Description and Foundation of the Mid-Atlantic Fishery Management Council's Acceptable Biological Catch Control Rule

September 13, 2016

Scientific and Statistical Committee

Mid-Atlantic Fishery Management Council

Purpose of this Document

How the Mid-Atlantic Fishery Management Council (MAFMC) determines catch limits has changed substantially in recent years. The modifications were primarily adopted because of changes in the 2006 reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) and subsequent changes to the National Standard 1 guidance. This document describes the approach that has been adopted by the MAFMC and its Scientific and Statistical Committee (SSC) to determine Acceptable Biological Catches (ABCs) to avoid overfishing as of 2014 and provides the rationale for several important aspects of the MAFMC's ABC control rule (i.e., approach to setting ABCs that buffer for scientific uncertainty so as to avoid overfishing per the requirements of the MSA). Additionally, information describing the ABC control rule for the MAFMC is currently in several locations, some of which are unpublished. Thus, this document provides much of the information about ABC determination in one location.

Introduction

The reauthorization of the MSA brought several important changes to U.S. federal fisheries management. One of the primary changes was a requirement for Annual Catch Limits (ACLs) which should avoid overfishing and not exceed the recommendations from the Council's SSC or peer review process:

> *Each Council shall… develop annual catch limits for each of its managed fisheries that may not exceed the fishing level recommendations of its scientific and statistical committee or the peer review process established under subsection (g); (MSA 301.109-479.6, 2006)*

The MSA also added a 15th required fishery management plan (FMP) provision to avoid overfishing, that FMPs shall:

> (15) establish 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. (*MSA 301.109-479.15 2006*)

The MSA also clarified the role of the SSCs in the process:

> *Each scientific and statistical committee shall provide its Council ongoing scientific advice for fishery management decisions, including recommendations for acceptable biological catch, 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 302.101-627, 109-479.g.1.B, 2006)*

NOAA revised its National Standard 1 guidance in response to changes in the MSA by providing definitions of ACL and ABC and clarifying the roles of the SSC and the Council in the process of setting catch limits. In particular, it specified that ACL ≤ ABC ≤ OFL (overfishing limit), that the SSC determines the ABC, and that the Council determines the ACL with the constraint that the ACL must be less than or equal to the SSC's ABC recommendation. Thus, the SSCs recommendation for an ABC sets an upper limit on the ACL in order to avoid overfishing. National Standard 1 further defines ABC as

> *Acceptable biological catch (ABC) is a level of a stock or stock complex's annual catch that accounts for the scientific uncertainty in the estimate of OFL and any other scientific uncertainty (see paragraph (f)(3) of this section), and should be specified based on the ABC control rule. (National Standard 1, 2009)*

This National Standard 1 guidance indicates that a control rule should be used to determine an ABC that is lower than the OFL and that scientific uncertainty should be considered when determining ABCs. While control rules were commonly used to set catch limits or targets in federally managed U.S. fisheries prior to the 2006 reauthorization, they did not commonly include accounting for scientific uncertainty. In the response to comments, National Standard 1 further elaborates the roles of the Council and SSC in determining the ABC control rule

> *NMFS believes that determining the level of scientific uncertainty is not a matter of policy and is a technical matter best determined by stock assessment scientists as reviewed by peer review processes and SSCs. Determining the acceptable level of risk of overfishing that results from scientific uncertainty is the policy issue. The SSC must recommend an ABC to the Council after the Council advises the SSC what would be the acceptable probability that a catch equal to the ABC would result in overfishing. (National Standard 1, 2009)*

Thus, according to National Standard 1, the Council has the responsibility of determining an acceptable probability of overfishing and communicating that decision to the SSC. Furthermore, the SSC has the responsibility of using estimates of scientific uncertainty, combined with the Council's acceptable probability of overfishing, to develop ABC recommendations. Therefore, the approach to determining ABCs should have four elements: 1) it should follow a control rule, 2) the control rule should use the OFL as an upper threshold on ABC, 3) the difference between ABC and OFL should incorporate scientific uncertainty, and 4) the control rule should use the acceptable probability of overfishing from the Council.

MAFMC ABC Control Rule

The MAFMC and its SSC jointly developed a control rule to determine ABCs for MAFMC-managed stocks that considers both how uncertainty is handled in assessments and the biological characteristics of the stock in question. In conjunction with the Council's risk policy, the control rule uses a probabilistic approach to specify ABCs for stocks with stock assessments in three categories and ad hoc approaches for Catch-based ABC assessments. Stock assessments are categorized among four levels based primarily on 1) whether an estimate of the OLF is available and accepted by the SSC and 2) how uncertainty in the OFL is characterized in the assessment. Furthermore, the MAFMC-adopted control rule uses the Council's risk policy to determine an acceptable probability of overfishing (P*) as a function of the stock biomass and life history of the species (Fig. 1). Lower stock size and/or life history characteristics that increase susceptibility to overfishing (and are not incorporated into assessments) require greater confidence that overfishing will be avoided (via larger buffers). The probabilistic approach was adopted for three of the levels because it explicitly incorporates uncertainty and the MAFMC's acceptable probability of overfishing in determining ABCs. It was also recognized that uncertainty would be very difficult (or impossible) to fully and quantitatively characterize in some situations. The Catch-based ABC portion of the control rule was designed to accommodate these cases. The probabilistic approach adopted by the MAFMC and its SSC is based on Prager and Shertzer (2010).

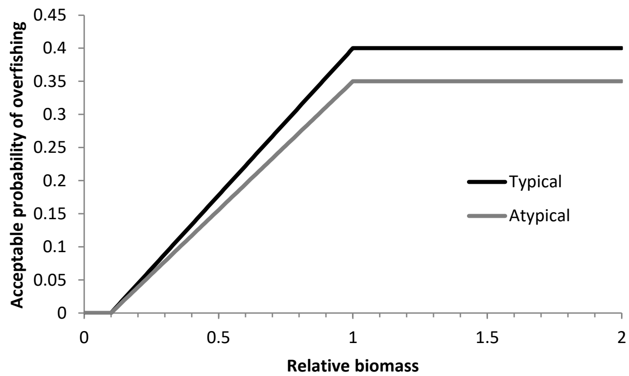

Fig. 1. Acceptable probability of overfishing (P) as a function of stock size adopted by the MAFMC in an Omnibus Amendment (July 2011). The threshold acceptable probability of overfishing is 0.4 for species with a typical life history and 0.35 for those with an atypical life history. The acceptable probability of overfishing is zero if relative biomass (projected biomass divided by the expected biomass if the stock was fished at the maximum fishing mortality rate threshold) is less than 0.1. The acceptable probability of overfishing increases to its threshold as relative biomass approaches 1. Whether a species is deemed typical or atypical depends on the degree to which its life history has been incorporated in the development of fishing mortality reference points.*

Analytically-based ABC: Assignment of a stock to this level implies that all important sources of uncertainty are fully and formally captured in the stock assessment model and the probability distribution of the OFL calculated within the assessment provides an adequate description of uncertainty of OFL. Accordingly, the OFL distribution will be estimated directly from the stock assessment.

For a stock assessment to fit into the Analytically-based ABC category, the SSC must determine that the OFL probability distribution represents best available science. Examples of attributes of a stock assessment that would lead to its inclusion in Level 1 are:

- Assessment model structure and any treatment of the data prior to inclusion in the model includes appropriate and necessary details of the biology of the stock, the fisheries that exploit the stock, and the data collection methods;
- Estimation of stock status and reference points integrated in the same framework such that the OFL calculations promulgate all uncertainties (stock status and reference points) throughout estimation and forecasting;
- Assessment estimates relevant quantities including F_{MSY}[1], OFL, biomass reference points, stock status, and their respective uncertainties; and
- No substantial retrospective patterns in the estimates of fishing mortality (F), biomass (B), and recruitment (R) are present in the stock assessment estimates.

The important part of the Analytically-based ABC category is that the precision estimated using a purely statistical routine will define the OFL probability distribution. Thus, all of the important sources of uncertainty are formally captured in the stock assessment model. When a Level 1 assessment is achieved, the assessment results are likely unbiased and fully consider uncertainty in the precision of estimates. Under Analytically-based ABC, the ABC will be determined solely on the basis of an acceptable probability of overfishing (P*), determined by the Council's risk policy, and the probability distribution of the OFL.

Expert-based ABC: Inclusion in this category indicates that the estimation of the probability distribution of the OFL directly from the stock assessment model fails to include some important sources of uncertainty, necessitating expert judgment during the preparation of the stock assessment, and the final OFL probability distribution developed during the assessment is deemed best available science by the SSC.

Possible attributes of a stock assessment that results in an Expert-based ABC include:

- Key features of the biology of the stock, the fisheries that exploit it, or the data collection methods are missing from the stock assessment;
- Assessment estimates relevant quantities, including reference points (which may be proxies) and stock status, together with their respective uncertainties, but the uncertainty is not fully promulgated through the model or some important sources may be lacking;
- Estimates of the precision of biomass, fishing mortality rates, and their respective reference points are provided in the stock assessment; and
- Accuracy of the MFMT and future biomass is estimated in the stock assessment by using *ad hoc* methods.

[1] With justification, F_{MSY} may be replaced with an alternative (i.e., proxy) maximum fishing mortality threshold to define the OFL. Proxies, such as $F_{35\%}$ and $F_{40\%}$, are commonly used in place of F_{MSY} because F_{MSY} can be very difficult to estimate.

For Expert-based ABC assessments, ABCs will be determined by using the Council's risk policy (similar to a Level 1 assessment), but with the OFL probability distribution based on the specified distribution developed in the stock assessment process and as accepted by the SSC.

Empirically-based ABC: Assessments in this level are judged to over- or under-estimate the accuracy of the OFL. Attributes of a stock assessment that would lead to inclusion in this category are the same as those that lead to an Expert-based ABC, except that the assessment does not contain estimates of the probability distribution of the OFL or the probability distribution provided does not, in the opinion of the SSC, adequately reflect uncertainty in the OFL estimate.

For Empirically-based ABC assessments, the SSC adjusts the distribution of the OFL and develops an ABC recommendation by applying the Council's risk policy to the modified OFL probability distribution. The SSC evaluates a set of default or other amounts of uncertainty in the OFL probability distribution based on literature review and an evaluation of ABC control rules. A control rule of 75 percent of F_{MSY} may be applied as a default if an OFL distribution cannot be developed.

To fully characterize OFL CV, the SSC considers the following:

- Uncertainty in the estimate of current biomass, including observation error and process error carried through the assessment
- Uncertainty in the estimate of the F_{MSY} reference point, including process error estimated at same time as B estimated in an integrated fashion
- Covariation in the B and F_{MSY} estimates
- Sources of uncertainty that could not be included in an individual assessment model, which could include
    - Model structural uncertainty (e.g., structured vs biomass dynamic models; single species vs multispecies models)
    - Parameter uncertainty (e.g. as currently included in sensitivity runs)
    - Uncertainty in current state of nature (e.g. ecosystem production regime)

The SSC discussed using measures of model forecast error in determining OFL CV, based upon information provided by NEFSC for several recent assessments comparing projected stock status from a past assessment to stock status estimated from a more recent assessment. Differences between past projections and current estimated could be used to derive a "forecast error" which could also be applied in estimating OFL CV.) One caution with this approach is that for it to be a true estimate of uncertainty, the current estimate would have to be unbiased (which is unlikely). However, examining this behavior over time gives some insight into the direction and potential magnitude of forecast error relative to the current assessment output.

An example of the forecast error calculation has been provided in recent summer flounder assessment updates (2015, 2016). Figures 2-3 compare projection performance from assessments starting in 2008 though the current 2016 update for spawning stock biomass (SSB, Fig 2) and fishing mortality (F, Fig 3). From 2012 through 2016, there is a downward revision of estimated SSB in each successive assessment, and an associated upward revision of estimated F. This differs from the internal model retrospective error calculation (although internal retrospective error affects this pattern of forecast error).

The usual Mohn's rho 'internal model retrospective error' calculation for a 7 year 'peel' in the ASAP model is currently at an 'initial overestimation' of +11% for SSB and 'initial underestimation' of -24% for F. The 2013 SAW 57 is the most recent benchmark, so when 2013 estimates/projections with those from the preliminary 2016 update there are 7 model 'estimates' and 4 'projections.' Over the 11 estimated/projected years, SSB has been 'over-estimated' by +28% and F 'under-estimated' by -22%. Over just the 4 projected years, SSB has been 'over-estimated' by +54% and F 'under-estimated' by -28%.

The question is how to turn this information into an estimate of OFL CV that reflects this pattern. Ultimately, an OFL CV that considers forecast error, model error, and bias caused by input data together represents the ideal.

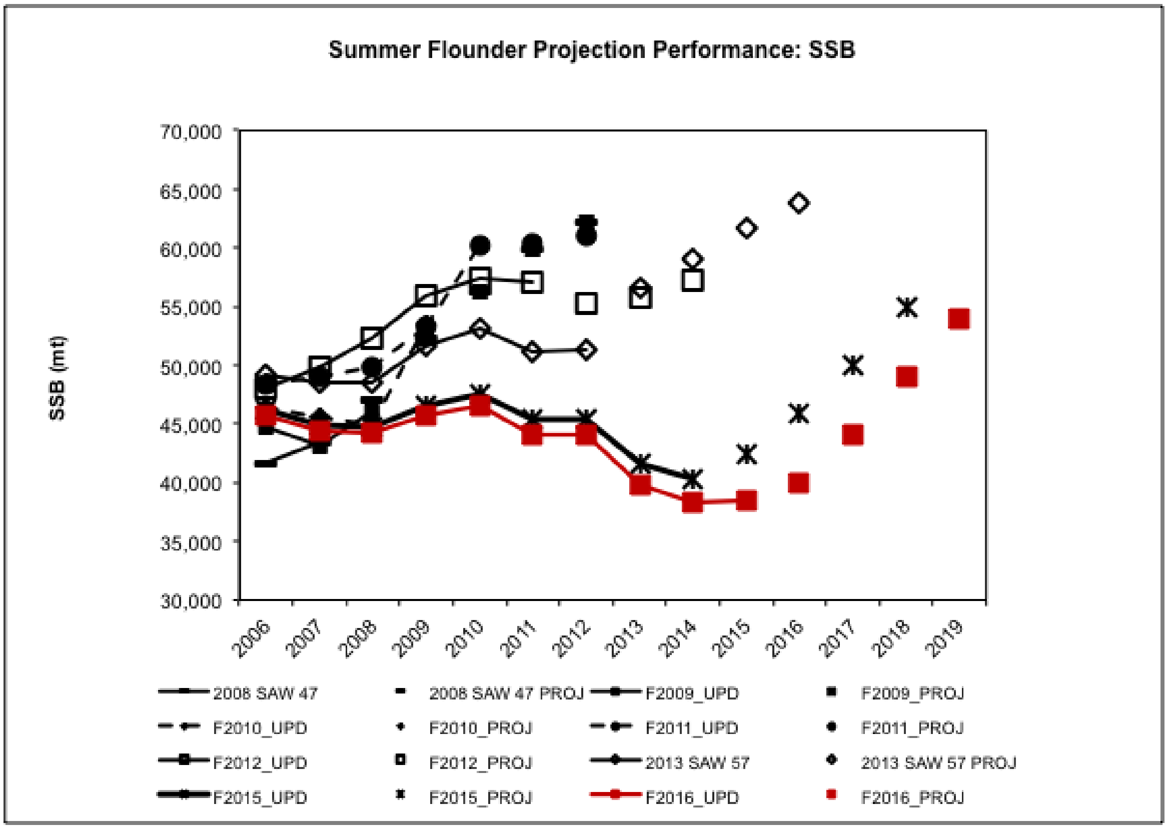

Fig 2. Comparison of assessed (line) and projected (symbol) summer flounder spawning stock biomass, 2008 to 2016.

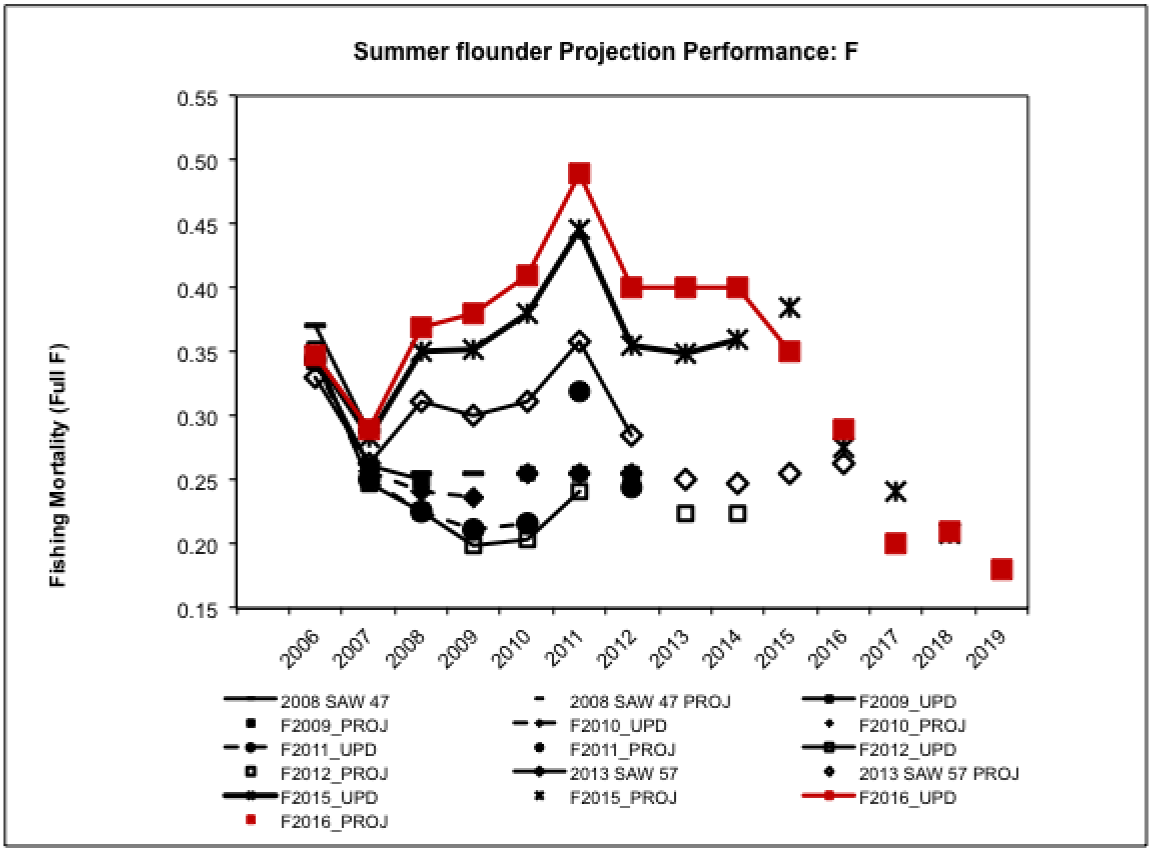

Fig 3. Comparison of assessed (line) and projected (symbol) summer flounder fishing mortality, 2008 to 2016.

<u>Catch-based ABC:</u> Stock assessments that result in a Catch-based ABC are deemed to have reliable estimates of trends in abundance and catch, but absolute abundance, fishing mortality rates, and reference points are suspect or absent. Additionally, there are limited circumstances that may not fit the standard approaches to specification of reference points and management measures set forth in these guidelines (i.e., ABC determination). In these circumstances, the SSC may propose alternative approaches for satisfying the NS1 requirements of the MSA than those set forth in the NS1 guidelines. In particular, stocks in this level do not have point estimates of the OFL or probability distributions of the OFL that are considered best available science. In most cases, stock assessments that fail peer review or are deemed highly uncertain by the SSC will be assigned to this level.

Examples of potential attributes for inclusion in this category are:

- Assessment approach is missing essential features of the biology of the stock, characteristics of data collection, and the fisheries that exploit it;
- Stock status and reference points are estimated, but are not considered reliable;

- Assessment may estimate some relevant quantities including biomass, fishing mortality or relative abundance, but only trends are deemed reliable;
- Large retrospective patterns usually present; and
- Uncertainty may or may not be considered, but estimates of uncertainty are probably substantially underestimated.

For a Catch-based ABC the SSC uses all available information to set ABCs on a case by case basis, and generally may not increase ABCs unless the following two circumstances are met:

1. Biomass-based reference points suggest that the stock is greater than B_{MSY}, and the stock biomass is stable or increasing. If biomass-based reference points are not available, best available science indicates that stock biomass is stable or increasing, and,
2. The SSC must provide a determination that, based on best available science, the proposed increase to the ABC is not expected to result in overfishing of the stock. The SSC must provide a description of why the increase is warranted, describe the method used to derive the increased ABC, and provide a certification that the increase in ABC is not likely to result in overfishing on the stock.

Uncertainty in the OFL

A central part the first three categories of ABC specification of the MAFMC ABC control rule is the determination of the uncertainty of the OFL. The MAFMC probabilistic approach begins with an estimate of the distribution of catch that can be taken when the population is fished at the fishing mortality threshold (FMT) given expected biomass when the catch limit will be implemented (OFL). The ABC is then determined by choosing the catch associated with a percentile (P*) of the distribution, such that the ABC achieves a pre-specified probability of overfishing. The P* represents the acceptable probability of overfishing, and the catch associated with a given percentile has a P* probability of overfishing. In principle, this approach requires an accurate description of the OFL distribution. If the distribution of OFL is not accurate, the meaning of the P* parameter is no longer the acceptable probability of overfishing – instead it simply is an ad hoc method for providing a buffer between ABC and OFL. There are two primary sources of uncertainty that affect uncertainty in the OFL: uncertainty in biomass and uncertainty in the FMT. Estimation of both of these quantities is subject to substantial uncertainty, but the true uncertainty (instead of precision) is very difficult to estimate. Therefore, the MAFMC's SSC has adopted a default probability distribution to describe OFL for level 3 assessments.

The relationship between ABC as a proportion of OFL, OFL CV and the MAFMC control rule is pictured in Fig 4. This illustrates the importance of estimating OFL CV.

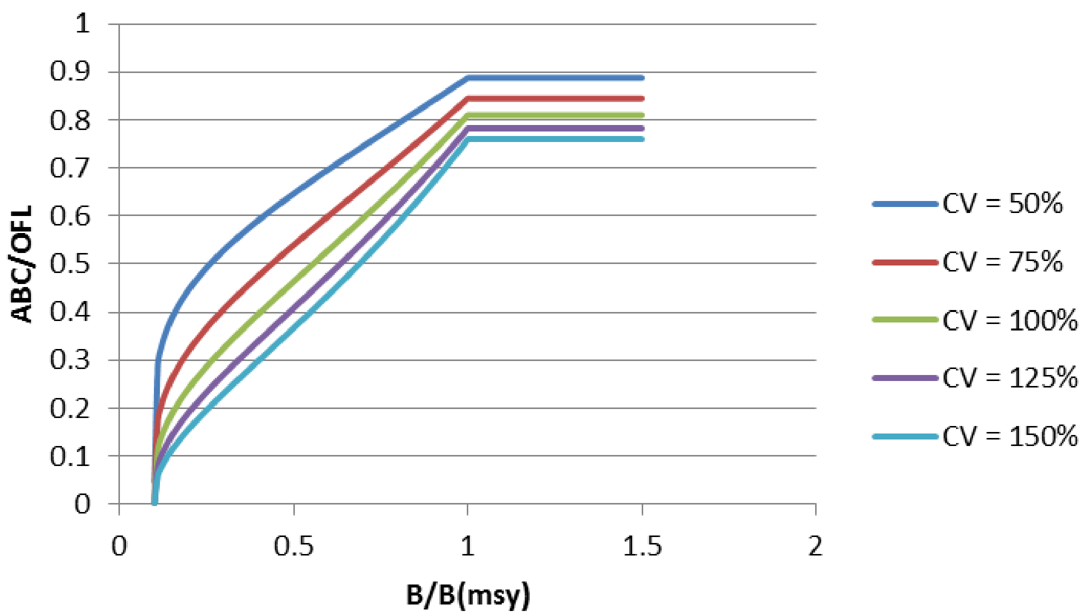

Fig 4.

The default distribution adopted by the SSC for Empirically-based ABC stock assessments is a lognormal distribution with a coefficient of variation (CV) of 100%. This distribution was chosen because the distribution of estimated biomass and other quantities in assessment models can often be described by a distribution similar to a lognormal (with a long right hand tail). The value of the CV was developed from an analysis of several simulation studies that evaluated the accuracy of estimates from statistical catch-at-age (SCA) stock assessment models. In one sense, simulation studies are ideal for considering the performance of estimation of OFL because the true values of stock size and fishing mortality are known and, therefore, the true accuracy of estimates can be determined. The downside of using simulation studies is that they often use simplified examples and the models used to simulate data do not include many of the real world complexities that are present in actual stock assessment situations. Thus, most simulation studies of assessment model performance include a caveat that the estimates of accuracy are likely optimistic because more assumptions will usually be violated in the real world.

We conducted a review of several simulation studies of performance of SCAs for estimating biomass in the last year of the time series and FMT (Table 1). We used reported coefficients of variation (CVs) of estimated biomass in the last year of an assessment. Yin and Sampson (2004) reported CVs of biomass in the last year in their paper. Bence et al. (1993) reported the proportion of assessment models where the estimate was within 20% of the true value, and we converted this value to a CV by assuming that the results were lognormally distributed. For Wilberg and Bence (2006, 2008), we used the original results (not reported in the papers) to calculate the CVs. Relative errors and the range of the 80% interval were presented in Punt et al. (2002). Results from three studies, Labelle (2005), Magnusson and Hilborn (2007), and Linton and Bence (2009) were primarily presented graphically, and CVs of estimates were not provided. However, their estimates in terms of magnitude in errors and skewed distribution of errors were consistent with the studies that presented results tabularly. Results from Conn et al. (2010) were used to estimate the uncertainty associated with F_{MSY} (results not reported in the paper).

Table 1. Simulation studies evaluated in the analysis of uncertainty of stock assessment estimates.

Study	Description
Bence et al. 1993	Determine effects of survey characteristics on SCA estimates
Ianelli 2002	Determine robustness of productivity estimation
Punt et al. 2002	Determine likely performance of several assessment techniques under a range of data generating scenarios for southern Australia fisheries
Yin and Sampson 2004	Determine effects of data, fishery, and stock characteristics on SCA estimates
Radomski et al. 2005	Compare performance of SCAs and forward VPAs
Labelle 2005	Determine performance of MULTIFAN-CL in several cases
Wilberg and Bence 2006	Compare alternative methods for estimating time-varying catchability in SCAs
Magnusson and Hilborn 2007	Determine characteristics that make fisheries data informative in SCAs

Wilberg and Bence 2008	Determine performances of deviance information criterion for selecting among SCAs that differ in their random effects
Conn et al. 2010	Determine when productivity can be estimated in SCAs.

Many factors influence the accuracy of stock assessment estimates. Biomass was more accurately estimated when fishing mortality was higher, with good indices of abundance, with more years of data, and with higher sample sizes for age distributions of the catch. Factors that affected the reliability of estimates were the survey selectivity pattern, the CV of survey measurement error, time-varying catchability of indices of abundance, and effective sample size of age composition of the catch. The CV of estimates of biomass in the last year varied among the alternative studies and among scenarios considered within each study (Table 2). In general, low fishing mortality rates, high survey CVs, and not having a good index of abundance for older age classes led to higher CVs in estimates of biomass in the last year. The overall mean CV in estimated biomass in the last year among the studies was 47%. When the assessment model was substantially different from the data generating model, assessment results could become quite biased (Punt et al. 2002; Wilberg and Bence 2006). However, levels of bias and the variability of the assessment model results depended on the conditions simulated for each species.

Few studies evaluated the accuracy of a fishing mortality reference point. Later analysis of results not shown in Conn et al. (2010), found that the CV of F_{MSY} was about 0.45 (approximately 0.3 and 0.6) for the two species examined (using the inverse prediction method) and that estimates of biomass and F_{MSY} had a positive correlation of about 0.6 on average (unpublished results). In contrast, Yin and Sampson (2004) found that spawning-potential-based (SPR) fishing mortality rate reference points were accurately estimated with CVs of approximately 5%, but because their simulation models contained little error in the inputs to the SPR model this is likely an underestimate of the amount of uncertainty that would be achieved in practice.

Table 2. Mean, minimum, and maximum coefficient of variation (CV) of biomass in the last year of the assessment for studies where the estimation model was similar to or the same as the data generating model.

Study	Mean CV (%)	Minimum CV (%)	Maximum CV (%)
Bence et al. (1993)	60	14	183
Yin and Sampson (2004)	35	9	94
Radomski et al. (2004)	19	0	77
Wilberg and Bence (2006)	65	17	407
Wilberg and Bence (2008)	31	14	48

A Default Level of Uncertainty for the OFL

The MAFMC's SSC has adopted a default lognormal distribution with a 100% CV for the OFL. While a CV of 100% is greater than that used by the Pacific Fishery Management Council[2], several lines of evidence suggest that the MAFMCs estimate of uncertainty in the OFL is a reasonable value. Uncertainty in stock assessment models has two components: precision and bias. Precision describes the degree to which repeated applications of the assessment model (to data collected under the same conditions) show the same results. Bias refers to a systematic difference between the mean estimate from the stock assessment model and the true value. Bias is caused by assumptions of the stock assessment model being violated. The major cause of uncertainty in stock assessment models is often bias (Mohn 1996), but we usually only have estimates of the precision. The simulation evaluations of the accuracy of age-structured stock assessment models indicate that in situations where the assumptions of the models are violated that the uncertainty can be extremely high. Because the OFL can be thought of as the product of estimated biomass and the estimated MFMT, the uncertainty in both of these quantities will factor into the uncertainty in OFL. Additionally, we need to know the covariance between the estimates of biomass and MFMT. The mean estimate of uncertainty in biomass from the simulation studies was 47% (Table 2), the mean estimate of uncertainty in F_{MSY} was 45% (Conn et al. 2010), and the correlation between these values was 0.6 (from the one study that estimated them, Conn et al. 2010). Combining all of these values together provides an estimate of the CV of the OFL of approximately 100%, the default value adopted by the MAFMC's SSC.

References

Bence, J. R., A. Gordoa, and J. E. Hightower. 1993. Influence of age-selective surveys on the reliability of stock synthesis assessments. 50: 827-840.

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

Deroba, J.J., and J.R. Bence. 2008. A review of harvest policies: understanding relative performance of control rules. Fisheries Research 94: 210–223.

Labelle, M. 2005. Testing the MULTIFAN-CL assessment model using simulated tuna fisheries data. Fisheries Research 71: 311-334.

[2] The Pacific Fishery Management Council uses a CV of 36% based on an analysis of the change in estimates of biomass among stock assessments that have been conducted over about the last two decades (Ralston et al. 2011). However, the approach used to develop that estimate of the CV of the OFL has several important assumptions: 1) the models used to assess Pacific stocks have been unbiased on average, and 2) that there is no uncertainty in the fishing mortality reference point. Both of these assumptions are likely to be violated, which, if it is the case, would mean that 36% is a minimum estimate of the CV of the OFL and that the true uncertainty is likely much higher.

Magnusson, A. and R. Hilborn. 2007. What makes fisheries data informative? Fish and Fisheries 8: 337-358.

Punt, A. E., A. D. M. Smith, and G. Cui. 2002. Evaluation of management tools for Australia's south east fishery 2. How well can management quantities be estimated? Marine and Freshwater Research 53: 631-644.

Wilberg, M. J., and J. R. Bence. 2006. Performance of time-varying catchability estimators in statistical catch-at-age analysis. Canadian Journal of Fisheries and Aquatic Sciences 63:2275-2285.

Wilberg, M. J., and J. R. Bence. 2008. Performance of deviance information criterion model selection criteria in statistical catch-at-age analysis. Fisheries Research. 93:212-221.

Yin, Y., and D. B. Sampson. 2004. Bias and precision of estimates from an age-structured stock assessment program in relation to stock and data characteristics. North American Journal of Fisheries Management 24: 865-879.

Glossary

Acceptable biological catch (ABC) is a level of a stock or stock complex's annual catch that accounts for the scientific uncertainty in the estimate of OFL and any other scientific uncertainty (see paragraph (f)(3) of this section), and should be specified based on the ABC control rule. (From NS1)

ABC control rule means a specified approach to setting the ABC for a stock or stock complex as a function of the scientific uncertainty in the estimate of OFL and any other scientific uncertainty (*see* paragraph (f)(4) of this section). (From NS1)

Annual catch limit (ACL) is the level of annual catch of a stock or stock complex that serves as the basis for invoking AMs. ACL cannot exceed the ABC, but may be divided into sector-ACLs (*see* paragraph (f)(5) of this section). (From NS1)

Catch is the total quantity of fish, measured in weight or numbers of fish, taken in commercial, recreational, subsistence, tribal, and other fisheries. Catch includes fish that are retained for any purpose, as well as mortality of fish that are discarded. (From NS1)