

RISK ANALYSIS IN SETTING ALLOWABLE HARVESTS: ANNUAL CATCH LIMITS UNDER THE MAGNUSON STEVENS REAUTHORIZATION ACT.¹

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ABSTRACT

Under the reauthorized Magnuson-Stevens Act (MSRA), US fisheries management councils must specify an annual catch limit (ACL) for each managed species and institute accountability measures (AMs) to ensure that actual harvest will not cause the stock to be overfished. While the details of implementation are still being developed, a set of Proposed Guidelines for performing ACL analysis has been developed. The purpose of this paper is to provide a preliminary assessment of these guidelines. The MSRA specifies two principles to be used as a framework for determining how Councils can comply with the ACL and AM measures. Both deal with uncertainty in the overall fisheries management process. The first is the separation between science and policy in setting the upper level on allowable harvests. The second is the requirement to take strong management actions to ensure that, given real world enforcement issues, the actual harvest in any year does not surpass the allowable harvest level. The procedure for applying the principles is quite complex and it goes beyond a strict interpretation of the written language in the law. However, it is consistent with current procedures and with commonly accepted principles in fisheries management policy. The Proposed Guidelines suggest that a distinction be made between scientific and implementation uncertainty. While the distinction may follow from the two principles, a preliminary look at the logical process of developing the required control rules for specifying Acceptable Biological Catch and Annual Catch Targets raises questions about the usefulness of this distinction in actual policy analysis.

Keywords: stochastic, uncertainty, ACLs.

INTRODUCTION

The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (MSRA) has several new provisions relating to Annual Catch Limits (ACLs) which are to be set by Regional Fishery Management Councils. Specifically, ACLs must ensure no overfishing, and the level at which catch levels are set must not exceed the levels recommended by the Scientific and Statistical Committees (SSC). The ACL requirements are outlined in section 302 of the MSRA, which instructs the eight Regional Fishery Management Councils to:

(6) 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 section 302(h)(6) amended by MSRA section 103(c)(3)) [Italics added.]

(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 section 303(a) amended by MSRA section 104(a)(10))

In addition to specifying Annual Catch Levels, (ACLs) Councils must also develop accountability measures (AMs) to be initiated if ACLs are exceeded.

The National Marine Fisheries Service has recently prepared Proposed Guidelines for the Implementation of ACLs and AMs.ⁱⁱ In addition to addressing the particulars mentioned in MSRA, they specify a rather complicated process that captures the spirit of the law as well as a good mix of existing practice and new insights. The need to take uncertainty into account is given detailed attention.

The purpose of this paper is twofold. The first is to review and evaluate those sections of the guidelines that deal specifically with the uncertainty issue. The second is to describe and present some preliminary results of an age class Monte Carlo model that will allow for a more rigorous discussion of the implications of the guidelines especially as they relate to uncertainty.

SUMMARY OF PROPOSED GUIDELINES

Although not made explicit in the MSRA, two principles are implicit in the process of determining ACLs and AMs. The first is the separation of science and policy in the setting of catch levels. As stated in the quotes in the first section, when the management councils set their annual catch levels, they may set them no higher than the *fishing level recommendation* of the Scientific and Statistical Committee. Presumably, Congress was responding to the frequently heard complaint that policy makers who are too close to the users of the resource may allow for an overly optimistic interpretation of stock conditions that would justify higher allowable harvests that may put the stocks in danger. The implied intent of the separation between science and policy is to circumscribe this type of behavior and make sure that allowable harvests are set at safe levels based on an unbiased view of the science.

The second principle is to ensure that actual harvests do not surpass the allowable harvests. The guidelines suggest that, in addition to using accountability measures, one way to do this is to use a limit/target framework. In simple terms, the limit catch level would be the maximum that, on average, could be allowed without harming the stocks. But in real world fisheries management programs, it is difficult to ensure that the actual harvest does not surpass the allowable harvest. This is true even for a TAC managed fishery because of the inability to have razor edge enforcement such that the fishery is shut down when the allowable harvest is taken. And the point is more applicable for fisheries managed with input controls because of the uncertain and elastic relationship between actual harvest and any specific input control.

The Proposed Guidelines applies these two principles by inserting cushions or buffers between limit and target catch levels at two administrative levels, each designed to address a specific type of uncertainty. The first limit is called the Overfishing Limit, OFL, and it can be interpreted as the point estimate of the safe harvest level. The OFL is calculated by applying the MSY fishing mortality rate to current stock size. In an overfished stock there are provisions to calculate the OFL using a lower “rebuilding” fishing mortality rate.

$$\text{OFL} = F_{\text{msy}} X_t \quad (1)$$

$$\text{OFL}' = F_{\text{rebuild}} X_t \quad \text{in overfished stocks.}$$

The first buffer is to be established by the Science and Statistical Committee and the purpose is to set an Acceptable Biological Catch (ABC) that is less than the OFL. The purpose of the buffer is to address “scientific uncertainty”.

$$\text{ABC} \leq \text{OFL} \quad (2)$$

Presumably, if there is little concern over scientific uncertainty, there is no need for a buffer and so ABC could equal OFL. The Guidelines specify that an ABC Control Rule must be developed but they do not define what constitutes scientific uncertainty or under what conditions it becomes a matter of concern such that buffers be required. The ABC is to be the “fishing level recommendation” specified in the MSRA that will be the upper limit on ACL. However, it is implied in the Proposed Guidelines that the ACL will (can) be set equal to the ABC.

The second buffer is to be established by the Council and the purpose is to set an Annual Catch Target (ACT) that is less the ACL.

$$\text{ACT} \leq \text{ACL}(\text{ABC})$$

The purpose of the buffer is to address implementation uncertainty. While the meaning of scientific uncertainty may be subject to different interpretations, the meaning of implementation uncertainty is straight forward. There are uncertainties in the management process itself. Setting an allowable harvest is one thing, but making sure that the actual harvest is constrained to that amount is quite another. This implementation uncertainty depends upon, among other things, the types of regulation, the utility functions of the participants and how well their activities can be monitored and controlled. The Proposed Guidelines also mandate the development of an ACT Control Rule.

The ACL is of significant policy importance because it is a critical indicator of when AMs are to be used. If, despite the ACT buffer, actual harvest approaches the ACL in any year, in-season measures must be taken, if possible. Further, if the ACL is surpassed more than 25% of the time, it will be necessary to restructure the process for setting the ACT.

The next section will provide a preliminary discussion on the necessary components for Control Rules to set buffers. Following that will be a description of basic components the age class stock projection model that can be used as a framework for discussing the difference between scientific and implementation uncertainty and for applying control rules.

A SUGGESTED PROCEDURE FOR SETTING A CONTROL RULE

Presumably an ABC or an ACT control rule is a set of steps to be taken or a protocol to be followed in order to establish the buffer that will determine the value of the harvest level in question. A control rule should be based on an accepted principle of fisheries management, and, in theory, there should be a formula for calculating that value using parameters that can be derived in standard stock assessments. Consider the simple MSY control rule. The underlying

principle is that striving to maximize sustainable yield is a laudable goal. The MSY harvest level at any point in time can be calculated by the application of equation 1. In the long run, the average of such harvest levels will equal the MSY.

A principle that is related to MSY is the concept of a stock rebuilding plan or a stock maintenance plan. Such a plan allows for the specification of a desired target stock size (X_{target}) for the next period. There are elements of policy in a stock rebuilding plan in addition to the cranking out of numbers with a stock projection model. For example, for a given current stock size, the X_{target} will be different depending upon whether the rebuilding path is based on a constant fishing mortality rate or a constant harvest rate.

Using the achievement of X_{target} as the ultimate criterion of success, a control rule protocol for addressing uncertainty in the specification of buffers for ABC and ACT can be summarized as follows.

1. Specify the minimum acceptable probability that $X_{t+1} \geq X_{\text{target}}$. Call it (P^*).
2. Set Buffer ($B^* > 0$) such that the probability $P(X_{t+1} \geq X_{\text{target}} | B^*) = P^*$.
If $P(X_{t+1} \geq X_{\text{target}} | 0) \geq P^*$, then no buffer is necessary.

Given tools of decision analysis and the appropriate data including probability distribution functions of key parameters, it is a relatively straightforward procedure to make the necessary calculations to find the value of B^* . The only policy decision at this level is the selection of the minimum acceptable probability, P^* . This is a whole other issue and will not be addressed here.

A MONTE CARLO AGE CLASS STOCK PROJECTION MODEL

The authors have developed an age class Monte Carlo stock projection model that can be used to apply the protocol. The model, which is constructed using Excel® supplemented with Crystal Ball®, cannot be explained in detail here due to space constraints, but details are available from the authors. Basically it is a traditional age class model that, given an initial age class size distribution, tracks age class size through time using a recruitment function and considering age specific natural and fishing mortality, and individual growth. See also Semmens (2008).

Heuristically, the workings of the model can be explained in terms a simple equation.

$$X_{t+1} = X_t + C_t - G(X_t, C_t) \quad (3)$$

C_t is current harvest by age class. $G()$ is annual net growth taking recruitment, individual growth, and natural mortality, and other relevant factors into account but not directly counting harvest mortality. $G()$ is a function of the characteristics of the current stock size including numbers and sizes of age classes, the relationship between recruits and the spawning stock biomass, and age specific fecundity and natural mortality rates. But in addition it is also a function of current harvest because of the relationship between natural and fishing mortality. Some of the fish that are caught would have died anyway.

For the moment consider equation 3 in terms of a deterministic framework with perfect information. The stock size next year is the sum of the stock size this year and the difference between net natural growth and harvest. The model can be used to build a deterministic stock growth or stock maintenance program by either choosing C_t^* such that desired stock growth is achieved or by selecting a harvest rule and then

tracking the way in which stock size changes. This can be used as the frame of reference around which to consider uncertainty.

Now think of the process described in equation 3 in more general terms taking uncertainty into account. What types of things should be included when considering uncertainty? There is a considerable literature on this topic and a good summary can be found in Francis and Shotton (1997). In the first place, the population dynamics of a fish stock is a stochastic phenomenon. For example, while recruitment may be related to the size of the spawning stock biomass, there is considerable variability involved. There are limits on how well these types of things can be predicted. This is called process uncertainty.

There are three related but conceptually distinct types of uncertainty involved with empirical biological research on stock population dynamics. Measurement and sampling error in data collection is called observation uncertainty. Model uncertainty involves the choice of the correct functional form for a particular relationship. Does the equation actually mimic the natural process? Is recruitment best captured by a Beverton-Holt or a Ricker equation? Finally there is uncertainty related to the process of estimating the parameters of whatever equation is chosen.

Considering both the workings of the stock projection model and the concepts of what is meant by uncertainty, is there any way to parse this into logical notions of scientific and implementation uncertainty? If they are to be considered separately, it must be possible to make a clear distinction between them. Because implementation uncertainty is perhaps more easily defined, one method would be to search for a clear definition of it and then let scientific uncertainty encompass everything else.

Implementation uncertainty deals with the distribution of the expected value of actual catch around the desired catch level. Now, total actual catch is a function of age class fishing mortality which is a function of fishing effort and age class specific catchability coefficients. Basically, in terms of the model, implementation uncertainty deals with age class fishing mortality and how it changes with different types of regulation programs. There are, of course, issues of stochasticity, and uncertainties with respect to model specification and parameter estimation.

Scientific uncertainty would then include recruitment, age specific natural mortality and individual growth, the estimation of the initial age class distribution as well as any of the other myriad of things involved in the population dynamics of a fish stock. While it is something of a simplification, scientific uncertainty deals with the composites of the $G(\)$ function, and implementation uncertainty deals with the expected distribution of C_t .

But even if there is a definitional distinction between scientific and implementation uncertainty, does this have any operational significance when performing a control rule protocol to find an ABC or an ACT buffer? Looking back at equation 3 again, it can be seen that the effects of both types of uncertainty will occur simultaneously. And, just as important, because of the interrelationships between fishing and natural mortality, it is not possible to separate the effects of one from the other.

To anticipate the arguments to be found below, there are reasons to believe that the two step distinction in the determination of ABC and ACT may not be theoretically sound.

The model has been calibrated with data from the Eastern Stock of Gulf of Mexico Red snapper fishery using data from the SEDAR program.ⁱⁱⁱ See SEDAR 7 (2005). The model has separate functions for commercial and recreational fishing mortalities which is important with respect to dealing with implementation uncertainty.

Year	Commercial	Recreational
1991	8.5%	7.0%
1992	48.6%	84.6%
1993	10.3%	89.5%
1994	5.3%	54.2%
1995	-4.1%	25.6%
1996	-7.2%	-18.5%
1997	3.4%	-2.2%
1998	0.6%	-2.7%
1999	4.6%	-2.6%
2000	4.0%	-25.5%
2001	-0.5%	-20.3%
2002	2.9%	9.0%
2003	-5.2%	2.8%
2004	0.4%	13.6%
2005	-13.1%	2.7%

Table 1

Some aspects of “scientific uncertainty” were added to the model by introducing probability distribution functions for recruitment, natural mortality, and initial age class size. For recruitment variability, a probability distribution was set around alpha in the following Beverton-Holt recruitment function,

$$R_t = \frac{\alpha \cdot \beta \cdot \frac{S_t}{S_0}}{1 + (\beta \cdot \frac{S_t}{S_0})}$$

where recruitment in year t is specified as a function of alpha (α) and beta (β) (recruitment parameters), and spawning stock size (S_t) and virgin spawning stock size (S_0). The probability distribution was specified as a lognormal distribution with a standard deviation of 0.4. For natural mortality variability, a probability distribution was ascribed to each age specific natural mortality as a normal distribution with the estimate as the mean and the 97.5% value as twice this estimate so that 95% of the values would fall between one half and twice the estimated natural mortality. This is similar to the method utilized by Francis (1993). Finally, the initial age class distribution numbers were ascribed probability distributions to simulate uncertainty in estimates of the initial population size. The probability distribution for each initial age class

estimate was set as a normal distribution with the estimate as the mean and the 97.5% value as 1.1 times the estimate so that 95% of the values would fall between 0.9 and 1.1 times the estimated initial age class size.

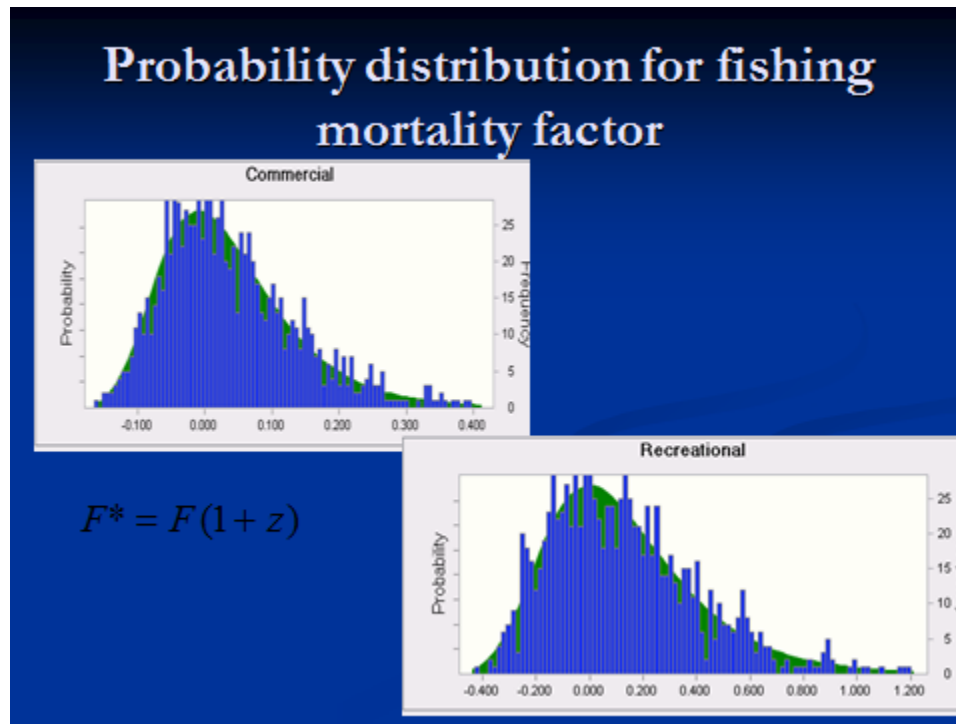


Figure 1

In order to introduce implementation uncertainty a factor (z) was added to the formula for calculating both the recreational and commercial fishing mortality rates with initial values of 0. These factors represent the percent by which actual catch surpassed the target. Actual data on these overages for both sectors were available from 1991 to 2005. See Table 1. Negative values indicate that the actual catch was less than the target. Admittedly, this is not much to go on but using a feature of Crystal Ball® it was possible to fit a probability distribution to the data series. A Max Extreme distribution was used for both the commercial (with a likeliest of -0.01 and scale of 0.08) and recreational (with a likeliest of 0 and a scale of 0.23) sectors, with the recreational fishing mortality rate allowed to vary more widely than the commercial due to the higher degree of uncertainty in managing the particular sector. The distributions are pictured in Figure 1. Notice there is a wider distribution for the recreational sector.

In order to look into the issue of separating scientific and implementation uncertainty for determining the appropriate sized buffers, two versions of the model were developed. The first only allows for variance in the parameters related to recruitment, natural mortality, and age class size distribution. Call this the S model because it considers “scientific uncertainty”. The second is the same except that also considers the variations in implementation factors. Call this the S&I model.

MODEL RESULTS

Using the mean values of the parameters in the calibrated stock projection model, it was possible to estimate the information displayed in Figure 2. Spawning Stock size is on the horizontal axis with the current stock size represented as the vertical line to the far left. The Spawning Stock for MSY is represented by the vertical line to the far right. The upper curve represents the sustainable harvest for the given stock size. The lower curve, and the one of critical policy importance here, represents the harvest path the will cause the stock to grow from the current stock size to the MSY stock size in ten years. It represents the OFLs, the starting points for the buffer analysis, over the range of stock sizes. Given that the current stock size is well below the MSY stock size, the OFL is less than the sustainable for any stock size because of the need to allow the stock to grow.

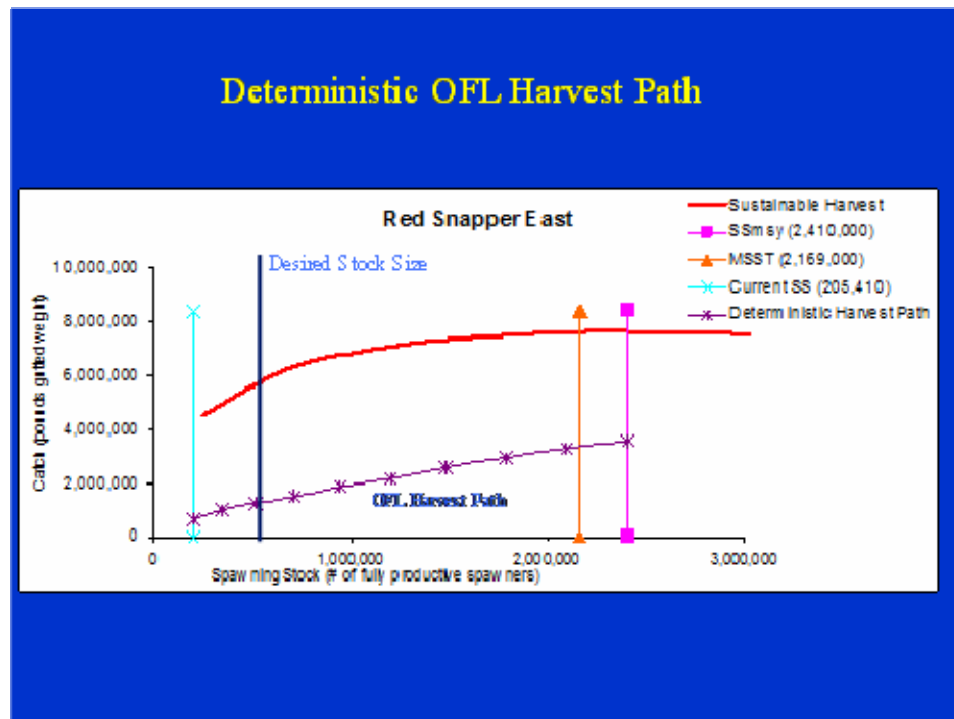


Figure 2

While the OFL curve specifies a desired catch level for any given stock size, the curve can also demonstrate points on the stock growth curve. Each succeeding pair of harvest points on the OFL curve has the following interpretation. If the harvest level at the first point is maintained at that stock size, then the stock will grow to the stock size at the second point in the next period. For specific reference for the analysis to follow, in a deterministic world, if, starting at the current stock size, harvest is kept to the first two points on the OFL curves during the first two years, in the third year the stock will be at the level represented by the vertical line labeled Desired Stock size.

To begin the analysis, consider first the setting of the ABC buffer. Using Figure 2 as a reference point, both models were used to evaluate the probability of obtaining this desired stock size with different buffers, and hence different values for the ABC. The results are displayed in Figure 3 where the probability of stock success is plotted against harvest as a percent of the OFL. For the

moment consider only the top curve which shows the results from the S model. With no buffer and the allowable harvest, ABC, is equal to the OFL, the probability of obtaining the desired stock level is about 50%. Movements to the left of the OFL line indicate larger buffers between the OFL and the ABC. The probability of success increases as the buffer is increased.

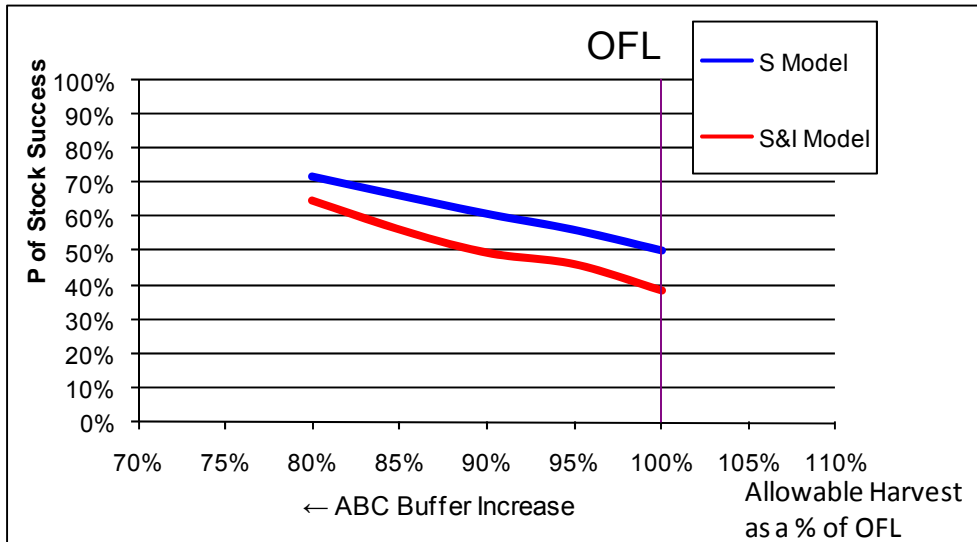


Figure 3

At this level of generality in the discussion of setting buffers to address uncertainty, these specific results are not that important. The main point is that these are the types of results that can be produced using stochastic stock projection models. The fact that the probability of success in obtaining the desired stock increases with the size of the buffer should come as no surprise. The real question is how the shape and position of the curve will change with different circumstances? All else equal of course, the steeper the slope the better, because increases in the probability of success will come at a lower cost in terms of forgone harvest. The main point is that this type of curve will allow for a straightforward application of a buffer control rule. Specify the desired probability of success and it is easy to find the size of the required buffer.

But now consider the question of separating the scientific and implementation uncertainty in the setting of buffers. To state the issue in its extreme case, assume that the SSC is about to determine the ABC buffer and they have the information provided in Figure 3. If they are to set the buffer *only* considering scientific uncertainty, they will have to use the results of the S Model, which will overestimate the probability of success, because it does not consider the chance of overharvest because of enforcement problems. To make a long story short, in situations where both scientific and implementation uncertainty can be considered in the decision analysis models, there appears to be no justification for not considering both from the start when setting the ABC buffer.

This raises the question of what do about setting an ACT. If the probability of obtaining the desired stock size can be evaluated in one step, is it necessary to do it twice? However, given that the ACT has a more specific purpose than the ABC, one can argue that a separate consideration is justified even with the interrelation between scientific and implementation uncertainty. In fact, the Proposed Guidelines suggest that since the purpose of the ACT is to ensure that the ACL is not surpassed, a possible criterion for selecting the ACT buffer is the probability that the ACL is surpassed. Formally, the ACT protocol could be the following.

1. Specify the minimum acceptable probability that actual harvest \geq ACL. Call it (P^{**}).
2. Set Buffer ($B^{**} > 0$) such that the probability $P(\text{actual harvest} \geq \text{ACL} \mid B^{**}) = P^{**}$.
If $P(\text{actual harvest} \geq \text{ACL} \mid 0) \geq P^{**}$, then no buffer is necessary.

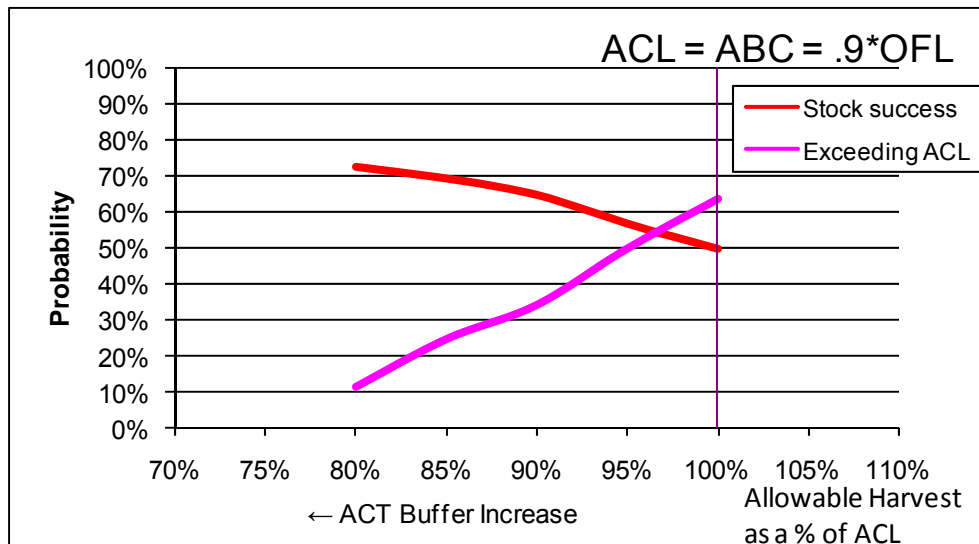


Figure 4

The full S&I model is also capable of performing the calculations to undertake this protocol. Assume for the moment that using the information in Figure 3, the ABC is set at 90% of the OFL. Then carrying on with the assumption that the ACL is set equal to the ABC, how can we set the ACT buffer? It is possible to use either protocol. The results are presented in Figure 4. The downward sloping curve shows how the probability of harvest surpassing the ACL decreases as the ACT buffer increases. The upward sloping curve is the probability of stock success curve used in Figure 3. To be precise, it is a replication and extension of that curve except that the horizontal axis has been change because the 100% of the ACL is equal to 90% of the ABC.

In trying to make the choice of which protocol to use, it is important to consider usefulness of the information that is provided. The probability of stock success would appear to be the most valuable. Obtaining a given stock size is the ultimate goal. Exceeding the ACL is not a bad thing in and of itself. Rather it is “bad” because of the effects it will have on stock size. Therefore using the probability of exceeding ACL as a criterion of success is to be one step removed from the real problem. This is especially true when data on the probability of stock success is available. And with a proper stock projection model, if you can calculate one you can calculate the other.

This brings us back to the first question. Does it make sense to separate the questions of scientific and implementation uncertainty when setting ACTs. If in fact it is necessary to separate out the setting of the ABC from the ACT because the use of the latter allows for a focus on the use of accountability measures, one possible solution would be to use different critical minimum probabilities of success in setting the two buffers. For example, set the ABC buffer such that the probability of achieving the desired stock size is 60%, and then set the ACT buffer such that the probability is increased to 70%.

FINAL COMMENTS

The discussion here only applies to situations where the stock assessment analysis can provide enough information to construct something similar to the stock projection model described here. While the principles behind the suggested protocol for the control rules for ABC and ACT hold in general, how they can be applied in “data poor” fisheries is a question that remains to be answered.

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ENDNOTES

ⁱ Support from NOAA Fisheries Office of Science and Technology is gratefully acknowledged, but the authors are solely responsible for the contents.

ⁱⁱ See www.nmfs.noaa.gov/msa2007/docs/NS_1_proposed_revisions.pdf

ⁱⁱⁱ The help of Drs. Clay Porch and Shannon Cass-Calay of the National Marine Fisheries Service in getting into the details of the stock assessment reports is gratefully acknowledged but the authors take full responsibility for data interpretations.