Agenda Item I.2
Attachment 2
March 2017

Report of the Groundfish Productivity Workshop of the Pacific Fishery Management Council's Scientific and Statistical Committee

NOAA Fisheries, Alaska Fisheries Science Center, Seattle, Washington

December 6-8, 2016

1. OVERVIEW

A workshop on approaches to modeling and measuring stock productivity for stocks managed by the Pacific Fishery Management Council was held at the Alaska Fisheries Science Center during December 6-8, 2016. The workshop focused on issues especially relevant to groundfish, but results may be useful for the assessment and management of CPS and HMS. The following is a list of issues that were addressed at the workshop:

- Comparison of conventional two-parameter stock-recruit relationships (Beverton-Holt and Ricker) with three-parameter curves with additional flexibility, including the development of guidelines for the use of 3-parameter curves in stock assessment.

- Other general approaches to modeling stock-recruit relationships, such as non-parametric approaches, for use in stock assessment.

- Elaboration and further development of priors for B_{MSY}/B_0 and F_{MSY}/M, including consideration whether these priors can be used to improve West Coast stock assessments.

- Review of the specification of B_{MSY} and F_{MSY} reference points, including appropriate proxies when stock-specific estimation is not reliable, taking into account new approaches for modeling stock productivity and the need for consistency between biomass and fishing mortality reference points.

- Consideration of how control rules can be modified to take into account long-term changes in stock productivity, such as basing biomass reference points on a dynamic B_0 calculation.

The intent of the workshop was to focus on practical applications that can improve the assessment and management of West Coast fisheries, and not on more theoretical matters, though some discussion on such matters was unavoidable. Participants at the meeting included invited experts, SSC members, NMFS scientists at the AFSC, the NWFSC, the SWFSC and HQ, scientists from DFO and IATTC, academic researchers from the University of California and the University of Washington, Council staff and other interested parties.

The workshop began with a welcome by the Chair, Dr. Martin Dorn, followed by a round of self-introductions from the workshop participants. After a brief review of the agenda and assignment of reporting duties, the workshop began with some discussion of the background and context for the workshop by Dr. Rick Methot, NOAA Science Advisor for Stock Assessments. Dr. Methot mentioned two national efforts related to the issue of modeling and measuring stock productivity. Work is underway to update the Restrepo et al. (1998) document that laid out guidance for constructing harvest control rules. Second, stock productivity is likely to be one focus for the January 2018 National SSC meeting, which will be hosted by the Pacific Fishery Management Council. In addition, the October 2017 CAPAM workshop will focus on recruitment, and NMFS work on an update to National Standard 1 Technical Guidance will also touch upon these issues. Dr. Methot also charged the group to think more broadly about productivity than just "how hard we can fish" and "impacts on spawning stock biomass per recruit." Issues related to ecosystem based fisheries management and economics should also be considered when relating productivity to reference points and harvest control rules.

The remainder of the report is organized as follows. Author's summaries are provided for each talk, followed by a recap of the panel discussion concerning the talk. In some cases the author summaries include recommendations or scientific opinions on stock assessment or fisheries management. These recommendations should be considered the views of the author, and not necessarily recommendations from the workshop panel as a group. The first two talks were keynote presentations from Dr. Marc Mangel (Univ. of California Santa Cruz) and Dr. Mark Maunder (Inter-American Tropical Tuna Commission), which introduced the issues dealt with at the workshop. A final section of the report summarizes the recommendations of the workshop.

In closing the workshop, the Chair thanked the AFSC for hosting the workshop and the AFSC staff who provided logistical support to the workshop. The Chair thanked all the rapporteurs for their work.

2. AUTHOR'S SUMMARIES AND PANEL DISCUSSION

2.1. Marc Mangel. Density Dependence, the Theory of Harvesting, and the Practice of Stock Assessment: A Perspective on Steepness and Its Implications

Density dependence, which in fisheries is usually understood as a nonlinear relationship between mature individuals (spawners) and the number or biomass of offspring produced (recruitment), is key for sustainable fisheries. I will first briefly review density dependence as it applies to fishery management and then introduce the concept of steepness, which is commonly defined as the fraction of unfished recruitment obtained when biomass is 20% of its unfished level. In order to provide a perspective on steepness, I will then discuss i) the statistical ecology of steepness (in both the 20th and 21st centuries), ii) the evolutionary ecology of steepness, and iii) the reproductive ecology of steepness (illustrated with Bluefin tuna as a test case). I will then turn to the management implications of steepness and show that fixing steepness in the practice of stock assessment can have many unintended consequences, most of which are poorly appreciated. I will show that using three parameter stock-recruit relationships (such as the Shepherd/Maynard Smith) rather than the standard two parameter ones due to Beverton and Holt and Ricker allows us a way forward.

Panel Discussion

The Panel discussed a recently published meta-analysis (Foss-Grant et al. 2016) that classifies stocks with regard to whether their stock-recruit (SR) relationships are Beverton-Holt like (i.e., without a peak to the curve) or Ricker like (with a peak to the curve). It was noted that how to represent stochasticity in SR relationships may be more important that finding a "correct" deterministic form for the SR curve.

The Panel discussed the idea, mentioned by Dr. Mangel, that the concept of "steepness" is very attractive for its simplicity, but the way the concept has been embraced in stock assessment practice was probably misguided. One alternative would be to focus on the ratio of recruits-per-spawning-biomass at the origin of the stock-recruit curve relative to recruits-per-spawning-biomass at the unfished state.

2.2. Mark N. Maunder and Kevin R. Piner. Quest for the Holy Grail: The Stock-Recruitment Curve in Fishery Stock Assessment.

Introduction

The current search for the correct specification of the stock-recruit relationship in fisheries stock assessment models resembles the quest for the Holy Grail as depicted in modern literature. Everyone believes that a relationship between spawners and recruits exists, but no one can find it amongst the noise in the data. What are originally thought to be strong clues to its existence, which are pursued without caution, turn out to be just quirks in the data. Glimpses of the relationship turn out to be just aberrations that disappear as quickly as they appear, as more data are collected or model assumptions are changed. However, the rewards are so high in terms of both academic achievement and management consequences, that we relentlessly continue the search, ignoring everything else. Pieces of evidence, no matter how unreliable, are put together in meta-analyses, propagating the same deception, but with more power. The theory that directs our search is flawed and in reality there is only a weak relationship between recruitment and stock size for most highly fecund species. The stock-recruit relationship is probably not important unless the population gets to such low levels that other factors should have already triggered management action. Therefore, research should focus rather on improving estimates of absolute abundance and natural mortality, and management strategies that are robust to uncertainty in these two quantities.

What is productivity?

One definition of productivity is based on the production curve similar to that represented by the Schaefer or Pella-Tomlinson surplus production models. The shape of the production function is controlled by the biological and fishing processes that are often fixed in the stock assessment model. Determining the stock's current position on the production function (the depletion level) and the absolute scaling of the production function are the goals of stock assessment. The shape of the production function is determined by combing the yield per recruit curve and the stock-recruit relationship. The yield per recruit curve is a tradeoff between natural mortality and growth as mediated through the selectivity of the fishery and fishing mortality. The relationship between spawners and recruits is usually assumed.

What influences productivity?

The shape of the productivity curve can be characterized by the biomass corresponding to maximum sustainable yield as a ratio of the unexploited biomass (B_{MSY}/B_0). When there is no relationship between recruitment and stock size, B_{MSY}/B_0 appears to be most sensitive to the value of natural mortality, otherwise B_{MSY}/B_0 appears to be most sensitive to the stock-recruit relationship (e.g., the steepness of the Beverton-Holt stock-recruit relationship, Maunder 2003; Maunder 2012). Another important parameter related to productivity is the fishing mortality corresponding to MSY (F_{MSY}). F_{MSY} appears to be most sensitive to the value of natural mortality. F_{MSY} and B_{MSY}/B_0 can also be sensitive to the selectivity of the gear or the allocation of effort among gears (Maunder 2002). Losses in yield can occur from recruitment overfishing, sub-optimal fishery selectivity, sub-optimal fishing mortality, and stock assessment errors. These losses, except assessment errors, appear to be similar and produce 80% of the MSY under reasonable values, but will differ depending on the application.

The specification of steepness of the stock-recruit relationship is particularly influential with harvest control rules (HCR) that use depletion level to adjust the fishing mortality rate. This is because lower steepness increases B_{MSY}/B_0, which is often used as a reference point in the HCR, and increases the estimated depletion level.

Does the stock-recruit relationship make sense?

The stock-recruit relationship is only a model. The commonly used Beverton-Holt and Ricker models are based on simplistic assumptions of constant linear density dependence. They also imply that survival changes quicker as a function of spawning biomass at high biomass levels. In actuality, density dependence is unlikely to be linear, is not continuous at a constant rate, probably occurs at a critical stage/period, and changes in survival due to density dependence should be strongest close to the carrying capacity. Despite this, the general shapes of the Beverton-Holt and Ricker make sense. A three-parameter stock-recruit model based on modelling survival allows more flexibility (Taylor et al. 2013).

Empirical data suggest that a hockey-stick stock-recruit relationship may be more appropriate. However, this type of relationship implies that survival reduces quickly at low biomass levels. One explanation is that the carrying capacity for eggs is substantially less than the eggs produced by adults at their carrying capacity.

Recruitment may be controlled by the temporal and spatial distribution of spawning rather than a simple stock-recruit relationship (Maunder and Deriso 2013). The expansion of the spawning stock at high biomass levels outside the suitable spawning habitat may also explain the hockey-stick type stock-recruit relationship. In any case, it is difficult to intuitively understand what causes density dependence in the open ocean and more ecological research is needed to understand this.

Is there a stock-recruit relationship?

Stock-recruit data for many if not most species does not show a strong relationship between spawning stock size and recruitment. Typically, increases in abundance are followed by increases in recruitment as the recruits grow and enter the adult component of the population. When a stock-recruit relationship is apparent, it is often a consequence of quirks in the data such as regime shifts or the result of misspecification of the stock assessment model.

Can we estimate the stock-recruit relationship?

Given the tenuous relationship between spawners and recruits, it is not surprising that estimation of the spawner-recruit relationship is considered difficult. Several simulation studies have shown natural mortality may be more reliably estimated than the stock-recruit relationship inside the stock assessment model (e.g., Lee et al. 2011, 2012). In many cases the estimate of steepness from integrated models based on an asymptotic stock-recruit relationship pins at the upper bound of 1, particularly if there is little contrast in the time series. The ability to estimate steepness is specific to each application and generally needs the stock to be depleted to low levels.

Do we need to worry about the stock-recruit relationship?

The stock-recruit relationship is important in determining B_{MSY}/B_0 and other management quantities. It is also important in determining the current depletion level of the stock. Proxy reference points based on spawner-per-recruit imply a specific value for steepness. Therefore, the stock-recruit relationship is an important, if not the most important, assumption in a stock assessment model. However, due to the flatness of the yield curve when there is no relationship between recruitment and stock size, assuming a lower level of steepness is likely to result in a lower loss of yield than assuming too high of a value (Zhu et al. 2012). If loss in recruitment is an important management concern, limit reference points based on loss in recruitment might be worth considering (Maunder and Deriso 2014).

Author's Recommendations

Due to the lack of fundamental understanding and good empirical data about the stock-recruit relationship for most, if not all, species, it is difficult to make any solid recommendations except that more research is desperately needed. Therefore, the first and most important recommendation is that more research be conducted and presented at the Center for the Advancement of Population Assessment Methodology (CAPAM) workshop on Recruitment: theory, estimation, and application in fishery stock assessment models, Miami, FL, USA, October 30th-November 3rd, 2017 (http://www.capamresearch.org/workshops). Next we make some tentative recommendations that should be updated based future research.

- When estimating the dynamics in data rich situations, specify the assessment model using settings that minimize the impact of spawner-recruit assumptions. In these situations the assumption that steepness is 1 may be appropriate.
- Focus on estimating natural mortality and absolute abundance.
- Don't let (length) composition data drive abundance estimates.
- Change selectivity to improve yields, but take into consideration discard mortality.
- Fish at levels less than those that would maximize yield per recruit (F_{MAX}), but consider short term losses that may occur if the fishing mortality needs to be reduced and biomass levels rebuilt.

- Focus on non-MSY management goals (e.g., catch rates, fish size, and economics).
- Use effort or fishing mortality based management to reduce biases due to calculating catch quotas from biomass estimates using inadequate stock assessments.

Panel Discussion

The Panel discussed a recent meta-analysis by Thorson et al. (2016) that did not show strong linkage for demersal species between productivity and range, as one might expect from the perspective of MacCall's density-dependent "basin model." However, studies by Gibson (1994) have indicated such a linkage for flatfish during specific life stages in the North Sea.

The Panel discussed Dr. Maunder's idea of a carrying capacity for the eggs/larvae that is separate from the carrying capacity of the spawning population. This early carrying capacity, e.g., life history bottleneck, could be the mechanism that sets average recruitment strength and then the sources that cause recruitment variability operate. Pacific salmon might be an example of this phenomenon.

An eel example was discussed where the adults occur in a special kind of limiting substrate in which they inhabit burrows. The Panel notes that remarkably little scientific progress has been made in determining when density dependence occurs during the life cycle. Researchers studying recruitment processes have tended to focus on interannual variability not density dependence. It might be possible to explore the issue of when density dependence occurs in the life cycle using a generalized stage-structured model that included the potential for changes in the basic functional form of density dependence.

The Panel discussed an odd situation in our harvest control rules in that the fishing mortality limit is tied so strongly to achieving MSY and target biomass levels that we tend to ignore other relevant quantities for a trade-off analysis. There are other metrics that might be worth considering across a range of fishing mortality rates, such as average body size of fish, CPUE, effort needed, or other metrics that are easily calculated along with spawning biomass per recruit. In response to the question "Why do we need to estimate spawner-recruit relationships?" it was noted that the Councils are required by law to estimate the status of stock biomass and identify stocks in need of rebuilding.

2.3. Martin Dorn. Design Considerations for a System of Stock Assessment and Reference Point Estimation for Use by the PFMC.

I review how the stock recruit relationship has been modeled in US West Coast groundfish stock assessments. The development of the fishing mortality and biomass reference points used in PFMC harvest control rules is also reviewed. Most full assessments of groundfish use the Stock Synthesis model with the Beverton-Holt stock-recruit relationship parameterized by steepness and unfished recruitment (R_0). In each assessment cycle, the SSC provides advice on a steepness prior based on a meta-analysis of likelihood profiles from previous rockfish assessments. This procedure was developed around 2005 because [at that time] the treatment of steepness was inconsistent among assessments, with some assessments attempting to estimate steepness without considering whether the data were sufficient to estimate steepness, and other assessments fixing steepness at a variety of values. The SSC recommendations on a prior for steepness have been helpful to ensure that assessments use a consistent approach for this important parameter that is based on a synthesis of available information.

One unexpected outcome of this procedure is that since 2007 the mean estimates of steepness have increased for rockfish (from 0.58 in 2007, to 0.77 in 2013 and 2015). There are several potential reasons for this increase, including changes in assessment practices, and a period of more favorable recruitment for rockfish beginning in 2000. A number of concerns have been raised about the reliability of the meta-analysis, including a concern that autocorrelation in recruitment within stocks causes bias in steepness estimates, the potential for correlation in recruitment across rockfish stocks due to similar environmental forcing, and potential biases in the estimation of steepness and the steepness profile.

F_{MSY} reference points used by the PFMC for groundfish are based on spawning biomass-per-recruit proxies: $F_{30\%}$ for flatfish, $F_{40\%}$ for whiting, $F_{50\%}$ for rockfish, $F_{50\%}$ for elasmobranchs, and $F_{45\%}$ for all other species. These differing harvest rates are intended to reflect the differing productivities of these taxa. The $F_{50\%}$ harvest for rockfish was based on Dorn (2002), a meta-analysis that considered all stocks of *Sebastes* (West Coast, North Pacific, and Atlantic), and integrated over the Beverton-Holt and Ricker stock recruit relationships. The spawning stock at 40% of unfished biomass, $B_{40\%}$, is used as a proxy for B_{MSY}, an approach that is based partly on National Standard One guidelines published by NMFS, and partly on advice by Clark (2002), who noted that maintaining the stock at $B_{40\%}$ tended to produce a large fraction of potential yield across a variety of assumptions. An exception is for flatfish, where $B_{25\%}$ is considered the B_{MSY} proxy due to their higher productivity.

Based on current scientific understanding, the current system of reference points should work reasonably well to attain a large percentage of potential yields while preventing stocks from becoming overfished. One potential problem is that the apparent increase in rockfish steepness suggests that the $F_{50\%}$ harvest rate can no longer be considered a risk neutral proxy for F_{MSY}, as was originally intended. This could result in a potential loss of long-term yield of about 20%. However, these conclusions depend on accepting the Beverton-Holt curve as appropriate way to model the stock recruit relationship, and this approach was questioned in other talks at this workshop.

Panel discussion

The patterns documented in Dr. Dorn's talk have contributed to concerns regarding the application of the steepness prior, particularly with respect to whether assessments may be perceived to be "misleadingly" informative about stock recruitment parameters, and the extent to which recruitment estimates can absorb other types of un-modeled process error. It was noted that West Coast assessments neither assume nor estimate autocorrelation in stock-recruit relationship, although it is likely present (as discussed in the presentation by Dr. Thorson later that day). Other concerns related to current practices included the observation that rockfish (and perhaps other) stocks appear to be responding in similar ways to environmental forcing (among-species correlation problem), and concerns that a steepness of one is unrealistic. However, it was also noted that a steepness of 0.77 is not atypical for marine fish populations, and that family level steepness estimates from earlier meta-analyses (e.g., Myers et al. 1999) ranged primarily from 0.75 to 0.95.

There have been discussions regarding the perceived desirability of having fishing mortality and biomass reference points be consistent, as should assessment productivity assumptions and fishing mortality rate reference points. This consistency is not present with contemporary practices as an SPR of 50% of the unfished spawning potential is associated with a steepness value of ~0.60, while the mean of the most recent prior is closer to 0.77 (which would be associated with an SPR closer to ~30%). Specific examples were discussed, some of which suggested some concerns regarding foregone yield, although it was also noted that the system is performing reasonably with respect to achieving a large fraction (e.g., over 80%) of potential yields, and flatfish reference points and productivity assumptions are consistent.

Alternative approaches, such as considering B_{MSY} to B_0 ratios by taxonomic groupings (0.4 did pretty well for everything but *Clupeiformes* in Thorson et al. (2012)), or F_{MSY}/M ratios (consistent with DB-SRA). There was discussion (a "strawman proposal") about whether we know more (or less) about steepness or M, and there is some appeal to having F_{MSY}/M based reference points (converted to F_{SPR}), potentially based on meta-analyses that could be conducted by taxon (e.g., rockfish, flatfish, roundfish and elasmobranchs, e.g., Zhou et al. (2012)).

There was also some discussion of the reluctance towards moving to a three-parameter spawner recruit relationship, particularly given the difficulty in confidently parameterizing two-parameter curves. Conversely, it was suggested that the widespread use and application of steepness could be "too convenient," and there could also be merit in exploring non-parametric frameworks for these analyses. A perceived need to be able to specify priors for any of the parameters used in an S-R curve was also mentioned, and the trade-offs in model stability versus the exploration of a broader range of plausible values throughout productivity relationships were discussed.

2.4. E.J. Dick and Nick Grunloh. Bias in Estimation of Biological Reference Points when Three-Parameter Stock-Recruit Relationships are Considered Appropriate -- An Extension of the Results of Mangel et al. 2013.

Stock assessments often assume a two-parameter functional form (e.g., Beverton-Holt or Ricker) for the expected recruitment produced by a given level of spawning output. Mangel et al. (2013) and others have shown that biological reference points such as F_{MSY}/M, B_{MSY}/B_0, and SPR_{MSY} are largely determined by a single parameter (steepness) when using two-parameter relationships. These functions introduce strong correlations between reference points that are pre-determined by the functional form, rather than a biological characteristic of the stock. Mangel et al. note that use of a three-parameter stock-recruitment relationship allows for independent estimation of these reference points. Our research seeks to understand the nature of biases in reference points resulting from fitting a two-parameter functional form when the true relationship follows a three-parameter stock recruit relationship. These biases arise from mapping a three-dimensional space onto two dimensions. We generated data (abundance indices) using a delay-difference (DD) operating model using a three-parameter (Deriso-Schnute) stock recruit relationship, and fit those data using a two-parameter (Beverton-Holt) relationship. Initial results indicate that biases in F_{MSY}/M and B_{MSY}/B_0 are greater for smaller values of natural mortality. We are currently examining the effects of observation and process error on biases in reference points using only biomass dynamics. We will then expand the DD model to its age-structured equivalent, allowing us to measure biases while relaxing assumptions regarding selectivity, maturity and growth.

Panel discussion

Some of the history for this exploration was based on the 2013 data moderate assessments, in which some preliminary comparisons of productivity functions (comparing exSSS and XDB-SRA, two and three parameter production functions respectively) led to different outcomes with different productivity functions. The STAR Panel report at that time stated that proper interpretation of model comparisons would require standardization of productivity priors.

The analysis focused on an evaluation of potential bias in the estimation of reference points in which data simulated from models with a three-parameter function spawner-recruit relationship was estimated with a two parameter Beverton-Holt function. The approach was to begin with delay-difference model, and eventually extend to age-structured model (not done yet). It was noted that the delay-difference model captures the dynamics of a simple age-structured model (recruitment, mortality, growth, knife-edge maturity), can fit to abundance and average weight data, incorporates observation and process error, and can act as a bridge between two the modeling approaches. The basic analysis used a Schnute-Richards spawner recruit parameterization to generate data in three parameter space, but then fit the model in Beverton-Holt (two parameter space) and evaluate the bias. Considerable bias was observed in grid spaces used to initiate the effort, and these biases seem to decrease (increase) with higher (lower) natural mortality assumptions, although it was also noted that there may be more debugging of the simulation before complete confidence in the results could be made. The model also does not yet include growth, which should be incorporated and improve model performance.

The bias was also greater when B_{MSY}/B_0 was outside of the nominal Beverton Holt SRR boundaries. There was considerable discussion regarding the feasibility of B_{MSY}/B_0 above 0.5 (e.g., 0.6), which led to the greatest biases in the simulation, and the extent to which there is a basis for assuming that SRRs are always constrained. Workshop participants debated whether the burden of proof was to show that Beverton Holt is always right, or that it can be wrong, and discussed the merits of looking beyond the Beverton Holt space. The plausibility of some of the preliminary results was also questioned, as some of the simulated biases had Beverton Holt curves producing F estimates as much as 20 times greater than M, which seemed infeasible. However, the general conclusion, that biases in reference points could be large if actual SRRs deviate from Beverton Holt space, is one that merits additional exploration. Future analyses related to this effort will also include plotting prior predictive distributions in the various spaces explored here (B_{MSY}/B_0, F_{MSY}/M) under a range of three parameter models, as well as simulating and fitting to average weight data and including growth in the model.

2.5. Jim Thorson. Autocorrelation in Recruitment and Its Effect on Estimation of Stock-Recruit Parameters.

Production of biomass for marine fishes arises from individual growth, birth and survival of juveniles, mortality (both natural and human-caused), and movement. Predicting production remains difficult for applied stock assessment, either when forecasting future changes or hindcasting historical trends. For example, birth and survival of juveniles (termed "recruitment") is often predicted using spawning biomass or output, but residuals around predictions may be correlated over time ("autocorrelated"). The potential impact of autocorrelated recruitment on estimating fish productivity is a topic of ongoing research.

In this talk, I first present results of a global estimate of recruitment autocorrelation, obtained using data from the original RAM stock-recruit database (Thorson et al. 2014). This meta-analysis suggests an average autocorrelation of 0.43 (SE=0.28), but some individual populations have extremely high values (>0.75). I therefore conclude that autocorrelated recruitment is likely to be widespread, and its potential impact warrants further study.

Next, I explore the potential impact of autocorrelated recruitment on a meta-analysis of the stock-recruitment relationship used to estimate productivity ("steepness") for West Coast rockfishes. To do so, I assemble a database of five of the 12 stocks used in the West Coast meta-analysis of steepness (I can replicate recent results and estimate autocorrelation for these 5 stocks). For each stock, I fix autocorrelation at the sample-autocorrelation of estimated recruitment deviations during years with abundant data. I then re-run the likelihood profiles for steepness for each of these five stocks when fixing autocorrelation at this value. This exercise shows that likely values of autocorrelation for these five models has little impact on likelihood profiles, and that autocorrelation is therefore unlikely to substantially impact results from the West Coast meta-analysis of steepness.

Finally, I present results for a recent simulation experiment (Johnson et al. 2016) where colleagues and I explored the potential impact of autocorrelated recruitment on forecasts of future population abundance from integrated assessment models (i.e., Stock Synthesis, SS). This experiment first contrasts two methods for estimating autocorrelation in SS, and concludes that the sample-autocorrelation of well-informed estimates of recruitment deviations is a sufficiently accurate estimator for true autocorrelation in the simulation model. We then compare the performance of forecasts of population abundance after the final year of data (termed "population forecasts") when fixing autocorrelation at its sample-autocorrelation estimator with population forecasts when either ignoring autocorrelation or fixing autocorrelation at its true values. This comparison shows that population forecasts using the sample-autocorrelation estimator performs nearly as well as forecasts when fixing autocorrelation at its true value, and substantially better (in decreasing bias and improving forecast interval coverage) than ignoring autocorrelation. This autocorrelation feature has been built into the new SS 3.30 (winter 2017).

Based on results from these three analyses, I conclude the following:

- Autocorrelated recruitment is plausible in a wide variety of marine fishes;

- Available evidence suggests that autocorrelated recruitment likely is not impacting meta-analytic estimates of productivity ("steepness") for West Coast rockfishes;
- Estimating and including autocorrelated recruitment during population forecasts can decrease forecast error and improve forecast-interval coverage using SS models. However, including autocorrelation only substantially impacts population forecasts when sample autocorrelation is substantially different from zero (e.g., $\rho > 0.25$). During future rebuilding analyses, I therefore recommend that analysts estimate sample autocorrelation for well-estimated recruitment deviations (perhaps this could be added to package R4SS). Then, if the sample autocorrelation is >0.25, then this value be used when forecasting abundance in rebuilding plans.

Panel discussion

The suggestion was made to further an analysis like this by conducting a more rigorous simulation study of different types of recruitment variation (random, regime shifts, autocorrelation, and spasmodic recruitment variability) to evaluate potential biases.

Dr. Thorson's results indicated that the internal estimate of autocorrelation tended to be biased, but the external estimate is surprisingly good, almost as good as using the true value. The bottom line was that strong autocorrelation could cause population forecasts to be overconfident, and to miss either substantially faster or slower rebuilding trajectories. The Panel agreed with Dr. Thorson's recommendation to evaluate first order autocorrelation in recruitment, and if these estimates exceed some pre-determined threshold, then forecasts should include the estimated autocorrelation term. In subsequent discussion there were questions regarding negative autocorrelation, which was not evaluated in this study.

2.6. André Punt and Jason Cope. Extending Integrated Stock Assessments Models to Use Non-Depensatory Three-Parameter Stock-Recruit Relationships.

Stock assessments based on the integrated paradigm often include an underlying stock-recruit relationship, which allows B_{MSY} and F_{MSY} to be calculated. However, the estimates of these quantities may differ from those used in the harvest control rules used to provide management advice. Moreover, the values for B_{MSY} and F_{MSY} are related functionally in population dynamics models based on two-parameter stock-recruit relationships such as Beverton-Holt and Ricker. Use of two-parameter stock-recruit relationships hence restricts the ability to fully quantify the uncertainty associated with estimating B_{MSY} and F_{MSY}. In principle, B_{MSY} and F_{MSY} can be set independently if the stock-recruit relationship is more general than the Beverton-Holt and Ricker relationships. This paper outlines eleven potential three-parameter stock-recruit relationships and evaluates them in terms of whether they are able to match a wide range of specifications for B_{MSY} (expressed relative to unfished spawning stock biomass, B_0) and F_{MSY} (expressed relative to natural mortality, M). Of the eleven three-parameter stock-recruit relationships considered, the Ricker-Power stock-recruit relationship is found to best satisfy the characteristics of (a) being able to mimic a wide range of B_{MSY}/B_0 and F_{MSY}/M values, (b) not to lead to negative recruitment for biomasses between 0 and B_0, and (c) not to lead to increasing recruitment in the limit of zero population size. Bayesian assessments of three example species off the US west coast groundfish (petrale sole, Dover sole, and aurora rockfish) are conducted using Simple Stock Synthesis based on the Beverton-Holt and Ricker-Power stock-recruit relationships to illustrate some of the impacts of moving to a three-parameter stock-recruit relationship.

Panel discussion
This research was motivated by a comparison of XDB-SRA and XSSS, which highlights the difference between allowing F_{MSY}/M and B_{MSY}/B_0 to be independent as for DB-SRA, and the dependence that arises from using the Beverton-Holt stock-recruit relationship in XSSS. The goal of this work is to add the ability to specify F_{MSY}/M and B_{MSY}/B_0 independently within Stock Synthesis, which is not possible with 2-parameter forms. Six of the eleven forms explored are depensatory (upward concavity), and therefore have non-unique expected recruitment values for some values of spawning biomass-per-recruit. These were eliminated from further consideration.

When the Ricker Power was compared to Beverton-Holt in XSSS, there were different results in terms of F_{MSY}/M and B_{MSY}/B_0, but similar distributions of OFL values. The original work was done with $F_{50\%}$ rather than F_{MSY} for setting OFL, but similar results were obtained when using calculated F_{MSY}.

The Panel discussed whether achieving generality by completely decoupling F_{MSY}/M and B_{MSY}/B_0 could result in shapes that would not be considered reasonable. For example, the Panel is aware of no assessed West Coast groundfish that has a strongly dome-shaped stock-recruit relationship. There may be a need to constrain the shape of 3-parameter stock-recruit curves to plausible shapes when using them in assessment models. A second issue is that the priors for F_{MSY}/M and B_{MSY}/B_0 are being considered independent since they were obtained from separate meta-analyses. However, there may be correlation between these parameters, which could be either statistical or biological in nature. In that case it would be important to correctly model the correlation structure in the prior.

It was noted that fishing mortality (F) can be difficult to define unambiguously in complex population models with two sexes and different fisheries each with their own selectivity pattern. Therefore, a prior on F_{MSY}/M is conditional on selectivity, or more traditionally on the age of selection in a yield per recruit sense. Natural mortality (M) can also vary by sex and age. There may be some benefit to using an alternative to F_{MSY}/M to serve as a leading parameter in 3-parameter stock recruit relationships, but it was not clear to the Panel which parameter that might be.

2.7. Steve Munch. Meta-Analysis Comparing Parametric and Non-Parametric Stock-Recruit Models

Current assessment methods typically use a stock-recruit (SR) model to help constrain estimates of recruitment and to make projections necessary for multi-year management specifications. Unfortunately, estimates of management reference points may depend heavily on the assumed shape of the SR model. Previously published simulations show that nonparametric approaches based on Gaussian process (GP) regression allow the data to drive the shape of the SR model and provide estimates of references points that are robust to structural uncertainty.

Because nonparametric methods assume no fixed shape, we must be concerned about overfitting. I therefore measure goodness of fit using out-of-sample predictions based on leave-one-out cross validation. Previously published simulations indicate that the GP can recover the shape of any SR model when there is shape information in the data, that it remains vague when such information is lacking, and that it produces reliable estimates of the maximum reproductive rate.

Ransom Myers' SR database collects 330 time series of stock and recruitment from around the world representing 72 species from 26 families. More recently, the RAM Legacy database compiled outputs from many more stock assessments representing more than 230 species. Unfortunately, many of the time series in this database begin with long flat spots, very smooth declines, or perfect SR relationships (i.e. zero residuals). After excising series that were not visibly influenced by real data, 302 time series remain representing 152 species. For simplicity, I will hereafter refer to these collections as RAM1 and RAM2 respectively.

Using the time series in both these databases, I tested whether GP SR models produced different estimates of the maximum reproductive rate than the more commonly used Ricker model and whether the greater flexibility of the GP resulted in reduced prediction errors. The GP- and Ricker-produced estimates of the maximum reproductive rate were nearly identical. The correlation between estimates was 0.982 for RAM1 and 0.996 for RAM2. The added flexibility of the GP reduced the prediction error relative to the Ricker, but only mildly: the mean (s.e.) difference between them was 11% (3%) in RAM1 and 2% (1%) in RAM 2. Since the GP can recover the shape of any SR model, and it does not substantially outperform the Ricker model, I suspect that there is little to be gained from adopting a three-parameter SR model in assessing productivity.

However, we also know that many factors affect recruitment, including temperature, dissolved oxygen, maternal effects, food availability, and predation. Recent developments in Empirical Dynamic Modeling suggest that we might increase our ability to predict recruitment using lags of stock and recruits as surrogate coordinates to account for dynamics driven by these unobserved variables. I extended the GP model to include up to five additional lags of stock and recruits. Unnecessary lags were trimmed out of the model using 'Automatic Relevance Detection,' resulting in fairly sparse models with good out of sample performance.

The inclusion of time lags reduced the forecast error in 90% of stocks in the RAM1 database by an average of 24% (2%). To test whether this approach is merely accounting for autocorrelated errors, I fit weakly regularized AR models using the same lags. The GP explains 32% (2%) more variance on average than the AR model, strongly suggesting that the GP is not merely explaining the 'noise.' For the time series in RAM2 the GP with lags outperformed the SR model for 72% of stocks, though the error reduction was rather more modest: 7% (1%).

This disparity in performance across databases leads one to contemplate its source. Both databases contain results from various assessment methods, including biomass dynamic models, statistical catch at age models (SCA), integrated analysis, virtual population analysis (VPA), and survey estimates of juvenile abundance. However the majority of the RAM1 estimates were derived from VPA while roughly half of the RAM2 time series were generated with integrated analysis and SCA models. This difference in the database composition suggests that there is less temporal structure to explain when recruitment estimates are derived from integrated analysis and SCA models. It is not clear whether this indicates that SCA models do a better job of accounting for recruitment variation or is merely an artifact of SCA models constraining recruitment too tightly. When recruitment estimates were derived from surveys of juveniles, the average error reduction obtained by the GP model with time lags was 25% and 29% for RAM1 and RAM2 respectively.

To summarize, it appears that 1) there is little to be gained from increasing the flexibility of SR models and 2) a substantial fraction of the variation in recruitment can be accounted for using time lags. Although I suspect that these results have some deep implications for the management of fisheries, their most immediate relevance is in developing rebuilding plans, where rebuilding times are currently based on simulations with fixed SR models and i.i.d. errors.

Panel discussion

The Panel noted that this approach is not fully non-parametric in that parametric i.i.d. noise is assumed.

Takens theorem (Takens 1981) was invoked to motivate looking at the time-series structure in the data and considering time-lags in the stock-recruit relationship. This approach looked quite promising in prediction using the RAM database, explaining an extra 24% of the variance overall, but for the RAM legacy database, which is newer, only 7% explained. The approach was tested via a leave-one-out procedure to see how well it can actually predict recruitment. It was suggested that leaving out more points – testing first and second half, for example, would be better. These results can be used to obtain reference points for use in management, then putting results into a dynamic programming algorithm to obtain a harvest control rule (numerically). The Panel notes that this is a statistical time-series method that that does not identify mechanisms. It was not clear how lagged spawning biomass and recruitment would be expected influence current recruitment.

The Panel thought that there would be benefits of using a non-parametric approach in a meta-analysis to derive priors (ideally by taxon) for leading parameters that could then be used in either two-parameter or three-parameter stock-recruit relationships embedded in stock assessment models.

2.8. Xi He and John Field. Effects of recruitment variability and fishing history on estimation of stock-recruit relationships: Three case studies from U.S. West Coast Fisheries

Many studies have shown that recruitment variability is one of several complicating factors that challenge the ability to correctly parameterize stock-recruit (SR) relationships. The Beverton Holt SR relationship is commonly used in the U.S. West Coast groundfish stock assessments. However, the steepness parameter (h) is often not estimated in the assessment models, but rather fixed at the mean of a prior developed from a meta-analysis of previous assessments. One primary reason is that there are often not sufficient data to estimate that parameter, particularly for species with very high recruitment variability (σ_R). In addition, some fish populations have not been fished down to the levels low enough to provide the contrast in spawning output necessary to have the SR function adequately estimated. We conducted a simulation study to evaluate effects of recruitment variability and fishing history on estimation of the SR relationship. Our explicit focus was on the interaction between varying levels of recruitment variability and the precision and bias in the estimation of the steepness parameter for what would be considered fairly "data rich" assessment models. In the study, we used three simulated stock assessment models (Models 1 to 3) that represented three different life histories, ranging from a short lived "flatfish" species (age-plus group = 11 years, Model 1) to a long lived "rockfish" species (age-plus group = 50 years, Model 3). In each model, three fishing histories were also simulated: (1) heavy fishing to have the stock depleted to about 10% of virgin spawning output, followed by stock recovery; (2) light fishing to have the stock depleted about 66%; and (3) median fishing to have the stock depleted about 33%.

We found that in the heavily fished models, as recruitment variability increased, the steepness parameter was estimated to be about 5% to 10% higher than the true values in Model 1, but was appropriately estimated in Models 2 and 3. Stock depletions were reasonably estimated at all levels of recruitment variability for the Models 2 and 3, but the stocks were estimated to be more depleted in the Model 1. With "light" fishing, the steepness estimates were biased considerably higher than the true values in all three models as recruitment variability increased. In some cases, the median values for steepness were estimated to be at the upper bound (1.0), even with relatively low recruitment variability (σ_R = 0.5), and in all cases the fraction of simulations that estimated steepness at the upper bound increased with increased recruitment variability. We also found that recruitment variability has greater effects on estimation of the SR relationship on short-lived species, likely due to a reduced number of recruitment estimates relative to the longer lived species, and that recruitment variability leads to greater bias and imprecision when steepness is high (e.g., ~0.8) than when steepness is low (e.g., ~0.4). We intend to expand on these results by evaluating the consequences of including either a correctly specified or a misspecified prior on steepness, and by evaluating whether we can identify specific data components that contribute to biases within the simulated estimation models.

Panel discussion

This study again highlights the difficulty in extracting any information about the shape of the stock recruit curve (such as steepness) from stock assessments. The Panel recommends that this study be extended to evaluate how using a prior for steepness affects estimation of steepness. It would also be of interest to evaluate whether the marginal or profile likelihood for steepness is biased in addition to the maximum likelihood estimate. This would be relevant to the steepness meta-analysis that has been used to inform West Coast rockfish assessments.

2.9. Aaron M. Berger, Ian G. Taylor, Z. Teresa A'mar, Melissa A. Haltuch. Shifts in stock productivity: on the use of dynamic management metrics

The concept of "Dynamic B_0" was developed 30 years ago by a team of scientists on the US west coast (MacCall *et al*., 1985), but since that time it has not been widely explored in this region. Dynamic B_0 involves projecting fish populations using a time series of recruitment deviations and other parameters estimated in a stock assessment, but with the impact of fishing removed. It can be used as an alternative to the static equilibrium unfished spawning biomass (B_0) as a basis for harvest control rules that takes into account changes in productivity attributed to external factors such as climate or shifting predator-prey interactions. We present dynamic B_0 time series relative to the fished population biomass time series for 18 recent west coast groundfish stock assessments and discuss differences in stock status as calculated from dynamic vs. static B_0. In general, many species do not show strong differences between the two measures. However, a few notable exceptions include sablefish, bocaccio, Pacific hake, and widow rockfish which were all estimated to have experienced above average recruitments in the 1960s or 1970s resulting in a subsequent period of 30 years or longer where the dynamic B_0 was above the static B_0. These results are related to other stock assessment examples where dynamic B_0 trajectories warrant examination. We also highlight results from a management strategy evaluation that compares 40-10 harvest control rules for sablefish using static B_0 and dynamic B_0 based reference points to show how control rule performance can differ depending on the history of population productivity. We conclude by describing some advantages and complexities of using dynamic B_0 time series at the assessment-management interface (e.g., assessment diagnostic, determining future reproductive potential of the stock, or as reference points for adaptive management).

Panel discussion

The Panel agreed with the authors that it will be important to consider the species (e.g., life history) and management context when using dynamic B_0 based reference points. For many groundfish species, the static B_0- and dynamic B_0-based reference points were very similar, suggesting that the history of exploitation is more important than environmental forcing in driving stock dynamics. Nevertheless, identifying the species for which the static B_0- and dynamic B_0-based reference points differed was useful for evaluating harvest policy robustness. The Panel recommends that dynamic B_0-based reference points be included the West Coast stock assessment toolbox since they may be helpful to understand stock dynamics under regime shifts and directional climate change. The need to consider these factors is only likely to grow in the future.

In response to a question, Dr. Maunder said that the status of tropical Pacific tuna stocks is routinely evaluated using dynamic B_0-based reference points. This approach is considered appropriate for tuna stocks because they clearly undergo decadal shifts in productivity.

There may be specific groundfish stocks that benefit from management using dynamic reference points, but the Panel recommends that the approach be studied further using MSE for the specific stock in question before being applied. The ongoing MSE work with sablefish is an example of where such an evaluation should take place. As always with MSE, the objectives of management must be articulated and performance metrics developed before performance of any strategy can be evaluated. As more stocks are affected by changing climate, a policy question must addressed: Should fisheries reference points be adjusted to track changes in productivity due to a changing climate, or should they be considered fixed relative to the conditions immediately prior to exploitation? Greater focus on fishing mortality-based reference points rather than biomass-based reference points may help to focus management attention on aspects of the system that are controllable.

2.10. Josh Nowlis. A Management Strategy Evaluation of Stock-Recruit Proxies.

No author summary was provided.

Panel discussion

Preliminary results were presented from a management strategy evaluation for an age-structured population that is assessed and managed according a 40-10 harvest policy. Results indicated that the economic productivity of the stock was maintained, and that ecological impacts were relatively modest. This result is most likely a result of the robustness of stock assessments and the 40-10 policy. These preliminary results are promising, but validation and additional study is needed. For example, it will be important to compare across life histories. Questions that need to be addressed include how much collecting data from early years prior to exploitation aids performance, and how the results are affected by environmental variability. The Panel also noted that economic performance depends on the perspective: small operations with high discount rates may respond differently than larger operations with lower discount rates.

2.11. Jim Thorson. A Multivariate Life History Analysis of Global Fisheries Data to Generate Priors on Length, Weight, Growth, Mortality, and Maturity Parameters for All 32,000 Marine Fishes.

Scientists and regulators need to know life history parameters (e.g., average mortality rate, individual growth rate, maximum length or mass) to understand and respond to risks to natural populations and ecosystems. For over one hundred years, scientists have identified "life history invariants" (LHI) representing pairs of parameters whose ratio is approximately constant across species. LHI then promise to allow prediction of many parameters from field-measurements of a few important traits. Using LHI in this way, however, neglects any residual patterns in traits when making predictions. We therefore apply a nonparametric, multivariate model for eight traits in all 32,000 marine fishes, and include taxonomic structure for residuals (with levels for class, order, family, genus, and species). We first show that this approach generates precise predictions for taxa with many or few data. We then use this model to explore three questions regarding life-history traits in fishes including: (1) How many traits must be known per species to precisely predict remaining life-history parameters? (2) What is the average relationship between relative growth rate and maximum size? and (3) Is the ratio of natural mortality and relative growth rate a LHI, or does it vary systematically based on timing of maturity? We distribute our predictive model as an R package to allow future life-history predictions to be conditioned on correlated residuals arising from all marine fishes worldwide.

In this talk, I recommend that this R package *FishTraits* could be used to generate plausible values for life-history traits (maturity, mortality, growth, and size) in future data-poor and data-moderate assessment models for West Coast species (and other fisheries-management regions)

Panel discussion

A remarkable result from this study is that perfect information about three traits (temperature, asymptotic weight, and von Bertalanffy K) is sufficient to calculate all other traits. This approach has obvious application in data-poor and data-moderate situations. The Panel would have liked to have seen some examples to demonstrate how this approach would be applied in particular examples, such as for a group of unassessed rockfish species. The Panel was also interested in seeing an evaluation of the method using out-of-sample predictions.

2.12. John Wallace. SPR vs. F_{MSY} in Assessment Models.

Statements made in Mangel et al.'s (2013) production model (MPM) paper were challenged with real data in a Stock Synthesis age structured model. Specifically, Mangel et al. (2013) stated that for the MPM as well as for age structured models: "SPR_{MSY} is independent of the selectivity curve". Figure 1 shows the results of profiling over steepness using a recent Petrale sole model across different selectivity assumptions. There is a clear influence on the SPR curve given selectivity.

After the productivity workshop, additional work was completed to show F_{MSY} vs. steepness (h) for the longspine thornyhead (*Sebastolobus altivelis*; Figure 2c). The MPM result (equation 15) is shown as a black line with circles. Additionally, the MPM equations 15 and 17 were combined to give the following production model results:

$$SPR_{MSY} = \frac{1}{\frac{F_{MSY}}{M} + 1}$$

$$F_{MSY} = M\left(\frac{1}{SPR_{MSY}} - 1\right)$$

$$M = \frac{F_{MSY}}{\left(\frac{1}{SPR_{MSY}} - 1\right)}$$

These results were the genesis for creating a plot of F_{MSY} vs. 1 – SPR_{MSY} (Figure 2d).

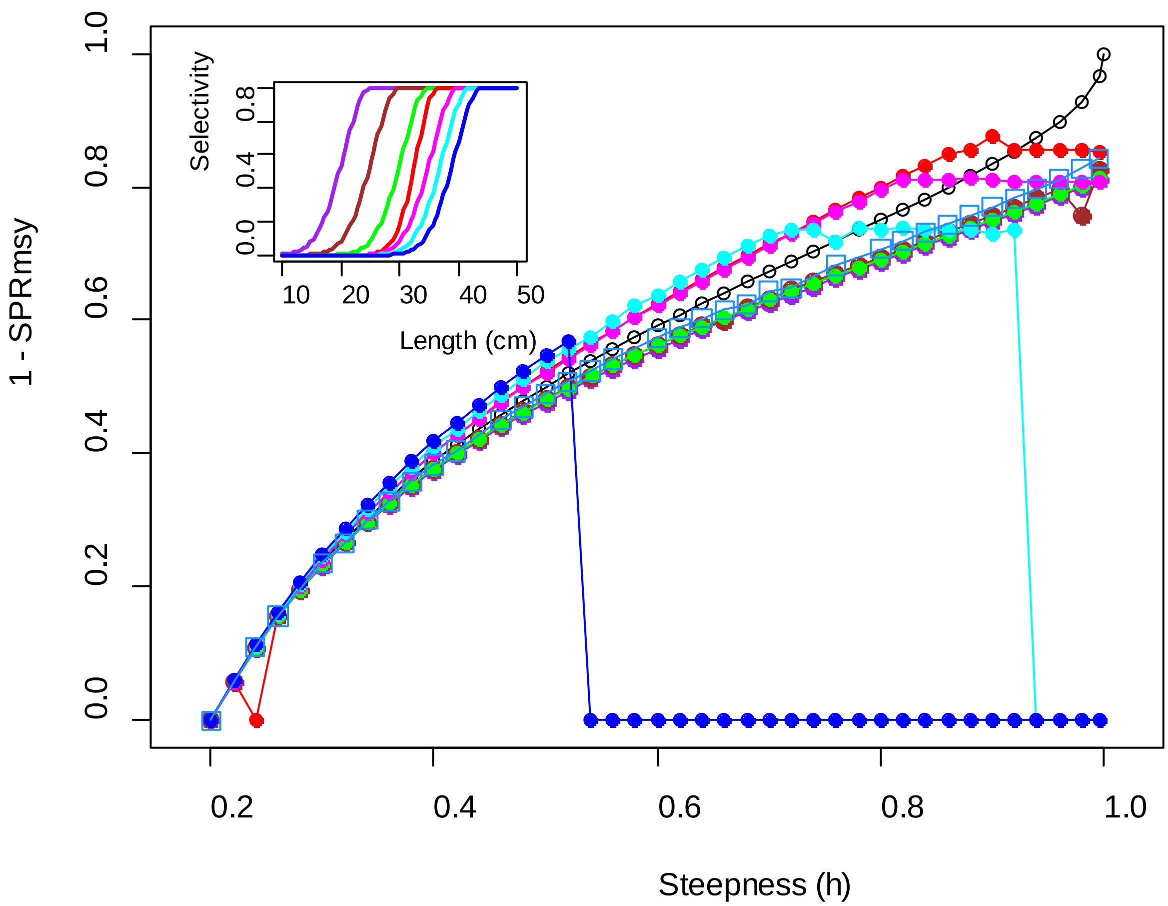

Figure 1. A profile over steepness (h) for a recent Petrale sole age structured model using various selectivity curves that span the length range of Petrale sole (insert). The selectivity curves were assumed to be the same for all fisheries and surveys in a given profile run. The black line with circles is the production model result from MPM (eq. 17). The Dodger blue squares are from the initial Petrale model.

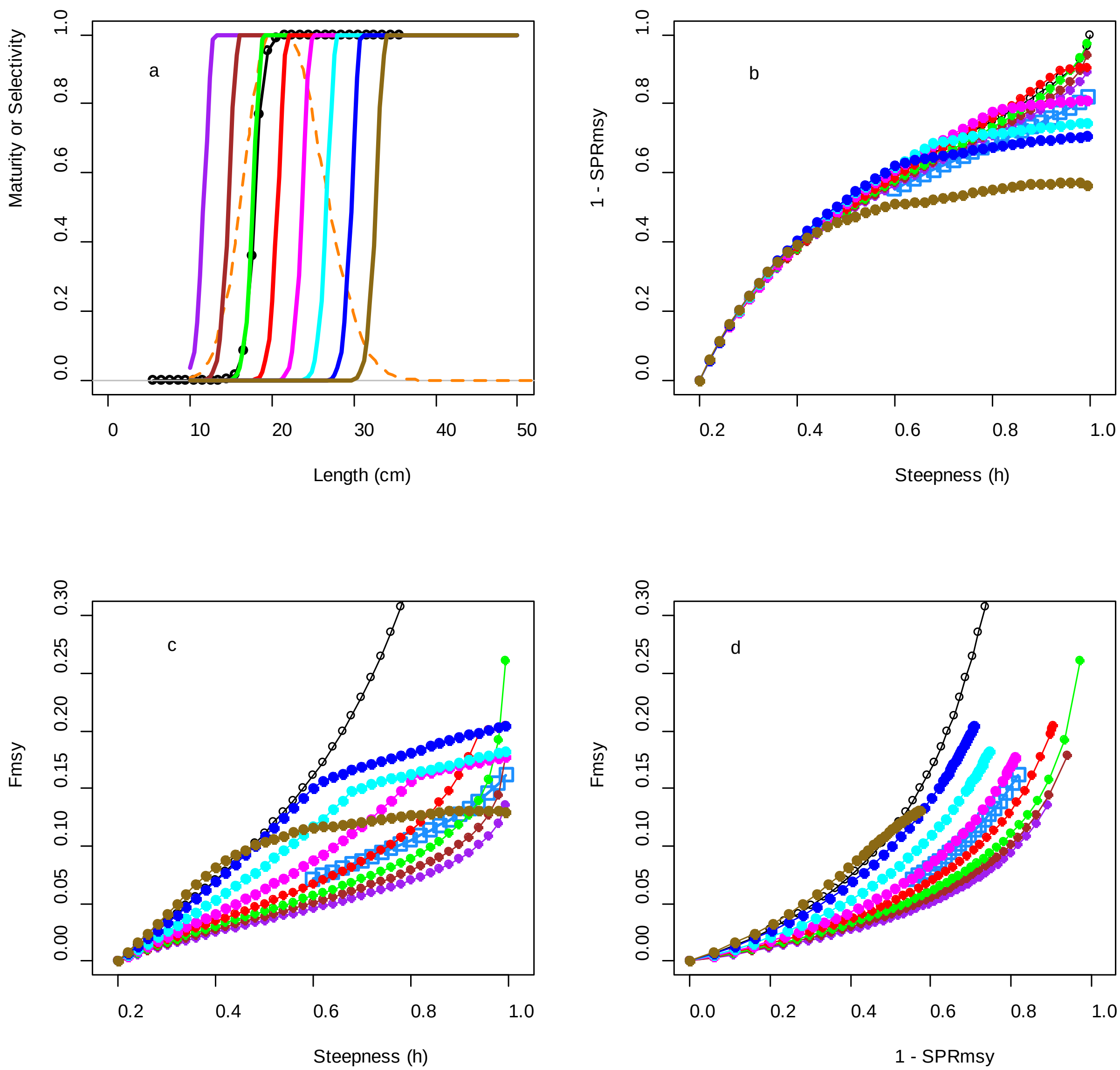

Figure 2. A profile over steepness (h) for a recent longspine thornyhead age structured model using various selectivity curves that span the length range of the longspine thornyhead (a). The selectivity curves were assumed to be the same for all fisheries and surveys in a given profile run. The black line with circles are production model results from MPM (eq.'s 15 and 17). The Dodger blue squares are from the initial longspine thornyhead model.

Panel discussion

Predictions of a simple production model about the relationships between steepness and other management quantities were compared to a full age-structured assessment model. While in general the predictions of Mangel et al. (2013) are not too horrible, it is clear that there is some deviation in the predicted functional relationships. SPR_{MSY} is not independent of the selectivity curve as asserted by Mangel et al. (2013), but selectivity only weakly affects the relationship of

SPR_{MSY} as a function of steepness (h). Work completed after the workshop and shown in the author summary suggest a more serious deviation in the predicted relationship between steepness and F_{MSY} due to the assumed selectivity pattern.

3. RECOMMENDATIONS AND CONCLUSIONS.

The Panel the identified a number of recommendations and conclusions on how to make progress on the issues addressed by the workshop.

1. Use of the Beverton-Holt stock-recruit curve and other two-parameter curves forces a strong relationship between steepness (i.e., the curvature of the SR relationship) and management parameters such as stock size at MSY, F_{MSY}, and the SPR that maximizes yield. These relationships are not a reflection of life history or population dynamics, but rather an outcome of the choice of a mathematical model with limited flexibility.
2. Three-parameter curves and non-parametric curves do not have these strong relationships, and this may provide some advantages. However, experience in working with such models in fisheries management is limited.
3. In most cases, there is not enough information in stock assessment data to support reliable estimation of the parameters of three-parameter stock-recruit curves. Therefore use of three-parameter curves will be highly reliant on the use of priors to provide stable estimation while enabling flexibility. A similar situation exists even for the two-parameter Beverton-Holt curve, where a prior for steepness has been recommended by the SSC for use in stock assessments for this same reason.
4. There was a diversity of scientific opinion regarding whether there should be a move towards use of three-parameter stock recruit models in stock assessment. Some on the Panel thought that it was better to continue using the Beverton-Holt stock recruit relationship (or even a constant mean) purely as a descriptor of the relationship between stock size and abundance. Others on the Panel favored adoption of three-parameter curves in stock assessments.
5. To make progress resolving these issues, the Panel recommends directed research on several topics:
    a. Continued simulation-estimation tests for both two-parameter and three-parameter models in stock assessments.
    b. Evaluation of different three-parameter models and alternative leading parameters for incorporation into Stock Synthesis.
    c. Exploration and evaluation of three-parameter curves in stock assessments, either when developing stock assessments, or for existing models.
    d. Further development of priors for leading parameters of stock-recruit models is needed, such as B_{MSY}/B_0, and slope at the origin. Non-parametric approaches to meta-analysis should be considered to directly estimate leading parameters.
6. The current practice of evaluating sensitivity to steepness in stock assessments by likelihood profiles and in decision tables should be continued.

7. Estimates of mean steepness for West Coast rockfish have apparently increased from around 0.6 to 0.8 based on meta-analysis of rockfish stock assessments. This increase in rockfish steepness suggests that the $F_{50\%}$ harvest rate for rockfish can no longer be considered a risk neutral proxy for F_{MSY}, as was originally intended. This could result in a potential loss of long-term yield of about 20%. These conclusions depend on accepting the Beverton-Holt curve as an appropriate way to model the stock recruit relationship, an approach that is now under question.
8. The Panel recommends that dynamic B_0-based reference points be included the West Coast stock assessment toolbox, since they may be helpful to understand stock dynamics under regime shifts and directional climate change. The dynamic B_0 output has been a routine part of the Stock Synthesis output for several assessment cycles, so all that is needed are guidelines for using it. The approach may be useful for specific groundfish stocks, but should be evaluated using MSE for the specific stock in question before being applied. The ongoing MSE work with sablefish is an example of evaluation that should take place.
9. Estimating and including autocorrelated recruitment during population forecasts can decrease forecast error if autocorrelation is substantially different from zero (e.g., $\rho>0.25$). If the sample autocorrelation is >0.25, then this value should be used when forecasting abundance in rebuilding plans.
10. If there is sufficient support from the West Coast science centers, a follow-up workshop should be scheduled for the next off assessment year in 2018, to evaluate progress on the above research recommendations.

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Appendix 1. Workshop Agenda

PROPOSED AGENDA

Groundfish Productivity Workshop
Pacific Fishery Management Council
Scientific and Statistical Committee

National Marine Fisheries Service
Western Regional Center's Sand Point Facility
Alaska Fisheries Science Center
Building 4, Traynor Room 2076
7600 Sand Point Way NE
Seattle, WA 98115

December 6-8, 2016

This meeting is open to the public and public comments will be accepted at the discretion of the meeting chair. Agenda times are approximate and are subject to change.

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Technical Information and System Requirements:

PC-based attendees: Required: Windows® 7, Vista, or XP

Mac®-based attendees: Required: Mac OS® X 10.5 or newer

Mobile attendees: Required: iPhone®, iPad®, Android™ phone or Android tablet GoToMeeting Webinar Apps)

TUESDAY, DECEMBER 6, 9:00 AM

Workshop Panelists
SSC members:
Aaron Berger, National Marine Fisheries Service Northwest Fisheries Science Center
John Budrick, California Department of Fish and Wildlife
Martin Dorn, Chair, National Marine Fisheries Service Alaska Fisheries Science Center
John Field, National Marine Fisheries Service Southwest Fisheries Science Center
Owen Hamel, National Marine Fisheries Service Northwest Fisheries Science Center
André Punt, University of Washington (December 7 only)

David Sampson, Oregon State University
Will Satterthwaite, National Marine Fisheries Service Southwest Fisheries Science Center
Theresa Tsou, Washington Department of Fish and Wildlife

Invitees:

Bill Clark, University of Washington
Jason Cope, National Marine Fisheries Service Northwest Fisheries Science Center
Edward "E.J." Dick, National Marine Fisheries Service Southwest Fisheries Science Center
Robyn Forrest, Department of Fisheries and Oceans, Pacific Biological Station
Nick Grunloh, National Marine Fisheries Service Southwest Fisheries Science Center
Xi He, National Marine Fisheries Service Southwest Fisheries Science Center
Marc Mangel, University of California, Santa Cruz
Mark Maunder, Inter-American Tropical Tuna Commission
Carey McGilliard, National Marine Fisheries Service Alaska Fisheries Science Center
Rick Methot, National Marine Fisheries Service Office of Science and Technology
Steve Munch, National Marine Fisheries Service Southwest Fisheries Science Center
Josh Nowlis, National Marine Fisheries Service Northwest Fisheries Science Center
Ian Taylor, National Marine Fisheries Service Northwest Fisheries Science Center
Jim Thorson, National Marine Fisheries Service Northwest Fisheries Science Center
John Wallace, National Marine Fisheries Service Northwest Fisheries Science Center

A. Call to Order

1. Call to Order and Introductions — Martin Dorn
2. Approve Agenda and Rapporteur Assignments

(*9 a.m., 0.5 hours*)

B. Density Dependence, the Theory of Harvesting, and the Practice of Stock Assessment: A Perspective on Steepness and Its Implications — Marc Mangel

(*9:30 a.m., 1 hour*)

C. Quest for the Holy Grail: The Stock-Recruit Curve in Fishery Stock Assessment — Mark Maunder

(*10:30 a.m., 1 hour)*

LUNCH (11:30 A.M. - 1:00 P.M.)

D. Design Considerations for a System of Stock Assessment and Reference Point Estimation for Use by the PFMC — Martin Dorn

(*1 p.m., 1 hour)*

E. Bias in Estimation of Biological Reference Points when 3-Parameter Stock-Recruit Relationships are Considered Appropriate -- An Extension of the Results of Mangel et al. 2013 — E.J. Dick and Nick Grunloh

(*2 p.m., 1 hour*)

F. Autocorrelation in Recruit and Its Effect on Estimation of Stock-Recruit Parameters — Jim Thorson

(*3 p.m., 1 hour*)

WEDNESDAY, DECEMBER 7, 9:00 A.M.

G. Extending Integrated Stock Assessments Models to Use Non-Depensatory Three-Parameter Stock-Recruit Relationships André Punt and Jason Cope
(*9 a.m., 1 hour*)

H. Meta-Analysis Comparing Parametric and Non-Parametric Stock-Recruit Models Steve Munch
(*10 a.m., 0.75 hours*)

I. Simulation/Estimation Study on the Influence of Recruit Variance (Sigma-R) on Estimates of Stock-Recruit Steepness Xi He
(*10:45 a.m., 0.75 hours*)

LUNCH (11:30 – 1:00 P.M.)

J. Use of Dynamic B_0 Calculations for Status Determination for West Coast Groundfish Aaron Berger, Ian Taylor, and Melissa Haltuch
(*1 p.m., 0.75 hours*)

K. A Management Strategy Evaluation of Stock-Recruit Proxies Josh Nowlis
(*1:45 p.m., 0.75 hours*)

L. A Multivariate Life History Analysis of Global Fisheries Data to Generate Priors on Length, Weight, Growth, Mortality, and Maturity Parameters for All 32,000 Marine Fishes Jim Thorson
(*2:30 p.m., 0.75 hours*)

M. SPR vs. F_{MSY} in Assessment Models John Wallace
(*3:15 p.m., 0.75 hours*)

PUBLIC COMMENT AND OPEN DISCUSSION
(*4 p.m., 1 hour*)

THURSDAY, DECEMBER 7, 9:00 A.M.

N. Analysts Report on Progress
(*9 a.m., 1 hour*)

O. Begin Drafting Workshop Report
(*10 a.m., 1 hour*)

P. Wrap-Up -- Workshop Recommendations
(*11 a.m., 1 hour*)

PFMC
11/28/2016