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Probabilistic Approaches to Setting Acceptable Biological Catch and Annual Catch Targets for Multiple Years: Reconciling Methodology with National Standards Guidelines

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Abstract.—In U.S. federal fishery management, acceptable biological catch (ABC) is set below (or equal to) the overfishing limit to account for scientific uncertainty, and annual catch targets (ACTs) are set below (or equal to) the ABC to account for implementation uncertainty (i.e., imperfect management control). In previous papers, we discussed probabilistic approaches to setting target and limit reference points for fishery management. Here, we explain how those approaches can be adapted to provide ABCs and ACTs over multiple years and otherwise made consist with recent revisions to the National Standards Guidelines, a part of the U.S. Code of Federal Regulations that describes implementation of the Magnuson–Stevens Reauthorization Act. Although described in terms of U.S. fishery management, our methods are sufficiently general for use by researchers in U.S. state agencies or elsewhere in the world. We demonstrate them via an example application to vermilion snapper *Rhomboplites aurorubens* in U.S. Atlantic waters.

Precautionary fishery management in much of the world, including the United States, makes use of the concept of target and limit reference points (Caddy and Mahon 1995). In the context of exploitation rates, a limit reference point quantifies the maximum degree of exploitation considered safe for a stock, and a target reference point sets the degree of exploitation aimed for by management. The difference between the two provides a buffer against frequent overexploitation. Computation of reference points through probability theory has been described by several authors.

Caddy and McGarvey (1996) proposed a method of setting a target reference point given a limit reference point F_{lim} specified as a point estimate, such that the realized fishing mortality rate in the next period (F_t) would exceed F_{lim} with only some chosen probability P^*. The method assumes that F_t will achieve the target without bias, but not necessarily with precision, to allow for imperfect implementation of management controls or imperfect estimation in the stock assessment.

In the Caddy and McGarvey (1996) method, the probability of overfishing in the next year is computed from F_{lim} and the probability density function (PDF) ϕ_{F_t} of F_t, namely,

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

In other words, the realized fishing rate in the next year, F_t, is described by a distribution, the central tendency of which is the fishing rate target. By setting the target, the distribution of F_t can be positioned such that the allowable probability of overfishing is achieved: $\Pr(F_t > F_{\text{lim}}) = P^*$.

In this and the similar methods described here, P^* is the allowable probability of overfishing in any single year. In a series of n years, the probability that overfishing will occur at least once, assuming independence among years, increases to $p_n = 1 - (1 - P^*)^n$. (For example, if $n = 5$ and $P^* = 0.2$, $p_n = 0.672$.)

Prager et al. (2003) extended the work of Caddy and McGarvey (1996) in three ways: (1) allowing for uncertainty both in estimating the limit reference point and in attaining the target, (2) using ratios to reduce possible covariance between quantities, and (3) considering reference points in biomass as well as in the fishing mortality rate. Also, the authors suggested that an adjustment (bias correction) be made when past catches have not been centered on their targets.

Prager et al. (2003) pointed out that F_{lim} should be described when possible by its PDF ($\phi_{F_{\text{lim}}}$) rather than by a point estimate to account for scientific uncertainty in the estimate of the limit reference point (which in the context of U.S. fisheries is the maximum fishing mortality threshold). Given that PDF, the probability of overfishing is computed as

$$\Pr(F_t > F_{\text{lim}}) = \int_0^{\infty} \left[\int_F^{\infty} \phi_{F_t}(\theta)\, d\theta \right] \phi_{F_{\text{lim}}}(F)\, dF, \quad (2)$$

where θ is a dummy integration variable. As before, a

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target is computed by positioning the corresponding distribution of F_t to achieve $\Pr(F_t > F_{\text{lim}}) = P^*$.

An assumption of equation (2) is that F_{lim} and F_t are independent. If the two are correlated, the probability of overfishing could be computed from the bivariate PDF $\phi_{F_{\text{lim}},F_t}$, namely,

$$\Pr(F_t > F_{\text{lim}}) = \int_0^{\infty} \int_F^{\infty} \phi_{F_{\text{lim}},F_t} \, d\theta dF. \qquad (3)$$

Although use of a bivariate PDF is more general and merits consideration, estimating $\phi_{F_{\text{lim}},F_t}$ might not be possible from most data sets. Fortunately, simulation analyses to date have supported the assumption of independence, and thus the less general equation (2) may in many cases be a suitable approximation (Shertzer et al. 2008).

New Requirements

In the United States, the Magnuson–Stevens Reauthorization Act (MSRA 2006) established several new requirements for federal fishery management. The most notable in the context of catch levels are that fishery management councils must set annual catch limits (ACLs) and that those limits may not exceed the recommendations of the councils' scientific advisers.

The National Standard 1 (NS1) Guidelines (USOFR 2009) provide guidance on implementing the MSRA. The guidelines suggest that, as one precursor to establishment of an annual catch limit, a council's scientific advisors should determine the acceptable biological catch (ABC) by reducing the overfishing limit (OFL) to account for scientific uncertainty. In that context, the OFL is generally defined as the catch obtainable from the current stock biomass by applying the limit reference point in the fishing mortality rate, F_{lim} (in practice often set to the fishing mortality rate associated with the maximum sustainable yield [F_{MSY}] or an appropriate proxy).

The ACL must then be set less than or equal to the ABC. Given ACL, an annual catch target (ACT) could optionally be set at some lower level. The ACT would serve as the management goal, with a buffer from ACL to account for management uncertainty (i.e., imprecision in achieving the target; Rosenberg and Brault 1993; Rice and Richards 1996; Fulton et al., in press). The approaches to be described here do not refer to an ACL explicitly, but leave the ACL to be set anywhere below or equal to the ABC and sufficiently above the ACT so that accountability measures (e.g., adjustments to ACT to account for past overages) will not be triggered too frequently.

In cases where the ABC is required for only a single year, Prager and Shertzer (2010) described a simple method, closely related to the method of Caddy and McGarvey (1996), for computation. For many stocks, however, catch levels might need to be set for multiple years, particularly when assessments are not conducted annually.

For multiyear applications, Shertzer et al. (2008) proposed a probabilistic approach to setting catch levels (PASCL). Although intended to apply to U.S. fishery management, that approach was not fully consistent with the subsequent NS1 Guidelines (USOFR 2009). Specifically, PASCL did not provide ABC and it did not separate the effects of scientific and implementation uncertainties. Here, we describe how PASCL can be reconciled with NS1 Guidelines to provide ABCs and ACTs over multiple years. Although devised with U.S. federal fishery management in mind, the following methods are sufficiently general for application in other systems as well.

Methods and Results

We have devised two variants of PASCL intended to reconcile it with the NS1 Guidelines. Each approach calculates an ABC to account for scientific uncertainty and an ACT to account for implementation uncertainty as well (although we note that ACT is not a formal NS1 requirement). One approach considers the two sources of uncertainty simultaneously, the other sequentially. We refer to the former as Integrated PASCL, the latter as Sequential PASCL.

The methods are based on probabilities of future events, probabilities whose allowable levels are assumed to have been set a priori, each less than 0.5 (Figure 1):

(1) P^* is the allowable probability that the ABC will exceed the OFL (P^* is used in both Sequential and Integrated PASCL).
(2) P^{**} is the allowable probability that the realized catch from the ACT will exceed the ABC (P^{**} is used in Sequential PASCL only).
(3) P^{***} is the allowable probability that the realized catch from the ACT will exceed the OFL, which in the two PASCL methods presented here is considered equivalent to the probability of overfishing (P^{***} is used in Integrated PASCL only; to ensure ACT $\leq$ ABC, $P^{***} \leq P^*$).

In each variant of PASCL, ABC is set below OFL such that, based on scientific uncertainty, the probability that ABC exceeds OFL is P^*. The corresponding ACT is set below the ABC, but the way that ACT is determined differs between approaches.

In Integrated PASCL, the ACT is set below the OFL in nearly the same way that the ABC is set below the OFL, but accounting for both scientific and implementation uncertainties. That is, Integrated PASCL sets the ACT such that, considering scientific and implementation uncertainty, overfishing will occur with probability P^{***}.

In Sequential PASCL, the ABC is set first, and the ACT is set from the ABC rather than directly from the OFL as in Integrated PASCL. Because the ABC has been set to account for scientific uncertainty, the ACT control rule here accounts only for implementation uncertainty. Sequential PASCL sets the ACT so that future catch exceeds the ABC with annual probability P^{**}.

The differences between the two methods can be summarized as follows:

(1) Integrated PASCL sets the ACT by reference to the OFL, while Sequential PASCL sets the ACT by reference to the ABC (perhaps also the ACL, if it is set equal to the ABC).
(2) Integrated PASCL sets the ACT to control the probability of overfishing directly, while Sequential PASCL sets the ACT to avoid exceeding the ABC (perhaps also to avoid exceeding the ACL, if it is set equal to the ABC).

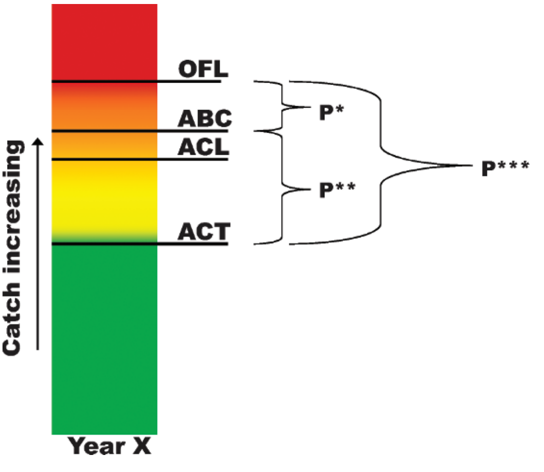

FIGURE 1.—Probabilities used in PASCL: P^* is the allowable probability that the acceptable biological catch (ABC) will exceed the overfishing limit (OFL) (Sequential and Integrated methods); P^{**} is the allowable probability that realized catch from the annual catch target (ACT) will exceed the ABC (Sequential method only); and P^{***} is the allowable probability that realized catch from the ACT will exceed the OFL (Integrated method only).

Integrated PASCL Method

In Integrated PASCL (Figure 2), the goals are to compute the ACT such that $\Pr(F_t > F_{\text{lim}}) = P^{***}$ and the ABC such that $\Pr(F_t' > F_{\text{lim}}) = P^*$. In this notation, the values of F_t' and F_t differ because they correspond to the different catch levels: F_t' are hypothetical fishing rates that would occur if the catch were set to achieve the ABC, and F_t are actual fishing rates predicted to occur when the catch is set to achieve the ACT. The goals can be accomplished through use of a projection model similar to those already in use for fishery management. When adapted to PASCL, such a model can be structured to describe any individual stock, and it can incorporate any sources of uncertainty considered important. For example, scientific uncertainties can include uncertainty in assessment results (e.g., in estimating F_{lim} or initial abundance) and stochasticity in future stock conditions (e.g., recruitment or life history characteristics). Implementation uncertainty is modeled as stochasticity in achieved catch from a target catch.

The probabilistic approach can be applied through a projection model with the following steps (modified from Shertzer et al. 2008):

(1) Initialize N replicates of the stock to reflect uncertainty in the estimated current state, with each replicate different in abundance and age structure as well as other parameters of interest (selectivity, natural mortality, spawner–recruit relationship, etc.).
(2) Compute the ABC:
    a. Choose a trial value C' of the ABC without considering implementation uncertainty.
    b. Compute for each replicate the fishing mortality rate F_t' that yields C'. This produces N values of F_t' that define its empirical probability density (ϕ'_{F_t}).
    c. Given ϕ'_{F_t} and $\phi_{F_{\text{lim}}}$, compute $P = \Pr(F_t' > F_{\text{lim}})$ from equation (2).
    d. Using a numerical optimization method, adjust C' until $P = P^*$. The adjusted C' is that year's ABC.
(3) Compute the ACT:
    a. In the presence of implementation uncertainty, each ACT will be the central tendency μ_{ACT} of a probability distribution ϕ_C. Choose a trial value of μ_{ACT}, and draw N values $\{C_1, \ldots, C_N\}$ from the corresponding distribution. Catch C_1 is the catch taken from stock replicate 1, C_2 that from 2, and so forth.
    b. To combine the uncertainties in state of the stock and implementation, compute for each replicate k the fishing mortality rate that yields C_k. This produces N values of F_t to define its empirical probability density (ϕ_{F_t}).

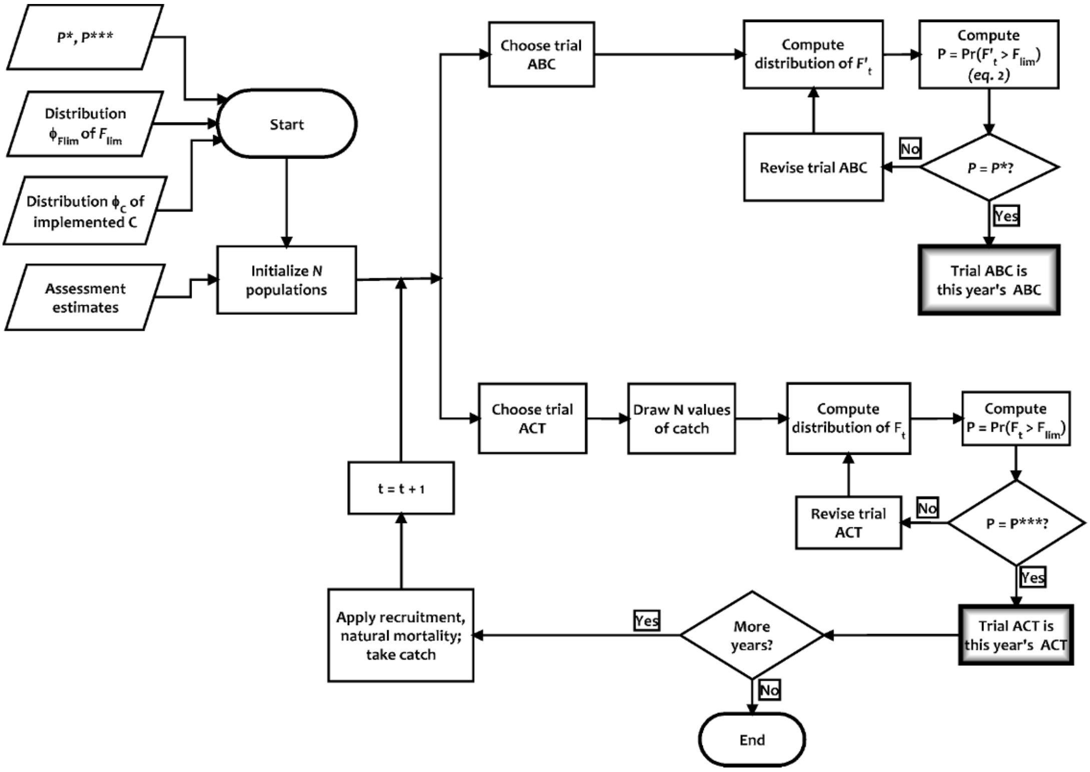

FIGURE 2.—Flowchart of Integrated PASCL; see text for details.

c. Given ϕ_{F_t} and $\phi_{F_{\text{lim}}}$, compute $P = \Pr(F_t > F_{\text{lim}})$ from equation (2).

d. Using a numerical optimization method, adjust μ_{ACT} until $P = P^{***}$. The adjusted μ_{ACT} is that year's ACT.

(4) Project each replicate k one year forward by applying recruitment and natural mortality and taking catch C_k.

(5) Repeat steps 2–4 for T years. The duration T should be chosen to extend the projection at least until catch levels based on the next assessment can be implemented.

The preceding procedure gives an ABC and ACT for each year in the period, with the annual probability of overfishing kept at P^{***}. (This P^{***} corresponds to P^* in the notation of Shertzer et al. 2008). To ensure that ACT $\leq$ ABC, the constraint $P^{***} \leq P^*$ should be applied (although this constraint may not always be necessary because the ACT accounts for additional [implementation] uncertainty). In Integrated PASCL, the order of computation of this year's ABC and ACT does not matter (step 2 could just as well come after step 3).

Example of the Integrated PASCL Method

In this example, we applied a 3-year projection with Integrated PASCL to compute values of ABC, ACT, and spawning biomass. The projection model extends from the 2008 assessment of vermilion snapper *Rhomboplites aurorubens* in U.S. Atlantic waters (SEDAR 2008). It includes stochasticity in future recruitment and in the initial stock structure (i.e., abundance at age). Analyses were programmed in R (RDCT 2009).

For demonstration, each projection used $P^* = 0.4$ and a 3×3 factorial design of P^{***} and the coefficient of variation (CV = standard deviation divided by the mean) of management implementation: $P^{***} = \{0.1, 0.2, 0.3\}$, CV = $\{0.2, 0.4, 0.6\}$. As one might expect, lower values of P^{***} resulted in lower ACTs but also higher stock biomass and consequently higher ABCs (Figure 3). For a given P^{***}, greater precision in management implementation (i.e., lower CV) allowed higher ACTs.

Sequential PASCL Method

In the sequential method (Figure 4), the ABC accounts only for scientific uncertainty, as before, and

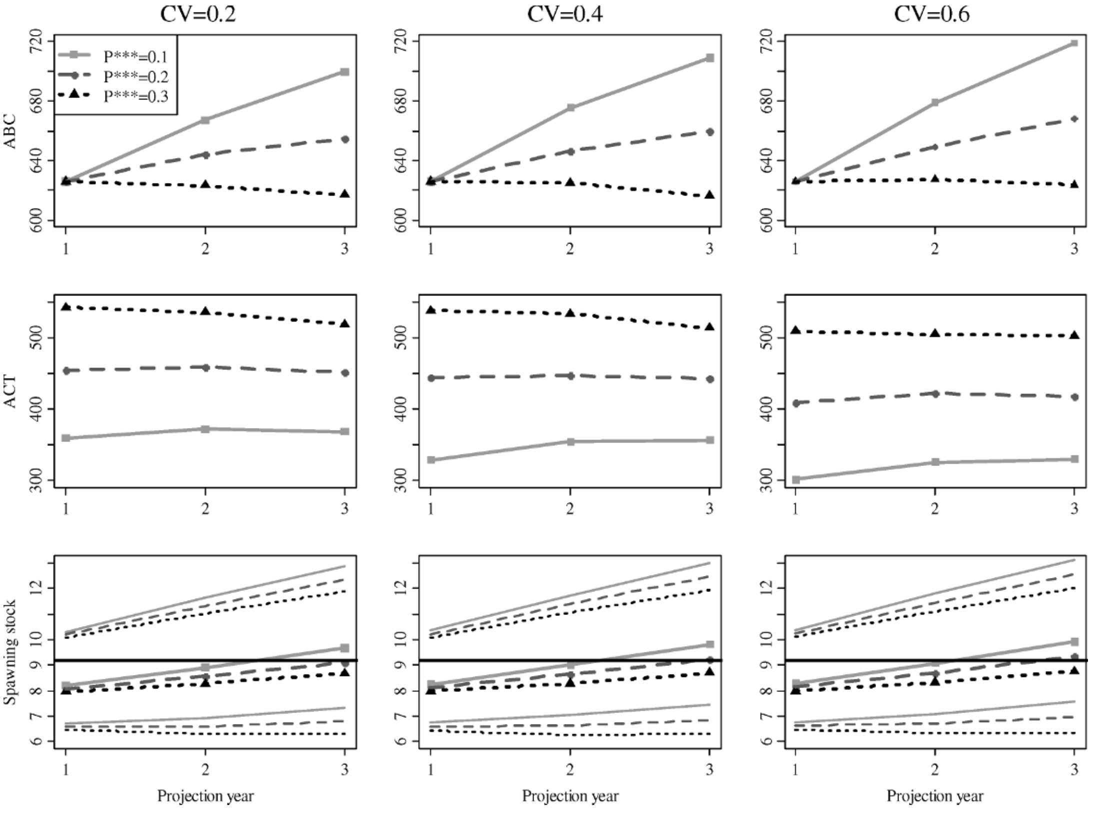

FIGURE 3.—Example of Integrated PASCL applied to vermilion snapper, with $P^* = 0.4$ and $P^{***} = 0.1$, 0.2, or 0.3, as indicated. The CV of management implementation was assumed to be 0.2, 0.4, or 0.6, as shown in the column headings. The top two rows show catch levels, ABCs, or ACTs (metric tons). The bottom row shows median spawning stock (10^{12} eggs) from 10,000 replicates, upper and lower quartiles, and the point estimate of spawning stock at maximum sustainable yield (heavy horizontal line).

is computed as in the integrated method such that $\Pr(F'_t > F_{\text{lim}}) = P^*$. Unlike in the integrated method, however, the value of the ABC is used explicitly when computing the ACT, so that the buffer between ABC and ACT accounts for implementation uncertainty only, with probability P^{**}. Any of equations (1)–(3) could be used but would be recast in terms of catch rather than fishing mortality rate. We expect that a modified equation (1) would most often apply, that is,

$$\Pr(C_t > \text{ABC}) = \int_{\text{ABC}}^{\infty} \phi_{C_t}(C)\, dC, \qquad (4)$$

where (ϕ_{C_t}) is the PDF of catch in year t, defined by the ACT and implementation uncertainty. As before, the ACT is adjusted to position the distribution of C_t so that the allowable probability of exceeding the ABC is achieved (i.e., $\Pr[C_t > \text{ABC}] = P^{**}$).

The sequential method could be applied in a procedure similar to that of the integrated method, but with the following modification to step 3:

(3) Compute the ACT:

a. Given implementation uncertainty in controlling catch, each ACT will be the central tendency μ_{ACT} of a probability distribution ϕ_C. Choose a trial value of μ_{ACT}, and draw N values $\{C_1, \ldots, C_N\}$ from the corresponding distribution. Catch C_1 is the catch taken from stock replicate 1, C_2 that from 2, and so forth.
b. Given ϕ_C and the ABC, compute $P = \Pr(C_t > \text{ABC})$ from equation (4).
c. Using a numerical optimization method, adjust μ_{ACT} until $P = P^{**}$. The adjusted μ_{ACT} is that year's ACT.

In the sequential method, step 2 must come before step 3 because the ABC is used to derive the ACT. To

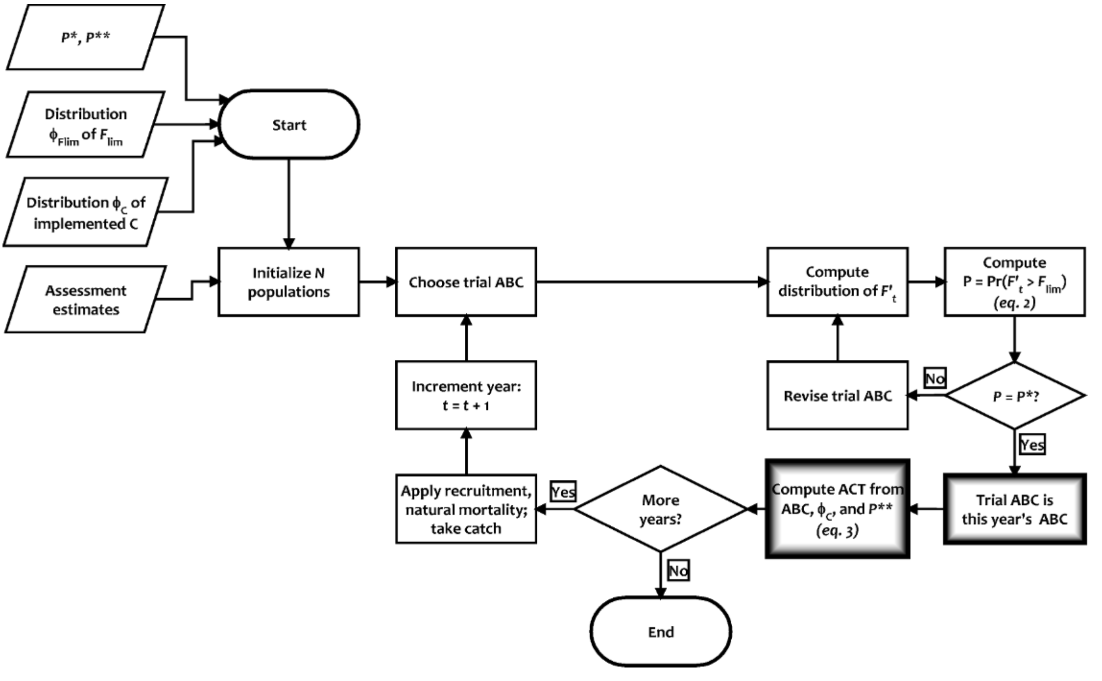

FIGURE 4.—Flowchart of Sequential PASCL; see text for details.

ensure that ACT ≤ ABC, it is not necessary that $P^{**} \leq P^*$.

Discussion

Although statistical assumptions of fishery analyses are rarely (if ever) met perfectly, we think the probabilistic approaches described here have value because they are objective, repeatable, and computable from standard assessment outputs (or clear assumptions about variance). What is more, they are explicit in the use of a priori probabilities of exceeding reference points. Because it is impossible to avoid overfishing with full certainty (unless $F = 0$), we find it critical to define the allowable probability of overfishing clearly and transparently.

In many places, our description of methods casts probabilities in terms of fishing rates rather than catch levels (C_t). This was purposeful, to reflect how computations were actually performed (i.e., $\Pr[F_t > F_{\text{lim}}]$ substitutes for $\Pr[C_t > \text{OFL}]$), although results are still in terms of catch levels. Furthermore, our description assumed that the limit reference point in F was set independently of current biomass or abundance. With minor computational modification, PASCL could accommodate an F limit that depends on biomass or abundance (e.g., the "40–10 strategy" of the Pacific Fishery Management Council; PFMC 2008).

Implementation Imprecision and Bias

When computing ACT, both variants of PASCL account for implementation uncertainty (Rosenberg and Brault 1993; Rice and Richards 1996; Fulton et al., in press) as well as scientific uncertainty. We have assumed so far that implementation is unbiased, that is, that actual catches are centered on the ACT. If, however, catches tend to be higher or lower than the ACT, that assumption can be avoided by including a bias-correction term in the computation (step 3). Prager et al. (2003) suggested that the correction could be based on a running average of observed bias in the immediately preceding years. Semmens (2008) recommended "adjusting for quota overages by sector after considering all sources of uncertainty." That procedure is theoretically equivalent to, but at times may be more practical than, including a bias correction in the overall computation.

Whether to account for imprecision or to correct for bias, an estimate of the form (distribution) of implementation uncertainty is needed. For some stocks, that will be estimable from data on fishery performance; if not, distributional assumptions will be required. With widespread application of ACTs, implementation uncertainty (including implementation bias) eventually should become estimable for many stocks.

Setting Catch Levels for Multiple Years

If catch levels are set just one year in advance, the ABC and ACT can be determined under separate consideration (Prager and Shertzer 2010). If catch levels for a series of years are required, it seems better to set ACT and ABC under joint consideration, as in the two PASCL methods, because of the feedback loop between catch level and stock abundance (Rice and Richards 1996). Each year's ACT influences the actual catch taken (C_t), which in turn influences the next year's stock size and age structure and thus its OFL and ABC.

Although it seems preferable to determine various catch levels jointly, NS1 Guidelines separate the responsibility of setting ABCs (the purview of the councils' scientific advisers) from that of setting ACLs and ACTs (the purview of the councils). This separation of responsibilities may lead in practice to separation of determination. If so, PASCL could still be a viable method for computing ABCs alone, by including only scientific uncertainty (i.e., assuming that implementation uncertainty is zero) and assuming that the projected catch is centered on the ABC. Fishery managers could then set ACTs below the annual ABCs to account for implementation uncertainty. This approach would be conservative in the sense that it would produce lower values of ABCs than if projected catch were centered on the ACTs. Nonetheless, separation of responsibilities need not imply separation of scientists and managers: collaboration will be critical as applications to meet NS1 Guidelines evolve.

*Choosing P**

What value should be chosen for P^* (and P^{**} or P^{***})? Risk tolerance is at least in part a policy issue, so no definitive answer can be given here. However, the decision could be informed by examining costs and benefits over a range of P^* values.

We note that setting ABC $\leq$ OFL is only one step of a multistep process. A council is then charged with setting annual catch limits and possibly annual catch targets such that ACL $\leq$ ABC and ACT $\leq$ ACL. Because accountability measures (e.g., future catch reductions) are invoked when the actual catch exceeds the ACL, councils may want to set the ACT low enough to avoid that condition. When this system applies several buffers to prevent overfishing (i.e., applies the strict inequalities ABC $<$ OFL and ACT $<$ ABC), it seems reasonable to set P^* higher than if the system had only one buffer, perhaps in the range $0.25 \leq P^* < 0.5$.

Several science and statistical committees (SSCs, the scientific advisers for U.S. Fishery Management Councils), have already deliberated over use of P^* methodology. The Western Pacific SSC considered P^* in the range of 0.0–0.5 for some stocks such as Hawaiian deepwater demersal fishes. The New England SSC considered the range 0.2–0.3 for the scallop fishery and adopted 0.25. The Gulf of Mexico, South Atlantic, and Mid-Atlantic SSCs apply (or are considering) tiered approaches to choose a value of P^* for each stock, with ranges of 0.15–0.45, 0.1–0.5, and 0.0–0.5, respectively. The Pacific SSC also uses tiers for groundfish, with P^* of 0.4 or 0.45, yet with buffers expanded by inflating scientific uncertainty for stocks not categorized as data rich. The North Pacific SSC is considering such variance inflation for crab stocks.

Integrated or Sequential Method?

While we have described both Integrated and Sequential PASCL for completeness, it seems likely that handling the uncertainties sequentially will result in more protection, and thus less catch, than might have been envisioned because of the fundamental nonadditivity of sequential probability events. That conclusion is supported by a study by Semmens (2008), who writes that

> [i]mportantly, the results suggest that all sources of uncertainty and variability should be assessed together to determine the appropriate buffer, a contrast to the currently suggested separation of biological and management steps where the SSC handles the biological uncertainty buffer and councils handle the management uncertainty buffer.

For that reason, when setting ACT, methods such as Integrated PASCL, which consider all forms of variability together, may be preferable to methods that consider them sequentially. We also note that by setting P^{***}, Integrated PASCL directly controls the probability of overfishing, an important consideration.

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References

Caddy, J. F., and R. Mahon. 1995. Reference points for fisheries management. FAO (Food and Agricultural Organization of the United Nations) Fisheries Technical Paper 347.

Caddy, J. F., and R. McGarvey. 1996. Targets or limits for management of fisheries? North American Journal of Fisheries Management 16:479–487.

Fulton, E. A., A. D. M. Smith, D. C. Smith, and I. E. van Putten. In press. Human behavior: the key source of uncertainty in fisheries management. Fish and Fisheries DOI: 10.1111/j. 1467–2979.2010.00371.x.

Magnuson–Stevens Fishery Conservation and Management Reauthorization Act of 2006. 2007. U.S. Statutes at Large 120: 3575, 3586–94.

PFMC (Pacific Fishery Management Council). 2008. Pacific Coast groundfish fishery management plan for California, Oregon, and Washington groundfish fishery as amended through Amendment 19. PFMC, Portland, Oregon. Available: pcouncil.org/groundfish/fishery-management-plan/. (September 2010).

Prager, M. H., C. E. Porch, K. W. Shertzer, and J. F. Caddy. 2003. Targets and limits for management of fisheries: a simple probability-based approach. North American Journal of Fisheries Management 23:349–361.

Prager, M. H., and K. W. Shertzer. 2010. Deriving acceptable biological catch from the overfishing limit: implications for assessment models. North American Journal of Fisheries Management 30:289–294.

RDCT (R Development Core Team). 2009. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. Available: R-project.org. (September 2010).

Rice, J. C., and L. J. Richards. 1996. A framework for reducing implementation uncertainty in fisheries management. North American Journal of Fisheries Management 16:488–494.

Rosenberg, A. A., and S. Brault. 1993. Choosing a management strategy for stock rebuilding when control is uncertain. Pages 243–249 *in* S. J. Smith, J. J. Hunt, and D. Rivard, editors. Risk evaluation and biological reference points for fisheries management. Canadian Special Publication of Fisheries and Aquatic Sciences 120.

SEDAR (Southeast Data Assessment and Review). 2008. SEDAR 17 document for peer review: South Atlantic vermilion snapper. South Atlantic Fishery Management Council, Charleston, South Carolina.

Semmens, K. A. 2008. Buffering uncertainty: setting annual catch limits under the Magnuson–Stevens Fishery Conservation and Management Reauthorization Act of 2006. Master's thesis. University of Delaware, Newark.

Shertzer, K. W., M. H. Prager, and E. H. Williams. 2008. A probability-based approach to setting annual catch levels. U.S. National Marine Fisheries Service Fishery Bulletin 106:225–232.

USOFR (U.S. Office of the Federal Register). 2009. Magnuson–Stevens Fishery Conservation and Management Reauthorization Act of 2006 Provisions: National Standard 1—Optimum Yield. Code of Federal Regulations, Title 50, Part 600.310. U.S. Government Printing Office, Washington, D.C. Available: ecfr.gpoaccess.gov/. (September 2010).