SCIENCE ADVICE FOR PRECAUTIONARY APPROACH HARVEST STRATEGIES UNDER THE FISH STOCKS PROVISIONS

Figure 1: The six administrative regions of Fisheries and Oceans Canada.

Context:

Bill C-68 received Royal Assent on June 21, 2019, resulting in revisions to Canada's Fisheries Act. *Changes to the* Act *include new Considerations and Fish Stocks provisions that introduce legal requirements to promote sustainability, avoid limit reference points and implement rebuilding plans for depleted stocks, all while taking into account fish biology and environmental conditions. The Fish Stocks provisions will apply to stocks prescribed under regulation; the requirements of the provisions will be interpreted through application of a suite of policies included in the Sustainable Fisheries Framework (SFF), in particular the Fishery Decision-Making Framework Incorporating the Precautionary Approach (PA Policy, DFO 2009).*

This is the first in a series of CSAS reports to provide advice to DFO Science to enable consistent and coherent approach for science support of FSP activities. The advice contained in this Science Advisory Report has specifically examined the legislative Considerations and Fish Stocks provisions for implications to fisheries science activities and scientific advice for fish stocks. This advice contains both what additional information, activities or analyses will better enable Science support, as well as suggestions for how this support should be provided.

Subsequent CSAS advisory processes will focus on specific FSP science topics, such as providing advice for management measures across a spectrum of data availability for Canada's fish stocks, and the estimation of limit reference points. The results of this series of FSP advisory processes will be used to develop operational guidelines for DFO Science Sector supporting the provision of fisheries science advice to meet the requirements of the new legislation and DFO's PA Policy.

This Science Advisory Report is from the May 26-27 and June 22-23, 2020 national advisory meeting on Science Advice For Precautionary Approach Harvest Strategies under the Fish Stocks Provisions. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule]() as they become available.

SUMMARY

- This Science Advisory Report (SAR) provides advice to the Science Sector concerning the implications of the revised *Fisheries Act* (2019), particularly the Fish Stocks provisions (FSP). The FSP are viewed in light of Canada's *Fishery Decision-Making Framework Incorporating the Precautionary Approach* (the 'PA Policy'). The advice is organized into sections according to the text of the new legislation. Key points selected from the recommendations in the body of this report appear below.

"Major fish stocks" in the context of the "limit reference point"

- A single limit reference point (LRP) may be required for those major fish stocks prescribed under the FSP, but at present it is not always the case that major stocks have a single LRP due to varying degrees of disaggregation of stock subunits.
- There is a need to consider the role of LRPs relative to three scenarios (i.e., the spatial distribution of the stock is the same as that of the biological unit, the stock (subunit) is smaller than the biological unit, and stock is larger than the biological unit).
- There is a need for Science guidelines to address situations where scale mismatch between the stock definition, LRP choice, and data collection may reduce effectiveness of management measures with respect to desired outcomes, as well as a need to identify approaches to resolving such effects.

"The level necessary to promote sustainability of the stock"

- Definitions of *sustainability* and related terms generally recognize both *time* (i.e., some state that is achieved or sustained over the long-term) and the need for equitable availability of *benefits* across generations of resource users. Both considerations are consistent with the precautionary approach and the PA Policy.
- Promoting sustainability based solely on consideration of biological elements would prioritize management objectives related to conservation alone, at the expense of considerations of resource use. Without targets or thresholds and management measures it is not possible to operationalize sustainability in ways that reflect not only conservation, but also socio-economic, cultural, or other objectives for the stock and dependent fisheries.
- A definition of a *level necessary to promote sustainability of the stock* is suggested as *"a threshold representing a specified level of practical and effective resource use over the long term*." This threshold, set below a higher target, must be above the LRP to be consistent with promoting stock sustainability.
- Thresholds representing a "*level necessary to promote sustainability of the stock*" in s 6.1(1) and lower levels that still enable a stock to be maintained acceptably above the LRP in s 6.1(2) differ as a result of trade-offs among conservation, socio-economic and cultural outcomes for the stock and fisheries.

- Fish stocks could be evaluated under the FSP using a composite performance measure of sustainability based on elements of the PA Policy. Evaluation would consider whether a stock is within limits (i.e., status exceeds the LRP and falls below a limiting fishing mortality rate represented by the Removal Reference (RR) in the PA Policy). Evaluation would also consider whether management measures perform acceptably with respect to avoiding limits and achieving targets over specified time frames.

"…Taking into account the biology of the fish and environmental conditions affecting the stock"

- There is a need to take into account a range of life histories, data availability and understanding of stock biology and environmental conditions in providing science advice. Science guidelines are needed to help the Science Sector:
  - communicate how biological and environmental considerations are reflected in analyses and alternative hypotheses about stock dynamics;
  - document what considerations were explored, and the rationales for their inclusion in advice, or explanations of why such linkages could not be demonstrated;
  - demonstrate how such considerations can be incorporated by providing science advice on management measures that aim to be robust to a range of plausible stock and fishery dynamics related to environmental considerations.

Status relative to "the limit reference point"

- Science guidelines should establish consistency in the way that stock status is determined and reported relative to the LRP, with respect to uncertainty and time. Where status determination has invoked the need for a rebuilding plan under s 6.2(1), consistency in the way stock status is determined and reported relative to an agreed upon rebuilt state should similarly be established.

"Minimizing further decline of the fish stock"

- Science guidelines for developing rebuilding strategies should describe the means by which alternative management measures can be evaluated with respect to defined management objectives and associated performance measures.
- Such evaluations can provide support for amendments to rebuilding plans under s 6.2(2) that could meet the legal obligation to minimize further decline of the stock, and the PA Policy intent of "no tolerance for preventable decline" when a stock is below a LRP.

"If… the loss or degradation of the stock's fish habitat has contributed to the stock's decline"

- As for the consideration of environmental conditions, it is recommended that science guidelines be developed that should address how to:
  - communicate habitat considerations;
  - link such information to hypotheses for stock response (documenting rationales for inclusion in advice, or explanations of why such linkages could not be demonstrated);
  - demonstrate how such considerations can be incorporated into science advice; and

    - advise on the likely tradeoffs that result from alternative habitat restoration measures.

Implementation Needs for Science

- Science guidelines should address the roles of limit, threshold and target reference points, and address how these may be expressed as biomass or fishing mortality metrics (or suitable alternatives) for a range of life histories and data/model availability.
- Science guidelines can distinguish reference points from management measures (e.g., operational control points in harvest control rules (HCRs)), and identify how different management measures that may include HCRs can be evaluated with respect to objectives concerning limits, thresholds and targets.
- There is a need for methods to meet PA Policy intent for data-poor contexts where it may not be possible to reliably determine reference points, stock status or whether fishing at rates above a limiting rate (overfishing) is occurring.
- International comparisons suggest that limit fishing mortality rates need not be segmented to vary with stock abundance. PA Policy intent can still be met by application of management measures that reduce fishing mortality rates as stocks decline in order to acceptably avoid LRP breaches. The Science Sector can report on stock status and evaluate management measures relative to limit fishing rates such as F_{MSY} or proxies, or suitable alternatives when available.
- Identification of the intended function(s) of the upper stock reference (USR) and RR in stock-specific contexts is needed to clarify science advice on the selection of management measures intended to meet specified objectives. Assigning the USR a role as a target or threshold reference point to be achieved, rather than its primary role in managing the risk of a LRP breach, means that distinguishing operational control points (in management measures) from reference points (in management objectives) is critical.
- It is recommended that the Science Sector engage in discussions with other DFO Sectors to clearly define the role of targets and thresholds in the context of conservation and sustainable resource use to ensure consistency of application across stocks, standardize reporting, and investigate the application of risk equivalency.

Roles and Responsibilities of the Science Sector

- Consistent with the PA Policy, the Science Sector establishes LRPs, and evaluates stock status against *B*- and *F*-based limit and target reference points whether based on maximum sustainable yield (or proxies), or alternatives.
- Science requirements for the implementation of s 6.1 can be interpreted as characterization of stock status, and support for the identification of effective management measures that aim to achieve thresholds that "*promote the sustainability of the stock*" (s 6.1.1) or lower levels that maintain stocks above the LRP (s 6.1.2).
- Reference points and the acceptable risks associated with failing to either achieve targets or thresholds, or avoid limits, over specified time frames are captured in fisheries management objectives. Objectives reflect value-based goals and cannot be established based solely on scientific considerations.

1. INTRODUCTION

Bill C-68 received Royal Assent on June 21, 2019, resulting in a revised *Fisheries Act* that contains new Considerations and Fish Stocks provisions (FSP) that relate to the management of fisheries. More specifically, Section 2.5 of the *Fisheries Act* ("Considerations for decision making") identifies factors that the Minister may consider when making decisions, including the application of a precautionary approach and an ecosystem approach, the sustainability of fisheries, scientific information, Indigenous knowledge of the Indigenous peoples of Canada that has been provided to the Minister, and community knowledge, among others. Section 6 of the *Fisheries Act* ("Fish Stocks") outlines new requirements to implement measures to maintain major fish stocks at or above the level necessary to promote the sustainability of the stock, or above the limit reference point, or to develop and implement plans to rebuild major fish stocks that have declined to, or below the limit reference point, all while taking into account the biology of the fish and the environmental conditions affecting the stock. The provisions only apply to major fish stocks prescribed by regulation.

These changes to the *Fisheries Act* have implications for fisheries science activities and scientific advice provision. Here the Ecosystems and Oceans Science Sector ("Science Sector") examines the implications of the revisions in the light of an existing suite of fisheries policies for Fisheries and Oceans Canada (DFO) encompassed by the Sustainable Fisheries Framework (SFF), and in particular the national *Fishery Decision-Making Framework Incorporating the Precautionary Approach* (PA Policy, DFO 2009; Figure 2). In the short term, the results of this analysis will be used by the Science Sector to develop national operational guidelines for fisheries science ("science guidelines"), analogous to those produced by other jurisdictions. The purpose of developing guidelines is to promote best practices and national consistency in the provision of science advice aligned with the obligations of the new legislation and the intent of the PA Policy. Science guidelines will support the broader Departmental endeavour to implement the FSP across multiple sectors.

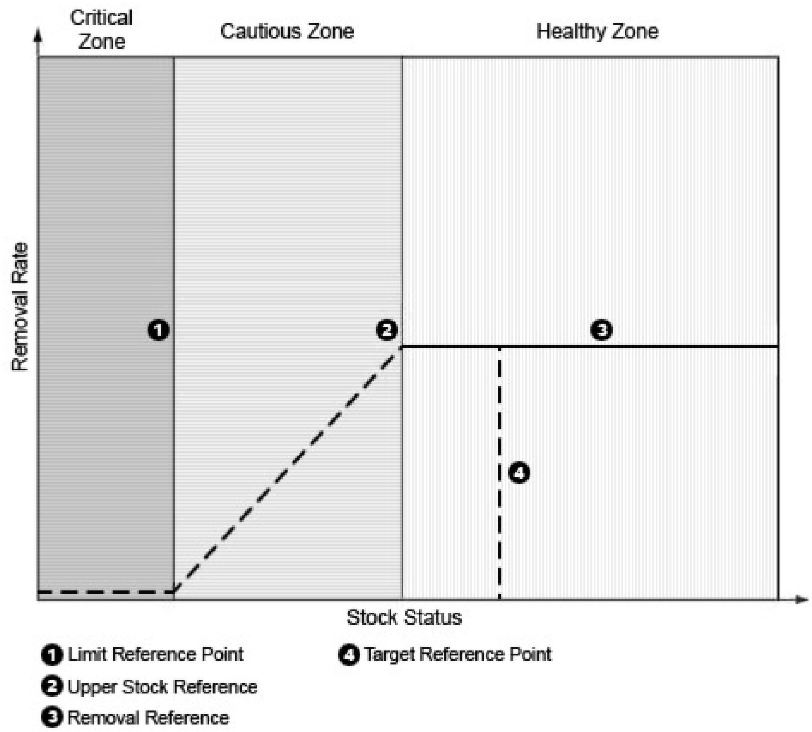

Figure 2: Canada's national Precautionary Approach Framework illustrating four types of reference points (limit reference point, upper stock reference, removal reference, target reference point) and three stock status zones (Critical, Cautious and Healthy) in terms of abundance, biomass or a proxy. The framework further classifies "fishery status" (stock status in terms of removal rate, fishing mortality or proxy) as either "at or below" or "above" the removal reference to yield a total of six zones. Other key components of the PA Policy include a harvest strategy with harvest decision rules, and the need to take into account uncertainty and risk, as well as an expectation to evaluate harvest strategy performance (DFO 2009).

Given the context outlined above, this Science Advisory Report (SAR) is a review of the scientific implications of the Considerations and Fish Stocks provisions, taking into account the broader body of peer-reviewed literature and current international practices in fisheries management science. The operational implications for the Science Sector are examined, followed by recommendations that should be reflected in the content of science guidelines. Finally, the overall implementation needs and the roles and responsibilities of the Science Sector in conducting activities that inform harvest strategies are described.

This is the second in a series of national advisory processes supporting the implementation of the new Fish Stocks provisions. The first national advisory process explored potential elements of Science guidelines to support development of rebuilding strategies and plans for Canadian fish stocks (DFO 2021). The advice and recommendations from these advisory processes will inform the development of science guidelines. It is also anticipated that policy guidance to support the FSP will be updated over time so the development of science guidelines should be expected to evolve iteratively with the emergence of new or revised policy.

2. ANALYSIS

2.1 "Major fish stocks" in the context of the "limit reference point"

Relevant Sections of the FSP [***emphasis*** added]:

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

6.1 (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.

2.1.1 Scientific Considerations

The Canadian PA Policy (DFO 2009) identifies two reference points that serve as limits, called the Limit Reference Point (LRP) and Removal Reference (RR). The LRP represents the stock status, usually in terms of biomass (or abundance), below which "serious harm" to the stock may be incurred. In Canada and elsewhere, serious harm is considered to include recruitment overfishing or other impairment to productive capacity (Shelton and Rice 2002). Serious harm to a stock may also have resultant impacts to the ecosystem, including associated species, and a long-term loss of benefits to resource users. The RR is the maximum acceptable fishing mortality (removal) rate for the stock and is understood to be a limit rate (Shelton and Sinclair 2008). The PA Policy indicates that the RR must be reduced as the LRP is approached, leading to the "segmented" depiction shown in Figure 2 as one expression of the policy intent.

A consequence of the wording of the FSP is that a single LRP may be needed for each *major fish stock* prescribed under regulations. Major stocks in Canada are generally considered to be those listed in the Departmental *Sustainability Survey for Fisheries* (Sustainability Survey, DFO 2019a) and when prescribed under regulation as *major fish stocks* will be defined, in part, geographically. Not all stocks listed in the Sustainability Survey have a single LRP due to varying degrees of disaggregation into subunits. For example, some major fish stocks consist of two or more distinct subunits each of which is assigned a unique LRP. Other major fish stocks represent a portion of a single biological population for which one overall LRP could be defined.

Definition of a Stock

Defining what constitutes a single *stock* generally involves consideration of both biological and management perspectives. A biological stock is a population of a given species that forms a reproductive unit with little or no spawning with other units, possessing shared homogenous traits such as occupying the same spatial distribution. Alternatively a stock may be defined on a functional basis for the purpose of fisheries management, in part due to uncertainties in defining spatial and temporal boundaries for biological units that are aligned with data collection. Thus, the term stock may be operationally defined with assessment and management units despite mixing of some components of the biological unit with other areas. Terminology used to describe stocks and their constituent subunits can vary widely as well; e.g., Stock Management

Units (SMUs) in the context of Pacific salmon (DFO 2005), stock components, or stock complexes (NOAA 2018).

Associating One LRP with a Stock

The LRP referred to in the text of the FSP is interpreted as being a biomass (or abundance) metric (or proxy) rather than some other metric such as fishing mortality. Hereafter the terms *biomass* (weight) and *abundance* (numbers) are intended to be inclusive of proxies that are proportional to stock size. Although avoiding serious harm is cited as the basis for biologically based LRPs, practical experience shows that it is difficult to uniquely define states of serious harm until they become quite severe; paradoxically, this is precisely the situation to be avoided. The difficulty of reliably estimating LRPs or other biological reference points based on theoretical considerations is well-established and is due to limitations in our ability to observe complex population processes (Hilborn and Walters 1992). It is easiest to associate a stock with a LRP as a threshold to serious harm when the defined stock unit for management equals the biological unit. However, stocks defined in Canada may also have multiple biological units, or may contain only part of a biological unit.

Even in cases where the stock defined for management purposes initially matched the biological unit, the biological stock boundaries can change faster than the management boundary. This can occur due to climate-driven changes in stock distribution or due to pressures from competing or predatory species. Correspondingly, collection of stock and fishery monitoring data can lag behind changes to biological stock boundaries. Where stocks contain multiple biological units, localized depletion of subunits can be masked by scale mismatch of data collection potentially resulting in a loss of genetic diversity, and stock dynamics as a whole may be harder to understand – there may be a need to consider risk tolerance for depletion of subunits (aimed at avoiding serious harm to the aggregate stock) in such cases. Where stocks contain portions of a biological unit, monitoring and evaluating productivity may be more challenging. Additionally, management strategies may need coordination across multiple “stocks” of the same biological unit to set appropriate limit thresholds and risk tolerances that ensure all components of the life history are protected. Conversely, life history characteristics may also mean that protection of components of the biological unit independently could improve the likelihood of rebuilding the biological unit from depleted states.

The PA Policy provides default guidance for the LRP in the absence of a stock-specific value and also provides alternatives to the default choice that depend on data availability. The default choice is 0.4 of the biomass at maximum sustainable yield (B_{MSY}) which assumes the biological unit equals the stock. Regardless of the stock definition, the rationale for selecting a biomass-based LRP for a stock should be described whether based on MSY reference points or proxies, historical experience, or a policy default in the absence of a stock-specific choice.

2.1.2 Implications for Science

The LRP is the only reference point cited in the Fish Stocks provisions; thus the LRP is pivotal to distinguishing science needs to support implementation of s 6.1(1) and s 6.1(2) and for determining the need for a rebuilding plan under s 6.2(1). Two scientific issues that arise are a) the biological relevance of the LRP as a threshold to possible serious harm, and b) evaluation of the performance of management measures intended to avoid a LRP breach. Poor performance of management measures can be caused by scale mismatch of control in fisheries systems that can weaken management ability to detect both undesirable states in fish populations and their responses to management measures. For example, undesirable localized depletion may occur in harvest control systems that act on an aggregate of biological subunits in the absence of any feedback about the response of the individual subunits to management measures. Thus, ensuring first that the LRP is appropriately matched to the defined stock, and second that data collection and management measures are linked to the scale of feedback effects is critical to preserving the desired risk tolerance for a LRP breach.

2.1.3 Section Summary and Recommendations

- A single limit reference point (LRP) may be required for those major fish stocks prescribed under the FSP, but at present it is not always the case that major stocks have a single LRP due to varying degrees of disaggregation of stock subunits.
- There is a need to consider the role of LRPs relative to three scenarios (i.e., the spatial distribution of the stock is the same as that of the biological unit, the stock (subunit) is smaller than the biological unit, and stock is larger than the biological unit).
- There is a need for Science guidelines to address situations where scale mismatch between the stock definition, LRP choice, and data collection may reduce effectiveness of management measures with respect to desired outcomes as well as a need to identify approaches to resolving such effects.
- A rationale should be provided for selecting a particular LRP for a stock, whether employing MSY or proxies, historical experience, empirical indicators such as in data-poor contexts, or a policy default in the absence of a stock-specific choice.

2.2 "The level necessary to promote sustainability of the stock"

Relevant Sections of the *Fisheries Act* [***emphasis*** added]:

Considerations for decision making

2.5 Except as otherwise provided in this Act, when making a decision under this Act, the Minister may consider, among other things,

(a) the application of a ***precautionary approach*** and an ecosystem approach;

(b) the ***sustainability of fisheries***;

(etc.)

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

6.1 (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

2.2.1 Scientific Considerations

Definition of Sustainability

Sustainability is not defined in the *Fisheries Act*. Common to many definitions of sustainability are two related ideas:

- **time** (i.e., there is reference to some state that is achieved over the long-term or an indefinite period), and;
- the need for **availability of benefits**, most commonly with respect to the needs of resource users, both in the present and future.

The concept of sustainability has long been recognized to consist of multiple dimensions, sometimes called axes, or pillars. This has complicated the development of performance measures to evaluate the extent to which the objective of sustainability has been—or is being—accomplished. Measures may vary widely, reflecting the components that organizations or individuals deem most important (Hilborn et al. 2015). Various international agreements and fisheries legislation in most jurisdictions recognize multiple axes of sustainability, including ecological, economic, social/cultural, and institutional objectives (Stephenson et al. 2019).

The ecological (sometimes biological) axis of fisheries sustainability receives perhaps the most attention (Stephenson et al. 2019). However, biological elements are often framed in the light of other socio-economic and cultural objectives, such as the ability to achieve maximum sustainable yield, maximum economic yield, or other targets reflecting socio-economic and cultural considerations.

Claims of sustainability (captured in DFO's schema for sustainable fisheries management, DFO 2019b) are supported by management systems that demonstrate: 1) objectives for fishing pressure and abundance, and associated monitoring; 2) assessments to determine if targets are being met acceptably; 3) feedback management systems that adjust fishing pressure in response to assessments; and 4) enforcement of management measures (Hilborn et al. 2015).

For the purposes of the Science Sector, a definition of *sustainability* is that it is a *process* (Hilborn et al. 2015) that conveys the ability to maintain *a specified level of practical and effective use of a fisheries resource over the long-term*. The term *specified level of practical and effective use* means that there are defined objectives related to stock conservation (such as avoiding recruitment impairment and/or other states considered to represent serious harm), socio-economic and/or cultural outcomes, and that these objectives are *measurable* whenever possible. Outcomes are both *practical* to achieve in terms of costs incurred to implement management measures, monitoring and assessments, and *effective* in that outcomes can acceptably meet objectives. Objectives for natural resources are value-based, necessarily conflict, and require specifying the acceptable degree of risk incurred by ongoing management choices.

"At or Above" Suggests a Threshold

The phrase *at or above* in FSP s 6.1(1) suggests a goal of aiming to either achieve, or surpass, a threshold to some higher target reference point. In Canada, targets reflect productivity objectives for the stock, broader biological considerations, socio-economic and cultural objectives for the fishery. Two biomass reference points in Canada's PA Policy can potentially serve as targets (Figure 2). The Target Reference Point (TRP) is meant to represent a desirable stock status state; targets are "required elements" under the United Nations Fish Stocks Agreement (UNFSA 1995, DFO 2009). The PA Policy also indicates the Upper Stock Reference (USR) can serve as a stock status target in lieu of a separately determined TRP. However, the primary role of the USR is to serve as a threshold to progressive reduction of the fishing mortality rate to avoid stock status reaching the LRP. The USR is also assigned the role of delineating the threshold between what are termed the Cautious and Healthy Zones.

Targets, like limits, are fundamental to the precautionary approach (FAO 1996) and are set to reflect a variety of considerations relevant to decision-makers. In general, targets are intended to be met on average, meaning about 50% of the time (Sainsbury 2008). Thresholds, buffers, triggers or other precautionary reference points, however, are used in multiple jurisdictions (Marentette and Kronlund 2020) and may be defined in relation to either limits or targets. In contrast to targets, a threshold reference point is intended to be exceeded greater than 50% of the time. In certain fisheries, or jurisdictions with mandatory or default HCRs, thresholds may be used as operational control points (OCPs) to trigger management action (e.g., Restrepo et al. 1998). They may also be used for performance reporting of stock status. A definition of a *"level necessary to promote sustainability of the stock,"* in line with the definition of sustainability proposed above, is that it is "*a threshold representing a specified level of practical and effective resource use over the long term*." Thresholds or other levels fulfilling either s 6.1(1) or s 6.1(2) differ with respect to trade-offs among conservation, socio-economic, and/or cultural objectives but must be above the LRP regardless of which section applies.

Exceptions Under s 6.1(2) Suggest Other Considerations

The phrase "*maintain the fish stock above [the limit reference point]*" cited in FSP s 6.1(2) refers to limits in biomass or abundance (LRPs) and not limits to fishing mortality or harvest rate (RR). Similar limits are used worldwide (e.g., limits in biomass or B_{lim}, for which various defaults or proxies are proposed (Sainsbury 2008)) and maintaining stocks above LRPs is integral to sustainable fisheries under management by reference points.

The dual use of "*to maintain*" (i.e., to cause or enable to continue) in the FSP ss 6.1(1) and 6.1(2) implies two different levels at which stocks are to be sustained, with the level inferred in s 6.1(2) being less than the threshold to a higher target in s 6.1(1) and with both levels above the LRP. Although neither a target nor a threshold is explicitly specified in s 6.1(2), objectives around *desired states* would be required to avoid stock biomass lingering near the LRP in the absence of an incentive for management measures intended to increase biomass to a higher level. A stock that persists near a LRP is more likely to lead to a situation that triggers the need for a rebuilding plan under s 6.2(1) of the FSP than one sustained at a higher level, possibly also incurring irreversible or only slowly-reversible serious harm. At the very least, stock biomass near a LRP may represent a loss of maneuvering room for decision-makers, loss of benefits to resource users, and potential risks to both ecosystem function and fisheries on coincident stocks.

The *feasibility or appropriateness* of the management measures provide the basis for managing a stock under s 6.1(2). Thus, the management measures intended to achieve either thresholds that represent a "*level necessary to promote sustainability of the stock*", or lower levels that enable a stock to be maintained above the LRP with some acceptable probability, will result in different conservation, cultural and socio-economic outcomes, and decision-makers will be considering trade-offs among these outcomes.

Targets Operationalize Considerations of Biological Sustainability

Acceptability of stock states has evolved over time. Limits for fishing mortality (*F*) and biomass (*B*) have been generally recognized as necessary to define what stock states can be considered sustainable since the 1980s. With the advent of the precautionary approach in the 1990s, there was a shift in view of what limits ought to be; that is, of MSY to be a limit, not a target (Mace

2001, Quinn and Collie 2005, UNFSA 1995). However, defining (biological) stock sustainability with respect to limits alone poses challenges. First, considerations of biological elements of sustainability alone would push management objectives to a logical extreme; for example, stock sustainability could be considered maximized at unfished biomass, resulting in low levels of surplus production and occurring at the cost of (any) resource use (MF 2011). On the other hand, since a broad range of stock sizes could be sustained in theory, stock sizes reduced to low levels (but above those levels associated with serious harm) could be “sustained” with some acceptable level of risk but would support only low levels of fishing on an ongoing basis (Figure 3a). Either situation would impact social, cultural and economic management outcomes with respect to resource use.

Elements of biological sustainability are thus effectively rationalized against other axes of sustainability by establishing targets and the management measures intended to attain them. For example, the determination of whether to pursue maximum long-term average yield (i.e., MSY), maximum economic yield (MEY), or any other target is a value-based choice. Identification of non-biological targets, and the certainty of achieving those targets, provide the basis for trade-offs among outcomes related to the stock preservation and benefits, and thus provides for *sustainable use* of the resource.

Evaluating Sustainability

Many jurisdictions and fisheries organizations have developed precautionary strategies that categorize stock status in ways that simplify evaluation and reporting, including Canada. However, reference points such as limits, targets and thresholds (and any associated stock status category labels) rarely mark significant or abrupt changes in actual risk (Figure 3, Sainsbury 2008). There is also “*no clear consensus or precise estimates of suitable thresholds for defining status of stocks*” (Ye 2011) across jurisdictions. Acceptable states, and the risks associated with objectives to avoid or achieve them, vary with jurisdictions according to their interests and values along multiple axes of sustainability. Some define states based on avoiding serious harm, others on achieving maximum sustainable yield, and others on a mix of both.

Stock states in the PA Policy are defined by six zones created by three categories along the stock biomass axis (i.e., Critical, Cautious and Healthy) and two categories of fishing mortality (i.e., greater than, or less than or equal to, the RR; Figure 4a). The zones relate to avoiding thresholds to impaired productivity or overfishing limits, achieving targets, and in many cases finding acceptable trade-offs with socio-economic and cultural outcomes.

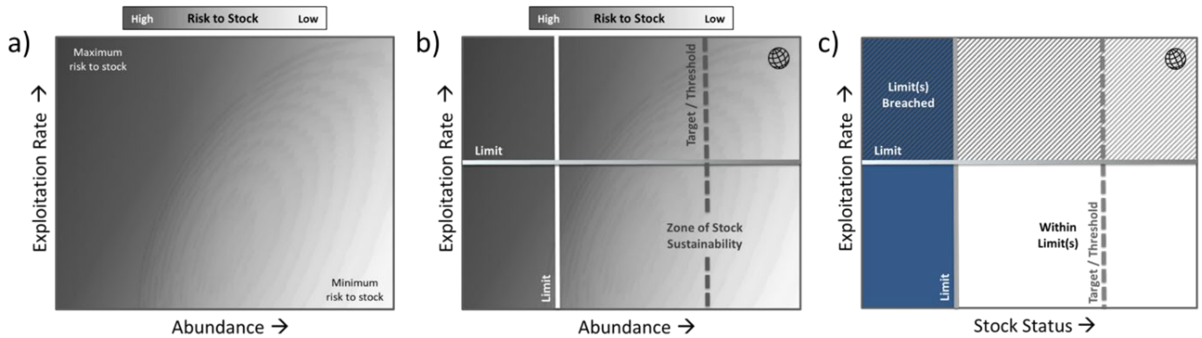

Figure 3: a) A conceptual schematic of the risk of collapse posed to fish stocks, which can be considered as a function of decreasing abundance (biomass, or proxy) and increasing exploitation rate (fishing mortality, or proxy), among other things. Actual risks, and the levels of abundance below which serious harm may be incurred, will vary from stock to stock and over time. Globes in panels b) and c) denote schematics applicable across jurisdictions. b) In general, the precautionary approach (PA) is fisheries management by limit and threshold or target reference points, that represent undesired outcomes to be avoided, and desired outcomes to be attained, respectively. These are established while taking into consideration conservation, socio-economic and cultural factors. Names, numbers and methods by which reference points may be established vary among jurisdictions, but limits are widely recognized to constrain acceptably sustainable stock states. c) Internationally, stock status can be categorized in relation to reference points represented in fisheries management objectives, as part of performance reporting (blue – below stock abundance limit, grey hatching – above exploitation rate limit, white = within limits). Names and numbers of stock status categories also vary among jurisdictions.

Canada reports on “fishery status” (with respect to stock status on the *F*-axis) as well as stock status (on the *B*-axis) for major stocks via the Canadian Environmental Sustainability Indicators (CESI) program and the Sustainability Survey. On the *B*-axis, states below the LRP (the PA Policy Critical zone) represent undesirable levels of stock abundance where serious harm may be incurred. The Cautious zone (stock states bounded by the LRP and USR) and Healthy zone (states above the USR) do not denote acceptability of stock states relative to limits or targets. These zones serve to differentiate relative levels of stock abundance, and/or zones where different types of management action may occur (although this is also true of the Critical zone). The specific management actions undertaken depend on fisheries management objectives, related to conservation, socio-economic and cultural outcomes, that specify the risk tolerance for avoiding or achieving those outcomes.

The management actions in the PA Policy generally treat stock states in the Healthy zone as desirable (e.g., management actions for stocks in the Cautious zone should promote rebuilding to the Healthy zone, and rebuilding plans in general may have long-term objectives to do so; DFO 2009, DFO 2013b), and in its development DFO (2004) noted that “[the Healthy zone] is the desired state for sustainable fisheries.” The USR, however, is not explicitly a boundary to acceptably sustainable stock states. This is because in most cases USRs are also *de facto* targets under the PA Policy, and fluctuations around targets are acceptable under the precautionary approach (e.g., UNFSA 1995). The Cautious zone is thus also not analogous to intermediary stock states conveying some degree of unacceptable risk in other jurisdictions (“increased risk”, ICES; “cautionary *F*” and “danger” zones, NAFO; “depleted”, New Zealand).

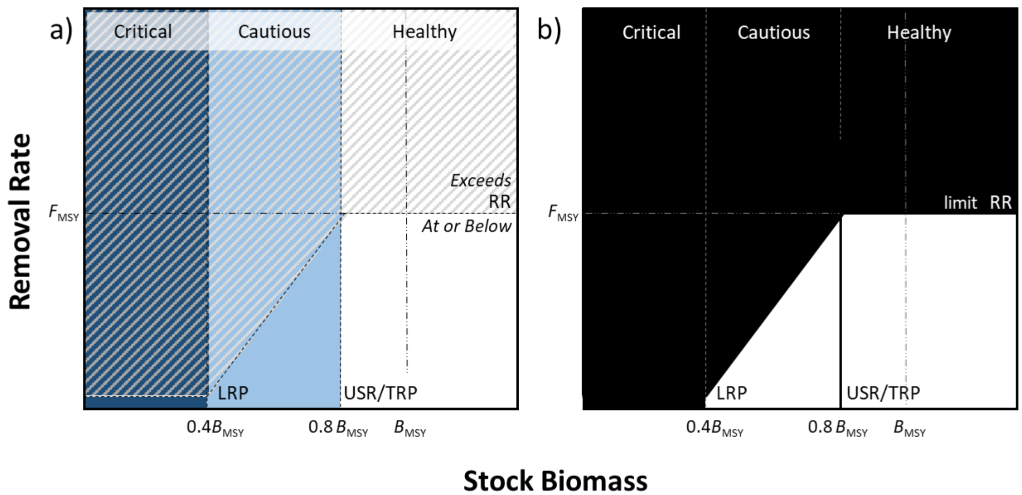

Figure 4: A comparison of a) stock status zones for the Canadian PA Policy, graphed with its default reference point configuration (LRP, USR, and three-segmented RR) with b) stock states consistent with some of the necessary conditions of sustainability proposed by Shelton and Sinclair (2008), contributing to possible performance measures for evaluating fisheries sustainability under the PA Policy. In this visualization, modeled after the style of Quinn and Collie (2005), black areas of stock states in panel b) exceed limits (LRP and/or RR) and are therefore generally considered undesirable.

Evaluating Elements of Sustainability under the Precautionary Approach

International practice and existing review of Canada's PA Policy in the context of sustainability (Shelton and Sinclair 2008) can be used to assist evaluation of sustainability claims. Criteria would consider whether:

a) stock abundance exceeds the LRP,

b) stock fishing mortality rate is below the RR (a limit), and

c) the harvest strategy contains management measures that perform acceptably with respect to achieving desired outcomes over specified time frames, i.e., stock abundance that attains and fluctuates around a target level (and/or acceptably above a threshold) and a fishing mortality rate that is acceptably less than the RR (Figure 4).

Acceptable performance with respect to these criteria c) could be demonstrated by either retrospective (past) or prospective (future) evaluation.

Evaluating Time, Other Biological Elements and Other Axes of Sustainability

Biological elements such as stock states in relation to reference points are often the most well developed form of performance reporting. These elements are directly relevant to components identified in the PA Policy, but it remains important to consider harvest strategies as a whole when evaluating sustainability. Limits, thresholds and targets along either the *F*- or *B*-axes of status determination do not function in isolation but are embedded in management objectives that constrain the choice of management measures expected to result in acceptable outcomes. Demonstrating that such objectives and management measures exist and function acceptably (as proposed by Shelton and Sinclair 2008) also accounts for the temporal aspects of biological sustainability (i.e., whether acceptable stock states can be expected to persist in the future).

Other axes of sustainability considered from a "*post-modern*" perspective (Quinn and Collie 2005) can be captured in objectives related to socio-economic, or institutional values, or even other biological elements such as habitat, trophic and ecosystem considerations, discarding and bycatch, or interactions with protected and iconic species (Fletcher et al. 2005, Stephenson et al. 2017). These other axes form important parts of harvest strategies in providing benefits to resource users and in implementing an ecosystem approach to fisheries management. They also can generate performance measures that can be used in supporting claims of a sustainable stock and dependent fisheries. Socio-economic and cultural axes of sustainability may merit further consideration by other Sectors.

2.2.2 Implications for Science

The inclusion of multiple axes in the definition of sustainability indicates that sustainability cannot be solely determined by biological considerations. The Science Sector can and ought to identify biological conditions necessary for stock preservation subject to specific assumptions. Scientists also have a role in evaluating the consequences of applying management options since scientific data and methods are likely to be needed for such analyses, including simulation-based evaluations of likely future management performance where feasible. Desired trade-offs between conservation, socio-economic and cultural outcomes may result in a target level above the LRP but below, for example, B_{MSY} targets in some contexts (e.g., in multi-stock fisheries). Conversely, the target level may be above B_{MSY} to increase fishery profitability through higher catch per unit effort at an increased level of biomass, or to provide needed ecosystem services for dependent predators.

2.2.3 Section Summary and Recommendations

- Definitions of *sustainability* and related terms generally recognize both *time* (i.e., some state that is achieved or sustained over the long-term) and the need for equitable availability of *benefits* across generations of resource users. Both considerations are consistent with the precautionary approach and the PA Policy.
- Promoting sustainability based solely on consideration of biological elements would prioritize management objectives related to conservation alone, at the expense of considerations of resource use. Without targets or thresholds and management measures it is not possible to operationalize sustainability in ways that reflect not only conservation, but also socio-economic, cultural, or other objectives for the stock and dependent fisheries.
- *Fisheries sustainability* can be defined as a *process* that conveys the ability to maintain *a specified level of practical and effective use of a fisheries resource over the long-term*.
- A *specified level of practical and effective use* means that there are measurable objectives related to stock conservation, socio-economic and cultural outcomes. These outcomes are *practical* to achieve in terms of costs incurred to implement management measures, monitoring and assessments; and *effective* in that outcomes can acceptably meet objectives. Objectives for natural resources are value-based, necessarily conflict, and require specifying the acceptable degree of risk incurred by ongoing management choices.
- A definition of a *level necessary to promote sustainability of the stock* is suggested as *"a threshold representing a specified level of practical and effective resource use over the long term*." This threshold, set below a higher target, must be above the LRP to be consistent with promoting stock sustainability.

- Thresholds representing a "*level necessary to promote sustainability of the stock*" in s 6.1(1) and lower levels that still enable a stock to be maintained acceptably above the LRP in s 6.1(2) differ as a result of trade-offs among conservation, socio-economic and cultural outcomes for the stock and fisheries.
- Fish stocks could be evaluated under the FSP using a composite performance measure of sustainability based on elements of the PA Policy. Evaluation would consider whether a stock is within limits (i.e., status exceeds the LRP and falls below a limiting fishing mortality rate represented by the Removal Reference (RR) in the PA Policy). Evaluation would also consider whether management measures perform acceptably with respect to avoiding limits and achieving targets over specified time frames.
- Other axes (such as socio-economic or cultural outcomes) and other ecosystem elements (such as biodiversity, trophic level, or habitat considerations) may also be incorporated into fisheries management objectives and could be accounted for in evaluating stock and fishery sustainability.

2.3 "…taking into account the biology of the fish and the environmental conditions affecting the stock."

Relevant Sections of the *Fisheries Act* [***emphasis*** added]:

Considerations for decision making

2.5 Except as otherwise provided in this Act, when making a decision under this Act, the Minister may consider, among other things,

(a) the application of ***a precautionary approach and an ecosystem approach***;

(b) the sustainability of fisheries;

(etc.)

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

6.1 (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***.

Plan to rebuild

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.

2.3.1 Scientific Considerations

The FSP require the Minister to implement measures while taking into account fish biology and environmental conditions (e.g., oceanography, climate drivers, habitat), a phrase that is common to ss 6.1 and 6.2(1). A LRP is also required under ss 6.1(2) and 6.2(1). In providing Science support to the FSP implementation, taking into account biology of the fish and environmental conditions indicates that scientific analyses to support decision-making should, where possible:

- Consider hypotheses to represent the effects of such factors on fish stocks, reference point selection, and on the management measures necessary to maintain fish stocks at specified levels or rebuild fish stocks from below a LRP; and
- Provide a means of evaluating the performance of management measures intended to take into account fish biology and environmental conditions in order to communicate trade-offs among management outcomes that may differentiate among ss 6.1(1), 6.1(2) and 6.2(1).

Fish Biology

Fish biology is almost always taken into account in stock assessments; most stock assessment models represent the biological processes of recruitment, growth and mortality from natural causes as well as mortality from fishing processes to varying levels of complexity. These processes are reflected in both the selection and estimation of biological reference points. For example, MSY-based reference points derived under catch-at-age assessment models require information on stock and recruitment, spatial and sub-stock dynamics, natural mortality, growth, maturity, and fishery selectivity. In fact, values of biological reference points are determined by structural assumptions about population processes in a stock assessment model, statistical error assumptions, and the available biological and fishery monitoring data. Estimates of key stock assessment parameters and biological reference points integrate fish biology as well as the environmental and fishing effects experienced by the stock over time, although the relative degree to which any given factor influenced the stock trajectory may be difficult to disentangle.

However, many existing methods for incorporating biology are tailored to finfish and difficult to apply to other life histories, such as those found in invertebrate stocks. Acceptable practice should be inclusive of the variety of life-history types, acknowledge international best practice, and focus on preserving PA Policy intent in the design of harvest strategies.

Environmental Conditions

The new *Fisheries Act* identifies both the precautionary approach and an "*ecosystem approach*" under the factors that the Minister may consider when making decisions in s 2.5. Sections 6.1(1), 6.1(2) and 6.2(1) note that management measures must take into account "*the environmental conditions affecting the stock.*" Single-species management that focuses on a single stock and dependent fisheries may be augmented by the addition of other factors such as climate, oceanographic and ecosystem drivers that can influence stock productivity, leading to an *ecosystem approach to fisheries management* (EAFM). The degree of complexity in accounting for environmental conditions may depend on the degree of understanding of underlying mechanisms, or estimates of the likely direction and magnitude of environmental effects on population processes. Management measures aimed at achieving desired outcomes when accounting for environmental conditions may depend on objectives (and priorities among those objectives) beyond those typically included in single-species management approaches.

Drivers of stock population processes due to environmental factors such as climate change may manifest as changes in productivity, migration, susceptibility to predators, or distributional shifts that can have profound effects on fish yield. Gaining improved understanding of the likely effects of such factors can be challenging due to transient linkages between environmental variables and recruitment time series, the difficulty of recruitment time series being shorter than the span of changes in productivity regimes or the extent of directional change, high variability that makes it difficult to detect changes, and the absence of a reliable means of predicting phenomena like regime shifts or cascading ecosystem effects. Nevertheless, development of scientific hypotheses that underlie environmentally-driven changes to fish stock dynamics is needed to facilitate their consideration in scientific advice. This is inclusive of both "mechanistic" and "empirical" approaches, which respectively estimate structural relationships between environmental factors and stock dynamics, or evaluate possible scenarios based on the likely effects of environmental drivers on key population parameters where mechanisms are not well-known (Punt et al. 2014).

2.3.2 Implications for Science

The need to take into account environmental conditions under the FSP has two implications. First, any approach to identifying reference points and maintaining fish stocks at a specified level, or rebuilding depleted fish stocks, needs to consider alternative hypotheses to represent the effects of such factors where they can be identified. Around a quarter of Canadian stock assessments incorporated environmental conditions (inclusive of climate, oceanographic and ecological considerations) in providing science advice. This varied considerably among taxonomic groups and was more common where mechanistic links to drivers were apparent, indicating that alternative approaches to providing risk-based advice may be needed, such as in considering the impacts of climate change (DFO 2019c, Duplisea et al. 2019, Pepin et al. 2020). Second, given the potential risks of adjusting reference points and management measures where mechanisms are not well understood, a means of evaluating the expected performance of management measures that account for environmental conditions should be introduced. One such approach relies on simulation experiments to test whether improvements to decision-making are likely to accrue. Reference points may or may not change as a result of accounting for environmental factors, but management measures can be adjusted in an attempt to improve the acceptability of management outcomes and eliminate those options that are likely to fail in practice.

2.3.3 Section Summary and Recommendations

- There is a need to take into account a range of life histories, data availability and understanding of stock biology and environmental conditions in providing science advice. Science guidelines are needed to help the Science Sector:
    - communicate how biological and environmental considerations are reflected in analyses and alternative hypotheses about stock dynamics;
    - document what considerations were explored, and the rationales for their inclusion in advice, or explanations of why such linkages could not be demonstrated;
    - demonstrate how such considerations can be incorporated by providing science advice on management measures that aim to be robust to a range of plausible stock and fishery dynamics related to environmental considerations.

- Risk-based methods can be used to evaluate the performance of management measures and impact of environmental conditions within a common framework.

2.4 Status relative to the "limit reference point"

Relevant Sections of the FSP [***emphasis*** added]:

Limit reference point

6.1 (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.

Plan to rebuild

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.

2.4.1 Scientific Considerations

Sections 6.1(2) and 6.2(1) of the FSP require determination of whether a stock is above, or at or below its LRP, respectively. A stock at or below its LRP triggers a requirement for a rebuilding plan. Prior definition of what constitutes a stock in need of rebuilding, as well as what constitutes a rebuilt stock, are cited as attributes of successful rebuilding plans (Murawski 2010, NRC 2014).

The determination of stock status relative to the LRP requires more than consideration of biomass relative to a limit. First, *uncertainty* in both the abundance metric and reference point estimate needs to be considered to determine the probability that the limit has been breached, where probabilities can be calculated. Then, the acceptable *risk tolerance* for a breach of the limit should be specified. Finally, *time* needs to be considered as the determination of a limit breach could be based on the current estimate of status, or the projected status of the stock at some future time.

The PA Policy guidance to initiate a rebuilding plan when the stock declines past the mid-point between the LRP and USR has analogous intent to actions triggered at the *soft limit* of the New Zealand harvest policy (MF 2011). However, in some contexts there may be a number of criteria that are used to determine status, i.e., no one single metric is used to trigger a limit breach, but a combination of factors that uses information on current abundances, trends in abundance over time, distribution of spawners, and fishing mortality relative to stock productivity (e.g., Pacific salmon, Holt et al. 2009).

There is no international consensus on when and if rebuilding plans should be in place and over what time periods; most jurisdictions indicate that rebuilding actions are required when stocks decline below a limit, but in New Zealand, this function is served by the *soft limit* (MF 2011) that is distinct from and greater than the *hard limit* but less than a target reference point. A stock is considered rebuilt when there is at least a 70% probability of exceeding the target biomass (e.g., B_{MSY} or proxy, possibly modified by other considerations). In addition, there should be at least a 90% probability that stock biomass exceeds the soft limit (MF 2011).

Sainsbury (2008) noted that internationally, rebuilding targets are set so that biomass will "mostly" (50 to 75% of time) be above B_{MSY}, and stocks at target levels should have a very low chance of being near the LRP. In addition, it should be demonstrable that management procedures, inclusive of harvest control rules (HCRs) and triggers (Dowling et al. 2015), have a good chance of allowing the stock to achieve targets and avoid limits. This capacity should be considered under a reasonable range of possible circumstances that the stock/fishery could face, not just on average conditions or assuming perfect knowledge.

2.4.2 Implications for Science

Guidance is needed to define criteria for determining the occurrence of a LRP breach, thus providing consistency in declaring the need for a rebuilding plan under s 6.2(1). Similar considerations are needed to define when a rebuilt state has been achieved in order to prescribe stocks under s 6.1 rather than s 6.2. Criteria for status determination should include probabilities (relative to reference points) where they can be calculated, and whether the status is based on a current or projected state. Further information is needed to understand how and whether requests for advice for recovery plans under the *Species At Risk Act* will intersect with rebuilding plans under the *Fisheries Act*, taking into account mismatches between defined stocks and Designatable Units as used by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). There is no consistent standard by which to determine and report stock status in science advice, which under the FSP may now invoke the need for a rebuilding plan.

There is also a need to interpret PA Policy intent for data-poor contexts where it may not be possible to reliably determine reference points, and therefore stock status in terms of biomass, abundance or fishing mortality (see Section 2.7 Implementation Needs for Science). In these cases, precautionary management could be defined by evidence that management actions can be reasonably expected to meet objectives, coupled with a plan to reduce data poverty. Acceptable approaches to implementing the PA Policy should not be static but should instead reflect a culture of learning and revision given domestic experience and international advances in practices.

2.4.3 Section Summary and Recommendations

- In general, stock status relative to the LRP requires consideration of uncertainty, time and specified risks of breaching the LRP.
- Science guidelines should establish consistency in the way that stock status is determined and reported relative to the LRP, with respect to uncertainty and time. Where status determination has invoked the need for a rebuilding plan under s 6.2(1), consistency in the way stock status is determined and reported relative to an agreed upon rebuilt state should similarly be established.
- Where necessary, the Science Sector should consider ways to integrate science advice for rebuilding plans with those of recovery plans for the *Species at Risk Act*.

2.5 "Minimizing Further Decline of the Fish Stock"

Relevant Sections of the FSP [***emphasis*** added]:

Plan to rebuild

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.

Amendment

(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*.**

2.5.1 Scientific Considerations

Section 6.2(2) of the FSP indicates that as a result of adverse socio-economic or cultural impacts, rebuilding plans or their implementation periods may be amended to mitigate those impacts while minimizing further stock decline. Reasons for the adverse socio-economic or cultural impacts cited in s 6.2(2) may be diverse, but result from the expected or realized tradeoffs in outcomes under management measures specified in (or under development for) a rebuilding plan under specific timeframes. It is possible that rebuilding plans may be amended because actual rebuilding performance may not meet prior expectations in terms of the rate of stock transition from depleted to target harvest levels. This result may occur for various reasons such as unforeseen losses in productivity due to climate change or other factors, or unanticipated difficulties in implementing rebuilding measures. Understanding what, and why, rebuilding plan amendments are being proposed is necessary for fishery scientists to help evaluate the consequences of adapting management measures or revising timelines.

To "*minimize*" means to reduce to the smallest amount, and "*further decline*" suggests the need to specify an acceptable risk tolerance for stock decrease from the current to the next evaluation period. Like other management objectives, rebuilding objectives should be measurable, consisting of a defined outcome, desired probability of achieving that outcome where one can be calculated, and a time-frame for evaluating whether the outcome has been achieved.

2.5.2 Implications for Science

Operationalizing criteria to judge whether *minimizing further decline of the fish stock* is achieved requires that the period for evaluation is specified. If the evaluation period is the length of the rebuilding plan period, then interim evaluations may be needed to assess performance, incorporate new information, and accommodate adaptation of the plan. In addition, a means of determining the recent or future stock trajectory based on stock reconstructions from assessments, forecasting, or simulations of the fisheries system may be needed. The challenge is that meeting this need depends on the extent of data- and model-poverty which in turn affects the availability and reliability of stock reconstructions and forecasts. Where there are limitations to providing risk-based evaluations, a pass/fail threshold, or subjective risk assignments might be made based on expert judgement in applying a weight-of-evidence approach (e.g., Health Canada 2018; IPCC 2010). Acceptable risk levels may be provided by decision-makers, but there may be little maneuvering room to avoid further decline, and ultimately complete cessation of fishing might be the only feasible option that creates conditions for stock growth. This might limit the range of feasible management measures aboutwhich science advice could be requested.

Providing advice in support of amended rebuilding plans under s 6.2(2) requires an understanding of feasible options for management measures, inclusive of input and output controls, and a means of evaluating their performance (i.e., defined performance measures) in light of specified rebuilding objectives. Science guidance for rebuilding strategies that support rebuilding plans should consider precedents, both positive and negative, from rebuilding strategy advice already provided worldwide over a range of stock contexts (e.g., NRC 2014).

An understanding of "further decline" requires information on stock trajectory, evaluation periods over which decline will be estimated, and acceptable risk tolerances. As noted above (Section 2.3 "…*taking into account the biology of the fish and the environmental conditions affecting the stock*.") and below (Section 2.6 "*If… the loss or degradation of the stock's fish habitat has contributed to the stock's decline*…"), there is a need to account for possible hypothesized drivers of stock depletion in science advice. This is a non-trivial task, as it includes consideration of how and whether environmental and/or fishing-related factors may have contributed to stock decline in the past and whether those conditions, and their relative impacts, have changed over time (or may do so in future). Such factors may also disproportionately confer risk to depleted versus more abundant stocks, such that taking those factors into account necessarily requires consideration of stock size. Attribution of stock depletion to environmental factors should not be taken as an indication that fishing mortality has little or no effect without evidence that is the case. An approach for proposed rebuilding strategies may be to evaluate the robustness of management measures in the face of uncertain and possibly multiple hypotheses regarding the interaction of biological and environmental conditions and the effects of fishing.

2.5.3 Section Summary and Recommendations

- Science guidelines for developing rebuilding strategies should describe the means by which alternative management measures can be evaluated with respect to defined management objectives and associated performance measures.
- Such evaluations can provide support for amendments to rebuilding plans under s 6.2(2) that could meet the legal obligation to minimize further decline of the stock, and the PA Policy intent of "no tolerance for preventable decline" when a stock is below a LRP.

2.6 "If… the loss or degradation of the stock's fish habitat has contributed to the stock's decline…"

Relevant Sections of the FSP [***emphasis*** added]:

Restoration measures

6.2 (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***.

2.6.1 Scientific Considerations

Fish habitat is defined in the *Fisheries Act* as:

> "*water frequented by fish and any other areas on which fish depend directly or indirectly to carry out their life processes, including spawning grounds and nursery, rearing, food supply and migration areas*."

This definition is similar to that found under s 2 of the *Species at Risk Act* for the term c*ritical habitat*, namely "*the habitat that is necessary for the survival or recovery of a listed wildlife species*". There is also recognition of the importance of habitat restoration and enhancement in DFO's policy guidelines for rebuilding plans (DFO 2013). For some stocks, habitat availability and suitability may play a role in overall rebuilding success, particularly for freshwater and diadromous species.

Science advice in support of evaluating the role of loss, or degradation, of fish habitat in stock decline (and the success of rehabilitation measures, where applicable), may employ tools such as pressure-state-response models and benefit from more systematic collection of habitat data. Earlier advice related to the Fisheries Protection Program (e.g., DFO 2014, DFO 2017) can provide useful tools such as Pathways of Effects or equivalency for calculating offsetting measures. Where available information on the role of habitat is limited, weight-of-evidence approaches and expert judgement may be required.

Habitat restoration may also be a goal in some rebuilding plans. Knowledge of limiting factors, appropriate structural designs, and long-term maintenance are all known to affect the success of habitat restoration or other offsetting projects. Establishing and evaluating acceptable performance with respect to habitat targets can be done in several ways, as reviewed by Smokorowski et al. (2015). For example, in nursery habitat, performance metrics can include density of juveniles and adults; for migration habitat, successful passage of all relevant life stages. Assessments should also be done at appropriate timescales before and after changes to quantify the results of interventions aimed at improving stock states via enhancements to habitat. A standardized before-after-control-impact (BACI) approach, with clear objectives and adequate expertise/personnel is ideal. Functional monitoring to assess the effectiveness of habitat restoration measures, when required in some rebuilding plans, may best apply when there is a clear link between fish productivity and habitat function.

2.6.2 Implications for Science

Fish habitat assessment and management is a complex problem compounded by scale. Multiple sectors/government agencies and stakeholders may be involved. DFO Sectors and programs that intersect with fish habitat include not only the Fish and Fish Habitat Protection Program, but also Fisheries Management, Species at Risk, and the Oceans Programs. Where information on habitat is limited, a heavy emphasis on expert judgement may be required.

2.6.3 Section Summary and Recommendations

- As for the consideration of environmental conditions, it is recommended that science guidelines be developed that should address how to:
    - communicate habitat considerations;
    - link such information to hypotheses for stock response (documenting rationales for inclusion in advice, or explanations of why such linkages could not be demonstrated);

    - demonstrate how such considerations can be incorporated into science advice; and
    - advise on the likely tradeoffs that result from alternative habitat restoration measures.
- Where a rebuilding plan includes habitat restoration measures, it is recommended that terms of reference and standard operating procedures for those measures be agreed to and documented.

2.7 Implementation Needs for Science

2.7.1 Scientific Considerations

Claims of fisheries sustainability can be upheld by following structured processes that meet acceptable scientific and management practice. Scientific activities such as stock assessment in support of precautionary approach harvest strategies would benefit from national guidelines that provide:

- a common interpretation of the implications of the FSP, and
- a consistent approach to scientific advice provision that meets an acceptable standard of fisheries science practice.

Topics for guidelines may include implementation of stock assessment models, communication of results, and performing simulation experiments to evaluate alternative management measures, including accommodating the need for risk equivalency across a range of uncertain stock and fishery dynamics (DFO 2016, Duplisea et al. 2019). Many fish stocks are infrequently assessed, and data availability varies in the types and quantity of observations. Consequently, stock assessments cover a wide range of analytical complexity. Some jurisdictions have technical guidelines to support stock assessors, although these vary in the level of technical detail and specified requirements (Marentette and Kronlund 2020). Regardless of the variation, advice derived from assessments needs to accommodate legal obligations and preserve PA Policy intent.

The FSP have been interpreted in large part according to the specifications of the PA Policy. Understanding PA Policy intent is key, as the default and provisional guidance in the Policy is centered on conventional reference point approaches such as estimating maximum sustainable yield. This focus poses challenges for assessing status for some taxonomic groups and for data-poor stocks. While the PA Policy is a national policy, Canada's major fish stocks include many that are also managed under other policies that have their own terminology or specification requirements for the elements of precautionary harvest strategies (e.g., Pacific Salmon; DFO 2005; and internationally-managed or transboundary stocks). Other implementation challenges for the Science Sector relative to the FSP are described below.

Upper Stock Reference

In the PA Policy, the USR is primarily assigned the role of managing the risk of breaching the LRP, and is simultaneously identified as the threshold delineating the Cautious and Healthy zones. The policy also notes that the USR can serve as a (target) reference point. The default USR value of $0.8B_{MSY}$ appears to be widely implemented, although the USR is not always used as an OCP in HCRs. More than half (62%) of USRs implemented for domestically managed and assessed major fish stocks have been set to levels that correspond to $0.8B_{MSY}$ (or 0.8 of a B_{MSY} proxy).

Multiple roles for the USR assigned in policy means that adjusting management objectives and measures for stocks managed under s 6.1(1) versus s 6.1(2) could entail simultaneously shifting USRs in their role as targets, or as thresholds to an implicit higher target (along with the associated risks relative to reference points), OCPs for management measures, and the definition of the RR. This in turn affects the designation of the Cautious-Healthy boundary, because all of those functions intersect with the USR. A requirement for this intersection, despite the conflict between the USR as a target or threshold and role as an OCP, could result in generally narrower Cautious zones and broader Healthy zones for stocks managed to lower versus higher targets. Furthermore, this requirement would result in changing risks (and risk tolerances) for breaching the LRP and/or the RR in ways that are not necessarily indicative of the conditions and management measures that would define a sustainable fisheries system.

Removal Reference

The RR is illustrated in the PA Policy as segmented, which is dissimilar to *F*-based limits in most other jurisdictions (Marentette and Kronlund 2020), although some fisheries management councils in the United States apply similar limits (NRC 2014, Restrepo et al. 1998). Domestically implemented RRs are also more frequently reported as fishing mortality or other management targets instead of, or in addition to, a role as limits. Equating targets and limits in the form of a single RR may result in acceptable outcomes for some fisheries, and facilitates reporting of whether stocks are harvested at approved levels, but could increase the likelihood of exceeding the RR and may not actually connote unacceptable stock states associated with “overfishing” as it is recognized internationally ($F > F_{MSY}$, Froese and Proelss 2012). Where RRs are only partially defined (one or two segments), it can also be more challenging to consistently report stock states on both *F*- and *B*-axes for many major fish stocks, even when F_{MSY} or suitable proxies are available. Here again, it is important to distinguish between a (limit) reference point such as the RR and the management measures intended to preserve desired risk tolerance, in this case of exceeding the RR.

The implementation difficulties posed by multiple roles for the USR and RR could be resolved, and PA Policy intent could be preserved, by separating the individual functions. This means that TRPs could be set apart from the USR, the RR set to indicate limit fishing mortality rates, and management measures (e.g., HCRs and other tactics) designed as necessary to acceptably meet management objectives. In particular, this means distinguishing between reference points and the OCPs where management actions are triggered so that the inflection points of a HCR do not need to match the reference points as in the PA Policy provisional HCR. Policy intent to reduce the removal (fishing mortality) rate as a LRP is approached (Figure 2) can be achieved through deliberate design of the management measures needed to acceptably meet the objective to avoid the LRP. However, the role and definition of the Cautious-Healthy boundary, particularly if no longer linked to either targets or OCPs, would be a value-based threshold and could not be within the purview of the Science Sector alone to define.

Data Poverty

Data- and model-poor stocks present a challenge to management by reference points as embodied by the PA Policy. Characterization of data-poverty is relative, but might be considered to apply to those stocks that lack reliable estimates of reference points (MSY-based or otherwise), “*current stock size or certain critical life history or fishery parameters*” and where “*stock assessments are minimal, and measurements of uncertainty may be qualitative rather than quantitative*” (Restrepo and Powers 1999). Thus, there is a need to interpret the PA Policy intent for data-poor contexts where it may not be possible to reliably determine reference points, stock status, or whether fishing mortality exceeds a limiting rate.

Procedural approaches based on simulation-evaluation of candidate management procedures over a range of stock and fishery scenarios offer one approach to data-poor contexts (e.g., Wade 1998, Pacific groundfishes; Anderson et al. 2021). Reference points and stock status are still an integral component of the approach and are a consequence of the assumptions and data applied in each scenario. However, the emphasis is not on determining a best set of reference points and a single stock status determination, but rather on eliminating management procedures that are unlikely to perform acceptably across the range of scenarios. Those management measures that remain for consideration may help to avoid unacceptable stock conditions and promote achieving desired outcomes when applied to the real stock and fishery.

The PA Policy allows for alternative (e.g., empirical) metrics that are "*demonstrably appropriate for the stock and … consistent with the* ***intent*** *of the PA*" [***emphasis*** added]. Precautionary management for data-poor stocks can be represented by defined measurable objectives, possibly based on empirical indicators, and harvest strategies with management triggers (i.e., feedback systems) that can be reasonably assumed to achieve objectives. Such triggers may invoke actions in response to changes in stock spatial distribution or spawning locations, trends in spawner abundance, changes to catch composition or fishing locations, etc. Invoking triggers can impact harvest and monitoring, initiate new analyses, invoke management measures to mitigate negative impacts and critically invoke increased data collection to increase understanding of the fisheries system (Dowling et al. 2015).

Weight-of-evidence approaches may also be applied to stocks considered to be data-poor (e.g., Marine Stewardship Council 2018). A common component of risk assessment and risk management, weight-of-evidence approaches encompass considerations both of the *totality* of evidence (evaluating the combined contributions of individual studies which by themselves may be insufficient) and typically expert judgement-assigned *weights* for each line of evidence in the composite. Each line of evidence may consist of one or more study or indicator (Health Canada 2018; Larcrombe et al. 2015). For such situations, a weight-of-evidence approach might involve the following steps (modeled after Health Canada 2018):

1. Totality of Evidence
    a. Gathering "all" available evidence,
    b. Assessing individual studies or indicators for quality, reliability, relevance, etc., against set criteria or expert judgement for inclusion or exclusion (e.g., empirical indicators, risk assessments, fishery-independent survey indices, quantitative stock assessments, simulation-tested management strategies),
    c. Assembling lines of evidence from individual studies or indicators (e.g., evidence of current state of stock depletion, evidence of reasons for stock decline, evidence of measures aimed to avoid or rebuild to the LRP, etc.).
2. Weighing Evidence
    a. Assessing each line of evidence for strength, plausibility, robustness, coherence, consistency, specificity, etc. (could be either qualitative or quantitative),
    b. Integrating multiple lines of evidence to support conclusion (could be either qualitative or quantitative).

2.7.2 Implications for Science

The Science Sector may be asked to help operationalize management objectives given limits, targets and risk tolerances for harvest strategies under various sections of the FSP. In this role fisheries scientists can help render objectives measurable and design performance metrics that quantify how well a given set of management measures might perform with respect to the objectives. Further elaboration may be required in science guidelines to understand how reference points for major fish stocks that were defined under different policies such as the Wild Salmon Policy (WSP, DFO 2005) and various international policies correspond to those in the PA Policy. These may include alternative reference points required for stocks with life histories that do not easily align with strategies that require biomass estimation and application of a harvest rate (e.g., many invertebrate species).

Given the multiple functions of the USR and the uncertain extent to which functions assigned to the USR can be separated while maintaining PA Policy intent, science guidelines can focus on the roles of limit and target reference points in general. Consideration should be given to how these roles may be expressed on both the *F*- and *B*-axes (or suitable proxies). Science guidelines should also distinguish reference points from the measures intended to avoid or achieve those reference points and describe how management measures, inclusive of HCRs, can be evaluated with respect to management objectives that embed reference points. Guidelines should also indicate how the intended function(s) of the USR in a stock-specific context can be distinguished and described to clarify science advice on harvest strategies.

International comparisons suggest that limit fishing mortality reference points need not be segmented (as depicted in Figure 2) and that a linear configuration of the RR (Figure 3) could also form part of a harvest strategy that meets policy intent by identifying measures (e.g., a HCR) that reduce the intended fishing mortality rate to avoid reaching the LRP. A single non-segmented limit fishing mortality reference point would also enable more consistent reporting of stock states on the *F*-axis. The Science Sector can characterize stock status relative to limit fishing mortality rates such as F_{MSY} or suitable proxies, consistent with international definitions of the term “overfishing” (Froese and Proelss 2012) and the minimum specifications of the PA Policy regarding the UNFSA (UN 1995).

2.7.3 Section Summary and Recommendations

- Science guidelines should address the roles of limit, threshold and target reference points, and address how these may be expressed as biomass or fishing mortality metrics (or suitable alternatives) for a range of life histories and data/model availability.
- Science guidelines can distinguish reference points from management measures (e.g., operational control points in harvest control rules (HCRs)), and identify how different management measures that may include HCRs can be evaluated with respect to objectives concerning limits, thresholds and targets.
- There is a need for methods to meet PA Policy intent for data-poor contexts where it may not be possible to reliably determine reference points, stock status or whether fishing at rates above a limiting rate (overfishing) is occurring.
- A composite performance metric of sustainability for stocks across the data spectrum could include evaluation of empirical indicators relative to management objectives. Procedural approaches that focus on identifying feasible management measures for a range of uncertain stock and fishery dynamics rather than explicit reference point estimation and determination of a single best stock status may be applied. A weight-of-evidence approach could also contribute to the evaluation of the status of stocks across the data spectrum.

- International comparisons suggest that limit fishing mortality rates need not be segmented to vary with stock abundance. PA Policy intent can still be met by application of management measures that reduce fishing mortality rates as stocks decline in order to acceptably avoid LRP breaches. The Science Sector can report on stock status (and evaluate management measures) relative to limit fishing rates such as F_{MSY} or proxies, or suitable alternatives when available.
- Identification of the intended function(s) of the upper stock reference (USR) and RR in stock-specific contexts is needed to clarify science advice on the selection of management measures intended to meet specified objectives. Assigning the USR a role as a target or threshold reference point to be achieved, rather than its primary role in managing the risk of a LRP breach, means that distinguishing operational control points (in management measures) from reference points (in management objectives) is critical.
- It is recommended that the Science Sector engage in discussions with other DFO Sectors to clearly define the role of targets and thresholds in the context of conservation and sustainable resource use to ensure consistency of application across stocks, standardize reporting, and investigate the application of risk equivalency.

2.8 Roles and Responsibilities of the Science Sector

2.8.1 Scientific Considerations

Consistent with the PA Policy, the Science Sector has a role in establishing and estimating LRPs, and in evaluating stock status against *B*- and *F*-based reference points (or suitable alternatives). The Science Sector also contributes to the evaluation of other elements pertinent to the biological (or ecological) axis of sustainability. This may include evaluating habitat and ecosystem impacts on stocks, and supporting performance evaluation of management processes in light of those impacts.

Under s 2.5, Indigenous knowledge that has been provided to the Minister may be considered when making decisions. Government-to-government work with Indigenous groups is an important part of Science Sector work, and also falls under Science roles and responsibilities, including the use of Indigenous knowledge of the Indigenous peoples of Canada in science and stock assessments.

PA Policy guidance indicates that the USR (when interpreted as a reference point) and TRP are not determined solely by biological considerations and therefore not by the Science Sector. Acceptable risks associated with failing to either achieve targets or avoid limits over time frames specified in fisheries management objectives are also not determined by the Science Sector. Performance evaluation of fishery management systems, either retrospectively or prospectively, is a process in which the Science Sector has a role – more specifically, a role in the evaluation of biological axes of sustainability and in estimating and communicating the tradeoffs in realized or expected management outcomes relative to objectives.

Decisions regarding the feasibility and/or appropriateness of management measures from a cultural or socio-economic perspective, that may inform management decisions for prescribed major fish stocks under s 6.1(1) versus s 6.1(2), or rebuilding plans under s 6.2(1) versus s 6.2(2) are not within the Science Sector's remit.

2.8.2 Implications for Science

Estimating F_{MSY}, B_{MSY} or proxies for either, and establishment of the LRP are all science activities. Default reference points (LRP, USR) defined as multiples of B_{MSY} in policy, and that the RR must not exceed $F_{MSY,}$ imply that maximum sustainable yield is an acceptable basis for harvest strategies. There is no requirement, however, to adopt biological reference points based on the concept of MSY in the FSP or PA Policy. Nevertheless, MSY-based criteria are commonly used internationally in evaluating sustainability and can provide for common benchmarks across stocks; this does not preclude the use of limit and target reference points based on other considerations in stock-specific cases or where MSY-based quantities cannot be estimated.

The inclusion of multiple axes in the definition of sustainability indicates that sustainability cannot be solely determined by biological considerations. Fisheries scientists can and ought to identify biological conditions necessary for stock preservation subject to specific assumptions, but satisfying these conditions is not sufficient to define sustainability. Scientists also have a role in evaluating the consequences of applying management options since scientific data and methods are likely to be needed for such analyses, including simulation-based prospective evaluations where feasible (FAO 1996).

2.8.3 Section Summary and Recommendations

- Consistent with the PA Policy, the Science Sector establishes LRPs, and evaluates stock status against *B*- and *F*-based limit and target reference points whether based on maximum sustainable yield (or proxies), or alternatives.
- The Science Sector, along with other sectors, engages with fishery interests and in government-to-government work, such as when Indigenous knowledge is provided and used in stock assessments.
- The Science Sector contributes to the evaluation of other elements pertinent to the biological or ecological axis of sustainability, such as conducting risk assessments for habitat, trophic level and other ecosystem factors.
- Science requirements for the implementation of s 6.1 can be interpreted as characterization of stock status, and support for the identification of effective management measures that aim to achieve thresholds that "*promote the sustainability of the stock*" (s 6.1.1) or lower levels that maintain stocks above the LRP (s 6.1.2).
- Reference points and the acceptable risks associated with failing to either achieve targets or thresholds, or avoid limits, over specified time frames are captured in fisheries management objectives. Objectives reflect value-based goals and cannot be established based solely on scientific considerations.

2.9 Sources of Uncertainty

At present, the requirements of the Fish Stocks provisions are interpreted here in the context of an existing suite of fisheries policies for Fisheries and Oceans Canada (DFO), the Sustainable Fisheries Framework (SFF); in particular the *Fishery Decision-Making Framework Incorporating the Precautionary Approach* (PA Policy, DFO 2009). Thus, recommendations for the Science Sector here do not take into account future regulations and policies, and/or clarification of requirements of the revised *Fisheries Act* via other processes.

3. CONCLUSIONS AND ADVICE

This Science Advisory Report identifies considerations for the Science Sector in providing advice and developing national operational science guidelines to support the implementation of the Fish Stocks provisions in the revised *Fisheries Act*, including implementation needs and Science Sector roles and responsibilities.

LIST OF MEETING PARTICIPANTS

Name	Affiliation
Abraham, Christine	DFO Science, National Capital Region
Ali, Zeba	DFO Economic Analysis and Statistics, National Capital Region
Andrushchenko, Irene	DFO Science, Maritimes Region
Beauchamp, Brittany	DFO Science, National Capital Region
Benoît, Hugues	DFO Science, Quebec Region
Bourne, Christina	DFO Science, Newfoundland and Labrador Region
Clemens, Marc	DFO National Fisheries Policy, National Capital Region
Cook, Adam	DFO Science, Maritimes Region
Couture, Estelle	DFO Science, National Capital Region
Cox, Sean	School of Resource and Environmental Management, Simon Fraser University
Cogliati, Karen	DFO Science, National Capital Region
Desgagnés, Mathieu	DFO Science, Quebec Region
Duplisea, Daniel	DFO Science, Quebec Region
Dwyer, Karen	DFO Science, Newfoundland and Labrador Region
Forrest, Robyn	DFO Science, Pacific Region
Gallagher, Colin	DFO Science, Ontario and Prairie Region
Healey, Brian	DFO Science, Newfoundland and Labrador Region.
Holt, Carrie	DFO Science, Pacific Region
Hutchings, Jeffrey	University of Dalhousie
Kanno, Roger	DFO Resource Management, Pacific Region
Krohn, Martha	DFO Science, National Capital Region
Kronlund, Rob	DFO Science, National Capital Region
Ladell, Jason	DFO Science, National Capital Region
Ladell, Neil	DFO Resource Management, Pacific Region
Lebeau, Amy	DFO National Fisheries Policy, National Capital Region
Marentette, Julie	DFO Science, National Capital Region
Matthews, Cory	DFO Science, Ontario and Prairie Region
McDermid, Jenni	DFO Science, Gulf Region
Olmstead, Melissa	DFO Science, National Capital Region

Name	Affiliation
Pepin, Pierre	DFO Science, Newfoundland and Labrador Region
Ricard, Daniel	DFO Science, Gulf Region
Rodger, David	DFO National Fisheries Policy, National Capital Region
Shaw, Jennifer	DFO Science, National Capital Region
Stenson, Garry	DFO Science, Newfoundland and Labrador Region
Taylor, Nathan	International Commission for the Conservation of Atlantic Tunas
Thompson, Susan	DFO Science, National Capital Region
Walkusz, Wojciech	DFO Science, Ontario and Prairie Region
Wysocki, Roger	DFO Science, National Capital Region

SOURCES OF INFORMATION

This Science Advisory Report is from the May 26-27 and June 22-23, 2020 national advisory meeting on Science Advice For Precautionary Approach Harvest Strategies under the Fish Stocks Provisions. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Anderson, S.C., Forrest, R.E., Huynh, Q.C., and Keppel, E.A. 2021. A management procedure framework for groundfish in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/007. In Press.

DFO. 2004. Proceedings of the National Meeting on Applying the Precautionary Approach in Fisheries Management, February 10-12, 2004. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2004/003.

DFO. 2005. Canada's Policy for Conservation of Wild Pacific Salmon.

DFO. 2009. A fishery decision-making framework incorporating the precautionary approach. Last updated 2009-03-23.

DFO. 2012. Guidance for the development of rebuilding plans under the Precautionary Approach Framework: Growing stocks out of the critical zone.

DFO. 2014. A Science-Based Framework for Assessing the Response of Fisheries Productivity to State of Species or Habitats. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/067.

DFO. 2016. Proceedings of the Pacific regional peer review on A Review of International Best Practices to Assigning Species to Tiers for the Purposes of Stock Assessment Based on Data Availability and Richness; May 30-31, 2016. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2016/051.

DFO. 2017. Science Advice on the Determination of Offset Requirements for the Fisheries Protection Program. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/009.

DFO. 2019a. Sustainability survey for fisheries. Last modified 2019-12-13.

DFO. 2019b. Canada's sustainable fisheries. Last updated 2019-03-16.

DFO. 2019c. Framework for Incorporating Climate-Change Considerations into Fisheries Stock Assessments. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/029.

DFO. 2021. Science Guidelines to Support Development of Rebuilding Plans for Canadian Fish Stocks. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/006.

Dowling, N.A., Dichmont, C.M., Haddon, M., Smith, D.C., Smith, A.D.M., and Sainsbury, K. 2015. Empirical harvest strategies for data-poor fisheries: A review of the literature. Fish. Res. 171: 141-153.

Duplisea, D.E., Roux, M-J, Hunter, K.L., and Rice, J. 2020. Resource management under climate change: a risk-based strategy to develop climate-informed science advice. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/044. v + 45 p.

FAO. 1996. Precautionary approach to capture fisheries and species introductions. Elaborated by the Technical Consultation on the Precautionary Approach Fisheries to Capture fisheries (Including Species Introductions). Lysekil, Sweden, 6-13 1995. FAO Technical Guidelines for Responsible Fisheries No. 2, 54 p.

Fisheries Act R.S.C., 1985, c. F-14. As amended by Bill C-68, June 21 2019.

Fletcher, W.J., Chesson, J., Sainsbury, K.J., Hundloe, T.J., and Fisher, M. 2005. A flexible and practical framework for reporting on ecologically sustainable development for wild capture fisheries. Fish. Res. 71(2):175-183.

Froese, R. and Proelss, A. 2012. Evaluation and legal assessment of certified seafood. Mar. Pol. 36(6): 1284-1289.

Garcia, S.M., Ye, Y., Rice, J. and Charles, A., eds. 2018. Rebuilding of marine fisheries. Part 1: Global review. FAO Fisheries and Aquaculture Technical Paper No. 630/1. Rome, FAO. 294 pp.

Hilborn, R., Fulton, E.A., Green, B.S., Hartmann, K., Tracey, S.R., and Watson, R A. 2015. When is a fishery sustainable? Can. J. Fish. Aquat. Sci *72*(9):1433-1441.

Hilborn, R., and Walters, C.J. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York.

Health Canada. 2018. Weight of Evidence: General Principles and Current Applications at Health Canada. Prepared for the Task Force on Scientific Risk Assessment by the Weight of Evidence Working Group. 18pp.

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

Larcrombe, J., Noriega, R., Stobutzi, I., 2015. Reducing uncertainty in fisheries stock status. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, xi+220 pp.

Mace, P.M. 2001. A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. Fish Fish. *2*(1): 2-32.

Marine Stewardship Council 2018. MSC Fisheries Standard. Version 2.01, 31 August 2018.

Ministry of Fisheries [MF]. 2011. Operational Guidelines for New Zealand's Harvest Strategy Standard, Revision 1, June 2011.

Murawski, S.A. 2010. Rebuilding depleted fish stocks: the good, the bad, and the, mostly, ugly. ICES J. Mar. Sci. 67: 1830-1840.

NOAA. 2018. National Standard Guidelines. Last updated February 7, 2018.

NRC. 2014. Evaluating the Effectiveness of Fish Stock Rebuilding Plans in the United States. Washington, DC: National Research Council, The National Academies Press.

Pepin, P., King, J. Holt, C., Gurney-Smith, H., Shackell, N., Hedges, K., and Bundy, A. 2020. Incorporating climate, oceanographic and ecological change considerations into population assessments: A review of Fisheries and Oceans Canada's science advisory process. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/043. iv + 66 p.

Punt, A.E., A'mar, T., Bond, N.A., Butterworth, D.S., de Moor, C.L., De Oliveira, J.A.A., Haltuch, M.A., Hollowed, A.B., and Szuwalski, C. 2014. Fisheries management under climate and environmental uncertainty: control rules and performance simulation. ICES J. Mar. Sci. 71(8): 2208-2220.

Quinn, T.J. and Collie, J.S. 2005. Sustainability in single-species population models. Philosophical Transactions of the Royal Society B 360, 147-162.

Restrepo, V.R., Thompson, G.G., Mace, P.M., Gabriel, W.L., Low, L.L., MacCall, A.D., Method, R.D., Powers, J.E., Taylor, B.L., Wade, P.R., and Witzig, J.F. 1998. Technical Guidance on the use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Technical Memorandum NMFS – F/SPO – 31, July 17, 1998.

Restrepo, V. R. and Powers, J. E. 1999. Precautionary control rules in US fisheries management: specification and performance. ICES J. Mar. Sci. 56(6): 846-852.

Sainsbury, K. 2008. Best Practice Reference Points for Australian Fisheries. Australian Fisheries Management Authority Report R2001/0999.

Shelton, P.A. and Rice, J.C. 2002. Limits to overfishing: reference points in the context of the Canadian perspective on the precautionary approach. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/084. 29 p.

Shelton, P.A. and Sinclair, A.F. 2008. It's time to sharpen our definition of sustainable fisheries management. Can. J. Fish. Aquat. Sci. 65(10): 2305-2314.

Smokorowski, K.E., Bradford, M.J., Clarke, K.D., Clément, M., Gregory, R.S., and Randall, R.G. 2015. Assessing the effectiveness of habitat offset activities in Canada: Monitoring design and metrics. Can. Tech. Rep. Fish. Aquat. Sci. 3132: vi + 48 p.

Stephenson, R.L., Benson, A.J., Brooks, K., Charles, A., Degnbol, P., Dichmont, C.M., Kraan, M., Pascoe, S., Paul, S.D., Rindorf, A., and Wiber, M., 2017. Practical steps toward integrating economic, social and institutional elements in fisheries policy and management. ICES J. Mar. Sci. 74(7):1981-1989.

Stephenson, R.L., Wiber, M., Paul, S., Angel, E., Benson, A., Charles, A., Chouinard, O., Edwards, D., Foley, P., Lane, D., and McIsaac, J., 2019. Integrating diverse objectives for sustainable fisheries in Canada. Can. J. Fish. Aquat. Sci. 76(3):480-496.

UN. 1995. United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks. August 4, 1995. 34 ILM 1542 (1995); 2167 UNTS 88.

Wade, P.R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Mar. Mamm. Sci. 14(1):1-37.

Ye, Y. 2011. Assessment methodology: 327-334, in FAO. Review of the state of the world marine fishery resources. FAO Fisheries and aquaculture technical paper, 569 (Appendix): 334 p.

THIS REPORT IS AVAILABLE FROM THE:

Canadian Science Advisory Secretariat (CSAS)
National Capital Region
Fisheries and Oceans Canada
200 Kent Street, Ottawa, ON K1A 0E6

Telephone: 613-990-0293
E-Mail: csas-sccs@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2021. Science Advice for Precautionary Approach Harvest Strategies under the Fish Stocks Provisions. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/004.

Aussi disponible en français :

MPO. 2021. Avis scientifique sur les stratégies de pêche fondées sur l’approche de précaution aux termes des dispositions relatives aux stocks de poissons. Secr. can. de consult. sci. du MPO. Avis sci. 2021/004.