A Scientific Perspective on Challenges and Successes with Annual Catch Limits, and Possibilities to Improve Fishery Sustainability

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Abstract

A major challenge for all participants in the fishery management process is the achievement of a balance between the prevention of overfishing and the attainment of high, sustainable catch levels and fishing opportunities. The rate of fishing needed to attain close to maximum long-term yield requires attentive monitoring of the stocks and frequent management adjustments. Scientific fish stock assessments guide these adjustments to minimize over- and under-fishing. Full stock assessments can estimate the current fishing rate and the rate that would be overfishing, but even the best assessments have uncertainty and most assessments do not have sufficient data to precisely calculate fishing rates and their impact on the fish stock. The National Standard 1 (NS1) Guidelines for prevention of overfishing and attainment of optimum yield call for a science-based approach in which the degree of uncertainty in scientific estimates is used to set a precautionary buffer between the target rate of fishing and the imperfect estimate of the overfishing rate.

All Regional Fishery Management Councils have included these buffers in their fishery management plan amendments for setting annual catch limits (ACLs) with accountability measures. For some Councils, the change to ACL management was a major shift from previous fishery management approaches, and numerous challenges have emerged. In this paper, the ACL approach is briefly outlined and refined approaches are described. Themes addressed include the relative roles of scientific and management uncertainty in the measurement of overfishing; the timeframe over which phase-in of ACL adjustments could be made; the identification of target, non-target, and ecosystem component (EC) stocks; and the contrasting approaches to management of stock complexes versus multi-stock fisheries.

Introduction

Fishery management in the U.S. has a long history of science-based approaches (Darcy and Matlock, 1999; Tromble et al., 2009; Methot et al. 2013). First implemented in 1976, the Magnuson-Stevens Fishery Conservation and Management Act (MSA) mandated the prevention of overfishing and the attainment of optimum yield from our fisheries. Its reauthorization in 2006 introduced new requirements to end and prevent overfishing through the use of ACLs and accountability measures (AMs). The MSA makes three statements that establish the foundation for this science-based ACL concept:

- The Councils must "establish a mechanism for specifying ACLs in the fishery management plan (FMP) ... at a level such that overfishing does not occur in the fishery, including measures to ensure accountability" (MSA section 303(a)(15)).
- Each Council shall develop ACLs for each of its managed fisheries that may not exceed the "fishing level recommendations" of its [Scientific and Statistical Committee] SSC or peer review process (MSA section 302(h)(6)). ACLs are required in all fisheries, with the only exception being interna-

tionally-managed fisheries and fish stocks with one-year life cycles.

- Each SSC "shall provide its Council ongoing scientific advice for fishery management decisions, including recommendations for acceptable biological catch [ABC], preventing overfishing, maximum sustainable yield, and achieving rebuilding targets, and reports on stock status and health, bycatch, habitat status, social and economic impacts of management measures, and sustainability of fishing practices" (MSA section 302(g)(1)(B)).

The NS1 Guidelines introduced, in 1998, a section on using a precautionary approach when implementing fishery management measures to prevent overfishing (Restrepo et al, 1998; Darcy and Matlock 1999). The 2007 Act's strong call for the prevention of overfishing, "...such that overfishing does not occur...," raises the question of just how confidently must the fishery management system prevent overfishing? Thus, the January, 2009 update to the National Standard 1 Guidelines clarify the role of scientific and management uncertainty in the fishery management process, and the guidelines describe the need to set a buffer between the level of fishing that is estimated[1] to be overfishing and the level of fishing that would prevent overfishing with a certain degree of confidence while still attaining a large fraction of the biologically sustainable yield. These buffers operationalize a precautionary approach. This ACL framework is described here, along with some challenges and potential adjustments.

In May 2012, National Marine Fisheries Service (NMFS) issued an Advanced Notice of Proposed Rulemaking (ANPR) with regard to the NS1 Guidelines. The NMFS is currently considering its response to the comments received on the ANPR. The discussion in this paper represents the views of the author from a scientific perspective. It is not a preview of the agency's action in response to the ANPR.

Annual Catch Limit Framework

The terminology used in the NS1 Guidelines refers to rates of fishing (F) and levels of catch (C). If B is the biomass of the stock that is available to the fishery, then catch is approximately equal to F * B. The assessment models make the relationship exact as they take into account age-specific, seasonal and other factors.

The ACL framework starts from the estimate of the fishing mortality rate (F) that would, in theory, produce the greatest long-term average catch (maximum sustainable yield, MSY) from the stock (Mace 1994) (Figure 1). The F level that would produce MSY is termed the F_{msy}. Because the stock's B fluctuates over time due to natural (climate, ecosystem, habitat) and fishery factors, the target level of catch must be adjusted annually if the F is to be maintained exactly at the rate that would produce MSY (Figure 1). Exceeding, or not attaining, F_{msy} will produce, over the long-term, less yield than MSY. Fortunately, over a range of F levels close to F_{msy}, an average catch only slightly below MSY can be obtained (Hilborn 2010). Scientific uncertainty, time lags, and management uncertainty prevent us from maintaining F at the perfect level, so MSY is best considered a theoretical upper limit that can be approached but never quite attained (Figure 1). In most cases, F_{msy} cannot be directly measured so scientists use a proxy for F_{msy} based upon studies that have shown that proxy to be a reasonable approximation for F_{msy}. Typically these proxies will target reduction of the stock to around 35-40% of its unfished level.

The F_{msy}, or its proxy, is then the basis for setting the fishing rate that would be considered overfishing. This is termed the maximum fishing mortality threshold (MFMT). The ACL that corresponds to the MFMT is the overfishing limit (OFL), so OFL = MFMT * B. Table 1 (next page) documents the relationship among some of these catch quantities used in the fishery management process.

1 The term "estimate" is used to mean that the rate of overfishing can only be measured approximately. With good data and accurate models of fish populations, these approximations can be quite good, but they will never be as precise as the application of a tape measure to determine the size of a box. The scientific estimates of fish abundance, fishing mortality rates, overfishing levels, and other quantities all have scientific uncertainty. By following a good scientific process, the degree of scientific uncertainty itself can be measured.

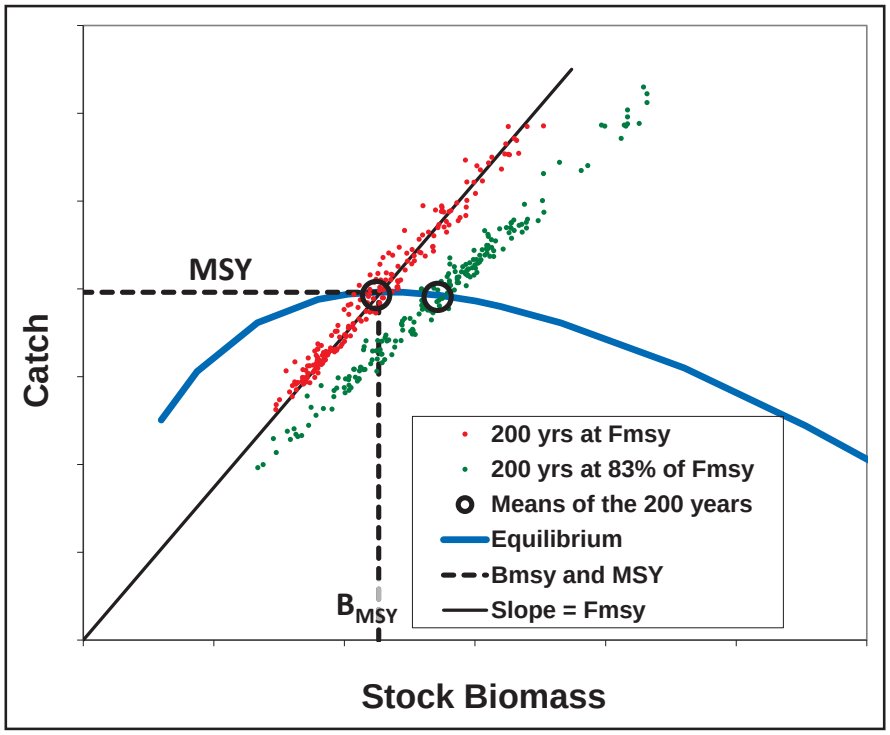

Figure 1. The scientific basis for sustainable fisheries shows that fishing at a moderate rate, F_{msy} (shown as the slope of the diagonal line) can produce a maximum long-term average catch, MSY, while maintaining the stock near an intermediate biomass level, B_{msy}. This MSY is a theoretical maximum because stocks are not perfectly in equilibrium, as shown by the blue curve, nor are scientific forecasts and fishery controls perfect enough to track the natural fluctuations over time. The red dots show that, if control actually was perfect, the long-term average would be close to the equilibrium value. The blue equilibrium curve is fairly flat over a range of F values above and below F_{msy}. Actual science-management systems cannot be perfect, so the realized F fluctuates over some range such that the realizable long-term average yield is somewhat less than the theoretical MSY. Setting target F somewhat below F_{msy} (83% in this example), can produce nearly as much catch as MSY while maintaining the stock, on average, above B_{msy}.

The Council's SSC is expected to recommend a level of catch, the ABC, that is below the OFL according to the degree of scientific uncertainty (which can be calculated scientifically) and the Council's acceptable chance of allowing overfishing (Shertzer et al. 2008; Ralston et al. 2011). The expected relationship between the SSC's role and the Council's role is shown in Figure 2 (next page). It is expected that the process for setting the ABC be specified in a control rule, which is set of formulas and procedures described in the Council's FMP. The complication is that the Council's tolerance to getting close to the overfishing limit depends, in a complex and hard to quantify way, on social, economic and ecosystem factors. So the factors that go into the ABC Control Rule are a step towards a process to define optimum yield (OY). Because the control rule becomes a statement of the Council's tolerance for allowing occasional (less than 50 percent) chance of overfishing, it is important that it is analyzed with short-term and long-term biological, social and economic impacts taken into account to the extent possible. Because the ABC Control Rule sets the catch below the OFL, there will be short-term reductions in fishing opportunity if previous levels of catch were near or exceeded the OFL. Fortunately though, lower fishing rates are expected to raise the average abundance of the stock, and then continuing to apply that lower rate to the larger stock will produce, on average, nearly as much long-term catch as the theoretical MSY (Figure 1). Of course, these expectations depend upon current ecosystem and environmental conditions persisting into the future. A recent study (Vert-Pre et al. 2013) indicated a large number of situations in which unexplained shifts in productivity seem to have occurred, thus adding more variability to forecasts of stock rebuilding and setting of ABC.

Table 1. Relationship among various annual and long-term catch quantities used in the fishery management process.

Basis	Annual Catch Quantity	Long-Term Average	Role
MFMT and biomass	OFL	MSY	Status determinations
OFL and scientific uncertainty	ABC	<MSY	Upper limit for ACL
Science-Management transition	ACL	N/A	Basis for accountability Measures
Management uncertainty	ACT (optional)	N/A	Optional target to ward against exceeding ACL
Additional social, economic, ecological factors	Variously named; modified ACT; annual catch target; annual OY	Optimum Yield (OY)	Actual expected performance of the fishery

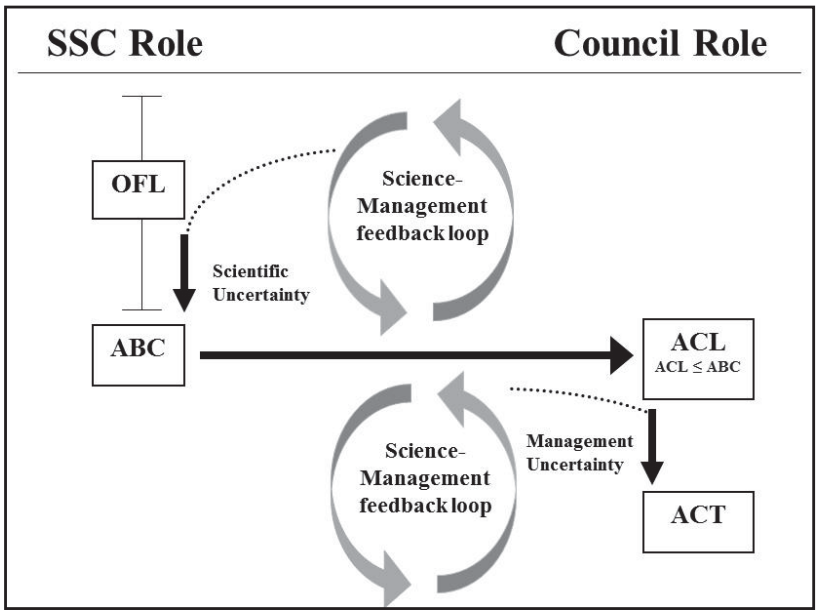

Figure 2. A schematic describing the related roles of the Councils and their Scientific and Statistical Committee (SSC) in translating scientific information into recommendations for catch limits.

The SSC's recommendation of the ABC then forms the basis for the Council setting the ACL. The ACL will typically be set equal to the ABC; it is the science-management handoff. There is an important distinction. The ABC is the endpoint of the scientific process. The ACL is a management limit and is no longer an estimate. It is the basis for management actions and accountability measures for a given fishing year. After setting the ACL, the Council may then need to make further adjustments (to create an annual catch target [ACT]) to account for management uncertainty regarding the capability of the system to manage actual catch close to the ACL. Other adjustments will account for bycatch reduction, interactions among fisheries, and other factors.

Discussion

What Does Overfishing Mean?

Overfishing is catching too many fish, which reduces the stock's abundance and productivity, and prevents the stock from producing as much catch, in the long-term, as the larger stock could have produced given the prevailing environmental conditions. Thus, overfishing jeopardizes a fish stock's capacity to produce maximum sustainable yield.

This reduced stock will also have a diminished role in its ecosystem, the higher fishing effort associated with overfishing may have more bycatch, and the catch per unit of fishing effort will be lower and less able to provide revenues over the costs of that fishing effort. So, there are several good reasons to prevent overfishing. ACLs with accountability measures are intended to prevent overfishing. Their perceived and real success in doing so requires some attention to the ways in which overfishing is measured, and the time frame over which it is measured.

Measuring Overfishing

The National Standard 1 Guidelines describe two ways to measure overfishing scientifically and then to make a formal status determination. One is to set a MFMT, and then use a subsequent stock assessment to measure whether or not the actual catch for the most recent year has resulted in a level of F that exceeds the MFMT. The other approach is to use a stock assessment (which could be as simple as a calculation made from historical average catch) to forecast a level of catch that is the OFL and then simply measure whether or not the actual annual catch exceeds this amount. OFL is in the same terms, catch amount (measured in weight or number of fish), as the ABC and the ACL. The MFMT is a rate, so is not expressed in the same terms as the ACL (i.e., catch). With some exceptions, the OFL approach is used predominantly in the FMPs of the Pacific and North Pacific Councils, and the MFMT approach is used predominantly in the Councils along the Atlantic and Gulf of Mexico. These two approaches and some of their pros and cons are outlined in Table 2 (next page), using the status determination for year 2014 as an example.

The OFL approach depends upon assessments to guide adjustments to OFL over time. Stocks are constantly fluctuating in abundance and productivity, so the catch limits needed to maintain the F rate below the threshold must also be adjusted, or there must be an effective control of fishing effort so that it remains constant at the level to produce the target F. For example, the abundance of North Pacific groundfish stocks fluctuates from year to year, so assessments for most stocks occur annually just months before the fishing season begins. Once the OFL has been set for the year, whether or not it is exceeded depends only on the timeliness and effectiveness of management practices for that year (i.e., management uncertainty). However, scientific uncertainty can compound that challenge. For example, the OFL for a year will typically be set before there is knowledge of the most recent level of recruitment of young fish into the stock. If this recruitment is much higher than expected, then fishermen may catch fish at a high rate, causing an earlier than expected attainment or exceeding of the OFL. But a subsequent assessment may show that because of the high recruitment, the F was not above the MFMT even though the OFL may have been exceeded. Conversely, if recruitment is poor the stock is smaller than expected and the catch will be concentrated on the remaining stock, thus causing a higher F even though the OFL was not exceeded. So, accurate and timely forecasts of the available biomass for the upcoming fishing season are important for good implementation of the OFL approach, even though the status determination itself only depends upon catch and the OFL.

The MFMT approach also needs assessments, as it is the assessment that hindcasts the fishing mortality rate for the previous year and calculates the probability that overfishing did or did not occur. So, because the MFMT approach depends upon an assessment, the scientific uncertainty associated with that assessment will also influence whether or not the assessment finds that F exceeded the MFMT. Stocks that have overfishing determined by the MFMT approach also will use assessments to forecast ACLs that will be intended to prevent overfishing. The catch could be less than that ACL, but the updated calculation by a subsequent assessment may show that the F caused by the catch could exceed the MFMT because of the scientific uncertainty associated with the assessments, including fluctuations in stock abundance. This reduces public trust in the value of the assessments because the management limit, the ACL, was followed but the subsequent assessment finds that overfishing still occurred. Whether the OFL approach or the MFMT approach is preferable largely depends upon the precision and timeliness of the assessments and the expected degree of OFL change from year to year. Given the need for forecasts of ABC and ACL for all managed stocks, the OFL seems advantageous in many situations.

Table 2. Outline of the procedures for making overfishing determination using the OFL approach versus the F approach.

OFL Approach for 2014	MFMT Approach for 2014
Use MFMT and 2013 assessment to forecast Biomass and OFL for 2014, and perhaps years beyond. OFL could also be from a non-forecasting, simpler assessment.	
Forecast of ABC and ACL for 2014 similar to OFL forecast	Same as OFL approach
Throughout 2014 and early 2015, catch for 2014 compared to ACL for accountability measures.	Same as OFL approach
Status Determination: In 2015, catch for 2014 compared to OFL to determine if overfishing has occurred. No updated assessment is needed.	
Assessment in 2015 or later will update estimate of B and MFMT for 2014 and calculate the F for that 2014.	Same as OFL approach
OFL based overfishing determination is not reconsidered on basis of the new assessment.	Status Determination: Calculation of F for 2014 compared to MFMT to determine if overfishing occurred.
Pro: Can be applied in situations where data are too limited to calculate F levels Pro: Formal status determination not directly influenced by scientific uncertainty Pro: Easily explained to public because OFL, ABC and ACL are in the same terms	Pro: If fishery effort is relatively constant, can work better when natural stock fluctuations are high
Con: If stock fluctuations are high and assessments not timely and precise enough to forecast changes, then OFL approach will cause fluctuations in F Con: No accountability measure is associated with later finding that F was greater than MFMT	Con: If assessments have much uncertainty, there is possibility for a finding of overfishing even if catch was kept below ACL. Con: Delayed assessments mean that status determinations cannot be updated Con: Harder to explain to public because the ABC and ACL forecast are based on a different assessment than the subsequent assessment used for the status determination

Types of Overfishing

Status determinations to determine if overfishing has occurred are designed to prevent the stock from experiencing actual overfishing and declining into an overfished state. However, scientific and management uncertainty mean that simply setting targets below limits does not necessarily prevent the stock from experiencing overfishing. We perceive overfishing on the basis of estimated F being greater than MFMT or catch being greater than OFL, but these are based on estimates so cannot perfectly reflect what is happening to the fish stock. Four levels of overfishing may be identified to clarify this situation.

The first level can, unfortunately, best be termed intentional overfishing. This occurs when the catch quota or other management measure is set above the overfishing level, or by allowing fishing to occur with no effective management controls. With the MSA and the Councils' implementations of the 2009 NS1 Guidelines, the U.S. has ended this type of overfishing by requiring ACLs that are below the overfishing level and by requiring accountability measures to assure that ACLs are not frequently exceeded. However, this does not mean that other types of overfishing will not occur in the future.

The second level of overfishing occurs due to management uncertainty. In this situation, the ACL has been set at a

level that, if followed, would prevent overfishing. But if the control of the fishery allows excessive catch, the ACL and the OFL (or MFMT) can be exceeded. This could be accidental (inseason management procedures were in place but they were implemented too late due to data lags or other factors, or failed to slow fishing effort sufficiently), or structural (no credible accountability measures were in place to keep catch under control within the fishing season). In fishery management plans that define overfishing on the basis of annual catch exceeding the OFL, management uncertainty will be the typical way in which a finding of overfishing will be made.

The third level of overfishing occurs due to scientific uncertainty that causes a subsequent assessment update to have an upward revision of historical estimates of fishing mortality rates, or downward revision of the MFMT. Whether or not this results in a formal finding of overfishing will depend upon whether the FMP uses the OFL approach or the MFMT approach. In either case, the best science information available now indicates that fishing has had too large of an impact on the stock. An accountability measure could be a larger buffer between OFL and ABC to guard against this type of overfishing. While management uncertainty can be corrected on annual basis through the use of accountability measures, scientific uncertainty can be persistent for many years before new information or assessment approaches cause a shift in the assessment outcome. Ralston et al (2011) examined the history of updated assessments for U.S. West Coast groundfish to determine the overall level of scientific uncertainty from the year-to-year assessment changes and used this to guide creation of a buffer between the OFL and the ABC.

The fourth level of overfishing is not yet formally defined, but is essentially ecosystem overfishing. This occurs when the model/paradigm under which the overfishing limits of single-species assessments are biased, and/or inadequately account for important factors. We may not find out about this until decades later. It is essentially a long-term form of scientific uncertainty. For an analogy, consider the many decades of forest fire suppression that occurred before finding that some level of fire was beneficial to forest ecosystem health. An example from fisheries might be a case where ecosystem shifts have caused a changed in natural mortality over time. Because single-species assessments have little inherent ability to detect such shifts, the natural mortality rate is held constant in the model year after year and a perplexing degree of retrospective bias in the assessment occurs as the model attempts in vain to deal with mismatches in the data being analyzed. Only after bringing results from ecosystem models into direct consideration is the shift in natural mortality detected and incorporated into the improved, next generation assessment. It is important to anticipate this possibility and consider the cumulative impact of fishing on the entire ecosystem (Murawski 2000). When managing at the system level, research suggests that MSY and other reference points should be more conservative than those based on traditional single-species stock assessments (Fogarty et al., 2012; Meuter and Megrey 2006). An explicit buffer for ecosystem uncertainty has yet to be addressed, although the 2,000,000 ton catch cap in the Bering Sea is a step in this direction.

Uncertainty Buffers

Concerns have been raised that stock assessment methods themselves, the accounting for scientific uncertainty, and the accounting for management uncertainty causes excessive and duplicative buffers in the prevention of overfishing. It is important that all sources of uncertainty be taken into account in a cumulative way so that the total buffer attains the desired degree of protection against overfishing, but this does not make them duplicative. The stock assessment itself should be as objective as possible and not take any steps that are intentionally conservative, so that a risk neutral estimate of MFMT and OFL is provided to managers along with information on the uncertainty of those estimates. Prior to the 2009 update of the NS1 Guidelines and its creation of an explicit buffer for scientific uncertainty, it is possible that some assessment calculations embedded that uncertainty into their baseline advice. That should no longer be the case. When the SSC asserts that the assessment is the best scientific information available, it does not mean that it is perfect information regarding the abundance and status of the stock. Perfection only occurs in a theoretical sense; reality has imperfection and uncertainty. The buffer associated with the determination of ABC acknowledges this scientific uncertainty. Once the operational limit, ACL, for the year has been set, then it is management uncertainty that controls how close to the ACL the catch will be. The investments needed

to reduce management uncertainty are different than the investments needed to reduce scientific uncertainty. Low management uncertainty typically requires a good, timely inseason catch accounting system and a responsive set of management tools. Reduced scientific uncertainty in assessments typically requires better fishery-independent surveys, data on fish ages, and ecosystem studies of process changes. Analysis of the impact of scientific and management uncertainty needs to take the combined effect of both into account, but they are measuring different aspects of the science-management system.

Time Frame for Updating Assessments and ACLs

The time frame on which assessments should be updated and ACLs adjusted depends upon four major factors: the expected frequency and degree of natural fluctuation in stock abundance, the level of uncertainty in the stock assessments, value of the stock (which generally leads the fishing community to want the stock's fishing mortality rate to approach the level of F_{msy}), and assessment capacity of the regional NMFS Center and the Councils to assess all managed stocks (the number of stocks managed by regions/Councils varies widely, as well as their capacity to assess each stock due to funding and data limitations). Stocks that have high natural fluctuations need frequent assessment updates to track the changes and reduce foregone yield due to over or under-fishing. Attaining MSY is theoretically possible if the ACL adjustments were perfect and occurred instantly as needed. On the other extreme, stocks that do not have frequent assessments typically have their ACL kept constant for several years because there is no information to guide ACL changes to track stock fluctuations. In between are the stocks for which the fishery management system attempts to adjust ACL frequently, but scientific uncertainty produces perceived fluctuations in stock abundance that do not match the actual changes in stock abundance. The ACLs are updated essentially in lock-step with the assessment results through a control rule that translates the assessment output into OFL and ABC values that limit the ACL. So there is a dichotomy between allowing an ACL to be unchanged for several years when there is no assessment update, then expecting it to fully change when a new assessment is completed, no matter how much uncertainty there is in the new assessment.

The up and down fluctuations in ACL to prevent overfishing and foregone yield is not always an ideal way to manage the fishery because in some cases they tend to have a negative short-term effect on fishing communities. This is particularly true for recreational fisheries, so it is important to assure that the ACL adjustments are beneficial. If the adjustments are strongly influenced by scientific uncertainty, then the long-term benefits of close tracking are diminished and could be out-weighed by the short-term negative effects. Management uncertainty has been shown to be increased by large scale fluctuations in the ACLs (i.e., > 20% change), because developing effective management measures for a moving target is a difficult task to achieve (Patrick et al. 2013).

A way around this problem is to build inertia into the OFL control rule to smooth out the changes over time. When the assessment is updated and a change in ACL is indicated, the change could be phased in according to a pre-agreed formula. Such an approach is commonly seen in the management procedure approach to control rules (Butterworth and Punt 1999). It is quite reasonable to also use such an approach in the application of assessment results to guide changes in ACL. For example, next year's ACL could be set equal to 60 percent of last year's ACL plus 40 percent of the ACL indicated by the new assessment. Other approaches could put a limit on the degree of ACL change allowed from year-to-year. For example, the International Pacific Halibut Commission adjusts its quotas according to a "slow up/full down" policy. Multi-annual plans for some European marine fisheries limit annual change to 15 percent under all but extreme conditions for the stock. The exact formula and percentage that would be helpful for management of U.S. stocks would be situation specific and would depend upon factors including the natural mortality rate of the stock (its inherent inertia to change), the status of the stock, the degree of scientific uncertainty in the assessments, the degree of variability in recruitment and other biological factors, etc. For each situation, a management strategy evaluation should be performed to investigate the performance of the proposed phase-in rule, including the degree to which the rule would still keep stock abundance near the target level of abundance while providing an average yield nearly as large as MSY, with less annual fluctuation than occurs when a constant fishing mortality rate is applied to point estimates of stock abundance. With such a prior investigation of the expected benefits, control

rules that incorporate inertia to change seem within the scope of the NS1 Guidelines.

This management strategy evaluation is essentially a computer simulation of the biological-scientific-management-fishery system. It is guided by stakeholder input and is designed to inform all participants about how the actual management approach will perform, rather than just assuming that the management approach will perform according to some ideal scenario. The management strategy evaluation can be used to investigate not only the phase-in approach, but also the impact of scientific and management uncertainty. They can include social and economic factors.

At first glance, this phase-in approach would appear to be underfishing during years of increasing stock abundance and possibly overfishing during periods of declining abundance. However, that would only be in comparison to a management regime that was based on nearly perfect, very timely assessments. That regime is ideal or theoretical, but essentially unattainable. The phase-in approach would be designed to prevent overfishing on a longer-term basis. This is essentially what happens today for stocks without annual assessments and with OFL and ACL held constant for several years in between assessment updates.

This phase-in of OFL and ABC changes is different from the multi-year averaging approach that can be used to determine whether the ACL is being exceeded. It seems possible that an approach to multi-year averaging of OFL overages/underages could be developed as an alternative to the phase-in approach to OFL changes. The multi-year averaging may even be preferable in situations with highly fluctuating stocks for which it is not feasible to forecast the needed OFL changes and for which an OFL phase-in would be too slow to keep up with the stock changes. The merit of phase-in versus multi-year averaging probably depends on the relative level of true stock fluctuations versus perceived fluctuations due to assessment uncertainty. The phase-in approach has the advantage of proactively reducing the degree of ACL change from one year to the next in situations where some of that change would have been based on assessment uncertainty and not true changes in the stock.

Stocks in a Fishery

The 2009 NS1 Guidelines created a category of fish stocks termed ecosystem component (EC) species. These were defined as non-target stocks that are listed in fishery management plans, but are not overfished or expected to become overfished and are generally not retained for sale or personal use. These ecosystem component species are not required to have status determination criteria or ACLs. The creation of the EC species category was necessitated by the great diversity in species inclusiveness that occurs across the many FMPs. Some FMPs are for single or a few species, and bycatch species, if any, are not included in the plan's list of managed stocks. Other FMPs have been broadly inclusive of species, some of which are clearly not targets of the fishery. The EC designation allows for a more uniform approach across FMPs. Although EC stocks are not part of the fishery, they deserve some monitoring and protection, as does the entire ecosystem, but this does not warrant the extra work to estimate the same quantities as are needed for the target stocks.

Target stocks are the focus of the fishery and are in need of management supported by stock assessments, status determinations and ACLs. Generally, they are the reason that the FMP exists. In between target and EC are the non-target species, which typically do not have sufficient data to support conducting full assessments. There are a large number of stocks in this potential category.

Table 3. Categorization of commercial and recreational catch in 1999. Salmon, corals, and highly migratory species are omitted for clarity. The rows and columns are the lower limit of a catch category, so "10" means catch is between 10,000 lbs and 99,999 lbs, inclusive. Tabulated values are the number of stocks with that level of catch in 1999.

		Recreational Catch in 2009 (1000s of lbs)							
		0	<1	1	10	100	1000	10000	ALL
Commercial catch (1000s of lbs)	0	53	5	4	5	4			71
	<1	17	4	7	7				21
	1	17	9	6	3	1			36
	10	25	3	9	8	9			54
	100	35	4	6	14	19	9		87
	1000	46		2	2	3	9	1	63
	10000	24	2		1	1	4		32
	100000	7	1		1				9
	1000000	1							1
	ALL	225	18	34	41	37	22	1	388

Table 3 uses commercial and recreational catch data from 2009[2] and summarizes into broad categories of catch levels (with units of thousands of pounds). Salmon, corals, and highly migratory tuna/billfishes are not included in order to focus the presentation. There are 53 stocks with no reported commercial or recreational catch in 2009, many of these were subsequently classified as EC stocks or merged into complexes and a few had no reported catch due to confidentiality or other reasons. The tremendous range of catch levels is striking, with many stocks showing catch levels less than one thousand pounds, and with 19 stocks showing 100,000 lbs. of both commercial and recreational catch. The large number of stocks with low catch levels indicates either that some stocks are exceedingly rare or they are only being incidentally caught by the fisheries. Designation of a non-target classification will be difficult, but could greatly assist in the prioritization of assessment efforts.

Typically, these non-target stocks may be retained when caught, so do not warrant the current EC designation, but they are part of the fishery, so are required to have status determination criteria and ACLs. However, the level of fishing mortality experienced by these non-target stocks relative to the level experienced by the target stocks with which they co-occur surely must cover a very wide range. Collecting enough data to conduct full assessments for these many non-target stocks is infeasible, so many of their ACLs have been based on approximate, preliminary assessments using limited data (Berkson et al. 2011), but these methods are no long-term panacea. A revised management approach for these non-target species seems useful, but a first step would need to be development of criteria to distinguish target from non-target stocks, and possible revise the dividing line between EC and non-targets. Simply sweeping them up into a complex is not advisable because they would then get even less individual protection.

If a non-target category of stocks could be adequately defined, then perhaps the ACL for un-assessed, non-target stocks could have a modified accountability measure. Rather than a trigger for accountability measures to immediately reduce catch, the ACL would be a trigger for longer-term actions. First, it seems reasonable to routinely use multi-year averaging of ACL overages for such weakly monitored stocks. Second, inseason accountability for the ACL overage of non-target stocks could be suspended in lieu of actions spread over a longer time frame, unless there was evidence of immediate jeopardy to the stock. By frequently reaching the ACL there is an indication that the stock could be becoming a target stock with a fishing mortality rate that needs to be closely monitored to prevent overfishing. In this case, there should be increased priority for improvements to that stock's data collection so that an assessment could be conducted in the future. Whether or not that data collection occurred solely through agency funding or through greater involvement of the fishing community could be situation specific. In general, the potential role of fishery participants in providing information to determine the sustainability of their fishery is

2 These catch data were assembled by a NMFS working group that is developing a prototype approach for prioritization of fish stock assessments. For more information, contact Richard.Methot@noaa.gov.

addressed through cooperative research. In some cases, it may make sense to seek a more concerted role in having them provide the primary information needed to support full stock assessments.

Multi-Stock Fisheries and Stock Complexes

There is a dichotomy between the management approach for stock complexes and the management approach for multi-stock fisheries. A stock complex is a collection of stocks in a region that are asserted to be sufficiently similar in geographic distribution, life history, and vulnerabilities to the fishery such that the impact of management actions on the stocks is similar. Management of complexes can be guided by tracking an assessed indicator stock; however, in many cases the recent average catch of the stocks within the complex are summed to calculate a stock complex level ACL. The stocks in the complex typically have little assessment data, so there is no realistic option to assess and manage them individually. Methods are available to estimate the vulnerability of stocks to overfishing (Patrick et al. 2010), but it is difficult to be confident that the chosen indicator stock is the most vulnerable member of the complex. Somewhat paradoxically, when a stock in a complex is first assessed there is a tendency for the Council to remove it from the complex and manage it with its own ACL and status determinations, rather than use it as an indicator for the complex; thus, stock complexes often lack indicator species and none have multiple indicators.

For a multi-stock fishery, there is recognition that the stocks are caught together in varying proportions depending on the fishing fleet (i.e., gear and vessel type) and region fished. These stocks each have enough assessment information to guide the setting of status determination criteria and ACLs for each individual stock. However, because of the ways in which the stocks are caught together, it is extremely difficult to design a fishery management system that can achieve each stock's ACL exactly, or for fishermen to target the catch of specific stock with sufficient precision that it does not result in the bycatch of other species. As a result, the mandate to prevent overfishing leads towards management systems for multi-stock fisheries that forego yield for some stocks in order to prevent overfishing other stocks.

So there is a logical discontinuity between the management approaches for un-assessed stock complexes versus assessed multi-stock fisheries. Unassessed stock complexes have higher levels of uncertainty but by being managed as a complex they are not limited by the most vulnerable stock, unless there is enough information to select the most vulnerable stock as the indicator stock and to keep it in the complex. On the other hand, assessed stocks that have lower levels of uncertainty but are managed as a mixed-stock fishery may forego yield of some stocks when the most vulnerable stock in the fishery approaches its ACL. Thus, greater scientific uncertainty for stocks in multi-stock complexes can result in relatively lower yields than what those might have produced when managed as a complex.

Reduction of this discontinuity could involve modification to both the complex and the multi-stock approaches. For complexes, there could be a greater effort to identify multiple indicator stocks and keep them in the complex so that there would be more information on the status of the more vulnerable members of the complex. Also, because most kinds of scientific uncertainty cannot even be calculated for the complexes, there could be an explicit buffer used when calculating ACLs for complexes from simple data such as the summed catch of all complex members. For the multi-stock fisheries, there could be a greater effort to conduct a bio-economic tradeoff analysis. In the multi-stock fishery, a fishing rate on some stocks that is slightly above the overfishing level will reduce that stock below its target level of abundance and will prevent attainment of the full MSY for that stock, but it will not necessarily reduce the stock below its overfished limit and it may allow fishing rates on the entire multi-stock fishery that would better attain the optimum yield for that entire fishery. This can be analyzed by stock assessment, ecosystem and economics scientists working together. This role of a bio-economic analysis will be as helpful in exploring feasible approaches to multi-stock fisheries as they will be in guiding the desirable degree of temporal phase-in of ACLs as described earlier.

Conclusion

The Regional Fishery Management Councils completed implementation of the ACL provisions of the reauthorized MSA in 2012. Implementation of science-based ACLs with accountability measures in all fisheries establishes a firm metric to reduce overfishing. Limited instances of overfishing may still occur due to management uncertainty, which allows catch to sometimes exceed the ACL, and scientific uncertainty, which acknowledges that the ACL set for a year is based on estimates and these estimates can change over time as more scientific information in collected. Whether overfishing is better measured as catch exceeding a catch threshold, or fishing mortality rate exceeding a fishery mortality threshold, depends upon the relative magnitude of management and scientific uncertainty and the scale of true fluctuations in the stock. The scientific process that provides the ACL estimates is limited in scope. Over a timeframe of decades we will learn to bring more ecosystem and climate factors into the analysis, and may find long term overfishing has been occurring in some situations.

Scientific and management uncertainty are taken into account when buffers are established between overfishing thresholds and fishery management targets. The magnitude of these buffers should balance the prevention of overfishing against short-term reductions in fishing opportunity needed to achieve that degree of prevention. A greater role of social and economic analysis is needed to better understand that tradeoff. Continued improvements in the scientific enterprise supporting sustainable fisheries are needed, in cooperation with the fisheries that benefit from this science.

Fishery control rules tend to be simple in form so that when a new assessment is conducted, the change in stock biomass results in a nearly proportional change in the recommended catch levels. The biomass estimates are intended to track true changes in the stock, but they also have scientific uncertainty that introduces noise into the system. It should be possible to use a management strategy evaluation to understand the pros and cons of building inertia into the control rules so that ACL changes over time are less extreme, while still preventing overfishing on a reasonable time scale.

The near 500 fish stocks in U.S. FMPs are quite varied with regard to the degree of fishing pressure they attract and the level of catch they produce. The 2009 NS1 Guidelines created a category of stocks termed ecosystem component species which are distinct from the managed stocks in the plan that need status determination criteria and annual catch limits. The managed stocks could perhaps be separated into target species and non-target species to assist in the prioritization of assessment efforts and in a differential management response for the non-target stocks.

Within the set of managed stocks, some are managed individually as members of a multi-stock fishery, and some are aggregated into stock complexes for management purposes. This creates a dichotomy because the stocks in a multi-stock fishery tend to be managed conservatively to protect the weakest stock from overfishing, and the stocks in the complex are managed according to a simple approach or by an indicator stock that may not be the weakest stock in the complex, so some stocks may be experiencing some level of overfishing. A more consistent middle ground would use multiple indicator stocks for the complexes in order to do better at protecting the weaker stocks, and would use more economic analysis of the multi-stock fisheries in order to determine the overall benefits that may be obtained by allowing small degree of overfishing of some stocks in order to obtain the full available yield from other stocks.

There is common ground between allowing smoothing of ACLs over time and allowing an overall harvest rate on a multi-stock fishery to obtain the best benefits for the fishery, essentially smoothing harvest rate across stocks. When the ACL for a stock is kept constant for several years, the system is tacitly allowing a smoothing over time; and when stocks are aggregated into a complex the system is tacitly allowing a smoothing of harvest rates across stocks. Data-rich, intensively managed stocks can be analyzed more completely to allow a reasonable degree of smoothing in time and across stocks to benefit the fishery, prevent stocks from becoming overfished, and make better use of the available scientific information. Beyond cooperative research, in some circumstances fishery participants may be able to

assist in providing more of the core scientific data needed to reduce assessment uncertainty.

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