

SSC Terms of Reference for Groundfish Rebuilding Analyses, DRAFT #3

Introduction

Amendment 11 to the Groundfish Fishery Management Plan (FMP) established a harvest control rule for determining optimum yields (OY). The 40:10 policy was designed to prevent stocks from falling into an overfished condition. Part of the amendment established a default overfished threshold equal to 25% of the unexploited population size¹ (B_0). By definition, groundfish stocks falling below that level are overfished ($B_F = 0.25 \times B_0$). To prevent stocks from deteriorating to that point, the policy also specifies a precautionary threshold equivalent to 40% of B_0 . At stock sizes less than $B_{40\%}$ the policy requires that OY, when expressed as a fraction of the allowable biological catch (ABC), be progressively reduced. Because of this linkage, $B_{40\%}$ has sometimes been interpreted to be a proxy measure of B_{MSY} , i.e., the stock biomass that results when a stock is fished at F_{MSY} . In fact, theoretical results support the view that a robust biomass-based harvesting strategy would be to simply maintain stock size at about 40% of the unfished level (Clark 1991, In review). In the absence of a credible estimate of B_{MSY} , which can be very difficult to estimate (MacCall and Ralston, In review), $B_{40\%}$ is a suitable proxy to use as a rebuilding target.

There are a number of ways that one could proceed in modeling stock rebuilding, but they fundamentally reduce to two basic kinds of approaches. These are: (1) an empirical evaluation of spawner-recruit estimates and (2) fitting spawner-recruit estimates to a theoretical model of stock productivity (e.g., the Beverton-Holt or Ricker curves). To date, however, rebuilding plans have largely been based on analyses of the former type (e.g., bocaccio, lingcod, POP#1, canary rockfish). Similarly, the cowcod rebuilding analysis involved an empirical evaluation of annual estimates of surplus production. Thus far, the only rebuilding analysis that has been based on the fit of spawner-recruit data to a theoretical model is the analysis presented in the last stock assessment of Pacific ocean perch (POP#2; Ianelli *et al.* 2000).

Estimation of B_0

¹ The absolute abundance of the mature portion of a stock is loosely referred to here in a variety of ways, including: population size, stock biomass, stock size, spawning stock size, spawning biomass, spawning output; i.e., the language used in this document is sometimes inconsistent and/or imprecise. However, the best fundamental measure of population abundance to use in establishing a relationship with recruitment is spawning output, defined as the total annual output of eggs (or larvae in the case of live-bearing species). Although spawning biomass is often used as a surrogate measure of spawning output, for a variety of reasons a non-linear relationship often exists between these two quantities (Rothschild and Fogarty 1989; Marshall *et al.* 1998). Spawning output should, therefore, be used to measure the size of the mature stock when possible.

For the purpose of estimating B_0 empirically, analysts have selected a sequence of years, wherein recruitment is believed to be reasonably representative of the natality from an unfished stock. These recruitments, in association with growth, maturity, fecundity, and natural mortality estimates, can then be used to calculate unfished spawning output. In selecting the appropriate temporal sequence of recruitments to use, investigators have generally utilized years in which stock size was relatively large, in recognition of the paradigm that groundfish recruitment is positively related to spawning stock size (Myers and Barrowman 1996). Moreover, due to the temporal history of exploitation in the west coast groundfish fishery (see Williams, In review), this has typically led to a consideration of the early years from an assessment model time series². Thus, for example, in the case of bocaccio the time period within which recruitments were selected was 1970-79 and for canary rockfish it was 1967-77.

An alternative view of the recruitment process is that it depends to a much greater degree on the environment than on adult stock size. For example, the decadal-scale regime shift that occurred in 1977 (Trenberth and Hurrell 1994) is known to have strongly affected ecosystem productivity and function in both the California Current and the northeast Pacific Ocean (Roemmich and McGowan 1995; MacCall 1996; Francis *et al.* 1998; Hare *et al.* 1999). With the warming that ensued, west coast rockfish recruitment was probably affected adversely (Ainley *et al.* 1993; Ralston and Howard 1995). Thus, if recruitment was environmentally forced, it would be more sensible to use the full time series of recruitments from the stock assessment model to estimate B_0 . Given that these two explanatory factors are highly confounded, i.e., generally high biomass/favorable conditions prior to 1980 and low biomass/unfavorable conditions thereafter, using all recruitments to estimate B_0 will usually result in a lower reference point than the situation where an abbreviated series taken from early in the time series is utilized.

At this time there is no incontrovertible information with which to distinguish between these two alternatives. If oceanic conditions along the west coast have shifted to a productive cold regime following the La Niña event of 1999, we may soon have observations of recruitment produced during a favorable environmental period from groundfish stocks at low spawning biomass. If the environmental and density-dependent effects are additive, it would then be possible to determine the relative importance of each of the two factors (e.g., Jacobson and MacCall 1995). In the interim, however, it would be prudent to favor calculations of B_0 that are based on an abbreviated time series of recruitments taken from a period when the stock was at a relatively high biomass and to favor the density-dependent hypothesis. Both theoretical and observational considerations support the belief that groundfish recruitment will decline as stock size dwindles (e.g., Myers and Barrowman 1996; Brodziak *et al.* 2001). Still, it would be informative to contrast the density-dependent based reference point with an estimate of B_0 based on the entire time series of recruitments (i.e., the environmental hypothesis). This was, in fact, discussed as a possible alternative in the Panel Report produced by the West Coast Groundfish Harvest Rate Policy Workshop sponsored by the SSC in March, 2000. With both numbers available it would be possible to evaluate the implication of each hypothesis on the calculation of stock reference points. As a refinement, for each of these two methods the actual distribution of B_0 can be approximated by re-sampling recruitments, from which the probability of observing any particular stock biomass can be examined under each hypothesis. This approach was taken in the original bocaccio rebuilding analysis, where it was concluded that the first year biomass was unlikely to have occurred if the entire sequence of recruitments were used to determine B_0 .

² Individual recruitments estimated from age-structured stock assessment models do not all exhibit the same precision or accuracy. Recruitments estimated at the very beginning of the modeled time period may suffer from mis-specification of the initial condition of the population (e.g., an assumed equilibrium age structure). Likewise, recruitments estimated at the end of the sequence may be imprecise due to partial recruitment of recent year-classes. Thus it may be advisable to trim the beginning and/or ending years classes to address this problem.

It is also possible to estimate B_0 by fitting spawner-recruit models to the full time series of spawner-recruit data (see Ianelli *et al.* 2000; Ianelli, In review). However, this approach is subject to the criticism that stock productivity is constrained to behave in a pre-specified manner according to the particular model chosen and there are different models to choose from, including the Beverton-Holt and Ricker. These two models can produce strongly contrasting management reference points (e.g., B_{msy} and SPR_{msy}) but are seldom distinguishable statistically. Moreover, there are statistical reasons to be suspect of resulting parameter estimates, including time series bias (Walters 1985), the “errors in variables” problem (Walters and Ludwig 1981), and non-homogeneous variance and small sample bias (MacCall and Ralston, In review). Consequently, analyses that derive stock management reference points by estimating a spawner-recruitment relationship shoulder a greater burden of proof. Thus, any such an analysis should attempt a balanced comparison of alternative spawner-recruit models, with explicit consideration of the estimation problems highlighted above. Moreover, in situations where a spawner-recruit meta-analysis is available (e.g., Dorn, In review), those results should be evaluated and considered. Ideally, reference points obtained by fitting a spawner-recruitment model (e.g., B_0 , B_{MSY} , and F_{MSY}) should also be compared with values obtained by empirical analysis of the data, similar to that suggested above. Such a comparison would help delineate the overall degree of uncertainty in these quantities.

Population Projections During Rebuilding

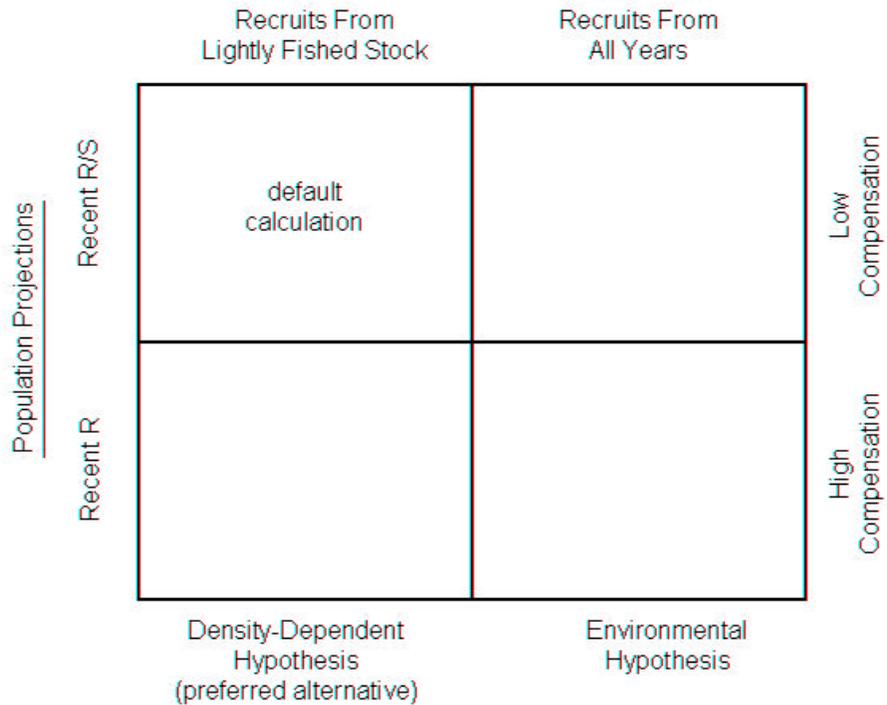
Given the population initial conditions from the last stock assessment (numbers at age vector) and the rebuilding target ($B_{40\%}$), one can project the population forward once renewal has been specified. For most rebuilding calculations that have been conducted thus far, two different approaches have been taken, both of which utilize contemporary recruitment estimates at the tail end of the time series (i.e., the most recent figures). For bocaccio, canary rockfish, and POP#1, recent recruitment was standardized to the size of the adult population (recruits per spawner = R/S_i), which was then randomly resampled to determine annual reproductive success. Annual R/S_i is then multiplied by S_i to obtain year-specific stochastic estimates of R_i . The population is then projected forward in time, with no fishing mortality, until S_i hits the rebuilding target. The process is repeated many times, until a distribution of the times to rebuild in the absence of fishing is obtained. Note that use of R/S_i as the basis for projecting the population forward ties recruitment values in a directly proportional manner to stock size; if stock size doubles, resulting recruitment will double, all other things being equal. As the stock rebuilds this becomes an increasingly untenable assumption because there is no reduction in reproductive success at very high stock sizes, which is to say there is no compensation (i.e., steepness = 0.20)³.

Another way of projecting the population forward is to use recent recruitments, rather than recruits per spawner, as was done in the lingcod analysis. This approach, however, errs in the opposite direction. Namely, recruitment does not increase as stock size increases, as would be expected of most rebuilding stocks. This type of calculation effectively implies perfect compensation (spawner-recruit steepness = 1.00). Thus, these two ways of projecting the population forward, by using re-sampled R_i or re-sampled R/S_i , includes a range of alternatives that is likely to encompass the real world.

Because stocks that have declined into an overfished condition are most likely to be unproductive (i.e., low spawner-recruit steepness), in the absence of any other information, rebuilding projections based on re-sampling recruits-per-spawner are generally to be favored over projections based on absolute recruitment. Note that the implied lack of compensation in rebuilding projections using this method is not likely to be a serious liability over the long term because it is based on re-sampling contemporary recruits-per spawner. As progress toward rebuilding is evaluated in the future, the set of R/S_i will be revised based on a new set of recent recruitments obtained from the latest stock assessment.

³The “steepness” of a spawner-recruit curve is related to the slope at the origin and is a measure of a stock’s productive capacity. It typically is expressed as the proportion of virgin recruitment that remains when a stock has been reduced to $B_{20\%}$.

Calculation of B_0 Reference Point



If the stock actually demonstrates a compensatory response during the course of rebuilding the R/S_i series will tend to a lower mean value. Although projections based on R/S_i represent a standard default way of proceeding, projections that use absolute recruitments (R_i) would be quite useful in establishing the overall uncertainty in the rebuilding analysis by providing an alternative model specification scenario. Moreover, a credible argument that a stock is relatively productive, as evidenced perhaps by observed high recruitment at low spawning biomass, may serve as a basis for favoring projections that utilize recent absolute recruitments (see figure).

Once the median time to rebuild in the absence of fishing is determined (T_0), whether using the R/S_i or the R_i , the total allowable rebuilding time frame is fixed (T_{max}). Namely, if T_0 is less than 10 years then $T_{max} = 10$ years. On the other hand, if $T_0 \geq 10$ years then $T_{max} = T_0 +$ one mean generation time. Mean generation time has been calculated as the mean age of the net maternity function.

Harvest During Rebuilding

Of course it will be the Council's prerogative to establish yields during the rebuilding period, as long as the stock recovers to the target ($B_{40\%} \approx B_{msy}$) within the specified time period (T_{max}). Nonetheless, the simplest rebuilding harvest policy to simulate and implement is a constant harvest rate or fixed F policy. All rebuilding analyses should, therefore, calculate the maximum fixed fishing mortality rate during the rebuilding time period that will achieve the target biomass, with a 0.50 probability of success ($F_{0.50}$). In addition, calculations representing a profile of different fixed F values that are incrementally less than $F_{0.50}$ (e.g., $F_{0.60}$, $F_{0.70}$, and $F_{0.80}$) are needed for the Council to implement a precautionary reduction in the $F_{0.50}$ value to increase the probability of rebuilding success. Note that selecting a probability greater than 0.50 for successful rebuilding within T_{max} is equivalent to electing to rebuild sooner than T_{max} with probability equal to 0.50. In addition, based on its interpretation of

Amendment 12 to the groundfish FMP, the National Marine Fisheries Service requires the expected time course of yield during recovery as a formal part of all rebuilding calculations.

Many other harvest policies could be implemented by the Council, based on whatever circumstances may mitigate against a constant harvest rate approach. For example, the canary rockfish rebuilding plan calls for a constant fixed yield over the entire period of rebuilding. Thus, as the stock rebuilds, the exploitation rate must decline, which makes bycatch avoidance a serious concern. For this reason the SSC recommends that the Council generally favor constant harvest rate policies over constant catch policies for all groundfish rebuilding plans. This would alleviate the problem of accelerating bycatch producing accelerated discard, an undesirable attribute of constant catch policies. Similarly, the Council may wish to implement some other form of variable rate harvest policy, e.g., a 40:10 adjustment similar to the default policy currently in use. Consequently, researchers conducting rebuilding analyses should be prepared to respond to requests by the Council for stock-specific projections on an individual case-by-case basis.

Documentation

It is important for analysts to document their work so that any rebuilding analysis can be repeated by an independent investigator at some point in the future. Therefore, all stock assessments and rebuilding analyses should include tables containing specific data elements that are needed to adequately document the analysis. Namely, information is needed on: (1) the time course of population spawning output and recruitment, (2) biological data on life history characteristics, and (3) initial values for projecting the stock into the future under exploitation. Therefore, two tables should include:

Table 1. Stock Population Trajectory

1. Year
2. Summary/Exploitable Biomass
3. Spawning Output
4. Recruits
5. Catch
6. Landings
7. Total Exploitation Rate

Table 2. Age-specific Population Characteristics.

1. Age
2. Natural mortality rate (μ and μ_{∞})
3. Individual weight (W and W_{∞})
4. Maturity (μ only)
5. Fecundity (μ only)
6. Terminal year (or other) composite selectivity (μ and μ_{∞})
7. Population numbers in terminal year (μ and μ_{∞})

In addition, all linkages with the most recent stock assessment document should be clearly delineated. This is important because assessments often present multiple scenarios that usually have important implications with respect to stock rebuilding. One scenario may be preferred by the assessment authors, while another may be preferred by the STAR Panel. Clear specification of the exact assessment scenario used as the basis for rebuilding analysis is essential. Further, all post-assessment analyses needed to produce the inputs for rebuilding analyses must be fully documented, e.g., the choice of selectivity estimates used for projections that are based on some composite of historical selectivities from the assessment.

Literature Cited

- Ainley, D. G., R. H. Parrish, W. H. Lenarz, and W. J. Sydeman. 1993. Oceanic factors influencing distribution of young rockfish (*Sebastes*) in central California: a predator's perspective. CalCOFI Rept. 34:133-139.
- Brodziak, J. K. T., W. J. Overholtz, and P. J. Rago. 2001. Does spawning stock affect recruitment of New England groundfish? Can. J. Fish. Aquat. Sci. 58:306-318.
- Clark, W. G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci. 48:734-750.
- Clark, W. G. In review. $F_{35\%}$ revisited ten year later. North American Journal of Fisheries Management.
- Dorn, M. In review. Advice on west coast harvest rates from Bayesian meta-analysis of stock-recruit relationships. North American Journal of Fisheries Management.
- Francis, R. C., S. R. Hare, A. B. Hollowed, and W. S. Wooster. 1998. Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific. Fish. Oceanogr. 7(1):1-21.
- Hare, S. R., N. J. Mantua, and R. C. Francis. 1999. Inverse production regimes: Alaska and west coast salmon. Fisheries 24(1):6-14.
- Ianelli, J. N., M. Wilkins, and S. Harley. 2000. Status and future prospects for the Pacific Ocean perch resource in waters off Washington and Oregon as assessed in 2000. In: Appendix to the Status of the Pacific Coast Groundfish Fishery Through 2000 and Recommended Acceptable Biological Catches for 2001 – Stock Assessment and Fishery Evaluation. Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, Oregon, 97201.
- Ianelli, J. N. In review. Simulation analyses testing the robustness of harvest rate determinations from west-coast Pacific ocean perch stock assessment data. North American Journal of Fisheries Management.
- Jacobson, L. D., and A. D. MacCall. 1995. Stock-recruitment models for Pacific sardine (*Sardinops sagax*). Can. J. Fish. Aquat. Sci. 52:566-577.
- MacCall, A. D. 1996. Patterns of low-frequency variability in fish populations of the California Current. CalCOFI Rept. 37:100-110.
- MacCall, A. D., and S. Ralston. In review. Erratic performance of logarithmic transformation in estimation of stock-recruitment relationships. North American Journal of Fisheries Management.
- Marshall, C. T., O. S. Kjesbu, N. A. Yaragina, P. Solemdal, and Ø. Ulltang. 1998. Is spawner biomass a sensitive measure of the reproductive and recruitment potential of northeast arctic cod? Can. J. Fish. Aquat. Sci. 55:1766-1783.
- Myers, R. A., and N. J. Barrowman. 1996. Is fish recruitment related to spawner abundance? Fish. Bull., U. S. 94:707-724.
- Roemmich, D., and J. McGowan. 1995. Climatic warming and the decline of zooplankton in the California Current. Science 267:1324-1326.
- Rothschild, B. J., and M. J. Fogarty. 1989. Spawning stock biomass as a source of error in stock-recruitment relationships. J. Cons. Int. Explor. Mer. 45:131-135.
- Trenberth, K. E., and J. W. Hurrell. 1994. Decadal atmosphere-ocean variations in the Pacific. Clim. Dyn. 9:303-319.

Walters, C. J. 1985. Bias in the estimation of functional relationships from time series data. *Can. J. Fish. Aquat. Sci.* 42:147-149.

Walters, C. J. and D. Ludwig. 1981. Effects of measurement errors on the assessment of stock-recruitment relationships. *Can. J. Fish. Aquat. Sci.* 38:704-710.

Williams, E. H. In review. The effects of unaccounted discards and mis-specified natural mortality on estimates of spawner-per-recruit based harvest policies. *North American Journal of Fisheries Management*.