yield for the snapper stock.

3.1.6. Inter-method performance trade-offs

There is a relatively well-defined inverse relationship between the expected probability of overfishing and expected stock status

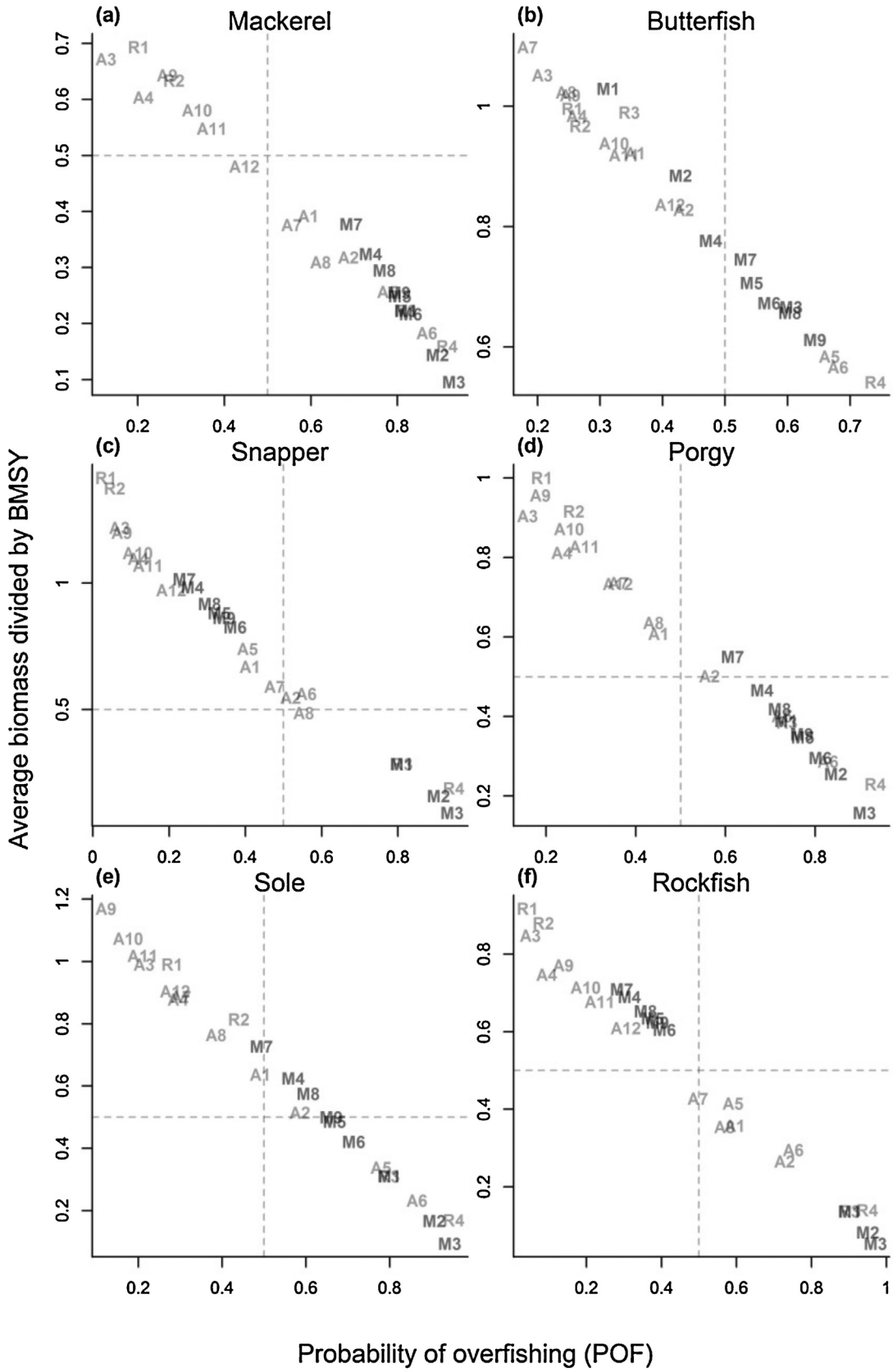

Fig. 6. The trade-off between average stock depletion (projected biomass divided by B_{MSY}) and the probability of overfishing (fraction of projected years for which fishing mortality rate exceeded F_{MSY}) for projections starting below 50% B_{MSY}.

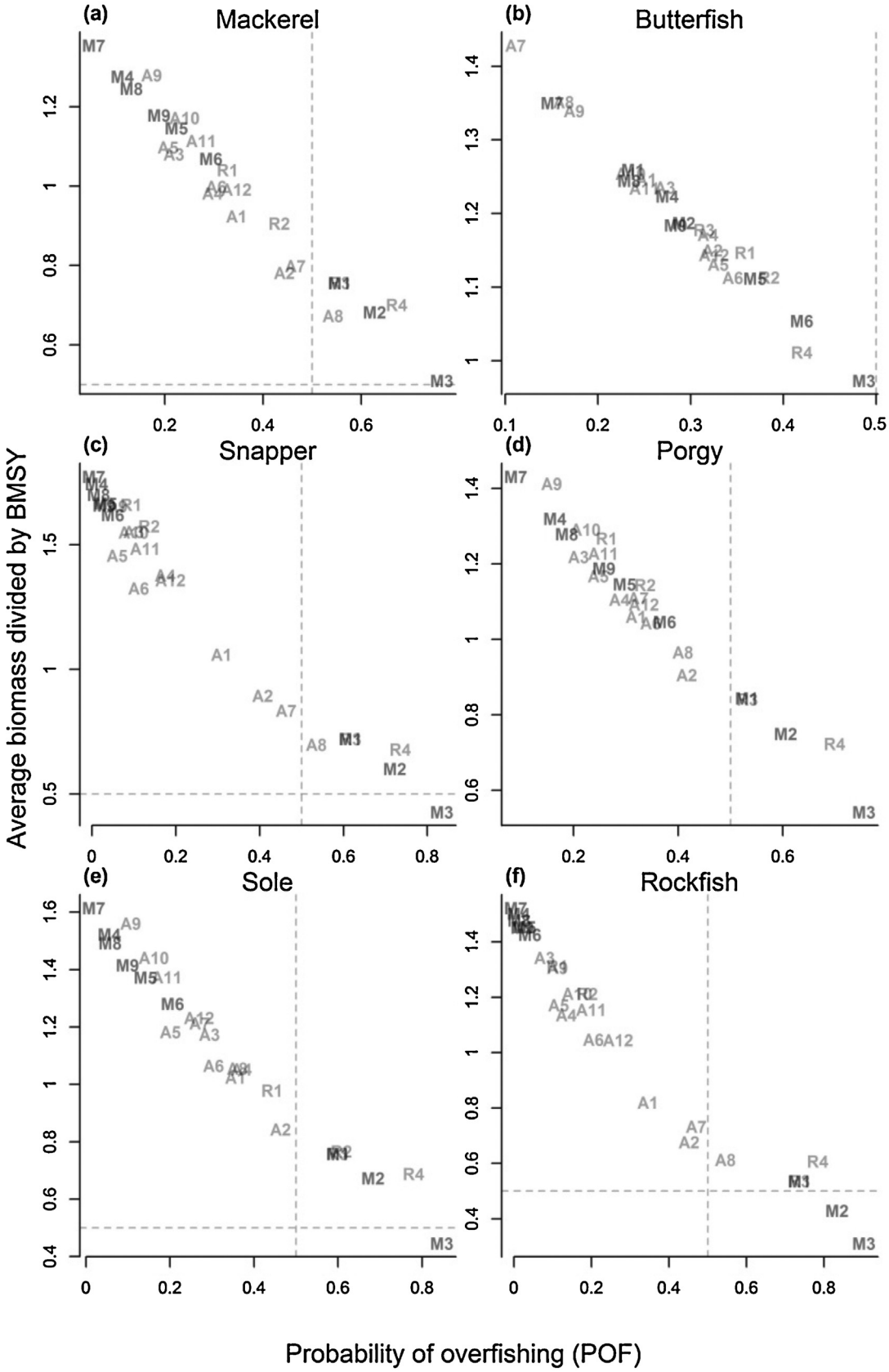

Fig. 7. The trade-off between average stock depletion (projected biomass divided by B_{MSY}) and the probability of overfishing (fraction of projected years for which fishing mortality rate exceeded F_{MSY}) for projections starting between 50% and 100% B_{MSY}.

(B/B_{MSY}) across all methods (Figs. 6 and 7). The ranking of methods in terms of these criteria is relatively clear. It is not surprising that a method that provides the lowest propensity to overfish leads to the highest abundance levels. The relationship between the probability of overfishing and long-term yield is less clear (Figs. 4, 5 and App.C.6). When simulations start from low stock sizes, the methods are either scattered in this trade-off space (snapper, butterfish and rockfish stocks) or show a weak negative relationship, where higher yields are achieved at lower probabilities of overfishing (mackerel, porgy and sole stocks). This is intuitive since stock recovery to productive biomass levels increases longer term yields. This pattern in this trade-off becomes weakly positive from intermediate starting depletion (50–150% B_{MSY}). The scatter in the trade-off plots indicates opportunities to select methods that can achieve both lower probabilities of overfishing and higher yields than other methods. As identified from Tables 4–6, methods A3, A4, A9 and A10 lead to high yields and low probabilities of overfishing across several starting depletions.

3.2. Performance for butterfish

Butterfish proved to be the most challenging test of the data-limited methods. We include the results of DCAC and DB-SRA even though these methods are not appropriate for stocks such as butterfish that have natural mortality rates higher than the guideline of 0.2 yr^{-1} (MacCall, 2009; Dick and MacCall, 2011). The relative performance of the methods for butterfish was unique among the species considered. In general, all methods led to moderate probabilities of overfishing without commensurate stock depletion (Table 4). Similarly, expected yield for butterfish was relatively high compared with other stocks even when applying the worst performing methods. Methods that led to the likely collapse of other stocks (e.g., average catch methods M1–M3) achieved a relatively high rate of rebuilding for butterfish when projections were started from below 50% B_{MSY} (Table App.C.2). This result emphasizes the larger role of temporal changes in stock productivity in determining abundance for species such as butterfish, which are short-lived and exhibit highly variable recruitment.

3.3. Value of different sources of information for each data-limited method

Current abundance, historical fishing effort, and stock depletion have the highest information content; only those methods that incorporated these sources of data had good performance across all depletion levels (e.g., could recover stocks from low stock sizes and did not lead to declines below 50% B_{MSY} in a high fraction of simulations). This additional value can be expressed in either the difference in the expected long-term yield or the probability of overfishing. Butterfish aside, benefits in yield and the probability of overfishing were very large at very low stock sizes (<50% B_{MSY}), but negligible or non-existent at more intermediate stock sizes (50–150% B_{MSY}). For example, methods A3, A4, A9–A12 lead to expected probabilities of overfishing that are between 70% and 35% lower than the other methods when biomass is initially below 50% B_{MSY}, while offering expected yields that are between 2 and 6 times higher. Overfishing may occur with higher frequency than other methods at moderate stock sizes, but yields generally remained between 10% and 30% higher for these dynamic approaches.

The yield and probability of overfishing varied more strongly with consistent bias in depletion and current biomass, indicating that accuracy in these inputs is a critical determinant of the performance of the associated methods (Tables 7 and App.C.6). This is particularly important as the methods that make use of these inputs are those that appear to perform best (e.g., methods A3 and A9). This sensitivity is to be expected since these inputs provide the dynamic link to changes in stock size, which is the central reason these methods perform well. Since M is a factor in the calculation of the OFL, it follows that the F_{MSY}/M methods are sensitive to uncertainty in this input. It may not be immediately clear why yields should vary to a larger extent across the bias in current biomass in comparison to M. The simple explanation is that twice the level of potential bias was prescribed for current biomass (a CV of 1 compared with 0.5 for M). While bias in depletion and current biomass led to large changes in yield for some methods, the precision of these inputs was much less important.

There is evidence that methods offering intermediate performance may be somewhat less sensitive to inputs. For example, the DACS methods (A1 and A2) appeared relatively robust to bias in depletion although they did not perform well at low stock levels. This result points to a possible problem in the interpretation of the performance metrics which aggregate across factors, that they do not convey the extent to which the performance of the methods degrades under misspecification of inputs. On average, bias in inputs was sampled with a mean of 1 (unbiased on average). It follows that it may be possible for a method to lead to a mean probability of overfishing of 20% but this performance is only representative of a small set of unbiased simulations. Examining the sensitivity of the methods A3, A4, and A9–A12 reveals this problem. This phenomenon is illustrated in Figs. App.D1–D4 where the slope in expected probability of overfishing is very steep at zero bias (a value of 1) in depletion and current biomass, respectively. Methods A3 and A4 that allow for dynamic update of depletion also exhibit considerably more sensitivity to M for snapper and rockfish.

3.4. Sensitivity of performance to population and fishing dynamics

Mackerel and porgy were the most difficult to rebuild. Snapper has the highest probability of increasing stock trends (P_{inc}) and of ending above the rebuilding threshold for all methods, with the notable exception of the average catch methods (Table 4).

There were relatively few interactions between the performance of methods and life-history type; while the absolute performance of most methods changed markedly among stocks, within each stock the ranking of methods was consistent. There are a few notable exceptions. For example, the average catch methods (M1–M3) have similarly poor absolute performance across the life history types, with the exception of butterfish. Methods M4–M9 also led to relatively low yields for the more long-lived stocks, such as snapper and rockfish when projections started at intermediate biomass levels (Tables 5 and 6). Mackerel and sole showed unexpectedly a high likelihood of dropping below 50% B_{MSY} for intermediate initial depletion levels for methods A3 and A4. Methods A7 and A8 also led to markedly better performance for the butterfish.

The most important characteristics determining the probability of overfishing for those methods that do not include dynamic updates in depletion or current biomass are the steepness of the Beverton–Holt stock recruitment curve and the annual increase in fishing efficiency (Table App.C.7). The success of these methods coincides with productive stocks (high steepness) subject to low historical fishing mortality rates due to their lack of feedback between the ABC and stock status. This difference is demonstrated by dynamic abundance-based methods A9–A10, for which probability of overfishing is much less affected by variability in the simulated population and fishery parameters.

Overall, the performance of methods was unaffected by different input values for inter-annual recruitment variability ("Proc. Err"), inter-annual variability in fishing effort ("Eff. CV"), spatial targeting ("Targeting"), the von Bertalanffy growth coefficient ("Von B K"), stock viscosity and the degree of overlap among vulnerability

Table 7
The sensitivity in the yield metric to imperfect knowledge. The variables are *CV* in observation error (Obs err), bias in depletion (Dep bias), *CV* in depletion error (Dep *CV*), bias in the ratio of F_{MSY}/M (FMSY/M), bias in the ratio of B_{MSY} relative to unfished (BMSY/B0), bias in natural mortality rate (M), bias in the age at 50% maturity (50% Mat), bias in the current biomass (B bias), *CV* of error in current biomass (B CV), bias in the von Bertalanffy growth coefficient K (Von B K) and bias in the length at first recapture (L 1st Cap). All numbers are the standard deviation in probability of overfishing across ten divisions of each variable (10 percentile ranges). Sensitivity scores over 10 are shaded light gray, scores over 20 are shaded dark gray.

Mackerel

Type	Code	Methods	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap
Catch-Based (Static)	M1	Median Catch - 3 Years	1										
	M2	Median Catch - 10 Years	1										
	M3	3rd Highest Catch	2										
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	1			1	1	8	1				
	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	1			1	1	8	1				
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	1			1	1	8	1				
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	1			0	1	7	1				
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	0			1	1	7	1				
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	1			1	1	7	1				
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	1	9	4								
	A2	Depletion Adjusted Catch Scalar - 100% scalar	1	10	1								
Depletion-Based (Dynamic)	A3	DB-SRA (Depletion Adjusted) - 25% P*	1	22	5	4	3	5	1				
	A4	DB-SRA (Depletion Adjusted) - 50% P*	3	22	3	4	4	3	2				
	A5	DCAC (Depletion Adjusted) - 25% P*	0	7	1	1	1	3					
	A6	DCAC (Depletion Adjusted) - 50% P*	0	5	1	1	1	2					
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar								31	1	5	2
	A8	Life History Analysis - 100% scalar								34	3	6	2
	A9	FMSY/M (Low) - 75% scalar						8		19	0		
	A10	FMSY/M (Low) - 100% scalar						5		17	1		
	A11	FMSY/M (Hi) - 75% scalar						4		17	1		
	A12	FMSY/M (Hi) - 100% scalar						5		19	1		
Stock Assessment	R1	Delay-Difference - 75% scalar	2										
	R2	Delay-Difference - 100% scalar	1										

Butterfish

Code	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap
M1	1										
M2	2										
M3	3										
M4	3			2	1	1	2				
M5	2			2	1	3	2				
M6	2			2	2	3	2				
M7	2			2	1	1	4				
M8	2			1	1	2	3				
M9	2			1	1	3	3				
A1	3	9	2								
A2	2	7	2								
A3	2	22	5	2	4	2	2				
A4	3	19	5	2	3	1	2				
A5	2	4	1	1	1	4					
A6	2	4	2	1	1	4					
A7								23	2	5	2
A8								21	3	4	2
A9						6		20	3		
A10						5		17	2		
A11						4		17	3		
A12						3		14	2		
R1	1										
R2	3										

Snapper

Code	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap
M1	1										
M2	1										
M3	1										
M4	0			0	0	12	1				
M5	0			0	0	14	1				
M6	1			0	0	15	1				
M7	0			0	0	11	1				
M8	0			0	0	13	1				
M9	0			0	0	14	1				
A1	1	12	3								
A2	2	11	3								
A3	4	35	14	2	7	19	3				
A4	5	29	19	4	7	10	2				
A5	0	15	1	3	3	7					
A6	0	12	1	3	2	6					
A7								32	4	3	3
A8								37	4	4	2
A9						16		26	3		
A10						15		24	3		
A11						14		22	3		
A12						11		19	4		
R1	2										
R2	2										

Porgy

Code	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap
M1	1										
M2	1										
M3	1										
M4	1			1	1	10	1				
M5	0			1	1	10	1				
M6	0			1	1	9	1				
M7	0			1	1	8	1				
M8	1			1	1	9	1				
M9	1			1	1	9	1				
A1	2	9	4								
A2	3	7	3								
A3	3	21	6	4	4	2	6				
A4	2	18	5	2	3	3	5				
A5	1	8	2	2	2	4					
A6	1	5	1	2	1	2					
A7								23	3	1	3
A8								27	3	2	4
A9						11		22	2		
A10						8		20	2		
A11						6		20	2		
A12						4		21	2		
R1	2										
R2	2										

Sole

Code	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap
M1	1										
M2	2										
M3	1										
M4	0			1	0	12	1				
M5	0			1	0	12	1				
M6	0			2	0	12	1				
M7	0			1	0	9	0				
M8	0			1	0	11	0				
M9	0			1	0	11	0				
A1	0	12	2								
A2	1	11	1								
A3	2	18	5	2	3	3	1				
A4	3	20	6	2	3	2	1				
A5	1	7	2	2	1	3					
A6	1	5	1	1	1	2					
A7								20	3	1	1
A8								23	3	2	1
A9						12		24	2		
A10						9		21	3		
A11						7		19	3		
A12						4		17	3		
R1	1										
R2	2										

Rockfish

Code	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap
M1	1										
M2	1										
M3	1										
M4	0			1	0	10	1				
M5	1			1	0	11	1				
M6	1			1	0	12	1				
M7	0			0	0	9	1				
M8	0			1	0	10	1				
M9	0			1	0	11	1				
A1	2	8	2								
A2	2	6	2								
A3	2	30	9	3	4	13	6				
A4	4	20	11	5	3	5	6				
A5	0	13	1	3	2	4					
A6	0	11	1	2	2	3					
A7								29	4	4	4
A8								33	5	5	4
A9						12		25	2		
A10						10		23	3		
A11						9		21	3		
A12						6		19	3		
R1	1										
R2	1										

and maturity curves ("50%V–50%M") (Table App.C.7). The lack of sensitivity to different spatial parameterizations is supported further by a set of simulations that was conducted without any spatial structure (Appendix E). Spatial phenomenon such as refugia and stock viscosity lead to small reductions in the probability of overfishing (typically between 1 and 3%). In general the results of the spatially aggregated simulations were within 2% of those of the spatially disaggregated simulations, and did not provide any meaningful differences in the ranking of the methods. Only snapper were simulated with refuges, and these averaged only 5% of the population. Much larger differences in the performance results arising from spatially explicit and spatially aggregated operating models may be expected where refugia are larger.

4. Discussion

4.1. Performance of data-limited methods

Setting an ABC at average historical catch levels (methods M1–M3) is likely to lead to poor performance in cases where stocks are below their most productive levels. Generally, the performance of such methods was comparable to the status quo reference methods that simulated current catch or current fishing effort. Method M3, third-highest catch, generally performed worse than maintaining current fishing levels. The main reason for the poor performance of methods M1–M3 is the lack of feedback between stock depletion and the ABC. Recent historical catches rates were often higher than those associated with F_{MSY}, ensuring that using their average as an ABC perpetuated overfishing. These methods lead to positive feedback between past and future ABC recommendations; future ABCs are based on previous ABCs and therefore tend toward a stable value over time. If the initial ABC is too high, exploitation rates become exponentially larger over time. In contrast, if this value is too low the stock tends toward some biomass above B_{MSY}. Consequently, these methods are often divergent and move the stock away from B_{MSY}.

Other static management methods that do not include feedback between the ABC recommendation and stock status can provide good performance, but only when stocks are at intermediate levels of depletion (e.g., the PFMC DB-SRA and DCAC methods M4–M9). While the performance of the static methods was generally poor at low stock levels, the static DB-SRA method still led to lower probabilities of overfishing and higher yields than the average catch methods (M1–M3). Unsurprisingly, methods that dynamically account for population changes achieved better performance when the stock is not near B_{MSY}. This was not the case for DCAC, which is designed to return a proxy for MSY, which is not an appropriate basis for OFLs for stocks at low population levels (as acknowledged MacCall (2009)). The dynamic DB-SRA and F_{MSY}/M ratio methods (A3 and A9) generally led to the best performance by some margin. While the aggregate performance of these methods may appear satisfactory, it is strongly affected by bias in two key inputs: depletion (DB-SRA) and current stock biomass (F_{MSY}/M methods). Methods which involve estimates of biomass or current depletion (rather than assumptions about them) would, however, generally not be considered to be data-poor, but rather data-moderate (PFMC, 2010; NPFMC, 2012).

The simulation testing of ABC control rules (e.g., 75% and 100% scalar multipliers) revealed that the largest downward adjustments in the OFL often led to higher expected long-term yields and lower probabilities of overfishing (e.g., F_{MSY}/M ratio methods A9 and A10). This was particularly the case for simulations starting below 50% B_{MSY} where lower exploitation rates could allow rebuilding to more productive stock sizes. However, the range of downward adjustments was not sufficient in some instances to achieve high probabilities of rebuilding. For example, the three ABC control rules based on methods M4–M9 ranged from a 9% to a 30% reduction in the OFL. The results of all three multipliers were similar, and did not span a sufficiently wide range of adjustment to allow stocks to recover from low levels, when depletion is assumed a priori to 40% (e.g., methods M4–M9).

4.2. Sensitivity of performance to inputs and value of information

In general, the performance differences were much greater across methods than across life-history types. The exception to this was butterfish. All methods led to relatively high rates of overfishing for butterfish without necessarily leading to stock declines or reductions in long-term expected yield because of the short life span and high recruitment variability of this stock. The biomass of butterfish can easily depart from the mean by a factor of 2 in the absence of fishing, making natural variability in productivity a much stronger determinate of stock status than exploitation rate. The results for butterfish demonstrate the challenge of developing

management systems for short-lived species. MSE for prawn species that examine both input (effort) and output (catch quota) controls (Dichmont et al., 2006, 2012) conclude that the effective use of quotas in such cases is dependent on the ability to predict and monitor recruitment. It may be beneficial to track current abundance and maintain close control of exploitation levels to prevent forgone yields and/or problematic stock declines for short-lived species. It follows that methods that rely on current information and aim for fixed exploitation rates such as the F_{MSY}/M ratio methods may be particularly suitable for species of short life history.

Previous simulation evaluations of DB-SRA and DCAC found sensitivity to misspecification in natural mortality rate for long-lived stocks (Wetzel and Punt, 2011), a result which is corroborated here for snapper and rockfish. This is due to propagating this error over a larger number of age classes and hence a larger fraction of the population.

The simulation of spatial population and fishing dynamics had very little impact on performance. All methods showed relatively weak sensitivity to variability in simulated spatial targeting, stock viscosity or spatial heterogeneity; a MSE with no spatial dynamics led to very similar results. Spatial phenomena such as refugia from fishing and stock viscosity led to very small reductions in the probability of overfishing relative to the differences among methods and simulated life-histories. This suggests that the subtleties of spatial stock dynamics are comprehensively overwhelmed by general problems associated with the inaccuracy and imprecision of the principal inputs such as natural mortality rate and stock size for the stocks simulated in this research. It is conceivable that spatial effects may be more critical for other stocks, for example sessile species or those that experience greater refuge from fishing.

All of the methods were most sensitive to imperfect information regarding either current stock depletion or current biomass. Consistent bias in these inputs strongly affected the expected probability of overfishing and long-term yield. On the other hand, relatively high imprecision in these estimates had little effect on performance: year on year, the estimates could vary strongly from the "true" underlying value of depletion or biomass. The dynamic DB-SRA method could lead to high probabilities of declining below 50% B_{MSY} when starting above B_{MSY}. This was due to the specification of OFLs much higher than MSY due to a positively biased input for depletion. An alternative ABC control rule which applies a downward adjustment to the smaller of the OFL or MSY may help to combat this problem and substantially improve the performance of the dynamic DB-SRA method in such instances.

4.3. Quantifying inputs

The inputs to these data-limited methods focus on those that can be developed quickly from existing sources, as opposed to those that require future data collection efforts. Given that the intent of the data-poor assessment is to provide information for immediate use, the latter category of inputs is less relevant to this discussion. However, additional or improved inputs may be needed if an attempt at assessment falls short due to lack of information, or if the results engender an urgent desire for a "more complete" assessment. A wide range of alternatives exist for supplementary data collection, depending on available labor and funding, and the time horizon for data delivery, but the result is to move toward a more data-rich approach that falls outside the scope of this study.

4.3.1. Depletion

The assessment methods that perform best included estimates of current depletion or abundance so it is instructive to discuss how these inputs may be obtained. Of these, depletion is perhaps the most difficult to obtain for data-poor stocks. Depletion is a data-rich quantity in many respects; it requires broad knowledge of stock trend, which in turn defines a data-rich stock in this paper and elsewhere (e.g., Punt et al., 2011). However, a case may be made that expert knowledge about depletion could be derived from anecdotal information such as changes in the spatial range of fishing. Expert judgment is especially useful when assessments have been carried out for other local stocks, and the similarity of fishing operations for the data-poor stock is suspected or known. For example, based on a calibration to 30 data-rich stock assessments, Productivity Susceptibility Analysis (Patrick et al., 2009) has been used by the PFMC to determine the mean of the prior for depletion when applying DB-SRA.

In some cases, a time series of fishery-independent surveys exists for other species, and the data-poor species may be caught occasionally. Although the data may contain an excessive number of "zeroes" it is often possible to derive an abundance index or estimate of depletion from a remarkably small number of positive samples, even if the time series has to be collapsed into a few multi-year time blocks. Examples of fishery-independent surveys include the Triennial trawl survey and slope surveys of the US West Coast (NMFS, 2013) and the MARMAP (2013) survey of the South Atlantic.

Trends in abundance inferred from catch and effort data can be included in methods such DB-SRA to update the depletion prior (Cope et al., 2013). Although historical effort is usually not known, it may be possible to "borrow" a time series of fishing rate estimates from assessments of other species in the region. Punt et al. (2011) have explored simultaneous assessments of multiple species using this "Robin Hood" approach. Other ways to construct estimates of depletion include recreational fishing databases (e.g. RecFIN, 2013) or the use of scientific observer data (NMFS (2013) includes a discussion of these sources of depletion information).

Our analysis of the value of information indicates that considerable *imprecision* in depletion estimates does not lead to dramatic loss of yield or increase in the probability of overfishing. *Bias* in depletion, on the other hand, strongly determines performance. This is potentially problematic because of difficulties in acquiring new information about past abundance trends.

4.3.2. Natural mortality rate

The DB-SRA, DCAC and F_{MSY}/M ratio methods all rely on an estimate of M, a common input in most stock assessments (the main exception being surplus production models). Although M is an uncertain parameter, stock assessments require only an approximate value. If tentative ages can be determined, covariates such as maximum age and von Bertalanffy growth parameters are estimable from quite small samples; tropical fishes lacking clear age indicators are more difficult. Useful meta-analyses have been published by Pauly (1980), Hoenig (1983), Hewitt and Hoenig (2005), and Gislason et al. (2010), among many others. If uncertainty in the value of M remains problematic, it may suffice to choose a most likely value of M from a simple list of candidate values (e.g., 0.2, 0.1, 0.05, 0.025 yr^{-1}). Note that many of these data-poor methods fail if $M > 0.2 yr^{-1}$, and values below 0.025 yr^{-1} for M are rare in fish.

While DB-SRA and DCAC have low fishery data requirements (historical catches), the remaining inputs are parameters and variables that strongly determine the methods' outcomes. Although direct estimation of these quantities requires conventional approaches used in data-rich assessments or meta-analyses (e.g., Punt et al., 2011; Zhou et al., 2012; Thorson et al., 2012b), data-poor assessments often require us to postulate values of key parameters by analogy to data-rich cases. Development of appropriate meta-analyses is an active area of fishery research that has gained impetus from the requirements of data-poor assessment methodologies.

4.3.3. Current abundance

In instances where it is not possible to estimate current depletion, future data-gathering efforts may focus on the estimation of current abundance which is an input to the F_{MSY}/M and life-history methods.

There are several possible ways to estimate current biomass that differ by cost and the assumptions on which they rely. The most conventional is a "fishery independent" research survey that uses a variety of fishing gears to sample the population from which total biomass may be extrapolated (Doubleday and Rivard, 1981; Gunderson, 1993). In the Gulf of Alaska and the Bering Sea, estimates of abundance from fishery-independent surveys are used in the F_{MSY}/M method to set ACLs for several stock complexes such as skates, sculpins, crab, and rockfishes (NPFMC, 2012). The principal limitation of surveys is their considerable cost which may not be justified in many data-limited situations, for example where the primary source of exploitation is bycatch. In addition, many species are unlikely to be fully selected by the survey gear or estimates from density in areas which can be surveyed may be extrapolated incorrectly to areas that cannot be surveyed leading to persistent bias in estimates of abundance. Such bias may dramatically affect the reliability of data-limited methods using these data.

An alternative approach to current abundance is to divide current catch by an estimate of current exploitation rate. If assessments have been carried out for other species, it may be possible to "borrow" their estimated fishing mortality rates. Punt et al. (2011) use this "Robin Hood approach" in simultaneous assessments of multiple species. Two possible direct means of estimating current exploitation rate are a tagging experiment or a catch curve analysis. The concept of mark-recapture analysis has a long history in fisheries science and was discussed at length by Beverton and Holt (1957). Tagging may be expensive, but can provide a relatively precise estimate of current fishing mortality rate and abundance. There are often challenges to the ready interpretation of these data, including tag mortality, shedding, reporting and detection rates, and a program may take many years especially if exploitation rate is low. To obtain exploitation estimates that can be generalized to the population requires knowledge of spatial distribution that may not be available in many data-limited situations. Perhaps the most important limitations of mark recapture analysis is that many species of fish are difficult to tag in sufficient numbers or not suitable candidates due to high post-release mortality rate or tag-induced mortality rate.

Catch-curve analysis can also provide estimates of current mortality rates, and is likely to be most successful in cases where fishing mortality rate, recruitment strength and age-vulnerability to fishing can be assumed to be relatively constant over recent years. Catch curve analysis (Ricker, 1975) assumes that after a certain age, individuals experience the same fishing mortality rate, allowing the descending proportion of catch-at-age (or catch-at-length) to be interpreted in terms of total mortality. An estimate of natural mortality rate is needed to separate fishing mortality from the total mortality rate estimated by catch-curve analysis. In a data-limited setting the primary advantage of catch-curve analysis is that it does not require historical data and relies only on catch composition data that can be collected today. Catch curves can be based on age- or length-composition data and can be used to form the basis for control rules for data-limited species (e.g., Klaer et al., 2012). There are a number of methods to account for temporal variability in recruitment and selectivity if multiple years of age-composition data are available (e.g., Schnute and Haigh, 2007). Despite the limitations of catch-curve analysis, it might produce estimates of current biomass that are no more biased or uncertain than the imperfect knowledge of biomass simulated in this analysis. This should be the focus of future simulation evaluation.

4.4. Methods that could not be simulation tested

There are data-limited assessment methods for setting catch limits that could not be simulation tested. These methods either did not provide estimates for OFLs (the methods of Patrick et al., 2009; Martell and Froese, 2012; Thorson et al., 2012a; Costello et al., 2012; Cope and Punt, 2009) or involved expert judgment that could not be simulated (the methods of Berkson et al., 2011; Punt et al., 2011).

The method of Martell and Froese (2012) aims to estimate MSY by reconstructing a stock history according to catches and discarding those simulations that cross certain thresholds (e.g., that fall out of a range of current stock depletion such as 5–95% of unfished biomass). This "MSY depletion method" is theoretically similar to DCAC. A central finding of Martell and Froese (2012) is that MSY may be well defined despite only weak prior information about maximum stock size, stock productivity and current depletion. However, this finding also explains our inability to include this approach in our analysis. While MSY is a theoretical quantity relating to the most productive level of depletion, the OFL is determined by current stock depletion (e.g., it tends to zero as the stock declines). It follows that MSY does not provide a means of setting the OFL without a control rule. Since the OFL can range from much higher than MSY to zero, the success of the method would rely on the control rule. It could be argued that a control rule should also be applied to DCAC since it is also an approximation of MSY. However in line with the recommendations of the PFMC (PFMC, 2010) we tested DCAC as a method of determining the OFL without such a control rule.

Thorson et al. (2012a) and Costello et al. (2012) use covariate information, such as life history characteristics and landings data to inform a predictive model of current stock depletion. These approaches use correlations between assessed stock status and other covariates to extrapolate the stock status of fisheries that are not assessed. It is possible that these methods could be adapted to provide OFL recommendations. However, doing so would require assumptions about the productivity of the stock with declining biomass (i.e., the shape of the productivity curve). It may be possible to combine these methods or DCAC or the method of Martell and Froese (2012).

Punt et al. (2011) propose a "Robin Hood" method in which data-rich assessments are used to inform the spawning stock biomass and exploitation history of data-limited stocks that are subject to fishing by the same fleets. A central assumption of this method is that the different stocks have comparable trends in exploitation rate. As such, the method relies on the existence of a contingent data-rich stock and a process to assess whether exploitation rates are similar. The choice of which fleets have the same trends in exploitation rate is based on expert judgment, which prevented a full evaluation of the method.

Cope and Punt (2009) outline a length-based approach that relates the observed fractions of fish of different classes (e.g., fraction mature) to stock status. While length-based reference points could provide a basis for designing control rules that provide OFL recommendations, these rules have yet to be established (Cope and Punt, 2009).

4.5. Limitations

Assumptions about how accurately and precisely the inputs to the data-limited methods may be quantified determines performance. It should be emphasized that the results are a product of the specific conditions of the simulation. For example, we may have found that methods which rely on M performed substantially better had the extent of error associated with M been assumed to be unrealistically low. This points to a fundamental circularity

in this analysis, one of simulating knowledge in inputs to methods that are to be applied in instances where these inputs are not known. All of the methods evaluated performed poorly when their fundamental assumptions were invalid or inputs were strongly mis-specified. We recommend that when reviewing the performance of the data-limited methods, the reader should take care to consider the sensitivity of the performance to misspecification in inputs (as presented in Table 7 for example).

The objective of this research was to evaluate the impact of the data-limited methods regardless of the rate of compliance. In all of the simulations we assumed that the ABC recommendations were taken as catch and no implementation error was simulated. In practice, there are often overages or shortfalls that affect the level of future catch limits. It is possible that implementation error may interact with some data-limited methods and alter their relative performance. However, since all methods provide the same type of advice (i.e., catch limits) it is probable that this additional source of error would have had a comparable impact across methods and would limit the generality of the results while reducing the clarity of the inter-method comparisons.

4.6. Conclusions and recommendations

- In circumstances where only fishery catch data are available, this simulation evaluation indicates average catch methods such as median catch over the most recent 10 years or third highest catch cannot be expected to provide a better basis for management than maintaining current catch or effort levels. These methods often perform even worse than the status quo methods of current catch or current effort when biomass starts below B_{MSY}. However, the catch-based methods appear to provide performance more comparable to that of the other methods if it can be established that a stock is above B_{MSY}.
- Additional information regarding depletion, historical effort, or current abundance can be very valuable. Our analysis points to large expected gains in yield for all stock types (except high-M stocks such as butterfish) when stocks are heavily depleted given information about depletion or trend in relative abundance, with more modest gains for less depleted stocks. When considering how to obtain data in addition to historical catch, perhaps the most cost-effective avenue for investigation is the availability of unprocessed data. For example, fishing effort data that may be used to calculate an index of historical abundance or for estimating current depletion. Multispecies surveys may also be available from which a time-series of abundance could be constructed (e.g., MARMAP, 2013; West Coast trawl surveys NMFS, 2013). A research priority is summarizing these data sources and characterizing stocks according to uncertainty regarding stock status and the potential benefits of obtaining additional data. Where historical abundance trends or effort data are not available there is an onus on the collection of current abundance information, for example using fishery independent surveys, catch curve analysis or tagging studies. Simulation evaluation may offer a basis for determining the cost-benefit of new data-collection programs by quantifying the potential for additional long-term yields.
- The mixed performance of the delay-difference methods provides food for thought for those analysts seeking to evaluate data-limited methods by comparison with stock assessments. The delay-difference models applied in this analysis assumed perfect knowledge of historical effort, growth, natural mortality rate, and the age that individuals are vulnerable to fishing. Nevertheless, these assessments assume stationary stock dynamics and a linear relationship between historical fishing effort and fishing mortality rate, assumptions that are commonly violated in these simulations. That performance for this method was "mixed" runs contrary to the view of data-rich stock assessments as a "gold standard" against which other approaches may be compared. Our simulation evaluation also confirms that classifying stocks solely according to the amount and types of data available may not be appropriate. A large quantity of data is no guarantee of reliable information on which to base decision making (data-rich stocks are often information poor). The way in which data inform management recommendations relies to a large extent on the validity of the assumptions of the assessment tool. For example, detailed historical data for a short-lived species such as butterfish should not necessarily motivate the use of a conventional data-rich assessment approach that may offer less reliable management advice than a simpler approach using a smaller amount of data that instead, provide information about current stock characteristics.
- Some of the terminology surrounding data-limited methods has the potential to be strongly misleading. One example is the term P^* (probability of overfishing). This simulation study and Punt et al. (2012) found that P^*s of 25% and 50% rarely corresponded to these probabilities of overfishing. Nor did a 25% P^* rule lead to half the probability of overfishing exhibited by a 50% P^* rule. Based on this terminology, decision makers may be led to believe they are choosing a specific outcome and this simulation evaluation reveals that this may not be the case.
- We have evaluated a broad suite of data-limited methods. Certain data-limited methods (e.g., the 'Robin Hood' method, the ORCS approach, PSA analysis) have been proposed, but could not be simulation-tested. We recommend that editors of journals who consider publishing new data-poor methods request authors to minimally outline how their method can be tested. Ideally, a reference set of simulation data sets should be made available to allow the results of this paper to be supplemented with those for new data-limited methods.
- Finally, the focus of this paper is on methods that have been identified for use in the management of fish stocks in U.S. waters. However, establishing data-limited methods is particularly relevant to developing countries where there is often less complete reporting of fishery data and fewer resources dedicated to analysis. Moreover, a broader suite of types of assessment methods could be examined for countries which mandate use of control rules, but are less prescriptive regarding the structure of control rules than the U.S. (see, for example, Smith et al., 2009).

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2013.12.014.

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Exhibit 3

Evaluating data-limited methods of setting catch-limits

Tom Carruthers, University of British Columbia

Alec MacCall, NMFS SWFSC

SAFMC SSC Meeting, Charleston, SC
23 October 2013

Carruthers, T.R., Punt, A.E., Walters, C., MacCall, A., McAllister, M.K., Dick, E.J., Cope, J.

Paper accepted for publication in Fisheries Research

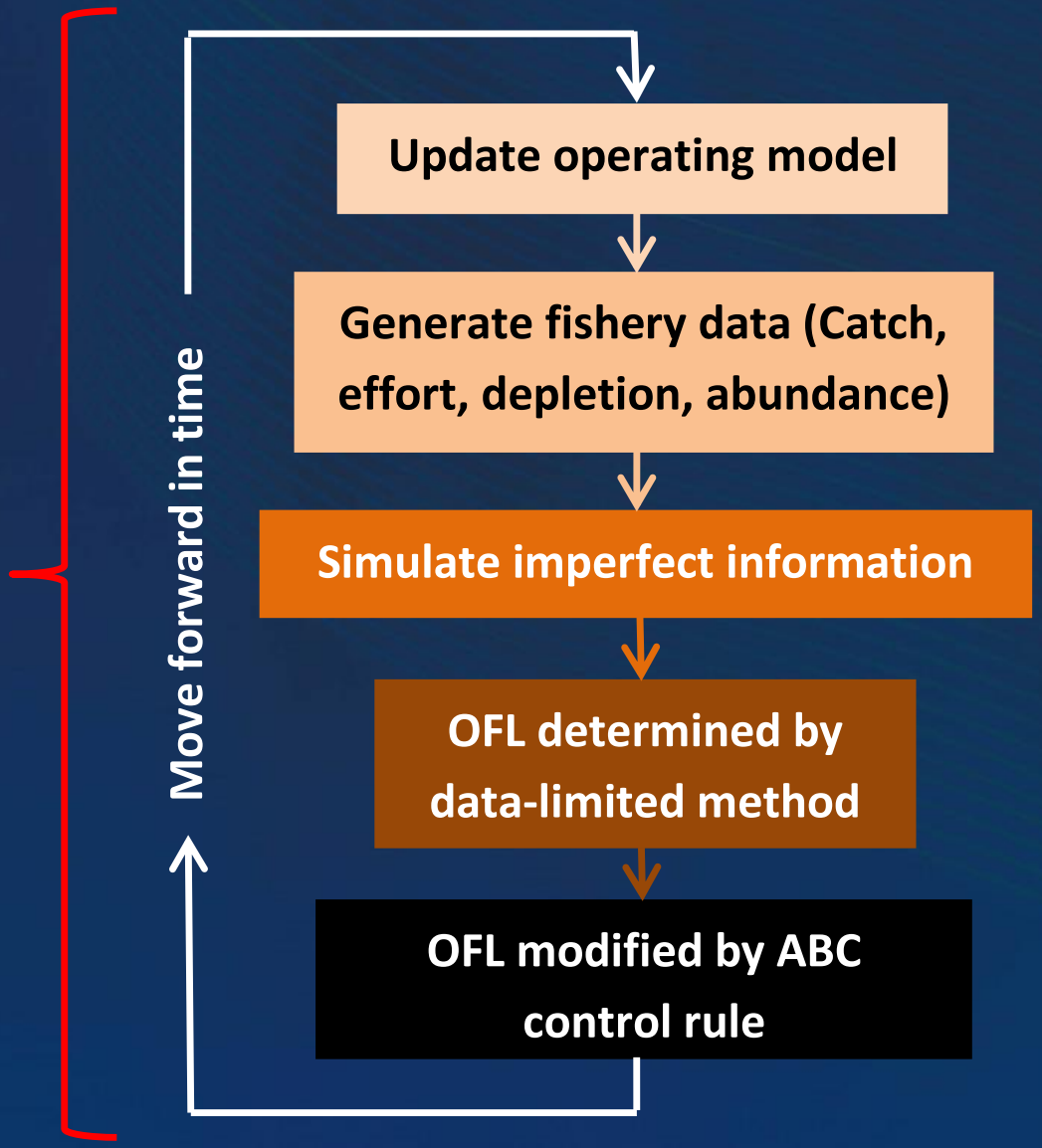
Objectives

We aimed to assess:

- the performance of data-limited methods used in US fishery management for a variety of life-history types
- the value of various sources of information
- trade-offs among management objectives

Management Strategy Evaluation

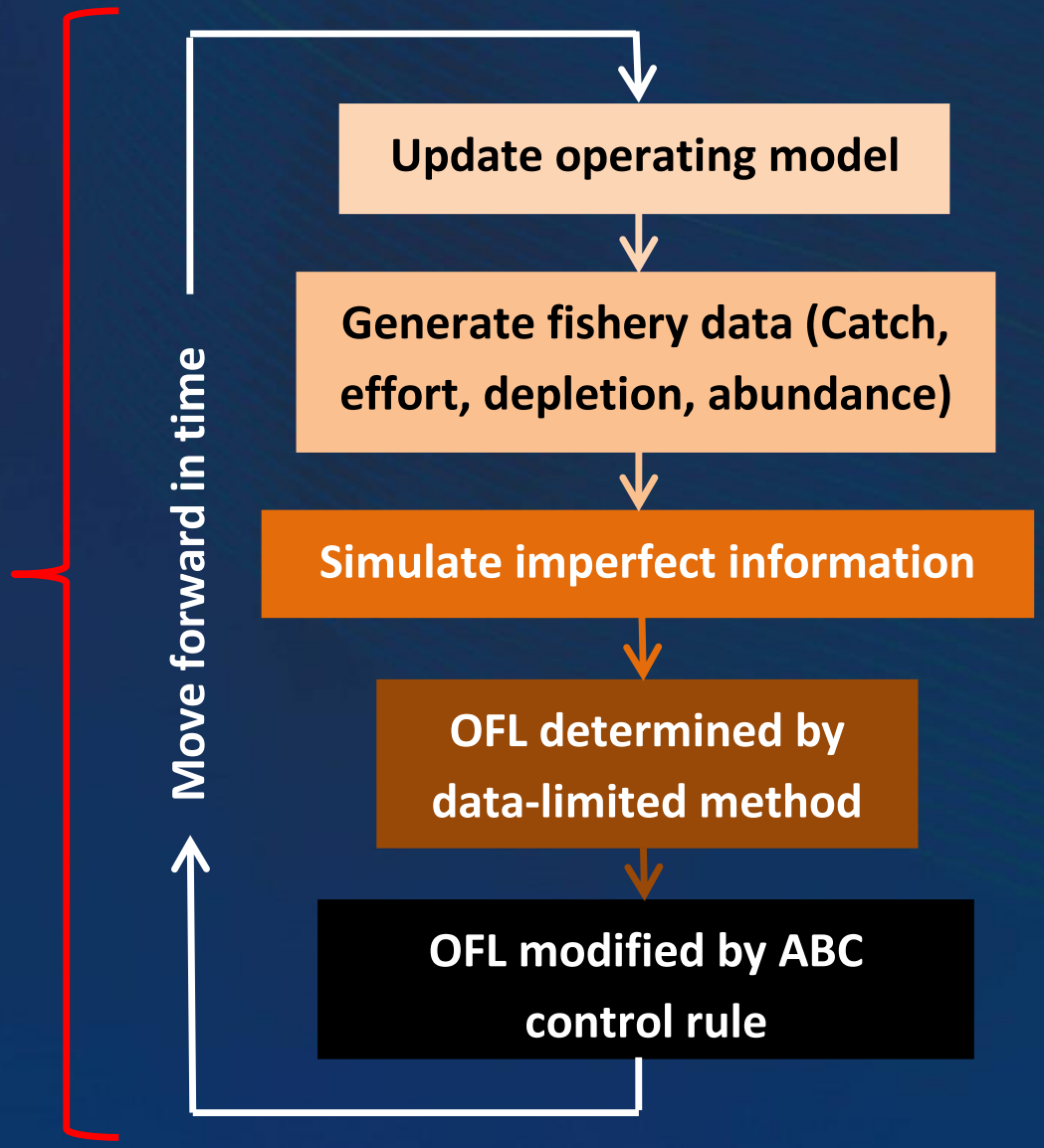
To be specified:



Management Strategy Evaluation

To be specified:

- Operating models
- Data-limited methods
- Imperfect information
- Performance metrics



1. Operating models

Six life-history types or 'stocks', n = 10,000

	M	Steepness	$CV_{recruitment}$
Mackerel	0.2	0.45	0.5
Butterfish	0.8	0.55	0.9
Snapper	0.09	0.65	0.6
Porgy	0.22	0.4	0.55
Rockfish	0.06	0.55	0.5
Sole	0.18	0.45	0.4

These are mean values: parameters were sampled from uniform ranges typically with a CV of 20%

2. Data-limited methods for setting the overfishing limit (OFL)

- DB-SRA (Dick and MacCall 2011)

  depletion, M, B_{MSY}/B_0, F_{MSY}/M, catch, age at 50% maturity
- DCAC (MacCall 2009)

  depletion, M, B_{MSY}/B_0, F_{MSY}/M, catch
- F_{MSY}/M ratio (*e.g.* 0.5, 0.75, 1)

  $B_{current}$, M, F_{MSY}/M
- DACS (ORCS ABC Control Rule, Berkson *et al.* 2011)

  depletion, catch
- Catch percentiles (*e.g.*, OFL = med. of historic catch)

  catch

3. Imperfect information

Log-normal (mean = 1) CV's for multipliers

	Bias	Imprecision
M	0.5	
F_{MSY}/M	0.8	
B_{MSY}/B_0	0.2	
K_{vonB}	0.2	
Length at 1st capture	0.5	
Catch		0.05 - 0.3
Depletion	1	0 - 2
$B_{current}$	1	0 - 2

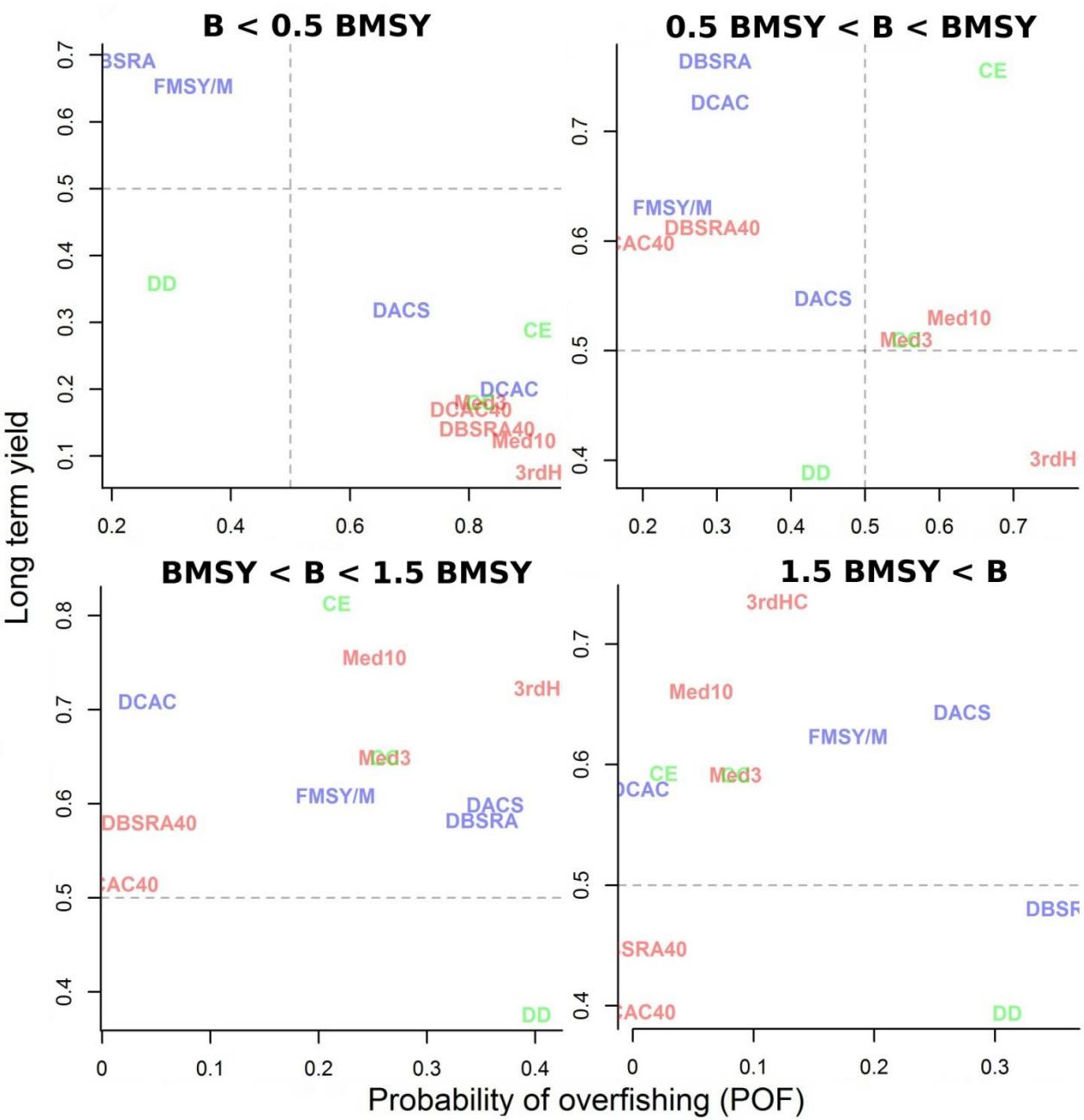
4. Evaluating performance

Magnuson-Stevens Act (MSA) National Standard 1 requires that "conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery…"

Related performance metrics:

- Probability of overfishing
- Yield

Performance of data-limited methods (Mackerel)



Rules

Dynamic approaches

DCAC = Depletion Corrected Average Catch

DBSRA= Depletion Based Stock Reduction Analysis

DACS = ORCS ABC control rule

FMSY/M = FMSY is half M

Static approaches

DCAC40 = DCAC with depletion fixed at 40%

DBSRA40 = DBSRA with depletion fixed at 40%

Med3 = Median of last 3 years

Med10= Median of last 10 yrs

3rdHC = 3rd highest catch

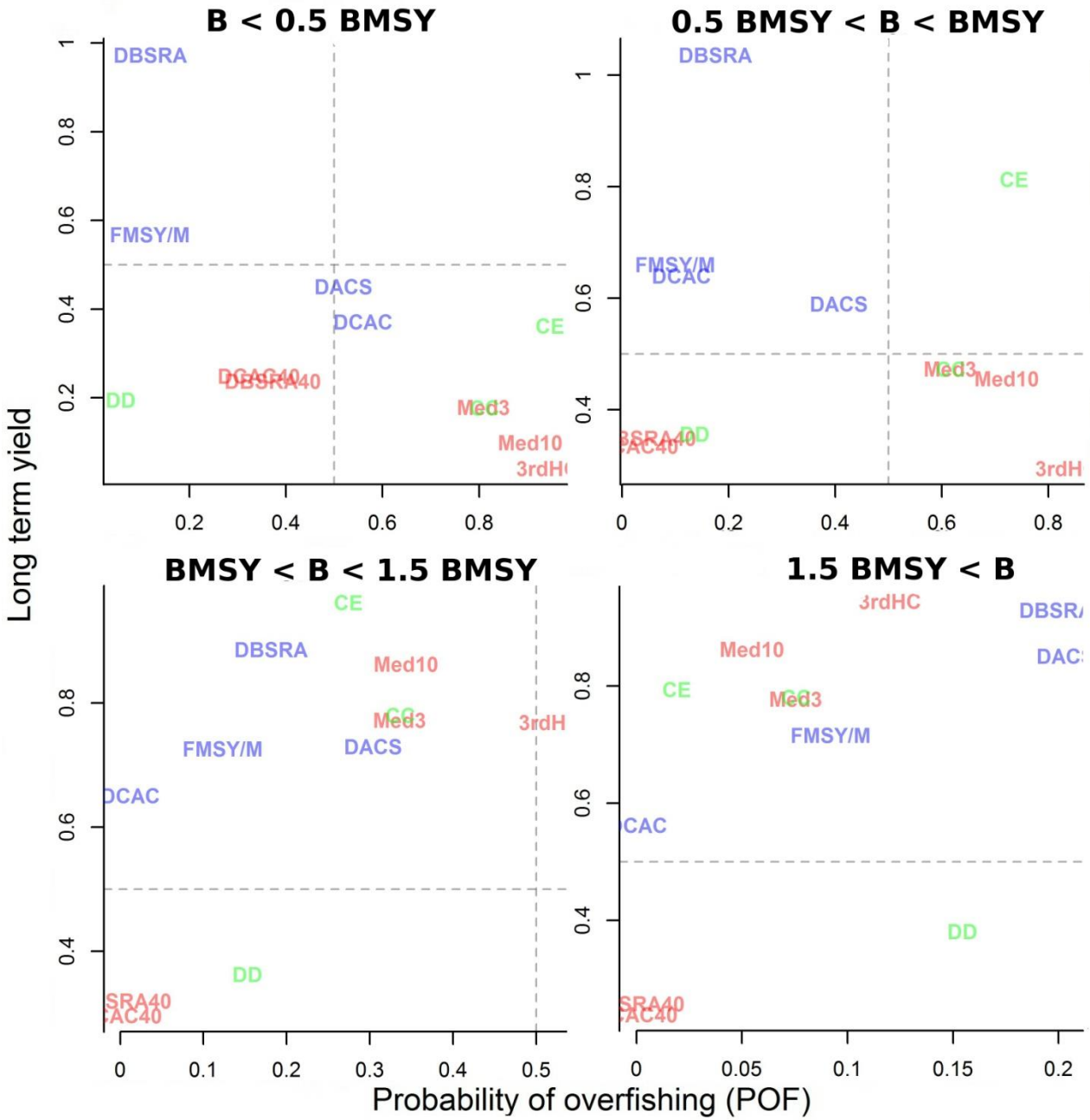
Reference approaches

DD = Delay Difference stock assessment model

CC = Current Catch

CE = Current Effort (fishing mortality rate)

Performance of data-limited methods (Snapper)



Rules

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Static approaches

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Med10= Median of last 10 yrs

3rdHC = 3rd highest catch

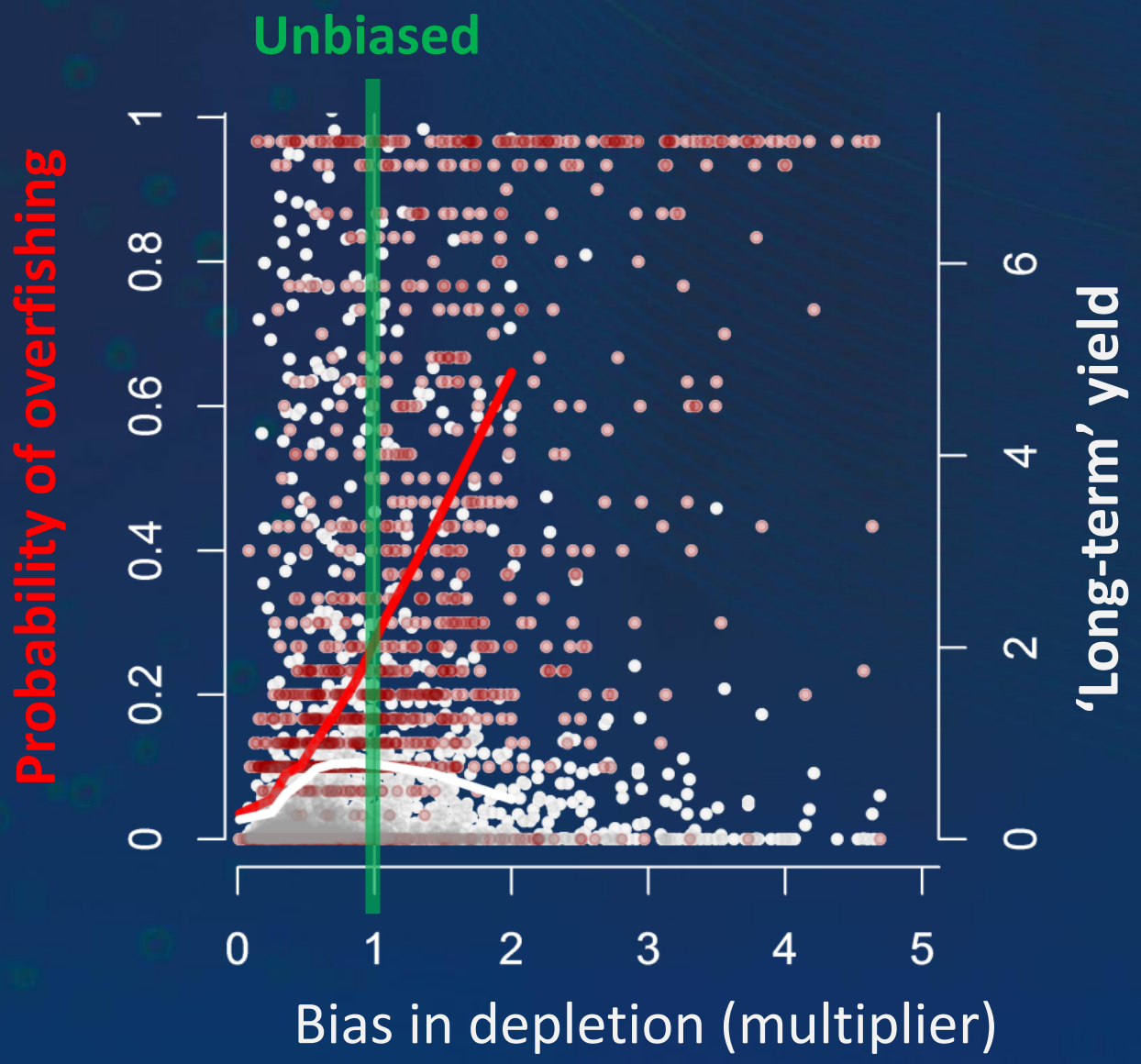
Reference approaches

DD = Delay Difference stock assessment model

CC = Current Catch

CE = Current Effort (fishing mortality rate)

Sensitivity to imperfect information / value of information (DB-SRA and the mackerel stock)



Value of information

Standard deviation in yield among 10 percentile 'blocks' of each input

Mackerel

	Obs err
Median Catch - 10 Yrs	1

Value of information

Standard deviation in yield among 10 percentile 'blocks' of each input

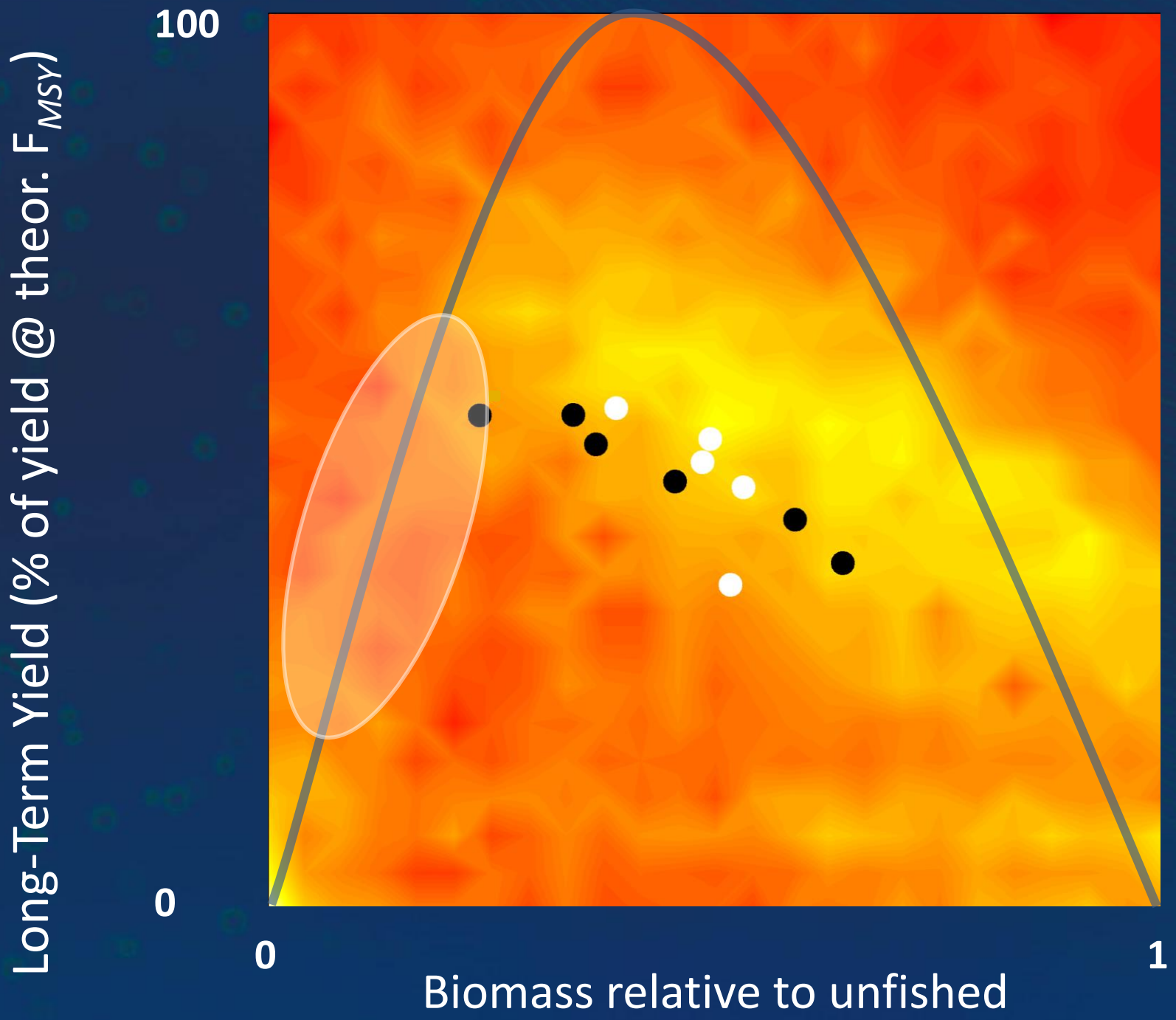
Mackerel

	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap
Median Catch - 10 Yrs	1										
DB-SRA 40% depletion	1			1	1	8	1				
DCAC 40 % depletion	1			0	1	7	1				
DB-SRA	1	22	5	4	3	5	1				
DCAC	0	7	1	1	1	3					
DACS (ORCS ABC CR)	1	9	4								
$F_{MSY}/M = 0.5$						8		19	0		
Delay-Difference	2										

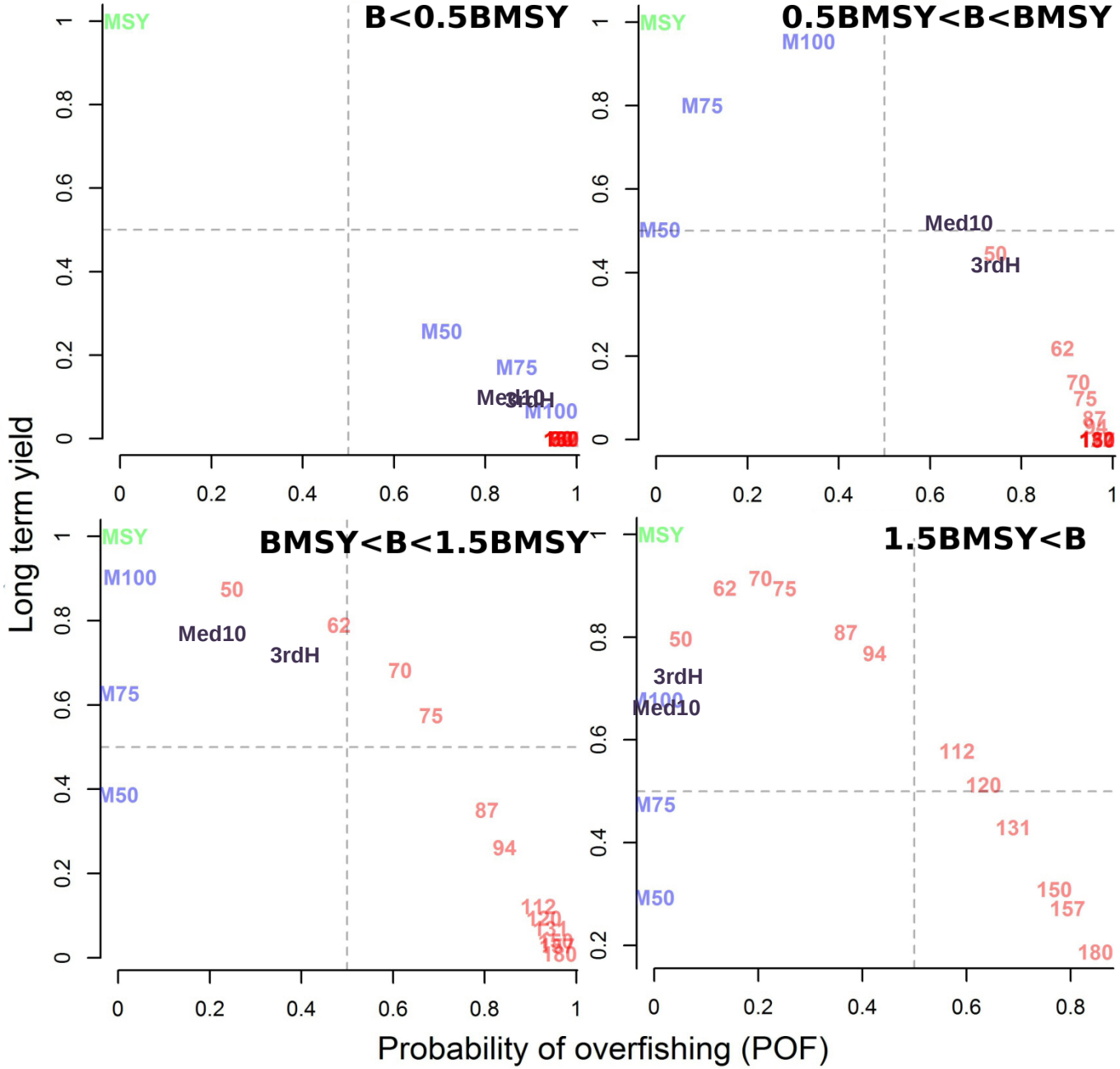
Value of information

Standard deviation in yield among 10 percentile 'blocks' of each input

	Mackerel										Snapper									
	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap
Median Catch - 10 Yrs	1											2										
DB-SRA 40% depletion	1			1	1	8	1					0			0	0	12	1				
DCAC 40 % depletion	1			0	1	7	1					0			0	0	11	1				
DB-SRA	1	22	5	4	3	5	1					4	35	14	2	7	19	3				
DCAC	0	7	1	1	1	3						0	15	1	3	3	7					
DACS (ORCS ABC CR)	1	9	4									1	12	3								
$F_{MSY}/M = 0.5$						8		19	0								16		26	3		
Delay-Difference	2											2										


100
0
0
1
Long-Term Yield (% of yield @ theor. F_{MSY})
Biomass relative to unfished

Performance of maximum catch rules (Mackerel)



Rules

Maximum Catch

50 = 50% Max Catch

62 = 62% Max Catch

70 = 70% Max Catch

...

Mean Catch

M50 = 50% Mean Catch

M75 = 75% Mean Catch

M100 = Mean Catch

Reference approaches

FMSY = OFL

Other approaches

Med10 = Median catch of last 10 years

3rdH = 3rd highest catch

Similar pattern across all species except butterfish

Conclusions (1/3)

- Maximum catch rules (*e.g.*, max. catch scalars, 3rd high. catch, etc.) lead to high probabilities of overfishing (> 50% probability @ $B < B_{MSY}$) and low yields, particularly for stock levels below B_{MSY}
- Avg. catch rules (*e.g.*, 75% of mean catch) and DCAC produce high probabilities of overfishing and low yields at low stock size ($B < 50\% B_{MSY}$), though outperform max. catch rules.
- DACS (ORCS WG Rule) generally outperforms avg. catch rules, but is also sensitive to biased (not necessarily imprecise) estimates of depletion.
- Dynamic DB-SRA (not DB-SRA 40) and F_{MSY}/M outperform all other methods at all biomass levels, but also sensitive to bias in current stock depletion/abundance.

Conclusions (2/3)

- DACS and, to a lesser extent, precautionary average catch rules (*e.g.*, 50-75% mean catch) may provide adequate short- to medium-term approaches, allowing additional data collection for use of other methods (*e.g.*, DB-SRA, imprecise survey + F_{MSY}/M, DCAC)
- At moderate stock sizes (> 50% B_{MSY}) DCAC and DB-SRA perform similarly well.
- Any dynamic feedback on current or relative abundance (from surveys, catch curve analyses, CPUE, etc.), even if imprecise, provides a solid basis for ACL-setting with higher yields and lower probabilities of overfishing.
- Some stocks assigned 'data-limited' status have more data available (*e.g.*, MARMAP stocks) that could provide large increases in management performance.

Conclusions (3/3)

- Dynamic approaches that account for stock levels not only perform better but also provide transparency in the derivation of the ACL.
- More precautionary buffers lead to both higher yields and lower probabilities of overfishing.
- Simulating a data-limited management system reveals that it may be difficult to manage stocks substantially below B_{MSY}
- Well-informed delay-difference models could perform worse than some data-limited methods (DB-SRA, imprecise survey + F_{MSY}/M) due to the assumption of temporally stationary productivity / fishing efficiency
- Spatial effects were not important in these simulations of data-limited methods

West Coast Groundfish - Experience

- ~ 90 spp, mostly long-lived, various F histories
  - Only 1/3 of these stocks have been assessed
  - ACLs were needed for ~60 data-poor stocks
- We developed "DB-SRA 40" to address this need
  - Reconstruct historical catches
    - Best guess scenarios
    - The same as is needed for data-rich – this is not new
  - Assume a plausible range of population parameters
  - Assume that each stock is <u>at its target</u> (40% of Bo)
  - Determine Fmsy level consistent with this
    - Median catch at estimated Fmsy (and B40) is basis for ACL

West Coast Groundfish - Results

- Only three stocks showed possible overfishing
  - These were assigned high priority for assessment
  - 2013 data-moderate assessments
    - Worst one turns out to be OK, 2 are borderline
    - Mgmt not finished yet, but probably minimal disruption
- Method got ahead of the review process
  - ACLs were developed for 2011 fisheries (urgently required)
  - SSC reviewed methods, with conditional acceptance
  - Special STAR Panel (like SEDAR) convened in 2011
    - Favorable review of methodology (tested against data-rich cases)
    - Introduced Bayesian "extended DB-SRA" (reviewed in 2012)
    - Suitable for "data-moderate" stocks – e.g., using recreational CPUE
  - XDB-SRA was used for 6 full assessments (3 spp) in 2013

West Coast Groundfish - Lessons

- The precedent set by conventional data-rich methods has been a handicap
  - Inappropriate expectations, false sense of accuracy and precision
  - Inappropriate data requirements
  - Tended to prevent thinking “outside the box”
- Once we showed that alternative approaches existed, conventional approaches loosened up
  - e.g., Jason Cope’s “Simple Stock Synthesis”
- Acceptance of new ideas is slow --Classical pattern of response:
  1. it is dismissed , 2. it is resisted, 3. it was obvious, what’s the big deal?

We can do a lot more than we tend to think we can!

- There is nearly always more and better data than we think
- Methods can be found or developed to address each case

Southeast Data-Limited Workshop

- Clay Porch & Alec MacCall are hosting a data-limited methods workshop in early 2014.
- Goals: review and promote best practices for data-limited fisheries.
- Components:
  - Educate participants on the data requirements and performance attributes of different data-limited methods
  - Demonstrate the application of different methods to a number of “case-study” stocks
  - Evaluate the sources, availability, and refinement of fisheries data and the applicability of data-limited methods for unassessed stocks in the Southeast region.
  - Recommend best practices and identify areas for further research.