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Proceedings of the National Peer Review on the Development of Technical Guidelines for the Provision of Scientific Advice on the Various Elements of Fisheries and Oceans Canada Precautionary Approach Framework

February 28 to March 1 2012
Ottawa, Ontario

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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.

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SUMMARY

A National Advisory Process on providing Science advice for the implementation of the Precautionary Approach (PA) was held in Ottawa from February 28 to March 1 2012. This process was led by Science and participants included regional scientists as well as members from Science, Resource Management and Fisheries Renewal from national headquarters. The two co-chairpersons were Estelle Couture and Denis Rivard, and four external experts were invited as reviewers.

In 2009, DFO published its policy for the implementation of the Precautionary Approach (PA) called "A decision-making framework for implementing a harvest strategy that incorporates the Precautionary Approach (PA)" (DFO 2009a). The Departmental policy on the Implementation of the PA is also guided by the federal framework on guiding principles for the application of precaution to decision making where there is a risk of serious or irreversible harm (PCO 2003).

The Department's PA framework applies where decisions on harvest rates must be taken for key harvested stocks managed by DFO. Although the policy is in place, and scientists have gained experience in providing advice for the implementation of the elements of PA frameworks, more specific guidance and best practices were needed for technical aspects of implementing the PA policy to ensure that scientific advice is delivered in a consistent manner across stocks and regions. The intent of this national advisory process was not to review the content of the PA policy itself but to provide guidance on its implementation.

The resulting guidance document on the Science components required for the development of a Precautionary Approach Framework is included here as Annex 4 called "*Current Approaches for the Provision of Scientific Advice on the Precautionary Approach for Canadian Fish Stocks*" This document was developed to assist scientist practitioners responsible for developing the science advice on the elements of the decision framework in the PA policy (i.e. Limit Reference Point, Upper Stock Reference, Target Reference Point, Removal Reference and Harvest Decision Rules in the three zones of the PA framework). The body of this proceedings is a summary of meeting discussions (general conclusions are in bold) and the guidance document is in Annex 4.

SOMMAIRE

Un processus consultatif national sur la prestation d'avis scientifiques relatifs à la mise en œuvre de l'approche de précaution a eu lieu à Ottawa, du 28 février au 1er mars 2012. Ce processus était dirigé par le Secteur des sciences et les participants comprenaient des scientifiques régionaux ainsi que des membres du Secteur des sciences, de la Gestion des ressources et du Renouvellement des pêches de l'administration centrale nationale. Les deux coprésidents étaient Estelle Couture et Denis Rivard et quatre experts externes étaient invités en tant qu'examinateurs.

En 2009, le MPO a publié sa politique sur la mise en œuvre de l'approche de précaution appelée « Un cadre décisionnel pour les pêches intégrant l'approche de précaution » (MPO 2009a). La politique ministérielle sur la mise en œuvre de l'approche de précaution est également guidée par le cadre fédéral sur les principes directeurs pour l'application de l'approche de précaution dans un processus décisionnel lorsqu'il y a des risques de dommages graves ou irréversibles (BCP 2003).

Le cadre de l'approche de précaution du Ministère s'applique lorsqu'il faut décider des taux de récolte pour les principaux stocks exploités qui sont gérés par le MPO. Bien que la politique soit en place et que les scientifiques aient acquis de l'expérience pour fournir des avis en vue de la mise en œuvre des éléments du cadre de l'approche de précaution, il était nécessaire d'avoir des lignes directrices et des meilleures pratiques plus précises pour les aspects techniques de la mise en œuvre de la politique d'approche de précaution, et ce, afin de s'assurer de donner des avis scientifiques uniformes pour l'ensemble des stocks et des régions. Le but de ce processus consultatif national n'était pas de revoir le contenu même de la politique d'approche de précaution, mais plutôt de donner une orientation sur sa mise en œuvre.

Le document d'orientation sur les composantes scientifiques requises pour l'élaboration d'un cadre d'approche de précaution est inclus à l'annexe 4 intitulée « *Approches actuelles de prestation d'avis scientifiques dans le cadre de l'approche de précaution pour la gestion de stocks canadiens* ». Ce document a été conçu pour aider les praticiens scientifiques responsables de l'élaboration de l'avis scientifique sur les éléments du cadre décisionnel de la politique d'approche de précaution (c.-à-d., le point de référence limite, le point de référence supérieur, le point de référence cible, le taux d'exploitation de référence et les règles de décision en matière de prises dans les trois zones du cadre de l'approche de précaution). Le corps de ce compte rendu est un résumé des discussions tenues au cours de la réunion (les conclusions générales figurent en gras) et l'annexe 4 contient le document d'orientation.

PRESENTATIONS

INTRODUCTION

Estelle Couture (co-chair) introduced the meeting. The following summarizes her introduction:

DFO's Precautionary Approach Policy was published in 2009 (DFO 2009a), and since that time there have been efforts across the country to calculate reference points and develop Precautionary Frameworks, including a number of Management Strategy Evaluation Approaches.

Looking back from 1995 the progress was slow in the beginning but it has gotten faster. The fisheries modernization initiative has helped to make management simpler and more efficient. Fisheries management needed to change, it was developed in patchwork manner with a complex web of roles and policies. Now there are number of tools to achieve consistency, including continued implementation of the PA for all commercial stocks.

Since the Policy was published the Department has gained much experience. Parts of the guidance in the Policy are being interpreted differently, and there needs to more consistency. Part of this consistency in implementation of the Science components needs to be informed by a group of Scientists with extensive experience working with the Policy. A steering committee was formed in May 2011, and the approach was to develop some draft technical guidelines over the summer. A subgroup developed a comprehensive Table of Contents. Since the mandate for the current process was only for the Science aspects of the PA, the science pieces were kept and the management pieces were set aside for a follow up workshop. Discussion for this meeting would review the Technical Guidelines and working papers to implementing the PA, but would also contribute towards that following workshop.

For development of working papers and guidance, the teams were asked to consider what is in the PA Policy (and state specifically what is written in the Policy in grey text boxes). It was explained that the lead for each team would give the presentation and that it would not be possible do a thorough peer review of everything that's in the working papers, but that the working papers would serve as background for what will be in the technical guidelines. Enough time would be reserved to go over the text in the technical guideline pieces. The intent was for each working paper to be published as a Research Document, and that there would be proceedings and an appendix of technical guidelines that could be extracted.

The possibility was mentioned of a second workshop, where the elements that will require more discussion with the managers could be covered.

It was highlighted that notes on issues that could be considered at the next workshop would be taken. These are included in the Outstanding Questions section.

Rapporteurs were Erika Thorleifson, Paul Brodie and Martha Krohn.

DFO PRECAUTIONARY APPROACH POLICY

This section was presented by Marc Clemens. The following summarizes the main points in the presentation and discussion.

Context

Mark Clements gave a presentation describing the PA policy and its history and highlighted some of the areas where clarification in the Policy is needed. It was noted that potential improvements/suggestions for the Policy were being recorded, and that the policy would not be rewritten as a result of this process. The points were recorded for future use in Policy-led exercise, or an exercise co-led by Policy, Management and Science.

Removal reference

In the presentation, it was highlighted that, in the PA policy, the meaning of the removal reference could be interpreted in three different ways:

- As an F limit (maximum acceptable removal rate)
- F target
- Harvest decision rule that applies across the range in stock status.

A clarification based on diagram was proposed, that the removal reference be the limit which is set above the target and rename the diagonal line the harvest decision rule.

The point was made that the separation of science and policy is not clear in the Policy when it comes to considering fishing mortality and harvest control rules, and what actions are expected in response to the removal reference points. The proposal was seen to address this issue, at least in part.

There was also a discussion of what the DFO policy is for removals below the LRP. It was suggested that the Policy should be clearer about what the policy is for fishing below the LRP. If directed fishing should close below the LRP, then the policy should say that. In addition, if fishing should not go above F_{MSY} then the Policy should say that.

There was a discussion on the difference between limits and targets. A limit should be avoided with a very high probability (low risk tolerance). A fishing mortality target should be set well below the limit, and that harvests should be set risk neutral around that target (neutral risk tolerance).

Risk tolerance and uncertainty

During the presentation, the point was made that there should be more specific language about risk in the Policy, and that clear guidance on risk tolerance is as important as the reference points.

During the discussion, it was agreed that there is also a weakness in the framework in terms of how to handle uncertainty, specifically regarding the role of uncertainty and who is it up to consider this. Is it up to Science to take all uncertainty into account in the reference points?

The point was made that the policy needs to be more precise on the role with respect to setting risk tolerance and the latitude for acceptable risk tolerance. It was pointed out that there is a table in the Policy but that it is not a prescriptive one.

In some cases, a lack of clarity in the area of risk tolerance can defeat the purpose of the PA, which is to manage the harvests such that there is a low chance of falling into the critical zone.

Uncertainty and risk tolerance were further discussed during the presentation *Reference Point Guidelines for Iteroparous Fish*.

Extirpation risk

The point was made that the concept of extirpation is not included in the Policy although it was included in the science advice in 2006, titled “A Harvest Strategy Compliant with the Precautionary Approach” (DFO 2006), where the limit reference point is defined as “the stock level below which productivity is sufficiently impaired to cause serious harm to the resource but above the level where the risk of extinction becomes a concern."

Specifically the policy should mention that the critical zone includes the area where the stock is at risk of extinction. A distinction was also made between commercial extirpation of the stock and extinction of the species. Also in most cases, it would be a question of extirpation of a population, not extinction of a species. This area of extinction was seen as a gap in the policy and points made in the discussion are included in the section on "Outstanding questions".

Additional Points

It was suggested that the Policy needs to be more precise on the relative position of USR and B_{MSY}. There is a need for some guidance on the relationship between those to avoid developing PA frameworks having a high risk of the stock going into the critical zone.

It was pointed that, in ICES, the role and responsibility for when F has to start dropping (at what stock size) is a Science one.

It was also pointed out that there is a lack of guidance on timeframe in the Policy. This is discussed further in the section on targets.

General conclusions on the discussion of the PA Policy

Points in gaps in the Policy that were highlighted as important to consider at future meeting (led by EFM and or policy) were recorded and the discussions are included in the last section on "Outstanding questions".

Was general agreement with the proposal on clarification on terminology for "removal reference" which was:

- **As an F limit (maximum acceptable removal rate)**
- **F target**
- **Harvest decision rule that applies across the range in stock status.**

The removal reference should be the limit which is set above the target and the diagonal line should be renamed the harvest decision rule.

ESTIMATION OF REFERENCE POINTS FOR ITEROPAROUS SPECIES

Daniel Duplisea presented the working paper. Key points made during the discussion are included here, and the guidance is included in Annex 4.

Context

The iteroparous working paper provided current approaches/best practice for how to implement the PA policy requirement to adopt PA reference points for iteroparous commercial stocks. Iteroparous stocks are for those fish that reproduce more than once in their lifetime and include most commercial groundfish stocks as well as most commercial pelagic species. An extensive working paper worked through the range of situations from data poor to data rich and which reference points should be used with commonly used assessment models and empirical approaches in Canada as well as internationally. Methods for adopting MSY reference points and alternatives were both presented.

The first six sections included below, as well as parts of the others sections, reflect discussion at the meeting that was generally applicable, that is, discussion of topics that are relevant for implementing the PA for all stocks, not just the iteroparous ones. In fact, most of the discussion of the iteroparous working paper was recognized as applying to other species groups as well.

The working paper for this section was not an exhaustive list of all models, but included examples of approaches used in Canada. The documented Canadian experience with implementing the PA for iteroparous stocks can help guide the choice of approaches for developing reference points for iteroparous as well as for other stocks. The information can also help to choose between two or more models.

There was a discussion about whether the working group should be including the aspect of model choice, or just given the model, how to set the reference points. It was decided that the working paper would not published as a Canadian Science Advisory Secretariat (CSAS) Research Document as it was felt that the modelling approaches are available elsewhere in a more comprehensive form. Rather, guidance specifically on reference point adoption and how to best comply with the current policy across the "data hierarchy" were extracted for the guidance document (see Annex 4) from the more comprehensive working paper.

Chosen time periods

When one refers to "average biomass" to establish an estimate of B_{MSY} (i.e. when B_{MSY} cannot be established from a model) how long is long enough to be considered an average? Some of the reasoning could be based on the COSEWIC criteria, where trends are based on 3 generations.

An example of the use of an "average time period" is redfish on the Scotian shelf (unit 3) (DFO 2012). It was not possible get a good fit to the Surplus Production Model, as there was not a clear signal in the biomass time series, so the mean of the survey biomass index over the 41 year time series was used as B_{MSY}. There are a number of similar Canadian examples. Alternatively, average biomass over a subset of the data during a productive period could be used.

Uncertainty

There was a discussion on how to categorize the errors. It was decided that the terms "process error" and / or "model uncertainty" should be used for error that is due to a lack of fit with the model because the model does not accurately reflect the stock dynamics. The term "observation error" should refer to errors from data collection and estimation of inputs such as catch and a non-representative survey index.

The importance of considering the different kinds of uncertainty that are associated with different model fittings and how they are incorporated was discussed. Such considerations were included in the working paper and were extracted into the guidance.

It was highlighted that, in surplus production models, the assumption of the balance between the process error and the observation error makes a big difference in how the model describes how productive the stock is. There was a recommendation about being explicit about the proportions of errors. (i.e. partitioning the observation and process error.) See more on the topic of setting errors in the section below on Surplus Production Models.

The question was asked whether there should be a requirement on the DFO decision making framework to characterize uncertainty. Should this be a priority? Is it pivotal to a manager? It was mentioned that, in most stock assessments, the uncertainty of survey data is not included in the way that it should be and that catch data is usually treated as a census without any error at all. The issue was not discussed further as it was seen as an assessment issue rather than a Precautionary Approach issue.

General conclusions on discussion on uncertainty:

The terms "process error" and "model uncertainty" should be used for error related to a lack of fit with the model because the model does not accurately reflect the stock dynamics.

The term observation error should refer to errors from data collection and errors in estimation of inputs such as catch and a non-representative survey index.

How to handle risk and the roles of Science and Management

It is the role of Science to describe the shape of the risk functions (e.g. yield vs probability of decline), and management decides where they want to be within that relationship. What risk tolerance should we be working with? Management/policy should, ideally, be telling Science what range they are interested in before the simulation work is carried out.

The point was made that one has to be careful about separating (1) the description of the risk function and (2) setting risk tolerance as they can easily become blurred. During the science exercise of setting reference points, often the "more conservative" option is chosen by Science, but where we want to be on the risk function, and what should be the risk tolerances should be a management decision. It was recognized that the blending of these two roles is pervasive and compete separation is difficult if not impossible.

It was recognized that a full MSE to analyse risk associated with different management options is not possible for every stock, but another option that has worked well in Pacific region and elsewhere is to use decision tables where, for example, the probability of decline is provided over a range of exploitation levels. This helps managers determine which risk level they want to work with. An example is decision tables developed for yellow rockfish (tables 3 to 14) in Stock assessment and recovery potential assessment for Yellowmouth Rockfish along the Pacific coast of Canada (Edwards et al*.* 2012).

In response to the question "How do we keep it separate?" the answer was given that one must decide if the questions are science or policy, and that one must be vigilant to keep a clear distinction - "You have to strive to keep the separation as part of the culture". Part of the purpose of the PA framework was to better distinguish between the science role and the management role.

It was pointed out that it is clear in the policy that the limit is clearly a Science responsibility and that the target reference point is a management decision. However, the responsibility of setting the upper stock reference point, although it is science-based, is considered to be a management one. The policy is not clear on what role management has in setting the USR. The common understanding is that science would set the upper stock reference point a safe distance above the lower limit reference point, creating the cautious zone, such that there would be low risk above the cautious zone that the true stock is in fact in the critical zone. That risk level would be chosen by management (e.g. 0.1% or 1% chance that when the estimated stock biomass is in the healthy zone, the true stock is in fact in the critical zone. Anytime we address questions of tolerable risk, the decision is a management decision.

It was felt that there should be further discussion on this and it should be clarified in the policy or elsewhere.

General conclusions on discussion of handling risk and the roles of science and management

- **It is the role of Science to describe the shape of the risk functions (yield vs probability of decline), and management decides where they want to be within that relationship.**
- **Management/policy should tell Science what range they are interested in before the simulation work is carried out.**
- **Using an MSE to analyse risk associated with different management options is a recommended approach to help managers decide which risk level they want to work with.**
- **Where an MSE approach is not possible, decision tables are recommended, where, for example, the probability of decline is provided over a range of exploitation levels. This approach can also help managers determine which risk level they want to work with.**
- **In the case of the USR, Science should set the upper stock reference point a safe distance above the lower limit reference point, creating the cautious zone, such that there would be low risk above the cautious zone that the true stock is in fact in the critical zone. That risk level would be chosen by management.**
- **Anytime we address questions of tolerable risk the decision is a management decision.**

Meaning of USR

An approach used in New Zealand to estimate the USR was discussed. USR is scaled to natural mortality (USR = 1-M), the idea being that, when natural mortality is high, so is variability in the stock and the need for a larger buffer to account for the variability around the target. One difficulty with this is we often have a poor understanding of natural mortality level.

The impact of the USR on the performance of a management strategy was discussed. Choice of USR level is hugely variable, but that variability is not critical to the performance of the strategy. If the USR is set low, it will have little impact on whether you go into the critical zone, but it will inject variability in the catch. Where the USR is set affects variability in the catch, but has almost no impact on the risk of going below the limit reference point. Depending on how the USR is used, it does not necessarily have that much impact.

B_{MSY} is defined as an average biomass about which a stock, fished at F_{MSY}, will fluctuate and return a yield of MSY. Therefore, in any given year, a stock fished long-term at F_{MSY} has a 50% chance of falling below B_{MSY}. It was suggested one could consider the USR as the lower boundary of tolerable fluctuations in biomass if you are fishing at F_{MSY} and the stock is fluctuating around B_{MSY}. If you fall below the USR you need to reduce fishing mortality to rebuild to the target.

Two interpretations of USR were considered during the discussion: (1) The USR is the point we should avoid getting to, i.e. enough above the LRP to ensure a low probability of going into the critical zone (2) the USR is at the bottom end of the variability around B_{MSY}.

There has been a change in philosophy in ICES from the first interpretation above to the second. ICES has historically based a reference point (B_{PA}) on the low end of biomass (as in (1) above), a point above which there is a very low risk of being in the critical zone, to a reference point that is based on the high end, the lower end of the range of variability around B_{MSY} (as in (2) above). ICES has put in place F_{MSY} as the target fishing mortality, and, over time they will get data on the variability in biomass of those stocks and will be in a position to base Btrigger - the value of spawning stock biomass that triggers a specific management action - on that variability. In the interim, ICES is using B_{PA} (Precautionary reference point for spawning stock biomass).

A definition of USR was proposed, discussed and refined (see below). Agreement was reached that it was a workable definition (although it was not formally adopted). The exercise of clarifying the purpose of the USR will help because, from the Maritimes experience, there were two challenging aspects of setting the USR (1) how to do the calculations and (2) the scientific rationale for what was done, how do you justify your choices (and what are the risks associated with those choices). It was felt that the proposed definition of USR would help with the rationale for the chosen levels.

General conclusions from discussion on the USR:

- **Two interpretations of USR were identified (1) The USR is the point we should avoid getting to, i.e. enough above the LRP to ensure a low probability of going into the critical zone (2) the USR is at the bottom end of the variability around B_{MSY}.**
- **DFO has been operating under the first interpretation, and there was no suggestion that that approach should change to the second interpretation.**

Proposed definition of upper stock reference point (USR)

Biological Properties:

- **The USR has no defining biological properties itself. Rather it is defined by the functions it serves in the framework. As a minimum, it is a tool to manage the risk that the stock may fall to or below the LRP. Hence its position is defined relative to the position of the LRP.**
- **It should take into account the uncertainties in the assessment and the uncertainties regarding the ability of management to alter stock trajectory in the short term.**
- **It must be sufficiently higher than the LRP that if management decision-making aims to keep the stock at or above the USR, based on the median estimated stock size from the best assessment available, the risk that the actual stock will fall below the LRP during the fishery does not exceed the risk tolerance specified by policy / management.**

What happens there:

- **As soon as the stock is estimated to be below the USR, exploitation rate begins to decline from the removal reference.**
- **The rate of the decline in exploitation rate is not specified, but at all times must remain sufficient that the intended F applied to the assessed biomass continues to ensure that the risk that the actual stock will fall below the LRP during the fishery does not exceed the specified risk tolerance.**

Lower limit stock reference point

A definition of the lower limit reference points was proposed, discussed and refined. There was general agreement that it was a workable definition (but it was not formally adopted).

Proposed Definition of Limit Stock Reference Point

Biological properties:

- **The point below which the risk that the stock will suffer serious harm begins to increase rapidly. "Serious harm" has been interpreted as "impaired recruitment", which in turn has been interpreted as any changes to the biological properties of the stock that make rebuilding cease to be considered "rapid and secure".**
- **Biomasses below the biomass associated with recruitment overfishing, or below the ascending inflection point on a well-fit stock-recruit curve are biomasses where rebuilding would not be rapid and secure, but other biological changes, such as reduction in population structure, might also be in some cases.**

What happens there:

- **By the time the stock has reached the Limit Stock Reference Point, fishing mortality (and other sources of manageable human impacts) is as close to zero as is possible to achieve.**

Removal reference

It was highlighted that there are different interpretations of the meaning of F_{ref}. In some contexts we refer to it as a limit and some as a target. Historically, DFO set the removal reference at 2/3 of $_{MSY}$. Later, F0.1 was used as a proxy for $2/3_{MSY}$ (the point at which the slope of the yield per recruit curve is 10% of what it is at the origin**).** Currently, in an international context, F_{MSY} is generally considered as being a default limit fishing mortality. However, currently in Canada there is no legal or policy requirements on removal rates. There is a need for a policy on removal rates that would be decided on by a policy-lead discussion, not a Science meeting.

It was recommended that the Department should not lose sight of having a recommended removal reference, to ensure having a constant harvest rate in the right ballpark, and to justify it clearly.

A recommended limit for fishing mortality is particularly important for certification.

It was recommended that the definition of the removal reference (and other definitions, including LRP, and USR) should include both (1) the biological properties the removal reference has and (2) what happens management-wise when you are there.

The link between the target stock size and the removal reference should be clearly made, such that, if the target fishing mortality is some fraction of F_{MSY}, then the biomass around which the stock would fluctuate would be above B_{MSY}. According to the UN agreement, target fishing mortality must be below F_{MSY} and target biomass must be above B_{MSY}, and this is consistent with the DFO policy in which there is a provisional rule for F to be below F_{MSY}. F_{MSY} and B_{MSY} rep have to be logically consistent, because F_{MSY} is the fishing mortality rate that brings the stock to B_{MSY}.

The policy has a potential inconsistency in that the target could be as low as the USR (0.8 B_{MSY}), which should logically be associated with a target fishing mortality above F_{MSY}. The policy presents a provisional rule that F must be below F_{MSY}. This apparent inconsistency should be clarified.

Conclusions from discussion on removal reference

The Department should adopt a recommended removal reference, to ensure constant harvest rates in the right ballpark, and to justify the recommended removal reference clearly.

The policy as it reads now has a potential inconsistency in that the target could be as low as the USR (0.8 B_{MSY}) which would be associated with a target fishing mortality above F_{MSY}. However, the policy presents a provisional rule that F must be below F_{MSY}. This apparent inconsistency should be clarified.

A definition of removal reference was proposed, discussed and revised. There was general agreement that it was a workable definition (but was not formally adopted).

Proposed definition of removal reference (F ref):

Biological properties:

- **This is the maximum removal rate which, if applied in a risk neutral way in management, does not imply an equilibrium biomass below the USR. Any higher F, applied consistently, would result in the stock being reduced to below the healthy zone.**

What happens there:

- **Regardless of stock size in the Healthy Zone, science never advises a harvest greater than estimated by the removal reference times the assessed biomass. Whether the assessed F is estimated to be above or below the removal reference in a single assessment, as long as the stock is in the Healthy Zone, the removal reference is used to estimate the maximum advised harvest.**
- **If the stock is below the USR and consequently not in the Healthy Zone, the Harvest Control Rule determines what exploitation rate (including possibly zero) should be used in producing the maximum advised harvest.**

The term “serious or irreversible harm”

With respect to the term “serious or irreversible harm” from the Government of Canada “Framework on the Application of Precaution in Science–based Decision Making about risk”, it was pointed out that we refer less often to “serious harm” in recent years. Even when we do, there is not much specific discussion about what is meant by “harm”. It is commonly considered the point at which recruitment is severely impaired (sometimes quantified as 0.5Rmax, the point below which there is recruitment overfishing). We do not explicitly consider reduction in genetic variability, loss of stock structure, loss of genetic spawning components, selection on low growth, growth overfishing, or low probability of rapid and secure recovery if fishing is stopped.

A problem that was highlighted is that you don’t know when harm is irreversible until you’ve crossed that line. In a fisheries PA context, it is more helpful to consider “serious harm” than “irreversible harm”. Usually we are focussing on avoiding “serious harm”, i.e. the risk of not being able to have good recruitment, reducing the future prospectives of the stock, as opposed to focussing on “irreversible harm”, i.e. getting to a point that, no matter what, we could not recover the stock.

It was pointed out that when the language for the precautionary approach was first developed, and the term “serious or irreversible harm” was introduced, the word “irreversible” was included in the context of contaminants or radiation. For ecological population level changes, it’s the "serious" part of the definition that is important to focus on. Populations are in a "serious" state long before the population declines are "irreversible".

Currently, we tend to define the reference points as a fraction of B_{MSY}, rather than define them based on the concept of recruitment overfishing.

General conclusions from discussion on the term "serious or irreversible harm":

With respect to the term "serious or irreversible harm" from the Government of Canada "Framework on the Application of Precaution in Science–based Decision Making about risk", in the present context of fish population level changes, it's the "serious" part of the definition that is important to focus on. Populations are in a "serious" state long before the population declines are "irreversible".

Surplus production models

The three main types of production models were reviewed. Depending on the choice of surplus production model, the production vs biomass curves vary. While B_{MSY} is at 50% of K for the Shaeffer surplus production model, because the curve for the Fox model is right-skewed, B_{MSY} derived from Fox model is always less than 50% (36%) of K. If the Fox model is used, F_{MSY} and $_{MSY}$ will also differ. A discussion on the preferred model concluded with picking the model that fits best, but if the best fit is not clear then the Shaeaffer model should be used by default. This recommendation was made because the DFO policy recommendations were based on the Shaeffer model. If one of the other two (Pella-Thomasson or Fox) are used, then 0.2 K and 0.4 K should be used (rather than .4 B_{MSY} and 0.8 B_{MSY}) because the B_{MSY} is skewed for those models. The Fox model will produce a B_{MSY} at 0.36K, instead of 50% in the Shaeffer, and for the same for the same biomass it will produce a higher fishing mortality. In terms of "best fit", as discussed above, a good fit at the low end is most important.

With surplus production models there is both process and observation error, and you need to weigh the two types of error explicitly, and the risk associated with that weighting has to be determined. The states-based approach is recommended in part because of the ability to set the ratio of errors. It was noted that, in particular, the misidentification of process error matters, as it can lead to overestimation of the size of the stock.

It was pointed out that in some contexts the Fox model is believed to be superior than the Shaeffer because it better represents stronger compensation at low stock sizes. However, unless the Fox model is a better fit and can be justified, the Shaeffer is more conservative and is recommended because the cautious zone is very small in the Fox model. The Shaeffer model simply divides the surplus production vs biomass space in half which represents a symmetry in density dependence. The Fox model suggests stronger density dependence at lower stock sizes. In Canada, and elsewhere, the custom for SPM has so far been the Shaeffer model and the default policy reference points were based on the Shaeffer, not the Fox model.

Best practice needs for surplus production models would be to fit the data to the three models, plot the resulting reference points and compare the three sets to see which modelling approach makes the most sense. If there is clearly a better fit with Fox or Pella Tomlinson model, then that model should be used. The default should be the Shaeffer model.

General conclusions on using surplus production models:

- **When using surplus production models, it is necessary to weigh process and observation error explicitly as well as determine the risk associated with that weighting.**

- **The states-based approach is recommended in part because of the ability to set the ratio of errors.**
- **Best practice for surplus production models would be to fit the data to the three types of surplus production models (Shaeffer, Fox and Pella Tomlinson), plot the resulting reference points, and compare the three sets to see which model has the best fit and for which the reference points approach what makes the most sense. If there is clearly a better fit with Fox or Pella Tomlinson model, then those models should be used. The default, however, should be the Shaeffer model.**

Choice of assessment models

The working paper addressed both the choice of model and how to establish reference points from them. There was a discussion about how useful it is to have the model choice section when such information is available elsewhere. NOAA fisheries toolbox was given as an example and such examples could be highlighted in the guidance.

The point was made that the Department does not have a best practice on how to do stock assessment, and that such information could be useful for developing PA frameworks as has been done in New Zealand. There was not general agreement on this point as there are significant differences in the ways things are done between regions.

Increasingly in recent years more than one model is applied, that is two or three different possible states of nature are put forward. In many cases the time trends are robust, but where the population is in relation to the reference points is highly, as is how the catch scales to the modelled biomass.

It was also mentioned that, in recent years, any chosen model is rarely supported by all. There are very different opinions on competing models (there are now more choices and more opinions). For example, increasingly catch-at-age models are being used.

The working group made the distinction between (1) deriving reference points from stock-recruitment relationships and the age-structure production process, i.e. looking for the intersection of replacement lines on the stock-recruitment curve and (2) the rule of thumb approach of estimating the SSB as %50 of the maximum recruitment form a fitted model. Some of these methods are not based on mechanisms or processes and are therefore more easily calculated, but are nevertheless a relatively robust way of getting reference points.

The working group reviewed standard stock recruitment models –not a comprehensive list but an overview of the main methods including non-parametric ones. An illustrated example of a mock data set was provided for which reference points were calculated based on six commonly used methods. It was pointed out that, interestingly, they all underestimated the true reference point.

It was recommended to try a number of models for any given data set. The question was raised “What do you do when you fit multiple models to the same data?” Sometimes it is clear from the fit or the required assumptions or assumed mechanisms. But when there is more than one credible model, which one do you use? It was suggested that, in addition to best fit, you and should test for model robustness. If the two or more models have equally good fit and robustness, they could be averaged. Also, if predicted results are out of observed ranges, for example 0.5 of maximum recruitment falls at a biomass that is higher or lower than any observed biomass, the model should be rejected. It was pointed out that for severely depleted stocks, i.e. when the current biomass is close to the origin (of the stock recruitment relationship) and well below the limit reference point, it often does not matter which model you choose.

It was pointed out that, in terms of choosing the model with the best-fit, the fit at low biomass is particularly important. Most observations tend to be at higher biomass, however, and the purpose of setting the reference points is to make sure that management actions at low stock sizes do not jeopardize the stock. For example, it is critical that the model does not overestimate recruitment at the low end of the stock sizes on a stock recruit curve. Basing reference points on the steepness of a fitted SR curve to is tricky because it is the least well understood part of the curve (because most observations are at higher values).

General conclusions from discussion on choice of assessment models

- **It is recommended to try a number of models for any given data set. If there is a model that clearly has a better fit, then that model should be chosen.**
- **The fit at low biomass is especially important.**
- **The models should also be tested for robustness, and that can help inform the model choice.**
- **If two models perform equally well, one could consider averaging the output for the two models.**
- **If predicted results are out of observed ranges, for example 0.5 of maximum recruitment falls at a biomass that is higher or lower than any observed biomass, the model should be rejected.**

Setting empirically-based reference points

There was a discussion as to whether empirical reference points are less precise that modelled reference points. It was pointed out that, if historical catch is well estimated, more complicated approaches are not necessarily better. In one sense, they are more certain because they are observed quantities. However, their performance in a management strategy may be uncertain, and they should be tested. It was also pointed out that the production function is hard to capture empirically. If there is no model, and therefore no production function, it is harder to determine the productivity of the stock. You may know the biomass on a relative scale, but you are unable to capture the production. Another advantage of having a working model is that you can run the model forward to make projections under various catch scenarios).

An empirically-based reference point can come from a modelled data series - the distinction is that the calculation of the reference point itself is not taking into account productivity processes. For example, for southern Gulf cod, the LRP is based on Brec from VPA modelled biomass), and for 2J3KL cod, the LRP is based on Brecovery from a SURBA modelled biomass. For both these cases, the reference points would be considered to be empirical even though they are based on modelled biomass.

Data-rich cases

During the discussion on data-rich cases, it was highlighted that having a data rich stock does not guarantee a good model fit. You can have a lot data, but still not have a model that fits it well.

It was also noted that the biological reference points that are chosen are only meaningful in the context of the model that has been applied. There are scaling factors are specific to the assessment model, so if reference points are set with one assessment model, and the assessment model is changed, the reference points will have to be reconsidered.

General conclusions from discussion on data rich cases

Biological reference points are only useful as reference points if the biomass and /or fishing mortality is currently estimated from the same model as were the original reference points.

ESTIMATION OF REFERENCE POINTS FOR INVERTEBRATE SPECIES

Stephen Smith presented the working paper. Key points made during the discussion are included here. The guidance is included in Annex 4.

The working paper is published as a Research Document 2012/117: Technical Guidelines for the Provision of Scientific Advice on the Precautionary Approach for Canadian Fish Stocks: Invertebrate Species (Smith et al. 2012).

Abstract

This report summarizes progress to date on the development of reference points for the management of various marine invertebrate species commercially harvested in Canada. The implementation of the precautionary approach (PA) to fisheries management in Canada requires the definition of reference points reflecting the productivity and reproductive capacity of a stock. The different invertebrate species commonly fished in Canada exhibit a very diverse range of life history characteristics. For these species, reproductive success will be a function of life history factors such as effective female fecundity, spawning opportunities for females, spatial patterns of age–size structure, the relationship between spawner density and fertilization success — especially for broadcast spawners with sedentary or sessile adults, spatial and temporal aspects of breeding areas, and the relationship between benthic settlement success and habitat suitability. For many species the time period between spawning and actually being able to observe recruits may be long enough so that cumulative environmental influences on survival could radically reduce year-class strength. Also, there is often a mismatch between managed areas and stock area so that recruitment success in one area may be affected by spawning success in another area. The lack of adequate models to account for these complexities has often resulted in the use of empirical methods to define the type of reference points expected by the DFO PA policy. To date, empirical methods have used either an estimate of or an indicator of population biomass or abundance to represent the productivity of the stock. Given that biomass alone is an incomplete measure of productivity, many invertebrate stock assessments rely on secondary indicators such as population size, composition-based and sex ratio-based growth changes, spawner abundance or biomass, abundance of prerecruits, predator abundance, environmental changes and spatial patterns of density, to modify stock status advice. For many sedentary species (e.g., bivalves and echinoderms), primarily spatially-based limits and targets for fisheries may be more appropriate. However, methods for spatial approaches still need to be developed.

Context

The working group reviewed approaches to adopt LRP’s and other components of the PA framework for invertebrate fisheries. The emphasis of this review was on the experience garnered and the progress made since the 2002 DFO sponsored international workshop on the development of reference points for invertebrate fisheries (Smith and Sainte-Marie, 2004). The working group for this 2012 Science process has documented approaches to adopt LRP’s and other components of the PA framework that have been applied in the meantime.

Typically in DFO invertebrate stocks are assessed and frameworks are developed regionally, there is not as strong of a tradition of working inter-regionally on invertebrate stocks as there is on some other stocks (shrimp being an important exception). The working group noted that, for a number of reasons, the approaches have varied greatly among stocks, and it was difficult to draw generalities on best practices. They documented the range of approaches that have been used, and readers can see what has worked well and what has not. Nevertheless, some guidance was agreed upon. Concern was raised regarding this variability/lack of consistency of approaches. Because of the wide range of solutions that have been developed tailored to species and stocks with very different life histories and fisheries, as well as how much information we gather on them, we need to look at the impact of this inconsistency in approaches.

At first it was difficult to get interest and progress in PA development, but MSC certification has changed that and there are now some certified invertebrate fisheries.

It was recommended that it would be beneficial to develop MSE's on key invertebrate stocks to test how much risk we are facing with current approaches.

Stock recruit relationships

The point was made that it is rare to see clear stock/recruit relationships for most invertebrate stocks. This is one of the reasons models are seldom used to develop reference points for invertebrate stocks, although examples of Catch at Age (CASA) and Surplus production models (SPM) were given. From the discussion it was clear that we do not know to what extent this lack of relationship is because, in the real world, recruitment in invertebrate stocks is not as related to stock size as it is in other species, or whether it is because of a lack of appropriate data. Among potential reasons suggested for the latter were that (1) there is a spatial scaling problem – assessment/management units and biological units do not match so that recruitment can come from outside the assessment area and (2) this spatial scaling problem makes it more difficult to tease out environmental effects from stock-recruit effects. It may be important to get more information on the scaling issues, although it may also be an intractable problem.

Whatever the reason for the lack of stock/recruit relationships, application of analytical models have been problematic and empirical approaches appear to more promising than model-based approaches.

A surplus production model was used for shrimp (*Pandalus borealis*) within ICES. The questions were asked, "Is this something we should aim for?"

And how would reference points from that SPM effort compare with the reference points that would come from an empirical approach?

It was pointed out that an empirical alternative, such as looking for a productive period, may not so straightforward either.

Length of productive period

It was recognized that, to some extent, there is an arbitrary aspect to choosing the window one uses for a productive period. The question of what period to use comes up in particular with shrimp, as there has been a large change in productivity conditions since the 1980's. The need for guidance in defining "a productive period" was identified. The concern is that depending on what period you choose, you could get whatever answer you want for the reference points. A developed PA framework is very sensitive to input here.

The policy states that the average biomass over a productive period could be used as an estimate of B_{MSY}. The point was made that there is a need to defend the choices of the periods that were chosen, if full time series is not used for a productive period. For example, a relatively stable period could be chosen. A note of caution was added that high periods may be associated with (and be the result of) the implementation of strict management measures.

LRP decoupled from economics

The “Discussion” section of the working paper mentions that, in some cases where reference points for invertebrate stocks have been empirically derived, the reference points may represent a low point in biomass at which there would be severe economic consequences, and should be avoided for that reason. That is, the LRP might not represent a level below which there is risk of serious and irreversible harm to the resource. The USR then would not necessarily be directly related to a level of maximum productivity, but could nevertheless serve as a limit to minimize, with high probability, the risk of biomass declining to the LRP.

Concern was raised that historically the concept of the LRP was adopted due to a need to establish a Science-based point that is independent of economics. That is, while higher harvest levels would in the long term be of great economic benefit, and targets are clearly based on economics, limits should not be based on economics, but should be based on risk of harm to the resource.

On the other hand, it was emphasized that when working with stakeholders, the economics helps to convince them of the utility of the reference points and therefore economic aspects should also be emphasized. The concern of returning to low productivity is incentive to establishing reference points and that was seen by some as a balanced way of approaching their development and that there is no reason to shy away from economic arguments.

It was pointed out that economic considerations can allow for the PA to be framed in terms that industry can identify with. Others felt that if economic incentives kept fisheries sustainable then a meeting such as this one would not be needed. A concluding comment on the discussion was that “economics are great if it falls out but it’s not the rationale for setting the reference points.”

Spatial scale

For sedentary invertebrate species, there is a particular need to account for local densities and spatial patterns, and this can be done in part by using them as secondary indicators.

The question was raised about how do we account for this relatively fine-scale distribution when setting reference points. On the one hand, if reference points are adopted for a large area, smaller high density areas can be easily over-fished relative to their relatively high MSY’s. On the other hand, it was pointed out that management areas in invertebrate fisheries tend to be very small. There is no point to develop reference points for small geographic areas (management units) that don’t necessarily reflect biological units. In some cases, e.g. more mobile species, such as crab and lobster, the management units are smaller than the biologically relevant spatial scale, and in some cases the opposite is true, the biologically relevant scale is smaller than the management unit, for example in the case of more sedentary species such as scallops where high densities are found in areas of high habitat suitability.

Recommendation was that, for more mobile species, we should develop PA framework’s for larger areas than management area.

For sedentary species, a precautionary approach to protect the high density areas, would be to set total catches could be set based on the high density/high productivity areas alone.

Secondary indicators

Because the PA framework is not as good of a fit for invertebrate species, there is a particular need for secondary indicators for invertebrate stocks, such as local densities, spatial patterns, male size, as well as a number of reproductive parameters.

However, it is not clear exactly how they would be brought in to a framework. It was nevertheless recognized that there is a need to bring in other pieces of information (expert knowledge/secondary indicators) to the stock assessment and in some form to management frameworks.

General conclusions from discussion on invertebrates section:

- **Because of the lack of obvious stock-recruit relationships, the standard analytical models appear to have little utility. In many situations, empirical approaches appear to be more promising than model-based approaches.**
- **Because stock-recruit relationships established, biomass estimates may not be reliable indicators of stock productivity or stock status. Secondary indicators may need to be developed to provide more information on stock status.**
- **It was recommended that there could be benefits to developing MSE's on key invertebrate stocks to evaluate how much risk we are facing with current approaches.**
- **The need for guidance in defining and choosing "a productive period" was identified.**
- **Reference points should be based on scientific criteria, however that does not preclude using economics arguments to support their adoption.**
- **It was recommended that for some invertebrate stocks, we should develop PA frameworks for larger areas than management area that are more biologically relevant.**
- **When setting reference points and HCR's for some invertebrate species, it will be important to have a strategy to protect higher density areas that have a tendency to be exploited heavily and before the other lower density areas in the fishery.**

ECOSYSTEM CONSIDERATIONS AND FISHERIES REFERENCE POINTS

Presentation was given by Jake Rice, and guidance is included in Annex 4. Key points made during the discussion are included here.

Abstract / Introduction

There are two major classes of ecosystem considerations relative to the sustainability of fisheries: ensuring sustainability of the impact of the fishery on ecosystem components other than the target species, and taking account of how stock productivity may be affected by the state of the ecosystem. Each of these classes has several facets. This Working Paper summarizes the key considerations of each class in the context of their implications for positioning of reference points (RPs) for target species of fisheries and the possible need for fisheries management reference points for other ecosystem properties, consistent with the concepts in FAO (1996) regarding the precautionary approach in fisheries.

Bycatch and habitat impacts are discussed very briefly but no guidance is provided for either type of impact. In the case of bycatch, a separate meeting will provide advice on benchmarks for sustainability whereas for habitat impacts, neither the policy nor the science frameworks are sufficiently mature for comprehensive guidance on management reference points. For trophodynamic impacts, both benchmarks for forage species and for abundance of large predators are discussed, and proposals made. In both cases it is concluded that the considerations are better addressed in robust harvest control rules than by frequent adjustments to biomass or exploitation reference points. For forage species the HCRs may contain “escapement goals” to provide food for dependent predators, and provisions for avoiding local depletion of prey populations. In some cases harvest control rules conditional on predator or prey status may be appropriate. Cases when stock productivity is affected by environmental conditions are also discussed. Dominant conceptual models for how such relationships are expressed include the optimal environmental window and the match mismatch hypothesis. For both mechanisms it is argued that HCRs, robust to likely ranges of environmental conditions, will be superior to models which try to track changing environmental conditions with compensatory changes in management reference points.

Reference points for forage fish

It was highlighted in the discussion that DFO’s forage fish policy (DFO 2009b) addresses the need for reference points for forage fisheries that ensure not only the future recruitment of the target forage species but also ensure that the food supply for predators and predator productivity is not impaired. It was agreed that such reference points are important, but that given the level of information that is typically available, even more important is the establishment of robust harvest control rules, at least for fisheries in which a reasonable high biomass is maintained. Examples were given of setting escapement goals to provide food for dependant predators, rules preventing local depletion of t forage fish, and rules that that depend on predator status as well as on the status of the forage fish itself. The biomass should be kept above set limit reference points, but over and above those limits there should be harvest control rules that address the needs of predator species.

If a plausible estimate of natural mortality is obtainable, it is possible to test the control rule by treating the predators as fleets harvesting prey, and sampling from a distribution of predator requirements. Because reliable and regular estimates of mortality are not always possible, (and are one of the hardest components to estimate, along with consumption estimates), longevity can be used as an estimate of long-term mortality to address questions of ecosystem effects. The importance of getting the best estimate of mortality as possible was highlighted. This is an area that was identified as needing work.

Where population estimates, energetics and diet models are available, modelling forage fish consumption needs can be done, but for most fisheries this level of information is not available, and certainly not updated annually to reflect changes. The point was made that in these cases harvest control rules will be key.

The proposed guidance is consistent with the Departmental forage fish policy (DFO 2009b) and was developed to provide a framework that ensures that fisheries on forage species are planned and conducted in ways which are compatible with conservation of the full ecosystem, and that their sustainability is evaluated in that larger context. In 2009 the commitment was to review all existing forage fisheries against the policy, that exercise is ongoing.

The question was asked “What is now managed under the forage policy? Is it being applied? The policy was designed for emerging forage fisheries, although the principals apply more widely to all forage fisheries. The point was made that because we do not target many forage species, we do not need LRP’s for all prey, only the ones that we target.

The issue of double counting was raised, i.e. that predation requirements of forage fish should not be counted twice, that is they should be built in either into the LRP or the exploitation rate.

(That means if you increase to LRP to include biomass needed to sustain predators, you do not need to count predation mortality into F_{MSY} as well).

Maintaining large fish predator populations

While there has been little work done on precautionary approaches for top predators specifically, there is evidence in the literature that changes in predator abundance can lead to regime shifts or trophic cascades. If there are changes in key predators, there can be large-scale ecosystem level changes that can be difficult or impossible to reverse. It was noted that keeping exploitation rates low will go some of the way to avoiding age and size truncation.

Although it is recognized that the status of top predators is critical to maintaining enough top down control, it is not clear if managing all large species around B_{MSY} would provide adequate control of ecosystem structure or if additional rules would be required. This lead to a discussion on the feasibility of fishing all stocks simultaneously at F_{MSY}.

The point was made that if the estimate of F_{MSY} takes into account a reasonable estimate of natural mortality, then to some extent the species interactions will be taken into account. It is well recognized that it is not be possible to fish all species at F_{MSY}, but there has not been any guidance on what to do about that, how to go about setting priorities. The working paper explains that a dialogue is required to address the issue that all species cannot be fished at F_{MSY}, and that setting priorities should be considered. If all stocks cannot be fished at F_{MSY}, which ones do policy and management want to give priority to?

The distinction was made that while it is true that it is not possible to harvest MSY from all stocks at the same time, it’s not that you can’t fish at F_{MSY} on all stocks at the same time. The point was made that this is a theoretical result and may be too abstract for what needs to be achieved here, we may never have to worry about fishing at F_{MSY} for all stocks. Because we only exploit a portion of the species, should not be as much of a constraint as it appears. There is a natural buffering in the ecosystem.

A related practical example of multi-stock issues is the mixed Pacific salmon fisheries, where it is impossible to harvest individual runs of single species. There was no resolution to this issue, and it was recognized that the topic of setting reference points for mixed fisheries was not fully addressed at the workshop. Maritimes region has a flatfish quota that covers multiple stocks and NAFO is addressing reference points for multi-stock fisheries in one of its working groups (in the Flemish Cap).

It was agreed that the first step towards preventing overfishing of top predators is to get fishing mortality down to F_{MSY} on an individual stock basis. The second step would be to maintain the size spectrum (across species) of top predators. Even when it is not possible to specify specific slopes and intercepts of the predator size spectrum, it should be highlighted that the more waves and dips there are in the spectrum, and the more size truncation, the more likely we will have unstable ecosystems and the less likely they are to reverse. When there is equal exploitation of all size ranges and trophic levels, the impact on the ecosystem is minimized.

It was highlighted that the approach of balanced harvesting is an emerging literature. The approach involves not taking too high a level of harvest from one part of the ecosystem, and not being too selective on a narrow range of species.

There was a discussion on aggregate caps on an assembly of large predator populations to set a total cap on how many large predators can be harvested. This has been tried in a number of jurisdictions where the biological basis was clear and general enough. The blue whale was given as an example where the management approach was difficult to work with, where a common currency was set for a number of the large whales. Marine mammals were counted in the currency of blue whale equivalents. The distinction was made between aggregate caps and equivalencies.

Role of the environment as a driver of stock dynamics

It has been suggested in the literature that reference points can be/should be adjusted to the state of the environment using functional relationships between environmental variables and processes that affect stock productivity (recruitment, growth or survival). The argument made in the working paper that the more tractable way to account for effects environmental variability on stock productivity would be through establishing robust harvest control rules rather than by adjusting reference points to current conditions through environment/production relationships.

To effectively use environment – recruitment relationships, for example, a functional relationship that captures well the effect of the environment on stock productivity is required as well as stable parameters if the relationship is to be used in the future for management. The time frame across which the environmental conditions were taken into account is critical. It is the rare occasions when condition are extreme (hot or cold, more or less saline) that will drive the strongest effects on the stock, and it is rare that the functional relationships cover the whole range and that a model can be found to fit well across that range. Addressing environmental variability through the use of harvest control rules requires testing for robustness (same point as for foraging species). Some of these dynamics can be structured into the assessment model, whichever factors are expected to be most strongly affected by the environment (i.e. recruitment, growth, or natural mortality). It was agreed that annual variability in environmental conditions should not generally to be built into harvest control rules. It was agreed that the information available is generally not robust enough.

The point was made that were one to test robustness of harvest control rules to changing productivity conditions, correcting for autocorrelation in the productivity parameters would be important. Specifically, it was suggested one could build autocorrelation on a decade scale into a vital ray and then do a slightly shorter frequency than decadal as well. It would model a quasi-equilibrium state as opposed to an equilibrium situation.

The point was also made that when modelling effects of changing predator/prey dynamics, natural mortality rate is part of the abundance and autocorrelation may not capture this and could cause more risk.

When testing for robustness to changing conditions, not just one functional relationship would be identified, but a number of functional responses should be considered / simulated.

The point was made that we need a high level of confidence in our modeling capacity to try modelling these strongly non-linear relationships. It was then suggested that it could be as simple as analyzing a set of bad years of low recruitment, or high mortality to get at the heart of how robust the rules are and that there are opportunities for simplification. The fact that predator populations are typically more static than are the prey, when the fishing pressure is on the predators, was presented as a challenge that adds risk that may not be captured in the simulations based on autocorrelation. There may well be functional responses to changing productivity/predator conditions that would not be captured with autocorrelation.

It was suggested that guidance on when to use an autocorrelation approach to test robustness of harvest control rules would be a good idea, but specific guidance was not suggested at the meeting.

General Conclusions on Ecosystem Considerations and Reference Points:

- **It was agreed at the meeting that while reference points that take predator requirements into account are important, given the level of information that is typically available on predator needs, even more important, and more tractable, is the establishment of robust harvest control rules for the forage fish, that is rules that are robust to inter-annual variability in the requirements of predator populations.**
- **It was agreed that the first step towards preventing overfishing of top predators is to get fishing mortality down to F_{MSY} on an individual stock basis. The second step would be to maintain the size spectrum (across species) of top predators. Even when it is not possible to specify specific slopes and intercepts of the predator size spectrum, it should be highlighted that the more waves and dips there are in the spectrum, and the more size truncation, the more likely we will have unstable ecosystems and the less likely they are to reverse. When there is equal exploitation of all size ranges and trophic levels, you have the least ecosystem impact.**
- **This is consistent with emerging literature on balanced harvesting. The approach involves not taking too high a level of harvest from one part of the ecosystem, and not being too selective on a narrow range of species.**
- **It has been suggested in the literature that reference points can be/should be adjusted to the state of the environment using functional relationships between environmental variables and processes that affect stock productivity (recruitment, growth or survival). There was general agreement with the argument made in the working paper that the more tractable way to account for effects environmental variability on stock productivity would be through establishing harvest control rules that are robust to changing conditions rather than by adjusting reference points to current conditions through environment/production relationships.**
- **The simulation of changing productivity regimes to evaluate the robustness of harvest control rules to such changes could be as simple as modelling a series of years in which recruitment is low, or a series of years in which mortality is high. Autocorrelation could be built-in using fixed time scales, although assuming that all dynamics would be captured by using autocorrelation would lead to an underestimation of risk.**

REFERENCE POINTS FOR ANADROMOUS SALMONIDS AND SEMELPAROUS FISH

Gérald Chaput presented the working paper which has been published as a Research document 2012/146: Considerations for defining reference points for semelparous species, with emphasis on anadromous salmonid species including iteroparous salmonids (Chaput et al. 2013)

Key points made during the discussion are included here, and the guidance is included in Annex 4.

Abstract

The document was prepared in support of an advisory process meeting to produce a technical guidance document to assist science practitioners responsible for developing the science elements of the Precautionary Approach (PA) framework. It reviews the use of reference points in the assessment and management of semelparous species and anadromous salmonids including iteroparous salmon. Semelparous species and anadromous salmonids are treated collectively and separately from other aquatic species because they share a number of life history and population dynamic characteristics which are distinct from those of other aquatic organisms. In British Columbia and Yukon, the Wild Salmon Policy (WSP) guides the implementation of the precautionary approach in the management of fisheries on Pacific salmon. In the WSP, biological benchmarks are developed for four main classes of indicators: trends in abundance, abundance, fishing mortality, and spawning ground distribution as data permits. These indicators are further integrated into a single category of biological status. There are no management actions which are associated directly with a given status or benchmark. Rather, the biological benchmarks aid in the development of fishery reference points along with socio-economic factors and issues related to risk tolerance. Reference points for Atlantic salmon have been used to advise fisheries management since the 1970s. The use of a conservation objective defined as a limit reference point and the fixed escapement strategy has been adopted in Canada, by national governments in Europe and by international organisations. Candidate fishery reference points and WSP benchmarks are similar to the general list of reference points proposed in a number of publications for other species. Stock and recruitment models have a long and established history in Pacific and Atlantic salmon stock assessment and provision of science advice for fisheries management. Empirical methods consisting of life history models that use life history process parameters borrowed from a large range of studies on the species of interest are considered. In data limited situations for unstudied populations but for which information exists from other populations, reference points are frequently transported based on values from studied populations which are standardized using an exchangeable and transportable metric.

Context

Because of the unique life-history characteristics and population structure of semelparous stocks, different approaches to adopt reference points have been developed for this unique group of species. These approaches were described in the presentation. Key differences include the fact that all fish that are removed by the fishery have not spawned, that the populations are highly structured, and that they are limited by the amount of habitat in the freshwater phase of their life-cycle. The point was made that despite these differences, establishing reference points for semelparous species is similar to establishing them for other species groups.

A number of topics in the working paper were discussed and the points raised are summarized below. Most points below are specific to semelparous species, but some are of a general nature, that is they are relevant to other species groups.

Relationship between benchmarks, reference points and COSEWIC status

The Wild Salmon Policy (WSP) is the policy framework for the conservation and sustainable use of wild Pacific salmon and includes guidance on establishing biological benchmark for status evaluations. A lower and upper benchmark delineate respectively the red to amber and the amber to green WSP status zones. The lower benchmark is established at a level high enough to “ensure that there is a substantial buffer between it and a level of abundance that could lead to a conservation unit being considered at risk of extirpation by COSEWIC.” The point was made that under the PA, the limit reference point is the point at which the stock may be at serious or irreversible harm, and is also set comfortably above what COSEWIC would consider at risk (presumably higher than the lower benchmark in the wild salmon policy).

The point was made that COSEWIC’s “B” and “C” criteria will come into play much more often for Pacific salmon than for other species. (“B” and “C” are “Small Distribution, and Decline or

Fluctuation" and "Small Total Population size and Decline".) Because of the large numbers of small geographically isolated populations (based on freshwater spawning distributions), Pacific salmon are unique for COSEWIC to assess.

Shape of harvest control rules and setting exploitation rate

Removal references were discussed and F_{MSY} was recommended as a limit fishing mortality rate. In a study by Holt (2009), F_{MSY} was associated with less than 25% chance of extirpation in 25 years and greater than 75% probability of recovery to S_{MSY} within three generations. The point was made that the 25% extirpation risk is a high cut off point (one should consider a removal reference with a lower probability of extinction).

One of the removal rates in the list of candidate removal rate reference points in Table 4.1 of the research document, F_{max}, was suggested to be equivalent to F "crash" (F_{max} defined as the slope at the origin of the spawner-recruitment relationship) and therefore F_{max} should not be recommended as it is an unacceptably high risk of stock collapse, i.e. their use may result in unsustainable rates of fishing compared to F_{MSY}. F_{MSY} was recommended as a more reliable candidate for a limit removal reference point than F_{max}.

There was concern expressed over the shape of the harvest control rule in fig 3.1.1. A clear justification of a convex curve should be required, as harvest rate increases quickly through the moderate abundance zone. Almost half of the Total Allowable Mortality is taken in the bottom third of the moderate abundance zone. The line at 30% Total Allowable Mortality rate, (half of the max total allowable mortality of 60%) intersects only at about 1/3 of the way into the moderate abundance zone. It is hard to rationalize, under the precautionary approach, reserving most of the management interventions until the stock is close to the limit (For any given F_{ref}, a convex curve in the central zone is the highest risk.)

In the case of Fraser River sockeye, the convex shape of the Total Allowable Mortality Rule was tested, and the reference points were shifted higher to compensate for higher removal rates at the low stock sizes. This has the disadvantage of increasing the frequency of fishery closures.

There were some questions regarding the increase in escapement through the zone of high run size in Fig 3.1.2. It was explained that this continuing increase was not a recommendation, just an example of an approach that was taken.

In the particular context of salmon fisheries, mixed stock fishing is the rule, and, for some stocks, the removal rate of the least productive stocks sets the removal rate for the others. How to handle this constraint has to be decided by management and policy (how many populations do you want to protect? With what certainty? How much risk are they comfortable with?)

Accounting for uncertainty in the reference points

The point was made in the working paper that uncertainty in the reference point should be taken into account as well as uncertainty in the stock size (this is not just a semelparous issue). This point was discussed at some length, as it was considered by some to be potentially double counting the uncertainty. It was suggested the text be clarified so that it would not appear as though uncertainty was being double counted. The conclusion was that for Bayesian modelling, it is set up that way (to have a probability distribution for a reference point instead of a single value), but that for other cases a harvest control rule could be tested using a reference point that consists of a point estimate only.

The issue was discussed at ICES and it was concluded that it makes the system more workable and more understandable if the reference points in the framework are taken as point estimates.

People are used to seeing uncertainty in population estimates, but if the reference point itself is uncertain, there will always be debate as to which level to use.

It was explained that, within an MSE context, the robustness of the management strategy to uncertainty in the reference points can be tested, but the software has to be written expressly for that purpose.

Fitting of stock-recruit relationships

With reference to Fig. 4.1 in the Research Document , the point came up again about the importance of the fit of stock recruit curves at low stock sizes. Often at the low end, the steepness of the curve goes over the observed stock size. In this case you may be overestimating the level of depletion. However, if you do have a high number of negative residuals, your stock is in worse shape than the model suggests. It was highlighted that these issues are common and are under-recognized.

A bad fit on the right hand side of the stock-recruit curve is also a problem. In that case, you may need to use a proxy for carrying capacity, K. Ideally, the curve should fit well across the whole range in stock biomass. In reality, however, stock-recruit curves are rarely great fits throughout the range. Such “lack of fit” due to uncertainty and/or process error should be explicitly recognized.

When there is not enough data for stock-recruit relationships

The candidate reference points in Table 4.1, 4.2, and 4.3 of the Research document were discussed. It was pointed out that all the reference points in those three tables require fitting, but that in 90% of the populations, we don’t have suitable data to fit the stock – recruit curve to produce the reference points.

The question was asked “What about when you do not have enough data for a stock-recruit curve? How are the salmon stocks that do not have stock-recruit curves managed?

It was mentioned that, currently, in the salmon IFMP, there are harvest policies that are designed to be built for declining levels that could be categorized as empirical.

It was mentioned that a metric could be used, such as available rearing habitat to scale the production that is physically measurable.

It was agreed that, given the spatial complexity and population structure of salmon stocks, there is not the data available to have stock-recruit curves and modelled reference points for each stock, or even most stocks. Because of this, there is a history in Canada (and internationally) of using empirical approaches such as life-history modelling when the data is not available for stock recruit models.

Some empirical options are to consider limit reference points that look at the minimum density of eggs or juveniles and/or at the minimum amount of habitat. This approach has been developed for in particular for salmonids, but could be considered for other species that are not highly mobile.

Specifically, one empirical method used for salmon stocks with no stock-recruit relationships is to develop life history models based on parameters from a wide range of studies on different stocks of the same species. A stock-recruit model can then be derived from these life-history models and applied to a wide range of stocks of that same species.

When a population is unstudied, but adequate information exists for other populations, reference points can be transported by standardizing to an exchangeable metric representing the size of the population. Egg deposition /unit of resting area developed on a well-studied stock can be applied to one that is less well-studied. Area of juvenile rearing habitat has been used in the same way.

Meta-analysis based on a relationship between smolt abundance and juvenile rearing habitat has been used to set reference points for unstudied sockeye stocks in BC and Alaska. Similar approaches have been applied using relationships between stream length and smolt-abundance.

See sections 5.2 to 5.3. (p. 33 to 35) of the Research Document for a detailed description of approaches to establish reference points for semelparous stocks that do not require a fitted stock-recruit curve.

General conclusions from discussion on anadromous salmonids and semelparous fish:

- **While establishing reference points for semelparous species is similar to establishing them for other species groups, there are unique considerations and approaches because of the differences in life history characteristics and the many small geographically distinct stocks.**
- **F_{MSY} was recommended as a limit fishing mortality rate. However, if rate of extinction associated with that is unacceptably high, a lower F_{ref} should be chosen.**
- **F_{max} was not recommended as a limit removal reference point as there is high risk of stock collapse at low stock sizes.**
- **There is always uncertainty associated with any adopted reference point, and this uncertainty should be explicitly recognized. The manner in which the uncertainty is accounted for depends on the approach that is used to establish the reference point. For example, if Bayesian methods are used, the reference point is defined by a median associated with a probability distribution. In the case of MSE, the management strategy could be tested for robustness to the uncertainty in the reference point. For other approaches, a harvest control rule could be tested using a reference point that consists of a point estimate only, as first, the uncertainty may be accounted for in other ways and second, communicating a point estimate is simpler than communicating a reference point that consists of a probability distribution.**
- **While most of the candidate reference points provided are based on fitted stock recruit models, for most salmon populations, there is not suitable data to fit stock – recruit curves for all stocks. A number of approaches have been developed to use information from well-studied stocks and apply them to less well studied stocks so reference points can be established. These are described in detail in Annex 1 and in the Research Document.**

ESTIMATION OF REFERENCE POINTS FOR MARINE MAMMALS

Garry Stenson presented the working paper which has been published as a Research Document 2012/107: Applying the Precautionary Approach to Marine Mammal Harvests in Canada (Stenson et.al. 2012)

Key points made during the discussion are included here, and the guidance is included in Annex 4.

Abstract

In establishing harvest levels, resource management requires trade-offs among conservation, economic and political concerns. The Precautionary Approach brings scientists, resource managers and stakeholders together to identify clear management objectives and to agree on population benchmarks that would initiate certain management actions when these benchmarks are crossed. A conceptual framework for applying the precautionary approach to marine mammal harvests requires the identification of populations that are considered to be data-rich and those that are lacking sufficient data to determine the population dynamics and estimate reference levels. For a data-rich species, precautionary and conservation reference levels can be estimated as a proportion of a reference level identified as the carrying capacity or the maximum population observed or estimated. When a population falls below the precautionary reference level, increasingly risk-adverse conservation measures are applied. A more conservative, risk-adverse approach is required for managing data-poor species. The framework has been implemented for the management of commercial seal harvests in Atlantic Canada and some cetacean species.

Context

Garry Stenson described the precautionary approach framework that was developed for marine mammals in Canada (and adopted in 2003), before the national PA policy was published. He laid out the two different approaches, one for data rich stocks and one for data poor stocks. The current approaches used are described in Annex 1, and in more detail in the published Research document "Applying the Precautionary Approach to Marine Mammal Harvests in Canada" (Stenson et al. 2012).

Uncertainty, data availability and risk aversion

It has been suggested that, with greater uncertainty, decision making should become more risk averse. There was not general agreement on this point. It was pointed out that, within this framework, yield is adjusted downward when uncertainty is greater precisely so that the level of risk aversion remains the same. In the literature, it is sometimes framed as though risk goes up with greater uncertainty. It was agreed this is true, but only if yield is not adjusted downward. It was recommended that, to avoid confusion, we do not suggest that risk aversion should increase as uncertainty goes up.

For any level of risk aversion, as uncertainty goes up, the allowable yield will go down. The point was made that more adding data does not necessarily decrease uncertainty and increase yields. It can happen that, when more data are added, uncertainty goes up, not down (for instance when adding an abundance estimate with a large CV, the resulting averaged estimate can end up with a larger CV, the resulting averaged estimate can end up with a larger CV than prior to adding the data). Therefore, one should not assume that uncertainty will necessarily go down with more data, and that yield will necessarily go up. However, it is hoped that additional data will improve our understanding.

It was stated that one approach to dealing with the issue of risk aversion and uncertainty is with MSE (Management Strategy Evaluation). Simulations can be run to examine trade-offs between uncertainty, risk and allowable yield. It is the role of policy and management to specify a risk tolerance for serious harm to a stock, in consultation with Science. The framework should be set up such that, with increased uncertainty, risk tolerance remains constant while harvest is adjusted downward.

Challenges with estimating and using carrying capacity, K

There was discussion about the use of the Pella-Tomlinson model to reconstruct the time series of abundance for Northwest Atlantic harp seals back into the 1800's based on historical catch. Current survey data were used to fit the model, and then the model was run with those parameters and historical catch to project abundance back in time.

Question was asked about parameter estimation. It was explained that the Pella-Tomlinson model was a simple way of coming up with an approximation of K. The K could be considered a proxy until there was a better understanding of K. There is more confidence in the shape of the curve than in the absolute value of K. Prior to this exercise, the estimates of K for harp seals ranged greatly (from 3 million to 300 million).

The question was asked, "How much confidence is there in K when the model has to be projected so far back in time?" and "Would K still be the same now as it was so long ago?" It was understood that productivity may have been very different, and that even if accurate, estimates of pre-exploitation levels under historical conditions may not be realistic estimates of carrying capacity under current conditions. Because of these concerns, the authors did not feel it was appropriate to base the limit reference point on the value of K estimated from the reconstructed historical time series. Instead, they used a proxy for K, which was the highest observed biomass. The limit reference point is set as 30% of that maximum observed population. This approach has drawbacks as well – as the population recovers, the estimate of the maximum population can increase which may be confusing to others when developing management strategies with industry and managers.

The challenges with relying on uncertain estimates of K were discussed. It is on the one hand computationally difficult to estimate (and abstract to define), and on the other is a very influential parameter on the outcome of management strategies. It was highlighted that there is a need for guidance on how to estimate K. It was also emphasized that this is not an issue unique to marine mammals, it is relevant to all species groups. No specific additional guidance was suggested other than that the way K is calculated should be very clearly documented and described. It was also suggested that the implications of the uncertainty/errors in K should be explored using simulations, i.e. what happens if K is over estimated, underestimated or if it highly variable over time?

It was suggested that, because carrying capacity may be more relevant at an ecosystem scale (with multiple species competing for the same resources), the exercise of setting K species by species may be questionable. See section on ecosystem considerations.

Separation of COSEWIC criteria and reference points

The working paper and research document (Stenson et al 2012) discussed the potential use of decline criteria such as benchmarks used by COSEWIC to define conservation status. For example, a decline to 30% of a historical reference level could be used as a lower limit reference point. Although it was recognized that this approach has the advantage that it does not rely on uncertain estimates of K, there are several issues with this approach.

The PA in Canada has been tied to management for sustainable use, not to the prevention of extinction. Therefore, the PA frameworks should be designed to keep stocks well outside of the domain where extinction of the species comes into play. The LRP's are there to minimize risk of serious harm to the stock, not to avoid risk of extinction. It was recommended that, if stocks are managed effectively under a PA framework, dropping below the limit should not put a stock at risk of extinction and that we should not equate PA limit reference points directly with SARA risk of extinction.

For additional discussion, please see the section on the risk of serious harm relative to extirpation risk.

Use of ratios instead of carrying capacity

There was a discussion on the use or rations as an alternative to the use of limit reference points based on a fixed estimates of K. Ratios are seen in common fisheries theory. The advantage is that ratios may be more robust than expressing reference as absolute values of stock biomass.

Although ratios may avoid some of the issues associated with uncertain absolute values of biomass or abundance, at the end of the day, the ratio has to be translated into an absolute value to set the catch, so one cannot get away from needing an absolute estimate of stock size and reference points. Ratios can be seen as disguising the problem.

When different model formulations are used, the model outputs of biomass or abundance time series can vary. Often the absolute values change but the trends may be similar. Using fixed values for reference points can result in a perception of the status of the stock. Using relative values or a ratio can be more robust and result in no change in the relative position of the stock in relation to the reference point. On the other hand, the scaling can be such that the relative position of the stock in relation to the reference point can sometimes change between model formulations, i.e. the relative position of the stock biomass to the reference point can differ between models, giving a different the perception of stock status.

General conclusions from discussion on setting reference points for marine mammals

The general conclusions from the discussion were, for the most part, not specific to marine mammals, but were relevant for all species groups.

- **It is the role of policy and management to specify a risk tolerance for serious harm to a stock. The framework should be set up such that, with increased uncertainty, harvest is adjusted downward so that risk tolerance remains constant.**
- **The Pella-Tomlinson model has been used for harp seals to reconstruct the time series and to approximate K from historical population sizes (1800's) modelled using historical catch. There is more confidence in the shape of the time-series and the shape of the surplus production curve than in the absolute value of K, particularly given how long ago these virgin population sizes would have been seen. Therefore, estimating K based upon historical catches can be problematic. For Atlantic seals, a proxy for K was used, the maximum observed (or inferred) population. The limit was set as 30% of that maximum observed population. This approach has drawbacks as well – as the population recovers, K increases which can be a complication when working on management strategies with industry and managers.**
- **The challenges (for all species groups) with counting on uncertain estimates of K were discussed. K is both computationally difficult to estimate, abstract to define, and can be a very influential parameter on the outcome of management strategies. It was highlighted that there is a need for guidance on how to estimate K. Two recommendations were made (1) because of its importance, the way K is calculated should be very clearly documented and described and (2) the implications of the uncertainty/errors in K should be explored using simulations of the effect of over and under estimating K, as well as the impact of variability in K over time.**

- **Ratios can be used as an alternative to the use of limit reference points based on a fixed K, as ratios may be more robust than expressing reference as absolute values of stock biomass. However, the ratio has to be eventually translated into an absolute value to set harvest levels, and the approach was seen by some as delaying/disguising the problem.**

REFERENCE POINT GUIDELINES FOR DATA-DEFICIENT SPECIES

Jake Rice presented the working paper. Key points made during the discussion are included here, and the guidance is included in Annex 4.

Lobster case-study

There was some discussion on the use of catch data series to set biomass-based reference points, mostly focussed on the lobster fishery. Catch data are more commonly used to estimate exploitation-based reference points (e.g. F ref) but not biomass-based reference points. Despite caveats that landings and catch per unit effort may not always be a good indicator of biomass (see working paper for full discussion), this approach of using landings as a proxy for biomass is working well for several lobster stocks. (note: it was mentioned that it should be clarified in the guidance that when the text refers to biomass it should not be called catch, it should be called a proxy of catch.) In the lobster fishery, effort has been relatively constant, and some fishery-independent survey indices have shown a strong correlation with catch indices. This approach of using landings as an indicator of biomass has made it possible to have biomass-based reference points that are used to indicate if the stock is in the healthy, cautious or critical zone. The removal rate is then controlled through effort control and escapement, not quota.

The concern was raised that there is a tautology or paradox in using catch as a biomass index to set removals, for which you have had to assume that the catch has been sustainable. It was recognized that in the long-term it would be preferable to have a fishery-independent biomass index, but in the meantime this approach is working well, and the fishery is sustainable with currently high landings. As well, all secondary indicators are showing the stock is healthy.

A potential risk was highlighted that reported catches could be intentionally inflated given that catches are the basis of the position of the biomass proxy relative the reference points.

It was highlighted that even though the lobster fishery is data poor, there is a long history in the fishery and it is a well-understood stock. There is a high degree of control of effort allowing the fishery to be managed sustainably under a framework that uses catch as an index of biomass. Periods with high sustainable landings were used as a proxy for B_{MSY}, allowing a proxy for USR (0.8 B_{MSY}) and LRP (0.4 B_{MSY}) to be established. If the proxy for biomass (landings) goes below the USR then some new action has to be put into the system. The landings and effort have been relatively constant over the history of the fishery. Were landings to change significantly, and management actions were taken in response to those changes, the biomass index (landings) would no longer be reflective of the biomass.

The longer-term objective is therefore to develop some independent measures of biomass for the lobster fisheries.

It was agreed that the lobster fishery is very different from some other data poor stocks e.g. emerging fisheries with 10 years or less of history.

When is there not enough data to estimate reference points?

The question was asked if, in general, we should be providing science advice, and in particular reference points, when there is not a relatively solid biomass index?

It was suggested that reference points could potentially be obtained for all stocks, no matter how little data there are, but that the uncertainty could be conveyed to managers how high the uncertainty is.

On the other hand, the question was asked “at what point do we say we don’t have enough information?” When do we advocate using methods with very little data in the absence of anything else, and at what point do we say we don’t have enough information and we cannot set reference points. It was agreed there will be times when it is not possible with the available data to evaluate reference points, and that needs to be communicated. There will be times when all that can be said is “we do not know if the stock is below its limit reference point” and it will be important to be clear about that and to then highlight where should information is needed.

If there is an intention to manage fisheries with catch monitoring only, science will have to decide when to accept giving advice on data poor fisheries and when to say it is not possible. A set of conditions could be provided to demonstrate enough information has been acquired to establish at least empirically-based reference points.

It was highlighted that the guidelines should include the conditions for when a time series for (catch or survey series) can be used (see working paper for conditions, for example for a catch series to be used as an index of biomass, effort has to have been constant).

There was also discussion on communicating the higher level of risk in data poor situations. When there is less certainty in the data, this must be well-communicated to prevent increased risk to the stock.

The recommendations that are made based on data poor situations must take the high level of uncertainty into account. In the case of emerging fisheries, the exploitation should start very slow, and as there is an increased knowledge of the stock and fishery the exploitation can gradually increase. It was agreed that this point should be highlighted in the guidance. Catches should initially be set extremely low as a result of uncertainty, and this will highlight the need for more information on the stock.

The general point was emphasized that the department should be striving to move many of the data poor stocks into empirical, so at least there could be sound empirically-based reference points for all commercially harvested stocks.

Spatial approaches to setting reference points

There was a discussion on using spatial approaches (distributional data) to develop management plans consistent with the precautionary approach.

The point was made that 50% of habitat area defined as a refuge in the draft guidance is very high for many if not most situations. This will depend on the fishery, and the case of the sea cucumber this was appropriate.

It was agreed that in data poor situations, more focus on spatial approaches to management is recommended. It is expected that management frameworks will move increasingly in this direction. Applications of ecosystem approaches tend to bring spatial recommendations.

Surf clam in Quebec was highlighted as an example of a management framework for a data poor fishery that is spatially-based. Some surf clam beds that are well delineated. There are some large beds where recruitment occurs largely in one part of the bed, and it has been proposed to close off the recruitment area of specific beds, limiting the fishery to areas where there is little or no recruitment. Limit reference points would be based on a maximum fishing effort for each bed. Fishing effort would be set per bed, and the closed areas within the bed will be the way the PA requirements are addressed.

There was discussion on the use of M as a proxy for F_{MSY} in data poor situations. It has been argued in the literature (reference) that for a majority of species with a typical life history, 2/3 M is sufficiently conservative as an estimate of F_{MSY} set independently for each fished age-class. It was agreed at the meeting that before prescriptive guidance could be given to use 2/3 M, the question should be looked at more closely.

General conclusions from discussion on estimating reference points for data-poor fisheries

- **Data-poor fisheries will vary widely and solutions will vary widely depending on many factors including the age of the fishery, and on the extent to which populations are localized to defined areas, for example sessile invertebrates. A data-poor fishery with a long history such as the lobster fishery can take advantage of long reliable catch indices, whereas an emerging fishery cannot and should start out with very low exploitation rates. In such cases large refuge areas can be a more suitable approach to a precautionary management plan.**
- **In data poor situations, more focus on spatial approaches to management is recommended. It is expected that management frameworks will move increasingly in this direction. Applications of ecosystem approaches tend to bring spatial recommendations. Sea cucumber, surf clam and scallops are all good examples of where spatial approaches to a PA frameworks and management have been used.**
- **The department should be striving to move many of the data poor stocks into empirical, so at least there could be sound empirically-based reference points for all commercially harvested stocks.**
- **As resources for monitoring change, science will have to decide when to accept giving advice on data poor fisheries and when to say it is not possible. A set of conditions could be provided to demonstrate enough information has been acquired to establish at least empirically-based reference points.**
- **The higher level of uncertainty in data poor-situations must be well-communicated to prevent increased risk to the stock.**

TARGETS

Peter Shelton presented the working paper. Key points made during the discussion are included here, and the guidance is included in Annex 4.

Introduction

Canada is a signatory to the United Nations Fish Stocks Agreement (UNFSA) and formally recognizes the requirement to apply the Precautionary Approach to the management of wild marine capture fisheries by following the FAO Code of Conduct for Responsible fisheries (FAO 1995). This commitment has recently been solidified with the development of the DFO “Fishery decision-making framework incorporating the precautionary approach”, part of suite of policies comprising DFO’s Decision Making Framework for sustainable fisheries (DFO DMF). Reference points are an essential component of UNFSA and a requirement under the FAO Code of Conduct for Responsible fisheries. The PA defines two types of reference points, targets that delineate desirable outcomes of management, and limits that define undesirable outcomes with respect to stock conservation.

Fishing mortality target relative to Biomass target

The targets section of the meeting started with a discussion of the two types of targets:

1) fishing mortality target, F, or
2) biomass target.

The point was made that the target F should be lower than F_{MSY}, which would necessarily correspond with a biomass target above B_{MSY}. Currently the PA policy suggests (in the provisional rule) that the removal reference, F_{ref} should be below F_{MSY} (consistent with international norm of treating F_{MSY} as a limit to avoid). To be internally consistent, the target would then have to be above B_{MSY}. The point was also added that although logically inconsistent, given the “slop in the system”, the current inconsistency may not be a problem from a practical perspective.

Where should the target be placed relative to the USR?

It was highlighted that to be compliant with international agreements and norms, the target should be positioned so that risk neutral management will keep the stock above the USR. The suggestion of 0.6 K was made (i.e. above B_{MSY}) as that would lead to only a very small loss in yield (relative to B_{MSY}) and more efficient catches.

The point was made that if the target is placed at the USR, meaning that the slope of the removal reference increases right up until the stock reaches the biomass target, F will be reduced half the time (given a stock fluctuates around the target under risk neutral management). This could seen by some as adding unnecessary variability in catches. Tolerance for dropping below the target should be risk neutral and for dropping below the USR should be much lower, e.g. 5 % or 10%. The suggestion was made that the target be above the USR so that the removal reference remains constant around the target to maximize yield stability, if that is an objective.

A qualifying point was made that for some stocks, for example snow crab, there are large fluctuations in stock size in short periods of time even in the absence of fishing. The USR will often will be crossed and to expect the stock to stay in the healthy zone every year is not realistic. When setting targets for such stocks these high fluctuations could be taken into consideration.

An additional reason to not constrain the target to the USR is that the purpose of the USR is to maintain the stock a safe distance from the critical zone. Where possible, the USR should take into account the uncertainty in stock status, the life history of the species, as well as the capacity of the management system to respond when the stock drops into the cautious and critical zones. The target should not take all these factors into account and should therefore be separate. One purpose of the PA was to have science points (LRP and to some extent USR) separate from the socioeconomic (targets) so they would be protected from socioeconomic pressure. (Also came upagain, see below).

Do we need targets, or could maintaining the stock in the healthy zone be a good approach?

This question was asked in the context of a MSE approach (i.e. if you have a set of formalized objectives, is a target redundant?) In response to the question, the following points were made:

In support of setting a specific target, the point was made that the healthy zone is hard to define scientifically and basing a framework on that is challenging. It was then also pointed out that although it is computationally hard to estimate the boundary of the healthy zone (the USR), it may be easier than some of the other things that require estimation (B_{MSY}, F_{MSY}, LRP).

In DFO, discussion of the Precautionary approach up until recently has focussed on limits and getting stocks out of the critical zone where precaution is required. Now the discussion is starting about targets. So far, the focus has been on reducing risk of serious harm, but the other objectives must also be considered, such as maximizing yield and stabilizing catches. The thinking about harvest control rules should be adjusted such that they are not just in place to keep the stock above the LRP, but to keep the stock at the target. Harvest control rules need objectives, and some of those should be linked to the target.

Time horizon for the targets also needs to be addressed, and the probability of reaching them.

Could there be instances where it would make sense to set a target below B_{MSY}?

It was recognized that to maximize productivity of a given stock, and to maximize yields, the target should be at or above B_{MSY}. It was also seen by some participants that maintaining all stocks in the healthy zone is consistent with the Sustainable Fisheries Framework. Nevertheless, it was also pointed out that (1) it has been recognized in the scientific literature that it is not possible for all stocks in a given ecosystem to be simultaneously maintained at B_{MSY} and (2) for socioeconomic reasons there may be instances when there are reasons to have targets below B_{MSY}. There may be some stocks that could have lower targets in favour of the productivity of other possibly more valuable stocks. Also it may be beneficial to keep a key forage species at a higher level at the expense of another stock, given their critical role in the food web.

Targets in the context of conservation vs management of stocks

It was suggested the questions regarding the PA framework could be separated conceptually into precaution questions and the ones regarding management goals. The limit reference points are about conservation, keeping the stock out of the critical zone where there is risk of serious harm to the stock. The LRP defines the upper limit of the critical zone, and the USR defines a safe distance away from the critical zone. The PA target is about managing a fishery for optimum yield, and is less related to conservation. The target would typically be above the zone where conservation is the primary concern. Targets are typically more about delivering economic and social outcomes than about conservation.

It was agreed that for depleted stocks, one can set interim targets for conservation purposes, with the goal of getting the stock out of the critical zone.

For stocks in the rebuilding or recovery phase, these interim targets wouldn't have the same properties as the final targets (described below). It was suggested that they could be referred to as milestones to avoid confusion on two types of targets. The posted guidance on rebuilding plans refers to two types of objectives, long term and short term objectives (i.e. to get out of the critical zone), as well as milestones to get to either category of objectives. It was agreed it would be beneficial to stick to terminology which refers to reaching the LRP as a short term or interim objective or target as opposed to a milestone.

Properties and components of targets

It was agreed the target should typically have two properties:

1) that the yield that corresponds to the target satisfies economic goals for the fishery, on average

2) risk neutral management around it will result in the stock staying in the healthy zone.

and should consist of three components:

1) an index of biomass or abundance
2) a timeline within which the stock is expected to reach the target
3) a probability of reaching the target within the timeline.

General conclusions on targets

A target should be above the USR and typically at or above B_{MSY}, however there could be circumstances where a target may need to be set lower than that, because not all stocks can necessarily be kept simultaneously above B_{MSY}. There may be ecosystem and socioeconomic considerations that would support a lower target for one stock to benefit another stock(s).

A target should typically have 3 properties

1) **that the yield that corresponds to the target satisfies economic goals for the fishery, on average**
2) **risk neutral management around it will result in the stock staying in the healthy zone (in almost all cases)**
3) **Have three components: an index of biomass or abundance, a timeline, and a probability of reaching it.**

REVISING REFERENCE POINTS DUE TO PRODUCTIVITY SHIFTS

Martha Krohn presented the working paper. This topic was reviewed by DFO's Technical Expertise of Stock Assessment (TESA) group at a CSAS workshop in December 13- 15, 2011 (National Workshop for Technical Expertise in Stock Assessment (TESA): Maximum Sustainable Yield (MSY) Reference Points and the Precautionary Approach when Productivity Varies).

For the full guidance on when to revise reference points when productivity is changing, please see pages 36-42 in the Proceedings from that workshop:

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 (DFO 2012b).

Key points and suggestions made during the discussion at the February-March 2012 Precautionary Approach advisory meeting are included here, and they have been incorporated in the published document.

Abstract

Recent changes in productivity, particularly for east coast groundfish and invertebrate stocks, have raised the question of what time-frames are appropriate to use for establishing reference points for precautionary approach framework development. 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, and it could be argued that 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.

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 consider hypotheses related to productivity regimes and implications of the stocks and their management are strongly recommended.

Context

The Technical Expertise in Stock Assessment program ran a workshop in December 2011 that addressed setting MSY-based reference points in conditions of changing productivity. One of the products of this workshop was a report on "*When is it appropriate to consider changing precautionary reference points in relation to a perceived regime change*?" A draft of this report was presented at the PA workshop as it was seen as a relevant chapter to the guidelines. Comments from the discussion on this report follow and were integrated into the final report. This report was published as part of the Proceedings from the TESA workshop: 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 (DFO 2012b).

Terminology

It was agreed to change the terminology from "stable state" to "regime" or "constant external regime" or "constant environmental conditions that affect productivity" (to avoid confusion with the use in ecology for "stable state" as an internal state).

It was suggested to change the minimum time required to consider a new regime to be in place before adjusting reference points to the new regime. The timing should be the longer in duration of a decade or a generation (e.g. for cod this is only 6 years).

Predator pits and depensation

It was suggested to distinguish between depensation and predator pits because depensation can result in extinction while a predator pit implies a much smaller but still sustaining population. A stock cannot get out of a predator pit even if fishing pressure is reduced to zero without changes in other factors (some of which may be controllable but most not) The definition of a predator pit is a stable state, and even if you can stop fishing the stock still won't recover without a low probability chance event

It was agreed that if the stock is truly in a predator pit, then reducing fishing mortality alone would not rebuild the population. However, an important nuance is that when the stock is at a low abundance it should not be assumed that it is only due to high predation pressure (even if M is high), one should assume that there are management actions that could be used to rebuild it.

Productivity changes and harvest control rules

It was suggested that in the document there needs to be discussion about using full feedback simulation to show what are the benefits and costs of considering changing reference points due to changes in productivity regimes.

The point was made that, as data is accumulated, the understanding of K improves. It was felt that if minor adjustments are being made to reference points every year, the estimate K would change a bit every year. Harvest control rules would typically be robust to small changes in K. If an approach is used, as in the US, to run the model at each assessment with a new K and express the status as a ratio, the reference point will automatically change.

The point was made that robust feedback harvest control rules that have been tested using feedback simulations are often not based on reference points, but are based on stock sizes. It was felt that even when a regime change is occurring, a feedback rule based only stock size will likely out perform a rule that is based on reference points that take changes on productivity into consideration. In simulation studies, it is often assumed that reference points cannot be estimated well enough to use as triggers for changes in harvest rate, but reference points are in the simulations as part of the performance statistics.

Risk of extirpation and loss of stock substructure

There was concern that the line of reasoning of lowering the biomass reference points as a result of declining B_{MSY} may be logical for the USR, but should not be applied to the LRP. At small population sizes, there risk of extirpation. The concern was also raised that there is substructure in populations that we cannot measure and that lowering biomass reference points jeopardizes that substructure. The point was made that reference points never account for substructure at a scale below the stock assessment, either before or after a regime change.

The use of 0.4 Bmsy and 0.8 Bmsy as reference points is intended for large marine stocks that are not in danger of extirpation, even near or at the LRP. It was agreed that the document should be clarified that for smaller populations, there can be concern that lowering the LRP under low productivity conditions could result in unacceptably high risk of extirpation.

Need for caution in lowering biomass reference points when productivity changes

It was agreed that the document should help staff respond to pressure from industry to reduce reference points when productivity is low. Guidelines are needed for what needs to be demonstrated in order for reference points to be lowered.

It was agreed that a key message in the report should be that it is dangerous to stock productivity in the long term to lower biomass reference points, and that by default biomass reference points should not be lowered when productivity changes. It should only be done when a set of criteria are met, and that will be rare.

It was decided that the contribution to the guidelines should contain a description on the necessary criteria that needs to be met in order to change reference points, and that the targets and F are likely to change before the limits are changed.

One suggestion was that a practical way forward is to adopt harvest control rules that are less dependent on reference points. A response to that suggestion was that there will always be a need to estimate the sustainable harvest rate under current productivity conditions.

Additional points

It was suggested that asymmetry of outcomes and risks could use more attention in the chapter.

The point was made is that yes it is expected that over time reference points will be recalculated to make full use of the best data available which will hopefully be getting more numerous and better over time. The wording in the report should make the distinction between changing parameters in response to more information, and changing parameters because of changing the subset of data that will be used for the reference points.

HARVEST DECISION RULES

Rob Kronlund presented the working paper which has been published as a Research Document 2013/080: Current Approaches for the Provision of Scientific Advice on the Precautionary Approach for Canadian Fish Stocks: Harvest Decision Rules (Kronlund et al. 2014)

Key points made during the discussion are included here, and the guidance is included in Annex 4.

Abstract

An essential component of the DFO decision-making framework is the inclusion of a harvest decision rule in a management strategy. The inclusion of a harvest decision rule satisfies a requirement of the Precautionary Approach (FAO 1996) and the DFO decision-making framework to specify in advance actions to be taken when specified deviations from operational targets and constraints are detected. This document is intended as an aid to planning a more comprehensive process for the development of guidelines for harvest decision rules. The document does not contain specific recommendations on the choice of risk tolerance and the relative priority of stock and fishery objectives. The design of a stock-specific harvest decision rule should be considered in the context in which it is to be used and is dependent on a collaborative objective-setting process for the stock and fishery that involves assessment analysts, fishery managers, and resource stakeholders. There are two types of rules in the DFO decision-making framework: (1) a status-based rule where the intended removal rate is a piece-wise function of stock status, and (2) an acceptable risk-based rule in which the acceptable probability of stock decline is based on a combination of current stock status and the recent rate of change in stock status (i.e., increasing, stable, or declining).

The design of the rule (a tactic) should be decoupled from the reference points (the operational objectives that translate policy goals). This allows the form of the harvest decision rule to be adjusted for stock-specific applications so that a desired trade-off between conservation and economic performance can be achieved. Complex decision rules should be avoided in favour of the simplest rule that will satisfy the preferred performance trade-off between conservation and yield considerations. Some jurisdictions have promoted the adoption of default, or generic, harvest decision rules that are expected to provide reasonably good performance over a wide range of fisheries. However, there is no assurance that generic harvest decision rules will

achieve stock-specific objectives. Finally, harvest decision rules do not necessarily need to be limited to the status of a single target species; multi-species or ecosystem considerations can also be incorporated into rules. Experience with harvest decision rules that include multi-species or ecosystem considerations is limited in Canada, and would require extensive development and testing prior to implementation.

Context

The purpose for this section on harvest decision rules was not to identify specific guidance at this point, but to explore key issues for subsequent discussion in joint meetings with fisheries management. Nevertheless, it was possible to provide some general guidance on the topic using current approaches, which appears in Annex 1 of this document. The main points coming from the discussion of the working paper are below:

Generic rules

There was discussion as to whether generic rules, such as the provisional rule in the Policy, are helpful and how they should be tested/applied. Given that the capacity to develop tested fishery-specific harvest control rules is not available for all fisheries, it was proposed that generic rules could applied in the absence of a simulation-tested context-specific solution. (e.g., linear interpolation between F_{MSY} at the USR and no catch or low bycatch at the LRP as in appendix 1B of the policy). Without any prospective evaluation there would be no way of knowing that implementation of these rules would bring you to your objectives, but they would be a good place to start. (Significantly better than no harvest control rules, i.e. adhoc annual TAC setting.)

If default rules were to be used in the absence of stock specific ones, these rules will need to be evaluated. Default rules could be developed for a range of life-histories and stock dynamics. It was felt that if we are going to use default rules (provisional control rules) we need to test them at least for similar species. (A default rule for a salmonid may not be appropriate for groundfish). It was proposed that generic rules should be simulation-tested for a range of conditions, and then one can choose the harvest strategy configuration that most closely matches the particular situation. If it is known under which conditions a generic rule is expected to achieve some default objectives, the rule could be applied in those conditions. There will necessarily be uncertainty associated with such generic rules because one would not know how closely the specific context matches the generic testing.

As the PA policy is worded now, the provisional rule could either be interpreted as a default rule or it could be considered as a possibility. It was agreed that this needs to be clarified at the next meeting, i.e. the Policy document should clearly state the definition of “default” and “provisional”.

General conclusions on generic rules:

It is better to apply a provisional generic rule, even if it is untested, than have no rule if the alternative is ad hoc TAC setting. However, generic rules should be tested on a similar group of species although the uncertainty will be higher than for rules tested on the species and stock in question.

Risk based rule and status based rule

It was highlighted in the presentation that there are two sets of rules described in the PA policy, (a) status-based rules and (b) risk-based rules. There was general agreement on this point. Although it was not clear that the development of two distinct types of harvest control rules was intentional in the development of the policy, it was agreed that models testing these two types of rules would be set up differently.

For status-based rules the intended removal rate is a piece-wise function of perceived stock status, which must be reduced at some point with declining stock status. Harvest decision rules are chosen that meet the risk tolerance criteria (e.g. less than 10% chance of the stock dropping into the critical zone).

For the risk -based rules, the risk tolerance is built into the harvest decision rule and depends on both the stock status and the recent trend (e.g. the acceptable probability of decline is lower if the stock is declining).

Pros and cons of the risk-based rule relative to the status based rule that were identified:

Pros of risk-based rules

- The potential for a risk tolerance rule to be used to manage multi-species was explored. It was suggested that this type of rule could work well for multi-species complexes. The point was made that qualitative flexibility is required currently for the multispecies issues. This was countered with the point that risk-based rules are also quantitative and must be explicitly stated, although the decision managers make is a separate issue. Given that the Department has no experience with the risk-based rules (other than the work presented by R. Kronlund at the meeting), nor any HDR's covering multiple species, caution was advised.
- One benefit of risk based rules is the lower risk tolerance for declining stocks takes into account the additional vulnerability of a declining stock, and vice versa.

Cons of risk based rules

- There is a lot of flexibility in the risk-based rule and therefore testing for performance using feedback simulation is very complex. Testing for a risk-based rule applied to a multi-species situation could become impractically complex, for example the Pacific groundfish where the stocks are highly overlapped, and there is a multispecies fishery.
- It was noted that, in the policy, there currently is not a constraint for fishing mortality for the risk-based rule but there should be one. (F_{MSY} is provided as a limit for the provisional status-based rule).
- The risk-based rule may be too complex for communication (and computationally complex), were it to be tested over a range of scenarios/assumptions. Although the risk-based rule may well be capable of delivering the desired performance, it is impossible to guess at the likely performance of such a rule without simulation. It is likely that a simpler status-based rule could be found that did just as well.
- Simulations indicated that small differences in tolerance for decline can have significant impact on the stock abundance. It was pointed out that the rule needs a quantitative examination or it could be a risky tool to use (i.e. the behaviour of risk-based rules is very difficult to predict without context-specific simulations.)

Additional points on the risk-based rule

There was a discussion of the origin of the risk-based rule (the nine cell table from the Policy, Table 1). It did not come out of DFO's PA harvest strategy (DFO 2006), but rather was requested by the finfish industry. They suggested/recommended a higher risk tolerance written into the rules if the stock trend is increasing relative to a stable or declining stock.

The question was asked whether the intent was for the risk-based rules to be applied in a formulaic way, or as a qualitative tool. So far has only been applied qualitatively and that was possibly the original intent.

It was suggested that given the risk-based rule is in the policy, we need to evaluate it quantitatively.

Similarly to Table 1 in the Policy, in Pacific region the decision table approach has been used in a qualitative way, not with simulation testing. When you are above the B_{MSY}, the rule will result in a decrease in stock size, when below B_{MSY}, the stock is driven up.

Projections are carried out over a range in catches, for a series of forecast periods. The probabilities of reaching the B_{MSY} by a given year with a given catch is provided in a decision table and then management chooses the catch that matches the probability they are comfortable with – this is where the flexibility for management comes in (example is yellow perch 2012 assessment). Table 1 of the PA policy is the same idea, except that the probabilities must be explicitly stated before the simulations are carried out.

You can use Table 1 in the Policy in two different ways. One way is to use table 1 to explicitly program risk tolerances into the rule as was done in the working paper, and the second is to define measurable objectives and performance statistics and then search for a status-based rule that has to achieve the desired risk tolerances of not meeting those objectives. In the latter approach the risk tolerances would not be explicitly programmed into the rule, but rules that failed to meet the desired risk tolerances would be discarded as not being useful.

The 2008 Sable fish assessment (Cox et al. 2010) was given as an example of the latter, where they used Table 1 to set objectives as opposed to using it to set rules.

General conclusions on risk based vs status based rules

- **The use of a simulation approach to test the performance of a risk-based rule may be unnecessarily complex, and not have much advantage over using a simulation approach to test status-based rules.**
- **The risk-based rule has been practically applied when risk-tolerances are not programmed into the rule, but are chosen and then matched with corresponding catches and time periods from a table of projections.**

Decoupling reference points and the points of inflection for the harvest control rules

The suggestion was made to decouple reference points from the points of inflection for the harvest control rules, i.e. to not tie the lower and upper bound of the HCR's to the LRP and USR since that might not be the best choice in terms of meeting conservation and yield objectives. For example, it may be a good idea to have the harvest control rules change to a lower removal rate before or after the stock drops below the USR. This was discussed thoroughly and came up regularly throughout the meeting. The main points made regarding this suggestion follow:

In the PA policy, the reference points are dual purpose in that they delineate the PA zones (critical, cautious and healthy) as well as serve as the inflection points that trigger a new set of rules for that zone. (i.e. when the stock falls below the USR, the HCR changes). (aside: a third purpose for the USR is it can be used as a target.) Having this dual/triple purpose for the reference points was seen by many participants as being an unnecessary constraint and that the trigger points for changing the harvest control rules should not necessarily be tied to the values of the reference points (and therefore the PA framework zones). The change in removal rate could be triggered by other points than the reference points, and they could be higher or lower than the reference points. The working paper explains that as long as the desired trade-off performance can be achieved on average, the ramping down could occur before or after the USR (see full explanation in the working paper). It was suggested at the meeting that, if, under testing, the rules performed well (i.e. with the stock having a low probability of falling in the critical zone and a high probability of getting to/staying in the healthy zone) they could be consistent with the guidance in the policy, even if they do not coincide with the reference points.

It was also pointed out that if the trigger points were decoupled from and were higher than the reference points, you would get better conservation performance, but not as good yield performance.

It was generally agreed that to be consistent with the policy as it is now, you would not necessarily have to move the USR up (above 0.8 B_{MSY}) in order to reduce F earlier (at a higher biomass) in the healthy zone. You could have a trigger point for the harvest control rules that is in the healthy zone, as opposed to at the USR.

It was highlighted that The Royal Society of Canada Expert Panel Report on Biodiversity and Climate Change (2012) recommended the DFO PA policy decouple the lower HCR trigger point from the lower reference point. i.e. the rule should be to close a fishery before the stock declines into the critical zone not when it reaches the zone. They also advocated decoupling the point at which the removal rate starts to decrease from the upper stock reference point. It was pointed out at the meeting that this would help both conservation and yield objectives and would also be consistent with the policy.

In the context of the discussion of having trigger points lower than the USR, (i.e. having the upper trigger point in the cautious zone), the point was made that one of the key functions of the cautious zone is that we never “in the real world” know where the stock is, because the annual estimate of stock status is uncertain. When the estimate of stock status is the in the cautious zone, there is already some risk that the true stock is in fact below the lower limit reference point. If the estimated stock status is in the cautious zone, according to international agreements and the policy, it is necessary that priority will be given to increasing stock status. This was given as a concern regarding allowing the upper trigger point to be set below the USR.

There was concern expressed by some that there may issues in communicating decoupling of the points with industry. Departmental fisheries managers and scientists have spent a lot of time and effort explaining that the removals can increase once the stock reaches the reference points. If we then raise the stock level at which the removals can go up, this could lead to frustration on the part of stakeholders.

It was suggested that if targets are decoupled from limits, we should still say where those targets should be in relation to the limit points.

Decoupling limits and trigger points for some regions is sort of a paradigm shift relative to what has been done up until now. So far there has been a match between reference points and harvest control rules. It was also suggested that in some cases they could coincide, but just that they would not necessarily have to.

The question was asked “Do we necessarily need two trigger points, or even any trigger points, if you could show using simulations that you can reach your objectives” (including conservation, yield and yield stability objectives). A number of participants who apply the MSE approach considered the requirement of trigger points to be a constraint that may or may not contribute to achieving objectives. Flexibility on the requirement for trigger points was suggested by some as long as it has been shown with simulations that the objectives can be met without them.

Along the same lines, the question was also asked "Do we need reference points***?"***

The point was made that, because it is a PA framework, not a regular management framework, we need to maintain the zones. Without zones (i.e. only have objectives), we could not communicate the status of the stocks as clearly. Given the large number of compromised stocks, we need to maintain that context.

The question was asked whether there could be a trigger below the USR (as in fig 7.1(d) of working paper) if conservation objectives would still be met according to simulations. It was generally agreed that clarification on this question and the use of reference points as inflection points in general should be sought in future meetings.

The following suggested wording was put forward for consideration: "The harvest control rules should be developed to conform to the precautionary approach principle with $F <= F_{MSY}$ with F decreasing as biomass falls such that there is a low probability of being below the LRP and a high probably of being above the USR. The control rule parameters are not constrained to change at the reference points but should be chosen to implement the management obligations."

On a related topic, the shape of the decline curve (i.e. removal rate) is not specified in the policy. The working paper on HCR's includes diagrams of very gradual ramping down, and very fast ramping down, both of which could potentially be considered. consistent with the policy. It was also suggested that the performance of the three HCR curve shapes could be tested (concave, convex vs linear).

General conclusions from the discussion on decoupling:

- **To be consistent with the policy you would, as a minimum, have to ramp down the removal rate to a very low level when you get close to the lower limit reference point. This could be at <u>or</u> above the LRP.**
- **An HCR where the removal rate drops when the stock is at a point at or above the USR would be consistent with the policy.**
- **There should be a requirement to ramp down as the stock declines. If you took out the need to ramp down it with declining stock size the rules would be inconsistent with the precautionary approach and you would remove the feedback aspect.**
- **The trigger points could be decoupled from reference points if they are higher than the reference points. If the trigger points are lower than the reference points, then as a minimum you would have to show that you can nevertheless reach the objectives (even if you do not ramp down at the USR). Such a rule would need to be tested, and even then it is not clear that would be consistent with the policy.**
- **It was agreed that clarification on the question of whether an upper trigger point could be below the USR should be sought in future meetings as well as clarification on the decoupling of trigger points and reference points in general.**
- **We should maintain the requirement for reference points.**

MANAGEMENT STRATEGY EVALUATION

Rob Kronlund presented the working paper. It is published as a Research Document 2013/081: Current approaches for the Provision of Scientific Advice on the Precautionary Approach for Canadian Fish Stocks: Section 8 – Management Strategy Evaluation (Kronlund et al 2013).

Key points made during the discussion are included here, and the guidance is included in Annex 4.

Abstract

Fisheries management strategies require deliberate design to increase the likelihood that long-term sustainability objectives can be met. Compliance of management strategies with the Precautionary Approach and the DFO PA Framework means that a pre-specified plan should be developed with clear criteria for decision-making. Furthermore, the adopted plan should be evaluated to determine whether it can effectively avoid undesirable outcomes regardless of whether the outcomes relate to conservation or yield objectives. Management strategy evaluation is a simulation-based approach to assessing the relative performance of candidate management procedures under conditions that mimic plausible, though uncertain, stock and fishery dynamics.

The DFO faces increasing pressures to implement the Sustainable Fisheries Framework policy broadly across fisheries in Canada. This policy includes a suite of goals that relate to sustainable resource management, including the development of fishery reference points and harvest decision rules, the incorporation of habitat and eco-system considerations, development of formal measures for rebuilding depleted stocks, and the collaborative development of management procedures with resource users. Furthermore, the development of long-term management strategies, where formal stock assessment advice is updated periodically, has recently been promoted to increase the availability of government Science resources to support comprehensive policy implementation.

Management strategy evaluation is one means of examining the effects of such changes by considering the design of the management procedure used to integrate stock and fishery monitoring data, stock assessment methods, and harvest decision rules. For example, the consequences of adopting multi-year assessment schedules, or revising fishery-independent surveys, can be quantified using simulation outputs. The outputs allow the candidate management procedures to be ranked by how well each performs in relation to satisfying conservation and yield objectives. The approach is not without limitations; management strategy evaluation has been slow to become widely adopted due to lengthy development times and scarce technical resources to support implementation. However, management strategy evaluation is one of the few available methods that provide a consistent approach to inform resource use decisions and by design, demonstrates compliance with the requirements of precautionary fisheries management.

Context

Rob Kronlund gave a presentation based on a working paper on Management Strategy Evaluation. He went over how the MSE approach is well suited to designing PA frameworks, as well as some of the challenges. Points that were raised in the discussion follow.

Trade-offs in objectives

Following the presentation on MSE there was a discussion on trade-offs in objectives. The point was made that conservation and fishery objectives are not necessarily in opposition. Often along with achieving conservation goals, yields also increase in the medium to long term. However for rebuilding a depleted stock, in the short term there will be trade-offs. There are also clear trade-offs between yield stability and volume. To achieve a high stability average catch necessarily has to decrease. The sablefish fishery was given as an example of industry choosing catch stability over volume in the hierarchy of objectives.

The point was made that, to be consistent with the PA policy, there must be contraints to how objectives are weighed (i.e. conservation must weigh higher than yield objectives if the stock is depleted). For example, if the stock estimate is in the cautious zone, there is already some risk that it is in the critical zone and priority must be given to improving stock status according to the Policy and international agreements.

The point was then made that the weighing, or prioritizing, of objectives would be more straightforward if limit reference points, inflection points for HCR's, and target points were decoupled in the decision making framework diagram. In an MSE context, the objectives are set with respect to the true stock and the harvest decision rules are applied to the perceived stock. What is relevant in terms of performance is how well the true stock performs relative to the objectives. If you set the objectives such conservation has priority, the position of the inflection points will be constrained to result in achieving those conservation objectives.

Consultation on MSE

Consultation on MSE is more complicated than it is for a single assessment model- there is much more to explain and this can be an issue. It is important to find the right way to communicate, not too complex.

In the sablefish MSE example it was possible to work well with industry. It was a long process, meeting every two months for 3 or 4 years, with more frequent meetings earlier on. In general industry agreed with the model and came up with empirical decision rules.

The point was made that in general all stakeholders won't necessarily fully support the final plan but it's still a more workable for implementation if they have been part of the process. Having a consistent platform to interact with stakeholders in a controlled way goes a long way to having them be part of a process and trusting it.

There have been three thorough case studies for MSE that have gone through peer review processes and been implemented: sable fish, Greenland halibut and Pollock. They could be considered as a reference set of models.

There was concern expressed by a few that the consultative nature of the MSE process can potentially compromise the quality of the Science. This concern was not limited to MSE, but having industry involved with the Science processes. Effort must be made to ensure the normal safeguards of science are in place to and have a full scientific debate, review and agreement. In an industry/management forum the normal rules of science debate should still be followed. The MSE development for sablefish was successful in this regard.

The point was made that the potential for lack scientific rigour is not the fault of the MSE methodology but more of controlling the process and the participation of the parties involved.

Science policy must clearly out the rules, e.g. that conservation objectives take precedence over other objectives. Like any other consultation process on fisheries management plans, MSE can be vulnerable to shorter term/less sustainable interests. Strong Departmental policy can help this.

A suggestion was made that the Department may need to familiarize itself the literature on the application of science in different governance models. MSE is a process not a product. The issues raised at the meeting were not about the computational aspects of MSE. As with any simulation modeling there is a need to input as much information as possible. As a process, it is not completely a science based. MSE is designed to be inclusive of stakeholders and we should to familiarize ourselves with that literature and develop a process that is neither a CSAS process nor traditional consultations, but that takes advantage of stakeholder knowledge and input while maintaining a strong departmental standard for Science peer review.

The concern was raised that there will always be a need for peer review of the science elements, in an MSE context as well, and that stakeholders will usually be part of that process. We need to take the time to develop an effective process.

In Maritimes region, management plans are developed within a legally formal arrangement. If the management plans result in negative outcomes because of poor decisions, the failure can be seen as a science one. There needs to be evaluation using feedback simulation to minimize these negative outcomes.

A suggestion to develop an MSE compliant with the precautionary approach, you need a default plan in place before consultation with industry. You need to have MSE in place ready to discuss and you need to develop recommendations for a default.

Issues with how resource intensive MSE is

There was general agreement that we can’t do a full MSE on every stock due to how resource intensive the process is. The few full MSE’s that have been developed are good to explore what will happen in general for the management of other fisheries.

A suggestion was made that we could have a prioritized list of stocks for a full MSE approach that would be based on chosen criteria.

There was a discussion on an “MSE light” approach for some stocks, or a generic MSE based on generic rules for particular groups of species with similar life history etc. Key points that were made during the discussion:

Industry will not accept that generic rules apply to their species if the outcomes are unpopular.

We do not know how easy it would be to get an “MSE light” through a peer review process. If the management of the fishery is going to be based on a customized assessment, that makes a generic approach more difficult. You could go from a model based rule to an empirical based rule.

According to the PA policy, we are not required to evaluate rules. However, without evaluation, we have no idea if a given set of rules is going to work. “We have not tested whether the bridge will provide the required support.” The advantages of prospective evaluation are significant and some would argue we should require testing before the rules are implemented. This would not be the case with generic rules.

It was not clear whether a peer-reviewed set of generic rules would necessarily be better for any one stock than customized HCR’s that are based on an assessment model developed for a particular stock**.**

A suggestion was made for PA NAP 2: make some software available for the meeting and test the ideas regarding generic rules.

As a starting point for generic rules, it was suggested the default trigger points could be set at 0.4 and 0.8 B_{MSY} and the target higher than 0.8 B_{MSY}, and the F lower than 2/3 F_{MSY}. It was suggested the policy could be modified to having the F limit at 2/3 F_{MSY} as this has been used historically in Canada is and used internationally. These suggested starting points for generic rules would be appropriate to consider at a future meeting where we look more closely at generic rules, and where policy and resource management are fully represented.

General conclusions on MSE

- **In an MSE context when choosing and prioritizing objectives, to be consistent with the PA policy, conservation objectives must come first.**

- **MSE is designed to be inclusive of stakeholders and we should to familiarize ourselves with that literature and develop a process that is neither a CSAS process nor traditional consultations, but that takes advantage of stakeholder knowledge and input while maintaining a strong departmental standard for Science peer review.**
- **A suggestion was made that in developing an MSE compliant with the precautionary approach, you need a default science reviewed plan in place before consultation with industry. You need to have feedback simulation in place ready to discuss and you need to develop recommendations for a default before consultations begin.**
- **In terms of preferred approaches, a full MSE has advantages over other approaches as it tests the ability of proposed rules to bring and maintain the stock at agreed upon objectives, allowing us to reduce the risk of implementing a framework that will fail in meeting objectives for the stock and fishery. Given the level of resources required to fully develop MSE's, a number of suggestions were made.**
- **We could develop a prioritized list of stocks for a full MSE approach that would be based on chosen criteria.**
- **For other stocks an MSE light approach could possibly be taken, i.e. generic rules could be applied to stocks for which there are not the resources to develop custom MSE's.**
- **It was agreed that these rules should be tested on stocks with similar biological characteristics before being applied. If the alternative is no rules and ad hoc TAC setting, then untested rules are preferred.**
- **If there is an assessment framework developed for the stock in question, custom rules developed based on that assessment may be expected to outperform a more generic MSE-light approach and therefore be preferred.**

OUTSTANDING QUESTIONS

At the end of the meeting, the participants put together a list of outstanding questions that had come up during the meeting that could potentially be addressed a future meeting on implementing the Precautionary Approach (which would be co-lead by EFM, Science and Policy).

Extirpation risk

Should the concept of extirpation risk below LRP be raised in the Policy? It is in the DFO 2006 SAR on the PA. The distinction between the LRP and extinction risk should be highlighted in the PA Policy.

USR

PA Policy needs to be more precise on relationship of the USR, the upper trigger point for HCR's and the target.

There is a need for some guidance on those relationships to ensure that implementation of the PA will result in a low risk of going into the critical zone.

There is a need more clearly define what it represents and who's responsibility it is to set it. There are a number of definitions used internationally, including:

1) Target = B_{MSY}, and the USR is set according to the variance around that target (Ices current definition)
2) BPA (point where there is a low probability of being at the limit, and that points depends on level of uncertainty – ICES old definition)
3) 1-M* B_{MSY} and
4) Asymptote of the stock recruit relationship

In ICES, Science is responsible for setting the USR, i.e. the point at which F should start to drop. The role management plays in setting the USR should be specified.

Target

We need to be more specific about limits versus targets. A limit is what we are avoiding (with high probability), where as a target is typically risk neutral.

There is a need to address time horizon to get to the targets.

Do we always set targets? How should the policy speak to targets?

What should be the minimum properties of a target?

Where should it be relative to reference points, trigger points for HCR's and B_{MSY}?

Uncertainty and risk

More specific language about risk is required in the Policy. Risk tolerance is as important as the reference points. There is a table in the policy providing risk tolerance for different conditions, but it is not a prescriptive.

As uncertainty increases should level of risk tolerance in decision making be kept the same?

Removal reference (F)

Removal reference should be defines it more clearly, as there are three interpretations from the Policy as it is described now:

- F limit (maximum acceptable removal)
- F target
- Harvest decision rule.

Proposed clarification based on diagram:

- Rename the diagonal line the Harvest Decision Rule
- There would be a target removal reference distinct from the limit removal reference (F_{MSY})

Should we adopt F_{MSY} as a minimum standard for an F limit reference point?

Should target be closer to 2/3 F_{MSY} than F_{MSY}? (F 0.1 is a proxy for 2/3 F_{MSY}, not F_{MSY} itself.)

Should the setting of F targets and Biomass targets be logically consistent? (Because a fishing mortality of F_{MSY} brings you to a biomass of B_{MSY}, if F target< F_{MSY}, then B target > B_{MSY}.

HCR's

Consider building a risk tolerance into the HCR's, and having a varying risk tolerance depending on the declining or increasing trend.

The decision table in the PA policy: was the intent for it to be applied in a formulaic way, or as a qualitative tool?

HCR's need to be evaluated quantitatively, preferably with simulation testing. Possibly for sets of similar species with a default generic rule or set of rules.

Should the provisional harvest rule be considered as a default rule ? Should it be significantly lower than F_{MSY}? (< 2/3 F_{MSY})

Decoupling inflection points of the HCR with the RPs. Decoupling them could help us to gets around the issue of the target placement relative to the USR. (You would start reducing F at a higher stock biomass than USR)

Should limit reference points be decoupled from the HCR's?

Conceptual decoupling of 2 frameworks (for yield and harm)?

MSE

Process should be developed for deciding when we would do an MSE (conditions for choosing it, what decisions need to be made).

Explore the idea of MSE light and test some generic rules on specific groups of similar stocks.

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ANNEX 1: PARTICIPANT LIST

Name	Region	Sector
Denis Rivard (co-chair)	Ottawa, Ontario	Consultant
Estelle Couture (co-chair)	National Capital Region	Science
Laura Brown	Pacific	Science
Rob Kronlund	Pacific	Science
Jaclyn Cleary	Pacific	Science
Alan Cass	Pacific	Science
Dennis Rutherford	Pacific	Science
Ross Tallman	Central and Arctic	Science
Kevin Hedges	Central and Arctic	Science
Daniel Duplisea	Quebec	Science
Bernard Ste-Marie	Quebec	Science
Louise Gendron	Quebec	Science
Gerald Chaput	Gulf	Science
Amelie Rondeau	Gulf	Science
Cindy Breau	Gulf	Science
Ghislain Chouinard	Gulf	Science
Ross Claytor	Maritimes	Science
Stephen Smith	Maritimes	Science
Lei Harris	Maritimes	Science
Peter Shelton	Newfoundland and Labrador	Science
Garry Stenson	Newfoundland and Labrador	Science
Don Stansbury	Newfoundland and Labrador	Science
Bill Brodie	Newfoundland and Labrador	Science
Paul Ryall	Pacific	Resource Management
Tyler Jivan	Central and Arctic	Resource Management
Daniel Boisvert	Quebec	Resource Management
Réjean Hébert	Gulf	Resource Management
Jacquie Perry	Newfoundland and Labrador	Resource Management
Martha Krohn	National Capital Region	Science
Jake Rice	National Capital Region	Science
Erika Thorleifson	National Capital Region	Science
Marc Clemens	National Capital Region	Policy
Derek Osborne	National Capital Region	Policy
Sean Cox	External reviewer from Vancouver, British Columbia	Simon Fraser University
Anna Rindorf	External reviewer from Copenhagen, Denmark	Institute of Aquatic Research, Danish technical Univerity
Larry Jacobson	External reviewer from Woods Hole, Massachussets, US	Woods Hole Oceanographic Institute, NOAA
Alan Sinclair	External reviewer from Parksville, British Columbia	Independent fisheries scientist

ANNEX 2: TERMS OF REFERENCE

Development of Technical Guidelines for the Provision of Scientific Advice on the Various Elements of Fisheries and Oceans Canada Precautionary Approach Framework

National Peer Review – National Capital Region

February 28-29-March 1, 2012
Ottawa, ON

Co-Chairpersons: Estelle Couture and Denis Rivard

Context

The United Nations Agreement on Straddling and Highly Migratory Fish Stocks (UNFA), which came into force in 2001, commits Regional Fisheries Management Organizations to use the Precautionary Approach in the management of fisheries and indirectly commits Canada to do the same for domestic stocks. In 2003, the Privy Council Office, on behalf of the Government of Canada published a framework applicable to all federal government departments that set out guiding principles for the application of precaution to decision making where there is a risk of serious or irreversible harm.

In 2006, Fisheries and Oceans Canada (DFO) Science published A Harvest Strategy Compliant with the Precautionary Approach (SAR 2006/023) that outlined the Precautionary Approach (PA) framework with three zones based on stock status: Healthy Zone, Cautious Zone and Critical Zone. The boundary between the Cautious and Healthy Zones is the Upper Stock Reference and the boundary between the Critical and Cautious Zones is the Limit Reference Point. This framework also introduced the PA requirement that the removal reference (commonly fishing mortality) should decrease when the stock declines from the Healthy Zone into the Cautious Zone, and that removals should be minimized in the Critical Zone.

In 2009, DFO published its policy for the implementation of the PA called “A decision-making framework for implementing a harvest strategy that incorporates the Precautionary Approach (PA)” based on SAR 2006/023. The framework applies where decisions on harvest strategies or harvest rates for a stock must be taken to determine Total Allowable Catch or other measures to control harvests. The framework applies to key harvested stocks managed by DFO; that is, those stocks that are the specific and intended targets of a fishery, whether in a commercial, recreational or subsistence fishery. While application of this framework to key harvested stocks is the minimum requirement, it may be applied more broadly to other stocks where necessary and as circumstances warrant.

In recent years, eco-certification has been an important driver for the implementation of decision-making frameworks consistent with the DFO PA policy in a number of domestic fisheries, including northern shrimp and several groundfish fisheries. Third-party eco-certification requires that a fishery have a precautionary harvest strategy with limit and target reference points and harvest decision rules. International and domestic markets are increasingly demanding that seafood products come from fisheries that have received eco-certification. As a result an increasing number of fisheries in Canada are seeking certification.

Although the policy is in place and scientists have gained experience in providing advice for the implementation of some elements of PA frameworks such as limit reference points, more specific guidance and best practices are needed for all technical aspects of implementing the PA policy to ensure that scientific advice is delivered in a consistent manner across stocks and regions. An important consideration in this regard is to develop comparable methods that can apply to data deficient stocks, stocks with empirical data but no population model, and stocks with an accepted analytical assessment model. The intent of this national advisory process is not to review the content of the PA policy itself but to provide more detailed guidance on the implementation of the policy.

Objectives

The main objective of this advisory process is to produce a technical guidance document (hereafter referred to as “Technical Guidelines”) to assist scientist practitioners responsible for developing the science advice on the elements of the decision framework in the PA policy (i.e. Limit Reference Point, Upper Stock Reference, Target Reference Point, Removal Reference and Harvest Decision Rules in the three zones of the PA framework).

The Technical Guidelines will help to ensure that the science is delivered consistently and efficiently across Canada for all stocks, and that best scientific practices are followed. As such, the Technical Guidelines will provide clarification on the role of science and on the process to be followed in the provision of advice on the elements of the PA policy as well as the required input from fisheries managers. It is expected that those guidelines will contribute to a single science advisory framework for implementing all components of the PA policy for Canadian stocks. A similar science framework currently supports processes such as the Recovery Potential Assessments for species at risk.

Once DFO’s Technical Guidelines have been completed, they will be updated periodically as more information becomes available and as more experience is gained.

Proposed Approach

Similar Guidelines have been produced in various forms in other countries (e.g. New Zealand, Australia, United States, and European Union) and much effort has been put into them. Therefore the development of the DFO Technical Guidelines will be informed by these other countries’ experiences as well as our own.

Working papers will be requested from regional science experts on various aspects of the Fisheries and Ocean Canada policy on the Precautionary Approach and will take into account both current Canadian practices and international best practices. Based on this review the participants will agree on the best practices and key considerations which will form the content of DFO’s Technical Guidelines.

Expected Publications

The results of the meeting are expected to be documented through a CSAS Proceedings document that summarizes the discussion at the meeting. The Technical Guidelines will be included in an appendix and will be based on material submitted for review at the workshop.

Time constraints and the technical complexity of developing the guidelines means that it is possible that final preparation of the Technical Guidelines for publication as a stand-alone corporate document will require a second step. In this case, workshop participants will identify the gaps and formulate a plan to complete the document during a second Advisory Process. Regardless of the approach taken, Technical Guidelines resulting from this advisory process will be generated by an editorial team selected among a core group of PA experts who will work together to consolidate and finalize the document.

Participation

Given that this advisory process will focus on technical guidance for future DFO Science advisory processes, participation will be limited to experts from DFO as well as invited external participants with subject matter expertise.

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ANNEX 3: MEETING AGENDA

FISHERIES AND OCEANS CANADA
NATIONAL ADVISORY PROCESS:
TECHNICAL GUIDELINES FOR THE PROVISION OF SCIENTIFIC ADVICE ON THE PRECAUTIONARY APPROACH FOR CANADIAN STOCKS

Co-chairs: Denis Rivard and Estelle Couture

Location: Ottawa National Arts Centre, Fountain room

February 28, 2012

Time	Topic
8:45 – 9:00	Introductions and meeting logistics (co-chairs)
9:00 – 9:30	Opening Remarks: Meeting objectives and expected outputs Summary of pre-meeting process, development to date, context. (co-chairs)
9:30– 10:00	Presentation of the DFO PA policy (Marc Clemens)
10:00 – 10:15	Role of science and management (Estelle Couture)
10:30 – 12:00	Reference point guidelines for iteroparous species (Daniel Duplisea and Peter Shelton)
Lunch	
1:15 – 1:45	Reference point guidelines for iteroparous species (Daniel Duplisea and Peter Shelton)
1:45 – 2:45	Reference point guidelines for invertebrate species (Stephen Smith)
3:00- 3:45	Reference point guidelines for invertebrate species (Stephen Smith)
3:45 – 4:30	How do we take into account ecosystem considerations i.e. predator/prey, temperature. (Jake Rice)
4:30 – 5:00	Day 1 – Key Points heard that will go into the Technical Guidelines and– what will we take forward for PA-NAP2

February 29, 2012

Time	Topic
8:45 – 10:00	Reference point guidelines for semelparous species (Gérald Chaput)
10:30 – 12:00	Reference point guidelines for marine mammals (Garry Stenson)
Lunch	
1:15 – 2:30	Reference point guidelines for data-deficient species (Lei Harris/Jake Rice)
3:00- 4:30	Target Reference Point science considerations (Peter Shelton)
4:30 – 5:00	Day 2 – Key Points heard that will go into the Technical Guidelines and– what will we take forward for PA-NAP2

March 1, 2012

Time	Topic
8:45 – 9:45	Revising reference points due to productivity shifts (Daniel Duplisea)
9:45 – 10:15	General discussion on when should we revise reference points, what are the triggers (all)
10:30 – 12:00	Scientific guidelines for developing harvest decision rules (Rob Kronlund)
Lunch	
1:15 – 2:15	Management Strategy Evaluation (Rob Kronlund)
2:15-3:00	Outstanding issues, Day 3 Key Points heard that will go into the Technical Guidelines and– what will we take forward for PA-NAP2
3:15-4:00	Next steps and wrap-up (co-chairs)

ANNEX 4: GUIDANCE DOCUMENT

CURRENT APPROACHES FOR THE PROVISION OF SCIENTIFIC ADVICE ON THE PRECAUTIONARY APPROACH FOR CANADIAN FISH STOCKS

LIST OF AUTHORS

Bourdages, Hugo	Quebec Region	Section 5.2
Cass, Alan	Pacific Region	Section 5.4
Chaput, Gérald	Gulf Region	Section 5.4
Choi, Jay	Maritimes Region	Section 5.2
Cleary, Jaclyn	Pacific Region	Section 3, 5.1, 6, 8
Couture, Estelle	National Capital Region	Section 1
Dawe, Earl	Newfoundland Region	Section 5.2
Dionol-Valcroze, Thomas	Quebec Region	Section 5.3
Dunham, Jason	Pacific Region	Section 5.2
Duplisea, Daniel	Quebec Region	Sections 5.1, 9.3
Ferguson, Steven	Central and Arctic Region	Section 5.3
Gendron, Louise	Quebec Region	Section 5.2
Grant, Sue	Pacific Region	Section 5.4
Grégoire, François	Quebec Region	Section 5.1
Hammill, Mike	Quebec Region	Section 5.3
Hardie, David	Maritimes Region	Section 5.2
Harris, Lei	Maritimes Region	Section 5.5
Hedges, Kevin	Central and Arctic Region	Section 5.1
Holt, Kendra	Pacific Region	Sections 3, 5.1, 7, 8
Huang, Anne-Marie	Pacific Region	Section 5.4
Krohn, Martha	National Capital Region	Section 5.1??
Kronlund, Rob	Pacific Region	Section 7,8
Orr, David	Newfoundland Region	Section 5.2
Osborne, Derek	National Capital Region	Section 2,3
Rice, Jake	National Capital Region	Sections 5.5, 6, 7, 9.2
Roddick, Dale	Maritimes Region	Section 5.2
Rutherford, D	Pacific Region	Section 5.2
Sainte-Marie, Bernard	Quebec Region	Section 5.2
Savard, Louise	Quebec Region	Section 5.2
Shackell, Nancy	Maritimes Region	Section 5.5
Shelton, Peter	Newfoundland Region	Section 5.1, 5.2, 6, 7, 8
Smith, Stephen	Maritimes Region.	Section 5.2
Stansbury, Don	Newfoundland Region.	Section 5.2

Stenson, Garry............................Newfoundland Region. ....Section 5.3
Stewart, Rob..............................Central and Arctic Region............................Section 5.3
Tallman, Ross............................Central and Arctic Region.....................Section 5.1, 5.5
Taylor, Nathan............................Pacific Region...Section 3, 5.1
Tremblay,John............................Maritimes Region..Section 5.2
Veinott, Geoff..............................Newfoundland Region ....Section 5.4
Zhang, Zane...............................Pacific Region...Section 5.2

1. INTRODUCTION

In 2009, Fisheries and Oceans Canada (DFO) published its policy on the Precautionary Approach entitled "A fishery decision-making framework incorporating the Precautionary Approach" (from hereon referred to as the “DFO PA Framework”). Implementation of the framework is ongoing i.e. reference points have been identified for several stocks and harvest rules defined for some stocks.

Although the policy is in place and scientists have gained experience in providing advice for the implementation of some elements of PA frameworks such as limit reference points, more specific guidance and best practices are needed for all technical aspects of implementing the PA policy to ensure that scientific advice is delivered in a consistent manner across stocks and regions. An important consideration in this regard is to develop comparable methods that can apply to data deficient stocks, stocks with empirical data but no population model, and stocks with an accepted analytical assessment model.

A national workshop was held February 28 to March 1, 2012 in Ottawa and was attended by 41 participants. The objective of the workshop was to begin a process towards the development of technical Guidelines to provide further guidance on the implementation of the DFO PA Framework. The meeting documented current approaches related to the implementation of the DFO PA framework for several groups of species, and where possible, provided some preliminary guidance. The current document provides a summary of these approaches while the research document presented at the workshop provide more details.

The workshop has shown regional differences in the scientific methods and application of the precautionary approach. These differences will be further explored and be considered in future workshops

2. POLICY CONTEXT

2.1 DRIVERS FOR ADOPTING A PRECAUTIONARY APPROACH

There are many reasons why DFO is incorporating the precautionary approach into its fisheries management regime. They include domestic and international commitments, market forces and, as well as a general need for increased accountability and transparency in the decision-making process.

Domestic commitments on the use of the precautionary approach include the Government of Canada’s *Framework for the Application of Precaution in Science-based Decision Making about Risk* (Privy Council Office, 2003). This Framework outlines guiding principles for the application of precaution to science-based decision making in areas of federal regulatory activity for the protection of health and safety and the environment and the conservation of natural resources. The *Atlantic Fisheries Policy Review - A Policy Framework for the Management of Fisheries on Canada's Atlantic Coast* (DFO, 2004) outlines four policy strategies to ensure that conservation is of paramount priority for resource management and that all fishing activities are conducted at sustainable levels. One of these strategies is the development and adoption of a comprehensive risk-management framework that incorporates precautionary decision making as a key strategy. Canada’s *Policy for the Conservation of Wild Pacific Salmon* (DFO, 2005a) and the *Wild Atlantic Salmon Conservation Policy* (2009) also recommend the incorporation of the precautionary approach in the management processes for these species.

Canada is party to several international agreements which also support the implementation of a precautionary approach to fisheries management. The *United Nations Agreement for the*

Implementation of the Provisions of the United Nations Convention on the Law of the Sea of December 10, 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks - commonly referred to as the United Nations Fisheries Agreement or UNFA – (United Nations,1995) was signed by Canada in 1995 and ratified in 1999. UNFA provides a framework for the conservation and management of straddling stocks and highly migratory fish stocks in high seas areas regulated by regional fisheries management organizations, and requires signatories to use the precautionary approach and the ecosystem approach when managing these fisheries. Canada also adopted the Food and Agriculture Organization (FAO) *Code of Conduct for Responsible Fishing* (FAO, 1995a), which provides an important reference tool for the sound management and responsible prosecution of fisheries on a national and international basis. This voluntary international agreement encourages States to apply the precautionary approach widely to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment. The associated *FAO Technical Guidelines for Responsible Fisheries - Precautionary Approach to Capture Fisheries and Species Introductions* (FAO, 1996) was developed to provide further support in the implementation of the Code of Conduct. The precautionary approach has now been widely-adopted by numerous international fisheries bodies, including the Northwest Atlantic Fisheries Organization (NAFO), of which Canada is a member. NAFO adopted its own provisional precautionary approach framework in 2004.

The application of the precautionary approach is also directly linked to the competitiveness of Canada's fishing industry. Third party eco-certification programs such as the Marine Stewardship Council program require proof that a fishery incorporates the precautionary approach through the use of appropriate harvest decision rules and reference points for the target stock, and that the stock is being maintained at healthy levels and is not depleted.

2.2 THE CANADIAN PERSPECTIVE

2.2.1 The Canadian Precautionary Approach Policy

As a result of the various drivers discussed in Section 2.1, Canada published the *DFO* PA Framework in 2009 under the auspices of the Sustainable Fisheries Framework (SFF). This policy applies to key harvested fish stocks managed by DFO; that is, the fish stocks that are the specific and intended targets of a commercial, recreational, or subsistence fishery. It may be applied more broadly to other stocks, if necessary or as circumstances warrant.

The DFO PA framework requires that a harvest strategy be incorporated into respective fisheries management plans to keep the removal rate moderate when the stock status is healthy, to promote rebuilding when stock status is low, and to ensure a low risk of serious or irreversible harm to the stock. It also requires a rebuilding plan when a stock reaches low levels. Applying the DFO PA framework to fisheries management decisions entails establishing a harvest strategy that:

- Identifies three stock status zones (Healthy, Cautious and Critical) delineated by a Limit Reference Point (LRP) and an Upper Stock Reference (USR) (Figure 1).
- Establishes the maximum removal rate (Removal Reference) in each of the zones; progressively decreasing from the Healthy to the Critical zones. The Removal Reference in the Healthy Zone is less than or equal to the maximum sustainable yield at which a fish stock can be harvested (F_{MSY}). This harvest rate must include mortality from all types of fishing sources, including targeted fisheries and by-catch
- Adjusts the removal rate according to fish stock status variations (i.e., spawning stock biomass or another index/metric relevant to population productivity), based on pre-agreed harvest decision rules.

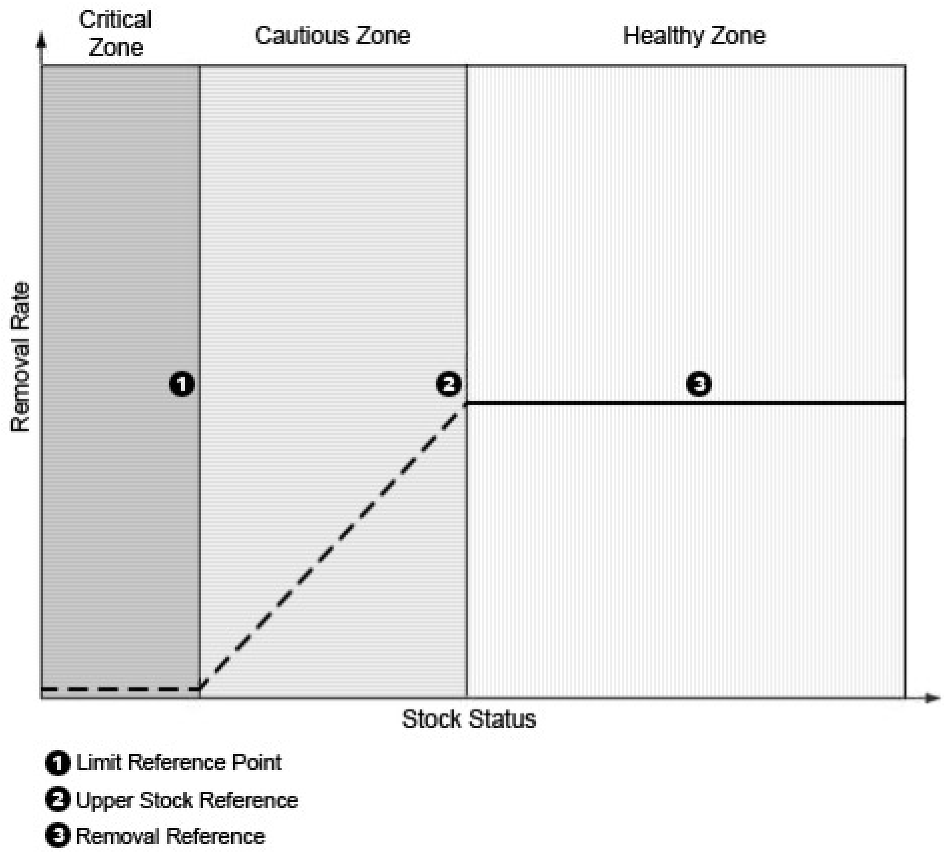

Figure 1. The Precautionary Approach Framework, as presented in the Fisheries and Oceans Canada's A Fishery Decision-Making Framework Incorporating the Precautionary Approach (DFO 2009).

Pre-agreed actions and risk tolerance (i.e. Harvest Decision Rules) guide management decisions on harvest rates under various stock status conditions. In the Healthy zone, fisheries management decisions and harvest strategies are designed to maintain fish stocks within this zone. In the Cautious zone, decisions and strategies promote stock rebuilding to the Healthy zone. In the Critical zone, stock growth is promoted and removals are kept to the lowest possible level.

The DFO PA framework was written jointly by representatives of the Fisheries Renewal, Fisheries Management, and Science sectors, and informed by The Canadian Science Advisory Secretariat Science Advisory Report 2006/023 titled *A Harvest Strategy Compliant with the Precautionary Approach* (DFO. 2006). As part of the process to consult on and finalize the DFO PA framework, it was presented to DFO personnel at meetings in each region and at public engagement sessions held throughout the country, involving harvesters, Aboriginal groups and other relevant stakeholders.

3. REFERENCE POINTS AND UNCERTAINTY UNDER THE DFO PA FRAMEWORK

3.1 REFERENCE POINTS

The DFO PA Framework uses three main stock status-based reference points: the limit reference point (LRP), the Upper Stock Reference (USR), and the target reference point (TRP).

Stock status is usually represented by spawning stock biomass or a suitable proxy. The LRP is a biologically-based reference point as it represents the stock level below which productivity is sufficiently impaired to cause serious harm. The USR is the point at which the harvest rate should be reduced if stock status declines below the USR. Under the DFO PA Framework, the reference points are also used to delineate the three stock status zones termed Healthy, Cautious and Critical (Figure 1).

3.1.1 Limit Reference Point (LRP)

The LRP marks the boundary between the Cautious and Critical zones; it marks the point below which the risk that the stock will suffer serious harm is high. "Serious harm" has been interpreted minimally as "impaired recruitment" (DFO, 2005b). At this stock status level, there may also be resultant impacts to the ecosystem, associated species and a long-term loss of fishing opportunities. When a stock is at or below the LRP, fishing mortality (and other sources of manageable human impacts) should be set as low as possible.

The development of the LRP is based on the best available biological information and is led by the Science sector.

3.1.2 Upper Stock Reference (USR)

The USR point marks the boundary between the Healthy and Cautious Zones. The USR is used to manage the risk of the stock falling to or below the LRP. Hence its position is defined relative to the position of the LRP. It should take into account the uncertainties in the assessment and the uncertainties regarding the ability of management to alter stock trajectory in the short term. It must be set sufficiently higher than the LRP to ensure that the risk of the stock falling below the LRP does not exceed the risk tolerance specified by policy / management.

When a stock status falls below this point, the removal rate at which the resource is harvested must be progressively reduced in order to avoid the stock falling into the critical zone. The USR, at a minimum, must be set at an appropriate distance above the LRP to provide sufficient opportunity for the management system to recognize a declining stock status and sufficient time for management actions to have effect. The rate of the decline in exploitation rate is not specified, but at all times must be sufficient to maintain the risk of the stock falling below the LRP below a pre-agreed risk tolerance. The USR may also act as a Target Reference Point.

The development of the USR is led by the Fisheries Management sector in cooperation with key fishery interests, with advice and input provided by the Science sector.

3.1.3.Target Reference Point (TRP)

Under the DFO PA Framework, the target reference point (TRP) is a stock status-based point which represents the trade-off between maximizing yield, achieving low risk of serious harm and achieving social, economic and ecological objectives considered optimal by managers. In practice, the TRP can be set at or above the USR but should be at or above B_{MSY} to meet the UNFSA requirement that F_{MSY} be considered a minimum standard for a limit reference point.

3.2 UNCERTAINTY

An important aspect considered by the DFO PA Framework is uncertainty. The policy states that both scientific uncertainty and uncertainty related to the implementation of a management approach must be explicitly considered. Uncertainty should be incorporated in the calculation of stock status and biological reference points. It is desirable that scientific uncertainty be quantified to the extent possible and used to assess the probability of achieving a target or of a stock falling to a certain level under a specific management approach over a specified time period.

3.2.1. Considering uncertainty in reference points

There are several types of uncertainty that should be considered in the calculation and interpretation of reference points. Though uncertainty and error are often equated, there are cases where this is confusing so we use the following to describe the uncertainty present in reference point calculations:

- *Process uncertainty* is the underlying stochasticity in population dynamics, such as variability in recruitment for similar spawning stock sizes. Process uncertainty, commonly called process error, arises from natural variability that is not explained within the model.
- *Observation uncertainty* arises from errors during the collection of basic fishery data and the estimation of quantities such as total catch, biomass (from survey) or effective fishing effort.
- *Model uncertainty* is the result of misspecification in the model structure. Model uncertainty and process uncertainty are linked.
- *Estimation uncertainty* is the combined effect of process, observation and model uncertainties on variables estimated by assessment models. Estimation uncertainty is reflected in uncertainty in estimates of model parameters (e.g., natural mortality, selectivity), indicators (e.g., the estimated stock size), or reference points (e.g., B_{MSY}).
- *Implementation uncertainty* occurs with the implementation of management measures, including how effective they will be and how well fishers will comply with them.
- *Institutional uncertainty* refers to how well participants in a process can communicate with each other, to what extent people are willing to compromise etc.

The incorporation of uncertainty by species groups is covered in these Guidelines and discussed in Section 5.

4. MSY-BASED REFERENCE POINTS AND MSY IN CANADA

The most common classes of reference point are those based on the concept of Maximum Sustained Yield (MSY). The DFO PA Framework states the Removal Reference must be less than or equal to the removal rate associated with maximum sustainable yield (i.e. F_{MSY}). B_{MSY} is defined as an average about which a stock fished at F_{MSY}, will fluctuate and return an average catch of MSY. The default use of F_{MSY}, as a maximum removal rate therefore implies that the target reference point should by default be > B_{MSY}.

Annex 1b of the DFO PA Framework provides guidance to identify reference points. It suggests using 40% and 80% of B_{MSY} for calculating the LRP and the USR, particularly where the is insufficient information to develop stock-specific reference points, as these are broadly consistent with international practice. However, where sufficient information is available, the preferred approach is always to have reference points and harvest rules based on the best information available on stock biology and fishery characteristics while taking into account the limitations of the data.

5. CALCULATION OF REFERENCE POINTS

Examples of alternative reference points that can be obtained from modelled biomass trajectories include the lowest biomass observed from which there has been a rapid recovery

($B_{recover}$), and the lowest biomass observed (B_{loss}). In many cases, it may not be possible to use population models to estimate reference points. In these cases, empirical reference points may instead be developed. Mace (1994) provides a thorough treatment of biological reference points and definitions.

The present chapter documents current approaches and best practices when providing advice on reference points for the following groups of species: 1) iteroparous species, 2) invertebrate species, 3) marine mammals, and 4) semelparous species and anadromous salmonids, under various analytical situations and data availability.

5.1 ITEROPAROUS SPECIES

Iteroparous species are defined as species that reproduce more than once before dying. In this context they include a large number of pelagic and ground fish species such as herring, cod, rock fish, redfish, haddock, halibut and many more.

5.1.1 Empirical Approaches

Empirical approaches are generally used when population model or population process based estimates are not possible but indices from direct observations are available. These indices can include commercial catch magnitude, research vessel survey indices, commercial catch rates, size composition, sex ratio, spatial distribution, length at maturation, and others. From these, inferences about population size and productivity can be made. These inferences can be applied in a PA context to derive reference points and possibly harvest decision rules. Data used in an empirical approach may be subject to some form of statistical modelling or smoothing in order to reveal the underlying signal, but this is still considered to be an empirical approach because it does not include a model of the population or a model of a population process. The incorporation of species-specific life history information can be an advantage.

- Analysis to determine PA reference points typically involve one or more of the following approaches: some form of averaging, smoothing, computation of percentiles, evaluation of the relationship between relative stock size and catch (depletion) and the consideration of life history characteristics.
- Data poor situations where only catch data are available, typically only allow inferences about MSY. When only survey data are available inferences about biomass reference points may be possible. When both survey and catch data are available the inferences about both biomass and fishing mortality reference points can be made.
- Minimum data requirements for calculating biological reference points include a survey index of abundance and catch data. In the absence of these data sources, F-based reference points may be assumed.
- Empirical based reference points should be subject to partial testing for their congruence with mechanistic determination of reference points in data rich stock and more thorough simulation testing.

5.1.2 Modelled Approaches

5.1.2.1 Data moderate Cases

Production models

Production models are data moderate approaches requiring at minimum a catch per unit effort series and total removals expressed as biomass. These models are widely fitted to many stocks and used for assessment and reference point development. They are often criticised however for being overly simplistic as they do not account for length or age structure, varying recruitment or mortality pulses, or changes in fisheries selectivity. Some of these difficulties can be addressed through state-space modelling approaches which account for process and observation errors and Bayesian implementations appear to do well in accounting for uncertainty.

There are three common formulations for Surplus production models (SPM): Schaefer, Fox, and Pella-Tomlinson. The Schaefer model has frequently been applied in Canada for groundfish stocks (particularly *Sebastes*) while the Pella-Tomlinson model has been applied for Pacific spiny dogfish. Although each model has its own strong assumptions, the Schaefer model is proposed as the parsimonious default, not least because it is the most widely applied and explored approach globally and in Canada.

Reference points from production models are directly related to fitted parameters and no further simulations or projection after the initial fitting is required to derive PA reference points (Table 1).

Table 1. MSY-based reference point calculations from production model fits. K is the carrying capacity, r is the intrinsic population growth rate, p is the shape parameter of the Pella-Tomlinson model. e is Euler's number (2.718).

	B_{MSY}	F_{MSY}	MSY
Schaefer	K/2	r/2	rK/4
Fox	K/e	r	rK/e
Pella-Tomlinson	K*(1/(1+p))^(1/p)	r/(1+p)	r*K*(1/(1+p))^((1/p)+1)

Surplus production modelling software freely available

ICCAT 2003. Bayesian Surplus Production model (BSP). Uses SIR algorithm.

Meyer, R, and Millar, R.B. 1999. BUGS in Bayesian stock assessments Can. J. Fish. Aquat. Sci. 56:1078-1087.

NOAA Fisheries Toolbox, 2012. A Stock Production Model Incorporating Covariates (ASPIC).

Recommendation for developing reference points from production models

- If possible, fit all three models and test for best fit in consideration of biological issue. Use the Schaefer model over Fox or Pella-Tomlinson unless there is good reason and evidence to suggest the other models are more applicable.
- It is wise to consider the limit and upper stock biomass reference points to be 20% K and 40% K, respectively, to avoid issues related to the shape of the production curve.
- F_{MSY} would be the maximum removal rate in accordance with international norms.
- State-space implementations are the preferred methods presently. Process errors should be considered in the reference point estimates coming from these models.

SURBA – survey based assessment

When only age-disaggregated survey indices are available, a cohort smoothing procedure, SURBA, can be applied to develop estimates of cohort total mortality (Cook 1997). With an assumption on M, an estimate F is derived and projections under various F values can be developed. SURBA has been used to provide estimates of total mortality, relative recruitment strength, and relative estimates of total and spawning biomass from the DFO summer survey for 3Ps and 2J3KL cod (Cadigan 2010). Further, estimates of relative stock size and reference points have been derived (Cadigan 2010). $B_{recover}$ estimates from SURBA were used as the limit reference point for these stocks.

5.1.2.2 Data rich cases

Most data rich cases involve the application of age-structured models including virtual population analysis (VPA), statistical catch at age (SCA), and the companion yield per recruit and spawner per recruit methods. Derivation of reference points in the age structured data rich context may be based on the recruitment component of production only or on the composite aspects of production involving, recruitment, growth, maturity and total mortality (natural and fishing).

Stock-recruitment based reference points

Stock recruitment based reference points have been calculated for many stocks in Canada and they have been accepted as the basis for the precautionary approach for many of these stocks. These methods involve the fitting of a stock-recruitment model and then determining the biomass giving some percentage of maximum modelled recruitment – usually 50%. These SSB@50%Rmax points are rules of thumb which have been demonstrated for our commonly assessed data rich stocks in Canada (typically groundfish stocks) to prevent recruitment overfishing (Myers et al 1994) and recover stocks to healthier biomass levels.

There is a multitude of stock recruitment models that could be fitted to data and there is often little basis for distinguishing which is more appropriate based on model fit alone. Models can often be eliminated because of poor fit or because they may not represent the appropriate mechanisms for the species being studied. Still several credible models can often be fitted. In the best case, the models give similar reference point estimates. In many cases they do not, which requires robustness testing, model averaging, or selecting a model based on the most conservative method.

An important consideration in choosing a stock recruitment model is the possibility that depensation can occur. One should try to account for depensation in the stock recruitment relationship and the calculation of reference points.

Age structured production model approach

This is an approach based on projection in the spawner per recruit sense (Quinn and Deriso 1999). Once a fitted stock-recruitment model is selected, the population in the absence of fishing is projected assuming M at age, weight at age and the maturity ogive. From this, the replacement line is derived which extends from the origin and intersects the stock-recruitment curve at the maximum unfished biomass. Likewise with a fishing selectivity curve, one can determine the replacement intersection for F_{MSY} which will be B_{MSY} and then apply multiples of this. These methods are elegant yet require a considerable amount of information and consist of full projections under a range of conditions that one expects to remain constant.

Yield per recruit reference points

Yield-per-recruit models (i.e. Russell, Beverton and Holt, or Thompson and Bell) examine the relationship between yields (relative values) and fishing mortalities. The expected outcomes from a yield-per-recruit analysis are a target fishing mortality and according to the model used, a target age at first capture (Haddon 2011). Age at first capture can be used to set regulations regarding gear type while the target fishing mortality can be used to define target removal rates. Two target removal rates are derived from the yield-per-recruit analysis, F_{max} and $F_{0.1}$. F_{max} is defined as the fishing mortality that gives the maximum yield per recruit for a given size at first capture. At F_{max}, the slope of the yield-per-recruit curve is zero but for some situations, there may not be a clear maximum. Empirical evidence indicates that F_{max} tends to be too high and has led in the past to stock declines (Haddon 2011).

Spawner per recruit reference points

The spawner-per-recruit (SPR) analysis is an extension to the yield-per-recruit analysis when information on maturity and fecundity at age or size is available (Gabriel et al. 1989). Unlike yield-per-recruit which shows a maximum with increasing F, SPR decreases monotonically. SPR is usually expressed as a percentage of the SPR under unfished conditions and is designated as %SSBR or %SPR (Caddy and Mahon 1995). The fishing mortality which produces any particular %SPR is designated $F_{\%SPR}$. Reference points based on %SPR are defined from the relationship between SPR and the survival ratios (R/SSB) obtained from pairs of stock-recruitment (S-R) observations. For any fishing mortality level there is a corresponding straight line through the origin of the S-R relationship. Using this method, one can determine any number of F reference points that will keep the stock at certain biomass levels or F levels where the stock will decline, stay the same or increase. Readers should consult (Mace 1994) for more information on these reference points.

5.1.2.3 Incorporating Uncertainty

Uncertainty about stock status and policy choices given one, or several, competing models can be represented using decision tables (Hilborn and Walters 1992, Walters 1986, Walters and Martell 2004). Typically, such tables present alternative models, or states of nature, in columns and identify management options (such as effort or catch levels) in rows. The decision table elements represent measures of how well the management option in that table row will perform given the model in the column (Walters and Martell 2004). These measures can include, for example, the probability of being in the Critical, Cautious or Healthy stock zones, as has been done in some recent Canadian stock assessments that considered model uncertainty. (DFO 2009 for Canary rockfish, DFO 2011 for Pacific Ocean Perch). Management can view the range of consequences of choice, given the range of models or states of nature (columns), by looking across rows. Decision table rows need not necessarily be catch quotas; they may instead be a particular decision rule that is applied assuming implementation errors.

It may not possible for scientists to choose which models in the columns of a decision table are the most defensible; the choice of different models can only be achieved by considering the management cost of choosing one model over another. However, science can illustrate what the potential management costs are, given a range of model choices and decision rules, using management strategy evaluation (see section 8, as well as Cox et al. 2011 for an example of Management Strategy Evaluation (MSE) applied to Canadian sablefish fisheries in the context of the DFO decision-making framework). Decision tables are required outputs for presenting management advice in Pacific region groundfish (NPFMC; North Pacific Fisheries Management Council) and BC wild salmon stocks.

Reference points and components of PA frameworks must carefully consider the impacts of different types of error on their estimates. For examples, if process errors are large relative to observation errors, an impact can be that stocks may appear more productive than they are and thus management advice derived from such a situation could be more risk-prone than thought.

5.2 INVERTEBRATE SPECIES

Technical Guidelines for the Provision of Scientific Advice on the Precautionary Approach for Canadian Fish Stocks: Section 7 – Invertebrate Species (Smith et al. 2012)

5.2.1 Empirical Approaches

The lack of adequate stock recruitment models for invertebrate species has resulted in the use of empirical methods to define the type of reference points expected by the DFO PA Framework. To date, empirical methods have used either an estimate of or an indicator of population biomass or abundance to represent the productivity of the stock over the time period that the estimate or indicator is available.

5.2.1.1 Proxy for B_{MSY}

In cases where population biomass estimates and catch data are available, estimates of surplus production (i.e., difference between biomass this year and last year plus catch) can be investigated for evidence of maximum sustainable yield. If there is evidence of a biomass level associated with maximum sustainable yield then this could be used as an estimate of B_{MSY}. Otherwise, the mean (or median) of the time series could be used.

For the other indicators of population biomass such as survey biomass (or abundance), commercial catch rates or landings, evidence should be provided to show that these indices exhibit a constant relation with biomass (or abundance). The policy indicates that the mean or the median value of an indicator over a productive period can serve as a proxy for B_{MSY}. Within this constraint, the longest time series available should be used for biomass estimates or indices.

5.2.1.2 Selection of Productive time period

The whole time series could be used to reflect a range of conditions that the stock has experienced in the past and that it will possibly experience into the future. However there may be strong evidence that there have been consistent periods of high and low productivity in the past that may reflect changing environmental conditions, or exploitation at sustainable and unsustainable levels, respectively. In the former case, expectations of future conditions may require the use of estimates from a period of similar conditions. In the latter case, estimates from the period in which exploitation was sustainable may provide a better indication of expected productivity in the healthy zone of the DFO PA Framework. The choice of a time period to use for a species like snow crab can be difficult because the abundance of males may change in a cyclic manner such that the fishable biomass can regularly decline below a USR or could even decline below a LRP due to natural fluctuations. The reasons for using different time periods of biomass estimates or indices to calculate reference points should be included with the calculations (see DFO 2010/014 for example).

5.2.1.3 Limit Reference Points

While the DFO PA Framework proposes 40% of B_{MSY} for the LRP with B_{MSY} as the mean or median biomass, the lowest estimated biomass that the stock has recovered from ($B_{recover}$) can also be used. However, this latter approach should not be considered if there is strong evidence that the stock could not recover from that level again given current or future conditions with respect to environment, exploitation patterns or other determining factors.

5.2.1.4 Upper Stock Reference

The DFO PA Framework proposes that the USR level be set to 80% of B_{MSY}. However, the purpose of this reference point is to define a level below which management action must aim to avoid reaching the LRP and therefore the exact setting of this level will also have to reflect considerations such as expected growth rate, generation time, and the target level (if one is set).

5.2.1.5 Removal Reference

The removal reference (the limit) can be set using exploitation estimates if these are available from a model or otherwise from relative removal rates (Catch/biomass proxy). The limit can be set to the exploitation level at which biomass change is minimized. The AIM method from the NOAA toolbox offers another way of using catch and one or more biomass indices to estimate the level of relative fishing mortality at which the population is likely to be stable.

5.2.1.6 Secondary Indicators

Given that biomass alone is an incomplete measure of productivity, many invertebrate stock assessments rely on secondary indicators such as size composition-based growth changes, sex ratio-based growth changes, spawner abundance or biomass, abundance of recruits, predator abundance, environmental changes and spatial distribution of density, to modify stock status advice. While these kinds of indicators are not covered in the DFO PA Framework, they can be quite important in assessing stock status and their continued use is encouraged. However, a formal framework to incorporate these indicators into the provision of advice does not currently exist and their application tends to be species/stock specific.

5.2.1.7 Testing

These empirical methods and associated harvest decision rules should be evaluated using simulations or a Management Strategy Evaluation approach. For example, simulations have been used to test various options for harvest decision rules for Gulf northern shrimp.

These best practices pertain to methods to implement biomass-based reference points. For many sedentary species (e.g., bivalves and echinoderms), primarily spatially-based limits and targets for fisheries may be more appropriate. There are a few cases in Canada (e.g., Scotian Shelf sea cucumber, Atlantic surf clam along the Northern Gulf of St. Lawrence) where such limits are being proposed.

5.2.2 Modelled approaches

Standard assessment models are rarely used to define productivity for invertebrate species in terms of long-term dynamics as a function of reproductive capacity. Stock recruitment relationships are difficult to demonstrate possibly due to the lack of appropriate data or the lack of evidence of a relationship even when spawning stock and recruitment biomass estimates are available. While the former case might be mitigated through investment in additional monitoring or data collection programs, the latter may be a consequence of the “important aspects in the mating systems” as described in the Invertebrate Reference Point workshop (Smith 2003, Smith and Sainte-Marie 2004). The different invertebrate species commonly fished exhibit a very diverse range of life history characteristics. Reproductive success is a function of a number of factors related to life history that may include effective female fecundity, spawning opportunities for females, spatial patterns of age-size structure, the relationship between spawner density and fertilization success (especially for broadcast spawners with sedentary or sessile adults), spatial and temporal aspects of breeding areas, the relationship between benthic settlement success and habitat suitability. For many species the time period between spawning and actually being able to observe recruits may be long enough so that cumulative environmental influences on survival could radically modify year-class strength. Also, there is often a mismatch between managed areas and stock area so that recruitment success in one area may be affected by spawning success in another area.

5.3 MARINE MAMMALS

Applying the Precautionary Approach to Marine Mammal Harvests in Canada (Stenson et al. 2012)

5.3.1 Introduction: The first application of Precautionary Approach in Canada

The first application of the precautionary approach to fisheries management in Canada was the Atlantic Seal Management Plan (DFO, 2003). Adopted in 2003, which was well before the publication of the DFO PA Framework in 2009, the management plan (originally known as Objective Based fisheries Management, OBFM) was developed in response to the Eminent Panel report on seal management (McLaren et al. 2001). OBFM provides a framework for data-rich and data-poor populations, and identifies precautionary and critical reference points (i.e. equivalent to USR and LRP in the DFO PA Framework), along with management actions that are triggered when thresholds are exceeded to reduce potential damage to the resource. This approach was initially applied to commercially hunted seals in Atlantic Canada: harp (*Pagophilus groenlandicus*), hooded (*Cystophora cristata*) and grey (*Halichoerus grypus*) (Hammill and Stenson 2003, 2007, 2009). It has subsequently been adopted, with only minor changes, by ICES to provide advice on harp and hooded seals and is used by Norway and Russia to manage these species (ICES 2004, 2006a,b, 2008). The general concepts of this approach have also been used, and as of 2012 continue to be used to provide advice for other marine mammals in Canada.

In comparison to fish, numbers rather than biomass are used for mammals. Historically, MSY was used to provide advice on harvest levels for marine mammals (e.g. the New Management Procedure of the International Whaling Commission) but it was soon realized that the information required to estimate MSY was not available for most populations (e.g. de la Mare 1986, Cooke 1994), and other approaches were developed. Theoretical studies have suggested that MSY may be between 50 and 85% of the population at carrying capacity (de la Mare 1986, Wade 1998, However, many marine mammal populations have been heavily exploited historically and there are few examples of populations near carrying capacity (K) to allow us to estimate the dynamics of populations at high densities. Also, estimates from one period may not be appropriate for a population living under a different set of environmental conditions (Punt and Smith 2001).

5.3.2 Setting Reference Points

The amount of information available for resource management varies among marine mammal populations. Therefore, it is important that 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’).

Currently, criteria for data-rich species are defined for seals. They must have three or more abundance estimates over a 15-year period, with the last estimate obtained within the last five years, and current (≤ 5 years old) information on fecundity and/or mortality to determine sustainable levels of exploitation. If these data are not available, the species information is considered data-poor.

Criteria to define ‘Data Rich’ populations vary depending upon the life history of the species. Appropriate criteria for other species groups such as large, or small, cetaceans must still be developed.

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. The critical reference level (i.e. LRP) is set at 30% of the maximum observed or estimated population size (Nmax). The maximum population size (estimated or inferred) is used as a proxy for the carrying capacity (K) because of difficulties estimating K for most species.

The precautionary reference point (i.e. USR) should be set to ensure that the cautious zone is sufficiently large that there is a low probability (5%) that the stock status will be below the LRP (estimated using simulation testing). Based upon previous studies on various marine mammals, and in absence of simulation studies, the default value for the USR is 70% of Nmax (Figure 2). 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.

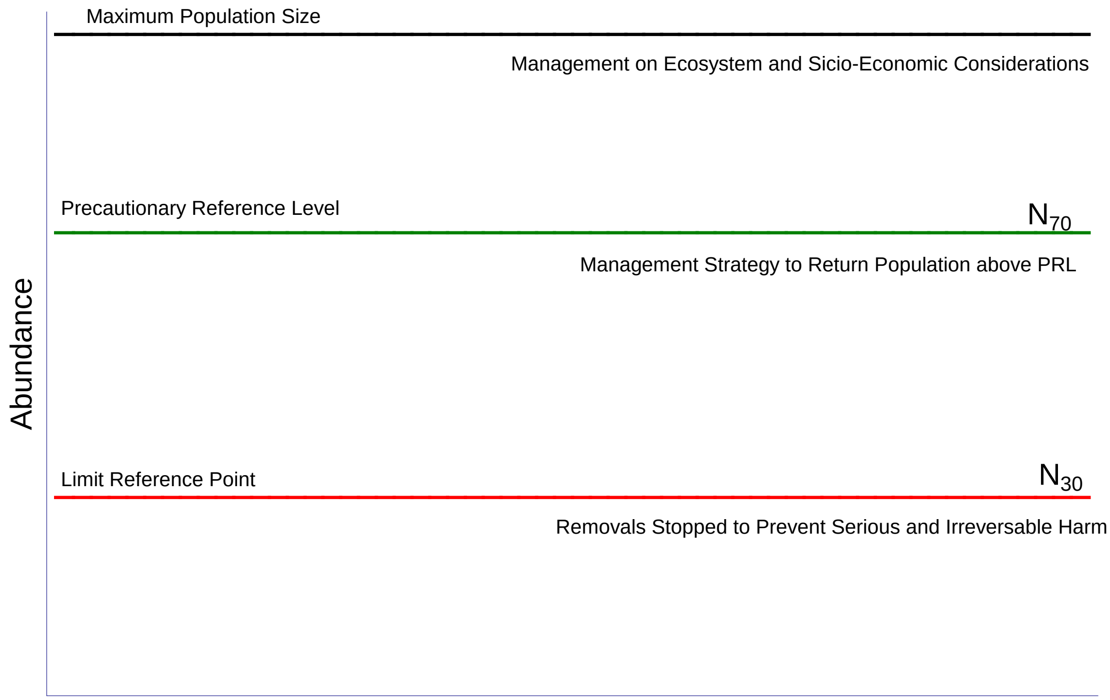

Figure 2. Reference points for the management of marine mammal species considered to be ‘Data Rich’.

For species not satisfying the data-rich criteria (i.e. ‘Data Poor’), the uncertainty associated with resource status and with the effects of particular management actions increases. Therefore, a more risk-adverse approach is needed. If a maximum population can be estimated, the critical limit (i.e.) LRP can be set at 30% of the maximum. If no maximum can be estimated, a critical limit can be assigned based upon the IUCN/COSEWIC criteria for a small population. A population below this limit would be considered to be in the critical zone and human induced mortality should be prohibited or reduced to a minimum. Above this level, removals should be cautious (Figure 3.) and maximum removals can be estimated using the Potential Biological Removals (PBR) approach.

Developed in the United States under the Marine Mammal Protection Act, the PBR has been subjected to extensive simulation testing to examine how it behaves under different scenarios, with the objective that the population must have a 95% probability that it will not become depleted. PBR is calculated as:

$$PBR = 0.5 \cdot R_{max} \cdot f \cdot N_{min}, \quad (1)$$

where R_{max} is the maximum rate of population increase, f is a recovery factor (between 0.1 and 1) and N_{min} is the estimated population size using the 20-percentile of the log-normal distribution of the most recent population estimate. Currently, for Atlantic seals, f is set at 1, unless there is an obvious serious conservation concern. In the absence of data, R_{max} is assumed to be 12% for pinnipeds and 4% for cetaceans.

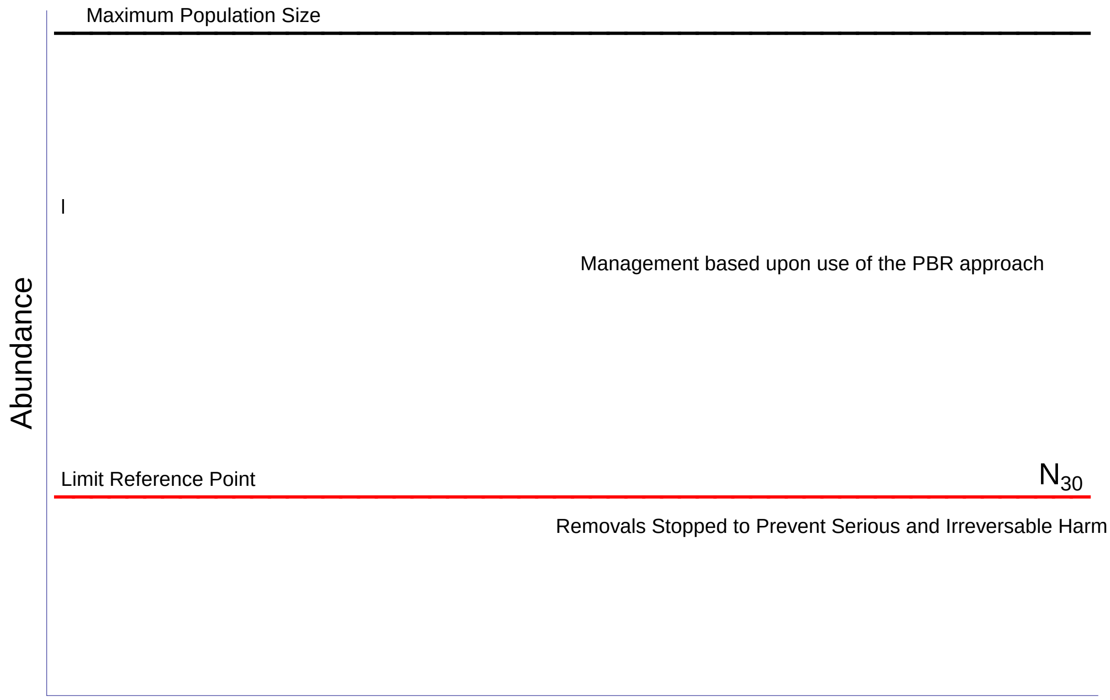

Figure 3. Reference levels appropriate for marine mammals that are considered to be Data Poor.

The steps above can be summarized as the following decision tree:

1) Do you have a good understanding of the current abundance and factors affecting population dynamics (defined criteria)?
   a) If Yes, consider the population to be Data-Rich
   b) If no, consider the population to be Data-Poor

2) If Data poor

    a) Can you estimate Nmax? If yes, identify Nlim as 30% of Nmax

    b) If not, use IUCN/COSEWIC limits for small population size

3) If Data Rich

    a) Determine Nmax (Estimated from recent data or Inferred)

    b) Critical Reference

    c) limit - 30% of Nmax

    d) Precautionary Reference point (Upper Stock Reference)

        i) Estimate 'buffer' required to ensure a high probability that LRP is not exceeded using simulation studies

        ii) In absence of simulation studies, assume 70% of Nmax

5.4 SEMELPAROUS AND ANADROMOUS SALMONID SPECIES

Considerations for defining reference points for semelparous species, with emphasis on anadromous salmonid species including iteroparous salmonids (Chaput et al 2013)

Spawning stock abundance in semelparous species is determined exclusively by the abundance of first time spawning individuals and as a result there is no opportunity for spawning stock to accumulate over years. Fisheries on this group of species occur exclusively on animals that have never spawned. Some iteroparous but short lived species have life history characteristics which are similar to those of semelparous species; the dominant component of the annual spawning stock is comprised of first time spawners and there are few year classes in the annual spawning run. Anadromous salmonid species additionally use two distinct environments and are characterized by extensive population structuring with well established density dependent population regulation, generally in freshwater. Spawning and rearing habitat is highly spatially structured in freshwater.

The choice of management strategy influences the types of reference points required. For example, in exclusively a fixed escapement strategy which has frequently been used for managing salmon fisheries, an escapement reference point is all that has been required. However, there is a need to reconcile reference points used historically in a fixed escapement management strategy to the reference points, both limit and upper stock abundance reference points and the removal rate reference point, required in the DFO PA framework.

The following sections (5.4.1-5.4.3) summarize practice to date:

5.4.1 Fishery reference points

Fishery reference points and Wild Salmon Policy benchmarks for Pacific salmon are similar to reference points proposed in other sections of this report and in a number of other fora and publications.

5.4.1.1 Fishing mortality reference points

The default fishing mortality reference point recommended is F_{MSY}. Results for some simulation analyses for Pacific salmon species indicate that this reference level is associated with a low probability of extirpation and high probability of recovery to S_{MSY} within three generations. This reference level is also robust to variability in stock productivity and is consistent with the proposed limit removal rate reference level in the DFO PA Framework.

5.4.1.2 Biomass limit reference points

Performance indicators for assessing possible limit reference points for Pacific salmon are the risk of extirpation and probability of recovery for assumed values of intrinsic productivity, underlying modeled population dynamics for Pacific salmon. The two reference points that are the most robust and indistinguishable in terms of extirpation risk and recovery potential are $S_{50\%Rmax}$ and a reference point termed S_{gen} (the spawner abundance that will result in recruitment equal to spawners at S_{MSY} in one generation in the absence of fishing under equilibrium conditions).

Other possible reference points that have not been fully developed to date would take into account the spatial structuring of habitat and populations. Examples include minimum density of spawners per area, number of spawning groups with abundances greater than a threshold value, number of spawning groups that contain some cumulative percentage (e.g. 80%) of the total abundance, and abundance which results in the presence of juveniles in a given proportion (e.g.90% as measured in surveyed sites) of the accessible watershed.

5.4.1.3 Upper Stock Reference points

The choice of upper stock reference points must be in part determined by the choice of the limit reference point and management objective. A default upper stock reference point commonly referenced in literature, that complies with the Wild Salmon Policy abundance indicator upper benchmark definition, and is consistent with DFO's PA Framework is $80\%S_{MSY}$.

5.4.1.4 Target reference point

Obvious target reference points include S_{MSY} and for some fisheries, such as recreational catch and release fisheries for which fish-fishery interactions are of greater value than yield, S_{Rmax}.

5.4.2 Derivation methods

5.4.2.1 Modelled approaches

Stock and recruitment models have a long and established history in anadromous salmonid stock assessments and provision of advice for fisheries management. When a suitable time series of spawner and recruitment data are available, biological benchmarks should be based on S_{MSY} and F_{MSY}. The standard Ricker model has been used extensively in stock assessments of Pacific salmon and it is now standard practice to capture parameter uncertainty using Bayesian inference methods.

Beverton-Holt models have been used in several instances to analyze a range of Atlantic salmon spawner to juvenile data sets and also as the underlying function in population viability analysis. A variant of the Ricker model, the so-called Larkin model, has been explored as an alternative model to describe dynamics in cycle lines of some Pacific salmon species. In this formulation, three additional parameters are added to the Ricker model to estimate delayed-density dependence among cohorts in the 4-year generational period. Other variants of SR models have been used to model depensatory mortality in recruitment for Pacific salmon when spawner abundances were below a specified threshold.

Walters and Martell (2004) show that a state-space modelling approach can reduce bias in Ricker parameters when applied to sets of stocks that have been subject to shared environmental effects. Their approach can be applied to stocks subject to the same fishing mortality history and survival patterns (SR residuals). This approach was recently applied to Skeena sockeye and is considered to be a superior method for assessment data for multiple stocks with blanks in the times series due to inconsistent escapement monitoring.

5.4.2.2 Empirical

Empirical methods include life history models which are constructed based on life history process parameters borrowed from a large range of studies on the species of interest.

In the absence of quantitative information, empirically derived escapement targets based on limited and low quality escapement monitoring is often the basis for managing terminal chum fisheries during the course of the fishing season. In-season monitoring of relative abundance in test fisheries is often used as the principal method for setting in-season fishery targets along with in-season escapement monitoring. Other empirical methods rely on freshwater survey data of juvenile habitat capacity and indices of marine survival from very limited indicator systems with both freshwater and marine indicies of abundance.

The use of Spawner per Recruit analyses using basic life history parameters, measured or inferred, is an empirical method for developing reference points. Basic life history data can be readily obtained from different regions of the species distribution and the reference levels could be tailored to those variations in life history characteristics. The approach was applied to American eel based on measured growth rates, probability of maturing and natural mortality from empirical relationships developed for the European eel.

5.4.2.3 Data poor

Bayesian methods have become widely used in stock recruitment analyses. They are hierarchical modelling approaches that provide the means of incorporating information from multiple stocks and studies to assist in parameter estimation and in transfer to stocks with limited information (Prévost et al. 2003; Michielsens and McAllister 2004).

Reference points for data-poor situation could be inferred based on a spawner abundance value from studied populations standardized to an exchangeable metric representing the size of the population. For Atlantic salmon, default reference points based on egg deposition requirements per unit of rearing area have been used since the early 1990s. Most recently Bayesian hierarchical models have been used to transfer reference points scaled to the area of juvenile rearing habitat to unstudied populations. Latitude was used as an additional conditioning variable to adjust the reference points across rivers in Europe (Prévost et al. 2003).

For sockeye, Chinook and coho Conservation Units (CUs), habitat models have been developed for estimating habitat capacity and abundance-based benchmarks. When lake-rearing habitat is limiting production, juvenile sockeye production is assumed to be related to primary production capacity in a lake. A meta-analysis developed for Alaskan and BC sockeye rearing lakes is based on the relationship between maximum smolt abundance and lake rearing habitat. This is viewed as a cost effective method for data-limited systems wherein habitat of sockeye rearing lakes is measured using lake surveys. Independent habitat capacity estimates and their variances are being used as Bayesian priors in SR models for some data limited Fraser and Skeena CUs. This has been shown to effectively reduce uncertainty in parameter estimates where juvenile production is assumed to be lake-limited.

Chinook productive capacity is shown to be related to freshwater habitat area in a meta-analysis of 25 Chinook populations distributed between Alaska and northern Oregon and representing a broad range of environments and life history types. The relationship can be used to estimate the key management parameters S_{MSY} and $S_{equilibrium}$, associated fishery reference points and uncertainty. The use of habitat-based methods has allowed the number of Chinook CUs with modelled fishery reference points to increase to more than half of the Chinook CUs in the Region. The application of GIS for mapping spatial habitat data (i.e. accessible freshwater habitat area) is a promising tool for extending the habit-based approach.

A habitat-based method has also proven to be a useful predictor of coho production in streams distributed from Alaska to Oregon based on relationships between stream length and smolt abundance. Based on that method, smolt productive capacity and the number of spawners that are required in order to fully seed the available habitat and produce the maximum number coho smolts (S_{max}) were estimated for 102 coho streams (two CUs) in the Nass River areas.

5.4.3. Considerations for stock structure and uncertainty

Anadromous salmonids are characterized by population structuring at the scale of individual rivers and in some Pacific salmon species down to subwatershed scales. Almost all the harvested catch of Pacific salmon that spawn in B.C. is from mixed-stock and mixed-species fisheries. Sustained yield from mixed-stock fishery situations will always be less than yield when each stock is harvested separately and the trade-off between reduced catch and protecting smaller or less productive populations must be recognized (Hilborn and Walters 1992).

The formulation of fisheries management advice should take account of the complexity of the mixed stock fishery being managed, and the number of distinct production areas that are being exploited. As the number of stocks being prosecuted in mixed stock fisheries increases, the total escapement objective for the complex being exploited must be increased to ensure a given probability of simultaneously achieving the individual stock reference levels. Increasing the reference levels as described above in an attempt to account for the number of stocks being exploited in a fishery or in an attempt to compensate for lower productivity will result in reduced catch options.

If mixed-stock fisheries are allowed to take place, the number of populations to be protected simultaneously and the level of risk for simultaneous attainment of reference points must be provided by management.

Quantifying uncertainty in the development and use of reference points consists of two components: uncertainty associated with the derivation of the reference point and the probability level of the reference point estimate to be used in management. Bayesian modelling approaches are now widely used in stock assessments for the provision of management advice and these allow for a more complete quantification of the uncertainties. Hierarchical Bayesian methods are most appropriate in situations where reference points from data rich situations are transferred to populations with limited to no information (Prévost et al. 2003). From such Bayesian models, posterior distribution summaries of parameters of interest, including reference points, provide information to characterize uncertainty. In some cases, a value other than the median of the posterior distribution can be selected. Alternatively, the full posterior distribution of the reference point could be retained and applied jointly to the posterior distribution of the population assessment metric. The marginal probability distribution of having met or exceeded the objective could then be derived and this would indeed be a full integration of uncertainties in the assessment and uncertainties of the reference points.

5.5 DATA-POOR SPECIES

There are a variety of different information sources that can be used in data-poor situations. Guidance is provided on two situations commonly encountered:

1) when there are only data from catch monitoring;
2) when there are only data from surveys and basic life history information. A third situation was reviewed briefly, but it was concluded that it is premature to provide general guidance at this time, and;
3) when there are only data on habitat quality and quantity and some information about how abundance may vary with habitat.

It should be an exceptional case to have full commercial fisheries managed in a data-poor context. Rather, in most cases data-poor conditions should only be encountered when a fishery is in early stages of its development. In those early stages, the types of provisions called for in the draft Policy for New and Developing Fisheries should be used to maintain a low risk of the fishery causing serious harm to the stock. The new and developing fishery itself should be managed to increase the knowledge available for its management. A reasonable precondition for a fishery to progress from management under provisions such as those in the Draft Policy on New and Developing Fisheries to management under a “typical” Integrated Fisheries Management Plan (IFMP) would be that sufficient information be available to allow use of at least empirical methods for application of precaution.

There are exceptions to the generalization that data-poor conditions should only occur in new and developing fisheries, and some long-standing fisheries have been managed with apparent success using data-poor approaches, such as lobster fisheries. The lobster fisheries are managed through input controls (no quota). There are no direct estimates of biomass and for many lobster fishing areas (LFAs), landings are the only information available. Given a number of assumptions and a long history in the fishery (> 100 years), landings were used as a proxy for biomass to set reference points (e.g. Magdalen Islands lobster fishery). Caveats using landings can be dealt with by using secondary indicators (reproduction, recruitment, demography) in defining stock status. W data-poor methods are considered the only suitable basis for management of an on-going commercial fishery, case-specific justification needs to be provided. This justification should include the rationale for why the risk of overfishing the resource can be managed effectively in the medium and long term with insufficient data for the estimation of biologically based management reference points, and for their use in management decision-making and periodic evaluation of the fishery’s impact on the resource.

5.5.1 When only commercial monitoring data are available

When data from commercial catch monitoring are considered “best available information”, those data must be used with caution because landings and CPUE are often not proportional to abundance. However, with appropriate caution, CPUE might be used as a relative index of initial biomass. When considering if a catch or CPUE series, or a subset of the catch series data is a suitable basis for the management of a fishery, the following conditions should be met:

a) The fishery needs to cover most of the stock area, or at least the management plan is developed for only the portion of the stock in the area which produced the CPUE series.
b) The time series of catch data needs to cover at least two mean generation times and be from a period when fishery controls have been relatively constant. Fishery control factors in this context include:
    i) effort, including number of licences and fishers on the water and,
    ii) technology (e.g. traps, boat HP, winch strength, boat size, fishermen’s knowledge, sounder technology, etc ...)

c) Spatial area of the fishery should not have changed markedly over time, nor should the distribution of effort over the stock area have altered substantially.

d) Conditions should not have changed such that the target species have become more or less accessible to the gear.

e) The fishery landings need to be well monitored with a large % of catch monitored at the wharf, and discarding, if it occurs, should be reported fully or reliably estimated.

f) There should be little incentive amongst fishers to cheat, such that estimated black landings and poaching should not be significant relative to legal landings.

g) The spatial distribution of landing proportions should be relatively constant.

In situations where landings or CPUE are believed to reflect abundance, historical catch may be used as a proxy for MSY or B_{MSY}. Limit and harvest decision rules could be developed by multiplying the average catch from a stable period in the time series (no decline) by a factor which would depend on the status of the stock. The determination of stock status may rely on expert opinion in data-poor situations. Several illustrations are available on the use of catch-based methods in Canada.

Quantitative methods for using catch data are also available. The Depletion-Corrected Average Catch (DCAC) is a method for estimating sustainable yields for data-poor fisheries based on the idea that the average catch has been sustainable if there has not been a substantial change in abundance. Data requirements are catch data and an estimate of natural mortality. The resulting DCAC values are expressed as a probability distribution, and tend to be somewhat smaller than MSY values. Depletion-Based Stock Reduction Analysis (DB-SRA) is a method for determining a reasonable yield and management reference points, merging stochastic Stock-Reduction Analysis with Depletion-Corrected Average Catch. If at the beginning of the catch series abundance is at unfished biomass, and at a known fraction of that level at the end of the series, then the unfished biomass can be determined. Standardized methods for establishing the “known fraction” were not reviewed, and may not have been developed. Monte Carlo exploration provides a probability distribution of the results. Outputs include the time trajectory of biomass, the current catch at F_{MSY}, and the probability that fishing pressure has exceeded F_{MSY}.

Exploring the performance of these models with simulations has determined that both methods are sensitive to the assumed distribution for the relative stock status. We find that when we assume that the current status of the stock is relatively healthy, the estimated sustainable yield is increased. The review suggested that information from assessed stocks with a similar life-history should be used to make inferences about the relative stock status. Both models were found to be fairly robust to biases in the distributions of the biological parameters, and harvest levels tended to be low relative to the true values.

5.5.2 When only data from habitat characteristics and spatial distribution is available

When data from habitat characteristics and spatial distribution are considered “best available information, distributional data, ecological principles, and knowledge from other jurisdictions can provide a basis for credible science advice for management. Both the research document and the information in the section on invertebrate fisheries give examples of how spatial approaches to management combined with habitat information can form the basis for the determination of reference points and can inform the management of invertebrate fisheries. However, these are still viewed as a compendium of case histories that have not yet been fully synthesized into a unified basis for robust guidance on how to manage fisheries in a consistent precautionary framework based on habitat characteristics and densities of the target species. Further work with such approaches, including careful documentation of the approaches and results, are encouraged.

5.5.3 When only data from research surveys and life history parameters is available

When data from research surveys and life history parameters are considered “best available information”, one may use survey records to document changes in abundance of a species or populations if the following four conditions are met:

a) The survey design has been consistent over time, or changes in survey design are documented and their effects on estimating population status are taken into account.

b) The gears and methods of fishing have been standardized over the period of the survey or if they have changed, the surveys have been inter-calibrated.

c) The species is considered likely to be retained by the survey gear if encountered.

d) The species is recorded consistently when taken in the survey.

In order to serve as basis for management advice, abundance information should be combined with information on the level of removals from the fishery. When life history information can be provided for a species, either from the literature or from analysis of the survey data, then it may be possible to provide estimates of sustainable removal rates that can be used in precautionary management frameworks.

In this context, reference points for a given species can be determined by following the steps below:

1) Establish that the four preconditions listed above are fulfilled, or not likely to be seriously violated.

2) Produce a population estimate with an appropriate confidence interval or probability density function for each year of the survey taking into account the specific survey design.
Guidance is widely available on how to produce population estimates with confidence intervals. This estimate should be treated as a minimum population estimate since:

   a) it assumes that catchability (q) of the species in the survey is 1.0, which is rarely true, and;

   b) the survey may not cover the entire range of the species.

3) Obtain a working estimate of natural mortality (M) for the ages of the stock that are being taken in the fishery.

   Two frequently tractable ways are:

   a) estimate maximum M either from direct aging of a representative sample of the population or from a suitable growth model and estimate of Lmax and then log M = 1.46 – 1.01 log Amax or $M = k\ (L/Lmax)^{-1.5}$ (where K is from the vonBertlanffy growth equation); or

   b) if the population is a relatively poorly studied stock from a species or species group with a number of well studied stocks, “borrow” the typical M of the well studied populations.

4) Take a fraction of M that is considered low risk. Or if estimates of the uncertainty in M are available, take that fraction of the probability distribution function (pdf) of M.
   The meeting did not agree on a specific fraction of M that would be recommended, but literature reports range from 0.5 M to around 0.7 M with several papers suggesting values in the neighbourhood of .65 M. A DFO workshop on Bycatch management examined these options in detail, and a research document from that should be consulted for further guidance.
5) Multiply the results of step (4) by step (2). The resultant pdf is that of sustainable catches taken from the population size estimated in (2) given the M estimated in (3).
6) Annual maximum removals from the stock consistent with the precautionary approach framework would be the median of the pdf of sustainable catches for that year (from 5). In these data-poor situations, this would correspond to the Removal Reference.
7) For the chosen level of risk aversion used to position the USR relative to the LRP in model-based cases, apply the same level of risk aversion to the pdf of catches from (5). In addition, if the LRP for model and empirical situations is being set as more risk averse than the median for the parameter being used to anchor those LRPs biologically, then the position on the probability density function of M (or catches calculated as per step (6), given the estimate of M) corresponding to the risk tolerance can be applied for the data poor situations as well. This provides the level of catches for the year of interest beyond which measures to reduce catch should be taken, functioning like the USR in model in empirical situations.

If surveys are not conducted annually, then the uncertainty in the pdf of survey catches will underestimate the uncertainty in stock size over the period when that pdf will be used to calculate maximum sustainable removals.

6. TARGET REFERENCE POINTS (TRP)

The DFO PA framework defines two types of reference points, a target that sets desirable outcomes of the fishery, and limits that define undesirable outcomes with respect to stock conservation.

Both F-based and SSB-based targets are recognized in PA frameworks however, the Target Reference Point (TRP) defined in the DFO PA Framework is based on biomass only. The TRP is an important component of the DFO PA framework. The TRP is set to satisfy biological, social, and economic objectives established by interaction of science, fisheries management, and many sectors of society including the fishing industry and the general public.

To be consistent with national and international policy standards, an acceptable TRP in the fisheries decision making framework should be set well within in the healthy zone such that the probability of the stock falling into the Cautious Zone within a specified period of time while being fished at the fishing mortality rate consistent with the biomass TRP is moderately low.

The multiple objectives associated with single species and ecosystems considerations together with economic prosperity creates a complex decision-making landscape that requires careful evaluation by managers of the trade-offs when setting TRPs.

The DFO PA framework is explicit about the need to consider risk and uncertainty in the estimation of reference points. With respect to TRPs there are two important considerations; the risk of not achieving the TRP and the time frame over which this risk is evaluated.

6.1 THE ROLE OF SCIENCE

For Science to be effective in providing advice and support to fisheries managers with regard to achieving targets, it is important that timelines and risk tolerances be clearly specified by managers.

Science can advise and support the management of Canadian fisheries by providing values for targets relative to B_{MSY} and F_{MSY} or other biological or ecosystem properties, and carrying out analyses of the expected performance of alternative harvest decision rules in achieving targets and avoiding limits.

For depleted stocks, science can carry out analyses of alternative management strategies that determine the risk associated with not rebuilding the stock to the TRP within a specified amount of time.

7. HARVEST DECISION RULES

Current Approaches for the Provision of Scientific Advice on the Precautionary Approach for Canadian Fish Stocks: Harvest Decision Rules (Kronlund et al. 2014a)

The DFO PA Framework stipulates that (1) harvest decision rules are an essential component of a PA Framework (management strategy), (2) harvest decision rules should be designed to achieve the desired conservation and yield objectives for the stock and fishery, and (3) harvest decision rules should be sufficiently well-described to allow evaluation of the performance of management strategies with respect to their ability to satisfy conservation and yield objectives. The specific design of a harvest decision rule is dependent on an inclusive objective-setting process for the stock and fishery that involves assessment analysts, fishery managers, and resource stakeholders.

7.1 CONSIDERATIONS FOR HARVEST DECISION RULES CONSISTENT WITH THE DFO PA FRAMEWORK

There are two types of rules outlined in annex of the DFO PA framework:

1) a 3-zone status-based rule where the removal rate is a function of estimated stock status (Figure 1.), and;
2) an acceptable risk-based rule in which the acceptable probability of stock decline is based on a combination of current stock status and the recent rate of change in stock status (i.e., increasing, stable, or declining) (see Table 1 in DFO 2009a).

The former is a feedback decision rule whereas the latter does not specify a reference removal rate and also incorporates a feed-forward step.

Complex decision rules should be avoided in favour of the simplest rule that will best satisfy the conservation and yield objectives. For example, the quantitative evaluation of acceptable risk-based rules requires a significantly larger number of *a priori* decisions and a far greater computational burden than for status-based rules. Status-based rules require far fewer design choices in comparison to an acceptable risk-based rule, making them easier to develop and explain to stakeholders. Simple status-based harvest decision rules that do not rely on an estimate of current spawning stock biomass, but respond directly to an empirical index of stock abundance have been implemented for several fisheries in Canada under a Management Strategy Evaluation framework. These include sablefish in the Pacific Region, the western component of Pollock in Atlantic Canada, and the Greenland halibut stock off Newfoundland.

Performance statistics that capture the risk of stock decline can be included in the evaluation of simple status- based rules.

The choice of the inflection point of the decision rule should not be restricted to match the fishery reference points, although such alignment is one option. This flexibility allows the harvest decision rule to be adjusted for stock-specific applications so that a desired trade-off between conservation and economic performance can be achieved. Such choices may result in a more desirable trade-off between total catch and catch stability, provided conservation objectives are met. For example, the lower inflection point of the rule may be set higher than the limit reference point or the removal rate at some value lower than the reference removal rate to emphasize conservation or rebuilding outcomes. Similarly, the upper inflection points of the rule stock status bound may be set at some value near the target reference point to encourage higher biomass levels and potentially higher profitability through improved catch rates.

Some jurisdictions have promoted the adoption of default, or generic, harvest decision rules that are expected to provide reasonably good performance over a wide range of fisheries. However, there is no assurance that generic harvest decision rules will achieve stock-specific objectives. If DFO wishes to develop a generic harvest decision rule, simulation testing of several possible rules over a reference set of life history and stock configurations should be undertaken, as has been done in some other jurisdictions.

Harvest decision rules do not necessarily need to be limited to the status of a single target species. Multi-species or ecosystem considerations can also be incorporated into rules, but this often adds substantial complexity and would require extensive development and testing prior to implementation.

7.2 THE ROLE OF SCIENCE

The role of Science in the development of decision rules relates directly to the requirements to:

1) design harvest decision rules to achieve conservation and yield objectives, and;
2) to assess or evaluate the performance of a management strategy.

Science is involved in identifying conservation objectives and has a role in proposing options for how policies are rendered operational because the objectives used to judge policy success will depend on scientific data and methods. This role includes assisting in the evaluation of the ability of a harvest decision rule combined with the stock assessment procedure, to avoid undesirable outcomes and attain desired outcomes. This requirement was termed prospective evaluation in the FAO Precautionary Approach to fisheries guidelines (FAO 1995).

8. MANAGEMENT STRATEGY EVALUATION (MSE)

Current approaches for the Provision of Scientific Advice on the Precautionary Approach for Canadian Fish Stocks: Section 8 – Management Strategy Evaluation (Kronlund et al. 2014b)

8.1 WHAT IS MSE?

Management strategy evaluation (MSE) is the systematic determination of the ability of a pre-specified management system to satisfy a set of measurable objectives. A management strategy is defined as a combination of management objectives, fishery and stock monitoring data, stock assessment, and harvest decision, or control rules. The methodology mimics the sequence or set of steps whereby scientific information is collected, processed, and used to provide advice in setting fishery management measures, e.g., annual catch or effort limits. In particular management strategy evaluation uses a combination of computer simulation and iterative stakeholder consultation to evaluate the likely consequences of applying alternative management strategies under a range of hypotheses for the stock and fishery. Results are reported in a way that exposes trade-offs in management strategy performance against a suite of conflicting objectives (i.e. conservation and yield). Ideally this prospective evaluation (FAO 1995) of a procedure is conducted prior to implementation; however, existing management systems can also be evaluated using MSE to verify their ability to meet intended objectives and to help re-design the procedure to address performance shortfalls. Key considerations for the application of MSE are listed below.

For each management strategy considered, a mathematical-statistical model is used to project the simulated true fishery system forward in time. Observed monitoring data with measurement error is generated from the true fish population, and an estimate of population status (i.e., the perceived population) is developed by applying an assessment method to the observed data. The assessment method may be a population dynamics model or may be a data-based summary of a stock index. Simulated management decisions throughout the projection time period are made based on the perceived state of the stock, which leads to management actions such as a catch recommendation that affect the true population (i.e., feedback or closed loop simulation). Performance measures are calculated based on the state of the true population, and the uncertainty in achieving stated management objectives is evaluated over specified time periods across multiple runs of each the simulation to capture uncertainty.

The purpose of MSE is not to provide an optimal strategy or solution, but rather to provide decision-makers with information that can be used to select a strategy that best satisfies the requisite trade-off among objectives and risk tolerance in the context of the overall management system. In addition, it allows the robustness of candidate management strategies to be considered, where robustness represents its ability to produce acceptable trade-off relationships over a range of scenarios representing plausible hypotheses about uncertain stock and fishery dynamics.

The MSE methodology is compatible with the Precautionary Approach, as specified in FAO (1995), as well as other aspects of the DFO PA framework because it demonstrates robustness in the face of possibly irresolvable uncertainty by testing the performance of candidate management strategies against a range of stock and fishery scenarios. Specifically, the approach is able to:

1) consider alternative data collection and stock assessment approaches for characterizing stock status;
2) evaluate alternative forms of decision rules that specify how harvest levels should be adjusted based on information about the stock and fishery;
3) demonstrate, via computer simulation, whether management strategies are likely to meet fishery objectives while avoiding undesirable outcomes;
4) take into account model (structural) uncertainty where the choice among competing models that represent different plausible hypotheses cannot be resolved with the available data or may never be resolved;
5) include process error that represents variability not captured in the model, and;
6) include observation error.

Stakeholder participation is an important aspect of MSE applications, and can occur throughout the process, including (1) the development of measureable fishery and societal objectives, (2) the identification of candidate management strategies, (3) the identification of key uncertainties to be considered, and (4) participation in trade-off debates about acceptable performance across conflicting objectives. Experience has shown that the inclusion of a variety of stakeholders into the MSE process in this way can lead to practical management strategies that are acceptable to diverse sets of stakeholder groups while ensuring that conservation objectives are met.

8.2 CHALLENGES AND A POTENTIAL SOLUTION

Despite the apparent advantages of adopting an MSE approach, experience has shown that several challenges also exist. Difficulties in adopting formal and mathematically explicit management strategies appear to derive from several causes, among them lengthy development time, high development costs, reluctance to accept advice that provides a single catch or effort recommendation as a result of applying the selected management strategy (i.e., a perception of lack of flexibility), and a lack of guidance regarding the appropriate trade-offs among objectives.

Given that case-specific MSE applications may not be feasible for all Canadian fisheries, simulation testing of management strategies supported by the DFO PA Framework over a range of generic stock and fishery scenarios may help identify interim generic strategies that are expected to perform well for most species. For example, the performance of the 3-zone harvest decision rule based on the provisional LRP, USR, and Target reference point identified in the DFO PA Framework could be evaluated for a wide range of stock and fishery dynamics and levels of uncertainty.

8.3 OTHER APPLICATIONS OF MSE

Several situations exist in Canadian fisheries management where application of feedback simulation and consultation within the management agency, and/or with external stakeholders, could be advantageous. These situations include:

1) Evaluation of the properties of <u>survey programs</u> (e.g., How do the expected benefits of increasing sample size or spatial coverage compare to the associated costs, and vice versa? How will reductions in survey frequency affect the ability of a management strategy to achieve conservation objectives?);
2) Evaluation of <u>multi-year stock assessment</u> advice in contrast to annual advice by comparing trade-offs between the ability to meet long-term conservation goals, the costs of stock assessment, and the expected stability of catches;
3) Evaluation of the expected performance of alternative monitoring and management measures aimed at <u>rebuilding depleted stocks</u>;
4) As an alternative to relying on expert-judgment alone for the management of <u>data-poor fisheries</u>. High uncertainty about population parameters, current stock status, and the reliability of available data can be addressed by testing candidate management strategies over a wide range of scenarios about population dynamics, observation error, and the possibility that observed stock index data are not proportional to true stock status;
5) Exploration of <u>ecosystem considerations</u>, such as environmental impacts and/ or predator prey dynamics, on the performance of management strategies although this undertaking is highly complex.

9. OTHER ISSUES

9.1 REVISING REFERENCE POINTS DUE TO PRODUCTIVITY SHIFTS

This topic was reviewed thoroughly by DFO's Technical Expertise of Stock Assessment (TESA) group in December 13-15, 2011.

General Conclusions from that workshop are below. For the full guidance on when to revise reference points when productivity is changing, please see pages 36-42 in the Proceedings from that meeting which are published on the CSAS site: Proceedings of the National Workshop for Technical Expertise in Stock Assessment (DFO 2013)

9.1.1 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.

9.2 HOW DO WE TAKE INTO ACCOUNT ECOSYSTEM CONSIDERATIONS?

There are two major classes of ecosystem considerations relative to the sustainability of fisheries:

1) ensuring sustainability of the impact of the fishery on ecosystem components other than the target species, and;

2) taking account of how stock productivity may be affected by the state of the ecosystem.

Each of these classes has several facets.

Bycatch and habitat impacts are discussed very briefly but no guidance is provided for either type of impact, because they have been addressed in other CSAS advisory meetings. For by-catch refer to Guidance Related to Bycatch and Discards in Canadian Commercial Fisheries (SAR 2012/022) and for habitat impacts refer to Potential Impacts of Fishing Gears (Excluding Mobile Bottom-Contacting Gears) on Marine Habitats and Communities (SAR 2010/003), and

Impacts of Trawl Gears And Scallop Dredges on Benthic Habitats, Populations and Communities (SAR 2006/025)

9.2.1 Predators and Prey

Indirect impacts of fishing include alterations to ecosystem processes that result from the changing abundance of species and their habitats. Fisheries may reduce the abundance of forage species, affecting the productivities or survivorship of dependent predators. They may also reduce the abundance of top predators possibly reducing the degree of top-down predation control on system dynamics, and in extreme cases may result in regime shifts or trophic cascades.

Addressing community-scale impacts is part of an ecosystem approach to fisheries management, and ways to include them in appropriate forms of management reference points will also be needed. However, there is currently no policy in place for taking community-scale impacts of fishing into account. Such a policy framework will need to be developed before technical guidance can be provided on how precaution can be applied.

9.2.1.1 Forage species

With regard to exploitation of forage species, the advised approach is to include the impact of predators on prey population dynamics, and the feeding requirements of dependent predators, in robust harvest decision rules. Many reviews and policies have concluded that the basic approach to management of fisheries on forage species, including the setting of LRPs, should take the needs of predators into account, an approach that dates back to the 1970s in Canada for some forage species. Trophodynamic models have an important role in helping to set appropriate average levels of *M2* (predation mortality) and *M* (natural mortality) in the population dynamics models used to set biomass and fishing mortality reference points. However, they are much less robust at guiding adjustment of those reference points on annual or near-annual time scales. Rather, it is usually more tractable to address predator needs through a robust harvest decision rule rather than through modelling the predator-prey relationships dynamically which requires regular updates of the key population and diet data sets.

Best practices for precautionary management of forage species should include the following steps:

a) To the extent feasible, estimate an absolute amount of prey needed to satisfy the requirements of dependent predators, assuming “typical” levels of those predators in a well-parameterized abundance-energetics model for key predators or a multispecies trophodynamic model. This requires some estimate of the expected abundance of the predator(s) over the period where the HDR will be used, the annual energetic requirements of the predator(s), and percent of the diet of the predator comprised by the forage species. This estimate should be a reserve or “escapement goal” taken off the top, and the yield produced by the harvest decision rule should not reduce the prey stock below this predator reserve.

b) To the extent feasible, the population dynamics model for the forage species should include a value for natural mortality that reflects the contribution of M2 to total mortality (Z).

c) Once the population dynamics model for the prey species has estimated a plausible value for M, the robustness of harvest decision rules should be tested for the plausible range of predator pressures on the forage species. Also when relevant, the rule should be tested for a plausible range of recruitment variation due to environmental influences.

This could be done by either 1) treating the predator population as another “fleet” removing individuals from the population (Benoit et al. 2011) or 2) resampling M from a distribution that for an “average” historical prey population size would have produced a distribution of consumed prey centered on the average prey consumption produced in step (a) and with a variance comparable to the variance in the observed predator populations.

Note that steps (a) to (c) imply that the LRP should not be less than the predator requirements estimated in (a). However, the predator requirements should not be “double counted” by both setting a predator reserve in the LRP *a priori*, and then *incrementally* allowing for predator needs in the model(s) used to determine how harvest rate should vary with size of the exploited forage species in the harvest decision rule. Rather, when such modelling approaches are taken to test harvest decision rules, the estimated predator reserve in step (a) could serve as a condition to be fulfilled by any acceptable harvest decision rule. The combination of F and B reference points in the decision rule would work together to ensure that fisheries do not reduce the population below the estimated predator requirements and spawning requirements for the plausible range of environmental conditions and predator abundances.

In addition, a fishery on forage species should not cause local depletions of the target species. This would not affect setting LRPs for the prey population, but could be an additional decision rule for managing the fishery. No general guidance can be provided on how this should be done, because risks of local depletion of target species in fisheries depend on details of fishing practices and behaviour of the target species. However illustrations of such rules can be found in Greenstreet et al. 2006, and Daunt et al. 2008.

9.2.1.2 Top-level predators

Less guidance exists on what status of top-level predators should be maintained in precautionary management frameworks, but there is growing recognition that it is important to maintain large predators in marine food webs. If single species exploitation rates are kept below appropriate fishing mortality levels for single-species sustainability, major age truncation should not occur in the predator population. However there is currently insufficient knowledge to determine if such a single-species strategy is sufficient to maintain adequate top-down control on food webs, even if uniformly applied to all species in a food web.

A few jurisdictions have adopted aggregate caps for harvest of top predators. In these cases, a total maximum removal level for all fisheries is set. The aggregate removals from all fisheries cannot exceed this cap even if the sum of all single species quotas is larger than the cap. In Canada however, there is currently neither strong scientific evidence nor a policy directive that requires such aggregate harvest caps. Regardless, even without additional research, there is ample science and policy justification for rebuilding depleted populations of large predators into their respective Healthy zones. One biological justification for limiting the total removals of top predators from fish communities is because of size-based predator-prey dynamics.

Monitoring the linearity and slope of the size spectrum of the fish community through existing (or new) multispecies surveys can be an efficient approach to detecting a reduction in large predators in the fish community. Similarly, this approach can also be efficient to detect a selective reduction in the size components of the predator population that may have cascading impacts on the community as a whole. Methods for using size spectra to detect a reduction in large predators can be found in the Report of the Symposium on Rebuilding Depleted Fish Stocks (ICES, 2009. To date, experience in using the results of this approach to trigger a management response is very limited. In the future however, this approach could be used to prompt more focused investigation of the status and trends of the species in the community that are contributing to the anomaly, as a basis for follow-up action.

The now commonly raised concern is that not all species can simultaneously be harvested at rates consistent with their respective single-species F_{MSY}. Losses to species interactions are incremental to losses to fishing which means that some populations may be overexploited, depending on how M is treated in the estimates of harvests at MSY. To address this concern, consider the following:

a) When estimating F_{MSY}, take into account plausible ranges of M2 to generate an appropriate F_{MSY} estimate that takes into account these species' interactions;

b) When providing advice on targets for stocks that are well below plausible estimates of B_{MSY}, best practice would be to rebuild these populations to the internationally agreed biomass targets, rather than to focus on the above concern which is yet to be demonstrated to be a serious problem in real-world fisheries management;

c) Even if all populations were rebuilt to the neighbourhood of B_{MSY} or larger, Canadian fisheries do not exploit nearly all the species in any food web. Consequently, this issue would be likely to remain a theoretical concern, rather than a real one, even if all exploited stocks were in the Healthy Zone.

9.2.2 Environmental Conditions

Many studies have documented that environmental conditions can affect recruitment, growth, or natural mortality of exploited fish populations. In a few cases, these environment /recruitment relationships have actually been represented by extra variables and parameters in a stock/environment/recruitment relationship, and even in full Management Strategy Evaluations. In order to adjust reference points for the state of the environment using a functional relationship between the environmental variable and the position of the reference point, there would have to be a well established functional relationship between the environmental variable and of the key population dynamics processes with stable parameters over the range of the environmental variable. This condition is unlikely to be met for several reasons. Among the important reasons are the concepts of the "optimal environmental window" and the match-mismatch hypothesis, which are two conceptual frameworks commonly used for explaining the mechanisms behind environment/recruitment interactions. Neither of these two mechanisms implies that the actual relationship is unlikely to be either smooth or continuous, and if the optimal environmental window applies, it will not be monotonic. In both mechanisms, most of the dynamics of importance to conservation and sustainable use of the stock occur during extreme environmental conditions, which are not commonly observed. Parameterizing a functional relationship with all the observations is likely to have the functional relationship either dominated by a few outliers with high statistical leverage (and often high uncertainty), or if the influence of outliers is buffered by statistical transformations, the functional relationship will be determined by interannual noise in the observations under the more typical conditions. Neither is a very sound basis for regular adjustments in the position of LRPs and USR.

A robust alternative is to take the environmental considerations into account in the HDRs rather than the reference points. HDRs should be tested for robustness to the range of productivities expected under the range of environmental conditions likely to be encountered during the time the management strategy is in place. Such testing is much more tractable than trying to capture the environment/productivity relationships in parameterized dynamic models. At least two approaches are possible:

a) First characterize the shape of the probability distribution functions (pdf) of the population dynamics parameters of interest; for example the pdf of observed recruitments. This would involve:

   i) an analysis of the relationship of the population dynamics parameter to the environmental condition(s), using General Linear Models (GLMs), General Additive Models (GAMs), or other methods appropriate to the types of data and functional relationships expected between the environment and productivity of the stock;

   ii) Once that relationship is quantified, specify the frequency distribution of the environmental condition(s) expected over the period when the HDR will be used. It may be appropriate to assume the past is the most informative guide to the future, or there may be models of how environmental conditions are expected to be changing with climate and other drivers. Oceanographers can play an important role in these types of tasks;

   iii) With the results of (i) and (ii), the pdf of the population dynamics parameter can be constructed;

   iv) Then the simulations used to find the optimally robust HDR can resample directly from the pdf in (iii).

b) When the information to describe the general shape of the relationship of specific population dynamics parameters to specific environmental conditions (step a-i) is not available, it is possible to simply put some degree of autocorrelation in various terms in the models being used to test the robustness of the harvest decision rules. Which parameters and the degree to which they carry the autocorrelation are case specific, depending on what is known or hypothesised about the environment-population dynamics relationships.

Special cases

There are two special cases to consider if this approach is taken.

a) The first is when the environmental impact on recruitment (or other life history parameter) is infrequent but may be very large when it does occur. In this case, best practice is to seek an indicator that has a very low miss rate for the rare but important event that can give a warning of the possibly large anomaly enough in advance to allow management responses. Then partition the data to be used in the parameterization of the HDR into one subset of the "anomalous years", and another subset of all the "typical" years. Using this information develop an HDR with a conditional rule;

b) The second type of special case occurs when the environmental conditions have two (or more) different regimes. This situation was also reviewed in depth by the TESA group of DFO in December 13-15, 2011.

9.2.3 Mixed fisheries

Although not exactly an "ecosystem consideration" many fisheries in Canada and globally harvest a number of species in mixed catches. Individual fleets or fishers may target on particular stocks, but that strategy usually just alters the proportion of different species in the catch, and does not restrict the catches to solely the intended species in their intended proportions.

Managing to ensure no single stock is overharvested means that fisheries are closed once the quota (or other limit) is met for the first species in the complex being harvested. On the flip side, managing to allow full harvest of the most productive or valuable species in a mixed fishery complex means some stocks and species often will be overharvested.

Aside from the material on the Wild Salmon Policy for Pacific Salmon and discussed in Section 5.4.3, essentially all material in this document is developed for single stock/species management frameworks and does not take mixed fishery effects into account.

The magnitude and nature of mixed fishery effects are highly case-specific. They can be greatly affected by strategies of individual fishers, which in turn can be influenced by incentives in the management plans and markets. With this degree of flexibility in the mixed stock fishery effects, and their dependence on behavioural and economic factors as well as ecological factors of how species and stocks mix, we are not in a position to recommend any best practices for including such effects when developing and testing harvest decision rules or individual parameters in the DFO PA framework. Rather, there are policy decisions that are needed to guide management of mixed fisheries to clearly decide on the risk tolerances that will be applied to various stocks of higher or lower value and/or productivity. These risk tolerances can then be taken up in the standard practices for developing and testing harvest decision rules. However in cases when the risk tolerances will allow some stocks or species in a mixed fishery to be reduced to levels where they are at risk of serious harm / impairment of productivity, the public information about the stock(s) and its(their) management should be fully transparent about those risks.

9.3 WHEN TO RE-ESTIMATE REFERENCE POINTS AND WHAT ARE THE TRIGGERS

The idea behind reference points and anchoring frameworks for making better management decisions in the face of uncertainty for a precautionary approach usually does not entail the re-estimation of the anchors every time the stock is evaluated. These points usually must be remain constant relative to the evaluation for some period of time but for just how long depends on many factors. Specifying a time frame and for what reasons reference points should be re-evaluated is also important.

Under other circumstances it may make sense to re-evaluate a reference point every time a stock is assessed. This would be especially true for stocks for which very little data is available thus a new data year is an important addition of new information.

In cases where a management approach has not been agreed by stakeholders, other triggers for re-evaluation of reference points should be considered:

a) The biology of the species

Some species are characterized by highly variable abundance and their reference points may need to be re-evaluated frequently. For example a short-lived species with recent variable recruitment dynamics should probably be re-evaluated more frequently.

b) An important addition of new data

A body of new data (not just a new year but several new years) might entail a re-evaluation especially if the new data reveals something previously unknown about the state of the stock. For example if a stock decreases to a new low and recruitment is lower than predicted by previous recruitment models then it could suggest a phenomenon such as depensation that was previously un-recognised. Another example could be that a selective pressure has acted on the stock such that its production dynamics have changed genetically and therefore the reference points should change too.

Based simply on the addition of new data points, this might be done something like once each five years but conceivably less if our knowledge of the stock is improved substantially.

c) Knowledge of changes in the environment that would affect stock dynamics in a way that requires a change in reference points

If environmental conditions have been demonstrated to have changed significantly and especially if there is a mechanistic understanding of how these changes affect stocks which subsequently affect the reference points then it may be appropriate to re-evaluate them.

d) Significant improvements in methodology applied to the stock

If a new and significantly better assessment methodology is applied to a stock and provides different levels for the reference points then this is good grounds for re-evaluation. One must ensure though that this change is truly an improvement and not just applying a different method that has more or less the same assumptions and is equally weak or as strong as the already accepted method.

e) Other considerations

Stakeholder buy-in

When reference points will be re-evaluated is something that usually is of great concern to stakeholders – the industry in particular. There is sometimes the misconception that even if reference points are discovered to be mis-specified, that we are stuck with them. This is clearly not the case in Canada and when a significant change in information is available for a stock, reference points should be re-evaluated. In some cases, communicating a time-frame for re-evaluation can be what achieves the final buy-in from stakeholders. There are at least two cases in Canada where the communication of the time-frame for PA re-evaluation has been important with accepting the results of science meetings and moving towards PA implementation: (1) east coast redfish PA reference points (DFO 2012) where new and probably better methods are on the horizon and if they are applied properly, these should be accepted as the basis for new reference points. For example, the redfish Science Advisory Report specifically mentions a time-frame for which the estimated reference points were expected to last for (3-5 years) and it was hoped that the new methods would be available within that time. (2) Gulf of St Lawrence shrimp (Savard 2012) where the management strategy evaluation suggested a harvest decision rule for 2-4 years. Industry, though quite comfortable with the science presented, was still worried about the thought of a long-term lease but the 2-4 year figure was seen as quite acceptable and industry found the time frame reasonable.

f) Cases where reference points should be re-evaluated on each assessment:

1) When a management strategy has been adopted by all stakeholders and the overall strategy is designed to achieve pre-set objectives and specific values for reference points are not a contentious issue

2) On emerging fisheries where information on the stock productivity is not well known and addition of a new data point is an important addition to overall knowledge of the stock.

3) Short-lived species where the assessment interval may be the only view of each cohort and productivity where conditions may change on short notice owing to variable recruitment dynamics.

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