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SETTING ANNUAL CATCH LIMITS FOR U.S. FISHERIES:
An Expert Working Group Report

Working Group Participants:

Andrew Rosenberg Department of Natural Resources, Institute for the Study of Earth, Oceans and Space, University of New Hampshire
David Agnew MRAG, Ltd.
Elizabeth Babcock Pew Institute for Ocean Science, Rosenstiel School of Marine and Atmospheric Science, University of Miami
Andrew Cooper Department of Natural Resources, Institute for the Study of Earth, Oceans and Space, University of New Hampshire
Charlotte Mogensen Directorate for Food, Fisheries and Agri Business, Ministry of Food, Agriculture and Fisheries, Denmark
Robert O'Boyle Department of Fisheries and Oceans Canada, Bedford Institute of Oceanography
Joseph Powers Department of Oceanography and Coastal Sciences, Louisiana State University
Gunner Stefánsson University of Iceland
Jill Swasey MRAG Americas, Inc.

MRAG Americas

MRAG Americas, Inc. convened the Working Group and prepared this report.

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1 Introduction

This report provides guidance on the application of annual catch limits for US fisheries based on the recommendations of a working group of national and international fisheries experts, with participation by NOAA Fisheries as technical advisors to the working group, convened by the Lenfest Ocean Program. The purpose of the group was to develop recommendations on methodology for setting annual catch limits and implementing accountability measures to improve management of all US fisheries managed under Federal FMPs. The process recommended by the Working Group is general and applicable to other fisheries as well.

The Working Group members (Andrew Rosenberg, David Agnew, Elizabeth Babcock, Andrew Cooper, Charlotte Mogensen, Robert O'Boyle, Joe Powers, Gunner Stefánsson, and Jill Swasey) were chosen for their expertise in fisheries science and management. They served as individuals, not representatives of any organization, and the report presented here is the consensus view of these independent experts. The Working Group members brought experience and perspectives from many fisheries around the world to the two meetings held in the summer of 2007 in Boston, with MRAG Americas, Inc. providing staff support.

The Magnuson-Stevens Fisheries Conservation and Management Act (MSFCMA) is the primary law regulating marine fisheries management throughout the United States. The act was first adopted in 1976, amended in 1996, then recently amended again and reauthorized in January 2007 (DOC, 2007). The MSFCMA of 1976 was responsible for phasing out foreign fishing through the development of a US exclusive economic zone and the development of regional fishery management councils to manage and conserve fisheries. The 1996 amendments concentrated on sustaining fisheries by ending overfishing and rebuilding fish stocks, protecting essential fish habitat and reducing bycatch. The amendments made progress toward recovery of depleted stocks and sustaining stock health, but many stocks remain overexploited or have not been rebuilt (NOAA 2007, Rosenberg et al. 2006). As a result, the 2007 amendments are designed to improve accountability in management to prevent overfishing and rebuild stocks to levels that will support maximum sustainable yield.

Section 104 (a)(15) of the 2007 Magnuson-Stevens Reauthorization Act (MSRA) establishes "a mechanism for specifying annual catch limits in the plan (including a multiyear plan), implementing regulations, or annual specifications, at a level such that overfishing does not occur in the fishery, including measures to ensure accountability." Congress has set a "no fail" deadline to establish catch limits for all fisheries experiencing overfishing by 2010, and 2011 for all other fisheries. This Lenfest Ocean Program Working Group has developed an approach for establishing annual catch limits (ACLs) and accountability measures to meet the requirements of the revised MSFCMA. This report will be submitted to NOAA Fisheries as input during their rule-making process of creating guidelines for implementation of the MSRA.

The Working Group proposed the following principles should guide the process of setting ACLs:

- ***As a default or starting point, preventing overfishing applies to ALL stocks, therefore, so should ACLs.*** ACLs need to be set for all stocks in a fishery, not just the dominant stocks of a fishery nor those where the most complete information is available. The goal should be to sustainably manage all fishery resources, not simply those of greatest value. Therefore, ACLs and accountability measures are needed for data poor stocks and those that are minor components of the catch unless it is very clear that the fishery cannot impact a given stock in any significant way.
- ***To successfully end and prevent overfishing, OFL > ABC ≥ ACL.*** According to the MSFCMA, the Overfishing Level (OFL) is the estimated catch (in numbers or weight) beyond which overfishing occurs, and is based on Maximum Sustainable Yield (MSY). The acceptable biological catch (ABC) is a target catch which ensures that OFL is not exceeded accounting for

uncertainty (see below). In principle, if catches were set at or below a properly determined ABC then there is a low chance of overfishing (exceeding the OFL). Optimum Yield (OY), according to the MSFCMA, is proscribed based on MSY, as reduced by relevant economic, social and ecological factors and provides for rebuilding as needed. The OY is the target catch, below the ABC level, chosen by managers to additionally account for other factors related to the economic, social and ecological impacts of the fishery and fishery management. The ACL should ensure that overfishing does not occur and rebuilding requirements are met and therefore must be at or below the ABC level and should enable the fishery to achieve OY. This logically means that OFL will be greater than ABC which will be greater than or equal to ACL.

- ***ACLs should account for risk of overfishing for each stock.*** In this regard, the Working Group defines 'risk' as the probability of overfishing given the consequences of overfishing. So, for example, if the probability of exceeding a reference point for overfishing is relatively low, but the consequence of exceeding that reference point is a stock decline that may be difficult to recover from, then the risk would be higher than if the consequences of exceeding the reference point were less severe.
- ***Uncertainty is inevitable and should be accounted for in setting ABC and ACL.*** The probability of overfishing is, in general, a function of the uncertainty in the current status of the stock, the uncertainty at what level of catch overfishing occurs (OFL), and the ability to control and monitor the fishery. The first two of these factors are related to scientific uncertainty resulting from incomplete or inaccurate data, model error, and environmental variation, all of which occur in every fishery to varying degrees. The latter factor, termed implementation uncertainty, relates to the efficacy of management controls and monitoring. If the catch can be very well controlled, including landings and bycatch for all sectors of the fishery, and the data collected are of high quality, then implementation uncertainty will be low. It should be recognized, however, that in many fisheries, this is not currently the case and implementation uncertainty may be substantial, such that the probability of overfishing is increased and therefore the risk to the resource is increased.
- ***Consideration of risk must include some evaluation of the vulnerability of a stock to the fishery.*** The consequences of overfishing are a function of the vulnerability of the stock to the fishery. Here we consider vulnerability with respect to the ability of the stock to produce MSY on a continuing basis under a given level of fishing pressure. Stocks are more vulnerable if their productivity is low because of slow reproduction rates or other factors in the life history of the species, and /or high susceptibility to capture by the fishing gear used, impacts on essential fish habitat, or the current status of the resource, for example. We have not considered the consequences of overfishing beyond the consequences to the resource. Economic and social consequences should also be considered, always mindful of the fact that any economic or social benefits depend upon a healthy and productive resource in the long-term.
- ***Vulnerability and the consequences of overfishing primarily relate to individual stocks of fish, and therefore grouping of stocks into assemblages for management can undermine sustainability.*** Grouping of stocks into assemblages because of data limitations or convenience should be done with great caution and avoided where possible, i.e., where stocks can be monitored individually. In particular, stocks that are of substantially different characteristics such as life history, current status, vulnerability to fishing gear or distribution, should not be lumped together if it is possible to avoid it. Where grouping is necessary, catch limits must be set very conservatively to avoid overexploiting the most vulnerable stocks in the grouping. It is necessary to avoid overfishing of every stock in an assemblage, not just an indicator stock or the assemblage as a whole.
- ***The buffer or distance between the ACL and the OFL should be greater when the risk of overfishing is higher (i.e., when uncertainty is greater or the consequences of overfishing as expressed by vulnerability of the resource is higher).*** Setting more conservative catch limits should reduce the risk of overfishing. In effect, this means that when risk is high, the ABC and the ACL should be further below the OFL than when risk is lower. In all cases, except when all sources of uncertainty are negligible, the ACL should be below the OFL to account for uncertainty and vulnerability. Management should determine the level of caution needed (i.e., the probability of exceeding the OFL), based on the principles given here and the perceived risk to the stock.

- ***Setting ACLs for each fishery in the US should be considered as a performance measure for that fishery and, therefore, is the basis for assigning accountability to managers and the fishery for this important goal of the Act.*** That is, under the amended MSFCMA, the major objectives of each fishery management plan are to end or prevent overfishing and rebuild overfished stocks. Regardless of the specific management actions (e.g. catch quotas, effort controls, gear controls, bag or trip limits, closed areas or seasons) employed by managers for a given fishery in the management plan, the fishery output is some level of catch. Setting an annual limit and comparing the actual catch to that annual limit measures how well the management plan performed in controlling fishing by their chosen actions.

The Working Group outlined a process by which catch limits can be set for fisheries with varying degrees of available information, uncertainty and vulnerabilities. For each step described, we suggest methods for implementation of the process and provide caveats as needed. The Working Group recommended a final step to implement accountability measures. Central to this process is determining the "buffer" needed between the OFL and the ACL to ensure that the probability that overfishing doesn't occur is increased and rebuilding proceeds as needed. That is, the process is designed to determine how far the ACL should be set below the OFL to account for the various sources of uncertainty referred to in the principles above. In the same vein, accountability should reflect the implementation uncertainty in management, such that the buffer between the OFL and the ACL should increase if fishery performance indicates that the overall catch from the fishery has not been well controlled. Focusing on the size of the buffer between OFL and ACL provides consistency in the process of dealing with various sources of risk to the sustainability of the fishery.

The process developed by the Working Group for setting ACLs includes the following steps:

1. **Scientists evaluate vulnerability for each resource stock based on an analysis of its productivity and susceptibility to the fishery. In cases where vulnerability is minimal and unlikely to develop in the future, categorize them as *de minimus* and re-evaluate periodically to ensure that no vulnerability to the fishery has developed requiring an ACL. For all other stocks proceed to step 2;**

2. **Scientists determine a sensible OFL for each stock based on the concept of MSY and estimate uncertainty in the knowledge of stock status and trends;**

3. **Managers decide on the acceptable level of risk of exceeding the prescribed OFL considering the consequences of overfishing with respect to the vulnerability for a given stock or complex;**

4. **Scientists recommend an ABC below the OFL, such that the risk of overfishing isn't exceeded, accounting for various sources of uncertainty, including implementation uncertainty, by increasing the buffer distance of the ABC below the OFL. The scientifically determined ABC is a maximum for the ACL. Policy makers may choose to set the ACL at or below the ABC in consideration of other social, economic or ecological factors;**

5. **Managers and scientists evaluate performance of management regularly with respect to adhering to the ACL in terms of preventing overfishing over a series of years (1-3 yrs). As the accountability measure, modify the buffer as appropriate if the fishery has / has not exceeded the ACL or OY.**

2 Evaluation of Resource Vulnerability for ACL Determination

The Working Group recommends that the setting of ACLs for US fisheries resources be based on a **risk assessment approach** to management, which would include evaluations of vulnerability of the resource, uncertainties in scientific information, fishery operations, environmental effects, compliance with regulations and efficacy of management tactics. In effect, this means that the setting of ACLs should ensure that due precaution is taken to ensure that overfishing doesn't occur and that the degree of precaution needed is greater for more vulnerable resources and where uncertainty is greater. The group found that the framework developed by a recent joint Australian CSIRO CSIRO / AFMA project (Hobday et. al, 2006) for Ecological Risk Assessment (ERA) provides a good basis for the first step of this process - the evaluation of vulnerability of fishery resources.

The Working Group utilized Level 2 of the ERA, the Productivity and Susceptibility Analysis (PSA), for this purpose. Briefly, productivity and susceptibility tables list attributes for categorization of each fishery stock from high to low productivity and susceptibility. The rankings are based on a combination of susceptibility and productivity that determines the relative vulnerability of the unit of analysis (stock or assemblage) and are given a score (1 to 3 for high to low productivity, respectively; and 1-3 for low to high susceptibility, respectively). The determination of the relative productivity and susceptibility of a given stock is made based upon expert opinion, that is, stocks are ranked by knowledgeable experts. The Working Group used Tables 1 and 2 to illustrate the concept. A set of productivity factors is given in Table 1, including life-history features of the species and its role in the food web; example susceptibility factors are given in Table 2. The specific factors included in these tables and a consistent set of guidelines for scoring each factor as high, medium or low rank for application to all US fisheries should be further developed as part of implementing the framework for setting ACLs. In addition to clear and objective scoring guidelines for the factors in the table, the Working Group recommends that additional investigation and consideration be given to the following:

- The overall scores for productivity and susceptibility are given based on the sum of the scores of the factors in each table. The weighting of each factor in the summed score should be carefully considered as part of the scoring guidelines;
- The susceptibility table should include a factor related to the ability to control fishing mortality rates and catch in each fishery (i.e. including all sources of fishing mortality for a given stock) and the selectivity pattern of the fishery;
- Habitat attributes should only be scored on the susceptibility table and be based on existing essential fish habitat (EFH) determinations (Appendix B);
- Concerns with sub-stock structure and localized depletion should be considered for inclusion in the analysis;
- Wherever possible, vulnerability for each of the stocks within an assemblage should be performed separately. The Working Group considered examples of assemblages for sharks, west coast rockfish and Gulf snappers (Appendix C). In these examples, the risk of lumping species of very different vulnerability became apparent, especially for the shark complex. The consequence of creating an assemblage of species of different vulnerabilities is likely to be severe depletion of the more vulnerable species, like hammerhead sharks in the example.

The advantage of the ERA is that it allows the categorization of most, if not all species covered by NMFS FMPs – target, bycatch, or *de minimus* species – using a common definition of risk based upon productivity and susceptibility. For most stocks, it will be relatively straightforward to obtain information on the parameters related to productivity and susceptibility. In cases where information is lacking, it might be possible to derive these parameters through comparison with species of similar life history. Since the rankings are categorical and can be revised as more information becomes available, the method should be applicable to fishery resources even in data-poor situations. When a score is undetermined, higher vulnerability should be assumed, such that more vulnerable stocks have a lower probability of overfishing occurring, until information indicates otherwise.

Once the ERA is completed, the combination of susceptibility and productivity scores is a measure of the relative vulnerability of the unit of analysis (stock or assemblage). The scores for each stock are plotted on a simple productivity susceptibility graph (Figure 1) where the *x*-axis represents the measure of productivity, the unit's ability to recover after impact from fishing, and the *y*-axis represents the susceptibility of the unit to impacts from fishing. Vulnerability increases from the origin of the plot outward as the scores increase. More vulnerable stocks should be managed such that there is lower probability of overfishing occurring because the consequences for that fishery are greater (e.g., recovery times are longer or depletion more severe). The measure of relative vulnerability should be used by managers to determine the acceptable level of risk of overfishing in step 3 of the ACL setting process.

Table 1. Productivity Table

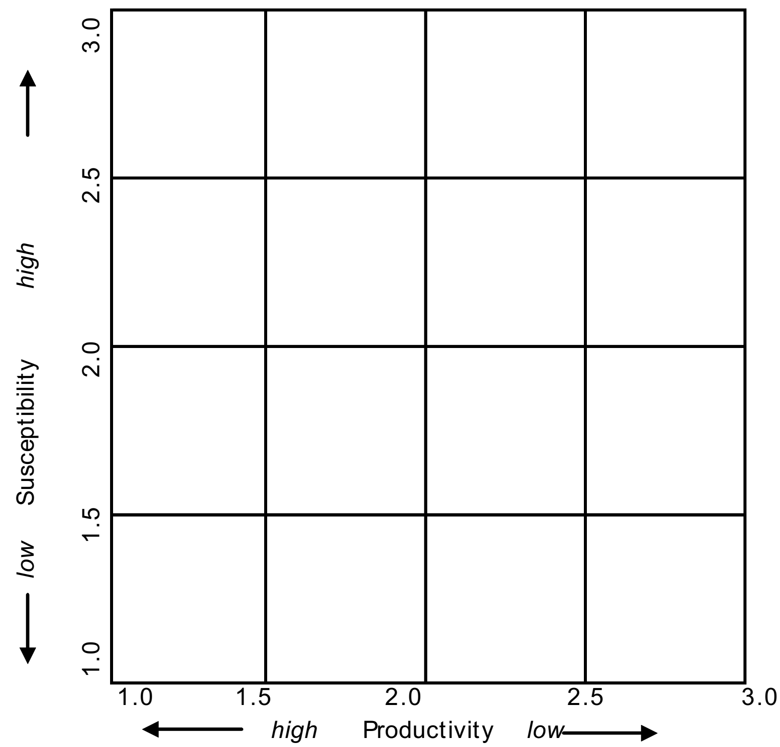
Stock or Complex:

Productivity Attribute		Rationale (examples) for attribute	Rank		
			High Productivity		Low Productivity
			1	2	3
Species-level attributes	Generation Time	Difference between size at birth and maximum; Age at maturity; Size at maturity			
	Average maximum age/size				
	Fecundity	Measured fecundity; Frequency of breeding			
	SSB/SSB_0				
	Reproductive strategy	($r \rightarrow K$)			
Habitat attributes	Persistence of effect of fishing activity	Recovery time			
Community attributes	Food web	Mean trophic level (H_0: low, more productive, can also indicates change)			

Table 2. Susceptibility Table
Stock or Complex:

	Susceptibility Attribute	Rationale for attribute	Rank		
			Low Susceptibility		High Susceptibility
			1	2	3
Species-level attributes	Availability (extent of overlap between the species' habitat and area fished)	Depth range; Habitat types			
	Catchability	Water column position; Schooling/aggregation behavior; Activity times Morphology - affecting capture			
	Survival	Survival after capture and release			
	Spatial refuge from fishery	Seasonal migrations; Closed areas; Vertical migrations			
Habitat attributes	Stability of habitat	Time for formation; Disturbance of habitat (mixing scale)			
	Elevation/size of habitat	Rugosity; Fractal dimension			
	Structure of habitat	Ordering dimension; Heterogeneity score; Viscosity; Grain size			
Community attributes	Trophic structure	Fishing at level where there are few species is likely to have a greater impact on the measure than fishing where there is a diverse assemblage at the trophic level.			
	Fishery specific	Number of trophic levels captured by gear and Fishing method; Number of gear types; Percent of each trophic level subject to fishing			

Figure 1. Productivity Susceptibility Graph



3 Determination of the Overfishing Limit and Characterizing Uncertainty

As noted in the principles discussed in the introduction, the OFL, ABC and OY form a progression of reference points in the management process. A procedure for setting ACLs then should begin with the determination of the OFL. The OFL is the best estimate of the maximum annualized catch that can be taken without overfishing the resource. It is based on the best estimate of F_{msy} applied to the current level of abundance, where available, and if the OFL is an unbiased estimate of MSY, then the long-term average OFL is then the MSY.

Then, accounting for all the various sources of uncertainty outlined in the principles and the vulnerability of the resource estimated in the first step of the process (the PSA), the scientific process advises on an ABC (acceptable biological catch) less than the OFL and is calculated to ensure that the risk of overfishing is within acceptable limits as defined by managers. The ABCs becomes the upper limits for the managers when setting the ACLs. When setting the ACL, managers take into account social and economic factors, other ecological factors, time lags in getting updated information, and uncertainty in control and monitoring of all sources of fishing mortality. ACL is the annual level of catch that is selected to prevent overfishing, rebuild overfished stocks and achieve OY. In this manner, the contribution of a stock to the fishery OY is then the long-term average ACL.

Consistent methods for setting OFL, ABC and ACL are needed even when data are limited. No matter what the level of data, OFL is the best estimate of the overfishing level, ABC builds in the scientific and management (implementation) uncertainty, and ACL builds in the social, economic and ecological factors. The first step is to estimate the OFL for each stock.

3.1 OFL and Uncertainty in Data Rich Stocks

In data-rich situations, where extensive stock assessments have been conducted, setting an OFL is relatively straightforward, though still will contain substantial uncertainty which must be considered in the subsequent application of that OFL. A stock assessment should provide parameter estimates that enable the calculation of MSY, and the biomass and fishing mortality rates that should obtain that MSY under conditions of stationarity (constant mean and variance) for a given fishery stock. The use of established assessment methods should also quantify uncertainty in the OFL estimate, estimates of stock status, and estimates of implementation uncertainty. In some cases where MSY is not explicitly calculated, some generally accepted proxies for MSY may be used or proxies for the fishing mortality rate that is expected to produce MSY. However, the OFL must be stated in either numbers or weight. In these data rich situations, the OFL estimate can be directly employed in subsequent steps of the framework recommended by the Working Group.

Note that even in data rich situations, it is important to go through the vulnerability analysis in step one in order to evaluate risk. Also, the uncertainty estimates from the assessment process may not reflect all sources of uncertainty. As retrospective analysis has frequently shown, assessments often appear more precise or accurate than they subsequently are revealed to be once additional data are available. Data-rich situations should not be considered synonymous with low uncertainty.

In evaluating a set of data-rich stocks with estimated OFLs, uncertainty and vulnerability can provide a good basis for evaluating the impacts of vulnerability and uncertainty on the process of setting ABC with respect to OFL. The Working Group recommends a simulation study of the impacts and consequences of uncertainty and vulnerability on fishery performance along the lines of the work of Shertzer, Prager and Williams (Appendix E), using results from assessments of all the data-rich stocks in the US. This should allow some analysis of the relationship between uncertainty and vulnerability shown schematically in Figure 2. The simulated performance of a specific ABC (set a specific distance below OFL, i.e., with various buffers) for each data-rich stock with different levels of uncertainty (only two are shown here for clarity) should be evaluated to develop a basis for relating the size of the buffer to uncertainty and vulnerability. This pattern, which should include stocks across a range of productivities and susceptibilities, will then inform the setting of ABCs for data poor stocks.

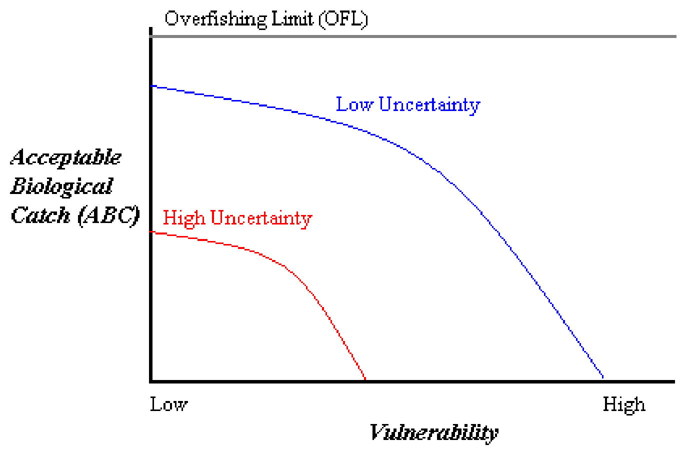


Figure 2. Schematic of the possible relationship between the ABC and vulnerability at different levels of uncertainty. The expectation is that in order to ensure that there is an acceptable level of risk to the resource, the buffer between OFL and ABC should be greater for more vulnerable resources. If uncertainty is higher, the buffer should be higher than in cases where uncertainty is less.

This type of analysis is a form of what is termed in the fishery literature, 'management strategy evaluation (MSE)'. The Working Group recommends that an MSE procedure is an essential component of any ACL setting procedure. In order to perform this simulation exercise for the data-rich stocks, the vulnerability analysis needs to be performed using the PSA as described above, and a simulation exercise of the type developed by Shertzer et al. (Appendix E) performed on that same range of stocks.

3.2 OFL and Uncertainty in Data Poor Stocks

For many fishery stocks, there is insufficient information to perform an adequate stock assessment. There may be some catch information available upon which to base determinations of OFL and ABCs. It has often been the case that catch quotas have been set at the average of historical catch and, sometimes, this policy has had disastrous consequences because average catches reflect overfishing of the resource and the stock has been depleted before management could respond (e.g. sharks, some west coast rockfish, Pacific Ocean Perch in Alaska). This highlights the importance of ensuring that data collection of basic fishery information is accomplished for all fisheries even for what may be currently considered minor components of the catch.

One of the difficulties in using historical average catches as a basis for setting ABCs is that we cannot easily distinguish how much of the catch was sustainable, and how much was due to fishing down the biomass. The determination of OFL for data poor stocks should be based on a minimum of average catch (or survey series) as modified by expert opinions on depletion and productivity as far as possible. While this approach may have substantial uncertainty, it is expected that it will provide the impetus to improve the timeliness, type, and precision of information available.

The Working Group discussed a straightforward method for estimating sustainable catch levels when we have little more than a time series of catches (The Windfall/Sustainable Yield Ratio method, MacCall unpub., see Appendix D) to provide an interim solution until a more complete assessment is available. The approach relies on a time series of catches, some basic life history parameters and expert opinion on the current level of depletion of the resource relative to the unexploited biomass level or the level of biomass needed to support MSY. Essentially, the average catch is discounted by the amount of that catch that can be considered part of the fishing down process, i.e., the difference between the unexploited biomass level and the MSY biomass level. That discounted average catch level can then be used as a basis for OFL, and uncertainty estimated by Monte Carlo methods by simulating performance for different buffer levels using the same sort of MSE approach described above. The Working Group noted that the performance for stocks of differing vulnerabilities can hopefully be related to the results of the data-rich stocks as indicated schematically in Figure 2. The Working Group noted that there should be a smooth progression in buffer size between the OFL and the ABC as uncertainty increases and that the pattern should be similar for data-rich and data-poor stocks.

For stocks where a time series of catches is not available, then the fishery should be managed very cautiously at as low a level of catch as possible until at least catch data are available to avoid overfishing. It is important that this be used as an incentive to acquire relevant catch information. It should definitely be the case that catch limits are set for stocks without catch information since then the incentive may be against acquiring basic fishery information. For cases where data are not sufficient for assessment, every effort should be made to explore alternative sources of information, such as time series of abundance from surveys, historical length-frequency data, or demographic studies, which could provide some indication of the status of the stock.

3.3 Setting OFL for Assemblages

Many fishery management plans treat groups of species or stocks as an assemblage without regard to the individual stocks that it contains. In some regions, because of the large number of species in the catches and the difficulties of monitoring, this practice has been considered essential for understandable reasons. However, the Working Group noted that species grouped into an assemblage for the purposes of setting OFLs and ABCs may not have similar characteristics with respect to vulnerability or uncertainty. In consequence, the more vulnerable stocks will be at greater risk of depletion or even extinction if exploitation is set based on the less vulnerable stocks. The Working Group recommends that the PSA vulnerability analysis be performed on all stocks individually as much as possible and that assemblages of fish with different levels of PSA scores be avoided to guard against this problem.

Similarly, a catch time series for an assemblage may inherently mask problems with one or more species in the grouping if discounted average catch is used to set the OFL. The OFL for an assemblage as a whole needs to ensure that the average proportion of each stock in the catch does not change over time and that the more vulnerable stocks still receive adequate protection. If it is not possible to distinguish the catches of individual stocks in the assemblage, this should be considered a major source of uncertainty such that the buffer between OFL and ABC is substantially increased to protect against overfishing.

4 Policy Decision on Acceptable Risk and Setting of ABCs and ACLs

The ACL is the target level of catch for a future year (or years) that is expected to keep the risk to the resource at an acceptably low level and other factors that contribute to the OY are accounted for as a matter of policy. It is always less than or equal to the ABC. Important to this determination is the concept that no estimates are perfectly precise and any attempt to obtain OY entails some risk of overfishing. The scientific goal is to calculate the buffer between OFL and ABC such that the probability of overfishing is within an acceptable level of risk as determined by policy makers in the statute, the courts and by managers at the national and regional level. In the process for setting ACLs recommended by this Working Group, decreasing the level of risk is addressed by increasing the buffer between the ABC and the OFL.

A related concept is that more knowledge should result in a narrower buffer; we should not use best estimates without any buffer in data-poor situations with unknown levels of uncertainty, and then introduce a buffer when we become able to calculate uncertainty. Instead, we need reasonable default levels of uncertainty to use in the data-poor situations so that we can always expect to improve both fishery average yield and performance in preventing overfishing as we obtain more knowledge. Of course, the new, more data-rich point estimates of OFL and ABC may be above or below the previous data-poor proxies, but the reaction to the more data-rich estimates should be a reduced buffer. One of the important considerations in the setting of buffers between OFL and ABC is to ensure that there is incentive to improve monitoring of the fishery. Linking reducing uncertainty to reducing the buffer size and therefore increasing ABC is one means of accomplishing this.

For stocks that have previously been determined to be overfished and are now on rebuilding plans, there is an additional condition that the ABC should meet. The ABC should both prevent overfishing and allow the stock to have a sufficiently high probability of rebuilding to B_{msy} within a specified number of years. In doing so, it is not just the prevention of overfishing that matters. Now the impact of the entire time series of ABCs on future stock abundance needs to be taken into account.

The logic used in setting ABCs for stocks in rebuilding plans can be extended to setting the ABC for any stock. This alternative formulation focuses on the MSFCMA's general definition of overfishing as a level of fishing that jeopardizes a stock's capacity to produce MSY. From this perspective, the projected stream of future ABCs could be calculated on the basis of whether they have a sufficiently high probability of leaving the stock at or above B_{msy} some specified time in the future. With such an approach, it would be straightforward to calculate the tradeoff between cumulative catch over a specified time period and the resultant risk of stock depletion. If this "time in the future" is taken to be 10 years, then this approach is seamless with a rebuilding plan for stocks that are biologically capable of rebuilding within 10 years.

Based on the PSA plots and vulnerability analysis, policy-makers should assign acceptable levels of risk (P*) values consistently across fisheries with similar vulnerability profiles. These P* values should be a result of setting buffers of different sizes for stocks based on their vulnerability and the uncertainty in their status and management, which follows from the efforts of Restrepo et al. (1998) to recommend precautionary management measures for fisheries. The process suggested here extends that work.

5 Accountability Measures

Accountability measures related to ending overfishing and staying within annual catch limits should use the same framework as setting those catch limits in the first place. Based on the discussion in the Working Group, this can be accomplished by relating a fishery's record of meeting its target (ACL) to the size of the buffer between the ABC and the OFL. For example, the OFL for a fishery should be defined based on MSY for the fishery as prescribed in the law. The ABC should be set based on the level of risk for that particular stock according to the framework described above by the Working Group. A stock with a higher risk level should have a greater buffer between the OFL and the ABC, and in all cases the ABC should be below the OFL. Then, on an ongoing basis, the risk level for the fishery should be re-evaluated as new information becomes available, monitoring improves, gear is modified and other factors in the risk assessment change or become clearer. In addition, the performance of the fishery with respect to the ACL should be considered such that a fishery that consistently stays within the ACL is considered to be at lower risk of overfishing (because management control is more certain), and therefore needs less of a buffer between the ABC and the OFL. Conversely, a fishery that exceeds the ACL in one or more years is considered to have higher implementation uncertainty such that the risk is higher and the buffer should be increased between the ABC and the OFL. In some cases, it may be that only a portion of the fishery exceeds it allocation of the ACL. Then, the buffer between the ACL and ABC for that portion of the fishery should be increased to account for implementation uncertainty, even if the overall ABC for the fishery remains the same.

The advantage of this approach is that a consistent framework is maintained. In addition, relating the performance to the size of the buffer between the ACL and the OFL can be done on a periodic basis such that some variability in performance can be accounted for but smoothed out. In theory, if a fishery continues to consistently perform poorly and exceed the ACL, then the buffer could become large enough to make the fishery bycatch only or even close the fishery, retaining this option in extreme cases. But if the fishery improves its performance, then the catch limits could gradually rise as the buffer size is reduced. Furthermore, other factors such as the quality of monitoring and fishery information are considered in the same framework in adjusting the size of the ACL or ABC to OFL buffer. That means, for example, if apparent performance is good but the reporting and monitoring of the fishery is declining in quality, then the buffer may not be reduced until all factors show improvement.

This framework for accountability has some clear advantages over systems that, for example, require overage of catches to be "paid back" in subsequent years. Here, the problem of building up substantial deficits is unlikely to occur, relating performance to other factors can be done in a consistent way, and changes are less likely to be abrupt in setting of ACLs. Furthermore, the buffer can be evaluated on a periodic basis as opposed to every year to smooth out some variability and improve fishery stability. On the other hand, a payback scheme is much more tangible and direct than changing the buffer between the ACL and the OFL and might be a stronger incentive to improve management. Clearly, if the accountability is related to the buffer size between the ACL and OFL, then the restrictions implied by an increased buffer need to be strictly applied and enforced, with immediate action taken to implement management measures to adhere to increased (or decreased) buffer sizes.

In using this framework, some additional principles must be applied. Logically, stocks that are at greater risk should have a greater consequence for poor performance than stocks that are at lesser risk. This means, for example, that if the ABC is exceeded for a stock under rebuilding, there should be a greater increase in the size of the buffer between the ABC and the OFL than for a stock that is not in an overfished condition. In other words, the recent status of the resource must be considered in deciding how the accountability measure should be applied.

Secondly, there always must be a direct link between the provision of accurate and complete data and the application of accountability measures that adjust the size of the buffer between the ABC and the OFL. In some sense, data collection is the lynchpin for judging the performance of the fishery. If data quality declines, the buffers should be increased in all cases, even if there is apparent adherence to the ACL. This is because that performance cannot be determined as well when the quality of the data declines. Of particular note is the need to ensure that all sources of fishing mortality: landings, discards, state waters catches, recreational catches, etc, are included in the monitoring of the fishery. The same is true of enforcement and compliance. Judgments on changes in data quality and compliance with the regulations need to be made along with the accountability measures.

Thirdly, it may be necessary to consider the application of the buffer between ACL and OFL for sectors of the fishery individually. For example, the commercial and recreational fishery may need to be evaluated separately and accountability of performance with respect to the ACL may need to be considered separately as well. While this is challenging, it may be crucial in ensuring that accountability is appropriately placed. At the same time, in general, the fewer sub-divisions of a given fishery the better in order to prevent the system from becoming hopelessly complicated.

6 Next Steps

The Working Group recommends the process outlined here: beginning with the vulnerability analysis, estimating OFLs and uncertainty, choosing an acceptable level of risk, advising on the needed size of the buffer between OFL and ACL, and the setting of accountability with respect to increasing or decreasing the buffer for setting precautionary and consistent ACLs across US fisheries. In order to implement this process, the working group recommends several specific efforts be undertaken:

- The Council Science and Statistical Committees (SSC) will have a major role in the process of setting ACLs and should be brought into the elaboration of the process outlined here;
- The vulnerability analysis and PSA plots for all managed species must be developed and will provide a critical basis for evaluating risk. This analysis is based on expert opinion and, from the examples done by the Working Group, can be performed relatively quickly;
- In order to complete the vulnerability analysis, a consistent set of factors, factor weights and scoring guidelines for US fisheries need to be developed. This should be done in a workshop setting and completed as soon as possible;
- A management strategy evaluation (MSE) simulation framework is needed to determine the relationship between the size of the buffer, uncertainty, and vulnerability for various stocks, beginning with the data-rich stocks and extending to the data-poor stocks. This can follow the results of the vulnerability analyses and will include an overall simulation study of the approach recommended here;
- The depletion adjusted average catch approach (MacCall unpub.) shows promise for dealing with data-poor stocks and should be tried on as many stocks as possible. An uncertainty analysis for this method should also be developed and considered in light of the vulnerability, uncertainty and buffer size MSE recommended above;
- This conceptual framework will be most effective if it can be presented and discussed in national and regional workshops including examples from different fisheries around the country.

With the implementation of the process suggested here, NOAA Fisheries has the opportunity to make a major improvement in the sustainability of fisheries in the US. The process is broadly applicable to fisheries around the country and internationally and builds on efforts underway around the world. While this is a conceptual framework, it can be implemented relatively quickly and is adaptive as new information becomes available.

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Appendix A – Useful Terms

Most terms have been adapted from National Standard 1 and Annual Catch Limit Terminology

Acceptable biological catch (ABC) is a level of annual total catch, including mortal discards, that may not exceed the amount corresponding to F_{lim} translated into an amount of catch on an annual basis (see Overfishing Level). For overfished stocks, a rebuilding ABC must be set to reflect the annual catch that is consistent with the rebuilding mortality targets

Accountability measures (AMs) are management controls implemented such that overfishing is prevented, where possible, and corrected, if it occurs. They include definition of OY and establishment of an appropriate OY control rule such that OY is achieved and overfishing does not occur, measures to monitor progress of the fishery during the season and take action to prevent catch from exceeding the overfishing level, and corrective measures to respond to overages that may occur.

Annual *catch limit (ACL)* is a level of catch specified for a stock or stock complex each year, that is based on the OY control rule and that does not exceed the annual harvest level recommended by the Council's scientific and statistical committee (SSC).

Biomass means the total quantity of fish in a stock and is used synonymously with stock abundance. Biomass (B_{msy} and B_{lim}) focuses on reproductive potential of the stock so that ''spawning biomass'' is used and is commonly measured as mature female biomass. If spawning biomass is not available, total biomass or other proxies are sometimes used. Biomass is usually measured in total tonnage of fish, but could be numbers or other units to be synonymous with stock abundance.

B_{lim} means minimum biomass limit.

B_{msy} means MSY biomass.

Buffer zone is the area between a limit reference point and a threshold reference point (e.g. OFL and ABC). The size of the buffer is related to perceived risk and preventing overfishing.

Fishing mortality rate means the rate of mortality imposed on the stock or stock assemblage due to fishing activities. F is an abbreviation for fishing mortality rate.

F_{lim} means maximum fishing mortality limit.

MSY means the Maximum Sustainable Yield and is calculated as the largest long-term potential average catch or yield that can be taken from a core stock or stock assemblage under prevailing (*e.g.*, generally current) ecological, environmental and fishery conditions while fishing according to a MSY control rule.

MSY stock size (B_{msy}) means the long-term average stock abundance level of the core stock or stock assemblage, measured in terms of spawning biomass or other appropriate proxy, that would occur while fishing according to the MSY control rule. The MSY stock size is the target stock size to which overfished stocks must be rebuilt.

Overfished means a stock or stock assemblage whose biomass has been determined to be below its B_{lim}. Determination of an overfished status triggers the requirement for development of a rebuilding plan.

Overfishing (to overfish) means to fish at a level that jeopardizes the capacity of the stock to produce MSY on a continuing basis.

Overfishing level (OFL) means the annual amount of total fishing mortality that corresponds to the estimate of F_{lim} applied to annual biomass. Catch exceeding the OFL would indicate that overfishing is occurring.

OY (Optimum Yield): The term "optimum", with respect to the yield from a fishery, means the amount of fish which—

(A) will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems;

(B) is prescribed as such on the basis of the MSY from the fishery, as reduced by any relevant economic, social, or ecological factor; and

(C) in the case of an overfished fishery, provides for rebuilding to a level consistent with producing the MSY in such fishery.

Rebuilding means implementing measures that increase a fish stock to B_{msy} or its proxy.
Stock assemblage means a group of stocks in an FMP that are sufficiently similar in geographic distribution, co-occurrence in fisheries, and life history so that SDC measured on an assemblage-wide basis or for an indicator stock will satisfy the Magnuson-Stevens Act requirements to achieve OY and prevent overfishing of a fishery. Not all stocks in an assemblage will have sufficient information to measure stock-specific status with respect to all reference points.

Appendix B – Susceptibility Attributes derived from EFH Determinations

Generic Susceptibility Table: The following table describes the methods that the Gulf of Mexico, New England, and North Pacific Councils have used to analyze the impacts of fishing gear on habitat. These methods could be used in come up with habitat attributes and ranks for the PSA tables.

Susceptibility Attribute		Rationale for attribute	Rank: Low 1	Rank: 2	Rank: High 3
Habitat	**Gulf of Mexico EFH Simple analysis:** Habitat sensitivity (to gear) For stocks managed by the **Gulf of Mexico Council**, see the EIS for EFH in Gulf of Mexico FMPs	How does the fishing gear interact with the habitat? Habitat sensitivity (the capability of a gear damaging habitat) is ranked on a scale of 0 to 3 (with 0 being negligible to 3 being high) Can use the habitat sensitivity ranks in table 3.5.1 of EIS for EFH in Gulf of Mexico FMPs to rank the species here.			
Habitat	**Gulf of Mexico EFH Comprehensive analysis:** Calculated a fishing impacts index For stocks managed by the **Gulf of Mexico Council**, see the EIS for EFH in Gulf of Mexico FMPs	Used a spatially structured index of fishing impacts, by gear and habitat, with the degree of fishing effort. If fishing effort is high in areas where habitat is sensitivity to the gear, then receive a high susceptibility score. (However, the results of this analysis are not straight forward and the lack of fishing effort data was a constraint in performing this analysis.) (See page 2-54 of EIS for EFH in Gulf of Mexico FMPs)			
Habitat	**New England EFH Simple analysis:** Habitat Sensitivity (sensitivity of the habitat to disturbance) For stocks managed by the **New England Council**, see the individual NEPA documents for the Scallop, Herring, Groundfish, and Monkfish FMP amendments. Do the other EHF EIS's for the other FMPs use the same ranking system?	How sensitive is the habitat to disturbance? The Habitat Sensitivity is scored on a scale of 0-2 (with 0 being not sensitive and 2 being highly sensitive). Can use the habitat sensitivity score from the EIS documents to rank the species here.			
Habitat	**New England EFH Comprehensive analysis:** Habitat Vulnerability For stocks managed by the **New England Council**, see the individual NEPA documents for the Scallop, Herring, Groundfish, and Monkfish FMP amendments. Do the other EHF EIS's for the other FMPs use the same ranking system?	Habitat vulnerability takes into account the habitats value to a species at a particular life stage, the habitat sensitivity (as describe above), and the extent to which the gear is used in areas that are designated as EFH for a given species and life stage. Habitat vulnerability has 4 scores: none, low, moderate, and high. Vulnerability score of none to low should receive a rank of 1 here. Vulnerability scores of moderate to high should receive a rank of 2 and 3, respectively, here.			
Habitat	**North Pacific EFH Simple analysis:** There wasn't a simple habitat sensitivity analysis used in Alaska. For stocks managed by the **North Pacific Council** - see EIS for EFH Identification and Conservation in Alaska	N/A			
Habitat	**North Pacific EFH Comprehensive analysis:** Used a quantitative effect and recovery model. The model outputs were then used by assessment biologists to carry out qualitative evaluations. For stocks managed by the **North Pacific Council** - see EIS for EFH Identification and Conservation in Alaska	Specifically, analysts assessed whether available info provides any indication that habitat changes caused by fishing would alter the ability of each stock to stay above its MSST over the long term. Results are summarized qualitatively for each stock in Appendix B of the EIS.			

Appendix C – Example PSA Tables for Sharks, Gulf of Alaska Pacific Cod, Gulf Red Snapper and the West Coast Rockfish Assemblage

Note the substantial difference in PSA scores for the two shark species, even though they are currently grouped in an assemblage for management purposes. This illustrates the risks of grouping disparate stocks.

1. Great Smooth Hammerhead Shark

Productivity Table: Great smooth Hammerhead Shark

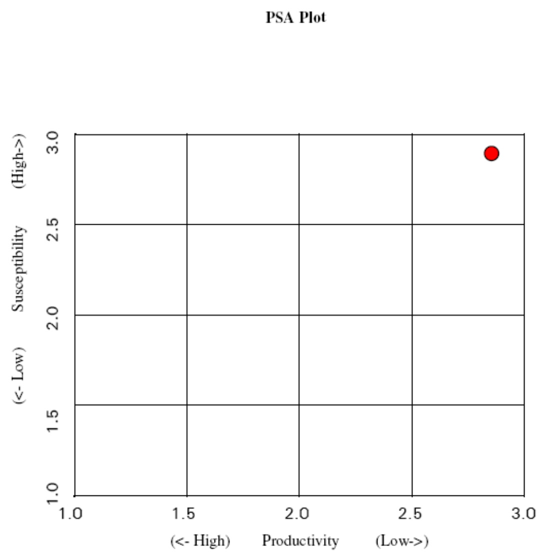
Productivity Attribute		Rationale (examples) for attribute	Rank: High Productivity 1	Rank: 2	Rank: Low Productivity 3
Species-level attributes	Generation Time	Difference between size at birth and maximum; Age at maturity; Size at maturity			X
	Average maximum age/size				X
	Fecundity	Measured fecundity; Frequency of breeding			X
	SSB/SSB_0				X
	Reproductive strategy	$(r \rightarrow K)$			X
Habitat attributes	Persistence of effect of fishing activity	Recovery time		X	
Community attributes	Food web	Mean trophic level (H_0: low, more productive, can also indicates change)			X

Average Rank: 2.85

Susceptibility Table: Great smooth Hammerhead Shark

Susceptibility Attribute		Rationale for attribute	Rank: Low Susceptibility 1	Rank: 2	Rank: High Susceptibility 3
Species-level attributes	Availability (extent of overlap between the species' habitat and area fished)	Depth range; Habitat types			X
	Catchability	Water column position; Schooling/aggregation behavior; Activity times; Morphology - affecting capture			X
	Survival	Survival after capture and release			X
	Spatial refuge from fishery	Seasonal migrations; Closed areas; Vertical migrations			X
Habitat attributes	Stability of habitat	Time for formation; Disturbance of habitat (mixing scale)			X
	Elevation/size of habitat	Rugosity; Fractal dimension		X	
	Structure of habitat	Ordering dimension; Heterogeneity score; Viscosity; Grain size	X		
Community attributes	Trophic structure	Fishing at level where there are few species is likely to have a greater impact on the measure than fishing where there is a diverse assemblage at the trophic level.			X
	Fishery specific	Number of trophic levels captured by gear and Fishing method; Number of gear types; Percent of each trophic level subject to fishing			X

Average Rank: 2.7



2. Atlantic Blacktip Shark

Productivity Table: Atlantic Blacktip Shark

	Productivity Attribute	Rationale (examples) for attribute	Rank: High Productivity 1	Rank: 2	Rank: Low Productivity 3
Species-level attributes	Generation Time	Difference between size at birth and maximum; Age at maturity; Size at maturity		X	
Species-level attributes	Average maximum age/size			X	
Species-level attributes	Fecundity	Measured fecundity; Frequency of breeding			X
Species-level attributes	SSB/SSB_0			X	
Species-level attributes	Reproductive strategy	(r → K)			X
Habitat attributes	Persistence of effect of fishing activity	Recovery time		X	
Community attributes	Food web	Mean trophic level (H_0: low, more productive, can also indicates change)		X	

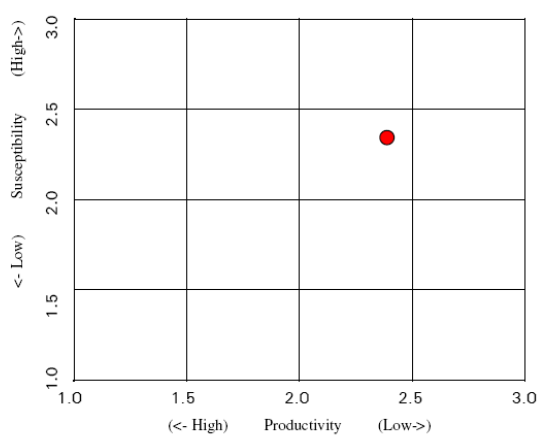
Average Rank: 2.4

Susceptibility Table: Atlantic Blacktip Shark

	Susceptibility Attribute	Rationale for attribute	Rank: Low Susceptibility 1	2	High Susceptibility 3
Species-level attributes	Availability (extent of overlap between the species' habitat and area fished)	Depth range; Habitat types			X
	Catchability	Water column position; Schooling/aggregation behavior; Activity times Morphology - affecting capture			X
	Survival	Survival after capture and release		X	
	Spatial refuge from fishery	Seasonal migrations; Closed areas; Vertical migrations			X
Habitat attributes	Stability of habitat	Time for formation; Disturbance of habitat (mixing scale)			X
	Elevation/size of habitat	Rugosity; Fractal dimension		X	
	Structure of habitat	Ordering dimension; Heterogeneity score; Viscosity; Grain size	X		
Community attributes	Trophic structure	Fishing at level where there are few species is likely to have a greater impact on the measure than fishing where there is a diverse assemblage at the trophic level.		X	
	Fishery specific	Number of trophic levels captured by gear and Fishing method; Number of gear types; Percent of each trophic level subject to fishing		X	

Average Rank: 2.3

PSA Plot



3. Gulf of Mexico Red Snapper

Productivity Table: Gulf of Mexico Red Snapper

Productivity Attribute		Rationale (examples) for attribute	Rank		
			High Productivity		Low Productivity
			1	2	3
Species-level attributes	Generation Time	Difference between size at birth and maximum; Age at maturity; Size at maturity		X	
	Average maximum age/size				X
	Fecundity	Measured fecundity; Frequency of breeding		X	
	SSB/SSB_0				X
	Reproductive strategy	$(r \rightarrow K)$			X
Habitat attributes	Persistence of effect of fishing activity	Recovery time			X
Community attributes	Food web	Mean trophic level (H_0: low, more productive, can also indicates change)			X

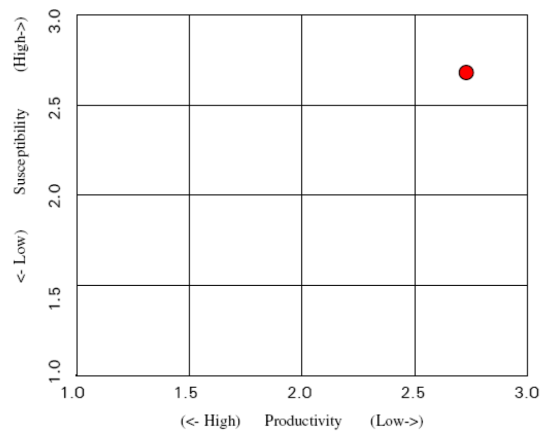
Average Rank: 2.71

Susceptibility Table: Gulf of Mexico Red Snapper

Susceptibility Attribute		Rationale for attribute	Rank		
			Low Susceptibility		High Susceptibility
			1	2	3
Species-level attributes	Availability (extent of overlap between the species' habitat and area fished)	Depth range; Habitat types			X
	Catchability	Water column position; Schooling/aggregation behavior; Activity times Morphology - affecting capture			X
	Survival	Survival after capture and release		X	
	Spatial refuge from fishery	Seasonal migrations; Closed areas; Vertical migrations			X
Habitat attributes	Stability of habitat	Time for formation; Disturbance of habitat (mixing scale)		X	
	Elevation/size of habitat	Rugosity; Fractal dimension			X
	Structure of habitat	Ordering dimension; Heterogeneity score; Viscosity; Grain size		X	
Community attributes	Trophic structure	Fishing at level where there are few species is likely to have a greater impact on the measure than fishing where there is a diverse assemblage at the trophic level.			X
	Fishery specific	Number of trophic levels captured by gear and Fishing method; Number of gear types; Percent of each trophic level subject to fishing			X

Average Rank: 2.66

PSA Plot



4. Gulf of Alaska Pacific Cod

Productivity Table: Gulf of Alaska Pacific Cod

Productivity Attribute		Rationale (examples) for attribute	Rank		
			High Productivity 1	2	Low Productivity 3
Species-level attributes	Generation Time	Difference between size at birth and maximum = 110 cm; Age at 50% maturity = 6; 50% maturity at 50.2cm M=.37, significant uncertainty		X	
	Average maximum age/size			X	
	Fecundity	Measured fecundity – 67cm cod produces over 1,000,000 eggs; Frequency of breeding: annual	X		
	SSB/SSB_0			X	
	Reproductive strategy	$(r \rightarrow K)$		X	
Habitat attributes	Persistence of effect of fishing activity	Recovery time	X		
Community attributes	Food web	PCOD one of 4 key species in GOA Food Web			X

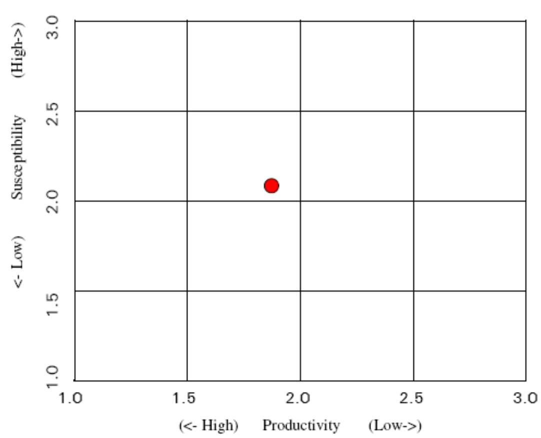
Average Rank: 1.86

Susceptibility Table: Gulf of Alaska Pacific Cod

Susceptibility Attribute		Rationale for attribute	Rank: Low Susceptibil 1	Rank: 2	Rank: High Susceptibility 3
Species-level attributes	Availability (extent of overlap between the species' habitat and area fished)	Depth range; Habitat types			X
	Catchability	PCOD taken with all gear types – trawl, longline, jig and pot In directed fishery as well as bycatch in all other major fisheries Begin to recruit to trawl fisheries at age 3; fully recruited to all gear types by age 7			X
	Survival	Survival after capture and release			X
	Spatial refuge from fishery	Seasonal migrations; Closed areas; Vertical migrations Fishing occurs throughout range – migrate in summer to shallower water where extensive fisheries occur			X
Habitat attributes	Stability of habitat	Time for formation; Disturbance of habitat (mixing scale)	X		
	Elevation/size of habitat	Rugosity; Fractal dimension	X		
	Structure of habitat	Ordering dimension; Heterogeneity score; Viscosity; Grain size	X		
Community attributes	Trophic structure	Fishing at level where there are few species is likely to have a greater impact on the measure than fishing where there is a diverse assemblage at the trophic level.		X	
	Fishery specific	Number of trophic levels captured by gear and Fishing method; Number of gear types; Percent of each trophic level subject to fishing		X	

Average Rank: 2.11

PSA Plot



5. West Coast Rockfish Assemblage (*Sebastes spp.*)

Productivity Table: West Coast Rockfish Assemblage (Sebastes spp.)

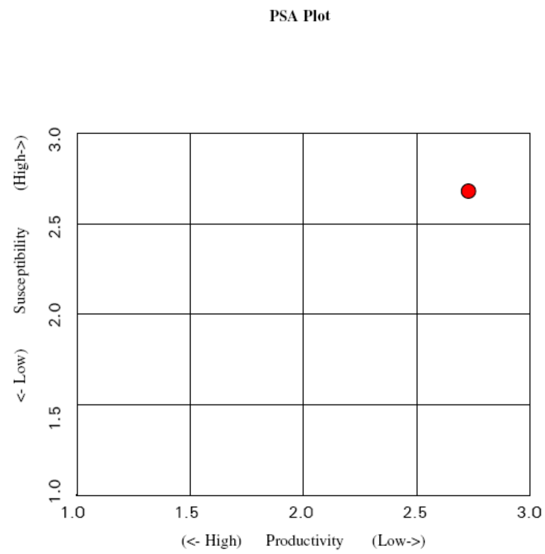
	Productivity Attribute	Rationale (examples) for attribute	Rank: High Productivity 1	Rank: 2	Rank: Low Productivity 3
Species-level attributes	Generation Time	Difference between size at birth and maximum; Age at maturity; Size at maturity			X
	Average maximum age/size				X
	Fecundity	Measured fecundity; Frequency of breeding		X	
	SSB/SSB_0			X	
	Reproductive strategy	$(r \rightarrow K)$			X
Habitat attributes	Persistence of effect of fishing activity	Recovery time			X
Community attributes	Food web	Mean trophic level (H_0: low, more productive, can also indicates change)			X

Average Rank: 2.71

Susceptibility Table: West Coast Rockfish Assemblage (Sebastes spp.)

	Susceptibility Attribute	Rationale for attribute	Rank: Low Susceptibility 1	Rank: 2	Rank: High Susceptibility 3
Species-level attributes	Availability (extent of overlap between the species' habitat and area fished)	Depth range; Habitat types			X
	Catchability	Water column position; Schooling/aggregation behavior; Activity times Morphology - affecting capture			X
	Survival	Survival after capture and release			X
	Spatial refuge from fishery	Seasonal migrations; Closed areas; Vertical migrations			X
Habitat attributes	Stability of habitat	Time for formation; Disturbance of habitat (mixing scale)		X	
	Elevation/size of habitat	Rugosity; Fractal dimension		X	
	Structure of habitat	Ordering dimension; Heterogeneity score; Viscosity; Grain size		X	
Community attributes	Trophic structure	Fishing at level where there are few species is likely to have a greater impact on the measure than fishing where there is a diverse assemblage at the trophic level.		X	
	Fishery specific	Number of trophic levels captured by gear and Fishing method; Number of gear types; Percent of each trophic level subject to fishing			X

Average Rank: 2.66


PSA Plot
(High->)
Susceptibility
<- Low)
3.0
2.5
2.0
1.5
1.0
1.0
1.5
2.0
2.5
3.0
(<- High)
Productivity
(Low->)

Appendix D – Depletion-Adjusted Average Catch

Alec MacCall, NMFS/SWFSC/FED (draft 9/6/07)

Unlike the classic fishery problem of estimating MSY, data-poor fishery analysis must be content simply to estimate a yield that is likely to be sustainable. While absurdly low yield estimates would have this property, they are of little practical use. Here, the problem is to identify a moderately high yield that is sustainable, while having a low chance that the estimated yield level greatly exceeds MSY and therefore is a dangerous overestimate that could inadvertently cause overfishing and potentially lead to resource depletion before the error can be detected in the course of fishery monitoring and management.

Perhaps the most direct evidence for a sustainable yield would be a prolonged period over which that yield has been taken without indication of a reduction in resource abundance. The estimate of sustainable yield would be nothing more than the long-term average annual catch over that period. However, it is rare that a resource is exploited without some change in underlying abundance. If the resource declines in abundance (which is necessarily the case for newly-developed fisheries), a portion of the associated catch stream is derived from that one-time decline, and does not represent potential future yield supported by sustainable production. If that non-sustainable portion is mistakenly included in the averaging procedure, the average will tend to overestimate the sustainable yield. This error has been frequently made in fishery management.

Based on these concepts, we present a simple method for estimating sustainable catch levels when the data available are little more than a time series of catches. The method needs extensive testing, both on simulated data and on cases where reliable assessments exist for comparison. So far, test cases indicate that it may be a robust calculation.

The Windfall/Sustainable Yield Ratio

The old potential yield formula $Y_{pot} = 0.5*M*B_{unfished}$ (Alverson and Pereyra,1969; Gulland, 1970) is based on combining two approximations: 1) that B_{msy} occurs at $0.5*B_{unfished}$, and 2) that $F_{msy} = M$. In this and the following calculations fishing mortality rate (F) and exploitation rate are treated as roughly equivalent.

However, it is possible to take the potential yield rationale one step farther, and calculate the ratio of the one-time “windfall” harvest (W) due to reducing the abundance from $B_{unfished}$ to the assumed B_{msy} level. After that reduction in biomass has occurred, a tentatively sustainable annual yield Y is given by the potential yield formula. So we have the following simple relationships:

$Y = 0.5*M*B_{unfished}$, and

$W = 0.5*B_{unfished}$.

Under the potential yield assumptions, the ratio of one-time windfall yield to sustainable yield is the windfall/sustainable yield ratio (or simply the “windfall ratio”) $W/Y = 1/M$. For example, if $M = 0.1$, the windfall is equal to 10 units of annual sustainable yield.

An Update

The assumptions underlying the potential yield formula are out-of-date, and merit reconsideration. Most stock-recruitment relationships indicate that MSY of fishes occurs somewhat below the level of $0.5*B_{unfished}$. We replace the value of 0.5 with a value of 0.4 as a better approximation of common stock-recruitment relationships.

The F_{msy} = M assumption also requires revision, as fishery experience has shown it tends to be too high, and should be replaced by a F_{msy} = c*M assumption (Deriso, 1982; Walters and Martell, 2004). Walters and Martell suggest that coefficient **c** is commonly around 0.8, but may be 0.6 or less for vulnerable stocks. Figure 1 shows the distribution of **c** values for West Coast groundfish stocks assessed in 2005. The average of **c** for those West Coast species is 0.62, but there is a substantial density of lower values. Because the risk is asymmetrical (ACLs are specifically intended to prevent overfishing), use of the average value is risk-prone. Consequently, we have used a value of c=0.5 in the following calculations.

The yield that is potentially sustainable under these revised assumptions is

$Y = 0.4 * B_{unfished} * c * M$,

or for c = 0.5,

$Y = 0.2 * B_{unfished} * M$.

The windfall is based on the reduction in abundance from the beginning of the catch time series to the end of the series,

$W = B_{begin} - B_{end} = DELTA * B_{unfished}$,

where DELTA is the fractional reduction in biomass from the beginning to the end of the time series, relative to unfished biomass. The analogous case to the potential yield formula is $B_{begin} = B_{unfished}$, and $B_{end} = 0.4*B_{unfished}$, in which case DELTA = 0.6. In practice, B_{begin} is rarely $B_{unfished}$, and DELTA is unlikely to be known explicitly. Although data may be insufficient for use of conventional stock assessment methods, an estimate (or range) of DELTA based on expert opinion is sufficient for this calculation. The windfall ratio is now

W/Y = DELTA/(0.4*c*M),

or in the case of c=0.5,

W/Y = DELTA/(0.2*M).

For example, in the case of fishing down from $B_{unfished}$ to near B_{msy} where DELTA=0.6, if c = 0.5, W/Y = 3/M. Thus the revised calculation gives a much larger estimate of the windfall ratio. For the previous example of M = 0.1, the windfall ratio is now estimated at 30 units of sustainable annual yield.

A Sustainable Yield Calculation

Assume that in addition to the windfall associated with reduction in stock size, each year produces one unit of annual sustainable yield. The cumulative number of annual sustainable yield units harvested from the beginning to the end of the time series is n + W/Y, where n is the length of the series. In this calculation it should not matter when the reduction in abundance actually occurs in the time series because assumed production is not a function of biomass. Of course, in view of the probable domed shape of the true production curve, the temporal pattern of exploitation may influence the approximation.

The estimate of annual sustainable yield (Y_{sust}) is

Y_{sust} = sum(C)/(n + W/Y).

In the special case of no change in biomass, DELTA = 0, W/Y = 0, and Y_{sust} is the historical average catch. If abundance increases, DELTA is negative, W/Y is negative, and Y_{sust} will be larger than the historical average catch.

Examples

The widow rockfish fishery began harvesting a nearly unexploited stock in 1981 and for the first three years, fishing was nearly unrestricted (Table 1). Reliable estimates of sustainable yield based on conventional stock assessments were not available for many years afterward. By the mid-1990s, stock assessments were producing estimates of sustainable yield ca. 5000 mtons, with indications that abundance had fallen to 20-33% of $B_{unfished}$.

Application of depletion-corrected catch averaging indicates good performance of the method within a few years of the beginning of the fishery. Two alternative calculations are given in Table 1. The first calculation assumes M = 0.15, c = 0.5, and that biomass was near B_{msy} at the end of the time period, so that DELTA = 0.6. The second calculation is closer to the most recent stock assessment (He et al., 2007) and assumes M = 0.125, c = 0.5, DELTA = 0.75 (ending biomass in year 2000 is about 25% of $B_{unfished}$).

Other examples would be worth exploring, especially were they can be compared with “ground truth” from a corresponding formal stock assessment.

Low biomasses

The yields given by these calculations can only be sustained if the biomass is at or above B_{msy}. If the resource has fallen below B_{msy}, the currently sustainable yield ($Y_{current}$) is necessarily smaller. A possible approximation would be based on the ratio of $B_{current}$ to B_{msy},

$$Y_{current} = Y_{sust}*(B_{current}/B_{msy}) \text{ if } B_{current}<B_{msy}$$

Implementation

This method is most useful for species with low natural mortality rates; stocks with low mortality rates tend to pose the most serious difficulties in rebuilding from an overfished condition. As natural mortality rate increases (M > 0.2), the windfall ratio becomes relatively small, and the depletion correction has little effect on the calculation.

The relationship between F_{msy} and M may vary among taxonomic groups of fishes, and among geographic regions, and would be a good candidate for meta-analysis. Uncertainty in parameter values can be represented by probability distributions. A Monte Carlo sampling system such as WinBUGS can easily estimate the output probability distribution resulting from specified distributions of the inputs.

With minor modifications, this method could also be applied to marine mammal populations. Although estimation of sustainable yields is not a central issue for marine mammals nowadays, the method would be especially well suited to analysis of historical whaling data, for example.

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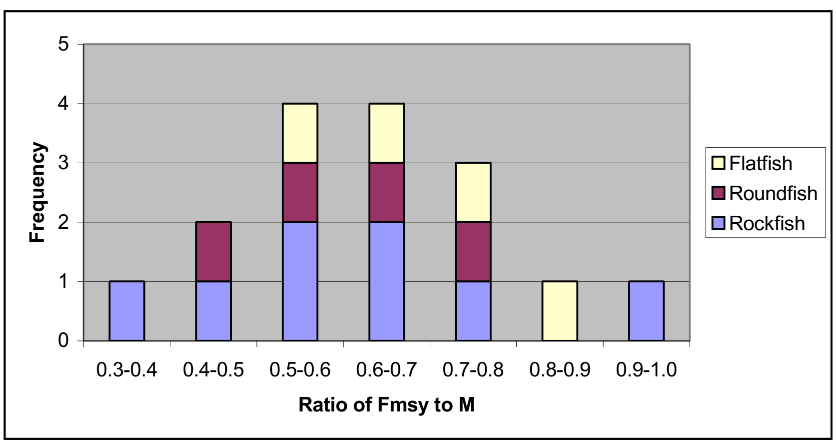
TABLE 1. Widow rockfish example of depletion-adjusted average catch, as if calculations were done in each year. Bold values indicate years when stock might have been assumed to be near B_{msy}. All calculations assume $B_{begin} = B_{unfished}$, and $B_{end} = 0.4*B_{unfished}$. Assumed natural mortality rate is 0.15, but is now thought to be lower. Widow rockfish was declared overfished in 2000.

year	annual catch	cumulative catch	cumulative production	estimated ABC(=MSY)
	1000 mtons		MSY units	1000 mtons
1981	22	22	21	1.0
1982	27	49	22	2.2
1983	26	75	23	3.2
1984	10	85	24	3.5
1985	10	95	25	3.8
1986	9	104	26	**4.0**
1987	13	117	27	**4.3**
1988	10	127	28	**4.5**
1989	12	139	29	**4.8**
1990	10	149	30	**5.0**
1991	6	155	31	**5.0**
1992	6	161	32	**5.0**
1993	8	169	33	**5.1**
1994	6	175	34	**5.1**
1995	7	182	35	**5.2**
1996	6	188	36	5.2
1997	7	195	37	5.3
1998	4	199	38	5.2
1999	4	203	39	5.2
2000	4	207	40	5.2



1. Distribution of ratios of F_{msy} to M for West Coast Groundfish species assessed in 2005. "Rockfish" is genus *Sebastes*. "Roundfish" represents remaining non-flatfish species.

Appendix E – A Probability-Based Approach to Setting Annual Catch Levels

A Probability-Based Approach to Setting Annual Catch Levels

Kyle W. Shertzer, Michael H. Prager, and Erik H. Williams
NOAA/NMFS Southeast Fisheries Science Center
101 Pivers Island Road
Beaufort, North Carolina 28516
September 14, 2007

Authors' note: The manuscript on which this appendix is based will be submitted to Fishery Bulletin*. We have prepared this appendix under the American Fisheries Society's guidelines for extended abstracts, to avoid any question of duplicate publication.*

Recent reauthorization of the Magnuson–Stevens Fishery Conservation and Management Act requires each FMP to "establish a mechanism for specifying annual catch limits … at a level such that overfishing does not occur in the fishery …" Because this requirement is new, scientific practice for setting ACLs is not yet established.

We propose an approach that keeps the annual probability of overfishing P^* below some preset level (e.g., 0.1), presumably meeting the requirement to avoid overfishing. This probability-based approach to setting catch limits, which we call PASCL, is an extension of the REPAST algorithm (Prager et al. 2003) for setting fishing targets. That paper in turn extended the work of Caddy and McGarvey (1996) on targets and limits. When used for setting ACLs, PASCL can accommodate uncertainty in many areas, e.g., in estimated stock status, in the estimated limit reference point F_{lim} (typically F_{MSY} or a proxy), in future stock dynamics (whether due to single-species or ecosystem effects), and in implementation of management measures.

In PASCL, uncertainty in stock dynamics is represented by a stochastic projection model. This approach allows setting ACLs for more than one year and facilitates including uncertainty, as mentioned above. Modeling non-equilibrium population dynamics, as here, is critical in developing harvest strategies (Hauser et al., 2006).

Stock assessment results generally include estimates of uncertainty. A key result used in PASCL is the estimate of F_{lim}, the limit reference point in fishing mortality rate, and its associated uncertainty, described by a probability density function (PDF), either parametric or nonparametric. If a PDF on F_{lim} is unavailable, PASCL can use a point estimate, but ignoring that source of uncertainty can make overfishing more likely (Prager et al., 2003). Another basic assessment result, the estimate of stock status with its corresponding uncertainty, is used to initialize stock replicates in PASCL's stochastic projection.

In PASCL, the level of risk deemed acceptable by managers is quantified as P^*, where *risk* is defined as the probability of overfishing in year *t* [i.e., $\Pr(F_t > F_{\text{lim}})$]. A smaller P^* corresponds to more risk-averse management. Always, $P^* < 0.5$ should hold, since $P^* = 0.5$ equates limit and target, with overfishing expected in half of all years. When P^* is defined as a constant probability, as here, the risk of overfishing in at least one of T years grows with the time horizon (T) as $1-(1-P^*)^T$.

In a simpler formulation, F_{lim} would be represented by a point estimate. In that case, the probability of overfishing in year *t* would be a function of F_{lim} and the probability density function (ϕ_{F_t}) of F_t:

$$\Pr(F_t > F_{\text{lim}}) = \int_{F_{\text{lim}}}^{\infty} \phi_{F_t}(F)\,dF = 1 - \Psi_{F_t}(F_{\text{lim}}) \qquad (1)$$

where $\Psi_{F_t}(F_{\text{lim}})$ is the cumulative distribution of F_t evaluated at F_{lim}. The distribution of F_t can be shifted so that the desired risk is achieved; i.e., so that $\Pr(F_t > F_{\text{lim}}) = P^*$.

The formulation used here is slightly more complex (and realistic) in that $F_{\lim}$ is described by its PDF, $\phi_{F_{\lim}}$. In this case, the probability of overfishing is computed

$$\Pr(F_t > F_{\lim}) = \int_0^{\infty} \left[1 - \Psi_{F_t}(F)\right] \phi_{F_{\lim}}(F) dF \qquad (2)$$

which is the weighted sum of probabilities computed by Equation (1) for all possible values of $F_{\lim}$. Again, the distribution of F_t can be shifted so that $\Pr(F_t > F_{\lim}) = P^*$.

The goal of PASCL is to set an ACL such that $\Pr(F_t > F_{\lim}) = P^*$ in each year of a multiyear sequence. The extensions from the formulation just described (Equations (1) and (2)) are the use of output controls (catches) for management and time frame of several years. The goal is achieved through a projection model (Fig. 1) and the following steps:

1. Initialize *N* replicates of the stock, each slightly different in size and structure to reflect uncertainty in estimated current stock abundance.
2. In the presence of implementation uncertainty in management, an ACL is the central tendency *X* of a distribution. Choose a trial value of *X*, and draw *N* values $\{C_1 \ldots C_N\}$ from the distribution to be the catches taken from the *N* stock replicates.
3. Compute, for each replicate, the fishing mortality rate that yields C_n. This produces *N* values of F_t to define its empirical probability density (ϕ_{F_t}).
4. Given ϕ_{F_t} and $\phi_{F_{\lim}}$, compute $P = \Pr(F_t > F_{\lim})$ from Equation (2).
5. Using an optimization algorithm, adjust X until $P = P^*$. The adjusted X is that year's ACL.
6. Project each replicate one year forward by applying recruitment and natural mortality and taking catch C_n .
7. Repeat steps 2–6 for *T* years.

The duration *T* of the projection period in general will extend until ACLs based on the next assessment can be implemented. The enumerated procedure gives an ACL for each year in the period, and in each year the probability of overfishing is kept to P^*.

The PASCL algorithm is quite flexible. It can be based on age-structured or age-aggregated projections, which can incorporate any source of uncertainty needed, including variability in life-history parameters, environmental influences, and multispecies effects. Rather than requiring data or results beyond those standard in stock assessments, PASCL reframes standard projection methods for use in setting ACLs.

This algorithm is not the only possible approach to setting ACLs. In particular, data-poor stocks will likely require a different approach, such as assemblage management.

A notable feature of PASCL is that managers choose the level of risk they consider acceptable. This choice can reflect socio-economic considerations in addition to biology. In some cases, higher risk of overfishing may be desired (e.g., if short term pain of reduced fishing effort outweighs long term benefits to yield (Shertzer and Prager, 2007)). In other cases, managers may be more precautionary. In either case, establishing the level of risk as an explicit choice increases transparency in the management process.

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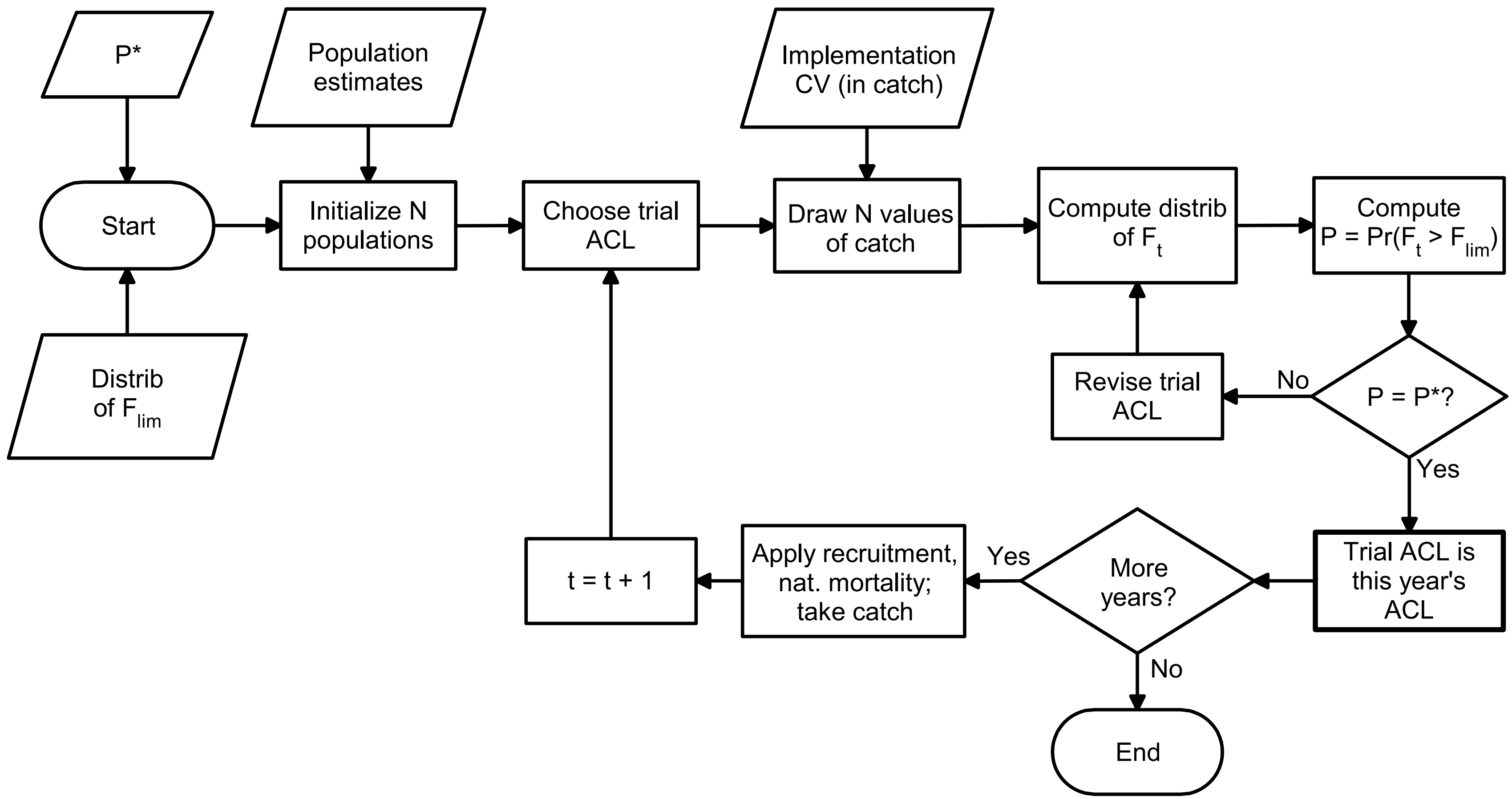

Figure 1. Algorithm for computing ACLs by PASCL method. Input quantities shown as parallelograms.

Appendix F – NMFS Staff in Attendance

NMFS staff were invited to attend the workshop and provide technical expertise to the workgroup. The following staff were in attendance.

Alec MacCall	NOAA Fisheries, Southwest Fisheries Science Center, Fisheries Ecologies Division
John McGovern	NOAA Fisheries, Southeast Region, Gulf Operations Branch
Richard Methot	NOAA Fisheries, Assessment and Monitoring Division
Mark Millikin	NOAA Fisheries Headquarters, Domestic Fisheries Division
Steve Murawski	NOAA Fisheries Service, Director of Scientific Programs and Chief Science Advisor
Michael Prager	NOAA Southeast Fisheries Science Center
Paul Rago	NOAA Fisheries, Northeast Fisheries Science Center
Fred Serchuck	NOAA Fisheries, Northeast Fisheries Science Center
Phil Steele	NOAA Fisheries, Southeast Region, Sustainable Fisheries Division
Galen Tromble	NOAA Fisheries Headquarters, Domestic Fisheries Division Chief

LENFEST
OCEAN
PROGRAM

1025 F Street NW, Suite 900, Washington, DC 20004
ph: 202.552.2131 • fx: 202.552.2299
email: info@lenfestocean.org
www.lenfestocean.org

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