Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

Canadian Science Advisory Secretariat (CSAS)

Proceedings Series 2012/055

National Capital Region

Proceedings of the National Workshop for Technical Expertise in Stock Assessment (TESA): Maximum Sustainable Yield (MSY) Reference Points and the Precautionary Approach when Productivity Varies

December 13-15, 2011
Montréal, Quebec

Co-Chairs :
D.E. Duplisea and N. Cadigan

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200, rue Kent Street, Ottawa, Ontario, K1A 0E6

May 2013

Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1701-1280

Correct citation for this publication:

DFO. 2013. Proceedings of the National Workshop for Technical Expertise in Stock Assessment (TESA): Maximum Sustainable Yield (MSY) Reference Points and the Precautionary Approach when Productivity Varies; December 13-15, 2011. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2012/055.

Aussi disponible en français :

MPO. 2013. Compte rendu de l'atelier national pour Expertise technique en évaluation de stocks (ETES) : Points de référence en matière de rendement maximal soutenu (RMS) et approche de précaution en situation de variation de la productivité ; du 13 au 15 décembre 2011. Secr. can. de consult. sci. du MPO, Compte rendu 2012/055.

TABLE OF CONTENTS

SUMMARY

The primary goal of the workshop was to detail problems with deriving maximum sustainable yield (MSY) and precautionary approach (PA) reference points (RP) for stocks with varying (i.e. non-stationary) productivity conditions or regimes. A secondary objective was to explore integrating MSY reference points and the PA such that management regimes neither collapse stocks nor forego unnecessary amounts of potential yield. The motivation for the workshop comes from the numerous stocks that are regularly assessed by Fisheries and Oceans Canada (DFO) (e.g. Northern cod) in which data suggests there have been substantial changes in productivity processes and where there are frequent questions on the applicability of RP derived from the entire data set for the current conditions. Terms of reference for this workshop were drawn-up in the context of these goals and background (Annex 1).

The three day meeting consisted of two main parts: The first two days consisted primarily of presentations on individual contributions followed by discussions. The second part on the final day consisted of three breakout groups around three basic questions that arose from the previous days discussions and rose to prominence as key issues. The three questions were centred on the topics (1) when are regime-specific RPs appropriate, and what are the risks of not considering regime changes? (2) What MSY RP options are available that could guide DFO when implementing the PA for stocks under changing productivity? (3) What is the influence of process error on stochastic MSY reference point estimates?

SOMMAIRE

L’atelier visait essentiellement à détailler les problèmes qui se posent lorsqu’il s’agit de trouver les points de référence (PR) du rendement maximal soutenu (RMS) et de l’approche de précaution (AP) pour des stocks dont les régimes ou les conditions de productivité varient (c’est-à-dire qui sont non stationnaires). L’étude de la possibilité d’intégrer les points de référence du RMS et de l’AP de manière à ce que les régimes de gestion ne provoquent pas l’effondrement des stocks ou ne renoncent pas sans raison valable à des rendements potentiels était un objectif secondaire. La tenue de cet atelier se justifiait par le grand nombre de stocks qui sont régulièrement évalués par Pêches et Océans Canada (par exemple, la morue du Nord) et pour lesquels les données évoquent des changements importants dans les processus de productivité et soulèvent des questions fréquentes quant à l'applicabilité des points de référence issues de l'ensemble de données complet aux conditions actuelles. Le cadre de référence de cet atelier était établi sur la toile de fond de ces objectifs et de ce contexte (annexe 1).

La réunion de trois jours comportait deux principaux volets : les deux premières journées étaient consacrées principalement aux présentations des contributions individuelles, suivies de discussions. Au cours de la deuxième partie de la dernière journée, trois groupes de discussion ont abordé trois questions fondamentales soulevées lors des discussions des deux journées précédentes, qui sont devenues des enjeux clés. Les trois questions étaient axées sur les sujets suivants : 1) Dans quelle situation les PR propres à un régime sont-ils appropriés, et quels sont les risques encourus si l'on ne tient pas compte des modifications subies par le régime? 2) Quelles sont les options de PR en matière de RMS qui pourraient orienter le MPO dans la mise en œuvre de l'AP visant les stocks pour lesquels la productivité varie? 3) Comment l'erreur due au processus influence-t-elle les estimations stochastiques des points de référence en matière de RMS?

INTRODUCTION

Welcome and opening remarks

Presented by N. Cadigan and D. Duplisea

The purpose of the workshop was described as how varying productivity should affect precautionary approach (PA) reference points (RPs), and, in particular, maximum sustainable yield (MSY) RPs. The specific terms of reference are provided in Appendix I.

The chairs cautioned that it was not the purpose of the workshop to decide if MSY RPs are useful for fisheries management. Rather, the workshop should focus on how to compute MSY RPs when elements of a stock's productivity vary. This is consistent with the scope of a Technical Expertise in Stock Assessment workshop, to provide technical guidelines, tools, or ideas, to DFO stock assessment scientists.

Even if it is felt that MSY RP's are not useful, it does not help the debate if we provide poor or imprecise estimates of these RPs. Currently, DFO stock assessments are asked to report (estimate) BMSY and FMSY, and an important goal of this meeting is to produce advice/examples on how this should be done when stock productivity has varied.

Workshop participants were asked to think more about whether we should adapt RPs to our current perception about stock productivity (i.e. shift the goal posts) or keep them the same. The Recovery Potential Assessment for cod held in February 2011 in St John's was cited as a good example of where the question was asked about whether projections should be based on current conditions only or should be based on the entire observed time series. This question is inextricably linked to reversibility and recoverability of cod to previous levels. An aim of this workshop was to provide some consistent though not prescriptive guidance on this issue.

PRESENTATIONS AND DISCUSSION

PRESENTATION 1: Precautionary approach frameworks around the world with some consideration on how they deal with productivity changes

Author: P. Shelton

The following topics are covered: (i) A quick scoping of the ontogeny of MSY-based PA frameworks (birth, death, reincarnation, denial); (ii) PA frameworks around the world (New Zealand, Australia, National Marine Fisheries Service, International Council for the Exploration of the Sea (ICES) and DFO); (iii) Overview of general causes of changes in productivity; (iv) Some specific examples - North Sea cod, Western bluefin tuna, Grand Bank American plaice; (v) How PA frameworks have addressed productivity shifts.

MSY as a basis for fisheries management has been severely criticised over the years (e.g. Larkin 1977). Nevertheless it forms the basis for the Precautionary Approach as outlined in the 1995 United Nations Fish Stock Agreement and MSY-based reference points have been implemented in management frameworks by a number of nations and international fisheries organizations. This implementation is supported scientifically provided MSY reference points are incorporated in clear decision rules that can be simulation tested for robustness (Punt and Smith 2001). The application of B_{MSY} as a target or limit varies among frameworks but F_{MSY} is more often considered to be a limit. There is a tendency across frameworks to consider $B_{MSY} < B_{TARG}$ for economic and ecosystem considerations. For highly skewed (resilient) production functions, B_{MSY} refers to a higher biomass based on %B0 (unexploited biomass) in a number of frameworks.

The impact of changes in productivity as a result of fishing and other factors is widely acknowledged but best practice has yet to emerge with regard to when to “move the goalposts” (reference points). It is noted that the DFO PA policy expressly states “These cases [where productivity has changed] need to be evaluated individually, but as a general rule the only circumstances when reference points should be estimated using only information from a period of low productivity is when there is no expectation that the conditions consistent with higher productivity will ever recur naturally or be achievable through management.”

Discussion

- There was some discussion on the differences between the approaches taken by Canada and New Zealand. New Zealand sets different reference points based on which of four productivity levels, ranging from high to very low, the stocks falls, but reference points are not adjusted over time based on changes in productivity within the stock.
- According to the presentation one of the strengths of the New Zealand approach framework is that there is little ambiguity in the framework while DFO’s approach requires some interpretation. This is the case with the upper stock reference point which, according to DFO’s PA policy, is set by resource managers yet is primarily a biological property of the stock.
- One method that was suggested was to apply robust harvest control rules to address productivity changes, although the harvest control rules also use reference points. There was discussion around the use of reference points in performance statistics to test the robustness of the harvest control rule which could be based on survey indices or population models. It could provide a robust feedback control that would help prevent stock collapse.
- One issue to consider is whether the productivity change is reversible. Productivity changes can be linked to fisheries as well as some oceanographic indices. The DFO decision making policy under the PA states that “as a general rule the only circumstances when reference points should be estimated using only information from a period of low productivity is when there is no expectation that the conditions consistent with higher productivity will ever recur naturally or be achievable through management.” There was discussion about trigger RPs, and whether they should be based on the natural mortality rate (M) or uncertainty about the target RP. It was indicated that the motivation for setting a trigger RPs to be less than the target based on some function of M is that we expect more fluctuation of the stock about B_{MSY} when M (Natural mortality) is larger.

PRESENTATION 2: Variable productivity and reference points: Priors, proxies, and pragmatism

Author: L. Brooks

This presentation had three main aims. First, analytical derivations were presented to demonstrate that there is a 1:1 relationship between steepness and spawning per recruit (SPR). This point was highlighted because in cases where data are weak for estimating a stock recruit (SR) relationship, a common ‘solution’ is to impose a prior distribution on steepness rather than falling back on an SPR-based proxy. It was noted that specifying a prior on steepness is equivalent to putting a prior on the reference point, thus the proxy approach where a %SPR is specified is no more or less subjective than the approach of specifying priors on stock recruit parameters.

The second aim of the talk was to suggest the possibility that reference points not be treated as 'points' *per se* but rather that they could be considered to be distributions. Related to the first point, whether a SR function is estimated or an SPR-based proxy is used, one needs to calculate unexploited spawners per recruit (i.e. the replacement line in a SR function, or the denominator in an SPR calculation). The year, or years, from which the biological parameters are selected and used in calculations, will impact the MSY reference point (in SR function) or the calculated proxy F_{MSY}. Considering all observed values of biological parameters and calculating a distribution for reference points implicitly assumes that there has been no regime change. Alternatively, recent observations could be compared to a distribution without those observations to determine if recent values appear to be from the same distribution (Figure 2-1).

Finally, the third aim of the talk examined reference points in the context of projections. Primary considerations included what is assumed about productivity in future years, how many years can be projected without unreasonable bias, and what rebuilding targets should be if productivity is not stationary. A further consideration was the starting population structure used in projections, and how the existence of a retrospective bias in the assessment can be magnified when projecting stock abundance. Results from previous simulations of projection performance demonstrated that the bias from retrospective patterns overwhelmed differences due to temporal changes in biological parameters.

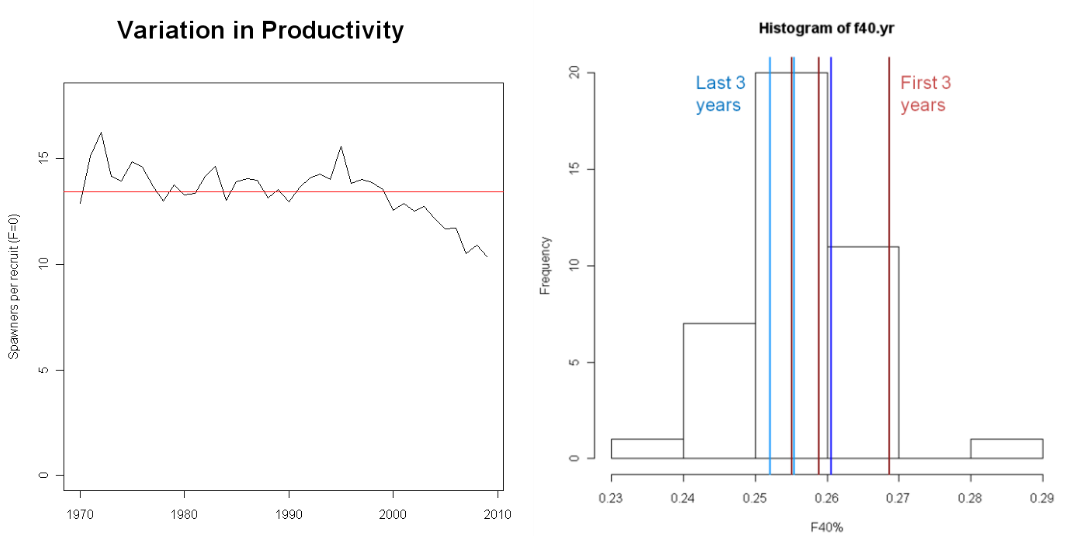

Figure 2-1. Annual value of unexploited spawners per recruit (φ0, left) and resulting distribution of F40% considering all values of φ0. The value of F40% calculated from the first three versus the last three values of φ0 are indicated by vertical brown or blue lines, respectively. The most recent three years of F40% estimates do not appear to be greatly divergent from the first three years.

Discussion

- There was some discussion of the reality and challenges of infrequent assessments. The last full assessment used for this work was in 2007.
- The retrospective work was done in a very stepwise way. Although structural problems may be present in the model, one of the issues is identifying what they are. In the work presented, recruitment information was less of a problem in the model than anticipated.
- One participant noted that recovery is often predicted poorly using the current regime, especially when some components of stock productivity are changing (e.g. growth rates)

- One conclusion from this presentation could be that MSY can be difficult to estimate in many stock assessments, and proxies may be required.
- The use of life history analysis in the modelling was found to be effective.
- The author found that what you assume about productivity and the stock-recruit steepness parameter defines your reference points. Selecting a steepness parameter is an important decision and it may be safer to assign a proxy for F_{MSY} or B_{MSY}. Assigning a proxy could be based on a %SPR analysis, and by repeating the simulation approach of Clarke (1991, 1993), using the data specific to the species and plugging in the biological parameters. One should choose a %SPR that is reasonable and can give a distribution for *F*. Some considerations are: when does the %SPR need to be changed; is the distribution of *F*'s still applicable to our current situation; i.e., are we in the same productivity regime? Problems can arise if there is a sustained decline or if the distributions are all in one tail.
- In response to whether the SPR proxy depends on the stock recruitment function, the author suggested looking at how the %SPR *F* compares to F_{MSY} in some simulations based on your stock. The true MSY can be seen in comparison to what is lost in proxy. For any one value of the steepness parameter there is a corresponding F_{MSY} that can be estimated. Since the real situation is unknown a %SPR needs to be chosen. What is a reasonable %SPR to pick and how does it compare to the true situation? It's about picking a proxy informed by the biological parameters. A good proxy doesn't lose much compared to the true value. But it is life history specific.
- Nonparametric stock-recruit model fits have not been tried for the data but that could be useful to look at.

PRESENTATION 3: Review of single species MSY points for Baltic cod stocks

Author: J. Simmonds

The purpose of the study is to evaluate target and ranges of constant *F* exploitation for both Baltic cod stocks, based on available assessment data. Recruitment is modelled though stochastic multiple model based simulation for 1000 constructed "populations" for each stock by randomly sampling with replacement selection at age in the fishery, natural mortality, maturity and weights at age in the catch and weights at age in the stock for the selected periods. SR models were fitted in a Bayesian framework. Three SR models with 3 parameters were fitted, Hockey-stick (HS), Ricker (RK) and Beverton-Holt (BH). Three time periods for SR are examined for each cod stock. The probability of each model type is selected for each model type with the distribution of values for coefficients that come from the Bayes fit using the statistical method proposed by Kass and Rafferty (1995) applied as described in detail for SR functions in Simmonds et al (2011) where it was used for the ICES management strategy evaluation (MSE) for mackerel. More complex models with more (4) parameters were tested initially and found to fit more poorly and would, therefore, have had a low probability in the combined modeling so were not tested further. When fitted independently, differences between slope to the origin are not significant among dataset and stocks. Modeling is repeated using a common model specific slope factor for each model type (BH, HS and Rk).

Variability in growth, maturation, and selection in the fishery is obtained by drawing historically observed values at random from subsets of the assessment data sets. To account for differences over time different groupings are selected for comparison.

Comparison is made between estimated F_{MSY} target values (Figure 3-1a&b) and the equilibrium yields against *F* (Figures 3-1c&d). The best point estimates of F_{MSY} for single species exploitation initially suggest that the values can change from about 0.25-0.4 (assuming consistent slope to the origin on the

SR). The rate of change of equilibrium yield with target F is much slower around the peak than the distribution of F_{MSY} (comparing Figure 3-1a&b with c&d). Over the same range of F (0.25 to 0.4) mean equilibrium yield is estimated to be greater than 0.96 max yield. Thus we can obtain significantly different estimates of F_{MSY} with negligibly different yields. The range of F that can maintain yields within 95% of yield at F_{MSY} is F= 0.25 to 0.45. The lack of sensitivity of yield to choice of F close to F_{MSY} appears to be a rather general result. The consequences are that precise estimates of F_{MSY}, which are often difficult to get, may not be needed in order to establish where high long term yields can be obtained. Adjustment of Target Fs may not be needed for the level of moderate changes in growth maturation etc. observed for Baltic cod. However, biomass at which MSY may be obtained can be uncertain.

Conclusions

- Based on single stock analysis there is insufficient data to detect differences in SR resilience (slope to the origin) across stocks or between periods.
- Carrying capacities are different across stocks and periods, particularly for Eastern Baltic cod.
- Reliance on single SR models without accounting for uncertainty in parameters and model functional form can give very different results
- High yields (>95% of max) for all situations can be obtained between F=0.2 to 0.5 with less than 4% loss of yield at the extreme point estimates of point estimates F_{MSY} 0.25-0.4
- For these stocks if the objective is to maintain yield it may not be necessary to change target F values in order to achieve yields close to MSY under different regimes in the Baltic.

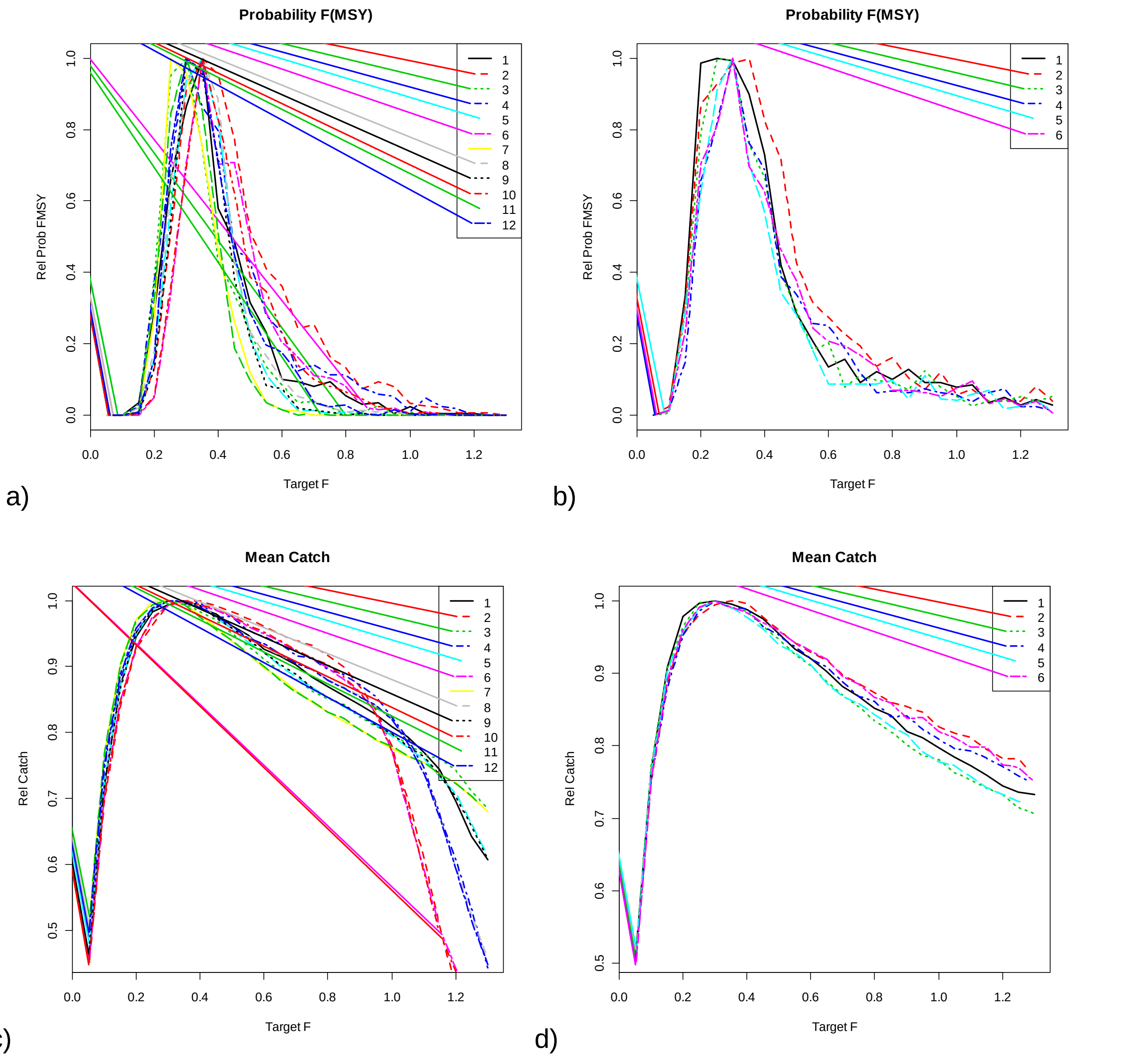

Figure 3-1 Equilibrium exploitation of Eastern and Western Baltic cod. Distribution of population F_{MSY} values (a,b) and mean catch verses F (c,d). Assuming SR slope to the origin (A parameter on SR function) is common across stocks and data periods.

Discussion

- There was discussion about the construction of the model that included how the population sets were used and what data were used and how it was incorporated into the model.
- There was a discussion on how this model accounts for varying productivity. The model does not account for varying productivity. The author found that for these two cod stocks the varying productivity does make a difference in the point value of F_{MSY} but these differences in *F* don't make a significant difference in the relative yield that can be achieved over a range of *F*. The productivity depends on being able to move back into a good regime, but because yield changes slowly with *F* it was found that there were common values of *F* for two SR regimes that produced good yield (i.e. within 95% of maximum).

PRESENTATION 4: Surplus production model, reference points in a random environment: What is MSY?

Authors: L-P. Rivest & Sophie Baillargeon ,Université Laval

Basic reference points for fishery management are derived from surplus production models. These models express the biomass at time t+1, B_{t+1}, as the sum of the biomass at time t, B_t, plus the recruitment at time t, f(B_t), minus the catch at time t, $C_t = FB_t$ where F is the fishing mortality. The model equation is

$$B_{t+1} = B_t + f(B_t) - FB_t$$

The stationary value of the biomass for a given fishing mortality F is the solution B_F of the equation $B = B + f(B) - FB$ and the optimal fishing rate is the F value that maximizes FB_F. This maximum value is the mean sustainable yield (MSY) and the fishing mortality for which FB_F is a maximum is F_{MSY}. B_{MSY} denotes the stationary value of the stock biomass when the fishing mortality is F_{MSY}.

This work focuses on the Pella and Tomlinson model for which $f(B)=(p+1)\times r\times B\times\{1-(B/K)^p\}/p$, where K, the carrying capacity, is the maximum biomass of the stock, r is the growth parameter and p is a shape parameter. The case p=1 gives the Schaefer model while as p goes to 0 one gets the Fox model for which $f(B)=-r\times\ln(B/K)$. The reference point calculations are easily carried out for this class of models. The results are well known, $F_{MSY} = r$, is $MSY = r\times K/(p+1)^{1/p}$ while $B_{MSY}=K/(p+1)^{1/p}$. We call these values the deterministic reference points since they are derived using deterministic surplus production models.

An alternative, possibly more realistic, model assumes that besides a deterministic recruitment, the stock undergoes a random multiplicative perturbation, ε_t, each year. The model equation becomes

$$B_{t+1} = \{ B_t + f(B_t) - FB_t \}\times\varepsilon_t,$$

where ε_t is a positive random variable with expectation 1 and variance σ^2. This defines a stochastic process and under suitable regularity conditions this stochastic process has a stationary distribution. Bousquet, Duchesne & Rivest (2008) provide some conditions for the existence for such a stationary distribution for the stochastic Schaefer model. In the context of the general Pella & Tomlinson family, these conditions become:

- $F < r\times(p+1)/p$ and a fishing mortality larger than $r\times(p+1)/p$ cause the population to collapse;
- The random perturbations ε_t have a bounded support,
- There is an upper bound for the variance of ε_t.

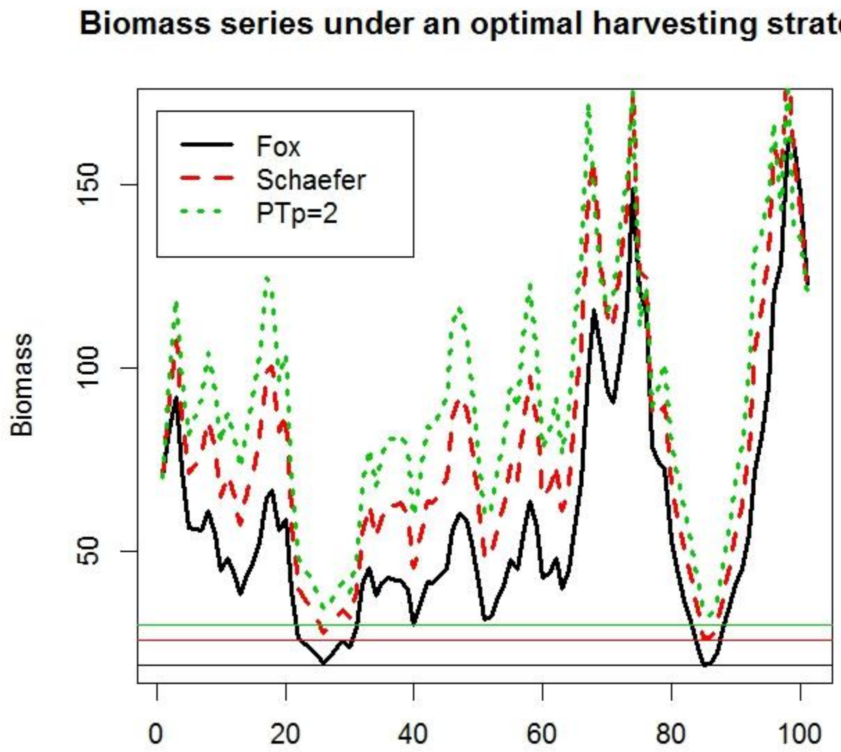

Figure 4-1. 100 successive realizations of B_{MSY} for the models of Fox, Schaefer and Pella & Tomlinson with p=2 when K=128, r=0.2, σ=0.18, and ρ=0.5

In a random environment the stationary value of the catch, FB_F, is a random variable that changes from one year to the next. In this context, the optimal fishing mortality F_{MSY} is the value for which the expectation of FB_F is maximal and the optimal stochastic MSY is the maximum value of this expectation.

This presentation gives a first order approximation to the stochastic reference points when the perturbation error variance σ^2 is small. When $\sigma^2=0$, the stochastic reference points are the deterministic reference points given above. The results presented below where obtained by carrying out Taylor series expansions for the expectation of the stationary biomass around its deterministic value. This was done in a general setting where the errors were assumed to follow an AR(1) process: $E(\varepsilon_{t+1}-1|\ \varepsilon_t)=\rho\times(\varepsilon_t-1)$ where ρ is the first order autocorrelation. The case ρ=0 gives independent perturbations. Values of ρ bigger than 0 account for the successive occurrence of sequences of good and bad years. Approximations of the stochastic reference points are

$$F_{MSY}(\sigma) \approx r - p\frac{1-r}{(2-r)^2}\frac{1+\rho-r\rho}{1-\rho+r\rho}\sigma^2 - \frac{pr\rho\sigma^2}{(2-r)(1-\rho+r\rho)^2}$$

$$MSY(\sigma) \approx \frac{rK}{(p+1)^{1/p}}\left(1-\frac{(p+1)}{2r(2-r)}\frac{1+\rho-r\rho}{1-\rho+r\rho}\sigma^2\right)$$

$$E\ B_{MSY}(\sigma)\ \approx \frac{K}{(p+1)^{1/p}}\left(1-\frac{1+r(p-1)/2}{2r(2-r)^2}\frac{1+\rho-r\rho}{1-\rho+r\rho}\sigma^2+\frac{pr\rho\sigma^2}{(2-r)(1-\rho+r\rho)^2}\right)$$

The stochastic reference points are smaller than their deterministic counterpart. The importance of the difference increases with the shape parameter *p*. The Fox model is less affected by random perturbations than the other models. The autocorrelation ρ has a multiplicative effect on the variance and increases the impact of the perturbations.

To illustrate the random variations of the biomass distribution, Figure 4-1 contains 100 successive realizations of B_{MSY} for the models of Fox, Schaefer and Pella & Tomlinson with p=2 when K=128, r=0.2, σ=0.18, and ρ=0.5. The F_{MSY} for the three models calculated with the above formula are 0.2 (Fox), 0.171 (Schaefer), and 0.143 (Pella and Tomlinson model with p=2). The colored horizontal lines correspond to the precautionary limits 0.4×B_{MSY}(0) for the three models. This figure highlights the volatility of the biomass series; the random perturbations ε_t can bring the biomass to very low levels even under an optimal stochastic harvesting strategy.

Discussion

- A main point of the work is that bias created by the autocorrelated process error acts like a boosting effect to the overall uncertainty.
- There was discussion about process errors. A participant noted that some people fit process errors when composing their models but do not consider that the reference points will change if there are process errors, and moreso if the errors are correlated.
- Another participant noted that if there is correlation in process errors, the model is wrong and is not capturing something.
- There was some discussion about when to use autocorrelation with the suggestion that if something needs autocorrelation then one needs to hypothesize what is going on.
- When productivity varies, MSY reference points depend on the amount of variation. Autocorrelation in productivity variability has a boosting effect on changes in MSY reference points.

PRESENTATION 5: Time varying production, regimes and HCRs

Author: R. Mohn

Case studies from two stocks in Atlantic Canada are presented which exhibit highly variable production over the time of investigation. One was eastern Scotian Shelf (4VsW) cod which has been closed to fishing since 1993. Figure 5-1 shows the change in biomass and catch since the late 1950's. (Mohn & Rowe, 2011) The other was haddock from the western Scotian Shelf (4X), which is still fished although at a lower level of catch than was seen up to the mid 1980s, Mohn et al. (2010). Figure 5-2 shows the dynamics for this stock since the early 1960s.

The stocks were estimated using a virtual population analysis (VPA) with random walk M (Mohn & Rowe, 2011). The data were extended beyond the standard assessments using some assumptions about growth and removals. Production was estimated using a version of a Sissenwine-Shepherd analysis with the input data broken down into moving windows to give some temporal resolution. The method is an extension of that reported in Mohn & Chouinard (2007). Figure 5-3 shows the moving window production of 4VsW cod in terms of the B_{MSY} and MSY. A rather clear change in productivity (in terms of MSY) is seen which took place in the early 1990s. Before this shift, B_{MSY} was in a vicinity of 100 kt whereas afterwards, it was less than 20 kt. Standard BRPs based on B_{MSY} would also be changed by a similar ratio. The influence of individual inputs to the time varying MSY has also been estimated. Figure 5-4 shows the influence of growth changes and natural mortality changes. The bulk of the change in productivity in terms of MSY is seen to be from the change in natural mortality.

An analogous analysis and results are produced for 4X haddock. Although B_{MSY} showed a plateau up to about 1974, the production shows a decreasing trend over the first half of the data period which was followed by a plateau with a bump centered around 1993 (Figure 5-5). Figure 5-6 looks at the contributions of changes in growth and natural mortality. Both natural mortality and growth are contributing well below the long term mean but recent good recruitment has offset their impact. Thus the stock is viable even though the production has been reduced.

Two questions need to be addressed. The first is has there been a regime change? The second, if so from what time period should biological reference points (BRP) be defined? A regime change may be defined as a rapid transition from one level of productivity to another. Our case studies will be examined against this criterion. Production and BRPs could be defined from the total data available, from the earlier productive period or from the recent unproductive periods. BRPs defined from the earlier period would be indicated if 1) the viability of the stock was compromised, 2) if return to that state were probable and 3) if return was facilitated by conservation interventions. Using the recent unproductive period to define the BRPs would be indicated when the resource is trapped in the current regime but the viability is not an issue. Using the entire time period would rarely be the preference.

For both cod and haddock there has been a significant change in production, although the cod is more regime-like in that the transition from the earlier state to the latter is relative quick amid two periods of greatly differing productivity. In the case of cod, the reference should be based on the productive period when it is possible (probable?) to return to a more productive set of conditions and that increased spawning stock biomass (SSB) will help. For haddock the biological references could be based on the recent parameters. This is because the stock is viable and a return to higher growth is unlikely in the near term.

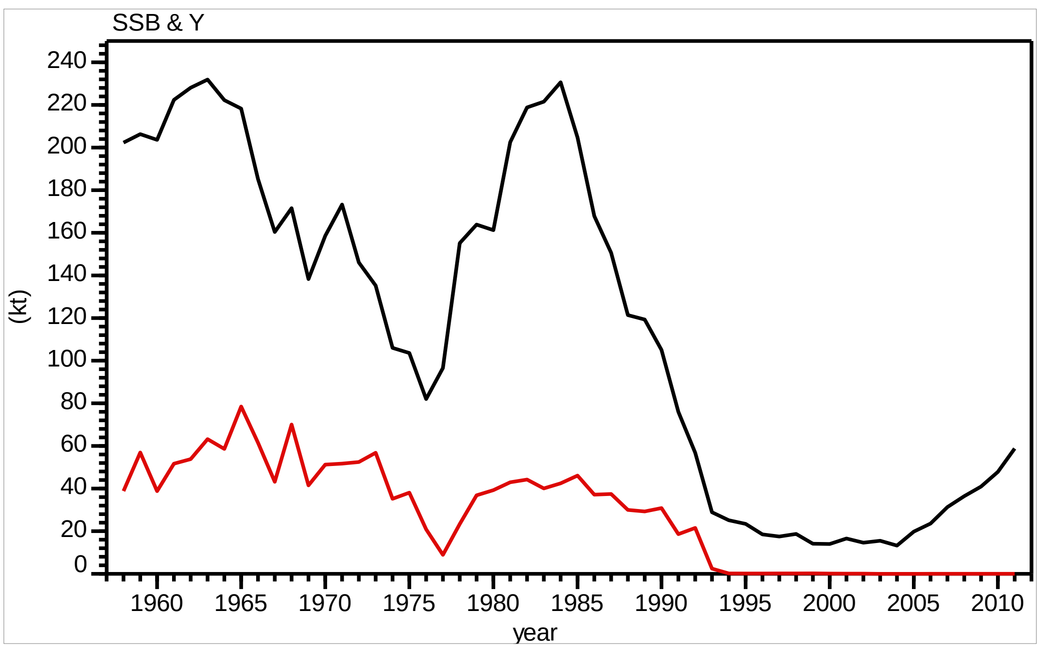

Figure 5-1. 4VsW cod total biomass (black line) and catch (red).

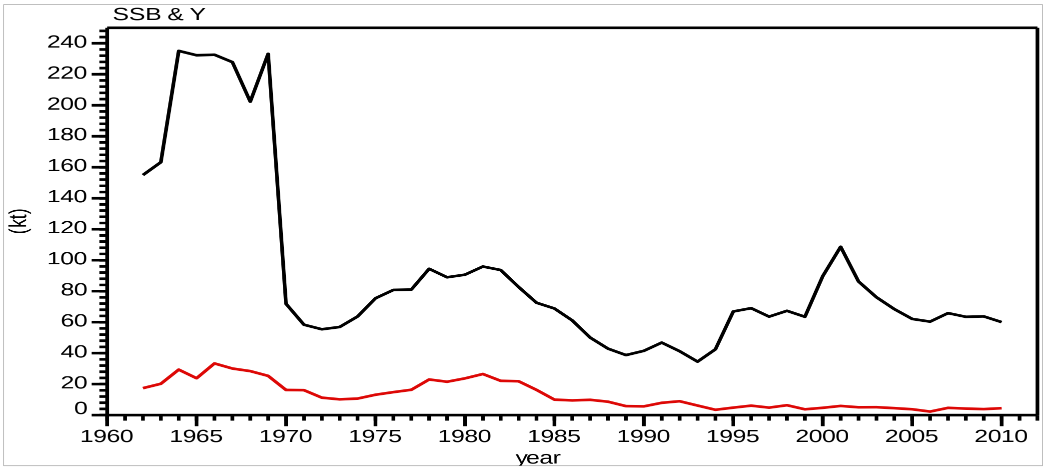

Figure 5-2. 4X haddock total biomass (black line) and catch.

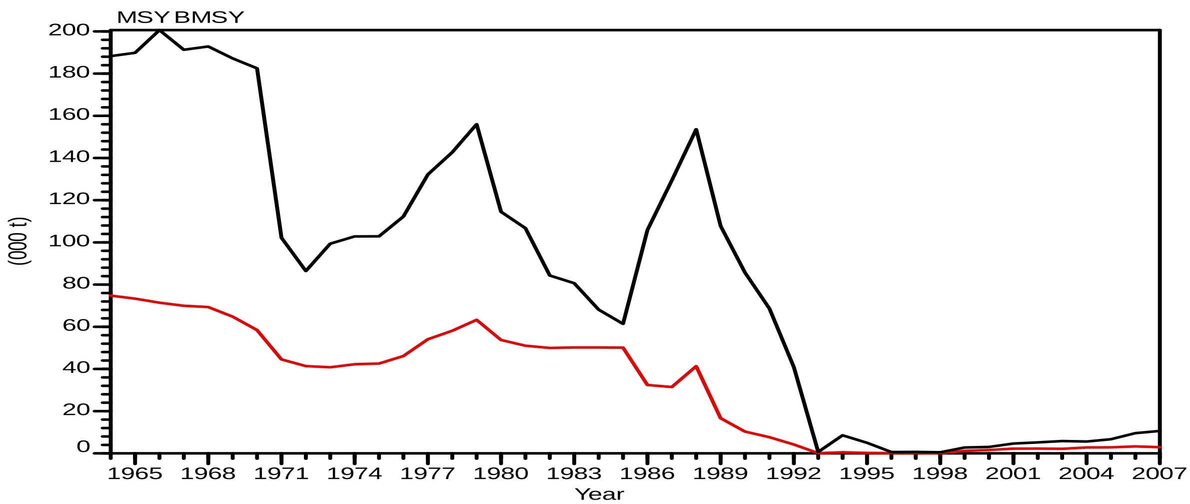

Figure 5-3. Estimated time varying MSY (red line) and B_{MSY} (black) for 4VsW cod.

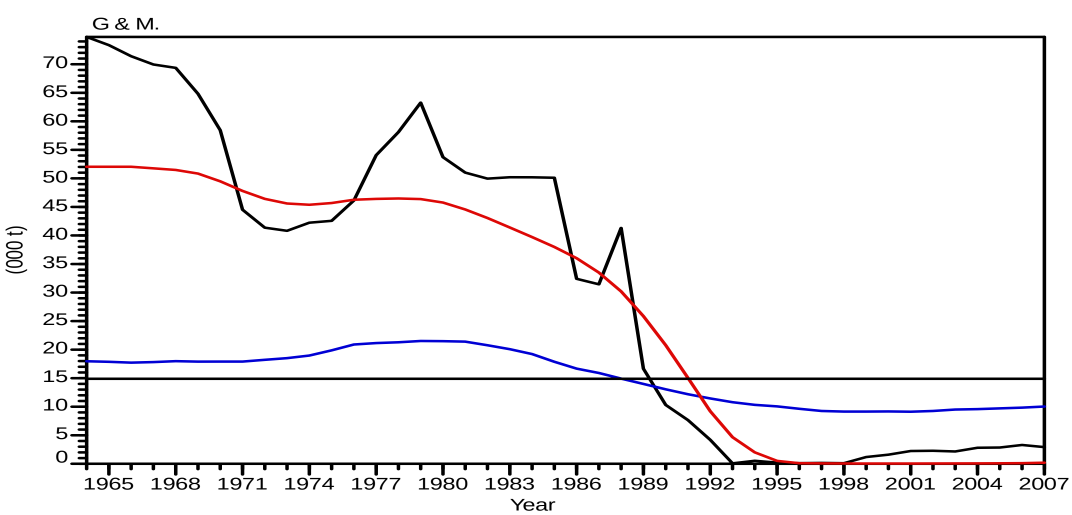

Figure 5-4. 4VsW cod time varying MSY and the contributions from natural mortality (red line) and growth changes alone (blue line).

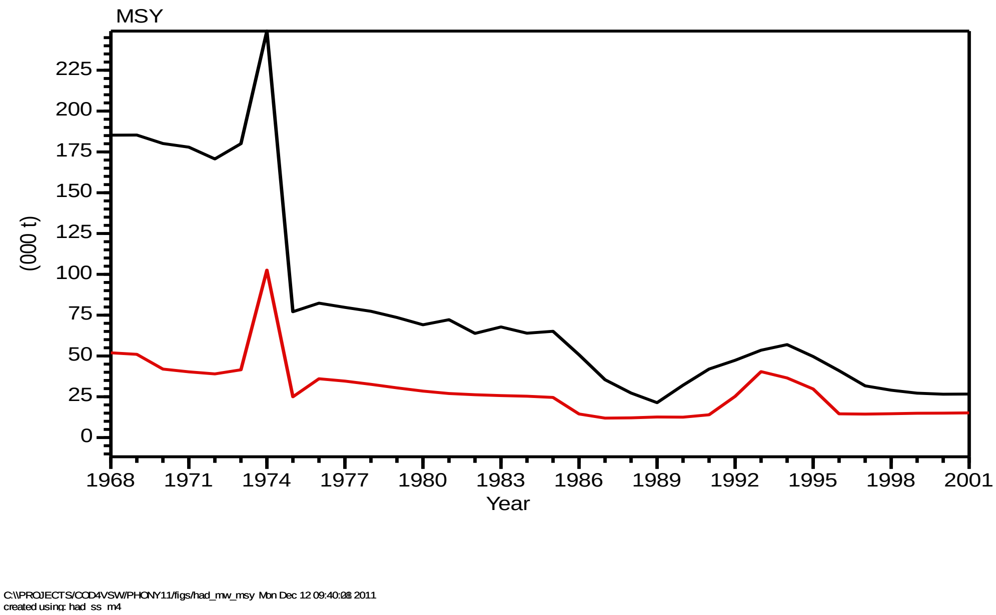

Figure 5-5. Estimated time varying MSY (red line) and B_{MSY} (black) for 4X haddock.

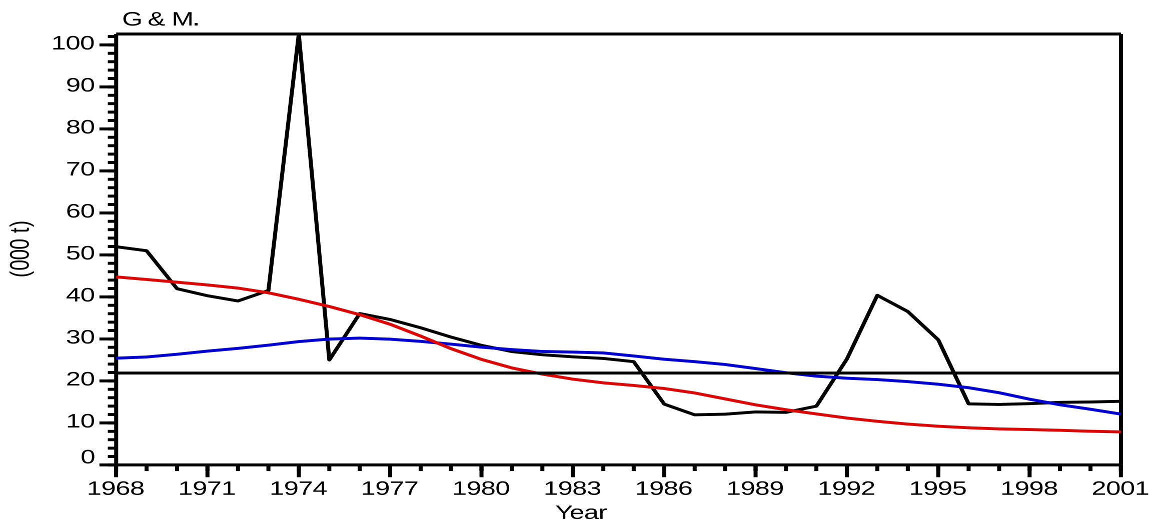

Figure 5-6. 4X haddock time varying MSY and the contributions from natural mortality (red line) and growth changes alone (blue line).

Discussion

- There was some discussion on the impact of changes in natural mortality, how to best incorporate this into a model, and whether changes in *M* are reversible or not. This may be case dependent. It is advisable to look at risks of fishing under different hypotheses about *M* in the future (i.e. reversible or not).
- There was discussion about lower recruitment within cods stocks despite the fact that reproduction seems to be good. Recruitment is lower because the growth is slow, but also because pre-recruit *M* may be high.
- There was a discussion of predictability of regimes and how far into the future those predictions are valid.

- There was more discussion about how reversible productivity regimes are.
- An important point raised was that productivity components should be examined individually to see what is happening.
- Uncertainty in targets and stock size should be computed in practice.

PRESENTATION 6: The relative roles of fishing and biological productivity in fish stock dynamics: history can help to understand the present and design the future

Author: Margit Eero. delivered by C. Ulrich

A major task for fisheries management is to ensure that the harvest is taken sustainably, facilitating, amongst others, the recovery of depleted fish stocks and maintaining the populations at healthy levels. The main instrument of regulating the harvest of commercially exploited fish stocks in North Atlantic is annual total allowable catch (TAC), corresponding to a certain level of fishing mortality. This paper analyses historically observed trends in biomasses of assessed fish stocks in the North Atlantic focusing on the relative importance of the level of fishing mortality versus stock productivity for determining trends in biomass. The results show that temporal variations in production rates have largely determined the observed declines and increases in fish biomasses, whereas fishing mortality alone has generally had only a limited connection to biomass trends. The importance of relative production rate for stock recovery is confirmed by a recent example of stock recovery of the eastern Baltic cod. The biomass of this stock rapidly increased in recent years, largely due to a temporarily high production rate, while similar positive developments have not been observed for any other depleted North Atlantic cod stock in recent decades, despite large reductions in TACs. Long time-series can help to understand changes in stock productivity, a major parameter driving changes in fish biomasses. Further, learning from historical patterns of drivers of stock dynamics could help to design management frameworks that would have a greater chance of being successful in rebuilding the depleted populations, which are not favoured by biological processes.

Discussion

- A concern was expressed about whether the stock productivity metric determines whether the biomass increases or declines or simply reflects that these changes have occurred.
- There was some discussion around the idea that knowing when something happened, one can think about what happened.
- There was discussion around the problem of black landings and the impact that would have on historical catch data. For the Eastern Baltic Cod the misreporting is normally considered to be 40%. There is also survey data that does not have the issue with black landings.
- Similar to black landings, many Canadian fish stocks are harvested for subsistence purposes and currently there are no reporting requirements for the rates of subsistence harvest. The fact that subsistence harvest is not reported and varies from stock to stock and year to year means its overall impact on a fishery is unknown.

PRESENTATION 7: General objectives of MYFISH

Author: C. Ulrich

MYFISH is a EU-Financed pan-European 4-year research project starting in 2012. The MYFISH project is motivated by the following major challenges to an effective implementation of MSY management today:

- How do we take into account that maximizing yield of one stock will have an impact on other stocks through the multi-fleet nature of the fishery and biological interactions between fish stocks?
- How do we balance potentially conflicting goals in terms of ecosystem, economic and social objectives with due consideration of risk to ensure that fisheries are sustainable in the broadest definition of this term?
- How do we consider variability and trends in environmental, economic and social conditions affecting fish stock productivity and distribution, species interactions, fishing techniques as well as fisheries dynamics and targeting behaviour?
- How should MSY-management be implemented to be acceptable, operational and efficient?

These challenges apply to all European waters and reach further beyond the borders of Europe as MSY management is becoming the global goal for fisheries management. The definition of MSY variants, the evaluation of the effect of aiming for them and the operational framework for the implementation all apply to wider areas than single locations and fisheries. Further, the need to implement MSY management applies to both data rich and poor stocks and fisheries.

MYFISH will provide definitions of MSY variants, evaluations of the effect and desirability of aiming for these variants and an operational framework for their implementation. To reach this aim and assure that the results of the project are consistent, operational and relevant at local, regional and global scales, MYFISH participants will work in continuous cooperation with stakeholders in all regional advisory committees (RAC) areas. The project will cover single and mixed fisheries for pelagic and demersal species in European regions ranging from the North Sea to the Mediterranean Sea and combine this with strong associations with scientists in Canada, the US and New Zealand. MYFISH will construct guidelines for MSY variants for stocks with long excellent time series and relevant biological parameters as well as for data poor situations and address the effects of non-stationarity in ecological, economical and social environments. The end result will be an operational framework which can be implemented for the future management of European fish stocks, and an example for the management of global fisheries.

The MYFISH project will cover all aspects of fishing from ecosystem effects over economy to social aspects. To ensure the highest scientific level in all these areas, the project will involve scientists with expertise ranging from fishing and ecosystem effects thereof, to economic and social sciences. The cooperation of scientists with complimentary backgrounds will ensure that the results of the project are acceptable and relevant both to specialists and the broader scientific community.

MYFISH will communicate with managers along the project life time to ensure that results are available for incorporation in management as quickly as possible. To ensure this, the project will make general guidelines on MSY variants available to managers within the first year, Decision Support Tables to provide the overview of the evaluation of different variants required for informed decision making available midways and recommendations including social impact assessments available in the final year. The cooperation with stakeholders will take place throughout the project to ensure the acceptance and uptake of results by stakeholders.

Discussion

- There was discussion around the difference between stakeholder focus in the EU compared to Canada. Stakeholders within the EU are, in general, more concerned about equity between countries.

PRESENTATION 8: Reference points and productivity changes

Author: J. Rice

Many methods may be used to estimate position of management reference points for biomass and fishing mortality. When single upper (precautionary) or lower (limit) reference points are estimated using all the available data on stock size and recruitment strength, it is implicitly assumed that there is a single underlying relationship between the size of a stock and its productivity. Of course there is annual variance around this relationship, which can be addressed in a variety of ways in the management strategy using the reference point. However, when a systematic relationship exists between some aspect of the state of the ecosystem and stock productivity, there has been interest in taking that relationship into account in estimation of the reference points themselves, rather than in the control rule.

Past work on reference points has documented that when the environment-productivity relationship has little or no interannual autocorrelation, it is more effective to deal with the relationship in the risk aversion applied in the harvest control rule than to have reference points that change every year. However, it has been argued that sometimes the productivity changes in a regime-like manner; that is, a stock varying in some range of biomasses may have a range of recruitments for some period of time and then fairly abruptly show a different range of recruitments that persist over a second period of time. Arguments have been made that these productivity regimes have been caused by changes in environmental conditions (such as the Pacific Decadal Oscillation), and by changes to the life history properties of the stock itself.

This presentation explored if, and under what conditions there would be benefits of changing reference points when productivity regimes were thought to exist for a stock. A major concern is that if productivity regimes do occur, there can be at least three different population dynamics processes that can change between regimes, and they have different implications for reference points. These differences were illustrated with both mathematical inequalities that describe the differences, and a narrative explanation of what goes on ecologically.

If the regime change results in a drop in the density-dependent carrying capacity of the ecosystem for the stock, then fewer recruits are needed to saturate the productive capacity of the ecosystem. Correspondingly fewer spawners are needed to produce the necessary number of recruits, and biomass reference points could be lower. If the regime change results in an increase in the density-independent mortality rate of the stock (particularly of pre-recruits) then more eggs and larvae have to be produced for enough to survive to maintain recruitment to the fishery and spawning stock. Consequently, biomass reference points would have to be higher. If the regime change results in energetic / physiological changes to adults such that female fecundity decreases, then more spawners are needed to produce enough eggs to take advantage of the productive capacity of the environment. Consequently, biomass reference points would have to be higher.

Changes to the population demographics that have similar effects (fewer individuals being supported by the ecosystem, lower viability of eggs or larvae, lower per capita or per kg fecundity of females; respectively) would have the same effect on reference points. If the reference points were to be changed appropriately, it would necessarily require exploitation rate to change in the proper direction to maintain stock productivity, so the guidance on exploitation rate would be coherent with the biomass reference point changes.

These more detailed considerations of biological processes associated with regime shifts, run contrary to the simple notion that “lower productivity regimes” necessarily would mean lower biomass reference points. Two of the three possible processes would require higher biomass reference points, instead. To actually be able to make the appropriate changes in reference points, several preconditions would have to be met: The regimes nature of productivity would have be well documented; Each productivity regime would have to persist for several years before changing; It would be necessary to know whether the mechanism(s) causing the regime change is a change in carrying capacity, a change in density-independent survivorship of young ages, or a change in fecundity of adults. Even after these preconditions were met, sufficient data would have to be available to estimate correct reference points for each regime. It will be rare that all the conditions will be met, and that the necessary data will be available. Consequently, it is more likely to be practical to address productive regimes through robust control rules with stable parameters, rather than through adjustments to the reference points or triggers used by the control rule.

Discussion

- The basic message was that reference points should be based on the entire series of data unless there appears to be a regime that has led to a change in carrying capacity and then one might consider using a subset of data representing the regime
- No guidance was given about how long a new regime must exist before we consider the change to be permanent, and not reversible. There is probably no correct answer here. What changes is our perception of the probability that the old regime may occur again. An approach considering the entire series and conditions spanning regimes could produce reference points and harvesting strategies robust to observed regime changes
- There was discussion about what constitutes a regime change and how to assign reference points if the productive regime is rare compared to the less productive regime. The example used was a 30 year time series with 5 years of a productive regime and 25 years of a less productive regime. There was some disagreement about whether that would be considered two different regimes or a rare event of a string of productive year classes within a lower productivity regime. The DFO PA policy calls for the assignment of reference points to be based on the higher productivity unless the regime change is irreversible which may not be ideal for managing the stock.
- There was a comment about the relatively short period of time that we have been monitoring stocks – perhaps no more than 20 to 50 years. It is not a very long time to understand regime structure.
- There was some discussion about the importance of understanding which factors are density dependent and which are density independent when looking at the productivity as this can be quite important in deciding if RP should be adjusted to regimes or not.
- Some species are undergoing systematic changes over time, a continuing trend rather than regime changes. This is the case for Fraser River sockeye.

PRESENATION 9: Model input parameter variability and autocorrelation and impact on reference points

Author: N. Cadigan

The impact of stock-recruit and natural mortality process errors on MSY reference points (RPs) was investigated using simulations of stochastic projections. Process errors are the main source of variability in MSY projections. If the stochastic population projections achieve a stationary (i.e. steady-state) distribution then the mean of the stationary distribution may be used for RP's for fisheries management, although the variance of the stationary distribution of population size should be accounted for in management decisions.

Two important characteristics of the process errors, namely their variance and auto-correlation, are varied to examine how these factors affect MSY RP's. Results suggest that when the process error variance or auto-correlation is large then values for MSY RP's may be lower. However, in this situation the stochastic projections may not lead to a stationary distribution depending on how the process errors are incorporated into the population dynamics model.

Discussion

- A couple participants noted that sensitivity to process error is life history dependent and recruitment related. That is, some species life histories will have inherently greater variability in population dynamic characteristic, especially recruitment. Does this variability lead to more difficulty in determining the long term stationarity of a process?
- The impacts of recruitment process errors were not large unless the process error variance was large or the amount of autocorrelation was large.
- John Simmonds summarized his discussion with the following text:
    - Life history and fishery selectivity characteristics can be summarised in yield per recruit (YPR) relationship. The interaction of the YPR and SR relationship dominate the MSY reference points and can help to evaluate their sensitivity to stochastic variability. The SSB (B_{MAX}) associated with mean recruitment and exploitation at F_{MAX} (if resolved on the YPR plot) can be located on the SR plot. If B_{MAX} is located on a flat part of SR function, then F_{MSY} and B_{MSY} will be equal to the YPR values (F_{MAX} and B_{MAX}), if the SR function is rising the B_{MSY} will be above B_{MAX} and F_{MSY} below F_{MAX}, if B_{MAX} is on a falling part of the SR relationship (Ricker type) then F_{MSY} will be above F_{MAX} and B_{MSY} below B_{MAX}. If SR modelling is likely to be uncertain in slope at B_{MAX} this will result in particularly uncertain estimates of F_{MSY} and B_{MSY}.
    - In addition, the likely influence of process error can also be inferred. If B_{MSY} lies on a relatively linear part of SR relationship then stochastic variability should have little impact on the estimate of F_{MSY} and B_{MSY}. Alternatively, if F_{MAX} is poorly defined and at a relatively high F then the MSY values will be determined by an interaction between SR function and YPR. In these cases the MSY points are likely to lie on a curved area of the SR function and in these cases the stochastic process error will result in different mean R and consequently variable SSB and this will variability will have a greater influence on F_{MSY} and B_{MSY}.
    - The situation can be examined by locating the B_{MAX} on the SR plot, this gives guidance on the need to consider the likely influence of different potential SR functions, and also the need to include or not stochastic variability in the evaluation.

PRESENTATION 10: Current issues with MSY-based reference points in 3Ps Cod

Authors: B.P. Healey, N.G. Cadigan, P.A. Shelton, and M.J. Morgan

The cod stock in NAFO Subdivision 3Ps is shared between Canada and France (in respect of St. Pierre et Miquelon). Although the spawning biomass has recently declined (refer to Healey et *al*., 2010), this stock has fared better than other Atlantic cod stocks, with only a three year moratorium on directed fishing during the mid-1990s.

At present, annual analytical assessments are based upon a survey-based approach (SURBA; Cadigan, 2010). This approach yields estimates of total mortality as well as stock size relative to the limit reference point of $B_{Recovery}$. The SURBA model used in annual assessments assumes that total mortality is separable into fixed age and year effects:

$$Z_{a,y} = s_a f_y$$

Recently, fisheries managers have requested provision of estimates of B_{MSY} and F_{MSY}. In order to determine F_{MSY} and MSY, we extend the assessment model by simply assuming that fishing mortality is the separable quantity, and supplying a nominal value for natural mortality:

$$Z_{a,y} = M_{a,y} + s_a f_y$$

In many situations, estimation of MSY-based reference points can require several important decisions. For the case of 3Ps cod, we illustrate the sensitivity of these estimates to the choice of:

i) assessment model,

ii) biological data (weights, maturities) & fishery selection patterns, and,

iii) stock-recruit model.

Though the current analytical stock assessment of 3Ps cod is based upon SURBA, VPAs had been used for many years to estimate historical stock size. VPA-based assessments for 3Ps cod were rejected as a result of several issues including uncertainty in the total annual removals. However, illustrative VPA-based estimates of B_{MSY} and F_{MSY} were computed via long-term deterministic projection. In this analysis, recruitment was generated from a hockey-stick model. Applying this approach yielded an estimated B_{MSY}=91Kt , and F_{MSY}=0.38.

Estimation of MSY-based reference points was also conducted using stock-recruit data from the 2011 3Ps cod SURBA-based assessment. Two stock-recruit models were fit to this data set: Beverton-Holt and a Watts-Bacon curve (refer to Mesnil and Rochet, 2010 for additional detail), which has the following functional form:

$$R(S) = \beta\left[S + \sqrt{S^{*2} + \gamma^2/4} - \sqrt{(S - S^*)^2 + \gamma^2/4}\right]$$

This model is a change point model (i.e. hockey-stick) with a smooth transition at the changepoint S^*, with the degree of smoothing controlled by the parameter γ.

After estimating the stock-recruit model parameters, MSY reference points were estimated deterministically using the Sissenwine-Shepherd approach (Sissenwine and Shepherd, 1987). As SURBA yields only estimates of SSB in the scale of survey units, B_{MSY} was calculated by adjusting the survey-scale B_{MSY} to the total area surveyed. Reference points were computed using each stock-recruit fit and with future productivity set at either a recent (2001-2010) or longer term (1983-2010) average of observed conditions (Figure 10-1). For 3Ps cod, weights at age have varied over time, but there has been a significant decline in the age at which 50% of fish mature. In addition to these biological factors, the fisheries selectivity pattern was also averaged over these same periods.

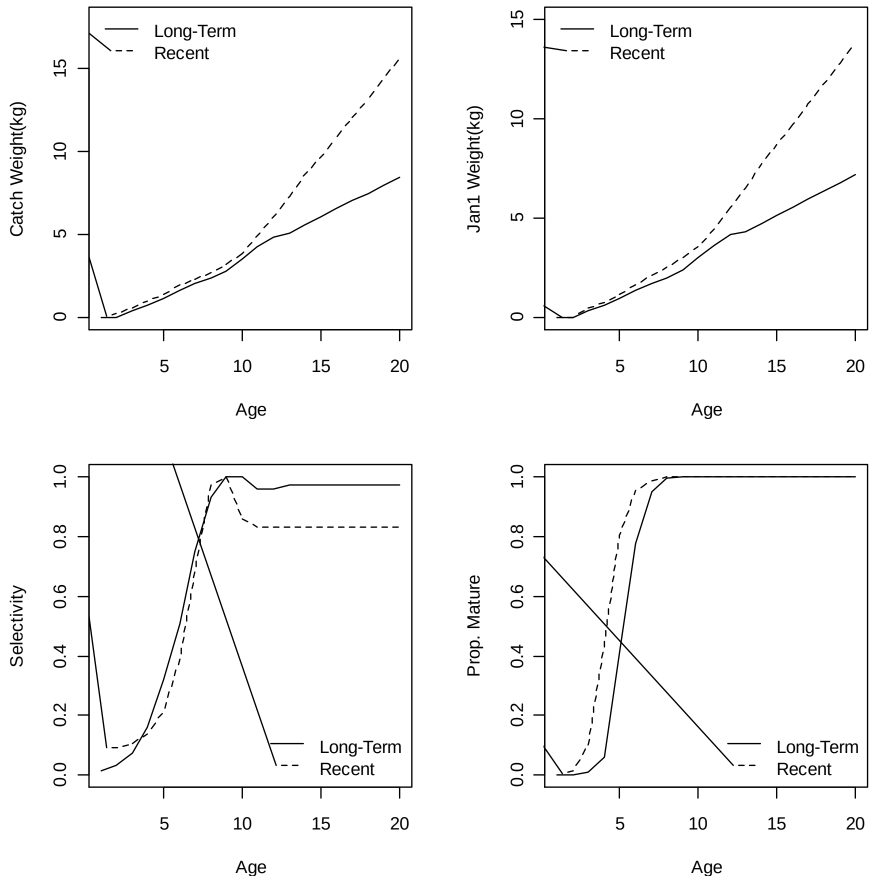

Figure 10-1. Biological and fishery parameters used to estimate MSY-based reference points for 3Ps cod. Recent values correspond to 2001-2010 averages, and Long-Term series are an average of 1983-2010 values.

Using the long term average conditions and assuming a Bacon-Watts recruitment mechanism, B_{MSY}=31Kt, with F_{MSY}=0.48. Using the Beverton-Holt parameter estimates B_{MSY} =19Kt, and with F_{MSY}=0.27. In general, hockey-stick models may be "dangerous" for estimation of MSY-based reference points, as F_{Crash} can be close to F_{MSY} (see discussion in Mesnil and Rochet, 2010). For 3Ps cod, with no clear evidence as to which stock-recruit model may be more appropriate, two arbitrary model choices yield a considerable difference in the resulting MSY reference points.

If more recent conditions are used to estimate the reference points, B_{MSY}=21Kt, with F_{MSY}=0.39 assuming a Bacon-Watts recruitment mechanism. If a Beverton-Holt formulation is used, parameter estimates B_{MSY} =30Kt, and with F_{MSY}=0.29.

Estimates of B_{MSY} and F_{MSY} for 3Ps cod are quite sensitive to the choice of assessment model, to the choice of stock-recruit model, and given the extent of changes in proportion mature and weights at age, to the biological inputs considered.

More generally, we suggest that simulation work is needed to evaluate the stability in MSY for some of the subjective choices required. If applicable, this should include evaluating the impact of various productivity scenarios.

All MSY-based reference points for 3Ps cod herein are provisional. The stock-recruit scatter considered does not clearly suggest one particular SR relationship over others. In addition, there are substantial differences in estimated reference points under two arbitrary choices (based upon historical observations) for assumed biological data / fishery selection patterns. The range of estimates obtained indicates additional study is required.

Discussion

- There was some discussion about the changing proportion of mature fish in the population. The change has been gradual.
- There was some discussion on which type of stock-recruit curve would be best to use for the data analysis. Accounting for uncertainty about the stock-recruit relationship is necessary.

PRESENTATION 11: Should reference points change when productivity changes? A perspective applied to 4T cod

Author: D. Swain

Whether reference points should be changed when productivity changes was addressed with respect to the cod stock in the southern Gulf of St. Lawrence (referred to as 4T cod). The discussion focussed on biomass reference points rather than reference points for fishing mortality (F). It was suggested that the answer to this question depends on the cause of the productivity change. If the change in productivity is related to a change in stock size, then reference points should not be changed. Examples of this type of productivity change are a density-dependent decline in productivity at high abundance and depensation at low abundance. On the other hand, if the change in productivity reflects a regime shift involving changes in conditions external to the population (e.g., changes in environmental conditions), then a change in reference points might be warranted, although the answer depends on the component of productivity that is affected. In general terms, it was argued that biomass reference points should be adjusted following a regime shift if the change in productivity is in carrying capacity K but not if it is in the intrinsic rate of increase, r (though F reference points would need to be adjusted in this case).

These issues were illustrated using the 4T cod stock. Productivity of this stock declined in the mid 1980s. Production per unit biomass fluctuated around zero in the 1990s, and there was a production deficit throughout the 2000s. All of the components of productivity (recruitment rate, individual growth rate, and natural mortality rate) contributed to the decline in productivity.

Estimated natural mortality of adult cod (ages 5+) increased during the 1980s and fluctuated at a level between 0.6 and 0.8 throughout the 1990s and 2000s (Figure 11-1). Swain et al. (2011) examined the evidence for a suite of hypotheses for the causes of elevated natural mortality of 5+ 4T cod. There was support for three of the hypotheses: 1) unreported catch in the late 1980s and early 1990s, 2) mortality due to poor fish condition combined with early maturation, in the early 1980s (due to a density-dependent decline in per capita food availability) and in the late 1980s and early 1990s (due to harsh environmental conditions), and 3) a predator pit caused by the collapse in cod abundance in the late 1980s and early 1990s, combined with increasing grey seal abundance. The main source of elevated natural mortality in the 2000s appeared to be this predator pit. A predator pit is a type of depensation. Depensation indicates that productivity has been seriously impaired and the stock is thus below the limit reference point (LRP or B_{LIM}). This type of productivity change should not trigger a revision to reference points (unless it is apparent that the LRP has been incorrectly specified, i.e. set at a level that is too low). Most of the causes of increased natural mortality earlier in the time series (i.e., unreported catch, fisheries-induced declines in size and age at maturation (Swain 2011), and poor condition due to a density-dependent decline in per capita food availability) also would not warrant revision to the biomass reference points.

Recruitment rate of 4T cod was unusually high from the mid 1970s to the early 1980s (Figure 11-2). This appeared to reflect reduced predation on cod eggs and larvae by pelagic fish, which had collapsed due to overfishing (Swain and Sinclair 2000). Pelagic fish biomass recovered and cod recruitment rates returned to more normal levels in the mid 1980s. This might be considered a regime shift, though in retrospect its duration was likely too brief to warrant revision to biomass reference points.

Size-at-age of 4T cod declined sharply in the late 1970s and the early 1980s, and has remained low since then (Figure 11-3). The decline in size-at-age primarily reflected a phenotypic response to a change in size-selective fishing mortality, as well as a density-dependent decline in growth (Sinclair et al. 2002). Changes in productivity for these reasons do not warrant a change in reference points. Reasons for the continued low size-at-age in this stock are uncertain. There is some evidence for a genetic response to size-selective fishing mortality in this stock (Swain et al. 2007), but this response should be reversible. Size-at-age may also now remain low due to size-selective predation mortality and reduced foraging success under increased risk of predation. These effects may be considered a combination of regime shift and depensation. The causes of reduced size-at-age in this stock are mostly of a type that should not trigger a revision to reference points.

The effect of a “regime shift” between high and low pelagic fish biomass (PFB) on a LRP based on RK_{50}, the spawning stock biomass where expected recruitment from a Ricker model is half the maximum, was examined by including PFB as a covariate in the stock-recruit relationship. Adding this covariate substantially improved the fit of this relationship. However, the estimated LRP was independent of the level of PFB.

Estimation of MSY-based biomass reference points when productivity varies was examined using a Schaefer production model with lognormal process error. It was suggested that changes in productivity should be modelled as changes in *K* if the changes are due to bottom-up effects (e.g., prey availability) and changes in *r* if due to top-down effects (predation). Changes in productivity of 4T cod were modelled as changes in *r*. A strong prior on *r*, estimated using demographic methods (McAllister et al. 2001), was used for the 1971-1982 period, and *r* was modelled using a random walk for the remainder of the time series. The model fit the data well, and biomass estimates corresponded closely with those estimated using VPA. However, there was a strong temporal pattern in process error. It was argued that this indicated a mis-specification of model structure, and that model structure should be revised before using it to estimate reference points.

It was concluded that biomass reference points should not be changed when productivity changes if the change is related to stock size (e.g., depensation, including a predator pit), or if the change is a reversible effect of fishing. If a regime change occurs, it was concluded that biomass reference points should be changed only if the regime change affects carrying capacity (bottom-up effects) and only if the change is a longterm change.

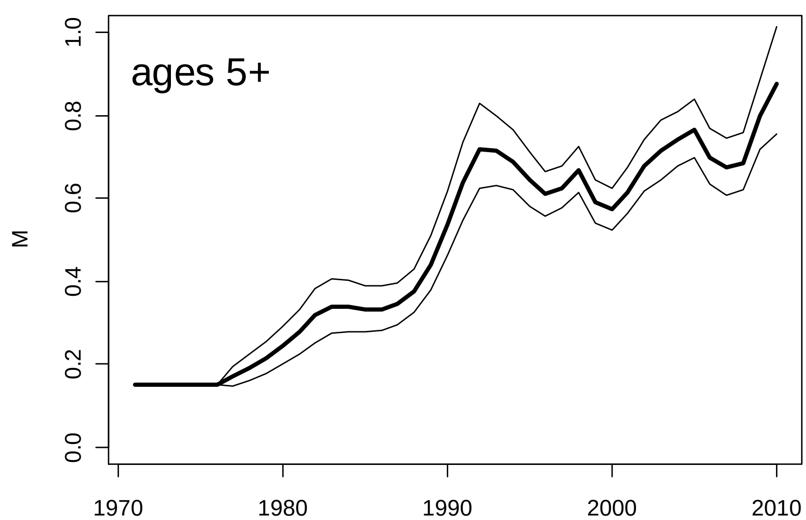

Figure 11-1. The estimated instantaneous rate of natural mortality M of southern Gulf of St. Lawrence cod aged 5 years and older.

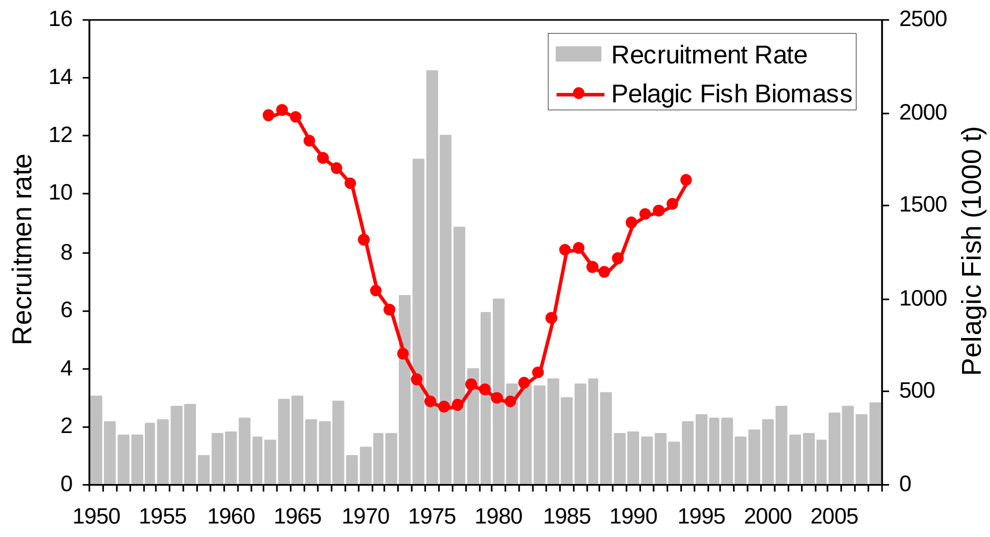

Figure 11-2. Recruitment rate (recruits per unit of spawner biomass) of cod (grey bars) and biomass of pelagic fishes (herring and mackerel) in the southern Gulf of St. Lawrence.

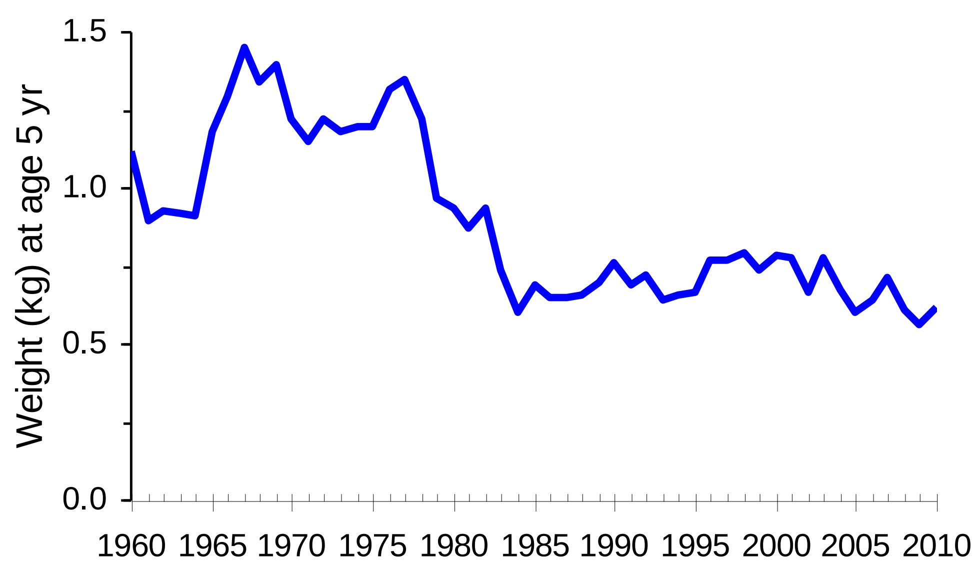

Figure 11-3. Average weight of a 5-year-old cod in the southern Gulf of St. Lawrence in September.

Discussion

- There was some discussion about the inclusion of a random walk in *r* and process error in the model and whether using an autocorrelated process would be beneficial. The presenter prefers to avoid a trend in the process error by using a better model.
- The presentation argues that reference points shouldn't change if there are some production changes.

PRESENTATION 12: Case study of Eastern Georges Bank haddock

Author: Y. Wang

The haddock on Georges Bank have supported a commercial fishery since the early 1920s. Record high landings reported from Eastern Georges Bank (EGB) were about 60,000 mt during the early 1960s. Prior to mid-1990s, EGB haddock had been over-fished for decades. The stock had experienced long-term declines in spawning biomass and recruitment and was considered by some to have been near collapse in the early 1990s. Improved recruitment in the 1990s and the strong 2000 year-class, lower exploitation, and reduced capture of small fish in the fisheries allowed the biomass to increase from near a historical low of 10,300 mt in 1993 to 82,600 mt in 2003. The dramatic increase of the biomass after 2005 was due to the exceptional 2003 year-class. The preliminary estimate for the 2010 year class is outstanding, which would make it the largest in the assessment time series: 1931-1955 and 1969-2010 (TRAC 2012). In this presentation, two questions will be discussed. One is if productivity has improved with the rebuilding of EGB haddock since mid-1990s compared to the early 1930s; another is what its implication is in the reference point calculations when incorporating the Precautionary Approach.

The values at age for natural mortality, fishery partial recruitment, fishery weight, spawning biomass weight, maturity, spawning stock biomass and recruitment data are derived from the 2011 assessment. These values are used for productivity comparison over the time period of 1931-2011 and reference point calculations.

There is no evidence of natural mortality, maturity and spatial distribution changes. The relationship between length at age and year class strength has shown density dependent effect on fish growth, also Fulton's *K* calculation shows decline in fish condition after 2003. With management regulations intended to reduce catch of younger fish after 1994 and fish size changes after 2003, the fishery fully recruited age shifted from age 3 in 1969-94 to age 4 in 1995-2002 and age 5 in 2003-2010. If recent changes in size at age are assumed to be density dependent effect, then these effects are transient meaning that the stock may return to earlier conditions and no regime change is considered, a long time period to average the mean weights at age will be more appropriate to calculate reference points.

Although the rebuilding of this fish population after mid-1990s has been driven by a few strong year classes, examination of stock-recruitment relationship shows that the recruitment has been highly variable associated with changes in biomass in recent years. No evidence of a change in recruitment productivity based on different level of productivity at the same biomass for two different time periods (Figure 12-1). Comparison of surplus production (B_{t+1}-B_t+C_t) with early years of 1931-1955 also illustrates no productivity regime changes with the rebuilding of EGB haddock in recent years (Figure 12-1).

Both the parametric Beverton-Holt and Ricker stock-recruit models were fit to the Recruitment and SSB, both models fit the data poorly, with strong time-series patterns in the residuals. Then a non-parametric Lowess smoother was applied (Figure 12-2). The Sissenwine and Shepherd production model was used to calculate the MSY and B_{MSY}, which resulted in B_{MSY} =76,000mt and MSY=20,000mt. If a proxy for B_{MSY} is used, which is the biomass corresponding to the biomass per recruit at F0.1 multiplied by the average number of recruits. The B_{MSY} was 86,000mt and 54,000mt, respectively, when the 3 strong 2000, 2003 and 2010 year classes were included or excluded in the calculation.

Some preliminary exploration was done on B_{LIM} using empirical LRP methods $B_{Recovery}$ and SSB50/90 (DFO 2002). Under the assumption of no productivity regime changes, $B_{Recovery}$ reflected the stock biomass dynamics and its resilience under different fishing pressure. The Sb50/90, which is very close to this value, also provided insight into the reliability of this metric. Further work and examination are needed in the future for the final decision on B_{LIM}.

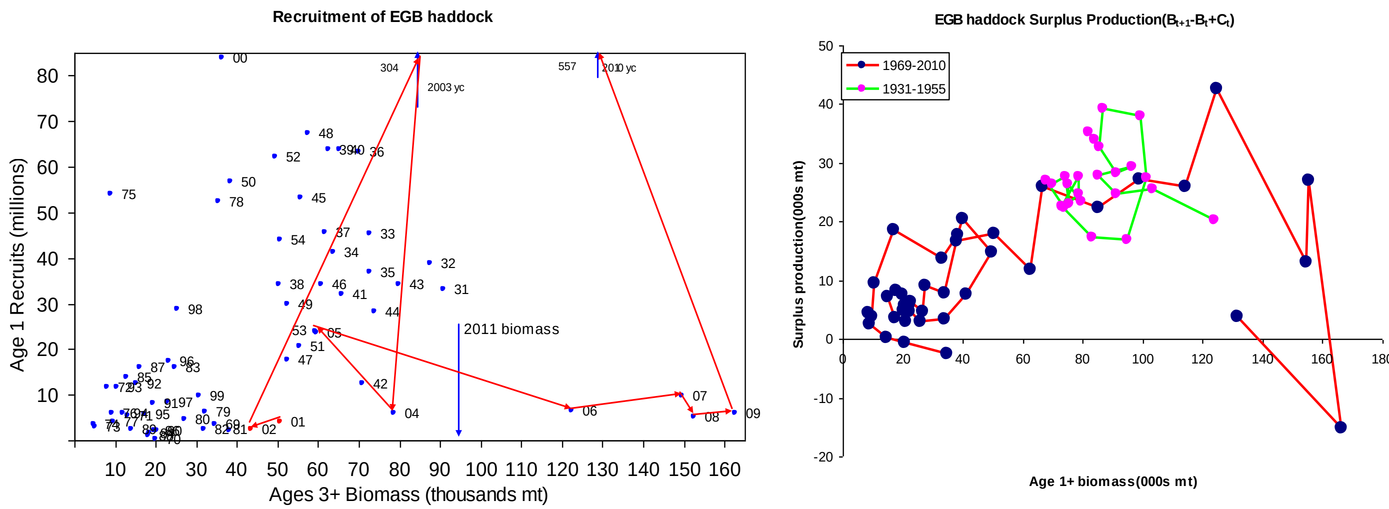

Figure 12-1. Scatter plots of SSB and Recruitment (left) and surplus production vs.SSB(right) of EGB haddock. The red arrows show (left) show the recruitment after 2000.

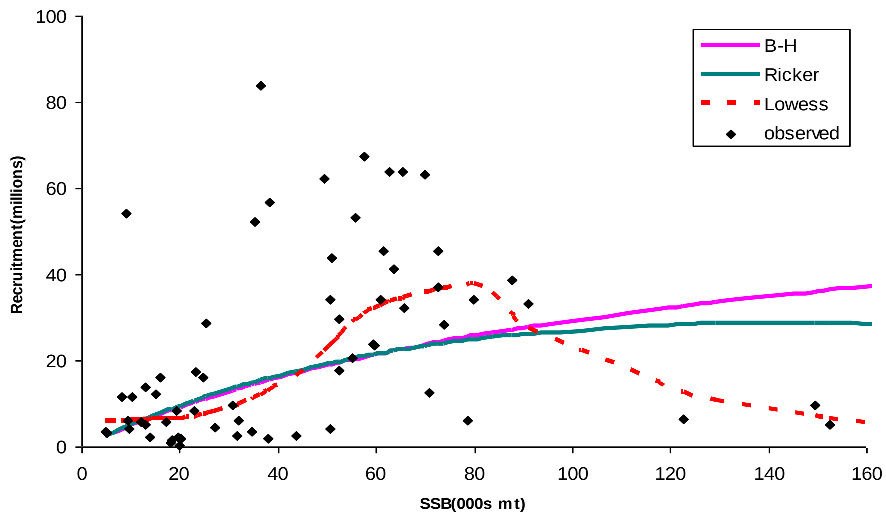

Figure 12-2. Parametric B-H, Ricker and non-parametric Lowess smooth stock recruitment curves fitted to EGB haddock SR data.

Discussion

- The similarities between Haddock stocks on both sides of the Atlantic were noted.
- This is an example of an earlier discussion – one productivity regime with a few anomalous years of higher productivity. Because the changes are a function of the stock's biomass, there is an argument for not changing biomass reference points.
- Should not adapt reference points to occasional strong recruitment years

PRESENTATION 13: Correlation between productivity of the North Pacific albacore tuna stock and Pacific decadal oscillation

Author: Z. Zhang and John Holmes

Albacore tuna (*Thunnus alalunga*) is a highly migratory species found in the temperate and tropical oceans of the world. The North Pacific albacore stock is harvested by Canada, Japan, USA, Chinese-Taipei, Korea, and Mexico using longline, pole-and-line, troll, purse seine, and gill nets. A stock assessment was conducted using the stock synthesis modeling platform in 2011, but oceanographic factors were not considered. Here we use a logistic surplus production model as an exploratory tool to identify oceanographic variables that may affect albacore stock dynamics. The data used in the model include catch-per-unit-effort (CPUE) from five major fisheries (US and Canada troll, US longline, Japan pole-and-line, Japan longline, and Chinese-Taipei longline) and total combined catches over the period of 1972-2009. We fit the model in Bayesian state-space fashion, and modeled both observation (measurement) and process errors using the lognormal probability distribution. Priors for all model parameters were set to be uninformative. Each of the five fisheries has its own catchability coefficient, through which the CPUE is associated with the abundance of the stock, and this coefficient is assumed to be time-invariant. To estimate the variability in stock productivity between years, we allowed the intrinsic population growth rate to vary, reflecting presumptive annual variation in recruitment, mortality, and growth, and we modeled process error using a random walk function. Since modeling both process error and variation in growth rate simultaneously may have a compounding effect on the estimation of variation in biomass we also conducted a model run in which variance for the process error was fixed to a small value (0.00001). We examined correlations between the estimated growth rate over the years 1973-2008 and five oceanographic indices, Pacific Decadal Oscillation (PDO), North Pacific Gyre Oscillation (NPGO), Multivariate El Niño Southern Oscillation Index (MEI), Northern Pacific Index (NPI), and Western Pacific Index (WPI). The correlation appears to be qualitatively good with the PDO index only. Both modeling approaches (process errors freely vary or enforced to be negligible) produced similar results. Figure 13-1 (with negligible process error) shows the correlation of growth rate and PDO with a 2-year time lag. The correlation is significant ($p<0.05$) for the winter and spring months (Dec-Apr), and is not significant for other months. The 2-year time lag is consistent with the fact that north Pacific albacore recruit to the major surface fisheries (troll, pole-and-line) as juveniles at age 2 and the winter timing is consistent with the main spawning and larval recruitment period in the north Pacific albacore stock. We plan to consider incorporating the PDO into the assessment model as a method of improving the model fit to existing data.

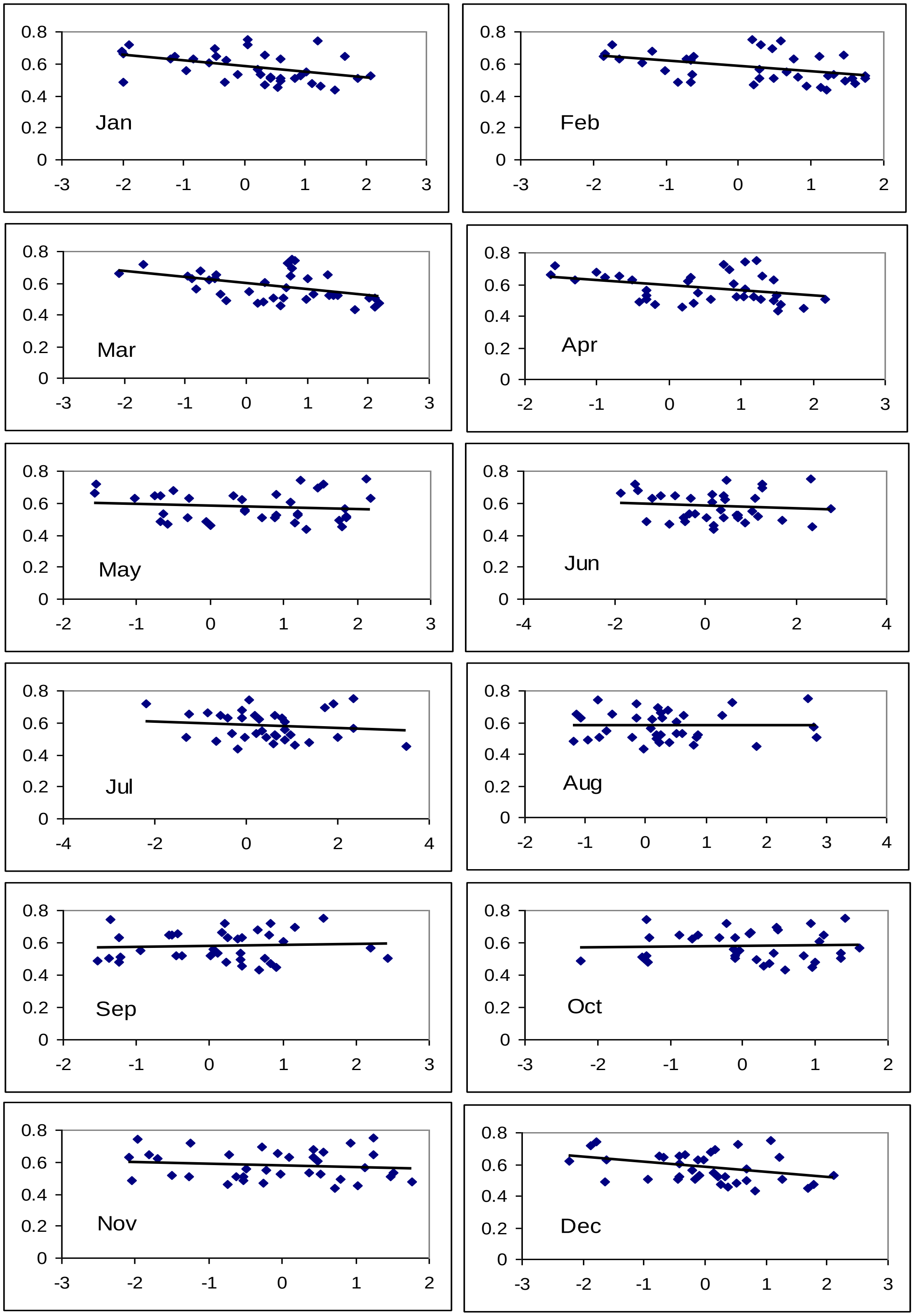

Figure 13-1. Correlation between estimated intrinsic population growth rates (r) over the years of 1973-2008 and Pacific Decadal Oscillation (PDO) with 2-year time lag.

Discussion

- It was noted that this is an example of a shifting regime rather than a regime shift.

PRESENTATION 14: Wild Salmon policy lower biological benchmarks with considerations of time-varying productivity: Fraser River Sockeye case study

Author: S. Grant

Productivity has systematically declined for most Fraser Sockeye stocks, independent of spawner abundances (Figure 14-1; Grant et al. 2010 & 2011; Peterman & Dorner 2011). Two notable exceptions are Late Shuswap Sockeye, which have not exhibited any systematic productivity trends, and Harrison Sockeye, which have increased in productivity in recent years. Harrison Sockeye, in particular, have a unique age-structure and life-history compared to all other Fraser Sockeye stocks. Harrison Sockeye migrate to the ocean shortly after gravel emergence (most other Sockeye rear in lakes for one to two years prior to ocean migration) and return as age-3 & age-4 fish (most other Sockeye return at age-4 & age-5) (Grant et al. 2010 & 2011). Fraser Sockeye productivity has been extremely variable in the last two brood years. The 2005 brood year productivities (2009 return year for most of these Sockeye) were amongst the lowest on record for most Fraser Sockeye stocks, including Harrison Sockeye (Figure 14-1). In contrast, 2006 brood year productivities (2010 return year for most of these Sockeye) were average for most stocks including Harrison (Figure 1), with the exceptions of Late Shuswap, Scotch and Seymour, which exhibited well above average productivities.

Understanding the mechanisms affecting survival of Fraser Sockeye is complex, given their broad distribution in both the freshwater and marine environment throughout their life-history (typically two years in freshwater followed by two years in the marine environment). For most Fraser Sockeye populations with juvenile abundance data, which can be used to partition total survival into early freshwater survival and late freshwater survival/marine survival, recent survival trends are more closely associated with marine (and late freshwater) survival, versus early freshwater survival (Peterman & Dorner 2011). In attempts to improve the predictability of Fraser Sockeye survival, return forecasts have incorporated environmental variables, both quantitatively into forecast models (Grant et al. 2010) and qualitatively into forecast advice (DFO 2009). Data reported annually in Canadian Science Advice Secretariat (CSAS) State of the Pacific Ocean reports (e.g. Crawford & Irvine 2011), in particular, have been used in the forecast process. However, to date, inclusion of environmental variables has not significantly decreased forecast uncertainty (i.e. it has not significantly explained annual Fraser Sockeye survival rates).

DFO's Wild Salmon Policy (WSP) (2005) requires that biological status (Red, Amber, or Green, representing a continuum from, respectively, poor to healthy status) be identified for each Pacific salmon conservation unit (a CU is roughly equivalent to a stock for Fraser Sockeye). In light of the systematic declines in Fraser Sockeye productivity (or increases in the case of Harrison Sockeye), biological status assessments for Fraser Sockeye CUs were compared using a combination of standard stationary productivity models (that assume time-series average stock productivity) and time varying productivity models (that assume recent productivity) to estimate biological benchmarks (Grant et al. 2011). Recommended WSP lower and upper biological benchmarks for metrics on abundance include, respectively, S_{gen} (the spawner abundance that would result in recovery to maximum sustained yield (S_{MSY}) in one generation) and 80% S_{MSY} (Holt et al. 2009), using the standard Ricker model in a Bayesian framework. For Fraser Sockeye CUs that have exhibited recent productivity declines, Ricker model forms that emphasize this recent (generally low) productivity in benchmark estimation, generally produced larger (more biologically conservative) lower benchmarks, compared to the standard (full time-series) Ricker model (Grant et al. 2011). This result is attributed to the negative covariation between the WSP *abundance* metric lower benchmark (S_{gen}: recovery to S_{MSY} in one generation under equilibrium conditions) and the Ricker model's intrinsic productivity ('*a*') parameter (Holt & Bradford 2011). Recent simulation results reported that while S_{gen} benchmarks increase as a population's intrinsic productivity decreases from moderate to low, other benchmarks (e.g. benchmarks that are percentages of S_{MSY}) don't change significantly (Holt & Bradford 2011). Therefore, during periods of reduced productivity, larger lower benchmarks (estimated from Ricker model forms that emphasize recent lower productivity) may assist with protecting CUs from extirpation, depending on how often benchmarks are re-estimated and how these results are applied to harvest management.

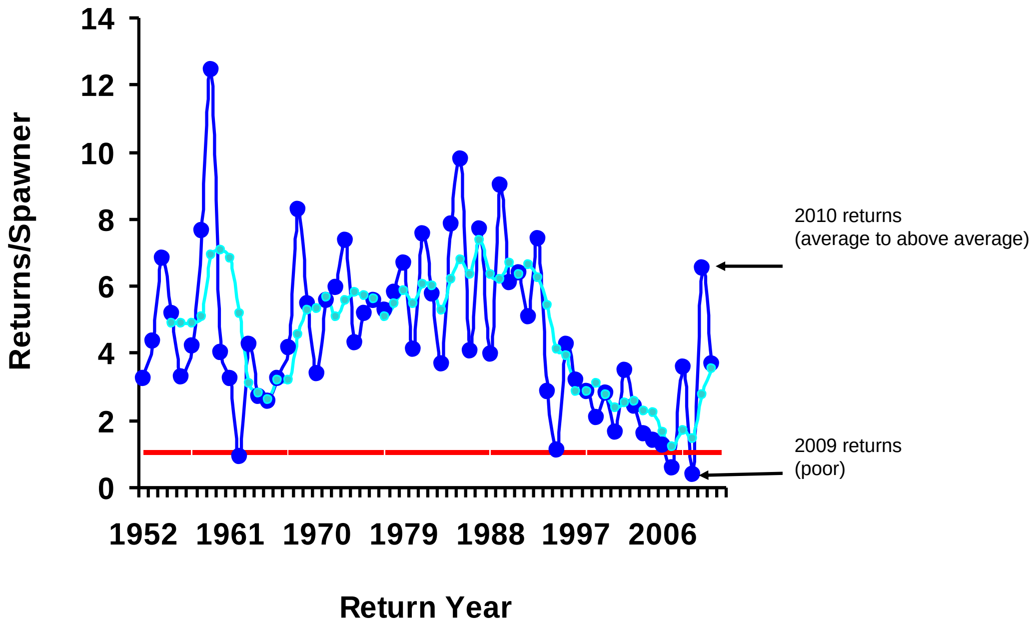

Figure 14-1. Dark blue line is total productivity (returns/spawner) for Fraser River Sockeye Returns from 1952-2011; light blue line is a four year running average (Data from M. Lapointe, Pacific Salmon Commission). This trend is dominated by Summer Run stocks, which contribute most to the total return abundance in any given year. There is considerable variability among stocks regarding this trend (Grant et al. 2011). Dashed (red) line represents replacement (1 return per spawner). Note: Return data from 2009-2011 are preliminary.

Discussion

- Points of clarification only.

PRESENTATION 15: Environmental influences on snow crab productivity

Author: B. Sainte-Marie

No Abstract Provided

Discussion

- The 95mm size limit is good protection for the stock; however, there can be a problem if the reference points are based on a biomass of large males. If the population shifts over to entirely large males but with fewer numbers, the size limit would be hard to deal with.

PRESENTATION 16: Scallop site based productivity difference and implications for setting reference points

Author: S. Smith

The spatial distribution of species such as scallops are often determined by habitat type and knowledge of habitat type can not only lead to more accurate and precise surveys but also provide insights into the spatial aspects of the population dynamics of the species and the spatial impacts of the fishery. Scallop fishing area 29 off the southwestern coast of Nova Scotia is an area where annual scallop surveys have been available since the fishery started in 2001, the area has been mapped using multibeam echo sounders, geophysical characteristics have been determined and fishing has been monitored with logbooks and satellite monitoring systems (VMS). In addition, a number of image surveys have been conducted where both the bottom type has been described and the species in the images have been identified. Species distribution modeling based on the multibeam and image data characterized the habitat suitability for scallops. Fishing pressure metrics from the VMS data matched the habitat suitability patterns with the higher pressures occurring on the more suitable habitat areas. The scallop survey data also matched the habitat suitability patterns with the higher densities occurring on the more suitable habitat. The combination of this information showed that the higher suitability areas were more productive and tended to be fished down first until densities were similar over all suitability types. The implication of this pattern is that if management ignores the relationship between habitat and productivity, the higher productivity areas will generally be overfished. Impacts of this kind of spatial dynamics on establishing reference points were presented.

Discussion

- An example where spatial variability in productivity is important
- There was discussion about whether this is a theoretical problem or an implementation of management rules problem. It is being managed by area but the harvest is in a large area with a lot of habitat types. The most productive habitats within that management area are fished intensively first and are fished below their MSY level. The fishing effort is distributed over a larger area as the productive areas become overfished.
- A precautionary approach may be to assign a lower quota than the productivity would suggest.
- There are MSY's specific to specific subareas where there is higher productivity. They get fished harder and are therefore more vulnerable to over exploitation, relative to their MSY.
- The challenge is to set the TAC optimally for each subarea.

PRESENTATION 17: Assessing Northwest Atlantic Harp seals during a period of changing fecundity

Author: G. Stenson

Population trends and reproductive status of Northwest Atlantic harp seals, *Pagophilus groenlandicus*, have been monitored since the 1950s. Total abundance is estimated using a population model that incorporates data on age-specific pregnancy rates since 1952, total human induced removals (i.e. reported catches in Canada and Greenland, bycatch in the lumpfish fishery and estimates of the number of seals killed, but not landed) and periodic estimates of pup production. Recently, a parameter has been incorporated to account for density dependent changes in mortality of young of the year seals.

Incorporating density dependence in the population model requires us to assume some level for the carrying capacity (‘*K*’). For most species, carrying capacity cannot be estimated at the present time. In the absence of estimates of *K*, estimates of pre-exploitation abundance have been used to provide an indication of possible current carrying capacity. Harp seals have been commercially exploited since the early 1700s, although significant catches did not begin until early in the 19^{th} century. Catch data from historical records and recent harvests were incorporated into a surplus production model to reconstruct the dynamics of this population back to the late 18^{th} Century. The initial population was estimated at 11 million (SE=2,000,000) animals. This population estimate serves as a proxy for current carrying capacity assuming that environmental conditions in the 18^{th} century were similar to conditions today.

Using 10 estimates of pup production between 1950 and 2004, and smoothed (‘trended’) estimates of age specific reproductive rates, the model predicted pup production in 2008 to be much lower than observed. However, examination of the reproductive rates indicated that although the model has captured the general decline in reproductive rates as the population has grown, there was also large interannual variation with fecundity rates (i.e. the proportion of sexually mature animals that are pregnant) being less than 40% in 2004, but >70% in 2008. When annual estimates of fecundity were included in the model, the fit to all of the pup production estimates was improved and the differences between the 2004 and 2008 estimates reconciled. Subsequent studies have shown that annual reproduction rates have continued to decline. Samples collected up to 2011, indicate that adult reproductive rates have declined to as low as 0.22, which is much lower than the estimate of 0.74 observed for 2008, the last year data were available for the 2010 assessment. As a result of these changes, our perception of the population trends has changed significantly in recent years.

A series of biological and environmental factors were examined in an attempt to explain the changes in fecundity rates. The best model ($r^2 = 0.845$) included two parameters: total population, which explained the overall decline, and annual estimates of the proportion of late term abortions which accounted for interannual variations in fecundity. Although the fit was not as good ($r^2 = 0.631$), the abortion rate could be explained by the extent of 1^{st} year ice in late January and the abundance of capelin in the multi-species bottom-trawl survey carried out the previous fall.

Harp seals have been managed under the precautionary approach (referred to as the Atlantic Seal Management Strategy) since 2003. Given that the amount of information available for resource management varies among populations, the first step in identifying appropriate reference levels is to distinguish between populations for which we have a reasonable understanding of their recent abundance and population dynamics (referred to as ‘Data Rich’) and those for which we do not (‘Data Poor’). Criteria for data-rich species have been defined for seals: they must have 3 or more abundance estimates over a 15-year period, with the last estimate obtained within the last 5 years, and current (≤5 years old) information on fecundity and/or mortality. If these data are not available, the species would be considered as data-poor. Northwest Atlantic harp seals are one of, if not the best, studied marine mammals in Canada and are considered to be data rich.

If a population is classified as being data rich, critical and precautionary reference levels can be set based upon an acceptable population model that estimates total abundance. Internationally, reference levels for many marine mammals are identified with respect to pre-exploitation levels or carrying capacity. For Atlantic seals, however, reference levels are set as a proportion of the maximum observed or estimated population size (N_{MAX}). The maximum population size (estimated or inferred) is used as a proxy for the carrying capacity (*K*) because of difficulties estimating *K*, particularly among species that were heavily exploited historically and are only now recovering. As the population recovers towards carrying capacity, N_{MAX} approaches *K*.

For Atlantic seals such as harp seals, the limit reference point (LRP) is set at 30% of the maximum population. The precautionary reference point (PRC) or Upper Stock Reference should be set to ensure that the cautious zone is sufficient to ensure a high probability (95%) that LRP is not exceeded. Based upon previous studies on various marine mammals, and subsequent simulation studies, the PRC has been set at 70% of N_{MAX}. Uncertainty in the abundance estimates due to the periodic nature of marine mammal assessments is accounted for by requiring that in order to be in the healthy zone, there must be an 80% probability that the population is above the precautionary reference level.

Estimates of abundance based upon population models tend to be heavily influenced by the most recent data. As observed in recent years, new surveys or reproductive data can change our perception of the population significantly. By using a maximum level that varies slightly with new data and identifying precautionary levels as a proportion of this maximum, these changes in absolute numbers do not necessarily change our understanding of the healthy of the population and subsequent management objectives.

Discussion

- There was discussion around some of the problems around using fecundity or mortality as parameters and the how density dependence changes those parameters.
- There was general consensus that estimates of B_{MSY} are uncertain. It may be better to manage to have low probability of being below MSY – explicitly taking uncertainty in stock size estimates and B_{MSY} uncertainty into account.

BREAKOUT GROUP REPORTS

After two days of presentation and discussion largely focused on the presentations, the third day consisted of three breakout groups in the mornings which were tasked with a specific question and had to return in the afternoon to report on these. The questions and the group reports form the substantive part of the report in terms of new conclusions reached along the lines of the terms of reference set out for the meeting.

Three questions and thus three breakout groups were:

1. When should reference points change in relation to supposed productivity changes and what kind of guidance can be offered on this?
2. What are some MSY options for reference points especially in regard to stocks in Canada?
3. How and should process error be accounted for in stochastic MSY reference points?

When is it appropriate to consider changing precautionary reference points in relation to a perceived regime change

Introduction

East coast groundfish abundance and productivity was high until the mid 1980s and then declined quickly afterwards reaching lows in the mid 1990s. Concurrent with the declines in groundfish productivity and biomass, the abundance and productivity of invertebrates such as pandalus shrimp increased markedly in east coast waters including in the Gulf of St. Lawrence and the Newfoundland and Labrador shelf. Overfishing has usually been identified is the primary culprit in this groundfish decline which released invertebrates from fish predation allowing their increase but even with a large reduction in fishing mortality, many of these groundfish stocks have failed to recover to previous levels suggesting that a change in productivity conditions for the stocks may have moved to a different state.

These changes in productivity have raised the question of what are the appropriate time-frames that should be used for establishing reference points for precautionary approach development for these stocks. Industry has raised concerns that if biomass reference points are set based on high historical stock sizes, many groundfish stocks would fall deep in the critical zone while current low productivity could be expected to continue for some time. These low reference points would require setting low catches to allow more surplus production to go to stock growth, while argue catches may be reduced unnecessarily as historical stock sizes may not be obtainable under current conditions. On the other hand there are concerns that "setting the bar low", i.e. based on recent low productivity conditions only, would reduce the possibility of ever returning to past stock sizes and could even lead to further declines.

The following text is a summary of a breakout group on "When it is appropriate to adjust reference points when productivity changes" during the TESA workshop. The paper is informed by presentations made at the workshop (see abstracts above). It was concluded that biomass reference points should rarely be adjusted to a new productivity regime by restricting the data to particular time frames but there are conditions under which it may be appropriate. This breakout group report outlines conditions where points could or should not be altered to accommodate the change to a new productivity regime. In addition, best practices are outlined to aid decisions on whether to change points in a regime specific way or not. Methods for changing the points themselves or by how much are not offered as these would necessarily be decided on a stock-by-stock basis by a group of appropriate experts.

The following guidance is designed to be consistent with DFO Precautionary Approach Policy (DFO 2009).

> When developing reference points efforts should be made to take into consideration the range of factors which may affect the productivity of the stock including changes in ocean conditions, where information is available.

> In general, as long as a time series as possible should be used in establishing reference points for a stock. Many stocks will show substantial variation in productivity over a long time series, and this variation should be taken into account when setting the reference points. […] These cases need to be evaluated individually, but as a general rule the only circumstances when reference points should be estimated using only information from a period of low productivity is when there is no expectation that the conditions consistent with higher productivity will ever recur naturally or be achievable through management.

Definitions of terms used here

Production: the net total effect of the biological processes of somatic growth, recruitment and mortality of a fish stock. Positive production means a stock is growing in biomass while negative production means it is decreasing.

Productivity: Productivity is the assessment of the level of production which is affected by the components of production itself. It is defined in relation to the conditions that lead to changed levels of production. High productivity conditions are through convention defined as conditions when stocks have achieved high biomasses in their time series and have supported relative large fisheries.

Surplus production: Surplus production is the rate of growth of a fish stock (including growth of individuals as well as recruitment) in excess of what is needed to compensate for losses due to natural deaths.

Productivity regime shift: A productivity regime shift is a change in environmental conditions that has led to a change in the production of a stock (or a change in multiple stocks and multiple species of an ecosystem). A change in production due to stock size alone is not a regime shift. Low production because of depensatory phenonmena at small stock sizes or density dependent processes at large stock sizes when the stock is approaching carrying capacity are not considered to be the consequence of a changing productivity regime. It may take many years of data to statistically distinguish a regime change from random variations caused by environmental conditions.

Constant external regime: A relative constancy of factors external to the stock (predators, food, chemical and physical environment) which affect a stock's production. There may be fluctuations seasonally, interannually, and spatially within that period; however, there is a lack of sustained directional trend in these factors. A change in regime would then be movement to a different level of these external factors that has persisted for some time and is expected to last in the medium to long term.

When should a regime shift be considered a credible explanation for change in stock productivity?

- When there is a shift to a new set of environmental conditions that affect stock production and which last a relatively long time (an example could be a decade or one generation, whichever is longer)
- Short term changes (less than decadal or less than one generation) are not considered regime shifts.
- In a single species management context, demonstrating a regime shift in the biomass and production of the species of interest is sufficient yet the case for demonstrating a regime shift is much more credible with evidence of changes in production of several species in the system and particularly over multiple trophic levels.
- Decreased stock production resulting from a decrease in stock biomass alone is not evidence of a regime shift. Apparently stable and lasting low stock production can result from low biomass and phenomena such as depensation, the Allee effect and predator pits.
- Observed increased stock production that can be explained by changes in biomass state of the stock and factors such as changed stock behaviours, such as changes in migration and movement leading to greater susceptibility to sampling or fishing gear are not evidence that a regime shift has occurred.
- The burden of proof should be on demonstrating a rational that there has been a regime shift not that conditions have remained constant

When should biomass reference points change when productivity changes?

The criteria below should all be met before one considers changing reference points in relation to perceived productivity changes:

- It is only appropriate to calculate a new reference point for a different regime when the conditions specified in the above subsection ("when should a regime shift be considered a credible …") have been met. It is possible to identify at least the major ecological mechanisms involved in the change: It is only appropriate to adjust reference points because of a regime change when key mechanisms by which the regime change is affecting stock production have been isolated and quantified. Normally this would require knowing which life-history stage is affected and a rough idea of the nature of the relationship (directionality, linear or not, appropriate lags between cause and effect on the stock). Any change in biomass reference points should be consistent with the knowledge of how the mechanisms affect stock production.

- The new regime is expected to continue: Biomass reference points should only be adjusted to a recent period if it the change is expected to continue over a period where management adjustment to the change will reduce risk of overfishing and/or depletion of the stock.
- The regime shift results in a change in carrying capacity (K): Biomass reference point estimates are often largely dependent on the implicit or explicit estimation of the system's unexploited equilibrium biomass or carrying capacity. In most cases if carrying capacity has not changed, there is no population dynamics rationale to change biomass reference points.
- Management of stocks to keep them within them with specified reference levels will require changes in F and when stocks move outside the specific reference levels, management should adjust first through more aggressive changes in F. It is only when it appears that stocks are not responding to these aggressive changes in F that the possibility of a regime shift should be considered and potentially modifying reference points.

When to consider changing fishing mortality reference points

- When productivity changes because of changing carrying capacity (K): because fewer recruits are produced under lower K, catch and F should be lower.
- When declining productivity leads to reduced recruitment rate (R/SSB), more SSB would be required to give the same level of R, therefore, catch and F must be reduced.
- When the changing regime reflected in increased natural mortality, M becomes a larger proportion of Z ($Z=F+M$) and catch and F must be reduced to maintain biomass within the bounds of biomass reference points.
- When the changing regime reflected in decreased fecundity from density independent effects, F must go down because more spawners are needed to produce the same number of eggs.
- When the changing regime is reflected in decreased growth from density independent effects, F must be decreased because: (1) for the same catch in weight, more individuals will need to be removed; (2) you will need more individuals in the stock for a given spawning stock biomass; and (3) fecundity will also be affected and you will need more individuals to produce the same number of eggs and recruits.

Adjustment of F and management in relation to productivity rather than adjusting biomass reference points

All ecosystems experience random annual fluctuations in environmental signals with varying degrees of autocorrelation. Unless the autocorrelation is relatively strong, most of these fluctuations would not qualify as regime shifts; nevertheless they have effects on annual stock production and even the production of a cohort throughout its life. Adjusting fishing mortality in relation to a stationary set of precautionary approach biomass reference points is a recommended means of dealing with this kind of varying stock productivity.

In most cases, when productivity changes it will be more appropriate to adjust total removals, exploitation rates, target sizes and/or timeframes to get to target stock sizes as opposed to changing reference points.

A good method of dealing with productivity change is within a management strategy evaluation (MSE) framework where simulations are performed with plausible hypotheses related to regime shift. Management strategies that are robust to the changes in productivity can then be identified, as well as the costs in yield compared to alternative strategies. Alternatively, using MSE, one can examine the likely outcomes of reacting to a purported regime shift by adjusting reference points and take into account the imperfect knowledge of the productivity change and how it is affecting stock production.

Implications of adjusting reference points to an assumed regime shift

There are important implications in adjusting reference points to an assumed regime shift. Before one embarks on adjusting reference points to regime changes, these implications should be considered.

If a stock is already in a very poor state relative to current reference points and the proposal is to adjust lower biomass reference points for a low productivity regime then the adjustment increases the possibility that the stock will remain in a low biomass state or decrease even further. This is because the new estimates of reference points will appear to make the stock look healthier and there is less pressing need to allocate surplus production to growth rather than fishing. A stock managed in this way less likely to be able to take advantage of good productivity conditions, if and when they arise, that could potentially move the stock to a higher biomass state. Additionally, size selective fisheries on small stocks could apply a strong selective force for early age at maturity and small size-at-age in the stock.

In practice, adjusting reference points to a new regime would restrict analyses to a recent subset of the data. This is not always the best choice, however. It may be better to use different approaches which need to be assessed case-by-case. At least three factors should be considered (1) the relative magnitude of the change in the productivity regime – larger changes give greater imperative for considering only the recent subset (2) the amount of data available for the new productivity regime and if that is sufficient for the methods being applied (3) the management question, i.e. next year's TAC or a long term recovery target – the latter would require that one consider the full productive scope of the stock.

Furthermore, in the case of decreased productivity, those most recent 10 years of data are likely to have been during periods where there were large fluctuations in the management regime in attempt to balance the productivity decrease with industry over-capacity and the subsequent social issues during those periods. This added complexity could present a challenge for correctly identifying changes in stock productivity conditions.

Recommended or best practices

Because the implications of adjusting reference points to supposed regime changes can be great, certain best practices should be used:

- Document evidence for regime shifts in the system in general and the species of interest in particular and eliminate the possibility of low production simply because of low stock size.
- Document evidence of mechanism, i.e., how the factors external to the stock (predators, prey, chemical and physical environment) associated with the regime shift are affecting the productivity of the stock. This should be both quantitative (numerical analysis and statistics such as correlations) and qualitative (description of the causal pathway and potential confounding effects).
- Provide calculations of new reference points compared to old reference points and outline the implications of management advice under each, including the stock status relative to points and the apparent sustainability of current catches. This should also consider using simulation approaches.
- Demonstrate that the duration of the regime is likely to be sufficiently long in relation to duration of the management plan that adjusting biomass reference points for the regime change can be practically responded to by management

- Estimate uncertainty in reference points in regime change vs no-regime change scenario. Assess how this uncertainty would affect risks for each and if they are substantially different.
- A change in reference points should be supported by simulation approaches to compare i.e., the ability of a management plan that includes adjusted reference points should be tested for its ability to meet management objectives

Pacific salmon: An alternative approach to reference points under varying productivity conditions

To designate biological status for Pacific salmon under the Wild Salmon Policy (Holt et al. 2009), a number of indicators (abundance, trends in abundance, distribution and fishing mortality) are used that may include one or more metrics. For each metric corresponding lower and upper benchmarks delineate, respectively, the Red (poor status), Amber and Green (good status) WSP status zones. For abundance metrics in particular, which are most directly applicable to reference points, Holt et al. (2009) recommend for lower and upper benchmarks, respectively the use of S_{gen} and 80% S_{MSY} (see definitions below). These would be estimated separately for each Pacific Salmon Conservation Unit (CU) with available stock-recruitment data, using typically Ricker model forms (although depending on the CU, other model forms may be more applicable such as the Larkin or Beverton-Holt). These WSP biological benchmarks are used specifically to designate biological status, and therefore, are only a starting point for fisheries reference point development. Subsequent fisheries management steps are required to develop fisheries reference points, which also incorporate other factors such as stake-holder risk tolerance, implications of mixed-stock fisheries, etc.

Definitions

S_{MSY}: the number spawners that would produce the maximum sustainable yield

S_{gen}: the number of spawners that would result in recovery to S_{MSY} in one generation in the absence of fishing (Johnston et al. 2000; Holt et al. 2009)

Time-Varying Productivity and WSP Biological Benchmarks

As discussed in previous sections, a stock's productivity can change through either density-independent (intrinsic stock productivity changes due to changing biological/environmental conditions) or density-dependent mechanisms (changes in stock productivity due to changes in spawner abundances and, therefore, carrying capacity effects also due to changing biological/ environmental conditions). For salmon, Ricker model forms are typically used to model the stock-recruitment relationship for these species. Using these models, the Ricker 'a' parameter represents a stock's intrinsic productivity (recruits-per-spawner) at low stock sizes in the absence of density-dependence and the Ricker 'b' parameter represents the carrying capacity of the system. These parameters are roughly analogous to the parameters r and *K* in a Schaefer production model.

In a recent publication (Grant et al. 2011), time varying intrinsic productivity was included in an evaluation of uncertainty in S_{gen} and 80% S_{MSY}.for Fraser Sockeye CUs. Most of these CUs have exhibited systematic declines in productivity, some starting as early as the 1950's. Therefore, instead of only using a standard Ricker model form to estimate WSP abundance benchmarks, which assumes an average intrinsic CU productivity over the entire stock-recruitment time series, model forms that focus on the recent low productivity period were also evaluated. For Fraser Sockeye CUs that have exhibited recent productivity declines, Ricker model forms that emphasize this recent (generally low) productivity in benchmark estimation generally produced larger (more biologically conservative) lower benchmarks, compared to the standard (full time-series) Ricker model (Grant et al. 2011). This result is attributed to the negative covariation between the WSP *abundance* metric lower benchmark (S_{gen}: recovery to S_{MSY} in one generation under equilibrium conditions) and the Ricker model's intrinsic productivity ('*a*') parameter (Holt & Bradford 2011). Recent simulation results reported that while S_{gen} benchmarks increase as a population's intrinsic productivity decreases from moderate to low, other benchmarks (e.g. benchmarks that are percentages of S_{MSY}) don't change significantly (Holt & Bradford 2011). Therefore, during periods of reduced productivity, larger lower benchmarks (estimated from Ricker model forms that emphasize recent lower productivity) may assist with protecting CUs from extirpation, depending on how often benchmarks are re-estimated and how these results are applied to harvest management.

Other considerations

Small populations and extinction risk

According to the DFO PA policy, the default reference points are proportional to each other, with the lower limit reference point being 0.4 Bmsy. If productivity conditions decline and result in a decline in Bmsy, then the lower limit reference point would decline by the same proportion. Therefore for low productivity conditions, the reference point may appear less conservative because it is closer to 0 than the previous 0.4Bmsy. This may be appropriate for large marine stocks where extirpation may not be a significant concern but for stocks with naturally small and isolated populations, it may be of more concern. A population viability analyses, or similar method, should accompany any decreases in the lower limit reference point.

Productivity changes internal to a stock

A factor internal to a stock is the genetically determined productive capacity of a stock from the sum total of individuals. Selection pressures could change this from one level of productivity to another, favouring one suite of traits more than another suite. For example, slow growth rates could be selected for by a fishery and if they have a strong heritable component resulting in lower productive capacity, i.e.. K and changes in production of the stocks reference points. Such changes would appear to be reversible only on evolutionary time-scales. In cases where there is good evidence for this kind of change, one could consider adjusting reference points based on the criteria outlined above taking into account the uniqueness of this situation.

Potential Case Studies for further work

Good case studies for examining why reference points might change and how it could be done could include some eastern Canadian cod stocks, eastern Canadian Pandalus stocks and Arctic fish stocks where climate change is already having impacts on their productivity. A brief description for the Arctic charr (Salvelinus alpinus) is provided:

Arctic charr is a northern circumpolar species that is well adapted to the Arctic environment. If climate change were to cause a regime shift resulting in warmer annual temperatures in northern and Arctic regions, this would most likely result in higher productivity within Arctic environments. The higher productivity would most likely be due to: 1) longer duration of the open water season; 2) an increase in biotic productivity in the environment (more prey sources for charr); and 3) potential range expansion of species charr may prey on. This may result in Arctic charr feeding for longer periods (increased open water season) and having access to increased prey resources (more biotic productivity and new prey sources), theoretically resulting in an increase of the overall population size and thus stock size (biomass) of Arctic charr. This entails a few assumptions: 1) carrying capacity for Arctic charr is based on food resources and not over-wintering habitat; 2) competition pressure on Arctic charr would remain constant with the regime shift (there would be no new competitors of Arctic charr who would expand their range with increased temperatures (e.g. brook trout)); 3) predator pressure would remain constant despite the regime shift; and 4) Arctic charr natural morality would remain constant despite the regime shift. In a situation like this it may be appropriate to consider changing the reference points to account for the change in stock productivity and biomass.

MSY options for PA reference points

Approaches for estimating MSY-based reference points, with a brief description of the methods and data requirements provided below, beginning with the most data rich cases and proceeding through to the most data poor. Some of the data-rich options may generally be inappropriate for many invertebrate stocks, in part due to differences between management areas and biological units (for which SR or productivity should be calculated).

The classical method of estimating MSY reference points involves estimating a stock recruit (SR) curve. If data are available to pursue this approach, it should be attempted. However, lack of contrast in the abundance of spawners or overwhelming variability in recruits, can mask the underlying relationship. In such cases, one should exercise caution and consider where the estimated reference points are relative to the available data. If there is substantial extrapolation involved in determining the reference points, one might want to consider a different approach. As an illustration, consider the schematic below illustrating the position of the limit reference point (LRP) and B_{MSY} relative to historic observations. Each panel shows a varying degree of contrast in spawners (range on the x-axis), with differences in the amount of overlap with B_{MSY} and LRP. The top left panel shows that the observed values (or model estimates) of spawners overlap both B_{MSY} and LRP; this is a desirable situation. The remaining panels show overlap with only one of B_{MSY} or LRP, or with neither; these are not desirable situations. The problem with the three remaining cases is that one is forced to extrapolate beyond the range of observed data to derive a reference point. Due to the importance of these reference points for management advice, one wants to be confident that the expected behaviour at the extrapolated point does indeed occur. The relative degree of discomfort that an analyst should have for the three panels that involve extrapolation is debatable. The general approaches one takes to evaluate how well determined a parameter is should obviously be followed here: consideration of the CVs on the SR parameters, perhaps profiling over steepness or R_0 to evaluate how strongly an estimate is supported over a reasonable range of alternatives, and how sensitive the implied reference points are to the SR parameters. These auxiliary analyses can be used to provide uncertainty about the reference points, or they can be used to demonstrate that the reference points are too uncertain given the available data and alternative approaches (such as discussed below) could be recommended.

It is advisable to account for the uncertainty in MSY RPs derived from the uncertainty in modeling the stock-recruit relationship. This includes both estimation error in stock-recruit model parameters, and model error. The latter may be more important when yield is maximized based on extrapolated recruitment values. In presentation 3 (Simmonds), a multiple-model approach was presented that partly addresses model uncertainty.

If it is not possible to estimate a stock recruit relationship, and if age-specific data are available, then consider specifying proxy reference points based on Yield per recruit (YPR) / Spawning potential ratio (SPR) calculations. YPR and SPR both require selectivity, as well as M and weight at age; SPR also requires maturity at age. For invertebrates, if growth rates are known, it may be possible to estimate YPR or SPR based solely upon length measurements. The approach of translating SPR and YPR into MSY and B_{MSY} reference points corresponds to long-term stochastic projections at a mean level of recruitment, i.e. it corresponds to a hockeystick SR model. One F_{MSY} proxy that is consistent with the hockeystick SR model is F_{MAX}. However, F_{MAX} is usually larger than F_{MSY} and can be too risky; the risk would be particularly acute for stocks that are already overfished. $F0.1$ is less risky than F_{MAX}; it is the fishing rate that achieves 10% of the slope of the YPR curve at the origin. Both F_{MAX} and $F0.1$ focus on the yield derived from a recruit given selectivity and F. As such, F_{MAX} and $F0.1$ are reference points for growth overfishing because they determine whether the fishing rate is or is not maximizing yield given the growth trajectory of a recruit.

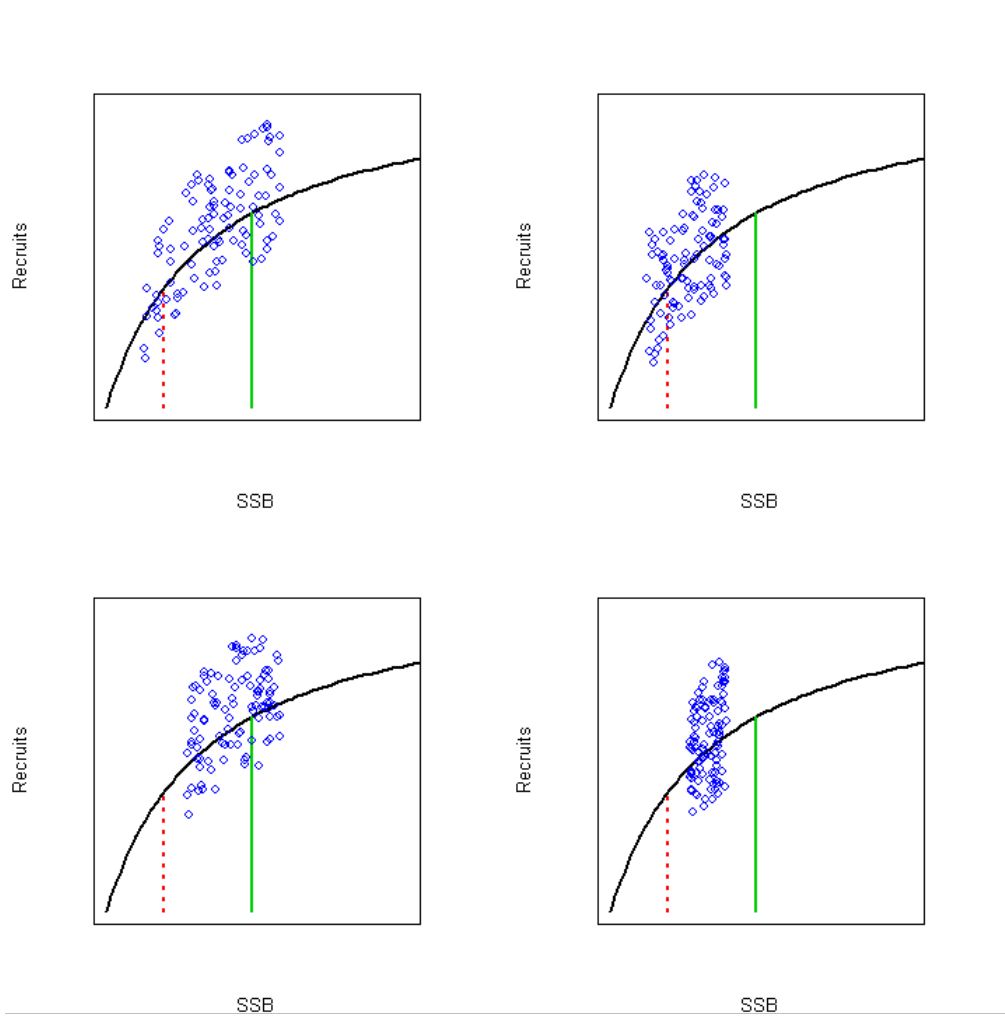

Figure Breakout-1: Relationship between stock-recruit data and SSB reference points. The solid green line represents BMSY, and the dashed red line = 40% BMSY (default Canadian LRP). Refer to text for details.

An alternative to focusing on the YPR curve is to consider how different levels of *F* reduce the potential spawning output of a recruit over its lifetime (SPR) compared to *F*=0. *F* values corresponding to %SPR can be computed and YPR compared across those values. Long term stochastic projections that implement *F*(%SPR) would yield the corresponding MSY and B_{MSY}. For groundfish life histories, a series of investigations by Clark (1991; 1993; 2002) found that *F*40% was shown to be close to *F*0.1, providing both sustainability and little loss in yield for a variety of groundfish-like life histories on the west coast of the US. However, it was noted that species that are long lived and that have less compensatory ability would require a higher % SPR (50% or 60%) to avoid risk.

All of the approaches discussed so far for estimating reference points required age-specific data. There are many stocks for which age-specific information is not available, or is deemed unreliable. Surplus production (SP) modelling does not require aged data, but it does require estimates of total catch and an index of abundance. SP models can directly estimate B_{MSY} and F_{MSY}. However, their lack of complexity (no age structure) leads to some criticisms. Specifically, the typical lag associated with time to maturation does not exist in SP models, so projections to evaluate management actions appear to be instantly reflected in the population. From an estimation standpoint, SP models have a tendency to estimate reference points within the range of the data. Also, unless the index of abundance has contrast, it can be difficult to find a solution. SP models will rarely converge if the index shows the "one way trip" trajectory, i.e. the index is trending in only one direction.

For data poor assessments where even SP models cannot be fit, there are several simple alternatives. An Index Method (AIM; developed by Paul Rago) attempts to fit a relationship between an index of abundance and catch, assuming linear population growth. The ratio of catch to index produces a relative exploitation rate, and a sustainable reference point is specified as the relative rate where the stock appeared able to replace itself. AIM is able to estimate an F_{MSY} proxy, but additional information is needed to derive MSY and B_{MSY}. The Depletion Corrected Average Catch (DCAC; developed by Alec MacCall) requires an input stream of catch, and some assumptions about natural mortality and the fractional reduction in biomass from the beginning to the end of the time period. With this information, the DCAC model provides an estimate of catch that is likely to be sustainable. Both AIM and DCAC (executable models and documentation) can be freely downloaded at the NOAA Fisheries Toolbox website: http://nft.nefsc.noaa.gov/index.html.

When catch data are unavailable, or not separated to species level, survey smoothing methods are sometimes used to estimate relative reference points. This approach requires that the proxy be specified in the same units as the index of abundance. For example, one might specify the time series median, or perhaps an average over a period of years considered stable. Stock status is then determined by comparing the most recent value (or mean of several recent years) to the specified proxy.

Productivity may have a spatial aspect and in such cases the reference points may need to reflect this. In fact, strictly managing to MSY reference points may not be appropriate or sufficient. One example relevant to this idea was presented during the workshop. In Scallop stocks off southern Nova Scotia, spatial variations in stock size and/or density, suggest managing towards a "whole-stock" MSY may not be appropriate.

If the estimated MSY-based reference points and limit reference points are close to each other (i.e. with limited scope for management options), then one should consider an MSE to test or identify alternate reference points.

If possible, PA frameworks should be "management strategy evaluated". The current Canadian PA policy identifies that an example B_{LIM} could be 40% B_{MSY}, though the efficacy of choosing this level has not been simulation tested. There is some precedence in other jurisdictions to set limits at 25-50% of B_{MSY} (e.g. New Zealand, Australia, US).

If possible, reference points should be based upon an MSE of the PA Framework. Prescribed limits will not work in all cases.

Process Error and Stochastic MSY reference points

Conceptually, calculation of MSY reference points involve evaluating long-term stock projections in which fishing mortality is varied to find the level (F_{MSY}) that maximizes long term yield. MSY is the maximized yield and B_{MSY} is the equilibrium stock size that gives MSY. If the projection is deterministic then the calculation of MSY RPs is also deterministic. In this context some theory has been developed related to MSY calculations (Sissenwine and Shepherd, 1987). In these traditional MSY calculations all population processes are assumed to be constant; for example, the age-based values of natural mortality, maturity, weight, and fishery selectivity in the spawner-per-recruit relationship are held constant in the long-term stock projections, as is the recruit-per-spawner functional relationship with SSB. Estimation error in these population processes contribute to uncertainty, and some bias, in MSY RPs.

In a stochastic steady-state (stationary) environment, harvesting according to the deterministic MSY rule has been shown to be an under-optimized strategy and can lead to strong decreases in the resource (e.g., Bousquet et al., 2008). The deterministic F_{MSY} is not optimal; on average, one cannot hope to harvest more than the stochastic MSY. Bousquet et al. (2008) showed for the Schaefer Surplus Production Model that the stochastic MSY, B_{MSY}, and F_{MSY} were less than the deterministic results.

There is evidence of variation in productivity for most stocks we are aware of. We propose that when productivity conditions have varied, and are expected to vary in the future in a way that results in a steady-state (i.e. stationary) stochastic distribution for stock size, then MSY RP's could be based on fishing mortality that maximizes long term expected yield in the presence of such variations in productivity. Note that with a stationary distribution there can still be time short-term time trends, but not persistent long-term trends over the entire projection time-period Roughly speaking, for MSY RP's, given that the future will be uncertain like that in the observed past, we will look for a level of fishing mortality that will maximize long term yield. This stochastic F_{MSY} is proposed to be an *F* limit, and the resulting equilibrium distribution for B_{MSY} can provide the basis for B_{LIM} and possible targets.

However, this requires that the variability in the future will be stable (i.e. stationary stochastic distribution). If productivity in the future changes in an unpredictable way then the approach discussed here will not be appropriate.

Research Recommendations

Research recommendation 1: Consider process errors when deriving MSY RP's for your model.

Research recommendation 2: for age-based models: Investigate statistical models of the data available on relevant population processes for MSY calculations, with a focus to forecast the distribution of values one can expect in the future for RP calculations. Investigate if addressing the components of variability is better than dealing with them in total.

For example, Dowden et al. (2007) have proposed an auto-correlated cohort model to account for temporal changes in the proportion mature in a stock. This model can be used to forecast the distribution of values that may occur in the future, which can be used for MSY RP calculations. A similar approach can be applied to forecast weights at age, possibly via forecasted lengths-at-age. Time series variations in SR relationships can also be used to forecast the variability that may occur in the future.

Some of the temporal variations that we see can not be model using simple time-series approaches. Sometimes we see very different productivity "states" (e.g. M) and conditions seem to jump from one state to another. This can be addressed using a mixture model approach where there is a probability that the stock is in a particular state, and this probability is constant over time (e.g. Munch and Kottas, 2009).

GENERAL CONCLUSIONS OF WORKSHOP

When are regime-specific reference points appropriate?

It is appropriate to change reference points when: i) the productivity change is known with high certainty to be due to a regime shift, i.e. when there is an understanding of the mechanisms linking the environmental change with the productivity of the stock, and an understanding of the life history stages that are affected by the regime shift; ii) the change is not believed to be reversible in the short or medium term (e.g. is expected to last at least a decade or a generation – whichever is longer); and iii) there has been a change in the capacity of the environment to support the stock.

From a conservation perspective, it is always more prudent to manage to a biomass reference point that includes productive periods, i.e. not to lower the baseline because there is currently a less productive regime. In most cases of declining productivity, all three criteria above will not be met, and even when they are, it will be difficult to bring spawning stock biomass back up if higher productivity conditions return. The cases where it will be appropriate to lower biomass reference points because of declining productivity are probably rare. Changes in recruitment rates, natural mortality, fecundity, or growth rates or not considered to be appropriate reasons to change biomass limit reference points though they are likely to affect fishing mortality reference points.

Feedback simulation approaches which considers hypotheses related to productivity regimes and implications of the stocks and their management are strongly recommended.

MSY options for precautionary reference points

The classical method of estimating MSY reference points involves estimating a stock recruit (SR) curve. If data are available to advance this, it should be attempted; however, lack of contrast in the abundance of spawners, or large recruitment variability, can mask the underlying relationship. If there is substantial extrapolation involved in determining the reference points, one might want to consider a different approach. It is advisable to account for the uncertainty in MSY RPs derived from the uncertainty in modeling the stock-recruit relationship. This includes both estimation error in stock-recruit model parameters, and model error. The latter may be more important when yield is maximized based on extrapolated recruitment values.

If it is not possible to estimate a stock recruit relationship, and if age-specific data are available, then consider specifying proxy reference points based on Yield per recruit (YPR) / Spawning potential ratio (SPR) calculations. For invertebrates, if growth rates are known, it may be possible to estimate YPR or SPR based solely upon length measurements. Potential F_{MSY} proxies are F_{MAX}, F0.1, and F40% for groundfish type species, although F50% or F60% may be better for longer lived species.

If age-specific data does not exist then MSY RPs may be estimated using a surplus production (SP) model, although such models are usually unrealistic in that they do not reflect the typical stock response time-lag associated with time to maturation. SP models are often difficult to estimate in practice because of insufficient data contrast. There are alternative proxies for data poor stocks that involve assumptions about when a stock has previously been near B_{MSY}.

An important consideration is that proposed reference points should be tested in conjunction with proposed management strategies that involve these reference points, to make sure that management objectives are achieved with a desired probability.

REFERENCES

Bousquet, N., Duchesne, T. and Rivest, L.-P. 2008. Redefining the maximum sustainable yield for the Schaefer population model including multiplicative environmental noise. J. Theor. Biol. 254 65-75.

Cadigan, N.G. 2010. Trends in Northwest Atlantic Fisheries Organization (NAFO) Subdivision 3Ps Cod (Gadus morhua) stock size based on a separable total mortality model and the Fisheries and Oceans Canada Research Vessel survey index. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/015.

Clark, W. G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci., 48: 734-750.

Clark, W. G. 1993. The effect of recruitment variability on the choice of a target level of spawning biomass per recruit. In Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations, University of Alaska, pp. 233–246. Ed. by G. Kruse, R. J. Marasco, C. Pautzke, and T. J. Quinn. Alaska Sea Grant College Program Report, 93-02.

Clark, W. G. 2002. F35% revisited ten years later. N. Amer. J. Fish. Mgmt. 22: 251–257.

Crawford, W.R., and J.R. Irvine. 2011. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/054. x + 163 pp.

DFO. 2002. Proceedings of the National Workshop on Reference Points for Gadoids; 5-8 November, 2002. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2002/033. v + 16 p.

DFO, 2005. Canada's Policy for Conservation of Wild Pacific Salmon. Fisheries and Oceans Canada, Vancouver, BC. 34 pp.

DFO, 2009. Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2009. DFO Can. Sci. Advis. Sec., Sci. Advis. Rep. 2009/022.

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach. http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm.

Dowden, J. Cadigan, N. Morgan, J. and J. Brattey. 2007. Improved estimation and forecasts of stock maturities using generalized linear mixed effects models. Presented to the Working Group on Methods of Fish Stock Assessments, Woods Hole, USA. Section 2.5 in Report of the Working Group on Methods on Fish Stock Assessments. ICES CM 2007/RMC:04.

Grant, S. C. H., Michielsens, C. G. J., Porszt, E. J., and Cass, A. J. 2010. Pre-season run size forecasts for Fraser Sockeye (*Oncorhynchus nerka*) in 2010. DFO Can. Sci. Advis. Sec. Res.Doc. 2010/042, -vi + 127.

Grant, S.C.H., MacDonald, B.L., Cone, T.E., Holt, C.A., Cass, A., Porszt, E.J., Hume, J.M.B., Pon, L.B. 2011. Evaluation of Uncertainty in Fraser Sockeye (*Oncorhynchus nerka*) Wild Salmon Policy Status using Abundance and Trends in Abundance Metrics. DFO. Can. Sci. Advis. Sec. Res. Doc. 2011/087. viii + 183 p.

Healey B.P., Murphy, E.F., Brattey, J., Cadigan, N.G., Morgan, M.J., Maddock Parsons, D., Power, D., Rideout, R., Colbourne, E., and Mahé, J.-C. 2011. Assessing the status of the cod (*Gadus morhua*) stock in NAFO Subdivision 3Ps in 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/076.

Holt, C.A. 2009. Evaluation of benchmarks for Conservation Units in Canada's Wild Salmon Policy: technical documentation. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/059. xii + 50 pp.

Holt, C.A., Bradford, M.J. 2011. Evaluating benchmarks of population status for Pacific salmon. N. Am. J. Fish. Manage. 31 (2): 363-278.

Holt, C.A., Cass, A., Holtby, B., and Riddell, B. 2009. Indicators of status and benchmarks for Conservation Units in Canada's Wild Salmon Policy. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/058. vii + 74 pp.

Kass, R.E., Raferty, A.E., 1995. Bayes factors. J. Am. Stat. Assoc. 90, 773–795.

Larkin, P.A. 1977. An epitaph for the concept of maximum sustainable yield. Trans. Am. Fish. Soc. 106:1-11

McAllister, M.K., E.K. Pikitch, and E.A. Babcock. 2001. Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. Can. J. Fish. Aquat. Sci. 58: 1871-1890.

Mesnil, B. and M.-J. Rochet, 2010. A continuous hockey stick stock-recruit model for estimating MSY reference points. ICES J. Mar. Sci. 67: 1780-1784.

Mohn, R. K., and Chouinard, G. A. 2007. Harvest control rules for stocks displaying dynamic production regimes. – ICES Journal of Marine Science, 64: 693–697.

Mohn, R.K., and Rowe, S. 2012. Recovery Potential Assessment for the Laurentian South Designatable Unit of Atlantic Cod (Gadus morhua): The Eastern Scotian Shelf Cod Stock (NAFO Div. 4VsW). DFO Can. Sci. Advis. Sec. Res. Doc. 2011/138: viii + 71p

Mohn,R.K., Trzcinski, M.K., Black, G.A.P., Armsworthy, S., Young, G.A., Comeau, P.A., and den Heyer, C.E.. 2010. Assessment of the status of Division 4X5Y haddock in 2009. DFO Can. Sci. Advis. Sec. Res. Doc 2010/085.

Munch, S.B. and A. Kottas. 2009. A Bayesian modeling approach for determining productivity regimes and their characteristics. Ecological Applications, 19, pp. 527-537.

Peterman, R.M. & Dorner, B. 2011. Fraser River sockeye production dynamics. Cohen Commission Tech. Rept. 10: 133p. Vancouver, B.C. www.cohencommission.ca

Punt, A.E. and A.D.M. Smith 2001. The gospel of Maximum Sustainable Yield in fisheries management: birth, crucifixion and reincarnation. p. 41-66. In: J.D. Reynolds, G.M. Mace, K.R. Redford and J.R. Robinson [Ed.] Conservation of Exploited Species, Cambridge University Press, Cambridge.

Sinclair, A. F., D. P. Swain, and J. M. Hanson. 2002. Disentangling the effects of size-selective mortality, density, and temperature on length-at-age. Canadian Journal of Fisheries and Aquatic Science 59: 372-382.

Sissenwine M.P., and J.G. Shepherd, 1987. An Alternative Perspecitve on Recruitment Overfishing and Biological Reference Points. Can. J. Fish. Aquat. Sci. 44: 913-918.

Swain, D. P. 2011. Life-history evolution and elevated natural mortality in a population of Atlantic cod (*Gadus morhua*). Evolutionary Applications 4: 18-29.

Swain, D. P., Benoît, H. P., Hammill, M. O., McClelland, G., and Aubry, É. 2011a. Alternative hypotheses for causes of the elevated natural mortality of cod (*Gadus morhua*) in the southern Gulf of St. Lawrence: the weight of evidence. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/036. iv + 33 p.

Swain, D. P., and A. F. Sinclair. 2000. Pelagic fishes and the cod recruitment dilemma in the Northwest Atlantic. Canadian Journal of Fisheries and Aquatic Science 57: 1321-1325.

Swain, D. P., A. F. Sinclair, and J. M. Hanson. 2007. Evolutionary response to size-selective mortality in an exploited fish population. Proceedings of the Royal Society B: Biological Sciences 274: 1015-1022.

STECF 2011. Scientific, Technical and Economic Committee for Fisheries (STECF) – Impact Assessment of Baltic cod multi-annual plans (STECF 11-05) - Annex 1. Simmonds, E. J., editor. EUR 24899 EN. Luxembourg (Luxembourg): Publications Office of the European Union; 2011.

TRAC. 2012. Eastern Georges Bank Haddock. TRAC Status Report 2012/03

APPENDIX I: TERMS OF REFERENCE

Technical Expertise in Stock Assessment (TESA): Maximum Sustainable Yield (MSY) Reference Points and the Precautionary Approach when Productivity Varies

National Workshop, National Capital Region

December 13-15, 2011
Montreal, Quebec

Co-Chairs: Noel Cadigan and Daniel Duplisea

Context

Fisheries and Oceans Canada (DFO) has committed to using a precautionary approach (PA) when managing fisheries. The basis of the PA framework has been outlined in the Sustainable Fisheries Framework released by DFO in April 2009 and described in "A fishery decision-making framework incorporating the Precautionary Approach" (see http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm). The framework identifies three stock status zones: healthy, cautious, and critical, according to upper stock and limit reference points (LRP). The framework also sets the removal rate at which fish may be harvested within each stock status zone, and adjusts the removal rate according to stock status and on pre-agreed decision rules.

An LRP marks the boundary between the cautious and critical zones. When stock size falls below this point, there is a high probability that its productivity is so impaired that serious harm has occurred. An LRP is therefore related to the classic concept of recruitment overfishing and is determined by scientific best practice. However, the productivity of a stock may not be only related to the size of the stock as captured in LRP concepts. For example, the productivity of most cod stocks in eastern Canada decreased in the mid to late 1980s when these stocks were still fairly abundant. Most of these stocks collapsed within 5-6 years of this change. A more detailed understanding of changes in productivity regimes should have implications on setting plausible management goals, LRPs, and removal rates. This is a key component of DFO's *New Ecosystem Science Framework in Support of Integrated Management* (see http://www.dfo-mpo.gc.ca/science/Publications/Ecosystem/index-eng.htm#a5_1).

At the World Summit on Sustainable Development in 2002 (WSSD), Canada committed to achieving the maintenance or restoration of depleted fish stocks to levels that can produce maximum sustainable yield (MSY). MSY reference points have been adopted by several inter-government fishery organisations (e.g., IWC, ICCAT, IATTC, ICES, NAFO) and other countries (e.g. US, New Zealand). Given this widespread adoption, it is important to consider what are sensible MSY based reference points for the types of variations in productivity (e.g. regimes) that may occur with Canadian stocks. It is also important to consider if, and how, MSY reference points should be incorporated into the PA framework. Stakeholders have criticized some aspects of standard applications of the PA because they do not address changes in stock productivity.

DFO submitted a letter of intent to be an Associated Partner in the European Union Seventh Framework Programme (EU FP7) Beyond MSY proposed project: *Beyond Maximum Sustainable Yield (MSY) in fisheries: defining management targets and their consequences* (MYFISH). This project will provide definitions of MSY variants, evaluations of the effect and desirability of aiming for these variants and an operational framework for their implementation.

TESA Background

The DFO Technical Expertise in Stock Assessment (TESA) program was created in 2008 to help rebuild capacity in fish stock assessment and to develop technical approaches in a common venue separate from advisory meetings. The TESA program is composed of three related elements: 1) Stock

Assessment Methods Committee (SAMC); 2) annual National Stock Assessment Methods Workshop; 3) Stock Assessment Technical Training/Upgrading program. TESA is led by a Steering Committee composed of the chair (Noel Cadigan), one stock assessment expert from each region, an NSDC champion and a Science manager.

Objectives

TESA is proposing an initial workshop to detail problems with deriving MSY and PA reference points for stocks with varying (i.e. non-stationary) productivity conditions or regimes. A secondary objective is to explore integrating MSY reference points and the PA such that management regimes neither collapse stocks nor forego unnecessary amounts of potential yield. The motivation for the workshop comes from the numerous stocks that are regularly assessed by DFO (e.g. Northern cod) in which data suggests there have been substantial changes in productivity processes.

The aim of the workshop is primarily scoping; to propose research recommendations and possibly solutions. This workshop is the first step in a two step process. Following this initial workshop, TESA proposes to develop and test strategies through a working group to derive MSY and PA reference points for stocks with non-stationary productivity. This may be linked with research on best practices for management strategy evaluations. The results of this working group will be reviewed at a future workshop.

Specific workshop objectives are:

1. A brief overview of MSY-based PA methods and frameworks around the world
2. Review working papers of case studies where productivity has varied over time, and what aspects of the PA framework have been addressed.
3. Review working papers that describe how time-varying productivity conditions (regimes) should influence the calculation of MSY or other PA reference points.
4. Describe when regime-specific reference points are appropriate, and what are the risks of not considering regime changes.
5. Contribution to the EU MYFISH project proposal (described above).
6. The ultimate goal of the study group is to propose MSY options for PA reference points. This could include developing a decision plan to guide DFO when implementing the PA for stocks under changing productivity. This decision plan will be considered at the initial workshop. At a future workshop, the decision plan will be fully developed for establishing PA reference points with specific case studies.

Proposed approach

The participants of the workshop will review approaches used by other agencies/researchers to address PA LRPs and MSY reference points when stock productivity varies. Invited experts will describe their experiences and approaches for dealing with varying productivity when calculating reference points. The workshop will also review case-studies selected from proposals from DFO regions.

Expected Publications

Proceedings Document, and Research Documents if appropriate, will be produced to summarize the workshop discussions and conclusions for computing MSY and PA reference points for the Canadian stocks chosen as case studies whose productivity regimes have changed over time.

Participation

Participation will include DFO stock assessment staff (especially those who proposed case studies considered at the workshop), members of TESA (see below), invited experts, and other local university researchers.

APPENDIX II: PARTICIPANTS

Family name	Given name	Region
Brooks	Liz	NOAA
Bundy	Alida	MAR
Cadigan	Noel	NLL
Cook	Adam	MAR
Davis	Ben	NLL
Desgagnés	Mathieu	QUE
Duplisea	Daniel	QUE
Grant	Sue	PAC
Harris	Les	C&A
Healey	Brian	NLL
Krohn	Martha	NCR
Lambert	Yvan	QUE
Martin	Zoya	C&A
Mohn	Robert	MAR
Rice	Jake	NCR
Rivest	Louis-Paul	Univ Laval
Sainte-Marie	Bernard	QUE
Shelton	Peter	NLL
Simmonds	John	JRC - EC
Smith	Steve	MAR
Stansbury	Don	NLL
Stenson	Garry	NLL
Swain	Doug	GUL
Tallman	Ross	C&A
Thorleifsson	Erika	NCR
Trzcinski	Kurtis	MAR
Ulrich	Clara	AQUA DK
Wade	Elmer	GUL
Wang	Yanjun	MAR
Zhang	Zane	PAC

APPENDIX III: SCHEDULE

TESA workshop on MSY reference points and the precautionary approach when productivity varies

13-15 December 2012. Delta Centre-Ville Montreal

TESA workshop TOR

Tuesday 13 Dec

Time	Name	Title
9:00	Noel Cadigan and Daniel Duplisea	Introduction, TOR, objectives, roundtable, appointment of rapporteurs
9:30	Peter Shelton	PA frameworks around the world with some consideration on how they deal with producitivity changes
10:30	**Coffee**	
10:45	Liz Brooks	Variable productivity and reference points: priors, proxies, and pragmatism
12:00	**Lunch**	
13:00	John Simmonds	MSY in two Baltic cod stocks
14:00	Louis-Paul Rivest	Incorporating environmental variability into surplus production models
15:00	**Coffee**	
15:15	Bob Mohn	Time varying production, regimes and HCRs
16:15	Clara Ulrich	European MYFISH project
17:00	**Finish**	

Wednesday 14 Dec

Time	Name	Title
9:00	Jake Rice	Reference points and productivity changes
9:45	Noel Cadigan	Model input parameter variability and autocorrelation and impact on reference points
10:30	**Coffee**	
10:45	Brian Healey	Current issues with MSY-based reference points in 3Ps Cod
11:15	Doug Swain	Shifting reference points as productivity varies - regime change or Allee effect? The case of 4T cod
11:45	Yanjun Wang	Have productivity increased with the rebuilding of Eastern Georges Bank haddock?
12:15	**Lunch**	
13:15	Zane Zhang	Correlation between productivity of the North Pacific albacore tuna stock and Pacific decadal oscillation
13:45		
14:15	Sue Grant	Wild Salmon Policy lower biological benchmarks with considerations of time-varying productivity: Fraser River sockeye case study
14:45	**Coffee**	
15:00	Bernard Sainte-Marie	Environmental influences on snow crab productivity
15:30	Steve Smith	Scallop site based productivity difference and implications for setting reference points
16:00	Garry Stenson	Changes in productivity of harp seals: are they approaching K?
16:30	Noel and Daniel (leads)	open discussions on the day, distill some main points
17:00	**Finish**	

Thursday 15 Dec

Time	Name	Title
9:00		Breakout groups
10:30	**Coffee**	
10:45		Breakout groups
12:00	**Lunch**	
13:00		Report back from breakout groups
14:45	**Coffee**	
15:00		Report back from breakout groups
17:00	**Finish**	

APPENDIX IV: ACRONYMS

Acronym	Definition
S^*	changepoint (p24)
AIM	An Index Method
B	Biomass
B_F	Biomass for fishing mortality F
BH	Beverton Holt
B_{LIM}	Spawning biomass limit reference point
B_{MAX}	Maximimum observed or modelled (K) biomass
B_{MSY}	Minimum biomass required to remove the maximum sustaintable yield form the stock
$B_{RECOVERY}$	The minimum observed biomass from which there has been a recovery
BRP	Biological reference points
B_t	Biomass at time t
B_{t+1}	Biomass at time t+1
B_{TARG}	Target biomasss
CPUE	Catch per unit effort
C_t	Catch at time t
CU	conservation unit
CV	Coefficient of Variation
DCAC	depletion corrected average catch
EGB	Eastern Georges Bank
F	Fishing mortality
F	Fishing mortality
F_{CRASH}	The fishing mortality which will evemtually drive the stock below Blim (i.e crash the stock)
F_{MAX}	Maximum acceptable fishing mortality
F_{MSY}	Fishing mortality which will produce MSY when the stock is a Bmsy
γ	degree of smoothing parameter
HS	hockey stick
ICES	International Council for the Exploration of the Sea
K	Carrying capacity
LRP	Limit reference point
M	natural mortality rate
$M_{a,y}$	Maximum economic yield at age (a) and year (y)
MEI	Multivariate El Niño Southern Oscillation Index
MSE	Management strategy evaluation
MSY	Maximum sustainable yield
N_{MAX}	maximum observed or estimated population size
NOAA	National Oceanic and Atmospheric Administration
NPGO	North Pacific Gyre Oscillation
NPI	North Pacific Index
p	Shape parameter (p13)

Acronym	Definition
PA	Precautionary approach
PDO	Pacific Decadal Oscillation
PFB	Pelagic fish biomass
ρ_0	Unexploited spawners per recruit (figure 2-1, p 10)
PRC	Precautionary reference point
r	growth parameter, intrinsic rate of increase
RAC	Regional advisory council
RK	Ricker
RP	Reference points
s_a	Selectivity of the fishery at age
S_{gen}	Spawner abundance that would result in recovery to maximum sustained yield (S_{Msy}) in one generation
S_{MSY}	
SP	Surplus production
SPR	Spawning per recruit
SPR	Spawning potential ratio
SR	Stock recruit
SSB	Spawning stock biomass
SURBA	SURvey Based Assessment technique
TAC	Total allowable catch
VMS	Vessel monitoring systems
VPA	Virtual population analysis
WPI	Western Pacific Index
WSP	Wild salmon policy
YPR	Yield per recruit
Z	Total mortality rate on a stock
$Z_{a,y}$	Total mortality at age (a) for a year (y)
ε_t	random multiplicative perturbation
ρ	first order autocorrelation
σ^2	Variance