NOAA Technical Memorandum NMFS-SEFSC-616

CALCULATING ACCEPTABLE BIOLOGICAL CATCH FOR STOCKS THAT HAVE RELIABLE CATCH DATA ONLY
(Only Reliable Catch Stocks – ORCS)

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U.S. DEPARTMENT OF COMMERCE
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National Marine Fisheries Service
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Miami, Florida 33149

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EXECUTIVE SUMMARY

In response to the 2006 reauthorization of the Magnuson-Stevens Act (MSA), the National Marine Fisheries Service established National Standard 1 (NS1) Guidelines, which included a requirement to set an acceptable biological catch (ABC) that accounts for scientific uncertainty in the estimate of a stock's overfishing limit (OFL). This is an exceedingly difficult task for the large number of stocks for which reliable catch data are the only information available, as these stocks cannot be assessed with traditional stock assessment methods. For the purpose of this document, these stocks will be called "only reliable catch stocks" (ORCS). Despite the inherent problem of setting ABCs for ORCS, the MSA requirement remains.

At the second National SSC meeting November 10-13, 2009 in St. Thomas, USVI, an ad-hoc Working Group was established to identify, suggest, and evaluate alternative approaches for the setting of ABCs for ORCS. Working Group members represent seven of the eight SSCs, five of the six NMFS Science Centers, NMFS Headquarters, as well as a regional fishery management council, academic institutions, a state agency, and an NGO. The goal of the Working Group was to develop an approach for addressing ABCs in ORCS that could potentially be applied in all jurisdictions under a flexible framework.

This report reviews existing methods for setting catch limits for ORCS. Each approach is briefly summarized followed by a description of the required data, the major assumptions and consequent cautionary advice in utilizing the particular approach, its potential for use in a risk-based decision-making framework, the status of the approach along with examples of its implementation, and the pros and cons of using the approach as viewed by the Working Group.

The Working Group also presents its own approach, designed to build on existing approaches, while strengthening the biological and population dynamics underpinnings. The method provides additional flexibility and allows policymakers to set risk levels, as required under the NS1 guidelines.

Ultimately, the Working Group recommends that the following tiered approach be used when setting ABCs for ORCS:

- Apply depletion-based stock reduction analysis (DB-SRA) to a stock, if possible. The main limitation here is the requirement for a complete time series of historical catches, which is often not available.

- If it is not possible to apply DB-SRA, apply depletion-corrected average catch (DCAC) to a stock. DCAC's main limitation is that it is only appropriate for stocks with moderate to low natural mortality rates ($\leq 0.20\ yr^{-1}$).

- If DB-SRA and DCAC are not appropriate, apply the ORCS Working Group's Approach. The main limitation with this approach is that a number of critical decisions are required before it can be made operational. Some would also view this as an advantage, as it provides flexibility in its establishment.

- Finally, in some cases none of the above methods are practical for setting ABCs for an individual stock, as specific ORCS may not be capable of being effectively managed or monitored. In these cases, it may be best to use a stock complex approach. There are many limitations of applying a stock complex approach as described in this report, and the ORCS Working Group cautions against overusing or misusing this approach, as it may result in the converse of precautionary management, exactly what MSA was designed to avoid.

It is important to note that the methods for setting ABCs for ORCS are in various stages of development and will be better understood and improved upon over time. For that reason, a list of research recommendations is included in the report that highlights the most important activities that must be supported to make substantive progress in the future.

The Working Group emphasizes that none of the methods discussed in this report are a substitute for additional data and monitoring. Therefore, all of the methods impose a certain risk and imprecision that fisheries managers must acknowledge when using the results of these methods.

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Symbols and Abbreviations used in this Document

Δ	The expected proportional change in stock biomass from the first to the last year of the catch series in DCAC; the proportional reduction in biomass relative to K in DB-SRA
ABC	Acceptable biological catch
ACL	Annual catch limit
ACT	Annual catch target
AM	Accountability measure
B_*	Equilibrium biomass at some level of fishing mortality F_* in the Pella-Tomlinson production model
B_0	Virgin biomass
$B_{20\%}$	Biomass level that corresponds to 20% of the unfished biomass
B_{MSY}	Biomass that would produce MSY
B_{peak}	The ratio of B_{MSY} / K as used in DB-SRA
c	Natural variability factor used in natural mortality-based approach
CCAMLR	Convention on the Conservation of Antarctic Marine Living Resources
CFMC	Caribbean Fishery Management Council
CPUE	Catch per unit effort
DB-SRA	Depletion-based stock reduction analysis
DCAC	Depletion-corrected average catch
EC	Ecosystem Component
F_{MSY}	The fishing mortality that produces MSY
GMFMC	Gulf of Mexico Fishery Management Council
h	Steepness of the Beverton-Holt stock recruitment relationship
ICCAT	International Commission for the Conservation of Atlantic Tunas
K	Carrying capacity
M	Natural mortality
m	Maximum productivity (MSY) in the Pella-Tomlinson production model
MAY	Maximum average yield
MCY	Maximum constant yield
MFMT	Maximum fishing mortality threshold
MSST	Minimum stock size threshold
MSA	Magnuson-Stevens Act
MSE	Management strategy evaluation
MSY	Maximum sustainable yield
NEFMC	New England Fishery Management Council
NGO	Non-governmental organization
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration

NPFMC	North Pacific Fishery Management Council
NS1	National Standard 1
OFL	Overfishing limit
ORCS	Only reliable catch stocks
OY	Optimum yield
P*	Risk level; Probability of overfishing
PFMC	Pacific Fishery Management Council
PGY	Pretty good yield
PSA	Productivity Susceptibility Analysis
r	Intrinsic rate of increase
R_0	Virgin recruitment
SAFMC	South Atlantic Fishery Management Council
SD	Standard deviation
SSC	Scientific and Statistical Committee
TAC	Total allowable catch
Y_{AV}	Average catch used in natural mortality-based approach
Y_*	Annual equilibrium yield for the Pella-Tomlinson production model

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I. BACKGROUND

A. Requirement for ABC specifications and ACLs

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) of 1996 required Regional Fishery Management Councils (Councils) to end overfishing and rebuild overfished stocks. It strengthened US fisheries law by putting in place firm timelines for rebuilding and specified requirements for rebuilding plans. In 2006, however, the majority of overfished stocks were still not rebuilt and overfishing continued to be a widespread problem because fishery management plans failed to sufficiently reduce exploitation rates (Rosenberg et al. 2006). As a result, Congress amended the MSA during the 2006 reauthorization with requirements for annual catch limits (ACLs) and accountability measures (AMs) for each managed fishery by fishing year 2010 for all stocks experiencing overfishing and by fishing year 2011 for all other stocks in the fishery (DOC, 2007). The reauthorized MSA further strengthened the role of science in the fishery management process by requiring that ACLs set by Councils may not exceed the fishing level recommendations of the Councils' Scientific and Statistical Committees (SSCs).

In the 2009 National Standard 1 (NS1) guidelines, the National Marine Fisheries Service (NMFS) provided specific guidance on how to comply with the new requirements of the MSA, including limit and target reference points for fisheries (NMFS, 2009) (Figure 1). The OFL is the annual estimate of the catch that would be obtained if a stock were fished at a rate producing the long-term maximum sustainable yield (MSY); overfishing occurs when catch exceeds the OFL. The ABC is the upper limit at which Councils can set the ACL. The SSCs were designated with the responsibility to set the acceptable biological catch (ABC), which is the catch level that accounts for scientific uncertainty in the estimate of the overfishing limit (OFL) and other sources of scientific uncertainty. The NS1 guidelines further require each Council, in conjunction with its SSC, to establish an ABC control rule that specifies how ABC is calculated based on the scientific uncertainty in the OFL estimate and the Council's risk policy. These requirements apply to data-rich stocks that can be assessed through quantitative stock assessment models, as well as data-poor stocks that cannot be assessed with traditional stock assessment methods. This report focuses on the ABC requirements for stocks that have only catch history data available for estimating harvest limits. We refer to these stocks here as "Only Reliable Catch Stocks" (ORCS).

B. History of dealing with ORCS

The 1998 NS1 technical guidelines (Restrepo et al. 1998) recommended that Councils "*adopt a precautionary approach to specification of [optimum yield] OY,*" stemming from the 1996 MSA requirement to end overfishing and rebuild depleted fishery resources. The precautionary approach was implemented to reduce the risk of overfishing in circumstances where scientific evidence of overfishing was not available (Restrepo et al. 1998). As it was recognized that all regions possessed data of varying states of quality for stock assessment and management purposes, subsequent guidance provided an array of precautionary control rules that could be used to set exploitation targets below the risk-neutral limits based on MSY-related benchmarks, such as the maximum fishing mortality threshold (MFMT) and minimum stock size threshold (MSST) or reasonable proxies for one or both of these status determination criteria (Restrepo et al., 1998; Restrepo and Powers, 1999).

In the absence of biomass and fishing mortality reference points, the 1998 Technical Guidance (Restrepo et al., 1998) for implementing the NS1 guidelines suggested using the historical average catch from a period during which there was no evidence of declining abundance as a proxy for MSY. This recent catch would be multiplied by a scalar (ranging from 25% to 75%) based on "informed judgment" regarding the qualitative estimate of stock size relative to B_{MSY} (stock biomass at maximum sustainable yield) and MSST to obtain the limit catch, but the performance of this recommendation was never investigated (Restrepo and Powers, 1999). From discussions among members of this Working Group, however, it appears that many Councils have used a constant scalar (e.g., 50%, 75%) as their precautionary approach regardless of the stock's size relative to B_{MSY} and MSST.

C. Unique problem for ORCS

The 2009 NS1 guidelines state that the ABC should be based, when possible, on the probability of overfishing, which cannot exceed and should be less than 50 percent. The guidelines further require that "*the ABC control rule must articulate how ABC will be set compared to the OFL based on the scientific knowledge about the stock or stock complex and the scientific uncertainty in the estimate of OFL and any other scientific uncertainty. The ABC control rule should consider uncertainty in factors such as stock assessment results, time lags in updating assessments, the degree of retrospective revision of assessment results, and projections*". Thus, the NS1 guidance for setting ABCs is clearly directed towards stocks that can be assessed through traditional stock assessment methods. Many stocks under US federal management, however, lack current stock assessments and are not likely to be assessed in the near future, due to substantial data limitations. For example, the 2009 Report to Congress on the Status of U.S. Fisheries reported that "*272 stocks or stock complexes have overfishing thresholds not defined or applicable, or are unknown with respect to their overfishing status*".[1] In these data-limited situations, the guidelines are vague with respect to factors that could be considered for setting ABCs and simply suggest the use of reasonable proxies.

Many of the ABC control rules that are currently being developed in the regions follow a tiered approach in which the size of the buffer between the OFL and ABC increases as the level of

[1] NMFS 2009 Report to Congress on U.S. Fisheries, May 2010. Available online at http://www.nmfs.noaa.gov/sfa/statusoffisheries/sos_full28_press.pdf

scientific uncertainty increases (Witherell, 2010). Since uncertainty is expected to increase with decreasing availability of reliable data, it follows that data-poor stocks should generally have larger buffers than data-rich stocks for the same desired risk of overfishing. Without a system in place that monitors key fishery indicators and responds to changes in these indicators, scientists and managers have no means of evaluating whether any newly established catch limits for ORCS are too conservative or too liberal.

D. Catch vs. landings

These two terms are not synonymous, since catch is considered the landed catch plus the total amount of dead discard (i.e., bycatch). Too often an evaluation of historical catch becomes an examination of historical landings. Bycatch levels in other fisheries, as well as discard rates and discard mortality levels, should be discussed and factored into the evaluation of historical catch. Anecdotal information, fishermen's knowledge, and local expertise should be considered in such cases.

E. Formation of the ORCS working group

At the second National SSC meeting November 10-13, 2009 in St. Thomas, USVI, an ad-hoc Working Group was established to address the question of how to develop ABCs for data-poor fisheries under the jurisdiction of Regional Councils, where traditional stock assessment techniques cannot be applied due to data deficiencies.

The Working Group was established to identify, suggest, and evaluate alternative approaches for the setting of ABCs for ORCS. Working Group members represent seven of the eight SSCs, five of the six NMFS Science Centers, NMFS Headquarters, as well as a regional fishery management council, academic institutions, a state agency, and an NGO. The Working Group has communicated general process-related comments, as well as stock assessment and management ideas through email and teleconference.

The overriding goal of the Working Group was to develop an approach for addressing ABCs in ORCS that could potentially be applied in all jurisdictions under a flexible framework process. To this end, the Working Group reviewed existing methods that have been used both nationally and internationally to address data-deficient fisheries, and developed a hierarchy of recommended models or techniques for use in a particular fishery, given only that the fishery possesses a time-series of reliable catch data.

F. Scientific and management uncertainty in ORCS

Unlike the 1998 NS1 guidelines, the 2009 guidelines make the distinction between two types of uncertainty that are to be considered in the catch-setting process: management and scientific. Management uncertainty arises from uncertainty in quantifying the true catch amount and uncertainty in the ability of managers to limit actual catches to the ACL. Councils have the flexibility to account for management uncertainty by setting an annual catch target (ACT) at or below ACL. Scientific uncertainty has been discussed earlier, and deals with the estimate of the OFL and ABC.

While the two types of uncertainty are distinct, they are not independent because the realized catch affects abundance and consequently, future OFLs, which then feed back into ACLs (Shertzer et al. 2008). It is not always possible to distinguish between scientific and management uncertainty, especially in the case of ORCS, where total catches may be highly uncertain because of missing information regarding bycatch and discard mortality, affecting both scientific and management uncertainty. The NS1 guidelines allow for both scientific and management uncertainty to be incorporated into a single control rule, but ABCs by definition address only scientific uncertainty, which is the scope of this report.

G. Incorporating risk

It is the responsibility of stock assessment scientists and the SSCs to determine the level of scientific uncertainty that exists in an assessment or estimated level of sustainable yield, but it is the role of the Councils to determine the acceptable risk of overfishing given the scientific uncertainty. When the probability distribution around the OFL estimate can be computed and characterized, the median estimate of the OFL implies a risk level of 50 percent, which is the level of risk the NS1 guidelines state is not to be exceeded in setting ABC. When the OFL and its statistical distribution can be estimated, probability-based methods can be used to compute the ABC that corresponds to the Council-desired risk of overfishing (e.g., Prager and Shertzer 2010). In the case of most ORCS, quantitative estimates of reference points from assessment models are unavailable, and formal risk statements cannot be made because the uncertainty is often not quantifiable. In those cases, an adaptive approach to developing ABCs that involves monitoring key fishery indicators may need to be adopted.

H. Report outline

The report is divided into seven primary sections:

- Section I, which you are currently reading, provides background on ORCS, the need to set ABCs, and the difficulties specific to ORCS.

- Section II reviews existing national and international methods that are currently in use or in the process of being further developed. Each approach is briefly summarized followed by a description of the required data, the major assumptions and consequent cautionary advice in utilizing the particular approach, its potential for use in a risk-based decision-making framework, the status of the approach along with examples of its implementation, and finally, the pros and cons of using the approach as viewed by the Working Group.

- Section III introduces a new approach for setting ABCs for ORCS developed by the authors of this paper.

- Section IV examines the suitability of the previously described methods for setting ABCs for stock complexes and presents any necessary modifications, additional assumptions, or important caveats that need be considered prior to applying each approach to stock complexes.

- Section V provides a discussion of the topics raised in this paper.

- Section VI provides research recommendations to further our ability to understand, set ABCs for, and manage ORCS.

- The final section, Section VII, puts forth a set of recommendations to Councils and SSCs for moving forward in addressing the 2006 MSA mandate, under the 2009 NS1 guidelines, for ORCS.

II. REVIEW OF METHODS

A. Scalar approaches

1. Summary of approach

Scalar approaches involve specification of future catch by using simple scalar multipliers applied to current or historical catch patterns. The primary reference for this approach is Restrepo et al. (1998) who formalized the concept in their Technical Guidance document for the 1998 National Standard 1. Scalar approaches were presented in the sections of the document specifying catch targets and catch limits in data-poor situations (this is henceforth termed the Restrepo approach). Although Restrepo et al. (1998) is the primary citation for this particular set of scalar tiers, it is quite likely that the concept was widely used historically in fishery management. The Restrepo approach proposed scalar multipliers for catch targets ranging from 0.25 to 0.75, depending on the estimated stock status at the time. For example, if the stock was overfished and hence below the MSST, then the catch multiplier for the Restrepo approach was 0.25 with the intent to reduce fishing effort and allow the stock to rebuild. If the stock was above B_{MSY}, the multiplier was 0.75, which reflected the precautionary buffer between the catch target and catch limit, with the catch limit being status-quo catch levels in a presumed healthy fishery. For intermediate stock conditions the multiplier was 0.5.

2. Data needs

The Restrepo approach uses an average catch. In the original document this was defined as the average catch during a time period, not necessarily the most recent, for which there is evidence of stable abundance. Ideally, there should be no quantitative or qualitative evidence of declining or increasing abundance trends in the selected time period. We note that approaches for deriving catch recommendations for stocks with decreasing trends are developed in sections II.E and F of this report. In an optimal situation there is an adequate catch data stream to objectively identify such a time period, and may vary temporally in location and span for particular stocks and fisheries. Since it was realized that stock status information is not available in many data-poor cases, it was suggested to explore several definitions of recent catch such as the mean or median catch during the last 5, 10, or 15 years. In minimal data situations, the Restrepo approach could be applied to a single year of fishery catch data, but this is obviously a tenuous application unless the single year of data was highly significant for some reason. A logical extension of the variable scalar multiplier would be to similarly reduce the value for shorter catch data streams owing to likely greater uncertainty.

3. Informed judgment

Some type of expert or otherwise informed judgment is required for the Restrepo approach if stock status information is lacking, which would likely be the case for any potential application of the approach. This judgment is critical because an overfished determination can result in catch limits that are adjusted downward to a third of what could conceivably be taken if stock status was not judged to be in an overfished condition. Such a declaration of stock status is generally difficult even with strong quantitative support. Scientific judgments should be supported with as much objective analysis as possible. Careful examination of all available biological and fishery indicators is warranted. Even if a formal stock assessment is lacking, a diverse assemblage of data (including qualitative and anecdotal information) can be evaluated in a meta-framework to infer stock status (e.g., Porch et al., 2006). The Restrepo et al. document mentions a variety of similar alternative approaches such as informed judgments, Delphi approaches, qualitative approaches, expert opinions, and consensus-building methods. In addition, Bayesian statistical methodology is an appropriate tool for heterogeneous data and variable prior knowledge.

4. Caveats

The primary assumptions of the Restrepo approach are that the fishery is at or near a sustainable equilibrium, the stock is stable, and some qualitative determination of stock status is possible. However, without adequate information, it can be difficult to judge stock status, and, likewise, without a protracted period of near-constant and/or sustainable fishing effort and catches, it can be difficult to verify stability. If fishing effort is highly variable or if a fishery is in development or experiencing overfishing, then the catch data stream will be problematic for the Restrepo approach.

5. Risk assignment

Restrepo et al. (1998) conducted simulation modeling to explore what an appropriate default target catch control rule for data-adequate stocks might look like and found that fishing at 75% F_{MSY} resulted in equilibrium yields of 94% MSY or higher and equilibrium biomass levels between 125% and 131% of B_{MSY} while reducing the probability that the stock would decline to ½ B_{MSY}. Based on these results, the recommended default target control rule became fishing at 75% F_{MSY}. The data-poor proxy of this default rule for stocks judged to be above B_{MSY} thus became 75% of recent catch. Additional risk can be built into the approach by simply reducing the scalar multipliers. This is analogous to the catch limit and catch target differential multipliers in the 1998 technical guidance document. Biological and/or fishery information can be incorporated into the approach by using natural mortality rate or risk assessments like the PSA (productivity susceptibility analysis; Patrick et al., 2009; 2010) inputs to the scalar specification. These potential improvements will be discussed in forthcoming sections of text.

6. Status of approach

The Restrepo approach and variants thereof are used in the management of many fisheries across the nation. Scalar multipliers range from 0.25 to 0.75 consistent with the original guidance. There is considerable variability in the time window of recent catch ranging from 1 year to 18 years. The location of this recent catch time window also varies considerably from recent years to over 30 years into the past. As pointed out earlier, these parameters for the recent catch specification will have to be tailored to individual stocks and fisheries on a case-by-case basis.

Some examples of current use for ORCS:

- *The Pacific Fishery Management Council (PFMC) coastal pelagics ABC is specified using a scalar multiplier of 0.25 applied to average catch and scaled by proportion of stock available in U.S. waters.*
- *The International Commission for the Conservation of Atlantic Tunas (ICCAT) specifies total allowable catch (TAC) to be no more than the product of scalars of 0.33 for white marlin and 0.50 for blue marlin applied to 1996 or 1999 landings, whichever is greater. These reference years were chosen because they were thought to be particularly reliable. The scalars reflect the understanding of the recent level of overfishing, particularly for white marlin.*
- *OY for some PFMC groundfish stocks is specified using a scalar multiplier of 0.50 applied to average catch.*
- *The North Pacific Fishery Management Council (NPFMC) specifies ABC using a scalar multiplier of 0.75 applied to average catch from 1978-1995.*
- *The Caribbean Fishery Management Council (CFMC) specifies ABC and ACL using a scalar multiplier of 0.85 applied to average catch from 1999-2005 or 2000-2005 depending on the management area.*

- *The New England Fishery Management Council (NEFMC) used a scalar of 1.0 for ABC of Atlantic herring because a provisional analysis suggested that the stock was not overfished and overfishing was not occurring.*
- *The NEFMC also used a scalar of 1.0 for ABC of red crab because there was no evidence of depletion since the beginning of the fishery.*

7. Pluses/minuses of approach as viewed by Working Group

Some advantages of the Restrepo approach are that it a) is straightforward and therefore easily explained and understood by scientists, policymakers and stakeholders, b) can easily be applied even by those not specifically trained in stock assessment procedures, and c) is broadly applicable across species with different biological characteristics. Some of the disadvantages are that a) the appropriateness and performance of the recommended multipliers has not been evaluated, b) the assumptions of a stable stock which is at or near sustainable equilibrium can often not be verified, c) it is not suitable for application to an ORCS stock that is very lightly exploited since it does not allow for a catch limit larger than recent average catch, d) it does not explicitly account for species differences in productivity, and e) continued application could ratchet catch downwards as the recent average catch was forced to decline. The method was intended to be used as a short-term fix, until either additional data could be collected or an improved method could be developed.

B. Scalar multiplied by the ABC of the target species, when ORCS are bycatch species

1. Summary of approach

In one international arena, ORCS species believed to be exploited well below MSY levels and caught incidentally in directed fisheries are regulated in concert with the targeted species, based on a proportion (or harvest cap) associated with the targeted stock's quota. In those cases, the targeted stock's ABC is multiplied by a scalar, for example 5%, to obtain the ABC of the bycatch species. Management for these bycatch species focuses on collecting additional information to elevate these fisheries to a formal assessment status as soon as possible and thereby allow what may have started as an exploratory fishery to safely expand to a targeted fishery.

2. Data needs

The only data required to carry out this management approach is a catch limit for the targeted species of the exploited assemblage.

3. Informed judgment

Judgment is needed for deciding what the proportion of the targeted species' catch limit should be that serves as the scalar for determining the ABC of the bycatch species which requires expert opinion regarding the abundance of the bycatch stock relative to the target stock. The choice of scalars should be guided by the precautionary principle to avoid overfishing but should also allow for data collection and potential fishery expansion. Where this method has been applied, quotas have ranged from 5-16% of the targeted species' catch limit.

4. Caveats

The appropriateness of the chosen scalar cannot be known initially, and therefore, ongoing monitoring programs are imperative to the application of this general approach. Precise estimates of species composition from the landings, as well as observer data and fishery-independent survey data are necessary to ensure current proportional allocations for bycatch species are representative of recent resource/fishery dynamics and are ultimately sustainable.

5. Risk assignment

Although formal risk cannot be explicitly assigned in this straightforward method, the risk of overfishing bycatch species is considered to be relatively low by the management body implementing the approach. Higher landings caps imply higher risk of overfishing.

6. Status of approach

This approach is being implemented by the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). In most cases, all bycatch species associated with the directed fisheries have recommended harvest levels that are defined in accordance with the CCAMLR.

7. Pluses/minuses of approach as viewed by Working Group

The approach is very simple to apply, as it involves multiplying a scalar by the quota of a targeted species. Given species are selected because they are believed to be underutilized, it is assumed that there is a relatively low risk of overfishing using this method, but ultimately, there is little information to inform the initial choice of any particular scalar. Since this method sets an ABC for a group of species rather than an individual stock, it is a special case of a stock complex approach, which is discussed in Section IV of this report. If implemented correctly, the method allows for fishery expansion to occur slowly and in a coordinated fashion.

C. Natural mortality-based approach

1. Summary of approach

The natural mortality-based approach (Anon 2009) is another variant of a scalar approach. It is based on the formula:

$$MCY = c\ Y_{AV}$$

Where MCY is the maximum constant yield, c is the natural variability factor (defined below) and Y_{AV} is the average catch over an appropriate period.

If the catch data are from a period when the stock was fully exploited (i.e., fishing mortality near the level that would produce MAY [= Maximum Average Yield]), then the method should provide a good estimate of MCY. In this case, Y_{AV} = MAY. If the population was under-exploited, the method gives a conservative estimate of MCY.

The natural variability factor is defined as in Table 2. It is assumed that because a stock with a higher mortality rate will have fewer age-classes, it will also suffer greater fluctuations in biomass. The deviations from values of c in the table are for stocks where there is evidence that recruitment variability is unusually high or low.

2. Data needs

Familiarity with stock demographics and the history of the fishery is necessary for the determination of an appropriate period on which to base estimates of Y_{AV}. The period chosen to perform the averaging will depend on the behavior of the fishing mortality or fishing effort time series, the prevailing management regime, the behavior of the catch time series, and the lifespan of the species.

The period should be selected so that it contains no systematic changes in fishing mortality (or fishing effort, if this can be assumed to be proportional to fishing mortality). The period chosen should also contain no systematic changes in catch. If the period shows a systematic upward (or downward) trend in catches then the MCY will be under-estimated (or over-estimated). It is desirable that the period be equal to at least half the exploited life span of the fish.

An estimate of natural morality is required to obtain the value of c, the natural variability factor. Knowledge of recruitment variability levels is needed to modify the natural variability factor, if necessary.

3. Informed judgment

In many cases informed judgment will be needed to select the period chosen to perform the averaging, as all of the information required to adequately select the period may not be available.

4. Caveats

The primary assumptions of the natural mortality-based approach are that the fishery is at or near a sustainable equilibrium and the stock is stable. However, it can be difficult to estimate stability without a protracted period of near-constant and/or sustainable fishing effort and catches. If fishing effort is highly variable or if a fishery is in development or experiencing overfishing, then the catch data stream will be problematic for this approach.

5. Risk assignment

Risk is incorporated through the use of the natural variability factor, which takes into account the natural mortality of the stock. It is assumed that because a stock with a higher mortality rate will have fewer age-classes it will also suffer greater fluctuations in biomass. In addition this can be modified where there is evidence that recruitment variability is unusually high or low.

6. Status of approach

The approach is currently being implemented for ORCS in New Zealand.

7. Pluses/minuses of approach as viewed by Working Group

The natural mortality-based approach has limited potential for application in the U.S. It is not designed for stocks that are currently in an overfished state. It is designed for stocks that have either been fully exploited or under exploited. It does not take into account cases where stocks have been over-exploited (overfished). Further, it requires a time period of stable catch, which may not be available for all stocks. Shorter life spans are viewed as inherently more risk prone and difficult to manage effectively, given they exhibit greater population fluctuations, requiring a smaller scalar to account for the increased risk. Other factors affecting risk are not incorporated into the method. The method has not been evaluated

D. Depletion-Corrected Average Catch (DCAC)

1. Summary of Approach

Restrepo et al. (1998) provide guidance on estimating sustainable catch in situations where only a catch time series is available, suggesting that a sequence of relatively constant catches is evidence that the average annual harvest is sustainable. Although this approach can be useful for providing catch advice for data-poor stocks, the inference of sustainability is only true if both fishing mortality and stock abundance are stable during the period in question. A constant catch could be produced during a period of increasing fishing mortality and decreasing stock abundance, in which case the catch may not be sustainable. Nonetheless, Restrepo et al. (1998) argued that an average catch taken from a time period of stable harvest is a useful proxy estimate of sustainable yield.

MacCall (2009) developed an approach that allows for changing population abundance during the period when catches are obtained. He described the method as "depletion-corrected average catch" (DCAC) because it accounts for the windfall augmentation of catch that occurs due to a one-time reduction in standing stock, also known as "fishing up." Conveniently, the method works just as well if a stock is increasing in abundance during the time interval. Fundamentally, DCAC is based on the premise that knowledge of natural mortality (M) is informative of F_{MSY}, a reasonable prior for relative B_{MSY} (B_{MSY} / B_0; B_0 = virgin biomass) is available, and some view of relative stock depletion can be obtained.

2. Data needs

The basic DCAC calculation requires: a) an average catch calculated over some period of years, b) an estimate of natural mortality, which may be obtained from the relationship between longevity and M developed by Hoenig (1983) or other indirect methods, c) an estimate of the ratio of F_{MSY} to M, which MacCall (2009) argues is typically in the range of 0.6–1.0, and d) an idea of how much stock abundance may have changed during the time period when catch statistics are summarized. This last input value is termed Δ and represents the relative decline (or increase) in stock size, with a larger value representing a greater decrement to the stock. In addition, the method has recently been generalized to include a prior distribution for relative B_{MSY} (Stock Assessment Toolbox; http://nft.nefsc.noaa.gov/index.html).

3. Informed judgment

The DCAC method is a generalization of the average catch approach because an adjustment is made for changes in stock size (Δ). This is, however, a quantity that is difficult to obtain, and expert opinion must be used to decide on relative stock status. Likewise, informed judgment may be helpful in deciding on the ratio of F_{MSY} to M and B_{MSY} to B_0. Prior distributions for Δ, ratio of F_{MSY} to M and B_{MSY} to B_0 could be based on meta-analysis for related stocks, rather than expert opinion.

4. Caveats

DCAC assumes that the catch statistics used in the calculation are unbiased. Also, the method is only appropriate for stocks with moderate to low natural mortality rates ($\leq 0.20\ yr^{-1}$) because the depletion correction becomes negligible at higher values of M. Moreover, in its initial implementation the calculation assumed that relative B_{MSY} occurs at 0.40. While this is a robust proxy supported by the simulations conducted by Clark (1991), the newest version of the calculation (i.e., the NOAA Fisheries Stock Assessment Toolbox) allows the user to specify a prior distribution for this quantity.

5. Risk assignment

Propagation of uncertainty is a strong point of the DCAC method, which is accomplished by Monte Carlo simulation based on draws from distributions of the key input quantities. In particular, the principal inputs (M, F_{MSY}/ M, B_{MSY}/ B_0, and Δ) are specified as distributions. Importantly, MacCall (2009) provides a variance statistic for M based on reanalysis of the data summarized in Hoenig (1983). The result of the algorithm is an output distribution of catch that would have been sustainable over the specified timeframe, conditional on the input distributions, which can be used as a basis for risk assessment (Figure 2).

6. Status of the approach

The NEFMC and its SSC evaluated an application of DCAC to deep-sea red crab and concluded that because it provides an estimate of a sustainable yield and not MSY, it was inappropriate to use in calculating OFLs. Moreover, because survey information did not indicate that the population abundance of red crab had changed between 1974 and 2005, no depletion correction was required and an ABC was set based simply on average landings during that time period.

Because the DCAC calculation utilizes a sum of catches calculated over a period of years, the PFMC endorsed its use in developing OFLs for seven groundfish stocks that are characterized by erratic and/or incomplete catch histories. Those stocks included six rockfishes (*Sebastes* spp.) and one elasmobranch (i.e., blue rockfish, blackgill rockfish, gopher rockfish, honeycomb rockfish, Mexican rockfish, squarespot rockfish, and soupfin shark).

7. Pluses/minuses of approach as viewed by Working Group

There are a number of appealing features of the DCAC method, including: a) it is based principally on catch statistics and basic life history information, b) the catch time series need not be comprehensive, c) stock abundance is explicitly allowed to vary, d) the method's inputs are approximate and are specified as distributions as opposed to point estimates, and e) uncertainty is propagated to produce a distribution of sustainable yield. Some of the disadvantages of the approach are: a) the estimated yield is typically sustainable, but not maximal, b) expert opinion is required to characterize stock depletion, and c) the estimated yield may not be sustainable if the stock at the end of the time series is not representative of the production that occurred during the time series (i.e., it is severely depleted).

E. Depletion-Based Stock Reduction Analysis (DB-SRA)

1. Summary of Approach

Depletion-Based Stock Reduction Analysis (DB-SRA) is an extension of DCAC that incorporates full stock dynamics (Dick and MacCall, In press). At a basic level stock production is the product of *per capita* production (= productivity) scaled by the total size of the population. For example, under Beverton-Holt spawner-recruit dynamics these quantities are represented by steepness (h) and virgin recruitment (R_0), respectively. Likewise, under a Schaefer surplus production model they are equal to the intrinsic rate of increase (r) and the carrying capacity (K). The DB-SRA method relies on specifying a plausible range of "scaled" production parameters and depletion levels in the form of prior distributions. Then, given the availability of a comprehensive catch history to scale the problem, virgin biomass can be uniquely calculated, conditional on each draw from the input distributions.

2. Data needs

Because the DB-SRA method is fully dynamic, a complete history of removals is required, i.e., annual catches from the beginning of the fishery are needed. Moreover, the method, at least in its current form, has been implemented as a delay-difference production model (Quinn and Deriso, 1999) and age-at-maturity is used to lag recruitment relative to production. Beyond those fixed inputs, the technique depends on the same four "prior" input distributions as DCAC, including: a) natural mortality (M), b) the ratio of F_{MSY} to M, c) the ratio of B_{MSY} to B_0, and d) stock depletion (Δ). The DB-SRA method is also formulated in a way that provides considerable independence between F_{MSY} and B_{MSY} by implementation of a generalized production function (Fletcher 1978; McAllister et al. 2000; Dick and MacCall, In press).

As with DCAC, F_{MSY} is scaled relative to the natural mortality rate, and the product of the scalar and M provides an estimate of F_{MSY}. By also drawing an estimate of relative B_{MSY} from its input distribution, production is then completely specified on a relative biomass basis. Next, the time series of catches and a random draw from the depletion distribution (Δ) are used to scale biomass and solve for the unique value of B_0 and current biomass that satisfy all conditions (Figure 3). Of course in some instances the time series of catches is impossible with the random draws from the input distributions and the population trajectory goes negative. Those realizations are considered biologically implausible and are dropped from the collection of feasible outcomes (see also Walters et al. 2006). The process is repeated numerous times and posterior distributions of B_0, $B_{current}$, MSY ($F_{MSY} \times B_{MSY}$) and OFL ($F_{MSY} \times B_{current}$) are summarized from the individual results.

3. Informed judgment

The DB-SRA method further generalizes DCAC and, like that method, requires expert opinion to provide a general idea of stock depletion at some point in the catch time series. However, the depletion distribution can be somewhat vague and/or uninformative without great loss in performance. Likewise, informed biological judgment is needed to provide the initial input distributions for the ratios of F_{MSY} to M and B_{MSY} to B_0. However uncertainty in those distributions can be captured explicitly in their variances and they are biological characteristics that can reasonably be informed by conventional scientific wisdom.

4. Caveats

Other than assumptions associated with generating the four key input distributions, the DB-SRA method is very general. In particular, the implementation of a generalized production function that uncouples F_{MSY} from B_{peak} allows a broad range of models to be explored. Also, the method is robust to stochastic variation in stock recruitment, as long as recruitment is not highly episodic or strongly autocorrelated. Nonetheless, the method requires the user to provide four distributional inputs, which can be difficult to specify. No doubt the most troubling of these is the depletion (Δ) distribution, which is perhaps the main output statistic obtained in a data-rich stock assessment; requiring it as an input would seem to undermine the utility of the DB-SRA approach. In practice, however, the same type of inference is required of all ORCS methods (see above), but with DB-SRA it is expressed quantitatively as a distribution. The obvious benefit of this is that the prior distribution of Δ can be vaguely specified, which is to say the variance about the mean of the distribution implies that not much is actually known about depletion. Also, given that the approach incorporates depletion as an input, it is not an appropriate method for determining relative stock status; rather its strength is in yield estimation (MSY and OFL). Finally, the method requires a complete time series of total catch (landings + discards) to implement. To the extent that discards are underreported or not accounted for the method will produce biased results.

5. Risk assignment

Expression and depiction of uncertainty is a major goal of the DB-SRA method and is accomplished by Monte Carlo simulation of four input distributions through to the output distributions of management concern, i.e., current biomass, F_{MSY}, unfished biomass, and OFL. An example of how uncertainty and risk are characterized within the DB-SRA framework is given in Figure 4, which shows the probability of overfishing for brown rockfish (*Sebastes auriculatus*) from 1920 to the present, as well as the posterior distribution of OFL values for 2011 (Dick and MacCall, 2010). Given a distribution of OFL, it is possible to develop a control rule that maps ABC onto the probability of overfishing, a direct expression of scientific uncertainty.

6. Status of the approach

In 2010, the PFMC SSC endorsed the use of DB-SRA to estimate OFLs for 42 groundfish stocks, including 34 rockfishes (*Sebastes* sp.), four flatfishes (Pacific sanddab, rex sole, rock sole, and sand sole), one roundfish (kelp greenling), two elasmobranches (leopard shark and dogfish), and one complex (grenadiers). All data-poor rockfish stocks are managed within assemblages that are defined based on: a) distribution north or south of Cape Mendocino (lat. 40°10'N), and b) cross-shelf distribution (nearshore, shelf, or slope). These 42 stocks include approximately half of the species listed in the PFMC Groundfish Fishery Management Plan and the development of OFL estimates for these species represents a significant improvement in the scientific information used to manage these stocks.

The medians of the bias-corrected posterior distributions of OFL were used by the PFMC as stock-specific point estimates of OFL. These were aggregated into single OFLs for each assemblage, and a semi-quantitative estimate of scientific uncertainty was endorsed for the DCAC and DB-SRA methods by the Council's SSC (i.e., quadrupling the uncertainty of Tier 1, data-rich assessments). The Council also established a policy on buffering all groundfish ABCs below their OFLs by limiting the probability of overfishing (P*) to ≤ 0.45. Harvest specifications for the 2011-2012 biennial fishing cycle are being developed under this general paradigm.

The DB-SRA method has been coded in R (R Development Core Team, 2009) and is documented in two manuscripts. The first of these describes application of the method to 31 different Tier 1 stocks and compares estimates of OFL, MSY, and B_0 from DB-SRA to those obtained from a full data-rich stock assessment, which have typically been conducted using the maximum likelihood based, integrated Stock Synthesis model (Dick and MacCall, In press). The second publication describes and documents the application of the DB-SRA method to the 42 data-poor, Tier 3 groundfish stocks listed above, including development of bias-corrections based on PSA and performance relative to data-rich stock assessments (Dick and MacCall, 2010).

7. Pluses/minuses of approach as viewed by Working Group

Like DCAC, DB-SRA is based principally on catch statistics and basic life history information, uses inputs that are approximate and are specified as distributions as opposed to point estimates, and allows for the propagation of uncertainty to produce a distribution of sustainable yield. The method was evaluated by comparison of OFL estimates from DB-SRA to those from 31 data-rich stock assessments. Results of that comparison showed that DB-SRA sometimes underestimates and sometimes overestimates OFL for individual stocks. As might be expected, the bias in OFL depended on PSA scores associated with each of the stocks. In particular, DB-SRA applied to flatfish generally underestimated OFL by a factor of 0.55. For high vulnerability non-flatfish stocks DB-SRA was largely unbiased, whereas for low vulnerability non-flatfish stocks the method underestimated OFL by a factor of 0.83. These biases were quantified and applied as an adjustment in estimating OFL for the 42 data-poor stocks by the PFMC. A primary disadvantage is that this method is rather time and resource-extensive and requires application by trained stock assessment scientists. In addition, for many ORCS species, it may not be possible to fully reconstruct catch history.

F. The Methot Table Conceptual Framework

1. Summary of approach

During the second National SSC meeting, NMFS's Rick Methot gave a presentation on the 2009 NS1 guidance regarding ACLs and the treatment of scientific uncertainty. In that presentation, a table was provided that showed an example of how ABCs might be set in catch-only situations. The original purpose of this conceptual framework was to generate discussion and inspire thought. The structured approach that it offered has since been used in discussions in different parts of the country to base ABC recommendations on, and the working group therefore deemed it appropriate to review the method here. The table, which we refer to here as "the Methot table conceptual framework", is based on the same basic concept as the Restrepo approach and requires an expert evaluation of fishery impact. The Methot table generates four fishery impact categories of historic catch: trivial, small, moderate, and moderately high and proposes a possible action for ABC determination for each (Table 1). The first impact category highlights the fact that trivial catches of non-targeted species are unlikely to affect the species population status and under these circumstances the Council should consider listing these species as "Ecosystem Components" (EC species) within their fishery management plan. EC species are not required to specify OFL, ABC, or ACL thresholds; however, their catch levels should be monitored to ensure they are not targeted by the fishery in the future. If historic catches are judged to be small (the second impact category), it is assumed that the stock is not overfished and that the target catch could be set at the historic level while setting ABC and ACL above that. If historic catches are moderate, the fishery should be capped because any increase in catches might mean the stock could become overfished. If historic catches are moderately high, the stock might be overfished and recent catches should be considered as the limit. In that case, ABC would be set below recent catch levels to allow the stock to rebuild. The approach is fairly qualitative in that it does not provide specific methods for calculating the degree to which catch should be set above or below historic levels. Methot does suggest that a stock's vulnerability should be a consideration.

2. Data needs

The data needs for this method are similar to the Restrepo approach. Catch history is required along with any information that may help to determine stock status from the catch data. In addition, vulnerability information is recommended. Vulnerability can be determined through risk assessments such as the PSA analysis that evaluates a stock's productivity and susceptibility to the fishery (Patrick et al. 2009, 2010). The final vulnerability score could be a factor in the setting of a scalar used to multiply recent catch; the scalar would be lowest for the most vulnerable species and highest for the least vulnerable species, scaled to fit within some predetermined range. This relates the level of allowable catch directly to the biology of the species.

3. Informed judgments

At the onset, expert judgment is needed in order to assign species to one of the four impact categories, analogous to the judgment call needed for the Restrepo method for determining stock status with respect to MSST and B_{MSY}. In addition, informed judgment is needed to determine how much the ABC should be set above or below historic catch levels, and a judgment call is also needed to determine what the appropriate period of recent or historic catch is relative to which ABCs should be set.

4. Caveats

Although the Methot method does not make any explicit assumptions about stock stability or fishery equilibrium, the period of historic or recent catch used to determine future ABCs could have potentially large impacts on the final ABC that is calculated. Moreover, this method in its current state of development provides only qualitative statements about relative catch. Establishing absolute values or formulas for how much to increase or decrease OFL from historic catch in the case of low or moderately high impact, respectively, and how vulnerability is used as a relative scalar would still need to be fleshed out.

5. Risk assignment

Risk for this method could be assigned by setting boundaries on how much ABC can be increased or decreased from historic catch. For example, in the case of low historic catch, it would be less risk-prone to specify that ABC can be maximally 50% higher than historic catch instead of 100% higher. Similarly, in the case of moderately high historic catch, higher reductions in ABC translate into a higher probability that the stock will rebuild quickly than low reductions. Risk could also be assigned by deciding how much weight should be given to vulnerability. The PSA risk categories of low, medium and high could be converted into discrete scalars, and how much these scalars differ is a reflection of how much more risk one is willing to take for less vulnerable species.

6. Status of approach

A variation of this approach is currently being developed by the SSC of the Gulf of Mexico Fishery Management Council (GMFMC). The current Gulf ABC control rule consists of three tiers, the lowest of which contains the ORCS. The Gulf SSC is considering only two of the four dimensions from the Methot Table Conceptual Framework: small and moderately high impact (tier 3a and 3b, respectively). In the case of small impact, recent average catch over a stable period would be designated as the target catch, ABC would be set at either 0.5, 1, or 1.5 standard deviations (SDs) above the target, and OFL will be set at 2 SDs above that target. The rationale for setting OFL at 2 SDs above the mean is that this will result in only a 2.5% probability of catches in any given year exceeding and OFL so defined. The choice of SD level for ABC reflects a choice of risk because even though the SSC would recommend that target catch be set at the mean of recent average catch, the ultimate setting of ACT and ACL rests with the Council, and the Council could choose to set both equal to ABC, in which case an ABC of 0.5 SDs above the mean would constitute a less risk-prone upper limit than an ABC set at 1.5 SDs above the mean. In the case of moderately high impact, the GMFMC SSC approach would set OFL equal to the recent average catch and ABC would be set at 65%, 75%, 85%, or 100% of the OFL. Neither GMFMC tier 3a nor 3b currently use species vulnerability as part of their ABC considerations.

7. Pluses/minuses of approach as viewed by Working Group

The Methot Table Conceptual Framework represents a general approach for addressing ORCS and offers only qualitative advice for adjusting the magnitude of future catch limits with respect to recent catches. This can be advantageous in that it allows flexibility in regional application but it is also a drawback in its lack of specificity because it could result in potentially inappropriate application of the concept. As the GMFMC SSC has found out, the expression "the devil is in the details" seems to hold true, in taking an intuitive concept and making it operational. Like the Restrepo approach, the Methot Table Conceptual Framework is intuitive and easy to explain and therefore extremely useful for scientists, policymakers and stakeholders. Another advantage is that it takes into account species vulnerability, thereby acknowledging the differences in resource response to exploitation. It can also be applied to stocks for which there is evidence that exploitation levels can be increased safely, and time and resources needed to apply this method are minimal because data needs are small and it does not require application by highly trained stock assessment scientists. The method's performance has not yet been tested in either simulations or application.

III. The ORCS Working Group Approach

A. Introduction

While this report has already summarized several control rules based on average catch scalars, the Working Group felt that the existing scalar approaches lacked a solid technical basis and that inadequate guidance had been provided for their application, leading to widespread misuse. Therefore, the Working Group developed a new control rule for the managers and scientists to address these issues. The proposed control rule for catch-only stocks builds on methods in Restrepo et al. (1998) and the Methot Table Conceptual Framework (summarized in Witherell 2010 and reviewed in section II F of this report). The Restrepo et al. (1998) approach assigns stocks to one of three status categories (less than MSST, between MSST and B_{MSY}, and above B_{MSY}) and uses a different average catch scalar for stocks in each category. The scalars are intended to be precautionary, so it would be difficult to use the Restrepo et al. (1998) approach in the new OFL/ABC framework where scientific uncertainty is explicitly taken into account. The new approach presented here also uses different scalars for three stock status categories, but defines the categories differently, and develops a scoring procedure for assigning stocks to these categories. Alternative buffers are proposed to account for scientific uncertainty in setting ABCs, since this is regarded as a policy decision.

The Working Group is fully aware that these methods rely heavily on assumptions and expert judgment, and are not intended to be a substitute for quantitative information on stock status and trend. Nevertheless there is a need for robust methods that provide useful scientific advice in less than ideal situations. Our goal is to improve on existing methods and provide a structured and transparent approach, but we recognize that further improvements are probably needed. With these caveats in mind, the basic approach is the following:

1. Assign stocks to one of three exploitation categories using an evidence-based scoring procedure;
2. Obtain an OFL by multiplying a statistical measure of historical catch (e.g., mean, median, maximum, minimum, percentile, etc.) by a scalar that depends on 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 (see Patrick et al., 2009; 2010).

B. Assigning stocks to exploitation categories

Stocks can be grouped into three broad exploitation categories for which different management objectives apply (Table 3): 1) lightly exploited; 2) moderately exploited; and 3) heavily exploited. For stocks that are considered lightly exploited, catches could generally be increased without harm to the stock. For stocks that are considered moderately exploited, management objectives will focus on maintaining status quo catch levels, and preventing non-sustainable increases. For stocks that are considered heavily exploited and possibly overfished, the management objective is to end overfishing and rebuild the stock to B_{MSY} levels as mandated by the MSA.

1. Background

The concept of 'pretty good' yield (PGY) provides a theoretical basis for broadly classifying stocks into exploitation categories. This concept, proposed by Alec MacCall and developed further by Hilborn (2010), is based on the observation that a large percentage of maximum sustainable yield (>80%) can be produced on a long-term basis over a broad range of stock sizes. This concept is particularly meaningful in data-limited situations, since it implies that successful management outcomes are possible even if stock status is not known precisely. To illustrate the PGY concept and to develop a technical basis for catch multipliers, a Pella-Tomlinson production model was used. The Pella-Tomlinson model duplicates the results of the more complex age-structured model used by Hilborn (2010), but allows equilibrium yield to be calculated directly for any percentage of unfished stock size.

Annual equilibrium yield (Y_*) for the Pella-Tomlinson production model is:

$$Y_* = \frac{\gamma\, m}{B_0} B_* - \frac{\gamma\, m}{B_0^n} B_*^n,$$

where:

$$\gamma = \frac{n^{n/(n-1)}}{n-1},$$

m is maximum productivity (MSY), B_0 is unfished biomass, and B_* is equilibrium biomass at some level of fishing mortality F_*, with $Y_* = F_* \; B_*$ (Quinn and Deriso 1999). Setting n = 1.2 results in a B_{MSY} that occurs at 40% of the unfished stock size, which is often considered a reasonable default value (Clark, 1991). For these assumptions, equilibrium stock abundance in a range from $B_{19\%}$ to $B_{65\%}$ of the unfished biomass provides at least 80% of the MSY yield on a sustainable basis (Figure 5). Stocks above this range would be considered lightly exploited, while stocks below this range would be considered heavily exploited (i.e., overfished). These results are comparable to those obtained by Hilborn (2010) for an age-structured population. Special cases of the Pella-Tomlinson model are n=2, which becomes the Graham-Schaefer production model where B_{MSY} is 50% of unfished biomass, and $n \rightarrow 1$, which translates to the Fox production model where B_{MSY} is approximately 37% of unfished biomass.

2. Guidelines for assigning stock status

Status assignments based on historical catches will not have the benefit of a stock assessment, but will instead need to rely on 'expert' judgment. Experts in this context are those with experience conducting research, working on management issues, or participating in a fishery, and may include scientists, fishery managers, fishermen, and other involved parties. It will be important to be as comprehensive as possible when making status assignments and evaluate multiple lines of evidence. Given the absence of definitive information, the effort to generate these assignments may not be straightforward. It is important to note that that the overriding goal here is simply to assign stocks to very broad status categories with acceptable accuracy (e.g., say greater than a 70% success rate), recognizing that some inappropriate assignments will be inevitable.

An evidence-based scoring procedure (Table 4) has been developed to help assign stocks to the different status categories. This table incorporates some of the susceptibility elements in a PSA analysis (Patrick et al., 2010), as well as several new elements. The susceptibility scores in PSA evaluate the likelihood that a stock is captured in a fishery and the probable levels of fishing mortality, but PSA also includes productivity scores as a second dimension that takes into account the consequences of stock becoming overfished. In the framework we develop, productivity is considered separately when setting a buffer between OFL and ABC. While scoring procedures are a relatively recent development in fishery management, multi-attribute scoring algorithms have been used to evaluate the risk of species extinction (see Musick, 1999 and Dulvy et al., 2003). Multi-attribute scoring algorithms are also used in the medical field for making diagnoses and deciding treatment plans (Ebell, 2001). Elements of the evidence-based scoring procedure are described below.

Overall fishery exploitation based on assessed stocks. In general, the characteristics of the fishery in which the stock is caught are the most important factor to consider when assigning stocks to exploitation categories. If there are assessed stocks in the fishery, are they mostly overfished, moderately exploited, or are most lightly exploited? Unless there are reasons to think that the stock is more or less vulnerable than assessed stocks, it may be reasonable to assign it the same status as an associated stock that has been assessed. Certain habitats may have an overall level of exploitation that can be used to infer the status of unassessed stocks that live in that habitat.

Presence of natural or managed refugia. A stock that is fished throughout its range is more likely to be impacted by fishing than a stock that is fished only in a portion of its range. Species with extensive natural or managed refugia are unlikely to become severely depleted. This consideration would only apply to species that are not highly mobile as adults in relation to size of the refugia.

Schooling, aggregation, or other behavior responses affecting capture. This element encompasses both the behavioral response of individual fish to fishing gear and group behaviors that affect capture such as schooling or aggregating for spawning in known locations. Individual responses may include, for example, herding or gear avoidance behavior that would affect catchability.

Morphological characteristics affecting capture. This element pertains to the ability of the fishing gear to capture fish based on their morphological characteristics. For example, are there aspects of morphological characteristics affecting capture (i.e., large spines) that could make the fish more or less susceptible to capture? Because gear selectivity varies with size and age, this measure should be based on the age or size classes most representative of the entire stock.

Targeted species or Bycatch; and rarity. Targeting behavior by the fishery may help inform stock status assignments. Targeting may be inferred if a species has high commercial value or is considered highly desirable in a recreational fishery. Stocks that are caught primarily as bycatch in fisheries that target other stocks are likely to be lightly exploited relative to the targeted stock. However a non-targeted stock may still become overfished if it is much less productive than the targeted stock. Some stocks are simply too rare to be targeted, and would tend have low fishing impacts.

Natural mortality compared to targeted species in the fishery. This element provides a relative gauge of the stock's productivity compared to the dominant or targeted species in the fishery. Generally, for stocks subject to similar fishing mortality rates, those with low natural mortality have a higher likelihood of becoming overfished than those with higher natural mortality.

Value or desirability. Highly valued fish stocks are more susceptible to overfishing or becoming overfished by the recreational or commercial fishery due to targeting behavior with the goal of maximizing profits or non-market value. To identify the value of the fish, we suggest using the approach of Patrick et al. (2010) who used price per pound, or retention rates for recreational fisheries.

Trend in catches and effort. Finally, trends in historical catches may also be informative under some circumstances. If fishing effort is stable, a declining trend in catches may be an indicator of stock depletion. Again, if effort is not increasing, stable or increasing catches are an indication that the stock is exhibiting resiliency and not likely being severely impacted by fishing, but caution is warranted when interpreting catch patterns in the absence of other indicators and sources of data. Qualitative measures of effort, such as the number of active vessels or employment in the fishery, are likely to be all that are available for data-poor stocks, but may be misleading if there are technological advancements in the fishery. Increasing catches could also be an indication of fishery expansion, i.e., a stock that is transitioning from lightly exploited to moderately or heavily exploited status.

The evidence-based scoring procedure provided (Table 4) includes default-scoring thresholds; however, we realize that revisions to the scoring procedure will likely be needed in different regional ecosystems and recommend that the scoring table be used flexibly. A starting point would be to assign status using the arithmetic mean of all attributes that can be scored, but weighting factors could be considered, or taking the geometric mean rather than the arithmetic mean. Careful consideration should be given to the logistics of scoring stocks. One possibility would be to assemble a core group of scientific experts that draws on information from formally appointed advisors that may include fishery managers, fishermen, and other knowledgeable individuals. Through trial and error techniques, it may also be useful to separate the scoring process into two steps by first ranking stocks along a continuum from lightly exploited to heavily exploited, and then identifying the break points between the lightly exploited, moderately exploited, and heavily exploited categories. Given management implications of identifying the break points, a higher-level science advisory body, such as the Regional Council's SSC, may be more appropriate for this task.

C. Determining an appropriate catch statistic for an OFL calculation

Calculating the OFL using the ORC methodology is based on two terms: a scalar (or multiplier) that is based on the stock status category (described above), and a catch statistic derived from a time series of historical catches. Ideally, historical catches should represent a period with a stable harvest rate, i.e., a harvest rate where fishing removals are balanced by stock production and the stock can be assumed to be in a steady state condition or at its long term equilibrium. Stability in catches should be considered relative to the longevity of the stock. Catches of a long-lived species can be stable over a long period even though the stock is declining during this period. Although historical catches can be very stable with low variability, more often they are highly variable, sometimes with large outliers, or could be characterized by alternate periods of stability and periods of high variability or strong trends. Catches of relatively uncommon stocks can vary for a number of reasons unrelated to increases or decreases in abundance. These stocks may be incidental catches in fisheries that target other stocks or are minor members in a multispecies complex. The greater or lesser occurrence of a stock in the catch could be a chance event, caused by changes in the spatial or ecological overlap between that stock and other stocks that are more actively targeted in the fishery. Furthermore, fishery sampling programs can produce imprecise estimates of catches of stocks that are relatively uncommon. Evaluation of historical catch should include discussion of data quality and potential bias of catch estimates. If landings are highly variable, an attempt should be made to identify the reason for the variation and evaluate implications on the sustainability of historical catches. Other potential reasons for high fluctuations or outliers could be species misidentification, underreporting, effort variability, gear changes, or changes to the regulations for targeted species.

Although in many cases taking the arithmetic mean of historical catches is appropriate for an OFL calculation, the use of an alternative catch statistic may be needed in some situations to provide useful results. Several issues are described below, and suggestions presented for dealing with them are provided.

1. Outliers

In some cases, catch time series include extreme outliers that cannot be fully supported or rejected with available information. Several approaches to handling outliers are possible. First, a trimmed mean can be used (i.e., the inter-quartile mean) when the extreme values are considered unreliable. A similar approach would be to use the Winsorized mean, which is obtained by replacing all the values greater than or less than some quantile of catches by the largest (or smallest) of the remaining values. Usually 10 or 25 percent of the tails of the distribution are replaced. This approach would be appropriate when the extreme values are thought to carry some information about the catch quantity, but their actual values are considered unreliable.

2. Avoiding a ratchet effect

If catches are highly variable, the use of average catch as an OFL may be more constraining than is necessary, particularly when stocks are considered lightly or moderately exploited. When the management objective is to maintain current catch levels, setting the OFL equal to average catch could have the negative effect of depressing the mean level of the catch in the future, since presumably the management measures will need to prevent catches from exceeding the OFL, thereby truncating half of the distribution that was used to calculate the historical average. One possibility is to define the OFL to be some upper percentile of the historical catch, e.g., the 75% percentile of historical catch, with the rationale being that such a value would be exceeded on average one year in four if the fishery was prosecuted similar to historical patterns. Using the maximum catch is another alternative to average catch, but this should only be considered for non-target species with compelling evidence that they are lightly exploited. A similar approach has been proposed by the GMFMC SSC to, in some situations, base OFL on average catch plus two standard deviations (97.5 percentile), but it is unclear whether this approach provides sufficient constraint to prevent stocks from becoming depleted.

3. Recent trends

The theoretical development of average catch multipliers assumes that stocks are in equilibrium at some level of biomass, but this is necessarily an approximation to the real world, and in some cases it may be an inappropriate assumption from which to proceed. When there are downward trends in the landings, the safest approach (i.e., the most precautionary approach) would be to use an average based on the more recent lower values. However, if the downward trend in catches can be clearly linked to a reduction in effort, as when management restrictions are implemented for other species in a multi-species fishery, average catches from an earlier period may be more appropriate. If catches are trending upwards, using an average over all years may be the most reasonable approach.

D. Obtaining OFL scalars for different exploitation categories

When catch trends are stable and the stock is considered to be moderately exploited, setting the OFL to current catch levels is an appropriate action. For these stocks, a multiplier of 1.0 is recommended for the OFL.

For stocks that are considered to be heavily exploited, fishing mortality will need to be reduced to at least F_{MSY} to end overfishing and begin rebuilding the stock to levels closer to B_{MSY}. Since catch is proportional to fishing mortality for the Pella-Tomlinson model, a proportional reduction in catch will result in the same proportional reduction in fishing mortality for a given stock size. There is a time-dependency implicit in this recommendation, since a stock will immediately start to increase when fishing mortality is reduced to F_{MSY}. The Pella-Tomlinson model suggests that multipliers on average catch that reduce fishing mortality to F_{MSY} range from 0.17 when the stock is close to zero to 0.61 when the stock is at $B_{20\%}$ (Figure 6) The average of multipliers from $B_{5\%}$ to $B_{20\%}$ is 0.48. Stock levels below $B_{5\%}$ were excluded because it is unlikely that fishing mortality could be high enough to reduce stock size to such low levels. These results suggest that a multiplier of 0.5 is appropriate for the OFL when the stock is considered to be heavily exploited. Since increased yields should be possible once the stock rebuilds, use of a 0.5 multiplier for the OFL should be considered a temporary measure that will be re-evaluated periodically.

When the stock is considered lightly exploited, fishing mortality is lower than F_{MSY} and thus could potentially be increased. However a multiplier on catch would result in an immediate decrease in biomass so that that F_{MSY} would quickly be exceeded. An alternative multiplier when the stock is lightly exploited is a multiplier that would increase yield to *MSY*, so that annual catches of this amount would move the stock into the moderately exploited category without overfishing. The average of yield multipliers from $B_{66\%}$ to $B_{90\%}$ is 1.98 (Figure 7). Stock levels above $B_{90\%}$ were excluded because these stocks would likely be classified as ecosystem component species. These results indicate that a multiplier of 2.0 is appropriate for the OFL when the stock is lightly exploited. Comparisons between the Pella-Tomlinson model with n = 1.2, the Graham-Schaefer model, and Fox model indicate that the recommended multipliers are reasonably robust to the shape of the production function. Due to the simple modeling approach used to derive these multipliers, we suggest using Table 5 as a starting point in discussions regarding appropriate OFLs.

Although three categories have been broadly defined in the above analysis, distinguishing between lightly exploited and moderately exploited stocks may be difficult in some circumstances (e.g., widely varying catch data). Under such circumstances, it may be more practical to combine these two categories and use a 1.0 scalar for both; however this would imply a decision to constrain the catch of stocks that may be lightly exploited.

E. Obtain an ABC as a proportion of the OFL

The last step in the control rule is determining the appropriate buffer between OFL and the ABC, which is based on the scientific knowledge about the stock and the uncertainty in the estimate of OFL (i.e., historical catch analysis). Since both risk policy and scientific uncertainty are involved in the choice of an ABC multiplier, input will be required from managers (i.e., Regional Fishery Management Councils) and science advisors (i.e., SSCs). Technical approaches to characterizing uncertainty are not yet possible for data-poor stocks, but it is clear that uncertainty is greater for these stocks than for data-rich assessed stocks. The size of the ABC multipliers derived from data-rich stocks provides a starting point for considering ABC multipliers for data-poor stocks. In developing ABCs, managers should consider distinguishing between high productivity stocks and low productivity stocks, the latter of which can be considered higher risk because they are more prone to becoming overfished and have long recovery times if they do become overfished. Assigning stocks to productivity categories is largely a scientific task, and can be done using productivity scores from a PSA analysis (Patrick et al., 2010) or other approaches. The degree to which different ABC multipliers are used for the productivity categories is more of a policy issue that should be decided by managers.

Table 6 lists some ABC options we developed as examples, but these are not meant to preclude managers from developing their own alternatives based on their risk preference. The alternatives in Table 6 have a greater or lesser degree of risk aversion, and contrast policy decisions to be more risk averse for low productivity stocks with those that do not. The most productive stocks tend to be coastal pelagic species such as anchovy and sardine, which have characteristics other than productivity that may be taken into account in setting the ABCs (or ACLs), such as decadal variability or importance as forage species. Other ways of grouping stocks into risk categories by productivity scores or some other characteristic are possible and should be considered.

IV. STOCK COMPLEXES

The National Standard One Guidelines (NMFS, 2009) describe the concept of a stock complex management, which is defined as a group of stocks that are managed as a single unit. Stock complexes are considered an approach to deal with stocks that are harvested together and cannot be assessed separately because of insufficient data or resources. Stock complexes can include similar species (e.g., southeastern U.S. reef fishes) or distinct populations of the same species that support mixed-stock fisheries (e.g., the Georges Bank-Gulf of Maine stock complex of Atlantic herring). In all fishery management systems, priority is given to assessing and monitoring stocks with the highest economic value or ecological importance. Nevertheless, marine ecosystems are diverse, and become increasingly so at lower latitudes. Although there is a general need for additional stock assessments, the cost of monitoring and assessing some stocks could potentially exceed the value of landings, suggesting that there is a limit to how many stocks should be individually assessed and managed. Management of stock complexes is an approach to addressing complexity by managing stocks at a higher level than an individual stock. Whether management by stock complexes is considered successful depends on how well the approach achieves management objectives, which can be evaluated like any other management strategy. Stock complexes are likely to be useful in the same data-poor situations as average catch assessments. This section discusses the issues that should be considered when these two approaches are used together.

The formation of stock complexes should take into account life history, geographic distribution, depth distribution, and vulnerability to the fishery (NMFS, 2009). When stock complexes are formed using these criteria, it is assumed that 1) a single catch limit will be sustainable for all members of the stock complex, and 2) fishery impacts are relatively uniform across the members of stock complex (i.e., there is no targeting of individual stocks in the complex). NMFS (2009) also recommends the use of indicator stocks, which is a stock selected as being representative of the complex, and is assessed periodically as a proxy for the other members of the complex. Indicator stocks have been used in various fisheries (e.g., Hawaii Seamount and Bottomfish Fishery, Alaska Salmon Fishery, North Pacific Groundfish Fishery, etc.) and have shown various levels of success. Shertzer and Williams (2008) evaluated the utility of stock complexes and indicator stocks as a proxy of status for reef fisheries off the southeast United States coast. Two difficulties were encountered: 1) species did not group naturally into well-defined complexes based on a cluster analysis of catch data, and, 2) fishery CPUE trends of member stocks within complexes showed little synchrony, suggesting that a single stock could not be used as an indicator for the complex. This study did not distinguish between the utility of using stock complexes and indicator stocks to prevent overfishing, as opposed to being simply used for status determination. At this point, it is not possible to conclude that Shertzer and Williams (2008) results generally apply to other stock complexes, and the indicator stock approach warrants further evaluation (see Branton and Richardson, 2011). Preliminary work with Pacific Coast groundfish using the results of a PSA as well as geographic distribution in a clustering algorithm to define stock complexes shows promising results, but is not expected to be implemented until the next management cycle (Cope et al., In press).

A stock complex can be managed in-season by monitoring the aggregate landings of the complex relative to an annual catch limit as a way to control the fishing mortality experienced by the stock complex in its entirety. Determination of stock status relative to target or limit stock size could be done for the complex as whole, or for an indicator stock that is a member of the group. Determining stock status may be difficult or impossible for data-poor stocks, but a management system that successfully limits catch to sustainable levels would be expected to prevent any stock from becoming overfished. While an inability to determine whether stocks are below a critical threshold is a weakness of average catch assessments, a management system that is designed to be precautionary should accommodate this uncertainty with an appropriate response.

It is difficult to find examples where stock complexes have been implemented following the principles in NMFS (2009), most likely because the guidance is relatively new (earlier versions of the NS1 guidelines did not provide guidance on the formation of stock complexes). Stock complexes have often been established based on broad taxonomic groupings. For example, in the North Pacific, stock complexes have been established for squids and sculpins, while in New England, skates are managed as a complex despite large differences in productivity and susceptibility for members of the complex. In other cases, stock complexes are treated as a kind of warehouse for stocks that have not been dealt with using other assessment and management approaches. For an example, the “Other fish” complex used by PFMC includes several skate, shark, deepwater (e.g., finescale codling and Pacific rattail), and nearshore species (e.g., cabezon and kelp greenling). A more appropriate use of stock complexes is the PFMC management of minor rockfish species, which are grouped into complexes based on geographic distribution (north and south of 40°10” lat. N.), and depth distribution (nearshore, shelf, and slope). Another example is the “Shelf Demersal Rockfish” stock complex in the Gulf of Alaska, consisting of an assessed stock, yelloweye rockfish, and a number of other rockfish stocks occupying similar habitats that are not assessed. ABCs and OFLs are based on the assessed stock with an adjustment to account for the percent of the total catch of the stock complex consisting of other members of the complex.

Reef fishes in the Gulf of Mexico and U.S. Southeastern Atlantic Ocean were grouped into assemblages for management purposes based on multivariate statistical analyses conducted by the NMFS Southeast Regional Office. The analysis was based on landings associations, life history, and PSA. In the Gulf of Mexico, depth was the most important factor influencing assemblage composition. In the U.S. Southeastern Atlantic Ocean, depth and latitude were both important factors. Each identified assemblage contained at least one targeted, assessed species.

OFLs and ABCs for stock complexes can be specified for indicator stock(s) of the complex or set for the complex as a whole. When indicator species is not a feasible option, and OFLs and ABCs need to be set for the complex as a whole, average catches can be compiled for the complex and the OFL and ABC calculations can be done for the entire complex. This is because the average catch of a complex is simply the sum of the average catches of the individual members of the complex. This approach would also be useful for stock complexes when estimates of the catch by species are unavailable, however some level of catch sampling is necessary to track the relative landings of stocks in a complex. Although the OFL and ABC of a stock complex can be the sum of the OFLs and ABCs for its individual stocks, the best scientific information available may not support the definition of stock-specific reference points. In the most data-poor situations, OFL and ABC may need to be based on the time series of aggregate stock catch.

The ABCs established for the indicator stocks for a complex as a whole should reflect the risk policy adopted by the Council. It is recommended by NMFS (2009) that indicator stocks be representative of the stocks within the complex with respect to their vulnerability to the fishery; otherwise the indicator stock should be chosen to represent the more vulnerable stocks in the complex. Similar rationale should be used when setting ABCs for the complex as a whole, which should take into account more vulnerable stocks within the complex. An important consideration in the use of stock complexes for management of data-poor species is that the catch of individual species within the complex is not monitored or controlled in-season. Consequently there is additional uncertainty associated with management by stock complexes that is not present when stocks are managed independently. If the objective is precautionary management, it may be necessary to build some additional conservatism into the system to account for the additional uncertainty associated with management using stock complexes. One approach would be to set an ACT for the stock complex that is less than ACL to account for management uncertainty.

V. DISCUSSION

This review of methods covers a wide range of scientific approaches to confront the challenges associated with recommending appropriate catch recommendations for data-poor stocks. Unlike previous guidance on data-poor stocks, we view the range of methods as a hierarchy, from the most informative to the most data-limited approaches, with the scalar approach recommended by Restrepo et al. (1998) for the bottom tier. A hierarchical approach to catch advice can be used for determining the most appropriate method for each stock in the short-term, depending on stock properties and data availability, as well as a broader perspective on how fishery and resource monitoring information can be improved to advance the catch advice to a more informative tier of methodology (e.g., Cadrin et al., 2004). The ORCS Working Group recognized these method-based tiers and developed an adaptive approach in which the appropriate method is hierarchical with the goal to eventually improve the scientific basis of catch limits.

The adaptive approach to determining appropriate methods for setting ABC accepts that lower-level approaches for the most data-poor stocks do not meet all of the needs of the mandated management system or the desires of fishery stakeholders. Although it is beyond the scope of this report, the top-tier of scientific support is a stock assessment that incorporates and fully accounts for key sources of uncertainty to yield an estimate of the distribution of the OFL. Given this information on OFL and its statistical distribution, Fishery Management Councils can develop ABC control rules in which ABC is derived from an evaluation of scientific uncertainty and their acceptable probability of overfishing (see for example Ralston et al., In press). Several intermediate-tier methods (e.g., DB-SRA) support such a probabilistic approach to ABC and fully comply with NS1 guidelines. By contrast, lower tier methods (e.g., scalars of average catch) are not explicitly based on the Council's desired risk tolerance.

Lower tier methods are designed to provide catch advice so that the fishery will be sustainable, but the optimality of the derived catch and the probability of overfishing are not known. These deficiencies of the lower tier approaches can impose substantial costs in the form of larger uncertainty buffers and substantial foregone yield. The hierarchical and adaptive approach to data-poor methods for determining ABC provides incentives for improving the scientific information.

Ideally, the performance of each method in the tiered system should be evaluated for avoidance of overfishing and maintaining optimum yield (and any other potential benefits identified as management objectives) through simulation of an operating model that is tailored to the stock of interest. Furthermore, the entire tier system could be evaluated through management strategy evaluation if a decision rule is simulated for improving data and moving from lower to higher tiers.

While it is important to improve methods used to set ABCs for ORCS, even improved methods will never take the place of data and monitoring. Informed judgment plays a critical part in every ORCS approach. It cannot be avoided or assumed away. Data collection through research and monitoring are needed to eliminate the need for informed judgment.

VI. RESEARCH RECOMMENDATIONS

Due to the new requirements of the reauthorized Magnuson-Stevens Act (2006), development of methods to evaluate the status of data-poor stocks, including ORCS, is an active area of research. In particular, status determination and characterization of uncertainty are two focal study areas where significant advances are being achieved. In this regard, we believe that continued progress could be accomplished if additional research is conducted along the following lines:

- Develop and accept formal methods to elicit expert opinion from scientists, stakeholders, and managers.

- Conduct Management Strategy Evaluations (MSEs) to evaluate the robustness of methods used to characterize data-poor stocks and control rules for their management.
- Collect basic life history information on data-poor stocks, especially maximum age, to better inform estimation of natural mortality.
- Conduct stock delineation for fish species that occur over extensive ranges and/or overlapping jurisdictions.
- Improve the coverage and accuracy of catch sampling programs.
- As a basis for risk assessment, complete Productivity-Susceptibility Analyses (Patrick et al. 2009) for all stocks that are currently under fishery management plans.
- Increase the study of data-rich stocks within a meta-analytic framework to develop priors and proxies for application to data-poor stocks.
- Coordinate efforts to assemble regional landings statistics into databases in a comprehensive, thorough way.
- Monitor fishery indicators to provide additional information on sustainability of data-poor catch limits.

VII. CONCLUSIONS

The problem of setting appropriate catch levels (now called ABCs) for ORCS is not new, is not going away, and doesn't have an ideal solution. As discussed earlier, methods to deal with ORCS go back to the Restrepo et al. (1998) technical guidance. It is not realistic to assume that all, the majority of, or even many of these "data-limited" ORCS stocks will become "data-rich," allowing for comprehensive stock assessments. Past, present, and proposed methods all require the incorporation of "informed judgment" and major assumptions in critical steps of the process.

Given this situation and all of the information presented in this report, the ORCS Working Group recommends the following tiered approach to setting ABCs for ORCS:

- Apply DB-SRA to a stock, if possible. The main limitation here is the availability of a complete time series of historical catch, which is often not available.

- If it is not possible to apply DB-SRA, apply DCAC to a stock. DCAC's main limitation is that it is only appropriate for stocks with moderate to low natural mortality rates ($\leq$ 0.20 yr^{-1}).

- If DB-SRA and DCAC are not possible, apply the ORCS Working Group's Approach. The main limitation with this approach is that a number of critical decisions are required before it can be made operational. Some would also view this as an advantage, as it provides flexibility in its establishment.

- Finally, in some cases none of the above methods are practical for setting ABCs for an individual stock, as specific ORCS stocks may not have the capability to be effectively managed or monitored. In these cases, it may be best to use a stock complex approach. There are many limitations of applying a stock complex approach as described above, and the ORCS Working Group cautions against overusing or misusing this approach, as it may result in converse of precautionary management, exactly what MSA was designed to avoid.

Finally, we recommend moving forward with the research recommendations listed above, given the methods for setting ABCs for ORCS are in various stages of development and necessarily depend on adequate attention and funding in the future.

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Table 1. The Methot table showing possible actions for determining ABC based on different fishery impact categories and expert opinion. Taken from the workshop report of the 2nd National SSC meeting.

Historical Catch	Expert Judgment	Possible Action
Nil, not targeted	Inconceivable that catch could be affecting stock	Not in fishery; Ecosystem Component; SDC not required
Small	Catch is enough to warrant including stock in the fishery and tracking, but not enough to be of concern	Set ABC and ACL above historical catch; Set ACT at historical catch level. Allow increase in ACT if accompanied by cooperative research and close monitoring.
Moderate	Possible that any increase in catch could be overfishing	ABC/ACL = f(catch, vulnerability) So caps current fishery
Moderately high	Overfishing or overfished may already be occurring, but no assessment to quantify	Set provisional OFL = f(catch, vulnerability); Set ABC/ACL below OFL to begin stock rebuilding

Table 2. The natural variability factor, c, used in the New Zealand approach, as determined by the value of the natural mortality rate, M.

M	c
< 0.05	1.0
0.05-0.15	0.9
0.16-0.25	0.8
0.26-0.35	0.7
> 0.35	0.6

Table 3. Potential management objectives depending on stock status for ORCS Working Group Approach.

Stock status	Potential management objectives
Lightly exploited	Maintain current catch levels or allow for limited increases in catch
Moderately exploited	Maintain current catch levels
Heavily exploited, possibly overfished	Reduce catches to end overfishing

Table 4. Table of attributes for assigning stock status for historical catch-only assessments.

Overall scores are obtained by an unweighted average of the attributes for which scoring is possible, although alternative weighting schemes could also be considered. An initial assignment to a stock status category is: mean scores>2.5—heavily exploited; stocks with mean scores 1.5-2.5--moderately exploited; and stocks with mean scores<1.5--lightly exploited. When the attribute does not apply or is unknown it can be left unscored.

	Stock status		
Attribute	**Lightly exploited (1)**	**Moderately exploited (2)**	**Heavily exploited (3)**
Overall fishery exploitation based on assessed stocks	All known stocks are either moderately or lightly exploited. No overfished stocks	Most stocks are moderately exploited. No more than a few overfished stocks	Many stocks are overfished
Presence of natural or managed refugia	Less than 50% of habitat is accessible to fishing	50%-75% of habitat is accessible to fishing	>75% of habitat is accessible to fishing
Schooling, aggregation, or other behavior responses affecting capture	Low susceptibility to capture (specific behaviors depend on gear type)	Average susceptibility to capture (specific behaviors depend on gear type)	High susceptibility to capture (specific behaviors depend on gear type)
Morphological characteristics affecting capture	Low susceptibility to capture (specific characteristics depend on gear type)	Average susceptibility to capture (specific characteristics depend on gear type)	High susceptibility to capture (specific characteristics depend on gear type)
Bycatch or actively targeted by the fishery	No targeted fishery	Occasionally targeted, but occurs in a mix with other species in catches	Actively targeted
Natural mortality compared to dominant species in the fishery	Natural mortality higher or approximately equal to dominant species ($M \geq \overline{M}$)	Natural mortality equal to dominant species ($M \approx \overline{M}$)	Natural mortality less than dominant species ($M < \overline{M}$)
Rarity	Sporadic occurrence in catch	Not uncommon, mostly pure catches are possible with targeting	Frequent occurrence in catch
Value or desirability	Low value (< $1.00/lb, often not retained (< 33% of the time)	Moderate value ($1.00 - $2.25), usually retained (34-66% of the time)	Very valuable or desirable (e.g., > $2.25/lb), almost always retained (>66% of the time).
Trend in catches (use only when effort is stable)	Catch trend increasing or stable (assign score of 1.5)	Catch trend increasing or stable (assign score of 1.5)	Decreasing catches

Table 5. Recommended OFLs using ORCS Working Group Approach.

Stock category		
Lightly exploited ($B > B_{65\%}$)	Moderately exploited ($B \sim B_{MSY}$)	Heavily exploited ($B < B_{20\%}$)
2.0 x catch statistic	1.0 x catch statistic	0.50 x catch statistic

Table 6. Example ABC options for catch-only stocks using the ORCS Working Group Approach.

Risk level	**Alternative A**	**Alternative B**	**Alternative C**	**Alternative D**
Low risk (high productivity)	0.75 x OFL	0.75 x OFL	0.90 x OFL	0.90 x OFL
Moderate risk (moderate productivity)	0.75 x OFL	0.75 x OFL	0.75 x OFL	0.80 x OFL
High risk (low productivity)	0.75 x OFL	0.50 x OFL	0.50 x OFL	0.70 x OFL

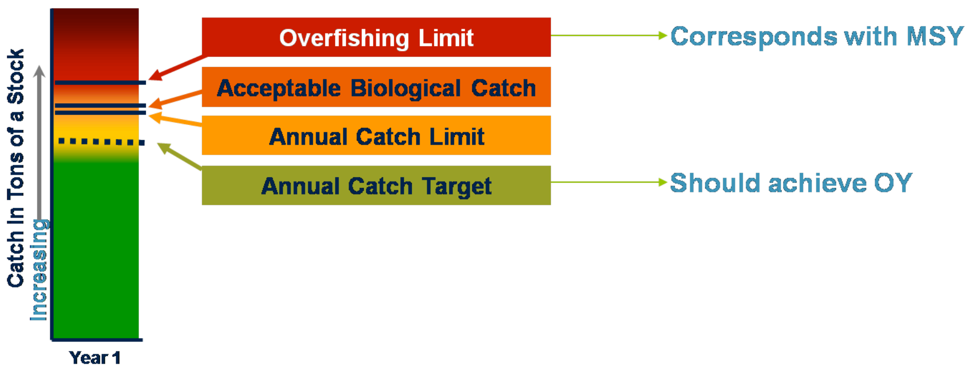

Figure 1. The relationship of catch reference points under National Standard 1.

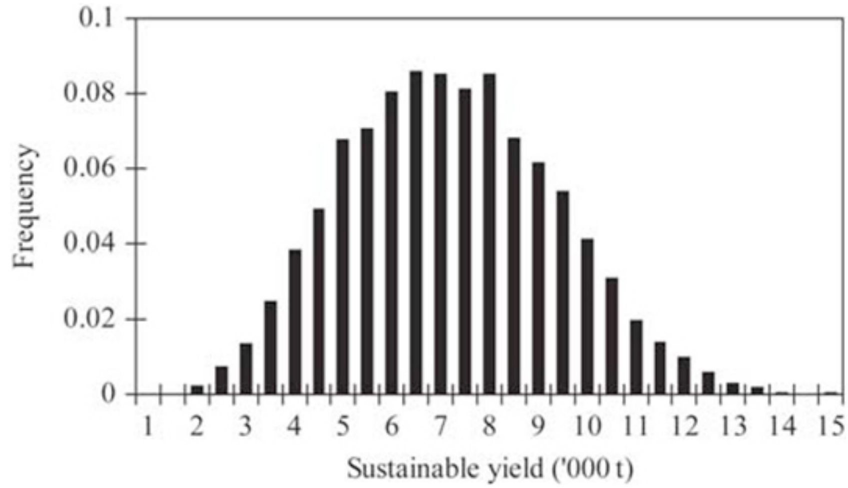

Figure 2. Distribution of 1989 widow rockfish yields from DCAC analysis (taken from MacCall 2009). The median of the sustainable yield distribution is 6,849 mt, which compares with MSY that was estimated to be 8,300 mt.

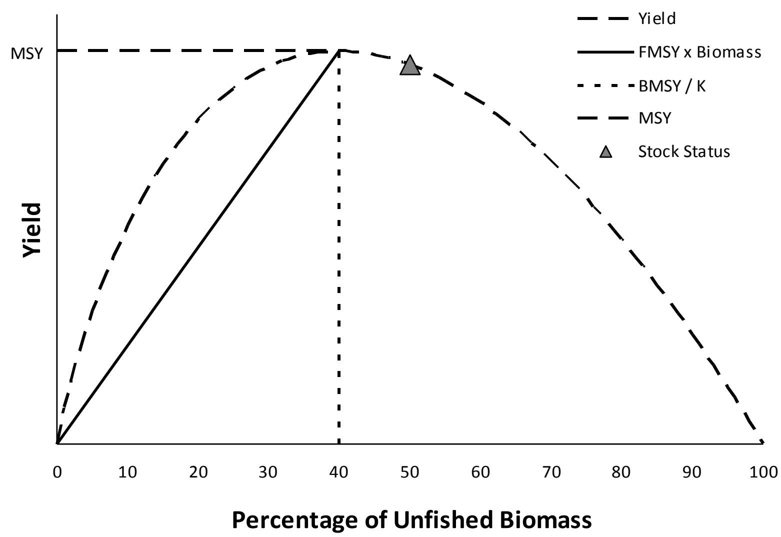

Figure 3. Graphical representation of one iteration of the DB-SRA method, shown on rescaled biomass ($B_0 = 1.0$).

The slope of the diagonal solid line is determined by the current value of F_{MSY}, which is the product of draws from the M and $F_{MSY} \div M$ distributions. The relative biomass that generates maximum sustainable yield (B_{MSY}/B_0) is also drawn from its distribution (value shown = 0.4). Lastly, stock status relative to unfished biomass is determined by a draw from the distribution of relative biomass depletion (Δ, value shown = 0.5). For each set of draws from the four input distributions, the catch time series determines the unique value of unfished biomass (B_0) that satisfies the current estimate of stock status. Figure courtesy of E.J. Dick.

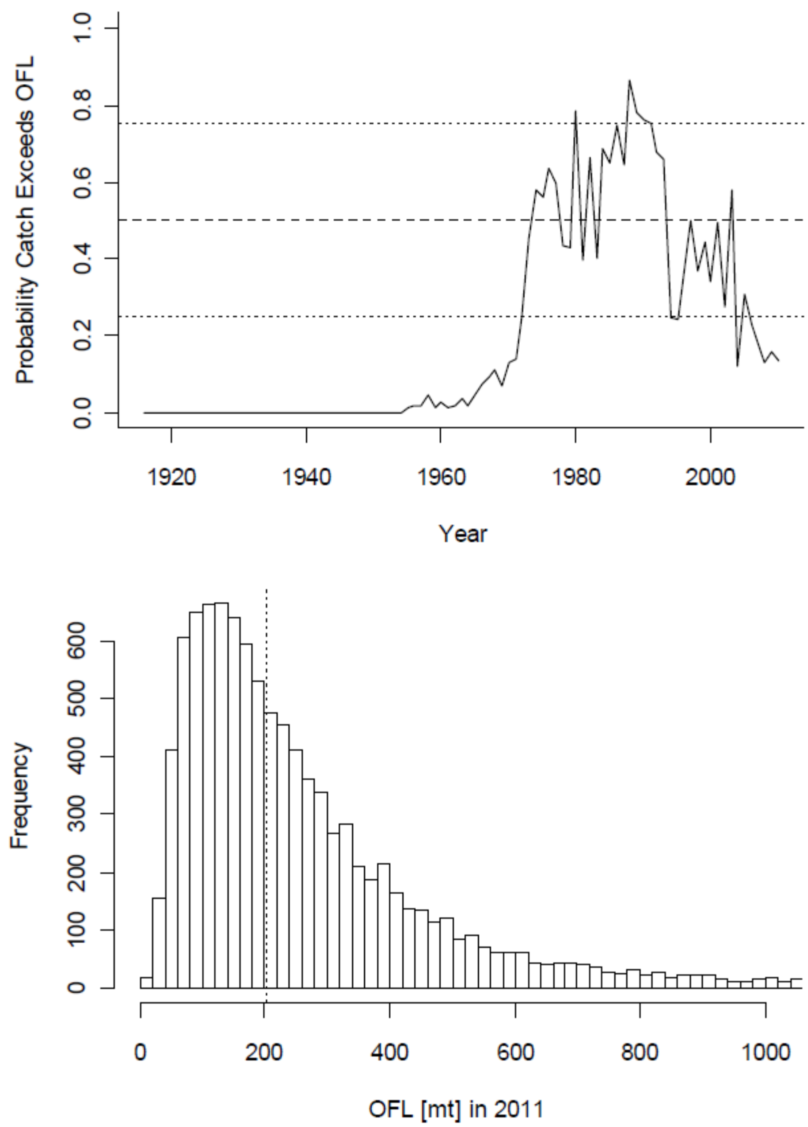

Figure 4. DB-SRA output for brown rockfish. The upper panel shows a time series of the probability that overfishing occurred in any particular year. The lower panel provides the posterior distribution of OFL in 2011 (vertical dotted line = median of distribution).

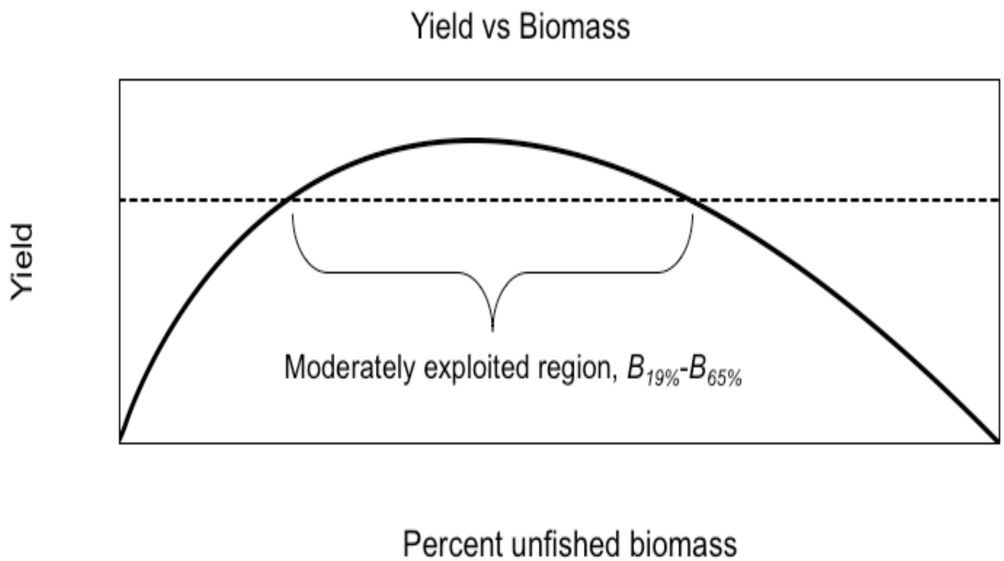

Figure 5. Equilibrium yield as a function of biomass for the Pella-Tomlinson model with n = 1.2.

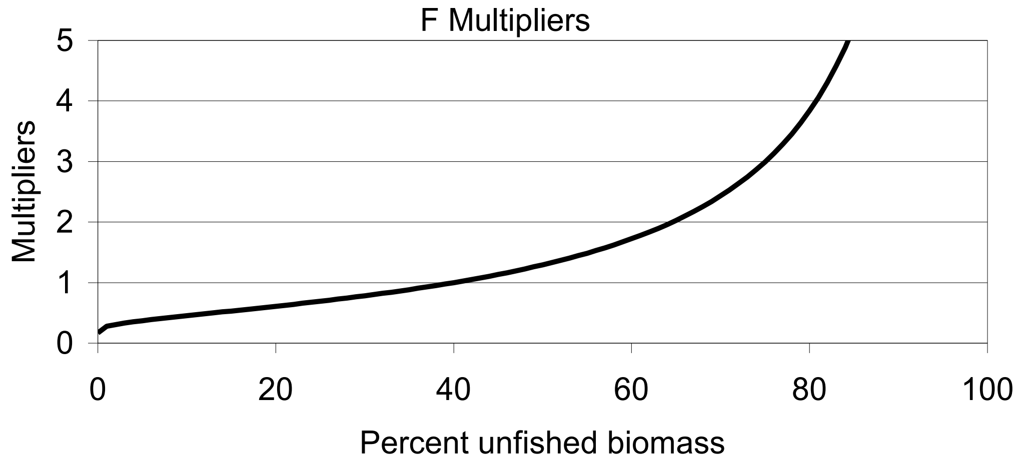

Figure 6. Multiplier for fishing mortality to reduce or increase fishing mortality to F_{MSY} for the Pella-Tomlinson model with n = 1.2.

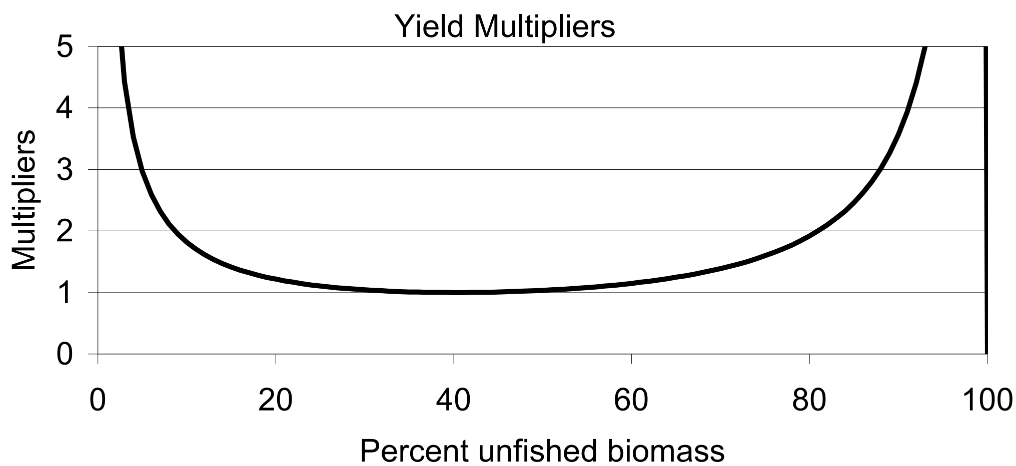

Figure 7. Multiplier for yield to reduce or increase yield to MSY for the Pella-Tomlinson model with n = 1.2.