Proceedings of the Limit Reference Points and the Fish Stocks Provisions: Joint Technical Expertise in Stock Assessment (TESA) / National Operational Guidelines (NOG) Task Force Virtual Workshop, November 29-December 3, 2021

Julie R. Marentette, Tim J. Barrett, Danny W. Ings, Mary E. Thiess, Melissa Olmstead

Fish Population Science Branch
200 Kent Street
Ottawa, Ontario, K1A 0E6

St. Andrew's Biological Station
125 Marine Science Drive
St. Andrew's, New Brunswick, E5B 0E4

Northwest Atlantic Fisheries Centre
80 East White Hills Road
St. John's, Newfoundland and Labrador, A1A 5J7

2022

Canadian Technical Report of Fisheries and Aquatic Sciences 3515

Fisheries and Oceans Canada | Pêches et Océans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

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Proceedings of the Limit Reference Points and the Fish Stocks Provisions: Joint Technical Expertise in Stock Assessment (TESA) / National Operational Guidelines (NOG) Task Force Virtual Workshop, November 29 – December 3, 2021

By

Julie R. Marentette[1], Tim J. Barrett[2], Danny W. Ings[1,3], Mary E. Thiess[1], and Melissa Olmstead[1]

[1]Fish Population Science Branch
Fisheries and Oceans Canada
200 Kent Street
Ottawa, ON, K1A 0E6

[2]St. Andrew's Biological Station
Fisheries and Oceans Canada
125 Marine Science Drive
St. Andrews, NB, E5B 0E4

[3]Northwest Atlantic Fisheries Centre
Fisheries and Oceans Canada
80 East White Hills Road
St. John's, NL, A1A 5J7

Cat. No. Fs 97-6/3515E-PDF ISBN 978-0-660-46538-8 ISSN 1488-5379

Correct citation for this publication:

Marentette, J.M., Barrett, T.J., Ings, D.W., Thiess, M.E., and Olmstead M. 2022. Proceedings of the Limit Reference Points and the Fish Stocks Provisions: Joint Technical Expertise in Stock Assessment (TESA) / National Operational Guidelines (NOG) Task Force Virtual Workshop, November 29-December 3, 2021. Can. Tech. Rep. Fish. Aquat. Sci. 3515: vii + 66 p.

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ABSTRACT

Marentette, J.R., Barrett, T.J., Ings, D.W., Thiess, M.E., and Olmstead M. 2022. Proceedings of the Limit Reference Points and the Fish Stocks Provisions: Joint Technical Expertise in Stock Assessment (TESA) / National Operational Guidelines (NOG) Task Force Virtual Workshop, November 29-December 3, 2021. Can. Tech. Rep. Fish. Aquat. Sci. 3515: vii + 66 p.

The Technical Expertise in Stock Assessment (TESA) group and National Operational Guidance (NOG) Task Force of Fisheries and Oceans Canada (DFO) co-hosted a national workshop from November 29th to December 3rd, 2021 to discuss requirements of, approaches to, and challenges with, developing limit reference points (LRPs) for fish stocks under DFO's PA Policy (DFO 2009). The workshop was chaired by Julie Marentette (National Capital Region) and Tim Barrett (Maritimes Region) and was attended by 70 participants, including DFO staff from all regions as well as three external experts.

Each day had presentations and discussion, followed by a breakout group session with practical exercises relating to the day's theme. Breakout groups presented their findings in a plenary session the next day. Main themes included varied data availability and management scales, time-varying productivity and underlying biological and ecosystem considerations. Four overarching principles to guide development LRPs were reviewed:

1. Consistency with an objective to avoid serious harm
2. Best available information
3. Operationally useful
4. Reliably estimable

Although these discussions will not constitute science advice or guidance, the information captured in these Proceedings will support development of national Science guidelines for LRP development as well as regional understanding of what is required for LRPs in accordance with the Fish Stocks Provisions under the revised *Fisheries Act* (R.S.C., 1985, c. F-14).

RÉSUMÉ

Marentette, J.M., Barrett, T.J., Ings, D.W., Thiess, M.E., and Olmstead M. 2022. Proceedings of the Limit Reference Points and the Fish Stocks Provisions: Joint Technical Expertise in Stock Assessment (TESA) / National Operational Guidelines (NOG) Task Force Virtual Workshop, November 29-December 3, 2021. Can. Tech. Rep. Fish. Aquat. Sci. 3515: vii + 66 p.

Le groupe d’expertise technique en évaluation des stocks (ETES) et le groupe de travail sur les directives opérationnelles nationales (DON) de Pêches et Océans Canada (MPO) ont tenu conjointement un atelier national du 29 novembre au 3 décembre 2021 pour discuter des exigences, des approches et des défis liés à l’élaboration de points de référence limites (PRL) pour les stocks de poissons en vertu de la Politique sur l’AP du MPO (MPO 2009). L’atelier était présidé par Julie Marentette (région de la capitale nationale) et Tim Barrett (région des Maritimes) et comptait 70 participants, dont des employés du MPO de toutes les régions ainsi que trois experts externes.

Chaque journée comportait des présentations et des discussions, suivis d’une séance de discussion en petits groupes comportant des exercices pratiques liés au thème du jour. Les petits groupes présentaient leurs conclusions lors d’une séance plénière le lendemain. Les principaux thèmes abordés étaient la disponibilité de données variées et les échelles de gestion, la productivité variable dans le temps et les considérations biologiques et écosystémiques sous-jacentes. Quatre principes primordiaux pour guider l’élaboration des PRL ont été examinés :

1. Cohérence avec l’objectif d’éviter des dommages graves
2. Meilleure information disponible
3. Utilité sur le plan opérationnel
4. Estimation fiable

Bien que ces discussions ne constitueront pas des conseils ou des directives scientifiques, l’information recueillie dans le présent compte rendu appuiera l’élaboration de lignes directrices scientifiques nationales pour l’élaboration des PRL et contribuera à la compréhension régionale de ce qui est requis pour les PRL conformément aux dispositions relatives aux stocks de poissons de la *Loi sur les pêches* révisée (L.R.C. [1985], ch. F-14).

ACRONYMS

B_0: unfished biomass

***B_{lim}*:** Common name for biomass limit reference point (Australia, ICES, NAFO)

***$B_{recover}$*:** Biomass from which the stock has "recovered" in the past

***B_{MSY}*:** Equilibrium biomass associated with F_{MSY}

COSEWIC: Committee on the Status of Endangered Wildlife in Canada

DFO: Fisheries and Oceans Canada

FAO: Food and Agriculture Organization of the United Nations

***$F_{40\%}$*:** fishing mortality associated with a reduction in spawning potential ratio of 40%

***F_{MSY}*:** fishing mortality associated with the production of maximum sustainable yield

FRDC: Fisheries Research Development Corporation (Australia)

HCR: Harvest control rule, referred to as a harvest decision rule in Canadian policy

ICES: International Council for the Exploration of the Sea

LRP: Limit reference point, based in biomass (DFO 2009)

MSY: Maximum sustainable yield (all jurisdictions)

MU: Management unit

NOG: National Operational Guidelines

PA Policy: Refers to Canada's national Precautionary Approach policy (DFO 2009)

RR: Removal reference (DFO 2009)

SFF: Sustainable Fisheries Framework (policy, Canada; DFO, 2018a)

SRR: Stock-recruitment relationship

SSB: Spawning stock biomass

TAC: Total allowable catch

Target: Target reference point, based in biomass or proxies

TEK: Traditional Ecological Knowledge

TESA: Technical Expertise in Stock Assessment

TRP: Target reference point (DFO 2009)

USR: Upper stock reference (DFO 2009)

WSP: Canada's Wild Salmon Policy (DFO 2005)

INTRODUCTION

PURPOSE

This report documents the Fisheries and Oceans Canada (DFO) workshop titled “Limit Reference Points and the Fish Stocks Provisions: Joint Technical Expertise in Stock Assessment (TESA) / National Operational Guidelines (NOG) Task Force Workshop” held virtually from 29 November - 3 December 2021. The TESA committee has had a mandate since 2009 to provide workshops and training related to fisheries stock assessment to DFO staff. The NOG Task Force, launched in 2020, is orchestrating the development of guidelines to support the Science sector in providing advice to implement the Fish Stocks Provisions (FSPs, Table 1). This workshop was chaired by Julie Marentette (NCR) and Tim Barrett (MAR), with technical support provided by Mary Thiess and Melissa Olmstead (NCR). A total of 70 participants, including staff from all DFO Regions and three external experts, attended the workshop (Appendix 1). The three externals were A.R. Kronlund (Interface Fisheries Consulting), the keynote presenter, as well as invited speakers Dr. Sean Cox (Landmark Fisheries Research) and Dr. Quang Huynh (Blue Matter Science).

The Terms of Reference and the Agenda for the workshop appear in Appendices 2 and 3, respectively. The motivation for holding the workshop was provided by amendments to the *Fisheries Act* (R.S.C., 1985, c. F-14) enacted when Bill C-68 received Royal Assent on 21 June 2019. The amendments include new FSPs (Table 1) that will apply to stocks that are prescribed by regulation, and as of December 2021 have not yet come into force.

Table 1: Text of the Fish Stocks provisions of Canada’s Fisheries Act in both English and French.

Fish Stocks **Measures to maintain fish stocks** **6.1 (1)** In the management of fisheries, the Minister shall implement measures to maintain major fish stocks at or above the level necessary to promote the sustainability of the stock, taking into account the biology of the fish and the environmental conditions affecting the stock. **Limit reference point** **2)** If the Minister is of the opinion that it is not feasible or appropriate, for cultural reasons or because of adverse socio-economic impacts, to implement the measures referred to in subsection (1), the Minister shall set a limit reference point and implement measures to maintain the fish stock above that point, taking into account the biology of the fish and the environmental conditions affecting the stock. **Publication of decision**	**Stocks de poissons** **Mesures pour maintenir les stocks de poissons** **6.1 (1)** Dans sa gestion des pêches, le ministre met en oeuvre des mesures pour maintenir les grands stocks de poissons au moins au niveau nécessaire pour favoriser la durabilité des stocks, en tenant compte de la biologie du poisson et des conditions du milieu qui touchent les stocks. **Point de référence limite** **(2)** S’il estime qu’il n’est pas possible ou qu’il n’est pas indiqué, en raison de facteurs culturels ou de répercussions socioéconomiques négatives, de mettre en oeuvre les mesures visées au paragraphe (1), le ministre établit un point de référence limite et met en oeuvre des mesures pour maintenir le stock de poissons au-dessus de ce point, en tenant compte de la biologie du poisson et des conditions du milieu qui touchent le stock. **Publication de la décision**

(3) If the Minister sets a limit reference point in accordance with subsection (2), he or she shall publish the decision to do so, within a reasonable time and with reasons, on the Internet site of the Department of Fisheries and Oceans.	**(3)** S'il établit un point de référence limite au titre du paragraphe (2), le ministre publie sa décision motivée, dans un délai raisonnable, sur le site Internet du ministère des Pêches et des Océans.
Plan to rebuild	**Plan de rétablissement**
6.2 (1) If a major fish stock has declined to or below its limit reference point, the Minister shall develop a plan to rebuild the stock above that point in the affected area, taking into account the biology of the fish and the environmental conditions affecting the stock, and implement it within the period provided for in the plan.	**6.2 (1)** Si un grand stock de poissons a diminué jusqu'au point de référence limite pour ce stock ou se situe sous cette limite, le ministre élabore un plan visant à rétablir le stock au-dessus de ce point de référence dans la zone touchée, en tenant compte de la biologie du poisson et des conditions du milieu qui touchent le stock, et met en oeuvre ce plan dans la période qui y est prévue.
Amendment	**Modification**
(2) If the Minister is of the opinion that such a plan could result in adverse socio-economic or cultural impacts, the Minister may amend the plan or the implementation period in order to mitigate those impacts while minimizing further decline of the fish stock**.**	**(2)** S'il estime que le plan pourrait entraîner des répercussions socioéconomiques ou culturelles négatives, le ministre peut le modifier ou en modifier la période de mise en oeuvre afin d'atténuer ces répercussions et de minimiser le déclin du stock de poissons**.**
Endangered or threatened species	**Espèce menacée ou en voie de disparition**
(3) Subsection (1) does not apply if the affected fish stock is an endangered species or a threatened species under the *Species at Risk Act* or if the implementation of international management measures by Canada does not permit it.	**(3)** Le paragraphe (1) ne s'applique pas si le stock de poissons touché est une espèce en voie de disparition ou une espèce menacée aux termes de la *Loi sur les espèces en péril* ou si la mise en oeuvre de mesures de gestion internationales par le Canada ne le permet pas.
Publication of decision	**Publication de la décision**
(4) If the Minister amends a plan in accordance with subsection (2) or decides not to make one in accordance with subsection (3), he or she shall publish the decision to do so, within a reasonable time and with reasons, on the Internet site of the Department of Fisheries and Oceans.	**(4)** S'il modifie le plan mis en oeuvre en vertu du paragraphe (2) ou décide de ne pas en élaborer un en application du paragraphe (3), le ministre publie, dans un délai raisonnable, sa décision motivée sur le site Internet du ministère des Pêches et des Océans.
Restoration measures	**Mesures de restauration**
(5) In the management of fisheries, if the Minister is of the opinion that the loss or degradation of the stock's fish habitat has contributed to the stock's decline, he or she shall take into account whether there are measures in place aimed at restoring that fish habitat.	**(5)** Dans sa gestion des pêches, s'il est d'avis que la perte ou la dégradation de l'habitat du poisson du stock concerné a joué un rôle dans le déclin du stock, le ministre tient compte de l'existence de mesures destinées à restaurer cet habitat.
Regulations	**Règlements**
6.3 The major fish stocks referred to in sections 6.1 and 6.2 are to be prescribed by regulations.	**6.3** Les grands stocks de poissons visés par les articles 6.1 et 6.2 sont prévus par règlement.

The *Fisheries Act* amendments introduce required:

- **Fisheries management objectives** for prescribed stocks
    - Maintaining stocks at or above the level necessary to promote sustainability of the stock (s 6.1(1))
    - Maintaining stocks above, or rebuilding above, limit reference points (LRPs) (ss 6.1(2), 6.2)
    - Mitigating adverse socio-economic and cultural impacts (ss 6.1(2), 6.2(2))
- **Means** by which to achieve those objectives
    - Implementing measures/rebuilding plans to achieve those objectives (ss 6.1, 6.2)
    - Setting an LRP (s 6.1(2))
- **Information** required to choose means/applicable provisions
    - Socio-economic and cultural impacts
    - Stock status relative to the LRP
- **Considerations** for decision-making
    - Biology of the fish and environmental conditions affecting the stock (ss 6.1(1), 6.1(2), 6.2(1))
    - Other legislation or agreements (s 6.2(3))
    - Other considerations that may be taken into account in the management of fisheries are also introduced in the Considerations provisions (s 2.5)
- **Process steps** for management
    - Prescribing stocks by regulation (s 6.3), which will include species names and geographic coordinates
    - Publishing decisions (ss 6.1(3), 6.2(3))

The wording creates a “one stock, one LRP” requirement for the Department to meet, such that for each stock prescribed to the FSPs, there must be one (and only one) LRP, and one designated stock status. This status determines whether s 6.1 or s 6.2 applies to the prescribed stock. The LRP is the only reference point mentioned in the FSPs, but it is not defined there. The LRP and the requirements of the FSPs are being interpreted through the lens of DFO’s (2009) Precautionary Approach (PA) Policy.

A CSAS Advisory Process, “Science advice on guidance for limit reference points under the Fish Stocks Provisions”, is scheduled for June 2022 with the aim of providing nationally applicable guidelines to meet the requirements of LRPs under the FSPs. Thus, the objectives of this workshop were:

1. To increase understanding and awareness of the requirements of the FSPs for Science, particularly with respect to LRPs and stock status;
2. To facilitate the sharing of knowledge and expertise on practical aspects of the process of (and some of the challenges associated with) selecting methods for identifying LRPs and estimating stock status, and;
3. To explore and/or recommend possible considerations for national operational guidelines for stock assessment experts in setting LRPs and estimating stock status in a range of situations.

WORKSHOP ORGANIZATION

The workshop was partitioned into

A. A **pre-workshop period**, that included a prerequisite survey examining candidate best practice criteria for LRPs (results of which are summarized Appendix 4) and pre-workshop LRP estimation exercises in both Excel and R, accompanied by an introductory presentation, that could be reviewed by participants in their own time in the four weeks before the live sessions began;

B. A series of **presentations** from external experts, regional and NCR DFO Science staff in the first portion of each day's live session, tackling or providing examples of different major themes or challenges faced by stock assessors in setting LRPs (Table 2), and;

C. Four **breakout group exercises** in the second part of each of the first four live sessions.

On the first and the final day of the workshop, the chairs introduced the workshop and summarized the discussions of the workshop participants, respectively. A.R. Kronlund provided both introductory and closing keynote addresses.

Six breakout groups, of up to eight participants each, undertook the four breakout exercises, with group composition changing each day. On the day following each exercise, breakout group leads presented a summary of their conclusions back to the full group for further discussion.

This report documents the proceedings of the workshop but is not intended to be a chronological record. Workshop organization and logistics were coordinated by Mary Thiess (NCR, TESA and NOG Coordinator) and Melissa Olmstead (NCR, FSP Education and Outreach). Meeting records are archived by the TESA committee and Breakout Group exercises can be found in a GitHub repository.

Public materials are available at:

Google Drive (for this workshop): Link

TESA GitHub (long-term code repository): Link

Table 2: List of presentations and presenters for the workshop.

Presentation Title	Presenters
The Fish Stocks Provisions, LRPs and You	Julie Marentette
Opening keynote talk: Pushing the Limits: Part 1 - LRP Lessons from Two Pacific Stocks	Rob Kronlund
LRPs in American Lobster: Precaution under Uncertainty	Adam Cook
The Art and Science of LRPs with a few examples from Canadian Fisheries	Sean Cox
Time Varying Reference Points	Daniel Duplisea
Accounting for parameter and structural uncertainty in stock assessment and MSE	Robyn Forrest and Sean Anderson
LRPs and Pacific Salmon	Carrie Holt

Visualizing reference points: Introduction to the Reference Point Calculator app	Quang Huynh
Closing keynote talk: Pushing the Limits: Part 2 - Can LRPs Sustain Fisheries?	Rob Kronlund

DISCUSSIONS

INTRODUCTORY REMARKS

The Fish Stocks Provisions, LRPs and You

Julie Marentette

The FSPs introduce a requirement to have one LRP and one stock status per prescribed major fish stock. Under DFO's PA Policy, the LRP fulfills several roles: it is a component of fisheries management objectives (it is a threshold to undesirable states of serious harm), management measures (it is often an operational control point for HCRs and when breached is a trigger for rebuilding plans), and metrics of stock status (it separates the Critical and Cautious zones). The LRP is also the only element of the PA that is set by DFO's Ecosystems and Oceans Science Sector (Science); all other elements are set by fisheries management informed by Science advice and other considerations. Other considerations include objectives pertaining to avoiding or rebuilding from states of serious harm, such as risks and timeframes, and which measures are chosen to achieve those objectives. The FSPs bring with them a renewed intensity of focus on LRPs and estimated stock status; in particular, a need to increase the number of stocks with LRPs/status to enable prescription, defensibility of choice after prescription, and to select LRPs and estimate status in ways that meet the "one stock, one LRP" requirement.

The FSPs have several implications for DFO's Ecosystems and Oceans Science Sector. For many stock assessment practitioners, meeting the "one stock, one LRP" requirement may not be a problem, even if management units do not align perfectly with the biological units to which they apply (and perfect alignment will be rare). However, as the scales of management, assessment and biology diverge, risks to stocks may increase, such as increased bias in reference points, misleading trends from indicators, risk of serial depletion, and from a science advice perspective, a reduced ability to apply "traditional" approaches to LRPs as thresholds to serious harm even if the overall harvest strategy is aimed to achieve PA intent. Many assessments also contain both "estimated status and trends" information as well as forward-looking advice to support the choice of management measures. Both forms of advice communicate information on stock status, but may not be available for every stock, may be emphasized differently across different paradigms, and may or may not change with different ways to account for "biology and environmental conditions" in decision-making (i.e., reference points versus measures).

Developing technical guidance to support DFO's Science Sector in providing advice to implement the FSPs will support the process of stock assessor choices, but not prescribe them. Guidance will aim to be flexible enough to apply to diverse situations for Canada's major fish stocks, but consistent with PA Policy and any FSPs policies to come. It will consist of three elements: basic principles or minimum criteria to meet, a technical "cookbook" of a range of options to meet those principles, and technical considerations such as pros, cons and caveats to help guide choices. There is a wide range of interconnecting circumstances to consider when operationalizing and reporting on an objective to avoid serious harm, including data, biology, management and assessment paradigms, the scale of the fishery, the management regime and environmental conditions facing the stock. The aim of the workshop was to touch on most of these considerations, even if they cannot be covered in depth in a single event.

The results of the prerequisite survey were reviewed (Appendix 4). The survey was designed to elicit input concerning what makes a “good” LRP or stock status indicator and to inspire thinking about reasons why one might choose a particular LRP or indicator. An overview of the breakout exercises was provided. The breakout exercises were based on a falsified data-set for a fictional stock (“Arctic Sardine”) and were designed to elicit LRP decisions under different circumstances, with an intent to capture feedback on how and why certain choices were made. Each exercise provided an incremental increase in data and/or information about the stock, and as such, the exercises moved from a data-limited scenario to increasingly data-rich scenarios. Feedback included information about which considerations mattered more than others, what was challenging and why, how rationales may have changed with new information or in different contexts, and how well decisions and rationale reflected candidate best practice criteria.

Candidate criteria for best-practice indicators and LRPs were as follows:

- Consistent with an objective to avoid serious harm to the stock
- Based on the best available information
- Operationally useful
- Reliably estimated

Discussion

Following the presentation, there was discussion highlighting the difficulties around operationalizing serious harm with respect to setting LRPs (i.e., serious harm can only be recognized once it has occurred, which goes against the PA Policy intent of setting LRPs above the level at which it occurs). Definitively finding the level at which serious harm is occurring for a stock would entail allowing the stock to decline to a level low enough that few would be comfortable (and rebuilding would be uncertain). It was noted that there are many perspectives from which serious harm can be defined, and consideration of scale is important (i.e., serious harm to population dynamics at the single species, demographic level versus serious harm to species function or performance at an ecosystem level). Presenters noted that further discussion and/or suggestions around this topic would be welcomed throughout the workshop.

OPENING KEYNOTE ADDRESS

<u>Pushing the Limits: Part 1 - Lessons from Two Pacific Stocks</u>
Rob Kronlund

Most fisheries jurisdictions rely on management by reference points to estimate stock status and inform decision-making on harvests. In Canada, a limit reference point (LRP) is imperative under the Fish Stocks Provisions (Section 6) of the *Fisheries Act*. Despite the common practice, management by reference points has been criticized because of the focus on status rather than harvest policy evaluation. An LRP implies the need to determine stock status and invokes specific management actions to rebuild the stock when below the limit. However, the theoretical basis for LRPs is relatively weaker than that for target reference points. In addition, current biomass (abundance) needed to determine status can be difficult to estimate. In Canada, the LRP is interpreted as a threshold to “serious harm” which is difficult to define and often only obvious once it has already occurred.

Claims of sustainable fisheries depend on the ability to adjust fishing pressure to appropriate levels rather than estimation of current abundance. Correspondingly, the search for management procedures that can be expected to achieve and maintain desired stock and fishery states is more important than status relative to LRPs. Sustainable fisheries depend on five elements: objectives for fishing pressure and abundance, monitoring of both, assessments to determine if objectives are being met, feedback management systems that adjust fishing pressure when it is too high, and enforcement systems. The most important elements are objectives and feedback management systems that establish a link between current management action and future stock response. In this talk I describe lessons learned from two Pacific stocks: Sablefish (*Anoplopoma fimbria*) and Pacific Herring (*Clupea pallasii*).

Sablefish has been managed under procedural control since 2011. A prescribed algorithm, or management procedure, applies a surplus production model to fishery landings and a fishery-independent trap gear abundance index and is coupled to a harvest control rule to compute a recommended catch limit. The choice of management procedure was guided by a set of five objectives, two of which embed the LRP of 40% of biomass at maximum sustainable yield (0.4 B_{MSY}). These two objectives establish constraints to (a) avoid spawning stock biomass (SSB) breaching the LRP over the long-term (36 years) with high probability (95%), and (b) decrease the tolerance for further stock decline from moderate (50%) at 0.8 B_{MSY} to high (5%) as SSB approaches the LRP, projected over a 10-year period.

For Sablefish, reference points including the LRP helped with a strategic choice of management procedure by eliminating bad options. More time was spent on objectives and evaluating performance than arguing about the LRP, which was based on fisheries policy. In fact, achieving a management system able to support claims of sustainability depended on two factors. First, a fully specified (but small) set of objectives, only some of which involve the LRP. Second, developing a feedback management system that adjusted fishing pressure in response to stock and fishery monitoring data. The LRP itself does not factor highly in annual Total Allowable Catch (TAC) discussions for Sablefish, even at the time when SSB was low because the management procedure did not require an annual status update to inform management choice.

Pacific Herring stocks have a long history of quantitative stock assessment and DFO had established a harvest control rule by 1986. Despite this history, three of five herring stocks declined to low abundance and experienced prolonged closures to commercial fisheries beginning in the mid-2000s. Reference points based on maximum sustainable yield (MSY) or proxies indicated that these stocks could be fished quite hard despite the empirical evidence to the contrary, making MSY-based and proxy reference points untenable choices for guiding the development of harvest strategies. Dynamic reference points also proved problematic for Pacific Herring because simulation experiments showed a progressive “ratcheting down” of the LRP to unacceptably low SSB. Instead, historical periods of persistent low biomass and low (including negative) surplus production were used to retrospectively diagnose conditions consistent with “serious harm”. This led to the establishment of 30% of the unfished equilibrium biomass as the LRP, 0.3 B_0, for all five stocks in 2017.

Experience with Pacific Herring supported the view that “serious harm” is hard to define and predict and is likely context specific. Diagnosing that serious harm may be occurring (or did occur) might rely on symptoms that are also hard to predict. Using the “rear view mirror” to retrospectively diagnose serious harm only works for depleted stocks; a situation to be avoided. The choice of LRP for Pacific Herring was not a theoretical quantity, rather it was based on retrospective evidence and guidance from international “best practices”. Because only three of five stocks showed persistent low biomass and low production periods, extending the choice of 0.3 B_0 to the remaining two stocks was not embraced by resource users, suggesting that arguments by analogy for LRPs might be challenging to implement. However, selecting an LRP for Pacific Herring, even if the current choice of 0.3 B_0 is later revised, allowed work on objectives and feedback management systems to proceed. Both are key steps to demonstrating sustainability.

Precaution in fisheries management does not come solely from the choice of reference points and practitioners should not attempt to inject precaution into their recommendations. Instead, precaution is derived from understanding how LRP choice interacts with the selection of risk tolerance and time frame used for evaluation of management outcomes. The “best” LRP can be compromised by poor specification of either risk tolerance or time frame. The opposite may also be true in that an ad hoc or pragmatic LRP choice could be successfully applied, provided risk tolerance and time frame are carefully chosen – the key is to evaluate and understand the expected consequences to management outcomes.

Discussion

Following the presentation, participants noted a key message: a “poor” choice of LRP can be offset by “good” management (i.e., ultimately, it is performance that matters, which can be achieved through reasonable choices around risk tolerance and time frame). As an example, suitably precautionary risk tolerance could be very important in cases where a proxy/provisional reference point is used. Presenters noted that it is often better to focus on assessing the consequences of particular choices (e.g., of LRP, of risk tolerance, etc.) rather than trying to make a “perfect” choice, recognizing that LRPs are often difficult to identify with certainty (given the previously noted challenge of identifying a level of serious harm before it occurs). Waiting for “perfect” information, or the ability to define the “best” reference point is likely not the best course of action.

Based on a participant’s question, the presenter discussed how the LRP for Pacific Sablefish did or did not factor into past TAC advice. It was noted that even during periods when the stock was thought to be near the LRP, management focus remained on controlling fishing pressure and assessing the strength of feedback control in the management system, rather than focusing on increasing the certainty of the stock’s proximity to the LRP.

The presenter was also asked about navigating the challenge of setting LRPs (a Science responsibility) when the choice of risk tolerance around the LRP was not entirely up to Science. The presenter reiterated that the focus should be on performance. Science should focus on simulating performance over various ranges of risk tolerance to help guide choices. It was further noted that keeping the species context in mind is also important (e.g., for long-lived species, it is very hard to reverse declines so best to try to avoid getting there to begin with).

Two questions tabled after the discussion had closed were parked for follow-up on the final day of the workshop (see the Risk Tolerance sub-section in “Day 5: Cross-cutting issues”).

DAY 1: DATA POVERTY AND SCALE MISMATCH

LRPs in American Lobster: Precaution under Uncertainty

Adam Cook

American Lobster are a culturally, socially and economically important resource in the Maritimes Region. This presentation provides contextual details around development of an LRP for American Lobster, including lobster biology, the fishery, and the associated management system. Considerations for LRP development are then identified and discussed, including the use of secondary indicators. This case study suggests that when faced with data limitations, practitioners should use the information available (and consider multiple indicators, where possible) to generate an initial LRP, as well as identify necessary steps to improve the LRP over time.

Discussion

Following the presentation, the importance of reporting secondary indicators in situations where status does not rely on fisheries-dependent data was discussed briefly. It was suggested that reporting on biological characteristics that can be tracked over time can be very useful, even if these types of indicators can’t be integrated into a broader population model. The presenter encouraged practitioners to use information available to them, make a plan to address deficiencies going forward, and recognize that improvements to reference points will occur over time—it is important to work with the information available. A participant also provided references to two papers that demonstrate how less quantitative indicators can be incorporated into management procedures (Dowling et al. 2015a and Dowling et al. 2015b).

The presenter was asked about the process or rationale for recognizing harvest control rules and reference points at scales smaller than the stock. It was identified that this outcome was the result of communities fighting for their local fisheries, and recognizing that the potential for localized depletion was a very important consideration for this species.

Discussions then moved to LRPs being associated with overfished states in many cases and questions about the possible impacts of constant effort in the lobster fishery over time. The presenter noted that predation pressure decreased with the decline of groundfish, while environmental conditions were improving, both supportive of increased productivity. It was noted that even if a $B_{recover}$-type LRP (where $B_{recover}$ is biomass from which the stock has “recovered” in the past) was used and suspected to be above a level of biological harm, it is still a state of stock biomass with many unknowns and little data that should be avoided.

Participants reiterated that ideally practitioners should do as much as possible with the information available. It should be acknowledged that community involvement is important, but the LRP is only one component of the full management system. The LRP should have scientific/biological justification (at the stock level rather than at the sub-stock), noting that the likelihood of localized depletion is a consideration that should be minimized. It was noted that by providing advice on smaller management scales, each stock is essentially a replicate with buffering in adjacent habitats to bring individuals back into an area that may be struggling, allowing replication of genetic units to support the broader population. The final comment was to reinforce that the LRP is not the single most important thing, but that it must be part of an overall management system that functions to meet objectives. It might be possible to consider the limit reference as a "function" rather than a "point", that includes different variables (e.g., in a weight-of-evidence type approach).

Breakout Exercise 1: Spatial Definition of a Stock & Data-limited Methods

Summary

Breakout Groups were asked to work through possible approaches to identifying an LRP for a fictitious data-limited "Arctic Sardine" stock, consisting of three Management Units (MUs). The data consisted of total catch (by MU), a relative index of benthic biomass (MUs 1 and 2) from a bottom trawl survey, a relative index of SSB (MUs 1 and 3) from an acoustic survey, and total catch and effort for the purse seine fleet in MU1. Some of the datasets were incomplete over the 50 year time series. Groups were asked to present their findings during the morning workshop plenary on Day 2, specifically describing:

- The spatial area chosen (MU1: the primary focus of data collection and reporting, or the entire stock: MUs 1, 2, and 3), along with the pros and cons of that choice
- The preferred stock status indicator, along with the pros and cons of that choice
- The preferred LRP and rationale for the choice
- Identify if the choice reflected any candidate best practice criteria
- Include a time series plot of the indicator and add a line to represent the LRP.
- Regardless of the spatial area chosen for the LRP, at which spatial scale would you recommend Arctic Sardine be prescribed (the entire stock or MU1 only) and why?

Background information, data files and an associated R script were provided to guide group deliberations (Appendix 5). At the start of Day 2, each Breakout Group presented a summary of their findings from the exercise. Some groups didn't have sufficient time to identify an LRP and other groups identified multiple candidate LRPs and didn't have enough time to narrow the options down to a single choice.

Table 3: The selected spatial area, indicator, LRP, and estimated stock status for Exercise 1 by group.

Group	**Choices** Spatial area Indicator LRP Status	**Comments**
1	MU1 Acoustic Survey Index No LRP (not enough time) No status	● MU with the most "complete" data set ● Assumed three biological stocks based on spawning site fidelity ● LRP - was looking for a spot in time series with stability and across multiple indicators: CPUE and the acoustic survey
2	Entire Stock Acoustic Survey Index $B_{recover}$ >LRP	● Used all MUs together as one biological stock ● Focused on the index that was most representative of the entire range (proportionality) ● LRP = mean of lowest 3 years of time series
3	MU1 Acoustic Survey Index Mean of B time series <LRP	● MU1 due to site fidelity and differing trends across MU time series ● Rationale: stock likely declined significantly prior to year 25, so entire period with data could be considered depleted with no evidence of recovery
	MU1 Acoustic Survey Index 50% max 3 observations (desired state) <LRP	● Rationale: beginning of the time period may be considered a desired state, with LRP at half that value
	MU1 Acoustic Survey Mean *B* (stability years 35-40) <LRP	● Rationale: relative stability in years 35-40 prior to further declines > year 45.
4	MU1 Acoustic Survey No LRP (not enough time) No status	● MU with the most "complete" data set ● Chose the acoustic survey because it had the lowest variation and covered the appropriate area ● Spent a lot of time trying to find another index to help with short acoustic time series (and its apparent lack of contrast) ● Considered incorporating one of the data sources to define the LRP
5	Entire Stock	● Chose the whole area as one stock due to

	Acoustic Survey Index (MU1 + MU3) 0.4 mean index over time period >LRP	mixed catches between areas; also maximized data used, some indication of representativeness for MU1 and 3 • Ruled out $B_{recover}$ and 20% B_0 because of their short time series; considered the mean of the acoustic survey as a proxy for B_{MSY} • Looked for consistency among indices (acoustic and button trawl)
6	MU1 Acoustic survey 0.4 B_{MSY} proxy (max in acoustic time series) >LRP	• Chose MU1 because it had the most data and also accounted for the majority of catch, but also recognized this meant discarding useful data in other areas • Rationale: maximum biomass as a proxy for B_{MSY}
	MU1 Model-estimated B or Acoustic survey 0.4 B_{MSY} <LRP	• Used JABBA to estimate B_{MSY} using package defaults and some guess work for priors • Rationale: policy default

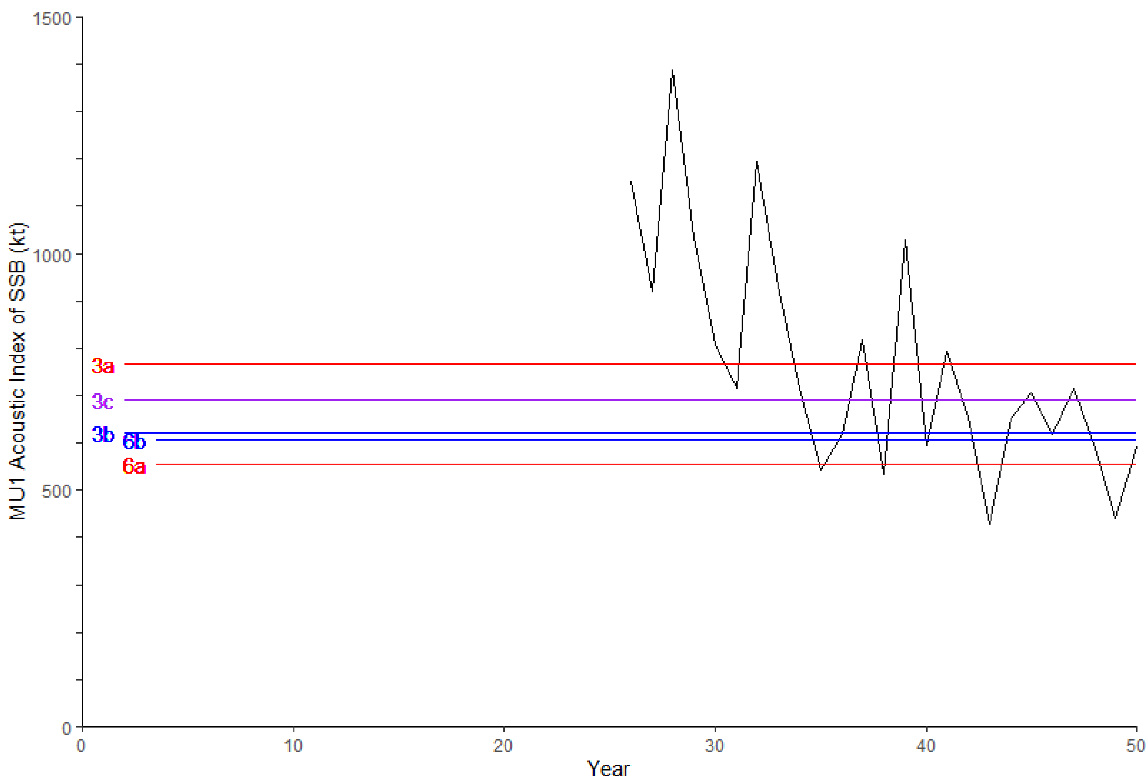

Figure 1: Time series plot for the acoustic index of SSB for MU1 with candidate LRPs for group 3 and 6 from Table 3.

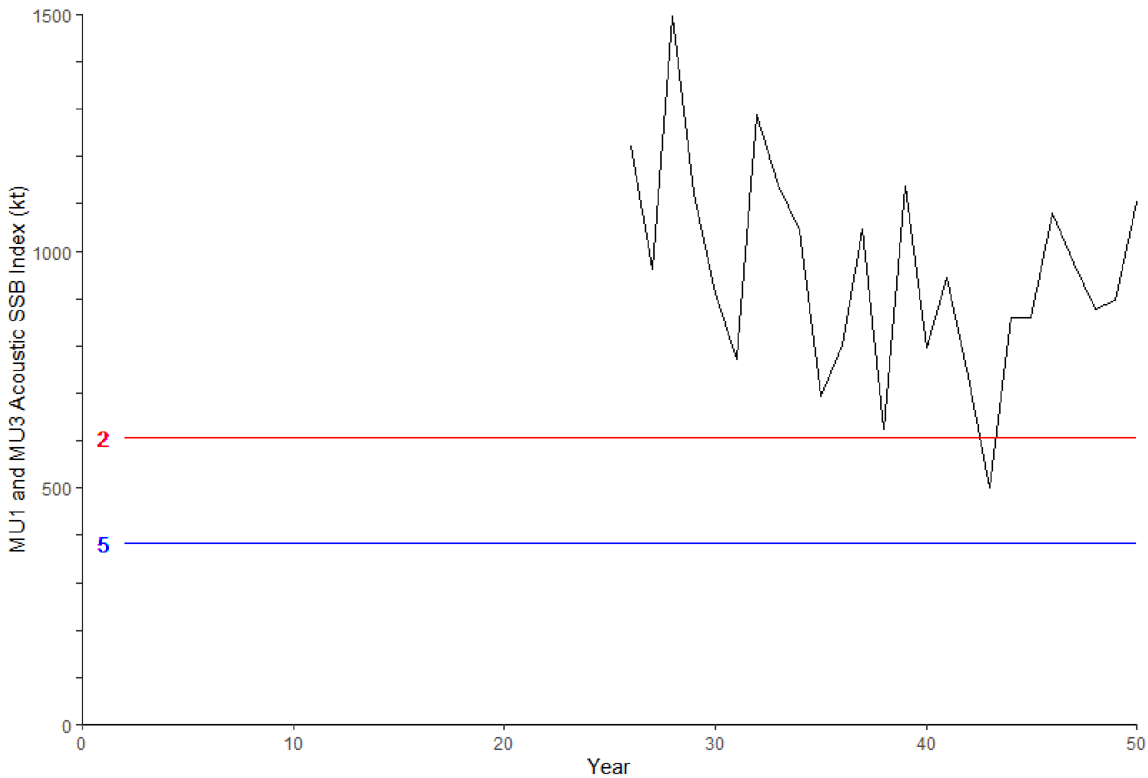

Figure 2: Time series plot for the acoustic index of SSB for MU1 and MU3 (representing the entire stock area) with candidate LRPs for group 2 and 5 from Table 3.

Discussion

Participants noted there was a risk of taking inappropriate management action if a single LRP was set for multiple components of the stock and if the components trended differently over time (e.g., if some showed increasing abundance trends while others were decreasing). Using a single LRP could also increase the risk of losing subpopulation structure. This was termed “scale mismatch of control”. A participant noted that a recent paper for Snow Crab in Newfoundland touched on this issue (Mullowney et al. 2020).

There was also recognition that the LRP would likely be most robust for MU1, where most of the catch originates.

A main challenge was trying to reconcile the management-assessment mismatch (management concentrated on one portion – i.e., one MU, while the LRP was intended to apply to the entire unit – i.e., all three MUs) and gauge the relative importance of conflicting information.

One group felt they were not able to make sound empirical decisions based on the data available, noting there wasn’t enough information to do a simple stock assessment like surplus production analysis or delayed difference model. Others questioned whether the example was actually data-poor given the variety of data sources available. It was difficult to identify among the conflicting signals across data sources which would be considered “best information”–recognizing that more data does not necessarily mean more information. A participant pointed out that this is a good example of the difficulty of identifying where serious harm is occurring; a downward trend in a survey time series does not automatically indicate serious harm.

Groups discussed the information provided by the CPUE time series. A series of diagrams from the 2013 ICES Annual Science Conference Plenary Keynote Lecture (Butterworth 2013) was shared to illustrate how changes in CPUE time series can be misinterpreted (due to underlying changes in fishery implementation, weather, etc.). It was also pointed out that the CPUE was from a purse seine fleet targeting a schooling fish which would likely not be proportional to biomass.

If given more time, groups wanted to investigate the signal from the bottom trawl survey further since it contradicted high catches in the earlier part of the time series. This highlighted the need to consider the appropriateness of a given type of survey for the species in question (e.g., whether bottom trawl surveys appropriate for assessing biomass of small pelagics).

Overall, there was some convergence on the idea that indicators need to be representative of the stock, which is part of the principle of being “consistent with an objective to avoid serious harm”, but there were differences in opinion of what a “stock” is or should be, which is central to the problem. Group discussions seemed to be relying on where the most quantity of data was available, what was most representative of the “stock” and concurrent consideration of what constituted the “stock” (tempered with differing opinions on the latter part, based on information provided about spawning behaviour and how “key” the stock was – i.e., would MUs 2 and 3 be considered “key” stocks?) There was some discussion about what was the best that could be done with the indicator, given the limited data available. Some participants also mentioned the concept of “operationally useful” since the indices provided were based on survey estimates that are generated every year.

A live poll was conducted at the end of the discussion to gauge participant’s view on a “best” approach given the points raised (Figure 3).

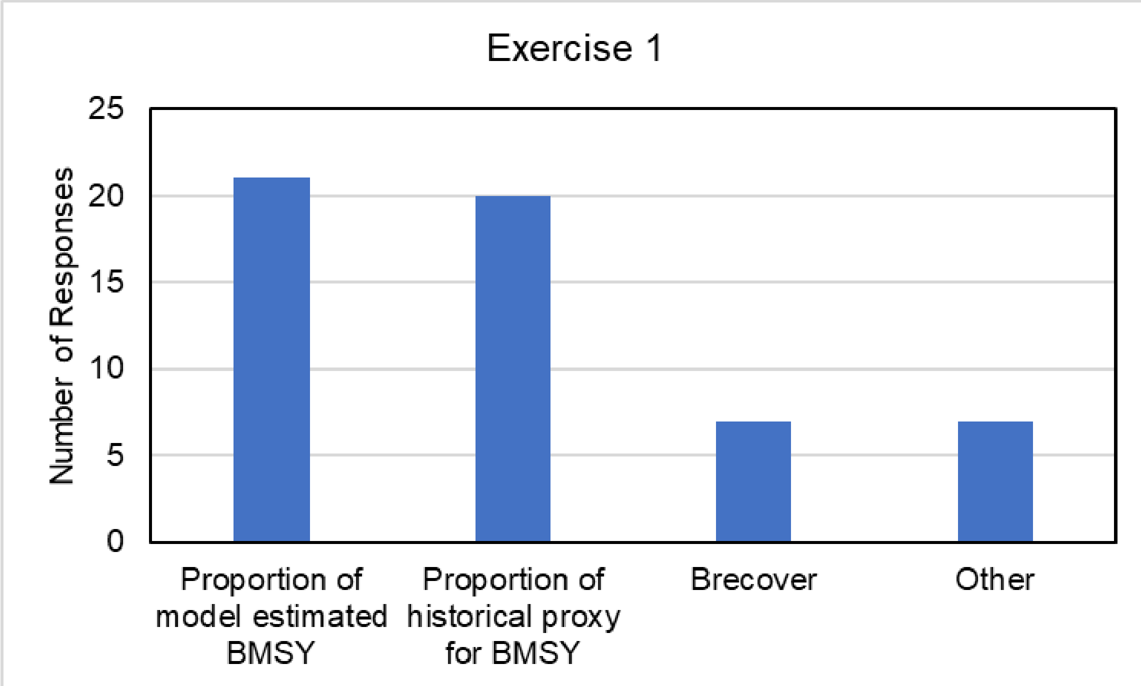

Figure 3: Poll for Exercise 1 - Based on these discussions, what is your preferred approach to defining an LRP for this stock?

DAY 2: DATA-RICH SCENARIOS

The art and science of limit reference points with a few examples from Canadian fisheries

Sean Cox

To date, no scientific theory has been identified for choosing a limit reference point (LRP) under compensatory stock dynamics. In most contexts, development of LRPs remains largely ad hoc and scientifically indefensible, leading people to revert to the art of "best practice". A notable exception exists for stocks such as Pacific Herring where depensation effects may be evident (though generally, depensation is rare and difficult to detect in fisheries). Even under moderate depensation, simulation-testing harvest strategies is critical to identifying LRPs. Progress on LRP development under compensatory stock dynamics should similarly focus on performance-testing harvest strategies and/or rebuilding plans to identify suitable LRPs that serve as both precautionary biomass levels to be avoided and minimum rebuilding targets for critically depleted stocks. Atlantic Halibut and Southern Bluefin Tuna are used to demonstrate the approach.

Discussion

Following the presentation, the presenter was asked for his thoughts on the relationship dynamics between natural mortality (*M*) and biomass-based reference points. For example, if *M* increases, leading to evidence of a decrease in productivity, biomass-based reference points also decrease–suggesting a lower LRP, but also a lower target harvest rate. Decreasing the LRP in this situation seems like a counterproductive response since “ratcheting down” reference points in response to decreasing productivity is not likely to be consistent with conservation objectives. It is recommended that the fishery-stock dynamic be considered as a whole when choosing reference points because both F_{MSY} and target F selected by fisheries management will be affected. As a general rule, the presenter suggested that practitioners do not use dynamic reference points, unless they are modeled as part of the dynamics and there is good reason to do so. The assessment model must reflect the known or believed population dynamics of the stock and must be fully documented.

Participants also questioned the ability to detect depensatory dynamics, suggesting that depensatory dynamics have been overlooked for a lot of stocks because of a focus on stock-recruit relationships. Cod-seal predation on Pacific Herring was given as an example. Discussions suggested that more research in the area of depensatory mortality is likely warranted. A follow-on discussion then took place about approaches in situations where depensatory dynamics are suspected. It was suggested that the LRP would not be impacted by depensatory dynamics, but that harvest control rules and target F should be adjusted to account for them. It was also noted that depensatory dynamics may emerge from multiple mechanisms, predation being only one form. Lack of forage fish was cited as an example of a different type of depensatory dynamic (e.g., lack of capelin for Northern Cod, Buren et al. 2014).

Finally, it was suggested that reference points can also be understood as a value resulting from a series of “reference functions", rather than thinking of them as simply fixed or time-varying. The previously mentioned case of cod-seal predation on Pacific Herring was identified as a good example of this concept.

Breakout Exercise 2: Data-rich methods (Arctic Sardine MU1***)***

Summary

Breakout Groups were asked to evaluate at least three approaches to defining an LRP for a data-rich stock (Arctic Sardine, MU1), and then identify a single “preferred” approach. The data consisted of estimated biomass, recruitment, and fishing mortality rate from an age-structured model and total catch over 50 years and an acoustic index of SSB over the later 25 years. Mean weight-at-age, maturity-at-age, and selectivity-at-age were provided to support reference point calculations and system dynamics were assumed to be at equilibrium (i.e., vital rates are assumed to be stationary). The groups were asked to report back on the following:

- Outline candidate approaches considered, and their pros/cons
- The preferred approach and rationale for choosing both the indicator and LRP (were any candidate “best practice” criteria used to make the choice? Are there any underlying assumptions?)
- How would advice be provided on whether the biomass was likely to breach or exceed the LRP in the short-term (e.g., next 2-3 years)?
- Recommend a status for the stock (above or below the LRP).
- Comment on how uncertainty in stock status was taken into account

Additional background information, data files and an R script were provided to support the group’s evaluation (Appendix 5).

At the start of Day 3, each Breakout Group presented a summary of their findings from the exercise (Table 4, Figures 4-5).

Table 4:Candidate LRPs and preferred approach for estimating stock status for Exercise 2 by group.

Group	Candidate LRPs	Preferred Approach, Stock Status, and Rationale
1	$B_{recover}$ 0.2 B_0 0.4 B_{MSY}	$B_{\underline{recover}}$ (year 20) Stock > LRP Rationale: choice was independent of stock-recruit relationship and therefore there was unanimous discomfort with it, close to 0.2 B_0, meets 3 of the 4 best practice criteria, but don't know if it meets the requirement to be consistent with avoiding serious harm
2	$B_{F40\%}$, $B_{F50\%}$ 0.3 B_0 0.4 B_{MSY}	**a) $B_{F40\%}$, b) $B_{F50\%}$** Stock < LRP Rationale: avoid knot of medium biomass and low productivity (serious harm) to avoid low biomass/low productivity (See Figure 5). Note, used SPiCT (Pedersen and Berg 2017) to investigate candidate LRPs.
3	$B_{recover}$ 50% median *B* (yrs 25-50) $B_{40\%SPR}$ 0.2 B_0 0.4 B_{MSY}	**Average across all 5** Stock > LRP Rationale: models with different assumptions gave similar results; hard to reconcile appropriateness of different assumptions
4	$B_{recover}$ 0.1-0.2 B_0 0.4-0.5 B_{MSY}	$B_{\underline{recover}}$ (year 8) Stock > LRP Rationale: consistent with others evaluated, easy to communicate
5	$B_{recover}$ Empirical % B_{MSY} % B_0 SRR	$B_{\underline{recover}}$ (years 19-24) Stock < LRP Rationale: chose more precautionary LRP because productivity is declining,
6	0.2 B_0 0.4 B_{MSY} *B* at 50% R_{max} $B_{recover}$	**Average across all 4** Stock > LRP Rationale: No clear best/worst candidate

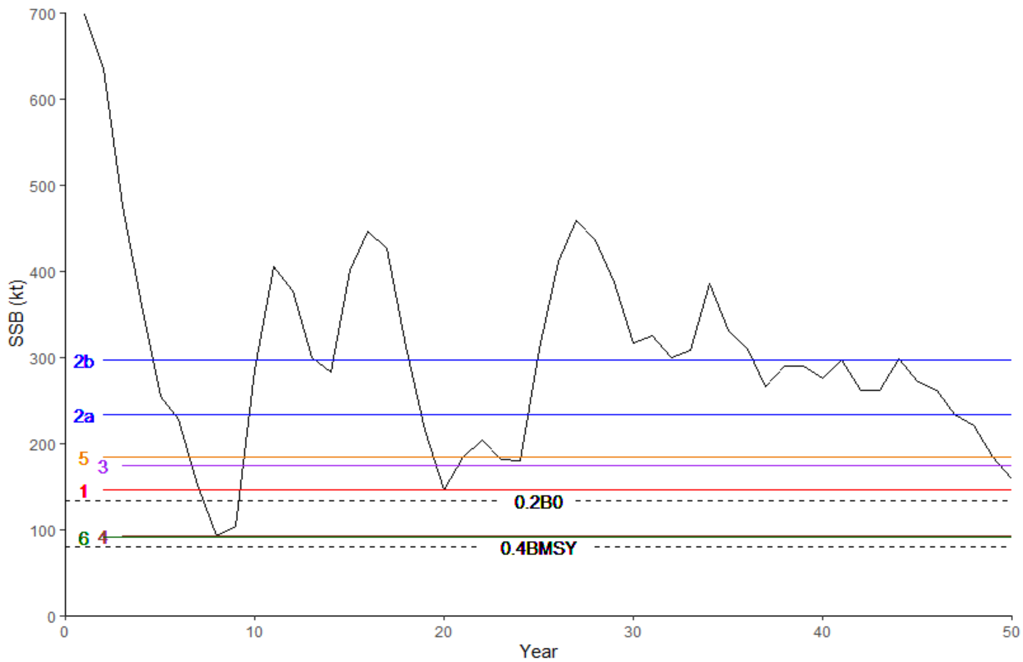

Figure 4: Time series plot of model estimated SSB for MU1 with candidate LRPs for each group (from Table 4) and dashed lines showing 0.2 B_0 and 0.4 B_{MSY}.

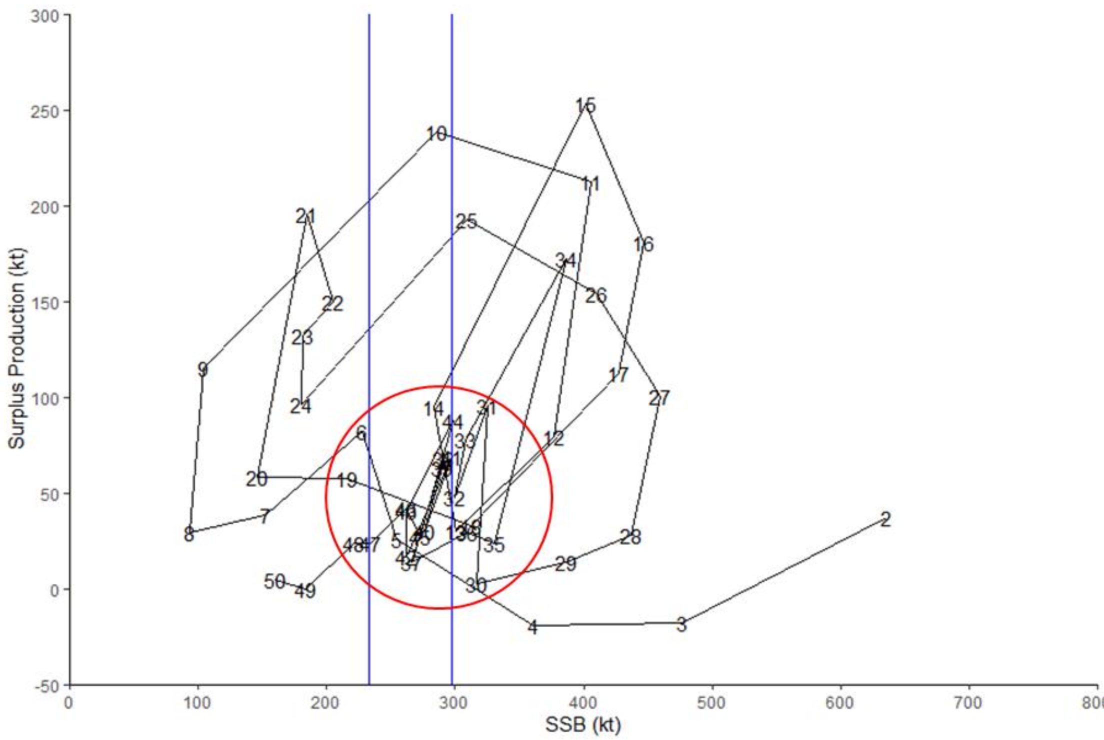

Figure 5: Phase plot of surplus production vs. SSB for MU1 with labels of year (2 to 50), vertical reference lines at $B_{F40\%SPR}$, $B_{F50\%SPR}$, and a knot of medium biomass and low productivity identified by group 2 circled in red.

Discussion

Although it was identified by two of the groups, averaging across methods has not been implemented in Canadian practice to date. There was variability in the application of $B_{recover}$ with one interpretation being twice as high as another (group 4 and group 5; Figure 4). There was little discussion of the choice of proportion of B_0 or B_{MSY} (i.e., 0.2, 0.4 or some other proportion). The equilibrium biomass at $F_{40\%SPR}$ and $F_{50\%SPR}$ were proposed as LRPs but it was pointed out during the discussion that $F_{40\%SPR}$ is commonly used as a proxy for B_{MSY}, so the equilibrium biomass at $F_{40\%SPR}$ would be a proxy for B_{MSY}, and a proportion of this may be considered a candidate LRP.

The lack of a relationship in the stock-recruit data was noted and a lack of data at very low biomass makes it difficult to estimate the SRR. A participant commented on the choice of $B_{recover}$ vs. SRR pattern: $B_{recover}$ depends on several choices, none of which can capture uncertainty and how it propagates into the future. A SRR can be better used in forward looking advice. The lack of a relationship in the stock-recruit data doesn't need to be an argument not to use it. Regardless of steepness, the recruitment is fairly flat (i.e., on average, recruitment is fairly stable). The choice not to use the SRR for one group was due to the lack of observations at low biomass which provides no information on a threshold for serious harm.

Some general comments on reference points were made near the end of the discussion. The concept of serious harm is elusive and when the stock is below or approaching the LRP, the question becomes 'what are we going to do about it?'. A lot of time can be spent on LRP choice but once the LRP is defined, is the management system going to respond? The issue is having a management system that doesn't respond fast enough and *F* isn't reduced and SSB declines and you end up with depensatory *F*.

It was noted that uncertainty should be captured in LRPs and estimates of stock status. Care should be taken to explain choices and an absolute number should not be used as an LRP, rather the approach or definition of the LRP should be defined since the estimate of the LRP will change with new data/models.

A live poll was conducted at the end of the discussion to gauge participant's view on a "best" approach given the points raised (Figure 6).

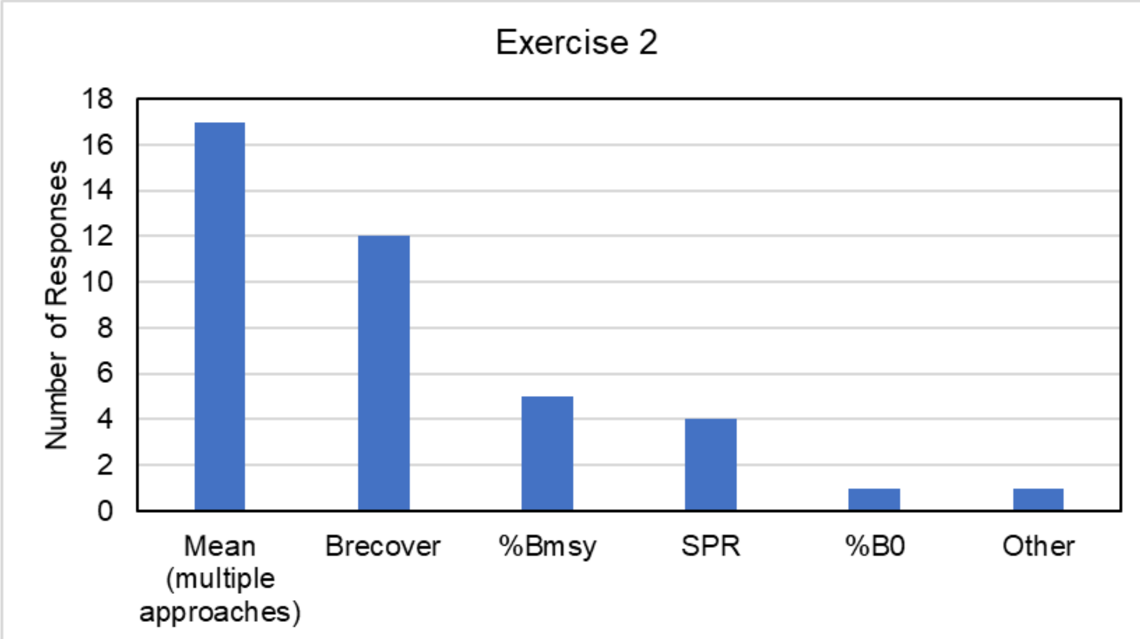

Figure 6: Poll for Exercise 2 - Based on these discussions, what is your preferred approach to selecting an LRP for this stock? SPR = spawning potential ratio, based on $B_{F40\%}$ or $B_{F50\%}$.

DAY 3: NON-STATIONARITY

Time Varying Reference Points

Dan Duplisea

The precautionary approach (PA) is the fisheries operationalization of the precautionary principle. A PA should also have defined risk tolerance levels for not achieving stock health objectives. As such, biomass reference points are components of the PA that embody consequences for stock health and the harvest strategy for *F* tells you how to achieve/avoid them. But, what if the PA consequence and action framework is not constant over time (i.e., what if the stock productivity changes over time?). The recommended management response to time-varying productivity depends on the type of variation observed. For example, random variation does not require special considerations beyond robust risk evaluation and management, while non-random (or non-stationary) variation (i.e., time series that display trend over time) requires special consideration. Static reference points will not adequately account for the change in consequence, leading to a management scheme that is mismatched to the stock, even on average. Links between changes in productivity and biomass/production are explored along with in-depth review of four common types of productivity non-stationarity hypotheses (regimes, cyclic, drifting, Allee effects/predator pits). A two-tier approach to providing advice around time-varying reference points may be useful: update assessments regularly and simulation-test assumptions to identify approaches that are robust to productivity changes, and use structured decision making (Resist-Accept-Direct Framework; National Park Service 2022) to communicate potential influence of predominant external drivers. An overview of the findings from several workshops was provided, including a 2011 DFO workshop (DFO 2013), ICES' workshop WKRPCHANGE 2020 (ICES 2021), and the Ocean Frontier Institute workshop in 2021 (Zhang et al. 2021).

In closing, a series of recommended practices (based on current advice) is proposed:

- Don't wait, do something now and practice adaptive management (RAD)
- Following a formalized process of pathways and changes is required in management and scientific evaluation; we should practice adaptive management
- Consider that stock ID may have changed, which can affect basic input data and can bias analysis
- Consider the mechanisms behind the changes and not just that change appears to have occurred
- Change *F* before you change the biomass reference points
- Develop a process to adjust harvest control rules with productivity and then biomass reference points may not require change
- Clear risk-based evaluations and management should be used
- Simulation-test proposed changes

The new Fish Stocks Provisions provide not only license to consider impacts of changing productivity but also highlights the need to routinely incorporate it as part of the assessment process, including subsequent impacts on *F*-strategies, reference points and advice.

Discussion

There was limited discussion following this presentation. A participant asked about combining multiple approaches, specifically if there were any real life examples using reference points derived from several quantities (i.e., not just biomass). This was not discussed by the group.

A discussion point was also raised in the live chat: The PA policy states that time-varying reference points should only be considered when there is enough evidence that changes are not reversible naturally or through management (not exact wording). This seems like an extremely high bar. Does the group have any insight/opinion about tackling that requirement? This point was not discussed by the group, but a second participant agreed in the chat that the bar [was] being [set] extremely high, and expressed similar concerns. Capelin in Newfoundland and Labrador was given as an example, having been in a collapsed state for 30 years but having insufficient evidence that it is not reversible to institute time-varying reference points.

A participant pointed out that North Pacific Albacore has a dynamic B_0, fluctuating depending on changes in recruitment, as one of the leading candidate LRPs (ISC 2021).

<u>Breakout Exercise 3: Time-varying productivity (Arctic Sardine MU1)</u>

Summary

Breakout Groups were asked to identify ways to define an LRP for Arctic Sardine MU1 in a data-rich context with time-varying productivity. Temporal changes in weight-at-age, maturity-at-age, and recruitment appear in the time series of data. The focus of the exercise and discussion was on identifying a time period to use for biological parameters and recruitment in the reference point calculations and the suitability of equilibrium reference points (over some time period) or reference points based on a fully dynamic (changing annually) B_0. Additional background information, data files and an R script were provided to support the group's deliberations. See Appendix 5 for details of the exercise.

Table 5: Candidate LRPs and preferred approach for estimating stock status for Exercise 2 by group.

Group	LRP	Time Period	Rationale:
1	0.4 B_{MSY}	Regime shift defined after year 30: Years 31-50 (weight-at-age, maturity at age). Recruitment based on SRR.	Uncomfortable with annual dynamic B_{MSY}; trade-off between accounting for shift and stationarity
2	1.X $B_{recover}$	$B_{recover}$ from second dip in time series (years 20-24) and selected to be year 22.	Easy to explain/calculate; stock has recovered – but this may protect against changing conditions; A multiplier of 1.X (e.g., 1.2) was considered to account for shift in productivity.
3	a) 0.2 B_0	Estimated using SSB-per-recruit from the first 5 years.	Choice of SSB-per-recruit averaged over the first 5 years or last 10 years depends on the assumption about if changes in weight at age are due to fishing and are reversible (then use first 5 years) or environmental drivers which may not be reversible (then use last 10 years, i.e., current conditions). Dynamic B_0 was not considered as the trends were driven largely by recruitment events.
	b) 0.4 B_{MSY}		
	c) 0.2 B_0	Estimated using SSB-per-recruit from the last 10 years.	
	d) 0.4 B_{MSY}		
4	0.4 $B_{F40\%SPR}$	Breakpoint in productivity defined after year 25.	Drift in SSB-per-recruit, weight-at-age, maturity-at-age.
5	0.4 B_{MSY}	Estimated using SSB-per-recruit from the last 10 years.	Reflects current environmental conditions
6	a) $B_{recover}$	$B_{recover}$ from second dip (year 20)	Coherence in overlap between the 3 options
	b) Static 0.2 B_0	Static 0.2 B_0 (entire time series)	
	c) Dynamic 0.2 B_0	Dynamic 0.2 B_0 (using mean recruitment, annual SSB-per-recruit)	

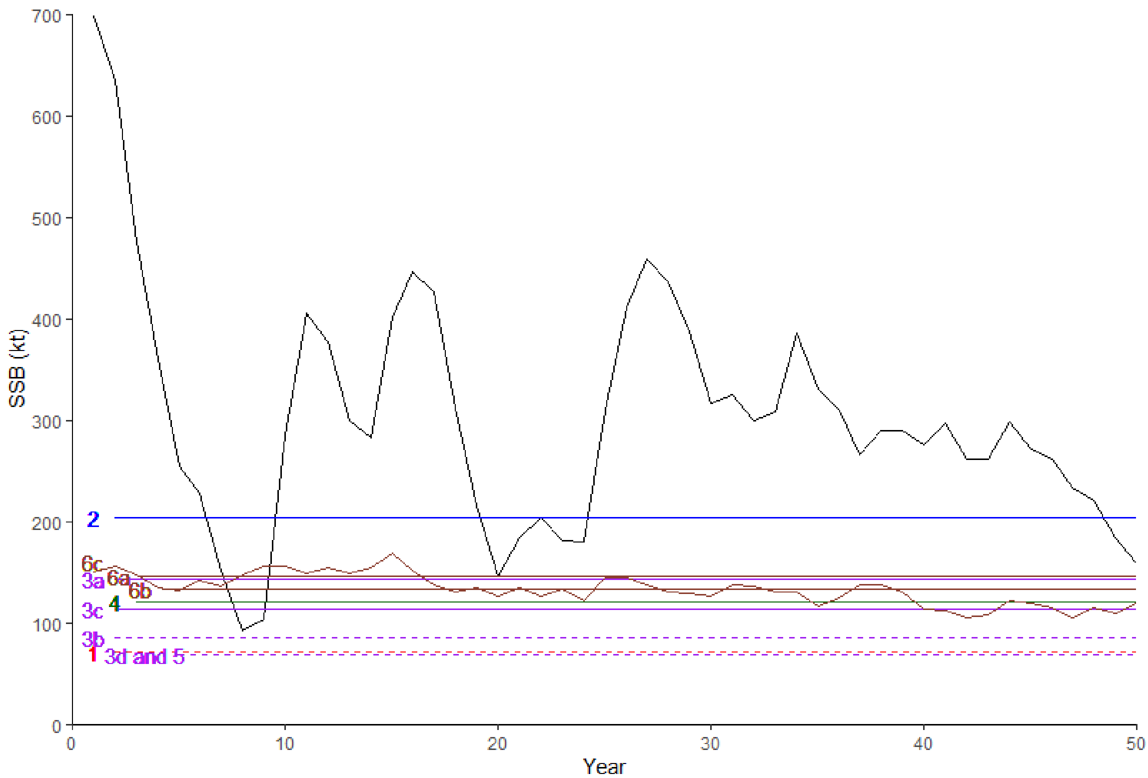

Figure 7: Time series plot of model estimated SSB for MU1 with candidate LRPs for each group from Table 5. MSY-based LRPs are plotted with dashed lines.

Discussion

Most groups focused on choosing between a static (equilibrium assumptions over some time period) or dynamic (annual time-varying) LRP in terms of B_0 or B_{MSY} and didn't specifically focus on the basis of the LRP (e.g., $B_{recover}$ vs. B_0 vs. B_{MSY} vs. SPR approach) since that was addressed in Exercise 2 (Table 5, Figure 7). There was a general consensus of the workshop participants that a fully dynamic (i.e., annual time-varying SSB-per-recruit and annual recruitment deviations) estimate of B_0 was not appropriate for an LRP and the volatility of the dynamic B_0 was not useful for providing management advice (e.g., high recruitment increases the LRP and low recruitment decreases the LRP). It was noted that a dynamic B_0 changes the risk perception over time and can lead to accepting a lower stock size in lower productivity periods. A participant noted that most of the literature on dynamic reference points has been related to reference points as operational control points rather than LRPs used to inform stock status.

A participant suggested that when productivity varies over time, *F* should be adjusted and the biomass-based LRP should not change. Participants identified that reversibility of the observed changes is an important consideration (e.g., fishery-based changes are considered reversible and ecosystem-based changes are considered irreversible) when deciding whether a regime-type change in productivity had occurred.

A participant noted that some of the LRP choices in the first three exercises were made in spirit of being more precautionary, but that effect can also be created through choice of risk tolerance and time frame which may be a more appropriate spot for that concept.

DAY 4: UNCERTAINTY AND OTHER PARADIGMS

Accounting for parameter and structural uncertainty in stock assessment and management strategy evaluation

Robyn Forrest and Sean Anderson

Reference points and uncertainty in stock assessment

We began by reviewing multiple roles of reference points in stock assessment and types of uncertainty present in stock assessment models. Roles for reference points include (1) components of objectives in stock assessments, (2) components of objectives in management strategy evaluation (MSE), and (3) components of operational control points in harvest control rules. Types of uncertainty in stock assessment models include parameter uncertainty and structural uncertainty. Parameter uncertainty represents uncertainty in the values of estimated model parameters arising from observation and process uncertainty. Structural uncertainty represents uncertainty arising from assumptions about the form of relationships in a model. Examples of structural uncertainty include decisions about the form of the stock-recruit relationship; selectivity-at-age or -length function; whether key parameters such as natural mortality are fixed, estimated or vary through time; and whether and how environmental covariates drive productivity.

Sensitivity analyses can be used to explore the consequences of uncertainty from alternative structural assumptions on model outputs and advice. A challenge is then how to incorporate multiple sensitivity analyses into advice. One option is to present sensitivity analyses separately, but this can create a complex decision-making environment and often requires a narrative to choose a best or most plausible model. Alternatively, multiple analyses can be combined in an ensemble.

Ensemble approaches in stock assessment

An ensemble approach is any method of combining inference for quantities of interest across multiple models (e.g., Anderson et al. 2017, Jardim et al. 2021). In stock assessment, those quantities of interest might be a reference point or stock status with respect to a reference point. An ensemble can combine models with, for example, alternative structural assumptions, distinct modeling platforms, parameters fixed at different values, or models with alternative priors. Any models that produce the same quantity of interest can be combined in an ensemble unless the ensemble relies on statistical weighting (e.g., AIC, Bayes factors), in which case the same statistical framework needs to be used.

When ensembling models, a decision has to be made about how to assign weights to the component models. Options include one model getting all the weight (model selection), equal weighting, tactical weighting (e.g., expert opinion, historical performance), model probabilities (e.g., Bayes factors), information theoretic values (e.g., AIC), or predictive ability. An additional more complex form of weighting by a 2nd-level model fit to known or trusted data is also possible (‘superensembles’, Anderson et al. 2017). Importantly, model selection can be thought of as an extreme version of ensemble modeling where one model is assigned all the weight (Jardim et al. 2021).

We provided several examples of various kinds of ensemble weighting in stock assessment. Assessments for Pacific Hake (Stewart et al. 2011) and Pacific Cod (Forrest et al. 2020) used equal weighting of parameter posteriors. Several other recent Pacific Canadian groundfish assessments have used equal-weight ensembles. Rossi et al. (2019) provides examples of weighting by predictive ability or information criteria for Georges Bank Atlantic Cod models. Maunder et al. (2020) provides an example of applying tactical weighting for Pacific Ocean Bigeye Tuna assessment models.

Assuming an ensemble is formed from a set of well-fitting plausible models, issues of model composition include too little overlap among models, too much overlap among models, or some combination of the two ('clumping' among models). With too little overlap, there is a risk of obscuring distinct plausible realities that would require alternative management actions—the best answer isn't necessarily in the middle (e.g., Anderson et al. 2017, Maunder et al. 2020). Solutions could include subgroup ensembles or not using ensembles at all. With too much overlap, the benefit of using an ensemble approach may be reduced since the component models may not be representing a sufficient diversity of structural assumptions. This may or may not be an issue; however, if it occurs within groups of models, it can result in undesired unequal weighting among broader hypotheses. Solutions include refining the composition based on broader hypotheses or considering a hierarchical framework to group hypotheses and assign weights (e.g., Maunder et al. 2020). An additional solution may involve clustering algorithms to group hypotheses.

We concluded this section with practical advice on ensembles. (1) Separate ensemble composition decisions from results if at all possible. (2) Do not use ensembles as an excuse to avoid rigorous model validation. (3) Consider models that can expand or simplify based on the data—e.g., estimating effects as random effects or letting parameters vary according to some constrained function. (4) Agreeing on tactical weights can be challenging in practice. (5) In MSE, do *not* post hoc ensemble management procedures (MPs) without testing the ensemble approach—the ensemble is then a new MP itself. (6) Consider whether ensembles obscure important information and if decision making might be more straightforward maintaining multiple distinct models.

Accounting for uncertainty in MSE

The goal of MSE is to identify MPs that meet the stated objectives across major sources of uncertainty. In MSE, structural and parameter uncertainty is built into the operating models (OMs). Best practice recommends developing both a reference and robustness set of OMs (Punt et al. 2016). The reference set represents the most important uncertainties thought to impact the performance of MPs (e.g., natural mortality, steepness, depletion, selectivity). The robustness set represents less plausible but potentially important uncertainties (e.g., predator-prey scenarios, alternative catch histories, time-varying selectivity, spatial scenarios, time-varying parameters). We demonstrated a number of graphical methods for presenting results from multiple MSE OMs drawing largely on Forrest et al. (2018) and Anderson et al. (2021).

We concluded that there are numerous ways to account for uncertainty in stock assessments and MSE. Sensitivity analyses are an important approach to explore the impacts of structural uncertainty. A variety of approaches are available to present sensitivity results separately or to combine results in ensembles; assessment scientists need to be careful not to bury important details in averaged results. How to present uncertainty within and across assessment models may take several iterations with colleagues, managers, stakeholders, and other partners to decide on the best format.

Discussion

Following the presentation, a participant had several questions:

1. What should practitioners do in situations where the LRP is not model-derived or pre-determined (i.e., the LRP has been fixed at a particular value)?
    - This situation is challenging. Ideally, the LRP will be model-derived.
2. What should practitioners do in situations where an ensemble model uses different data sources? Could you use AIC-type approaches to generate weights for models to contribute to the ensemble?
    - Cross-validation approaches are probably best for identifying the optimized form of ensemble model.
    - AIC cannot be used to compare models with different data sources.
3. Who chooses the reference sets versus the robustness sets?
    - Ideally, this selection will be done in collaboration with partners and stakeholders, through some form of consensus process. See Rademeyer et al. 2007 for some suggestions.

Another participant noted the difficulties of reporting the results of a management strategy evaluation (MSE) through the PA framework, noting the increasing desire to shift focus away from status and reference points to assessing the adequacy of a management system to meet its objectives (i.e., MSE results showing there is a high likelihood of achieving stated objectives within desired timelines).

Finally, a participant recalled an earlier comment that there is the potential to lose the benefits of ensemble models if the contributing models have too much/not enough overlap (as an example), and wondered if there were any general conditions to be cautioned against. In answer, it was noted that having models to choose from was a "good" problem to have. Practitioners need to ensure the full range of states of nature/plausible scenarios have been explored, rather than settling on a group of similar models. Further, taking time to ensure datasets are aligned, assumptions are clear, etc. can lead to forgoing use of ensemble models.

Breakout Exercise 4: Stock status in stock assessment paradigms with multiple hypotheses (Arctic Sardine MU1)

Summary

Breakout Groups were asked to identify ways to define a single metric of stock status for Arctic Sardine MU1 in a data-rich context when there is more than one model that provides an acceptable characterization of the stock's population dynamics and that may not provide similar results (i.e., they may suggest different status assignments for the stock). In this exercise there are two different assumptions for the historical equilibrium catch (4 kt vs. 80 kt) due to the uncertainty in removals from international fleets. Additional background information, data files and an R script were provided to support the group's deliberations. See Appendix 5 for details of the exercise.

Table 6: Candidate LRPs and preferred approach for estimating stock status for Exercise 2 by group.

Group	Approach	Comments
1	Model Average (equal weight)	Chose the ensemble model under the assumption that each hypothesis was equally plausible.
2	Single Model	Looked at historical catches compared to the catches at the start of the time series. Decided to go with SSB from model 2 with the main idea that the LRP was slightly higher which could account for some uncertainty. Also decreasing trend at the end of the time series warranted more precaution.
3	Model Average (equal weight)	No information provided to suggest unequal weights.
4	Need more information. Decision tree to choose.	Couldn't determine plausibility of one model vs. the other given the information provided. A decision tree for steps to take to choose a model. Q1: Is one model more plausible? Yes - LRP from that model No: Q2: Is the status the same for both models? Yes - pick a model (weighted average or based on expert judgement) No: average across both models.
5	Model Average (equal weight)	One model wouldn't allow dealing with structural uncertainty. Model averaging accounts for more uncertainty and is explicit about hypotheses for the system (useful when there are conflicting views). Model averaging was preferred approach. Having confidence intervals might have helped determine a weighting scheme.
6	Model Average (equal weight)	Looked at plots to see which one might be more conservative. Decided to go with average, however discussed the idea of whether we should be considering how conservative LRPs should be. One thought was to set them as appropriately as necessary, outside of management actions. Another thought was that LRPs should work in tandem with manager risk tolerance. Also considered that some fisheries are riskier than others. LRPs in this scenario are centered around harm to the stock, but that might occur at lower levels of biomass compared to harm to the ecosystem. As the ecosystem changes, does our LRP change, e.g., increasing marine mammal predation on fish stocks.

Discussion

The discussion focused on two options (single model and model average) of selecting an LRP (Table 6). No other options (e.g., empirical LRP based on the acoustic index) were proposed. It was noted that when using model averaging, the uncertainty around the models should be propagated in a visual way for simple, straightforward advice so that managers can make informed choices about their risk tolerance.

There was some discussion on the role of a small pelagic fish in the ecosystem and Sainsbury's text about best practices around setting LRPs for forage fish (Sainsbury 2008). There are other ways to account for environmental considerations outside of reference point approaches. For example, scorecards are being used in Alaska and sets of environmental indicators to let you know in which direction things are going.

A participant asked what can be learned from stocks that have collapsed and fisheries have closed. An invited expert noted that stock collapses are not generally a result of poor science. In the example of cod, it was becoming clear that something was going on and scientists recommended precaution that was not followed. Another participant noted a paper by Jeff Hutchings on the topic (Hutchings et al. 1997).

A participant asked about stock declines related to changes in the ecosystem (e.g., natural mortality) and not direct changes due to fishing. An invited expert noted that natural mortality from a single stock perspective is not necessarily under our control. The objective of LRPs in a management framework is that even though it may not be the fault of management that the stock is doing poorly, management still has a duty to do what they can to mitigate declines. An invited expert commented that it can be a slippery slope to try to second guess what the management decisions will be. Tools to communicate implications to management can help. If there are concerns about how advice will be used, one can strive for clarity in the advice to help management make informed decisions. A participant noted the importance of differentiating between precaution in action and precaution in scientific uncertainty.

DAY 5: CROSS-CUTTING ISSUES

<u>LRPs and Pacific Salmon</u>

Carrie Holt

Limit reference points (LRPs) are required for major fish stocks or Stock Management Units, SMUs for Pacific salmon prescribed by regulation under amendments to the Canadian *Fisheries Act*. Pacific salmon are unique among marine fish stocks due to their semelparous and anadromous life history and significant meta-population structure which results in differences in data availability and modeling approaches for assessments and LRP development. We identified principles for developing LRPs, adapted from those used for LRPs more broadly among marine species. One key principle unique to Pacific salmon is that LRPs should be aligned with Canada's Wild Salmon Policy (WSP) objective of preserving biodiversity of salmon at the scale of conservation units (CUs) which are often nested within SMUs. We identify a toolkit of LRP methods and provide guidance on how to implement them. In particular, we propose two types of LRPs based on either the proportion of CUs that have status above the 'red' zone for WSP status assessments, or aggregate-abundances to the entire SMU. 'Red' CU status is associated with elevated probabilities of extinction by COSEWIC. Aggregate abundance-based LRPs are identified at levels which have a desired probability of all component CUs being above the 'Red' zone. We identify uncertainties associated with each approach, and describe how they can be applied across a range of data types, qualities and quantities. Collaborators: Carrie Holt, Kendra Holt, Luke Warkentin, and Catarina Wor.

Discussion

There was limited discussion following this presentation. A participant commended the presenter on the innovative approach to LRPs that is proposed in this work and noted that it could prove useful for characterizing multi-species fisheries in other areas (e.g., the Grand Banks).

Visualizing reference points: Introduction to the Reference Point Calculator App

Quang Huynh

The variety of methods available for LRPs for Canadian fisheries can create a challenging environment for comparing how candidate values are calculated and their relation to modeled stock dynamics. The Reference Point Calculator (RPC) app (Blue Matter Science 2021) summarizes the assumptions behind various reference point methods, and provides summaries of stock dynamics relative to proposed reference points (in terms of probability and over expressed time frames). The app also provides features for exploring stock projections (with varying assumptions), implementing management procedures, and summarizing outcomes with performance metrics. Overall, standardized and automated reporting are convenient features that enable users to disseminate information quickly to a broad audience. The interactive features of the app also provide users with the ability to customize stock projections and presentations tailored to the case study of choice. A demonstration of the app was provided along with a summary of areas for future development.

Discussion

It was noted that the app could be used in a CSAS/breakout group setting to advance reference point development (once the guidance has been drafted to support the exercise). The initial effort was to get the app running, but seeing it put to use is a subsequent objective.

A participant also flagged that a similar Shiny app (Hamazaki 2022) is also available, for sake of comparison.

The presenter was asked to provide further details on the underlying intent of the “Sketch” function in the app. The Sketch function is intended for situations where there may not be an assessment or may not even have data. It provides a questionnaire about stock dynamics – if any of the elements are unknown, more uncertainty is given in the range of values going into the operating model. This has value for information analysis.

Several participants noted in the chat that the app held a lot of promise for future LRP development exercises and a willingness to try it out on their stocks.

Risk Tolerance

This topic was held over from the discussion following Monday’s keynote address. There were two questions:

1. Owing to a perceived lack of inclusion, transparent discussion of risk and risk tolerance in most fishery assessment and management processes seems problematic. Considering the challenges in setting an LRP for a stock do you

think management has a role to play in guiding science in setting an LRP (in terms of risk tolerance)? Or do you think that should be left to how it is implemented through an HCR or other processes? It seemed you were suggesting the latter.

2. If risk tolerances for avoiding LRPs were more narrowly defined in policy (e.g., like Australia or ICES have set out), would that affect the ease of choosing an LRP (either positively or negatively)? In other words, if the risk tolerance for avoiding the LRP became as strict as ICES for example (avoid with 95% probability in each year), would that create more emphasis on identifying the "correct" or at least "best possible for now" LRP, in lieu of (as a participant said) setting a provisional or good enough LRP and moving on to figuring out HCRs or management procedures?

Resulting discussion points included:

- It was recommended that objectives be cast in metrics that are tangible to participants beyond the Science community (e.g., stating performance in terms of potential number of years of fisheries closures).
- Another participant noted that risk is a function of value, so “low value” fisheries don’t have much to lose (unless they play a higher value role in the ecosystem?).
- A participant highlighted that people sometimes confuse the concept of uncertainty in biomass estimates (e.g., probability of current biomass being less than a given biomass limit) with probabilities related to acceptable risk.

Traditional Ecological Knowledge

Throughout the workshop, questions around the interplay between Traditional Ecological Knowledge (TEK) and Science processes arose on a few occasions. A number of participants asked about the role of traditional ecological knowledge in setting LRPs (particularly in cases where the LRP does not arise easily from pure Science considerations alone). Additionally, there were suggestions for suitable approaches to consider and more broadly, how to solicit information from partners and stakeholders around defining stock states that are undesirable.

It was noted that TEK has informed development of other objectives (separate from ones focused on increasing biomass), such as restoring older age classes or larger size classes, as well as setting Upper Stock Reference points (USRs) and target biomass objectives.

A participant noted that TEK cannot be “incorporated” or “used”, and that consideration of TEK is as much about process as it is a source of information. Reconciliation means giving back control of systems to Indigenous communities.

Two references were shared by participants:

- Reid et al. 2020: Cautions about simply, "assimilating" Indigenous knowledge into western science paradigms. The authors discuss important considerations of process development in addition to the ecological knowledge to be gained.
- Berkes 2018: Insights from this book were used to develop a survey method to guide First Nations objectives for use in an MSE process for a West Coast Vancouver Island fishery.

CLOSING KEYNOTE ADDRESS

Pushing the Limits: Part 2 – Can LRPs Sustain Fisheries?
Rob Kronlund

LRPs are identified in the harvest policies of most major fisheries jurisdictions worldwide. In Canada, an LRP is imperative under s. 6.1(2) and 6.2 of the *Fisheries Act* (Fish Stocks Provisions). In this talk I describe the case of the "outside" stock of Yelloweye Rockfish (OYE); Yelloweye Rockfish is a long-lived *Sebastes* on the Pacific Coast of Canada and has been a focus of conservation efforts since the 1990s. Characterizations of OYE stock status by COSEWIC as Special Concern in 2008 and Threatened in 2020 (ECCC 2021) appeared to be consistent with stock assessments conducted in the 2010s, which indicated stock biomass was very likely to be below a 40% of the biomass at maximum sustainable yield. However, reassessment of the stock in 2019 using previously unavailable age composition data and a statistical catch-at-age model presented a picture of a stock well above the LRP and likely to be near B_{MSY}. These contrasting perspectives on status illustrated that conflicts in status determination can occur where different models and criteria are applied (e.g., COSEWIC and DFO), and that administrative time lags in reporting results can create a confusing message to the public.

Change management therefore becomes critically important in presenting a narrative on stock status and prognosis. Scientific perspectives can be expected to evolve in response to new data, new understanding of stock dynamics and changes to management objectives. Communication of status within the narrative has always been important and will become more so under the Fish Stocks Provisions of the *Fisheries Act*. In the case of OYE it is true that the species is long-lived, has an "old" age of maturity, and is vulnerable to serial depletion. However, it is also the case that the species can be managed using principles of "fisheries management science" that involve setting objectives, monitoring the stock and fisheries, conducting assessments, and establishing feedback management systems. Scientists can establish a narrative that new data and hypotheses (models) can change perceived stock status, often to a significant degree. Therefore, fisheries scientists can condition audiences to expect evolving science and advice by communicating why those changes occur.

The experience of OYE illustrates that while policies and procedures are well-developed for declaring that rebuilding is needed, it is less clear what policies and procedures exist for exiting a rebuilding regime. In this case, science efforts to develop a rebuilding strategy redefined the problem as one of navigating OYE and dependent fisheries through a "choke effect" that limits the catches of coincident species in the conduct of a multi-species fishery.

Limits to fishing are important and often required by fisheries law and policy, as in Canada. However, the selection and application of LRPs alone is insufficient to claim fisheries sustainability. LRPs only become useful when they are considered as part of a fisheries management system and enter the system embedded in a (generally small) set of objectives related to desired conservation, socio-economic and cultural outcomes. Such objectives should be fully specified to include risk tolerance and time frames for evaluation whenever possible. Objectives that embed LRPs become useful when they help to discriminate between management options by providing constraints to acceptable choices. This utility requires that feedback control be established between selected management actions and future stock response.

A scientifically defensible and reliably estimated LRP can emerge for stocks with an adequate amount of high-quality data, but the relatively weaker basis for LRPs compared to target reference points such as B_{MSY} often leads to other rationales for LRP choice. These reasons may include alignment with national harvest policies, adoption of “best practices” based on international conventions, analogy to similar stocks, or a pragmatic choice possibly derived from historical conditions that are considered desirable to avoid. Regardless, I suggest that effort focused on how well LRPs are estimated and how they can be operationalized would yield more satisfactory results than prolonged discussions of whether a particular LRP choice is “precautionary” or debating whether it is theoretically justified.

Discussion

A participant noted that consideration of “serious harm” may also need to involve the ecological role of the stock. If so, it was then suggested that the collective DFO challenge would/will be to render such an "*ecosystem LRP*" concept operational within the DFO Policy framework. Participants noted two examples:

- Forage species like Northern Shrimp do not currently have any consumption analysis in assessing this role within the stock assessment, and this information may be very informative in defining reference points for these stocks.
- A paper citing the use of broader ecosystem information to develop reference points (Chagaris et al. 2020).

CONCLUSIONS

KEY CONSIDERATIONS FOR LRP CHALLENGES

On the closing day of the workshop, the major themes of the workshop were reviewed in the context of major challenges for practitioners in setting LRPs and estimating stock status, and the main points summarized with workshop participants.

Key Considerations for Data Poverty

One of the main themes that emerged from the discussions was a need for pragmatism, doing the best one can with what is available, and taking a flexible approach to operationalizing “serious harm.” Recognizing that science advice for fisheries management, and harvest strategies in general are not just about the LRP, there may be multiple indicators that can provide a weight-of-evidence role in harvest strategies whether or not they are taken into account in the LRP.

Key Considerations for Scale

Stock structure may be elusive, and climate change is expected to exert impacts on not only stock productivity but also stock ID as stock distributions and movements change with warming conditions. There is a risk of serial depletion or loss of stock structure which can also be considered “serious harm.” There are different ways that harvest strategies can mitigate these impacts, which speaks to a need for flexibility in how “serious harm” is operationalized.

Key Considerations for Non-Stationarity

Structured or adaptive management approaches, including from other environmental management fields such as Resist-Accept-Direct (National Park Service 2022), were recommended to be used to determine when and how management systems respond to ecosystem change. There should be clear consideration of risks, ecosystem drivers and a role for simulation testing.

Much of the discussion focused on the need to adjust fishing mortality, which is directly impacted by management measures, and not using time-varying biomass reference points (although some felt that this would sometimes be necessary). There is a need to avoid increasing fishing mortality as biomass declines, and to ensure focus remains at all times on identifying actions that would be consistent with an objective to avoid serious harm.

Key Considerations for Uncertainty Across Paradigms

It was recommended to explore parameter and structural uncertainty with sensitivity analyses. There are various ways to combine or separate results but by combining results (e.g., into a single stock status) there is a risk of burying important details. The best format for communication may take several rounds of consultations. In general, the PA is most easily understood in terms of traditional approaches to stock assessment, but not procedural paradigms.

CONSIDERATIONS FOR BEST PRACTICE CRITERIA

"Consistent with an objective to avoid serious harm to the stock"

Breakout groups sought indicators that best represented or were proportional to what was interpreted to be the “stock,” and to spawning stock biomass specifically. Groups sought evidence of serious harm, but this was challenging to demonstrate. Several groups also aimed for precaution in light of non-stationarity considerations.

Workshop discussions noted that serious harm was an elusive or not very tractable concept, and “stock” can be elusive as well. Multiple mechanisms can result in serious harm to stocks, but in the absence of evidence of harm such as depensation, LRPs are generally based on the art of “best practices.” It was also noted that LRPs invoke inclusivity considerations (science, versus broader interests in fisheries).

Under the PA, serious harm is interpreted as a single species objective (i.e., serious harm to the stock), but it is important to note that there may be other broader management objectives (e.g., ecosystem or multi-species objectives) and that in some cases (e.g., Atlantic Menhaden, a forage fish), LRPs are set differently to achieve those other objectives.

"Based on best available information"

Breakout groups preferred to avoid the policy provisional default LRP of 0.4 B_{MSY} and looked for evidence of serious harm on which to base their choice. Groups also looked for consistency with common practice. Workshop discussions emphasized pragmatism - doing the best one can with what is available.

"Operationally Useful"

Breakout groups highlighted tractability of calculations and ease of communication as reasons underlying some of their choices. In workshop discussions, the operational usefulness of LRPs also hinges on its role as one part of harvest strategies. Success at achieving an objective to avoid serious harm will depend on other choices such as target harvest rates, tolerated risks, and timeframes in measurable management objectives.

"Reliably Estimable"

Breakout groups looked at the quality of data and the frequency with which data were collected. They considered the stock-recruitment relationship and which reference point estimates might depend on it. When selecting from multiple options, breakout groups looked for coherence (weight-of-evidence) among those options to help support their choices. Groups also looked for ways to account for uncertainty in status and reference point estimation.

EXTERNAL EXPERT REPORT ON KEY WORKSHOP OUTCOMES

Rob Kronlund

Three Key Workshop Outcomes

1. The concept of “serious harm” did not factor explicitly into the choice of LRPs during group exercises; LRP choice was largely data-driven or based (sometimes loosely) on policy defaults. Any reference to serious harm by participants was related to (a) their concern over what *could* occur outside the range of observed data, or (b) a desire to inject precaution into LRP choice albeit without a solid scientific basis. This practice carries significant risks to credibility, as subjective adjustments to LRPs to demonstrate “precaution” are hard to defend using a scientific basis. Instead, precaution should be defined by specific (measurable) objectives, evaluation, and adaptation of management actions when necessary. This outcome highlights two considerations:
    a. the difficulty of operationalizing “serious harm” as commonly conceived in Canada,
    b. the need to assess whether the concept of “serious harm” is sufficient and adequately defined, and
    c. the need for guidelines to be clear on how risk tolerance and time frames interact with LRP choice, and the steps needed to provide advice on the expected management actions (and their consequences) that result from embedding reference points in objectives.

2. The Day 2 presentation and group exercise highlighted:
    a. the weaker theoretical basis for LRPs compared to those for target reference points such as those based on MSY or Maximum Economic Yield (MEY), and
    b. harm to stocks and dependent fisheries can arise from factors other than impaired recruitment which is the concern most often cited for Canadian fisheries (but less often demonstrated), such as adult mortality.

3. Discussion suggested that biomass (abundance) based limit and target reference points have received too much emphasis in Canada at the expense of considering fishing mortality limits and the ability of management systems to adjust fishing pressure. This situation may be because decision-makers (and the public) are more willing to respond to a low level of biomass than to a high

estimate of fishing mortality (which is less easy to understand). It may also arise from not appreciating the need to control fishing mortality *in advance* of pronounced stock decline to maintain target levels contemplated by say, s. 6.1(1) of the Fish Stocks Provisions. The PA Policy suggests fishing mortality limits (e.g., fishing mortality should not exceed F_{MSY}) and explicitly identifies the Removal Reference (RR). The RR is intended to represent the level of fishing mortality that should not be exceeded, with the policy intent to reduce fishing mortality in advance of status declining to the LRP. As discussed during the Workshop, such adjustments to fishing mortality are needed to avoid initiating *positive* feedback effects, where *F* increases with declining stock size (in contrast, negative feedback is stabilizing and required to promote stock growth).

Overall Comments

During Talk 1 on Day 1, Rob Kronlund discussed the risk that increased scrutiny of scientific advice under the Fish Stocks Provisions will overly restrict debate to the choice of LRP. This is because the choice of LRP may have an immediate consequence to dependent fisheries that draws objections from resource users or may appear to have no consequence, contrary to the perspectives of other interested parties. Somehow the debate must be refocused on:

a. how well reference points are estimated,
b. how reference points can be operationalized by embedding them in measurable objectives within a management system, and
c. evaluating whether improved management outcomes can be expected as a result of those choices.

This may require a renewed focus on controlling fishing mortality and emphasizing targets based on MSY or MEY, which both have a stronger scientific basis than biomass (abundance) based LRPs. There must be limits to fishing; it may be that policy-based defaults are a good starting point for reference point choice to discourage prolonged debate that delays establishing stock and fishery objectives and implementing feedback management systems (Hilborn 2002; Hilborn et al. 2015). For example, it was suggested by Dr. Cox during the Workshop that setting an LRP that is “in sight” and putting effort into designing management measures to (*i*) avoid an LRP breach, and (*ii*) promote achieving stock and fishery targets would be both pragmatic and likely to lead to improved management outcomes by emphasizing design of a fishery management system.

SUMMARY OF CANDIDATE BEST PRACTICE PRINCIPLES

Each of the four candidate principles was refined with descriptions that reflect input received during the pre-requisite survey (Appendix 4) and throughout the workshop.

"Consistent with an objective to avoid serious harm to the stock"

An objective to avoid serious harm to stocks is central to Canada’s PA Policy. It is commonly described in general terms of recruitment overfishing, impaired productivity, loss of resilience or an ability to recover from perturbation, depensation (Allee effects), or very depleted stock states where dynamics become uncertain. Serious harm could also include loss of genetic diversity, structure or distribution, contraction of age/size structure, and extirpation. It could be caused by overfishing or by ecosystem impacts (altered predator-prey dynamics, habitat loss, etc.)

A wide range of stock status indicators could be considered by which to define thresholds to serious harm. Whatever indicators are chosen should usually be representative of the entire “stock,” or at least a representative subunit of the stock, and may show proportionality with stock attributes they are intended to measure, but the relative importance of these characteristics in driving the choice of indicator may be context-dependent.

"Serious harm," not to mention "stocks," can be an elusive or intractable concept. While the responsibility for setting LRPs lies with Science under the PA Policy, in the absence of evidence (e.g., depensation), LRPs are based more on the art of "best practices."

"Based on best available information"

Best available information, which provides the advice basis for choice of indicators, reference points or stock status, will vary from stock to stock. Broadly speaking, it can be described as information that is: relevant (appropriate), peer-reviewed, verified and validated, inclusive, objective, timely, transparent, open and accessible, accounts for uncertainties, accurate, consistently gathered, conflicting or alternative information considered, adequate, representative, reproducible (repeatable), clear and complete.

From a pragmatic perspective, "best available" means doing the best with what is available. When possible, evidence of serious harm and meta-analysis (basic biological information) may be preferred rationales on which to base choices of LRPs. However, evidence of serious harm is rare and "best available" may simply be what is consistent with policy guidance (0.4 B_{MSY}) or common practice. Furthermore, choices may be also based on other stock- or context-specific “best available” information, such as specific stock dynamics or traditional knowledge, and will be ultimately constrained by data poverty.

"Operationally Useful"

Fisheries sustainability is not just about the LRP. LRPs are part of harvest strategies and success in achieving an objective to avoid serious harm to the stock will depend on other elements such as target harvest rates, tolerable risks of breaching limits and timeframes.

At minimum, indicators, LRPs and therefore stock status should be feasible to measure or estimate. Other operational reasons to consider indicators, LRPs or status metrics may be: cost-effectiveness (ease of measuring or estimation), communicability (ease of understanding), simplicity, the role that LRPs or stock status may play in HCRs or triggering the need for a rebuilding plan, or the need to estimate stock status to evaluate either trends over time or performance of management measures. These reasons are not mutually exclusive, and the relative priority of reasons that make a choice of indicator, LRP or metric of stock status “operationally useful” will be context-dependent, both within or across traditional versus procedural paradigms.

"Reliably Estimable"

Reliable estimation of LRP or stock status metrics can mean acceptable consistency, accuracy or precision of estimates (i.e., acceptably low variance or low bias), and robustness to a range of possible uncertainties (assumptions, stock scale, data points and/or model structure). Reliability of reference points or estimates of stock status may also depend on reliable and consistent data collection. Reliability may be evaluated by examining uncertainty in estimates, sensitivity tests, evaluating the reasonableness of assumptions, simulation testing and/or by comparison to other similar stocks.

Closing Survey on Candidate Best Practice Principles

After seeing the results of the pre-requisite survey and participating in the live sessions of the workshop, participants were extended a one-week opportunity to reconsider the importance of the four candidate best-practice principles, with accompanying descriptions (Figure 8). The survey used a five-point Likert scale to evaluate how important participants felt it was for stock assessors to meet these criteria in order to set defensible LRPs/stock statuses. Participants generally felt that the criteria were all important. In this post-workshop survey, “based on best available information” emerged as the most important criterion and “reliably estimable” the least, which represented a shift in relative importance from the pre-requisite survey where “consistency with an objective to avoid serious harm” had been considered the most important criterion and “operationally useful” the least.

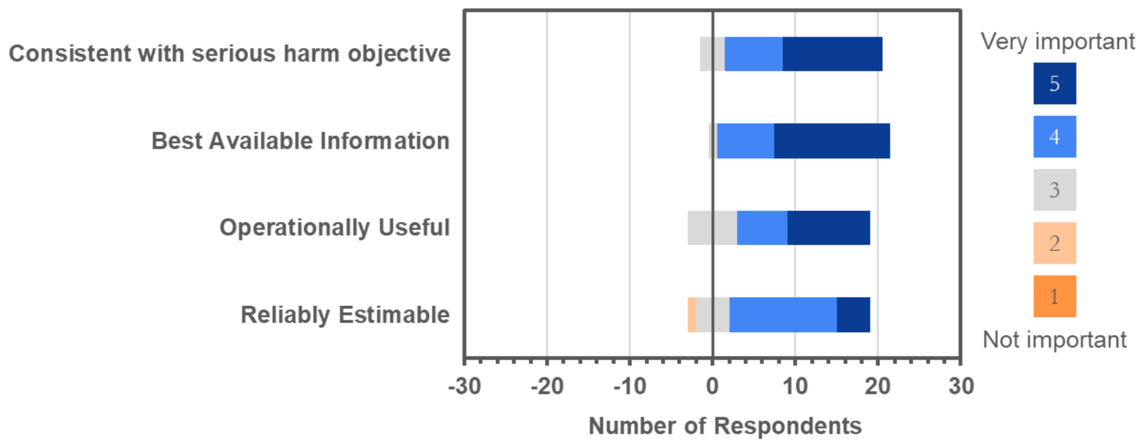

Figure 8: Diverging stacked bar chart showing the number of respondents ranking the importance of meeting different candidate “best practice” criteria for defensible LRPs and indicators using a five-point Likert scale. Responses have been standardized; positive responses are graphed to the right of the 0 on the X axis, in opposition to negative responses, while neutral responses are centered around 0.

ACKNOWLEDGEMENTS

We are grateful for the shared expertise of our speakers, the breakout group design and support provided by A.R. Kronlund, Sean Cox and Quang Huynh, and for the efforts of the DFO participants who served as breakout group facilitators: Irene Andrushchenko, Sarah Hawkshaw, François Turcotte, Carrie Holt, Danny Ings, Sarah Power, Jaclyn Cleary. Mary Thiess and Melissa Olmstead provided logistical support. Funding for the workshop was obtained through the DFO TESA committee. Finally, the meeting organizers thank the attendees for their collegial participation.

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APPENDICES

APPENDIX 1 – PARTICIPANT LIST

Participant	Affiliation
Anderson, Sean	DFO Science - Pacific
Andrushchenko, Irene	DFO Science - Maritimes
Araujo, Andres	DFO Science - Pacific
Aulthouse, Brendan	DFO Science - Pacific
Avlijas, Suncica	DFO Science - Gulf
Baker, Krista	DFO Science - NL
Barrett, Melanie	DFO Science - Maritimes
Barrett, Tim	DFO Science - Maritimes
Belley, Rénald	DFO Science - Quebec
Bennett, Lottie E	DFO Science - NCR
Boguski, David	DFO Science - Arctic
Boudreau, Mathieu	DFO Science - Quebec
Bourdages, Hugo	DFO Science - Quebec
Bureau, Dominique	DFO Science - Pacific
Burton, Meghan	DFO Science - Pacific
Carr-Harris, Charmaine	DFO Science - Pacific
Cassista-Da Ros, Manon	DFO Science - Maritimes
Chlebak, Ryan	DFO Science - NCR
Cleary, Jaclyn	DFO Science - Pacific
Cogliati, Karen	DFO Science - NCR
Cook, Adam	DFO Science - Maritimes
Cox, Sean	Landmark Fisheries Research
Dalton, Alexander J	DFO Science - Pacific
Duplisea, Daniel	DFO Science - Quebec
Duprey, Nicholas	DFO Science - NCR
Dwyer, Karen	DFO Science - NL

Participant	Affiliation
Forrest, Robyn	DFO Science - Pacific
Harbicht, Andrew	DFO Science - Gulf
Hawkshaw, Sarah	DFO Science - Pacific
Healey, Brian	DFO Science - NL
Herder, Erin	DFO Science - Pacific
Holt, Carrie	DFO Science - Pacific
Holt, Kendra	DFO Science - Pacific
Huang, Ann-Marie	DFO Science - Pacific
Huynh, Quang	Blue Matter Science
Ings, Danny W	DFO Science - NCR
Janjua, Muhammad	DFO Science - Arctic
Kanno, Roger	DFO Fisheries Management - Pacific
Keizer, Adam	DFO Fisheries Management - Pacific
Koen-Alonso, Mariano	DFO Science - NL
Krohn, Martha	DFO Science - NCR
Kronlund, Rob	Interface Fisheries Consulting, Ltd.
Ladell, Jason	DFO Science - NCR
Lebeau, Amy	DFO Fisheries Policy - NCR
Lewis, Keith	DFO Science - NL
Lochead, Janet	DFO Science - Pacific
Marentette, Julie	DFO Science - NCR
McDermid, Jenni	DFO Science - Gulf
Noble, Virginia	DFO Science - Pacific
Obradovich, Shannon	DFO Science - Pacific
Olmstead, Melissa	DFO Science - NCR
Osborne, Derek	DFO Science - NCR
Pantin, Julia	DFO Science - NL
Porszt, Erin	DFO Science - Pacific

Participant	Affiliation
Power, Sarah	DFO Science - Pacific
Regular, Paul	DFO Science - NL
Siegle, Matthew	DFO Science - Pacific
Simpson, Mark R	DFO Science - NL
Sutton, Jolene	DFO Science - Gulf
Tallman, Ross	DFO Science - Ontario and Prairies
Thiess, Mary	DFO Science - NCR
Turcotte, François	DFO Science - Gulf
Van Beveren, Elisabeth	DFO Science - Quebec
Varkey, Divya	DFO Science - NL
Wang, Yanjun	DFO Science - Maritimes
Wheeland, Laura	DFO Science - NL
Wor, Catarina	DFO Science - Pacific
Wysocki, Roger	DFO Science - NCR
Xu, Yi	DFO Science - Pacific
Zhu, Xinhua	DFO Science - Arctic

APPENDIX 2 – TERMS OF REFERENCE (ENGLISH)

Limit Reference Points and the Fish Stocks Provisions: Joint Technical Expertise in Stock Assessment (TESA) / National Operational Guidelines (NOG) Task Force Workshop

Dates: November 29 – December 3, 2021 (8:30 – 12:30 PAC; 11:30 – 15:30 NCR/QC, 12:30 – 16:30 MAR/GULF, 13:00 – 17:00 NL)
Location: Virtual (MS Teams)
Chairs: Tim Barrett, Julie Marentette

Context

Canada's *Fisheries Act* (R.S.C., 1985, c. F-14) was revised on June 21, 2019, resulting in new Fish Stocks provisions (FSP) that relate to the management of fisheries. The requirements of the FSP are being interpreted through the lens of the Fisheries and Oceans Canada's (DFO) Sustainable Fisheries Framework suite of policies, in particular the *Fishery decision-making framework incorporating the precautionary approach* (PA Policy, DFO 2009), and are expected to come into force with the prescription of the first batch of *major fish stocks* and associated regulations for rebuilding plan requirements.

Supporting the implementation of the FSP through the lens of the PA Policy means, among other things, that the Science Sector:

- Establishes a single limit reference point (LRP) for each candidate or prescribed major fish stock (the "one-stock-one-LRP" requirement; DFO 2021a);
- Estimates stock status relative to the LRP (the trigger for rebuilding plan requirements under s 6.2; DFO 2021b) or other reference points; and
- Supports the prescription of defined major fish stocks that are composed of one species, can be defined geographically, and for which a single LRP has been identified.

To support Science Sector activities in DFO's implementation of the FSPs, national operational guidelines (NOG) for science are under development through 2024, including the development of guidance for reference points and stock status. In this workshop, the NOG Task Force is partnering with the Technical Expertise in Stock Assessment (TESA) Program to explore limit reference points. The TESA Program is directed by DFO quantitative experts and aims to build capacity and promote technical expertise in fish stock assessment through annual delivery of training courses and national workshops on strategic topics in stock assessment.

Objectives

1. To increase understanding and awareness of the requirements of the Fish Stocks provisions for Science, particularly with respect to LRPs and stock status;
2. To facilitate the sharing of knowledge and expertise on practical aspects of the process of (and some of the challenges associated with) selecting methods for identifying LRPs and estimating stock status, and;
3. To explore and/or recommend possible considerations for national operational guidelines for stock assessment experts in setting LRPs and estimating stock status in a range of situations.

Our hope is that the results of these discussions will also help to inform a CSAS Advisory Process, “Science advice on guidance for limit reference points under the Fish Stocks provisions”, anticipated in 2022.

Format and Participants

Due to the ongoing COVID-19 pandemic, with its accompanying travel restrictions and workload challenges and pressures continuing through 2021, this workshop will be virtual in nature and limited to four hours per day in order to accommodate participants in different time zones.

Workshop participants will be from DFO, although guest speakers may be invited from outside the Department.

To assist with preparations for the meeting, we may provide in advance of the workshop:

- A **pre-requisite activity and shared materials** to assist participants (e.g., a survey on principles and best practices, Excel sheets and/or R code to do reference point calculations, key references) in preparing for the workshop.

Expected Products

- A **Proceedings** with workshop highlights, general findings, and breakout group summaries.
- **Online repositor(ies)** of documents, code, data and methods to facilitate the continued exchange of knowledge after the workshop has finished.
    - A folder within TESA’s GitHub account will be created. All participants will be invited to join.
- An **MS Teams** link to facilitate communications and follow-up collaborations after the workshop.

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APPENDIX 3 – WORKSHOP AGENDA

Limit Reference Points and the Fish Stocks Provisions:
Joint Technical Expertise in Stock Assessment (TESA) /
National Operational Guidelines (NOG) Task Force Workshop

Dates: November 29 – December 3, 2021
(8:30 – 12:30 PAC; 11:30 – 15:30 NCR/QC, 12:30 – 16:30 MAR/GULF, 13:00 – 17:00 NL)
Location: Virtual (MS Teams)
Chairs: Tim Barrett, Julie Marentette

Workshop materials can be found:
Google Drive (for this workshop): Link
TESA GitHub (long-term repository): Link

Day 1: Monday, November 29, 2021		
10 min	Welcome, Introductions and Housekeeping	Chairs
30 min	*Talk:* The Fish Stocks Provisions, LRPs and You ● Review of pre-requisite survey feedback	Chairs
30 min	*Opening keynote talk:* Pushing the Limits: Part 1 - LRP Lessons from Three Pacific Stocks	Rob Kronlund
30 min	*Talk*: LRPs in American Lobster: Precaution under Uncertainty	Adam Cook
10 min	Break	--
1.5 hr	Breakout groups (Topic 1: Empirical/Data Limited Methods/Spatial Scale)	All

Day 2: Tuesday, November 30, 2021		
5 min	Welcome to Day 2	Chairs
35 min	Presentation from breakout groups ● 5 min per group, 6 groups	Breakout Group Leads
30 min	Discussion (group)	Chairs
30 min	*Talk:* The art and science of limit reference points with a few examples from Canadian fisheries	Sean Cox
10 min	Break	--
1.5 hr	Breakout groups (Topic 2: Data Rich Methods)	All

Day 3: Wednesday, December 1, 2021		
5 min	Welcome to Day 3	Chairs
35 min	Presentation from breakout groups ● 5 min per group, 6 groups	Breakout Group Leads
30 min	Discussion (group)	Chairs
30 min	*Talk:* Time Varying Reference Points	Dan Duplisea
10 min	Break	--
1.5 hr	Breakout groups (Topic 3: Time Varying Productivity)	All

Day 4: Thursday, December 2, 2021		
5 min	Welcome to Day 4	Chairs
35 min	Presentation from breakout groups • 5 min per group, 6 groups	Breakout Group Leads
30 min	Discussion (group)	Chairs
30 min	*Talk*: Accounting for parameter and structural uncertainty in stock assessment and MSE	Robyn Forrest and Sean Anderson
10 min	Break	--
1.5 hr	Breakout groups (Topic 4: Procedural Paradigms)	All

Day 5: Friday, December 3, 2021		
5 min	Welcome to Day 5	Chairs
15 min	Parking lot and residual discussions	Chairs
10 min	*Talk*: LRPs and Pacific Salmon	Carrie Holt
10 min	Questions	All
10 min	*Talk:* Visualizing reference points: Introduction to the Reference Point Calculator app	Quang Huynh
10 min	Questions	All
10 min	Break (if necessary)	--
30 min	*Closing keynote talk:* Pushing the Limits: Part 2 – Can LRPs Sustain Fisheries?	Rob Kronlund
15 min	Questions	All
20 min	Summary and Synthesis	Chairs

APPENDIX 4 – PRE-WORKSHOP PREREQUISITE QUESTIONNAIRE

INTRODUCTION

Four weeks in advance of the workshop, participants were invited to answer 22 questions as a prerequisite to workshop exercises. The questions were aimed to: a) elicit input from workshop participants regarding four candidate guidance criteria that help to define what makes a “good” or "best practice" LRP/stock status indicator, and b) encourage participants to think about different rationales for choosing LRPs/indicators. Twenty-five respondents completed this activity.

The four candidate guidance criteria are:

1) Consistent with an objective to avoid serious harm to the stock,
2) Based on best available information,
3) Operationally useful,
4) Reliably estimable.

A "stock" can be defined in many ways, but for this purpose, can be considered a semi-discrete group of aquatic animals (fish, invertebrate, marine mammals) with some definable attributes in common that are of interest to managers. An "attribute" is a quality, characteristic or feature of the stock. An "indicator" is some measurement that provides information on the state of the stock, and may include model-based estimates of biomass, fishing mortality or exploitation rate, or suitable proxies for these such as survey indices. A reference point is some value of an indicator that represents a target or threshold that management measures aim to either achieve on average, or alternatively surpass (or avoid breaching); limit reference points are a type of threshold. Lastly, "stock status" is the relationship between some estimate of the indicator (e.g., the most recent or "current" estimate) and a reference point (e.g., the LRP). Stock status is a metric (or statistic). It can be used to evaluate performance (a statistic used to evaluate management measures, and can be calculated from simulated states of nature). It can also be used for monitoring (a statistic estimated and tracked retrospectively to provide information on realized stock or fishery performance over time).

The process of selecting an LRP may involve decisions made by stock assessors at several steps: selecting stock attributes by which to interpret serious harm, evaluating and selecting indicators to represent those attributes, evaluating and selecting thresholds to be LRPs, and estimating and reporting stock status as a metric.

There are various means by which to approach these steps and select an indicator/LRP, including theoretical, historical (both model-based) or empirical versions of fractions of K, B_0, or B_{MSY}, points from stock-recruitment relationship, $B_{recover}$, or other thresholds. "Model-based" indicators are estimates of quantities generated from models, while "empirical" indicators are directly observed (catch, catch-per-unit-effort or CPUE, survey indices). LRPs may be derived from theoretical values such as B_{MSY} (biomass associated with fishing mortality at maximum sustainable yield), B_0 (unfished biomass), K (carrying capacity), or a stock-recruitment relationship. They may also be derived historically (points along a time series; e.g., $B_{recover}$, the lowest biomass from which a stock has demonstrated a secure recovery).

RESULTS

Candidate Criterion 1: Indicators and LRPs should be "consistent with an objective to avoid serious harm to the stock"

This criterion first requires an interpretation of what "serious harm" means as an undesirable stock state to be explained, and then additional considerations to operationalize those definitions in a way appropriate to the stock. "Serious harm" is commonly described in general terms of recruitment overfishing, impaired productivity, loss of resilience or an ability to recover from perturbation, depensation, or very depleted stock states where dynamics become uncertain.

Question 1. How might you define and diagnose "recruitment overfishing", "loss of resilience", "impaired productivity" or "depensation"? What data do you need? (pick one of the terms to define and explain)

Respondents explored and described serious harm via its common interpretations, particularly recruitment overfishing, as shown in Figure A1. Serious harm in the context of recruitment overfishing was defined by participants as:

- Insufficient biomass, abundance or number of spawners to support "normal" recruitment levels, the ability to produce offspring, or the ability for the stock to maintain or replace itself
- Stock levels associated with the steep parts of the stock-recruitment curve, or those to the left of the inflection or break-point
- Associated with an increased risk of stock collapse if prolonged or combined with poor environmental conditions
- A result of overfishing or high exploitation rates

Impaired productivity was defined by participants as:

- Persistent periods of low productivity (in relation to some historical period)
- Non-responsiveness in terms of increasing biomass to changes such as reduction in fishing pressure

Loss of resilience was defined as the inability to adapt to environmental perturbations.

Depensation (also called predator pits or Allee effects) was defined by participants as:

- Inverse density-dependence, or declines in the per capita rate of growth of a population as stock density or size declines
- Caused by loss of reproductive potential through the loss of large fecund individuals or through density-dependent processes (e.g., fertilization success)

Respondents suggested a wide range data may be needed for a diagnosis of serious harm, including:

- Time series of declining or persistent low recruitment, spawning stock biomass, survey indices of biomass, and/or contracting size/age structure
- Time series of catches, landings or fishing mortality
- Time series showing response of stock to decreased fishing pressure

- Analyses of surplus production (and data required to generate these estimates)
- Information on fecundity, size/age structure, growth and natural mortality
- Understanding of the relationship between reproductive biology and density
- Ability to estimate the stock-recruitment relationship (longer the time series the better) and a threshold from that relationship
- Ability to apply alternative stock-recruitment models to test for inflection points due to depensatory effects
- Negative trends in the residuals of the stock-recruitment relationship
- Estimates of recruits per spawner < 1 (i.e., below the replacement line)

Figure A1: A word cloud of all terms used by respondents at least four times in their descriptions of various traditional approaches to serious harm, where font size is proportional to the number of times it was mentioned.

Question 2. In your opinion, are there other undesirable stock states or outcomes that represent "serious harm" and that are not mentioned above?

Respondents suggested several other outcomes that could constitute serious harm (Figure A2), including:

Other Outcomes	No. of Respondents
Loss of genetic diversity	6
Changes in stock structure or behavior (e.g., spawning and movement; range shifts; serial depletion)	5
Taking into account ecosystem considerations into thresholds of serious harm, or considering ecosystem thresholds (as a result of considering predator-prey interactions, habitat loss, or prevailing conditions)	3

Smaller size or age structure	2
Extirpation	2
Poorer condition	1
Evolutionary shifts toward smaller body size and earlier age of maturity	1
Growth overfishing and ecosystem overfishing	1

Figure A2: A word cloud of all terms used by respondents at twice when identifying other states or outcomes that could be associated with serious harm, where font size is proportional to the number of times it was mentioned.

Question 3. What are some of the possible difficulties you could face when trying to identify a threshold to states of serious harm using any given indicator, consistent with the undesirable stock states discussed or identified above?

Respondents identified a number of potential difficulties in selecting a LRP consistent with serious harm, including:

Difficulties	No. of Respondents
No or poor-quality indicators or data (short time series, fishery-dependent indicators only, or highly uncertain)	10
Missing or uncertain life history information	6

Picking one threshold from multiple options (because of uncertainty in estimates, that serious harm is a continuum or hasn't been observed, and subjectivity in choice)	6
A lack of a stock-recruitment relationship (or lack of one with a break-point)	5
Non-stationary environmental processes	5
Picking only one indicator for serious harm when several may be pertinent	3
Time and model poverty	1
Complex stock structure	1

Question 4. Common stock attributes that could have thresholds associated with serious harm include the size of the stock (measured with model-based or empirical indicators of abundance, biomass, or subsets such as spawning stock biomass), egg production, or surplus production. Can you suggest any alternative stock attributes that could have thresholds associated with serious harm? What indicators could be used to estimate (or approximate) those attributes?

Respondents suggested some additional stock attributes that might have thresholds that could be associated with serious harm, such as genetic diversity, sex ratios or the abundance of males (i.e., resulting in sperm limitation), environmental tolerance, and distribution.

Possible indicators of genetic diversity could be the number of genetic polymorphisms or rate of polymorphisms, measures of heterozygosity or genetic flow, the number of alleles, allelic richness and variants among alleles, and the average number of alleles per locus, and the proportion of polymorphic loci.

Other possible indicators that could be used to estimate or approximate important stock attributes (and from which a threshold to serious harm could be selected) were proposed. These indicators included the number of (or ratio of) males to females, age and size composition of the catch, length-at-age, body condition, and the proportion of mature fish. CPUE could serve as an indicator of stock abundance under certain conditions, and stock distribution could be measured in terms of area occupied or the distribution of spawning. A variety of indirect indicators of stock status were suggested as well, including removal rates (or fishing mortality), the extent of habitat alteration, the occurrence of extreme heat events, the distribution or rate of spread of aquatic invasive species, concentrations of pollutants, predator or prey densities, water temperature and oxygen concentration.

Question 5. Indicators may be model-based estimates (e.g., spawning stock biomass) or empirical (e.g., fishery-dependent or independent indices). How important is it to consider whether the chosen stock status indicator is...

a. **Representative of the state of the entire "stock"**
b. **Proportional (exhibits a linear relationship with) the stock attribute(s) selected to represent serious harm**

A majority of respondents felt that it was always important for indicators to be representative of the state of the entire "stock," and with the exception of two respondents, most also felt that the indicator should be proportional to the stock attribute it was intended to represent (Figure A3). Respondents who felt that these characteristics were more important in some situations than others were asked to expand upon that choice in question 6.

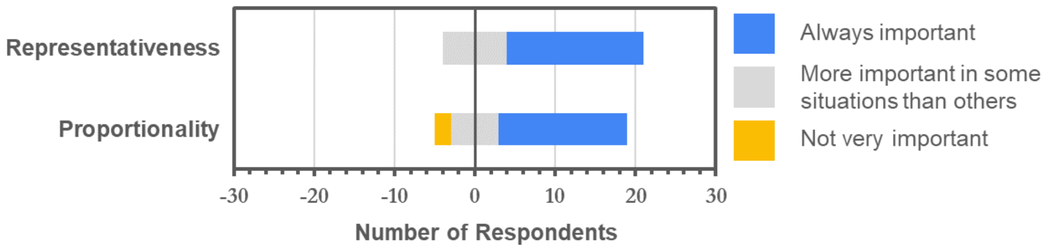

Figure A3: Diverging stacked bar chart showing the number of respondents ranking the relative importance of two characteristics in selecting an indicator to represent a stock attribute relevant to serious harm. Responses have been standardized; positive responses are graphed to the right of the 0 on the X axis, in opposition to negative responses. Note that neutral responses straddle positive and negative.

Question 6. If you selected "More important for some situations than others" in the question above for either proportionality or representativeness, can you explain what those situations are?

For representativeness, respondents noted that:

- It depends on the definition of a “stock”
- For stocks that are meta-populations, indicators could be used only for certain subunits, or for all subunits if a model is used that explicitly accounts for spatial structure
- In salmon management units (SMUs), which consist of multiple conservation units (CUs) some indicators may be used or be appropriate for some CUs but not others and this may have important implications for which management measures may apply to which CUs (and which threats each are subject to)
- Indicators used in multi-indicator frameworks may reflect only one component of a stock, where that component then serves as an “indicator” for the entire stock
- Empirical fishery-dependent indicators already do not inform on the state of the entire “stock” because they inform on only that component available to the fishery
- There may be smaller subcomponents of the stock that are not represented by a given indicator (and may not be assessed or frequently targeted by management measures), but the conservation risk to the stock may be low so long as they are small or not under intense fishing pressure. If these subcomponents were subject to fisheries or other sources of mortality, then representing them would become more important.
- Representativeness may be more challenging for large stocks versus small stocks (geographically speaking), and consideration should be given for larger stocks where distribution would not be consistent throughout the entire area

For proportionality, respondents noted that:

- Linear relationships between indicators and attributes are often assumed in models
- Linear relationships may not always exist (Type II or III responses)
- Some LRPs can be derived in the absence of some assumptions of linearity ($B_{recover}$)
- Empirical indicators often exhibit linear relationships with stock attributes
- Proportionality may not be essential for use of indicators in all cases as long as the indicator can be assigned a threshold to serious harm
- Non-linear relationships between indicators and attributes that are unknown or not accounted for can be problematic
- Indicators used in multi-indicator frameworks may have complex relationships to stock attributes

Candidate Criterion 2: Indicators and LRPs should be "based on the best available information" for the stock.

"Best available information" will vary from stock to stock and might produce different reasons for selecting an indicator/LRP. Some jurisdictions, like the US, provide criteria for evaluating scientific information as "best" that include such factors as relevance, inclusiveness, objectivity, transparency and openness, timeliness, verification and validation, and peer review, as appropriate. (https://www.ecfr.gov/current/title-50/chapter-VI/part-600/subpart-D/section-600.315)

Question 7. What criteria would you use to define what makes "best available information"?

Respondents suggested a range of terms that could be used to define "best available information". Several respondents found this a difficult question and potentially subjective. Some felt that "best available" does not mean perfect, but it also doesn't mean that any available information qualifies (i.e., while having some information is better than none, it might not be sufficient to support advice; 'information' is not the same as 'data', and risks associated with the quality of the information should be considered). Several noted Traditional Knowledge in the context of inclusiveness. Others cautioned that it may not be possible to maximize all criteria at the same time, particularly timeliness.

Criteria	No. of Respondents
Relevant (US criterion) [i.e., recent and pertaining to the stock/area]	9
Peer Reviewed (US criterion)	9
Verified and Validated (US criterion)	7

Inclusive (US criterion)	6
Objective (US criterion)	6
Timely (US criterion)	6
Transparent and Open (US criterion)	4
Acknowledges limitations and uncertainties	4
Accurate	3
Available and Accessible	3
Consistently gathered	2
Reliable	2
Alternative or conflicting information considered	2
Appropriate	2
Adequate	2
Representative	2
Defensible	1
Reproducible	1
Clear	1
Complete	1

Question 8. What priority would you assign different reasons to select a given threshold as LRP? Rank in order from more to less preferred (and assume all information is available). Please use each rank only once (no ties).

- **a. Consistent with policy choice or guidance [40% BMSY]**
- **b. Common practice (similar to LRPs elsewhere)**
- **c. Direct evidence (demonstrated serious harm in this stock)**
- **d. Meta-analysis (using basic biological information, e.g., "low productivity", or analogies from other stocks)**

Respondents strongly preferred to base a choice of LRP on evidence of serious harm for the stock (assuming such information was available), or failing that, based on meta-analyses or basic biological information over a choice consistent with policy guidance, or to an LRP selected because it might be common practice (Figure A4).

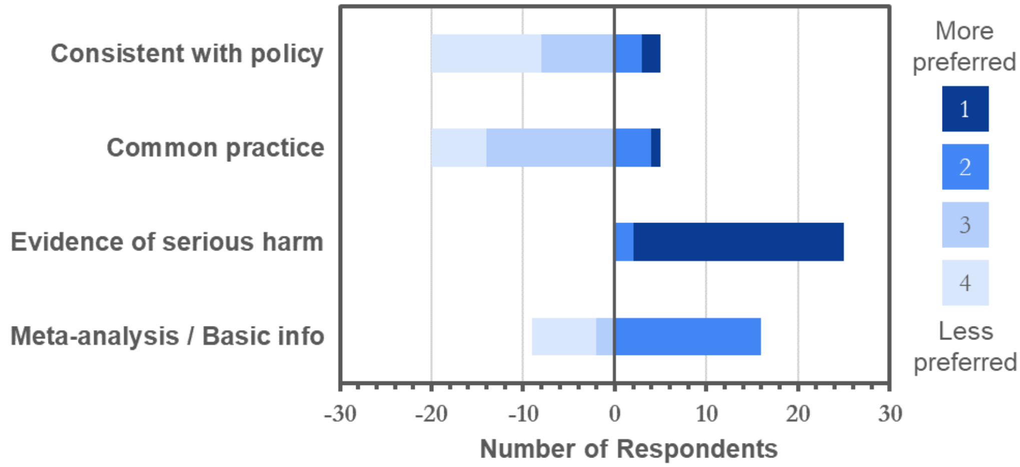

Figure A4: Diverging stacked bar chart showing the number of respondents ranking preferred rationales on which to base the selection of an LRP. Responses have been standardized; positive responses are graphed to the right of the 0 on the X axis, in opposition to negative responses.

Question 9. What reasons might produce LRPs that are more likely to be challenged? Rank in order from more to less likely to be challenged (and assume all information is available). Please use each rank only once (no ties).

- **a. Departing from policy choice or guidance [i.e., not 40% BMSY]**
- **b. Less common practice (dissimilar to LRPs elsewhere)**
- **c. Lack of direct evidence (demonstrated serious harm in this stock)**
- **d. No meta-analysis or basic biological information (e.g., “low productivity”, or analogy to other stocks)**

Respondents felt that LRPs selected in the absence of evidence of serious harm, or that deviated from common practices, to be the most likely to be challenged (Figure A5). LRP choices made in the absence of meta-analyses or basic biological information, on the other hand, were considered to be the least likely to be challenged.

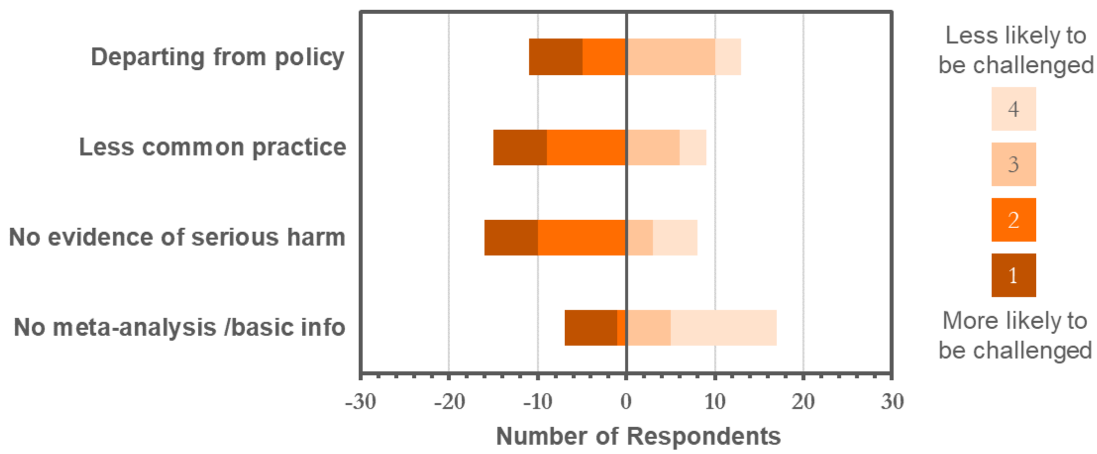

Figure A5: Diverging stacked bar chart showing the number of respondents ranking the likelihood that a choice of LRP that deviates from, or does not use, particular rationales will be challenged.

Responses have been standardized; positive responses are graphed to the right of the 0 on the X axis, in opposition to negative responses.

Question 10. Are there any reasons to select an LRP that are not included in the list of four above?

Several respondents suggested additional reasons to select LRPs:

- LRPs may be considered appropriate for stocks based on knowledge of its dynamics in a way that is unrelated to other stocks
- LRPs may be selected due to unknown dynamics below certain points ($B_{recover}$)
- LRPs may be selected because they are easy to understand, or easy to calculate/estimate reliably
- LRPs may be selected in the context of the management measures they may be linked to
- LRPs may be selected after consultations with fishery interests to determine agreed-upon undesirable states
- Data poverty may drive LRPs selected
- LRPs pre-dating policy guidance may also be considered appropriate for a stock in some circumstances, e.g., where there is large support for the choice

Question 11. What evidence would you use as a rationale to depart from the provisional default LRP of 40% B_{MSY} identified in the PA Policy? (For this question, assume you can at least estimate B_{MSY}.)

In general, respondents felt that there were a variety of reasons related to estimability, simulation testing and a variety of biological rationales that could be used to depart from a provisional default of 40% B_{MSY}. However, 40% B_{MSY} was noted as a convenience and may be a reasonable starting point in many cases.

- Where estimates of B_{MSY} are very uncertain or unreliable, and especially if B_{MSY}:B_0 is low
    - E.g., due to uncertainties in model parameters pertaining to selectivity, steepness or natural mortality
- Where estimates of B_{MSY} may be impacted by non-stationarity (changing productivity regimes)
- Where there is evidence of serious harm (in a given stock, or similar stocks) at levels higher than 40% B_{MSY} and thus 40% B_{MSY} is not expected to be sufficiently precautionary
    - E.g., Stocks with late maturity and/or slow growth
- Where other LRPs have stronger rationales and support given the historical data for the stock (or similar stocks), including:
    - Allee thresholds,
    - Periods of depressed productivity,
    - Demonstrated recoveries in the past below levels corresponding to 40% B_{MSY}
- Where other LRPs show better performance in closed-loop simulation

    - E.g., S_{gen} (the number of spawners that result in recovery to S_{MSY} within one generation in the absence of fishing under equilibrium conditions) for salmon
- Where the stock is not a finfish or has unusual life histories
- Where the stock is extremely productive
- Where the role that the LRP plays as an operational control point for management measures in relation to the USR may be a concern (e.g., narrower Cautious zones)

Candidate Criterion 3: Indicators and LRPs should be “operationally useful."

Like "best available information," what is considered operationally useful may vary widely from stock to stock. Here, "operationally useful" can be considered to mean the choice of indicator and LRP are "ready to use" in advice and management of a particular stock.

Question 12. What could be operational reasons to select a given indicator or LRP (the combination of which yields stock status)? Evaluate each in terms of their relative importance. Please use each rank only once (no ties) *HCR = harvest control rule

a. **Feasible (possible) to estimate status**
b. **Cost effective to estimate status frequently (i.e., considering costs of data collection and analysis, including modelling)**
c. **Status is easy to communicate and understand**
d. **Status is, or could be, an input (or LRP an operational control point) to a HCR**
e. **Status needed as monitoring metric: Can be applied to existing data/time series to estimate past/current status and trends**
f. **Status needed as performance metric: Enables provision of forward-looking advice (i.e., forecasts or simulations)**

Of all the operational reasons to pick an indicator or LRP, feasibility was ranked the most important by a strong majority of respondents (Figure A6). Cost-effectiveness and the role that indicators or LRPs might play in HCRs were generally considered less important. The role of status as a metric for monitoring status and trends was considered slightly more important than as a role as a performance metric in forward-looking advice.

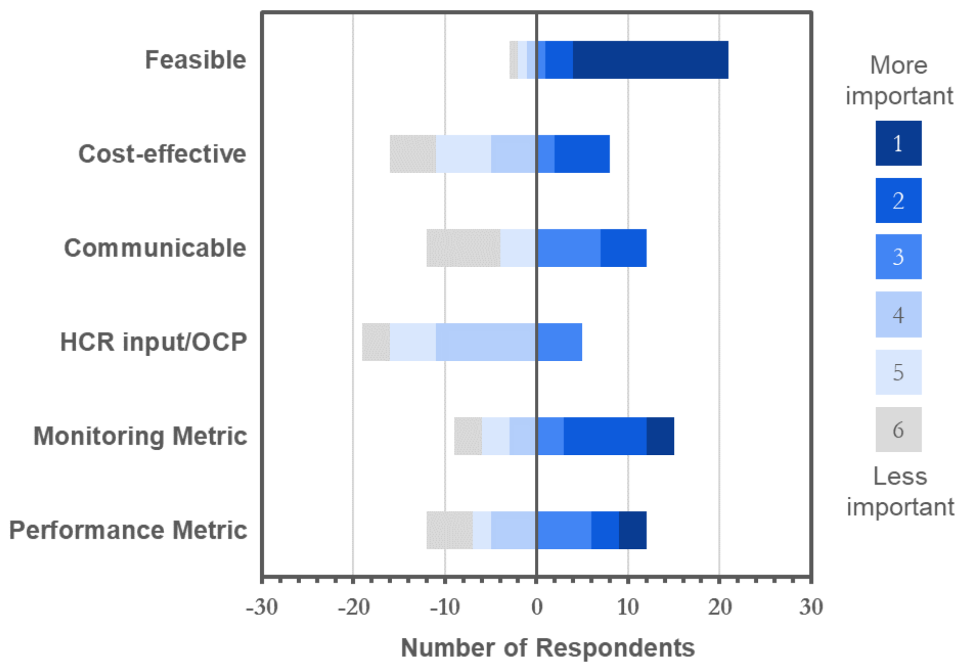

Figure A6: Diverging stacked bar chart showing the number of respondents ranking the importance of different operational reasons to select an indicator, LRP or method of estimating stock status. Responses have been standardized; positive responses are graphed to the right of the 0 on the X axis, in opposition to negative responses.

Question 13. Can you suggest any other considerations or reasons (apart from the six given above) that would make stock indicators or LRPs operationally useful?

Other operational considerations to select indicators or LRPs that were suggested by respondents included:

- Ease of measuring
- Utility in achieving management objectives such as avoiding collapse
- Supported by Traditional Knowledge
- Minimizing complexity – e.g., if two options perform equally effectively, it might be desirable to keep it simple and use only one
- Whether status is estimated with enough certainty to be used by managers to trigger management actions

Some respondents noted that ranking operational reasons to select indicators or LRPs in Question 12 was challenging:

- The options are not mutually exclusive and can be considered simultaneously
- Feasibility is mandatory; if something is not feasible or cost-effective, then none of the other may considerations matter
- Relative importance may also depend on the stock in question and that it was important to be flexible with operational considerations that may be pertinent to implementation in a variety of contexts

Question 14. Would the relative importance of different operational reasons to choose a particular indicator/LRP (question 12) change with different paradigms? If yes, please explain.

Most respondents (16) felt that yes, the relative priority of operational reasons to select a given indicator or LRP would change depending on the advice or management paradigm for the stock in question. Others felt that the operational reasons either might not or would rarely change (4), or weren't certain (3). The reasons for a change in priority were given as follows:

- The need to move to simulation for the purpose of evaluating management procedures
    - Monitoring metrics are more important for traditional stock assessment and the *Sustainability Survey*, while performance metrics are more important for MSE
- The need to consider uncertainty differently in advice given for management measures
- The need to accommodate different levels of data poverty or in the event of the rejection of models
- Different paradigms may result in advice being given at different frequencies (impacting cost-effectiveness)
- Several respondents noted that ease of communication may become more important in MSEs or consultative processes where HCRs are developed
- Cost-effectiveness of frequent updates may be more important for traditional stock assessment

Some noted that the choice of paradigm itself may be driven by operational reasons, with procedural approaches being increasingly preferable as data poverty increases. Furthermore, if the stock is in a very depleted state and is a candidate for rebuilding, a role of the LRP as HCR operational control point may be less prioritized over other operational considerations.

Candidate Criterion 4: LRPs and indicators should be "reliably estimable."

Reliable estimation can mean acceptable consistency or precision of estimates (i.e., acceptably low variance, low bias), robustness to uncertainty in assumptions, and/or robustness to uncertainty in stock scale.

Question 15. Are there other ways that you would define "reliable estimation"?

Seven respondents suggested that "reliable" LRPs and indicators should be supported by "reliable" data (consistent, feasible and sufficiently frequent data collection; i.e., not sporadic). Another noted that "reliability" could be defined via peer-review.

Several respondents highlighted robustness to uncertainty and expanded upon it as follows:

- Estimates should not be influenced by individual data points

- Estimates should be robust to model structure, e.g., via cross-validation or retrospective analysis

Question 16 How might you evaluate whether a LRP is reliably estimated?

Respondents provided a range of suggestions for evaluating reliable estimation, including:

- Examining the accuracy and precision of indicator and LRP estimates (i.e., confidence bounds)
- Evaluating the sensitivity of LRP estimates to missing data, assumptions or priors
- Simulation testing of the estimation procedure under different scenarios
- Considering the reasonableness of the assumptions
- Examining model diagnostics to evaluate the fit (and therefore of derived reference points)
    - Convergence, examination of established statistical criteria, magnitude of the standard error of the estimate, in Bayesian applications whether the posterior probability updated from the prior (is the result data-driven or prior-driven)
- Retrospective analysis
- Cross-validation using statistical techniques
- Comparison of estimates with different model-based approaches
- Comparison with other stocks of the same species or to similar species
- Over time, with periodic review of stock status and associated monitoring with consistent methods
- Comparison with time series to determine association with evidence of serious harm
- Ensuring estimates are reproducible
- More generally, that this must be done via peer review

Question 17. What characterizes a "reliable" stock status indicator?

Respondents characterized stock status indicators as reliable when they were associated with:

- Low uncertainty; accuracy and precision; low bias
- Robust to changing conditions
- Ability to provide information on changes in stock status quickly
- Ease of measurement
- A basis of trustworthy information that is readily and consistently available to support monitoring (and which is expected to continue to be so in the future)
- Data-richness, in general
- Consistency with other metrics of stock health
- Evidence that they are thought to be or demonstrated to be consistent with the state and dynamics of the stock and its attributes of “productivity” over time, even if not linearly related to those stock attributes
- Proportional to “true” abundance in a relative time series (assumption of constant catchability)
- Derivation from robust and consistent analytical methods

- Monitoring that subsequently confirms prior simulation testing, if simulation is used
- Being reliant on minimal or reasonable assumptions
- Being well-documented
- Providing information needed to sustainably manage the fishery and achieve desired goals

Question 18. Please rank the proposed minimum "best practice" criteria for LRPs and indicators that were highlighted above, from more to less important. Please use each rank only once (no ties).

A majority of respondents ranked a criterion of “consistent with an objective to avoid serious harm to the stock” as the most important of the four candidate criteria explored in this study, and tended to rank “operationally useful” as least important (Figure A7).

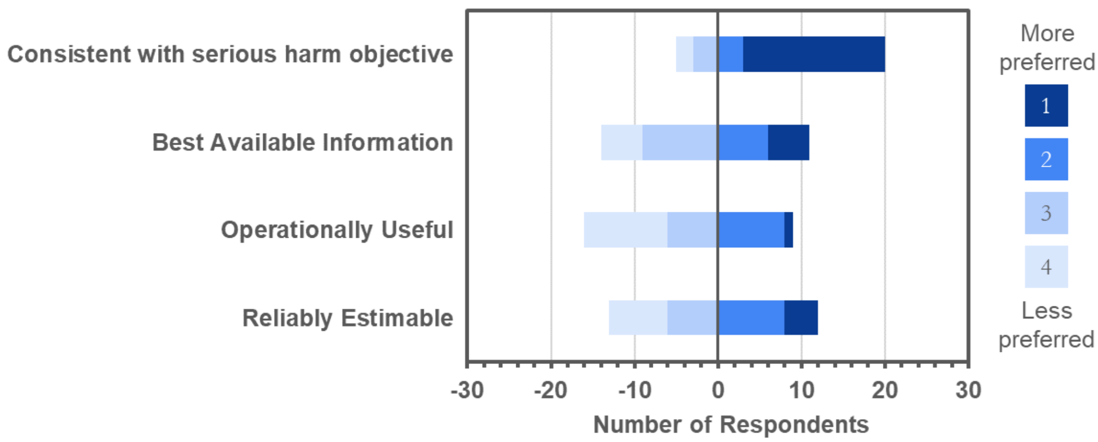

Figure A7: Diverging stacked bar chart showing the number of respondents ranking the importance of different candidate “best practice” criteria for LRPs and indicators. Responses have been standardized; positive responses are graphed to the right of the 0 on the X axis, in opposition to negative responses.

Question 19. Are any of these four proposed criteria listed above not essential (i.e., should not be part of a set of minimum "best practice" criteria for LRPs and indicators to meet)? If yes, please explain.

Eighteen respondents indicated that all four criteria were important, with several noting that the criteria were inter-related and that it was difficult to rank them.

Three respondents made recommendations or provided additional considerations. One participant suggested that “consistency with an objective to avoid serious harm” has not been consistently applied nor interpreted by managers. Another participant indicated that “operationally useful” may in fact be self-evident and not helpful when selecting an LRP, while a third clarified that “operationally useful” should be defined at minimum as an LRP and indicator that can function as a trigger for a rebuilding plan, if not an HCR.

Question 20. Can you suggest any other desirable 'minimum' best practice criteria that LRPs and stock status indicators should meet?

Several respondents suggested that the set of minimum criteria should be enhanced to mention:

- Less corruptible (less sensitive to changes in data available, such as fishery-dependent data or survey indices, or in situations with, for example, dome-shaped selectivity and cryptic biomass)
- Evidence-based
- Defensible
- Repeatable
- Enforceable
- Consistency with PA Policy
- Consistency with depensatory or Allee effects
- Peer-reviewed
- Not based on assumptions of stationarity
- Supported with timely data collection
- Refined as more knowledge is gained

Question 21. Would you like to share anything about your own experiences with setting LRPs? What challenges did you face? Please include the type of stock (e.g., large pelagic, etc.).

Respondents identified the following challenges based on their own experiences:

Stock Type	Challenges
Groundfish	• How to set LRPs when natural mortality due to predation is high • Whether to use a dynamic LRP • How to select LRPs and estimate stock status in MSE • Difference between LRP as a concept (e.g., Brecover, 40% Bmsy) and particular estimates of a LRP (in tonnes) that may change over time, e.g., in relation to MSEs and/or meeting Department reporting requirements • Mis-alignment between assessment and management units • Challenging stock-recruitment relationships (e.g., appearing linear, no evidence of density dependence in available time series) • Ability to estimate Bmsy • Estimating Bmsy from surplus production models in more data-limited contexts
Pacific Salmon	• Disconnect in scale when LRPs are set at level of salmon management unit (SMU) but conservation units (CUs) to be preserved under Wild Salmon Policy • Controlling harvest rates is at level of SMU, but additional management measures beyond controlling harvest (habitat and hatchery) that operate at the level of the CU • It is unclear what a potential SMU status metric (with LRPs set to ensure 100% of CUs are above “red status”) will be for rebuilding plans at the SMU level

Invertebrates	● Data poverty ● Reliance on fishery-dependent data ● For broadcast spawners, there is a disconnect between stock size and recruitment in the same location due to dispersal during pelagic larval period – traditional stock-recruitment relationships are not well-suited to these species
Small pelagics	● Using LRPs for one stock based on other stocks may not be appropriate, due to different productivities among stocks

Some respondents provided more general comments on challenges experienced in setting LRPs:

- Setting LRPs is less likely to be challenged when stocks are not depleted
- Setting LRPs is impacted by trade-offs between short-term economic objectives and long-term sustainability objectives

Question 22. What challenges would the "one stock, one LRP" requirement of the Fish Stocks provisions provide for you, and how might that challenge be resolved? Please include the type of stock (e.g., large pelagic, etc.).

Respondents suggested the following challenges posed by “one stock, one LRP” requirements:

- **MSE** (due to multiple operating models in contrast to traditional stock assessment paradigms)
- **Stock complexes** (salmon, redfish)
- **Stocks under co-management**: partners may not agree with LRP, scale of LRP, or choice of management measures; a solution could be a co-management agreement among member nations around decisions such as choice of management measures
- **Data poverty** (in general)
- **Management units that cover only part of biological units and/or have different data sources and methods for each** (Georges Bank haddock, shellfish)
- **Multiple assessment or biological units in one management unit**
    - For invertebrates – LRP at bed level or stock level?
    - **Resolution of mismatch between Salmon SMUs and CUs**: LRPs define on basis of one or more CUs falling into “red zone” of WSP
- **Sessile invertebrates** where life history parameters and environmental variables vary over fine spatial scales and which may be naturally more abundant in some areas than others; understanding of what a stock is may depend on “best available information”
- **Coast-wide stocks where management and assessment are very limited in scale** (swimming scallops, green sea urchins, some clams)
- **Incorporating ecosystem approaches (EAFM) into reference points** (i.e., non-stationarity versus intermittently static estimates of LRPs, the need for ecosystem-level LRPs)

- **Stocks depleted because of poor prevailing productivity conditions**
- **Identifying "stocks" and their scale/structure**
- **Definition of "stock"** (i.e., it should be biologically defined given that LRPs are supposed to be biologically based on concept of serious harm)

Recommended References

Several respondents suggested references for selection of indicators and LRPs:

- Forrest, R.E., Rutherford, K.L, Lacko, L., Kronlund, A.R., Starr, P.J., and McClelland, E.K. 2015. Assessment of Pacific Cod (*Gadus macrocephalus*) for Hecate Strait (5CD) and Queen Charlotte Sound (5AB) in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/052. xii + 197 p.
- Forrest, R.E., Holt, K.R., and Kronlund, A.R. (2018). Performance of alternative harvest control rules for two Pacific groundfish stocks with uncertain natural mortality: bias, robustness and trade-offs. *Fisheries Research*, *206*, 259-286.
- Kronlund, A.R., Forrest, R.E., Cleary, J.S., and Grinnell, M.H. 2017. The Selection and Role of Limit Reference Points for Pacific Herring (*Clupea pallasii*) in British Columbia, Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/009. ix +125 p.
- Mace, P., and Sissenwine, M. 1993. How much spawning per recruit is necessary. *Risk evaluation and biological reference points for fisheries management*, *120*.
- Peacock, S.J., and Holt, C.A. 2010. A review of metrics of distribution with application to Conservation Units under Canada's Wild Salmon Policy. Can. Tech. Rep. Fish. Aquat. Sci. 2888: xii + 36 p.
- Peacock, S.J., and Holt, C.A. 2012. Metrics and sampling designs for detecting trends in the distribution of spawning Pacific salmon (*Oncorhynchus* spp.). *Canadian Journal of Fisheries and Aquatic Sciences*. 69(4): 681-694.

APPENDIX 5 – BREAKOUT GROUP EXERCISES GITHUB LINK

Refer to the workshop Github repository for R code and supplementary materials.