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Promoting Sustainability in the context of the Fish Stocks Provisions and the Fisheries Decision-Making Framework Incorporating the Precautionary Approach

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Canada's *Fisheries Act* was revised on June 21, 2019, resulting in new Considerations and Fish Stocks provisions (FSP) that relate to the management of fisheries. The FSP (Section 6) contains new terminology: 1) a requirement to implement measures to maintain major fish stocks "*at or above the level necessary to promote the sustainability of the stock*" (s 6.1(1)); and 2) if those management measures are unfeasible due to cultural or socio-economic impacts, to maintain stocks above the limit reference point or LRP (s 6.1(2)), which is a biological threshold to serious harm.

Definitions of *sustainability* recognize both time and the need for equitable access to benefits across generations of resource users. Most jurisdictions recognize multiple axes of sustainability including ecological, socio-economic and institutional axes, but prioritize them differently. Consideration of all axes is necessary to operationalize fisheries management to support sustainable use, and science alone cannot advise on all of them. A pragmatic definition of *sustainability* in fisheries is that it is the process that conveys the *ability to maintain a specified level of practical and effective use of a fisheries resource over the long term*, where *practical and effective* reflects value-based measureable objectives related to biological, socio-economic and cultural outcomes. In the same vein, *a level necessary to promote sustainability of the stock* can be defined as "*a threshold representing a specified level of practical and effective resource use over the long term*." In the absence of clearly-defined value-based objectives for resource use or tolerance for risk to the stock, the threshold cannot be defined more specifically. Thresholds and other levels fulfilling s 6.1(1) or s 6.1(2) differ with respect to trade-offs among biological, socio-economic, and/or cultural objectives but both sections imply the stock be maintained above the LRP.

Limits, other thresholds and target reference points play important roles in constraining which stock states are considered sustainable internationally. Review of Canada's PA Policy suggests that fisheries sustainability could be evaluated, in part, by considering whether stock status exceeds the LRP and whether fishing mortality is less than the removal reference rate. The question of sustainability can also be assessed by evaluating whether management measures are expected to perform acceptably with respect to stated limits and targets over specified time frames.

The multiple axes of sustainability imply there is a role for multiple sectors in defining and promoting stock and fisheries sustainability. The Science Sector sets LRPs, evaluates stock status against reference points, and may contribute by evaluating other elements of the ecological axis of sustainability such as age or size composition of the stock, habitat, trophic level and other ecosystem considerations in relation to objectives. Setting targets, other thresholds, time frames and determining acceptable risks are value-based choices and cannot be established via scientific means alone.

All Sectors may benefit from Departmental guidance as to how s 6.1(1) and s 6.1(2) differ in implementation, particularly with respect to the use of PA Policy reference points in management objectives, and implications for management measures including harvest control rules.

1. INTRODUCTION

Section Key Points:

- Bill C-68 received Royal Assent on June 21, 2019, resulting in a revised *Fisheries Act.* Revisions include new Considerations and Fish Stocks provisions (FSP) that relate to the management of fisheries, and which can be interpreted through existing policies for Fisheries and Oceans Canada (DFO), particularly the *Fishery Decision-Making Framework Incorporating the Precautionary Approach* (PA Policy).
- The FSP contains terminology that is not found verbatim in either Canadian fisheries policies, or in policies of other jurisdictions. Specifically, there is a requirement in s 6.1(1) of the FSP to implement measures to maintain major fish stocks "*at or above the level necessary to promote the sustainability of the stock*."
- Definitions of *sustainability* and related terms generally recognize both *time* (i.e., some state that is to be achieved or sustained over the long-term) and the need for equitable *access to benefits* across generations of resource users.
- International agreements and fisheries legislation in most jurisdictions recognize ecological, social, economic, and institutional axes of sustainability. However, specific elements, values and performance measures assigned to each axis vary among jurisdictions.
- Axes of sustainability should be considered together to account for the various temporal dimensions of sustainability, such as whether management measures can be expected to support the persistence of desired ecological or biological states as well as desired socio-economic and cultural outcomes.
- Organizational properties such as "*effective mechanisms in place for making trade-offs between competing objectives*" are pertinent to the FSP where adverse socio-economic or cultural impacts may play roles in decision-making.
- A pragmatic definition of *fisheries sustainability* is that it is 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 defined objectives related to stock integrity (e.g., avoid impairment of recruitment or other states considered to represent serious harm), socio-economic and cultural outcomes, and that these objectives are *measurable* whenever possible. Objectives for natural resources are value-based, necessarily conflict, and require specifying the acceptable degree of risk incurred by ongoing management choices.
- Claims of sustainability are supported by management systems (the institutional axis) 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 (and/or other measures) in response to assessments; and 4) enforcement of management measures.

Bill C-68 received Royal Assent on June 21, 2019, resulting in revisions to the *Fisheries Act* (*Fisheries Act* R.S.C., 1985, c. F-14. As amended by Bill C-68, June 21 2019). Revisions include new Considerations provisions and Fish Stocks provisions that relate to the management of fisheries.

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 (s 6.1(1)), or above the limit reference point (s 6.1(2)) (LRP, see Section 2.1.2), or to develop and implement rebuilding plans for stocks that have declined to or below the limit reference point (s 6.2), 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, which are to be identified and prescribed by regulation.

The Ecosystems and Oceans Science Sector ("Science Sector") of Fisheries and Oceans Canada (DFO) is providing a perspective on the implications of the Fish Stocks provisions (FSP) to fisheries science activities. This perspective is needed to support the DFO mandate to implement the revised *Fisheries Act*. One Science Sector deliverable in support of the Departmental response to the revised *Fisheries Act* is to produce operational science guidelines for a variety of fisheries science topics that can be applied nation-wide. National operational guidelines for science can help to clarify expectations to DFO fisheries scientists and collaborators, harmonize approaches and reduce disparity in approaches.

In the Canadian context, interpretation of the FSP can rely on existing DFO policies published under the umbrella of the Sustainable Fisheries Framework (SFF; DFO 2019a). Of relevance is the national *Fishery Decision-Making Framework Incorporating the Precautionary Approach* ("PA Policy", DFO 2009, Figure 1). The primary objective of the SFF (and thus the PA Policy) is to provide "*the basis for ensuring that Canadian fisheries support conservation and sustainable use of resources.*"

However, the FSPs contain terminology that is not found verbatim in either of these Canadian policies, or in those of other jurisdictions. Specifically, there is a requirement in s 6.1(1) of the FSP to implement measures to maintain major fish stocks "*at or above the level necessary to promote the sustainability of the stock*." This new terminology requires scientific interpretation of *sustainability* and *sustainable use*, placed in the context of the broader body of peer-reviewed literature and current international practices in fisheries science. It requires an understanding of the role of biological elements in defining sustainability to support s 6.1(1) versus s 6.1(2).

We recommend that provisions under s 6 of the *Fisheries Act* must be interpreted together, rather than in a piece-wise fashion (see also Kronlund et al. 2021). This is analogous to interpreting precautionary approach fisheries policies in general. Such policies must be considered as a suite of components that together define the policy intent, rather than as disjointed elements (Sainsbury 2008). This approach is required to minimize contradictions and redundancies and also because implementing sustainability policies is dependent on a complex interaction among components, which represent multiple axes of the concept of sustainability (Garcia 1997, Dahl 2012). The complexity is derived from the policy need to choose limits, other thresholds and target reference points (TRPs, see Section 2.1.1) in biomass and fishing mortality. Implementation requires objectives structured around those reference points, the collection of stock and fishery monitoring data, application of assessment methods used to determine stock status, and selection of management measures intended to satisfy conservation, socio-economic, and cultural outcomes of interest.

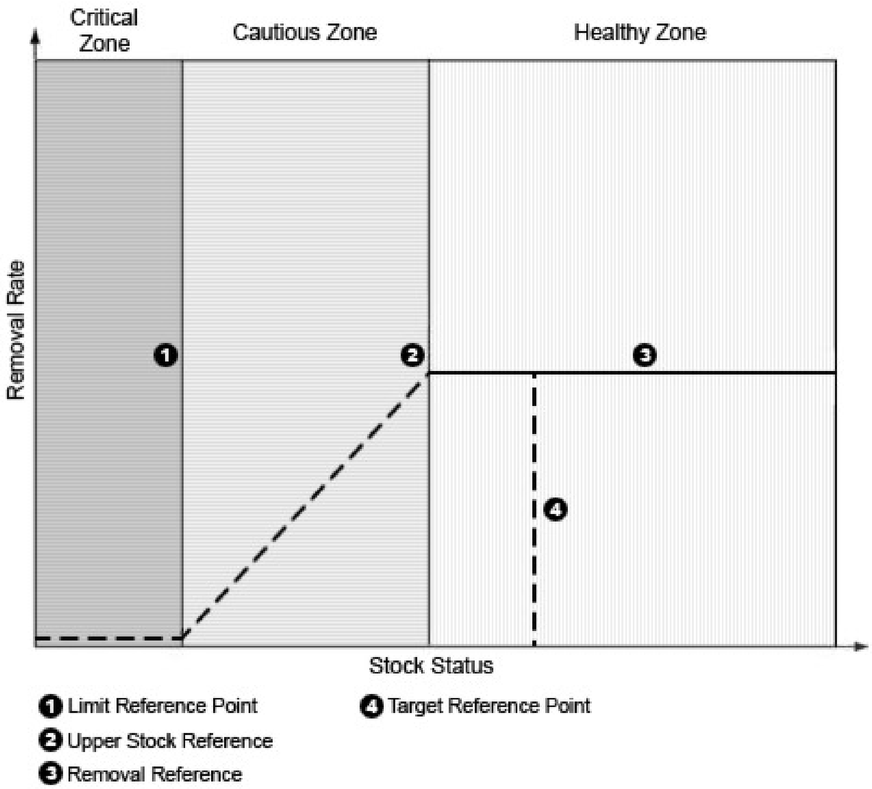

Figure 1: Schematic representation of Canada's national Precautionary Approach Framework illustrating four types of reference points (Limit Reference Point (LRP), Upper Stock Reference (USR), Removal Reference (RR), Target Reference Point (TRP)) and three stock status zones (Critical, Cautious and Healthy). The framework further classifies fishery status as either "at or below" or "exceeds" the removal reference. Other key components of the PA Policy include a harvest strategy with harvest decision rules (harvest control rules), and the need to take into account uncertainty and risk, as well as an expectation to evaluate harvest strategies (DFO 2009).

In this paper, we begin with a review of the concept of sustainability and how it has been defined, used and understood in both international and Canadian fisheries contexts. We then examine the new terminology in the *Fisheries Act* from a scientific perspective, focusing particularly on ss 2.5, 6.1(1) and 6.1(2) (Table 1). We note that the FSP sections on rebuilding (s 6.2) have been examined in depth elsewhere (Kronlund et al. 2021). We explore how some stock-specific elements of the ecological axis of sustainability are commonly evaluated across jurisdictions – namely, stock and fishery status relative to limit and target reference points in units of both biomass (*B*) and fishing mortality (*F*; see Glossary in Appendix A). We then propose criteria to evaluate sustainability using elements of Canada's PA Policy and a pragmatic definition for "*the level necessary to promote sustainability of the stock*". Implementation challenges are noted, where the Science Sector could benefit from additional guidance on the FSP and PA Policy. Finally, contributions that the Science Sector can make to this evaluation are identified for incorporation into Science guidelines.

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

Considerations

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;

(c) scientific information;

(d) Indigenous knowledge of the Indigenous peoples of Canada that has been provided to the Minister;

(e) community knowledge;

(f) cooperation with any government of a province, any Indigenous governing body and any body — including a co-management body — established under a land claims agreement;

(g) social, economic and cultural factors in the management of fisheries;

(h) the preservation or promotion of the independence of licence holders in commercial inshore fisheries; and

(i) the intersection of sex and gender with other identity factors.

Fish Stocks

Measures to maintain fish stocks

6.1 (1) In the management of fisheries, the Minister shall implement measures to maintain major fish stocks at or above the level necessary to promote the sustainability of the stock, taking into account the biology of the fish and the environmental conditions affecting the stock.

Limit reference point

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.

Publication of decision

6.1 (3) If the Minister sets a limit reference point in accordance with subsection (2), he or she shall publish the decision to do so, within a reasonable time and with reasons, on the Internet site of the Department of Fisheries and Oceans.

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

6.2 (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.

Endangered or Threatened Species

6.2 (3) Subsection (1) does not apply if the affected fish stock is an endangered species or a threatened species under the *Species at Risk Act* or if the implementation of international management measures by Canada does not permit it.

Publication of Decision

6.2 (4) If the Minister amends a plan in accordance with subsection (2) or decides not to make one in accordance with subsection (3), he or she shall publish the decision to do so, within a reasonable time and with reasons, on the Internet site of the Department of Fisheries and Oceans.

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.

Regulations

6.3 The major fish stocks referred to in sections 6.1 and 6.2 are to be prescribed by regulations.

1.1. DEFINITIONS OF SUSTAINABILITY

With the changes to the *Fisheries Act*, new terminology has come into place with respect to promoting *sustainability* (both of stocks and fisheries), but this widely used term is not defined in the *Fisheries Act*. It is also not defined in the SFF or DFO's PA Policy. However, *sustainability* and other related terms have been defined elsewhere in Canadian law and policy, including definitions provided by DFO in pursuit of its mandate (see references in Appendix B).

Common to many of these definitions 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 access to benefits, most commonly with respect to the needs of resource users, both in the present and future.

Temporal considerations are clearly integral to the concept of something being *sustained*. Beyond this, sustainability is almost always defined in terms of development or resource use (Hilborn et al. 2015). *Intergenerational equity* ("… without compromising the ability of future generations to meet their own needs"; DFO 2018a, DFO 2019b, and others) appears to be a key principle of sustainability in Canada, as well as other jurisdictions (e.g., DAWR 2018a), and likely originated in the report of the Brundtland Commission (UN 1987).

Consideration of access to benefits over the long-term is also a cornerstone of the precautionary approach. What is "long term" may vary from context to context. Time frames are part of measurable, value-based management objectives, and differ widely depending on biological (conservation), social, economic, etc., concerns. The FAO's technical guidelines (FAO 1996) to implementation of the precautionary approach for capture fisheries state that the precautionary approach, among other things, requires "consideration of the needs of future generations," and corrective management measures that are aimed to achieve their goals "on a timescale not exceeding two or three decades". Correspondingly, management plans should anticipate at least multi-decadal time frames, or "longer in the case of long-lived species," (FAO 1996). The guidelines add that "… short-term (1-2 y) projections alone are not sufficient for precautionary assessment; timeframes and discount rates appropriate to inter-generational issues should be used" (FAO 1996), although Francis and Shotton (1997) argued against the use of discount rates in consideration of intergenerational equity.

Both long-term timescales and access to benefits to support intergenerational equity are consistent with Canada's PA Policy. For example, the PA Policy states that restraint must be exercised through the recovery phase of stocks below the LRP to realize "long-term sustainable fishery benefits" and that "the fishery is a common property resource to be managed for the benefit of all Canadians" (DFO 2009).

1.2. MULTIPLE AXES OF SUSTAINABILITY

The concept of sustainability has long been recognized to comprise multiple dimensions. 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). In the development of fisheries-specific performance measures, Garcia (1997) cited fiscal, ecological, human, social, moral, ethical and spiritual axes of sustainability, each of which could lead to the development of performance measures to quantify sustainability as an overarching goal (although potentially evaluated over very different timescales). Indeed, national and international performance measures of sustainability are generally developed as sets, achieving various levels of success in integrating axes of concern for sustainable development goals (Dahl 2012).

Various international agreements and fisheries legislation in most jurisdictions recognize multiple basic axes, or pillars, of sustainability. Although the exact number or formulation varies (e.g., CESD 2011, Hilborn et al. 2015, Stephenson et al. 2017), each axis consists of multiple core elements, such as:

- Ecological objectives concerning productivity and trophic structure; biodiversity; habitat and ecosystem integrity;
- Economic objectives concerning economic value and viability; distribution of access and benefits; regional economic benefit; and livelihoods;
- Social and cultural objectives concerning sustainable communities; health and wellbeing; ethical fisheries; and
- Institutional objectives concerning obligations to law and to Indigenous peoples; good governance structure; and effective decision-making processes (Stephenson et al. 2019).

The ecological axis of fisheries sustainability receives perhaps the most attention. Complex systems of institutional scientific peer review and analysis have arisen to support these elements in many countries, often to the neglect of other axes (Stephenson et al. 2017, 2019). However, even here, ecological elements are often framed in light of other considerations. For example, social and economic considerations may be reflected in management goals such as maximum sustainable yield (Garcia 1997).

The temporal component of the definition of sustainability also means that individual axes are not informative when considered in isolation. The ability to achieve management objectives over an extended period relates not only to whether biomass levels are acceptable relative to reference points at any one point in time, but also to whether fishing mortality (relative to its reference point) and management strategies overall are such that acceptable biomass levels are expected to continue into the future. As Hilborn et al. (2015) noted:

> “A stock may be at high current abundance, but caught in a totally unregulated fishery and fished at rates that are not sustainable. Thus, the abundance of a fish stock does not necessarily say much about its sustainability, and sustainability definitions that rely on stock abundance as the primary indicator can often be misleading. A question with a more exacting answer is “Is it sustainably managed?” Sustainably managed stocks are far more likely to remain so and dynamically respond to changing circumstances and understanding. Thus, current exploitation rate would generally be a better measure of sustainability than current abundance.”

1.3. FISHERIES SUSTAINABILITY IN CANADA

In December 2011, the Canadian Commissioner of the Environment and Sustainable Development (CESD) conducted a study of managing fisheries for sustainability (CESD 2011). This report identified, among other things, key properties of sustainable fisheries based on generally accepted international principles and experience (Appendix B). A partial audit of these properties was conducted in 2016 with a focus on fisheries management planning (CESD 2016). A comparison with DFO's conceptual framework for the sustainable management of Canadian fisheries (DFO 2019b, Appendix B) shows that while the framework does not align verbatim with the properties identified by CESD (2011), it recognizes many of the same environmental, social, economic, and organizational principles. Absent is explicit mention of the CESD (2011) organizational property to ensure that "effective mechanisms are in place for making trade-offs between competing objectives." Typical stock assessment advice might represent one or two goals, namely, to avoid breaching a limit threshold, and to maximize yield. However, decision-making processes necessarily select acceptable trade-offs between outcomes of the biological, socio-economic and cultural axes of sustainability. The concept of competing objectives is explicitly reflected in the FSP (ss 6.1(2) and 6.2(2)), which make mention of considering "adverse socio-economic or cultural impacts" when managing fish stocks both above and below the LRP.

The key areas of DFO's conceptual framework (DFO 2019b) do, however, capture the basic elements of a sustainable fisheries management system that were proposed by Hilborn et al. (2015):

a. Specific objectives for fishing pressure and abundance;
b. Monitoring of fishing pressure and abundance;
c. Assessments to determine if targets are being met according to pre-determined performance measures;
d. Feedback management systems that adjust fishing pressure (or other measures) in response to the assessments and in particular restricts fishing pressure when it is too high; and
e. Enforcement systems to assure compliance with regulations.

For example, element (a) of Hilborn et al. (2015) maps to "*planning*" in DFO (2019b). Similarly, elements (b, c) of Hilborn et al. (2015) map to "*science activities*", and (e) maps to "*enforcement*." Element (d), which specifies that management systems should impose feedback control, is perhaps the operational step of highest importance. Sustainability requires an explicit and consistent control mechanism to reduce harvest and/or implement other measures when abundance is perceived to decline and increase it when it is perceived to increase. In the absence of the stabilizing effects of negative feedback there is no link between current stock status and future management actions that acts to correct deviations from desirable stock and fishery outcomes.

The ends objective (*sensu* Gregory et al. 2012) of the SFF is to foster the conservation and sustainable use of marine aquatic resources in Canada. Sustainability can be thought of as a process instead of a static achievement. Therefore, a sustainable fisheries process can maintain *a specified level of practical and effective use of a fisheries resource over the long-term*. A *specified level* means that there are defined objectives related to stock conservation (e.g., avoid impairment of recruitment or other states considered to represent serious harm), socio-economic and cultural outcomes, and that these objectives are measurable whenever possible. Objectives for natural resources are value-based, necessarily conflict, and require specifying the acceptable degree of risk incurred by ongoing management choices – the process is “far more like juggling than throwing darts at a bull’s-eye” (Hilborn et al. 2015). In the absence of defined objectives regarding resource use, this level cannot be specified here any further. Nor does a focus on a level alone necessarily determine the sustainability of the management strategy as a whole.

Claims of fisheries sustainability can be defended by following structured processes that meet acceptable scientific and management practice. Scientific defensibility of a specific choice of data assessment method, and harvest control rule (b-d, above) requires a systematic approach to operationalizing measurable objectives, investing in monitoring data, and reacting to the results of new information and analyses to identify management measures likely to promote acceptable outcomes. Defending fishery management actions requires demonstration that specific management measures provide, or are likely to provide, an acceptable trade-off between stock integrity, socio-economic and cultural benefits. It is unlikely that objectives for a fishery management plan would be fully specified along all axes of sustainability at the outset; the process (a-e, above) is iterative, to allow learning, incorporation of new information and the addition of new objectives or revision of existing objectives as conditions change over time.

2. ANALYSIS

2.1. ANALYSIS OF FISH STOCKS PROVISIONS

Section Key Points:

- The phrase “*maintain major fish stocks at or above*” in FSP s 6.1(1) suggests a management aim to either achieve or surpass some threshold below a higher target (e.g., TRP, B_{target}, etc.), which is set as part of a fisheries management objective.
- Targets, like limits, are fundamental components of the precautionary approach to fisheries management. In Canada’s PA Policy, targets reflect productivity objectives for the stock, broader biological considerations and socio-economic objectives for the fishery.
- The phrase “*maintain the fish stock above [the limit reference point]*” cited in FSP s 6.1(2) (Table 1) refers to limits in biomass or abundance (LRP) and not limits to fishing mortality or harvest rate (removal reference or RR). Biomass proxies may be used to preserve policy intent in situations where biomass cannot be estimated.
- The basis for LRPs is to serve as thresholds to irreversible, or only slowly reversible harm, due to the long-term impacts of fishing or other anthropogenic activities. Maintaining stocks above LRPs is integral to the biological sustainability of the stock and sustainable fisheries under management by reference points.
- The FSP identify the LRP separately from the need to maintain stocks at or above the “*level necessary to promote sustainability of the stock*.” Therefore, the FSP imply two different levels at which stocks are to be maintained, with the level inferred s 6.1(2) (above the LRP) being less than that in s 6.1(1) (*level necessary to promote sustainability*).
- While a necessary condition for biological sustainability, avoiding a LRP breach does not resolve the stock status level above a LRP that is considered to promote sustainability of the stock and dependent fisheries.

- Stocks managed under either s 6.1(1) or s 6.1(2) of the FSP are distinguished based on consideration of the socio-economic or cultural impacts on the feasibility or appropriateness of management measures.
- Therefore, thresholds representing a "*level necessary to promote sustainability of the stock*" (s 6.1(1)) and lower levels that still enable a stock to be maintained acceptably above the limit reference point (6.1(2)) differ in terms of trade-offs among conservation, cultural or socio-economic objectives for the fishery(ies) on the stock.
- As the objectives and considerations by which fish stocks are managed extend beyond stock status relative to the LRP under s 6.1(1), trade-offs among these are beyond Science remit.

In the following sections, the text in s 6.1 of the FSP is examined in more detail. The scientific implications for the design of the fishery management system are considered as well as Science Sector needs for implementation. In each section, specific text of the *Fisheries Act* is highlighted in a grey-shaded box. Emphasis is added to portions of the text in ***bold italics***.

2.1.1. "At or Above" Suggests a Threshold

Fish Stocks

Measures to maintain fish stocks

6.1 (1) In the management of fisheries, the Minister shall implement measures to maintain major fish stocks ***at or above*** the level necessary to promote the sustainability of the stock, taking into account the biology of the fish and the environmental conditions affecting the stock.

Section 6.1(1) refers to implementing measures aimed at maintaining major fish stocks *at or above* a level that is *necessary to promote* stock sustainability. The phrase *at or above* suggests a goal of aiming to either achieve or surpass some threshold that is below a higher target reference point (TRP).

Various non-limit thresholds (also called buffers, triggers or precautionary reference points) may be defined in relation to either limits or targets and are used in multiple jurisdictions (Marentette and Kronlund 2020). Limits are discussed in the next section (2.1.2). Targets, like limits, are fundamental to the precautionary approach (FAO 1995, FAO 1996) and are set to reflect a variety of considerations relevant to decision-makers. Targets are required elements under the United Nations Fish Stocks Agreement (UN 1995), the FAO (1995) Code of Conduct for Responsible Fisheries and the FAO (1996) technical guidelines for implementing the precautionary approach. The requirement for targets is recognized in the PA Policy where TRPs reflect productivity objectives for the stock, broader biological considerations and social and economic objectives for the fishery (DFO 2009). Target reference points in precautionary approaches worldwide represent desirable fisheries states inclusive of societal objectives (FAO 1996, Sainsbury 2008), and like limits are typically estimated in units of abundance, biomass (or some comparable metric), or estimated fishing mortality. Some jurisdictions have legislative or policy requirements to achieve specific fisheries targets such as maximum sustainable yield (United Nations Fish Stocks Agreement, New Zealand, ICES), optimum yield (USA), or maximum economic yield (Australia; see Appendix A for definitions). Targets should not be exceeded "*on average*" (UNFSA 1995); indeed "*it is expected that the actual state of the fishery will approach or fluctuate somewhat about these targets*" (Sainsbury 2008). It follows from this that a threshold set below a target would be intended to be exceeded greater than 50% of the time.

Two reference points in Canada's PA Policy can potentially serve as targets (Figure 1). The Target Reference Point (TRP) is meant to represent a desirable stock status state. The Upper Stock Reference (USR) can serve as a stock status target, either in the absence of, or in addition to, the presence of a TRP. However, the primary role of the USR is not as a reference point. Rather the USR is intended to serve as an operational control point (OCP), or a trigger for a decision to be made (Cox et al. 2013) in order to reduce the risk of approaching the LRP (DFO 2009). The USR is further assigned the role of delineating the threshold between what are termed the Cautious and Healthy Zones, with the Healthy Zone also representing a desirable stock state, but this threshold is not specifically defined in relation to either limits or targets (see Section 2.3.3).

Fishing mortality rates can also represent a target, denoted F_{target} in many jurisdictions. Selection of a target fishing mortality rate (or harvest rate) depends on probabilities assigned to:

1. breaching limit fishing rates (the RR in the Canadian PA Policy), or the LRP;
2. attaining desired stock biomass levels represented by the stock status targets (TRP or the USR, if used as a target); and
3. attaining other management objectives relating to catch variability, average yields, etc., all over various time scales.

Desirable states for fisheries can also be informed by the setting of other types of management thresholds that include, but are not limited to, other biological attributes of target stocks (e.g., maintaining a desired age or length structure in the population). Thresholds and targets could also be set to support the management of multi-species or mixed-stock fisheries, or to address other ecological objectives targeted by different types of management measures. For example, both restoring and maintaining the biodiversity of salmon populations, and their habitats, are goals of Canada's Wild Salmon Policy (DFO 2005a).

2.1.2. Exceptions Suggest Other Considerations

2.1.2.1. Limits have a Distinct and Separate Role in the FSP

> **Fish Stocks**
>
> **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.

Section 6.1(2) highlights the requirement to "set a *limit reference point*." Generally speaking, limits define thresholds to unacceptable outcomes. These include unacceptably high fishing mortality and unacceptably low biomass or abundance levels. The basis for limit reference points is in avoiding irreversible, or only slowly reversible harm due to long-term impacts of fishing or other anthropogenic activities (Sainsbury 2008, Shelton and Rice 1992). Thus avoiding the LRP is a necessary condition for promoting sustainability, though not sufficient for producing sustainable outcomes across multiple axes of sustainability.

The PA Policy identifies two reference points as limits: the LRP as a minimum for the stock in units of abundance, biomass or suitable proxies and the removal reference (RR) as a maximum for fishing mortality or exploitation rate (DFO 2009, Figure 1). As s 6.1(2) refers to maintaining stocks above the limit, this can be interpreted as corresponding to the LRP in the *Fisheries Act*.

In the PA Policy, the LRP represents

- the stock status below which irreversible or only slowly reversible *serious harm* is occurring to the stock (in this sense, impaired productive capacity or the ability to recover from perturbation); and where there may also be
- resultant impacts to the ecosystem, including associated species; and
- a long-term loss of fishing opportunities (DFO 2009).

Similar limits are used worldwide (e.g., limits in biomass or B_{lim}, for which various defaults or proxies are proposed; Sainsbury 2008, DAWR 2018b; see also, the "*point of reproductive impairment*" or PRI evaluated by the Marine Stewardship Council 2018). Kronlund et al. (2018) further noted that a LRP should be positioned **before** a state of serious harm occurs, rather than at the state of serious harm (e.g., at a biomass level above the level where the possibility of serious harm exists or at a fishing mortality rate lower than one expected to produce serious harm).

In the FSP, the LRP is mentioned directly and separately from the "*level necessary to promote sustainability of the stock*." This suggests that there are two different levels at which stocks could be "sustained" or maintained, with the level in s 6.1(2) less than that in s 6.1(1), with both above the LRP. The objectives that are acceptably met by managing fish stocks at one or the other level therefore involve considerations that extend beyond tolerance for breaching the LRP alone. While a necessary condition for biological sustainability, avoiding a LRP breach does not resolve the stock status level above a LRP that is considered to promote sustainability of the stock and dependent fisheries. Although a target is not explicitly specified in s 6.1(2), harvest strategies which specify a target would help to avoid stock biomass lingering near the LRP in practice.

2.1.2.2. A Role for Non-Ecological Axes of Sustainability

Considerations

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.]*

Fish Stocks

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.

Cultural reasons or *adverse socio-economic impacts* are cited in s 6.1(2) as the basis for exceptions to s 6.1(1). Considerations of cultural and socio-economic impacts also support s 2.5(b), which states the Minister may consider the sustainability of *fisheries*, which implies sustainable use of the resource. We note that this contrasts with the requirement for a rebuilding plan in the FSP which is governed solely by the status of a fish stock relative to its LRP (i.e., a stock that has declined "*to or below its limit reference point*" in s 6.2(1); Table 1).

It is the *feasibility or appropriateness* of the management measures that provide the basis for prescribing a stock under s 6.1(2). It is not sufficient to only consider stock biomass (or proxy) relative to reference points in decisions to invoke s 6.1(1) versus s 6.1(2). 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, are only different in the magnitude of trade-offs among conservation, cultural and socio-economic outcomes incurred by the management measures intended to achieve them. Therefore, the objectives and considerations by which fish stocks are managed extend beyond stock status relative to the LRP, and these considerations are beyond Science remit.

2.2. USE OF STOCK STATUS IN EVALUATING SUSTAINABILITY

Section Key Points:

- Under appropriate management, stocks may be sustained on average over a wide range of abundance levels and fishing mortality rates.
- Acceptably sustainable stock states are often delineated by limits and, to a lesser extent, other thresholds and targets in both biomass and fishing mortality, but such classification schemes remain somewhat arbitrary.
- Promoting stock sustainability alone would prioritize management objectives related to conservation at the expense of considerations of resource use.
- To operationalize fisheries sustainability across multiple axes, objectives with other thresholds, targets and management measures are needed that reflect not only conservation but socio-economic, cultural, or other considerations for the stock and dependent fisheries.
- Risk-based objectives that define tolerance for avoiding biological limits, achieving targets or surpassing other thresholds help to narrow the range of acceptable stock states, in ways that reflect jurisdictional interests along multiple axes of sustainability.
- Managing risks, including acceptable risks to stock sustainability, is a value-based process. It is informed but not determined by scientific risk assessment and is therefore beyond Science remit to define.
- Acceptably sustainable stock states vary among jurisdictions, where some evaluation frameworks emphasize achieving maximum sustainable yield, or avoiding states of impaired reproductive capacity, and others strive for a mix of both considerations.
- Stock status is deceptively easy to communicate, but is difficult to quantify accurately. A procedure-oriented approach to fisheries management focuses on whether candidate management measures will acceptably achieve objectives, and less on the stock status relative to reference points at any given moment. This is accomplished by evaluation of whether management options are likely to produce desired outcomes over time, usually via simulation methods.

The interpretation of the FSP in light of the PA Policy presented in Section 2.1 noted in part the use of reference points and characterization of stock status relative to those reference points. These features are common to precautionary approaches to fisheries management in many fisheries jurisdictions (Marentette and Kronlund 2020, McIlgorm 2013, Sainsbury 2008). While we noted that sustainability should be viewed as a process ("juggling"), because stock status relative to reference points can form a distraction in fisheries management (Hilborn 2002), status relative to reference points remains a commonly used and important part of evaluating sustainability worldwide and merits further attention. In the following sections, we examine how stock attributes in relation to reference points have been used in setting objectives and as metrics by which to evaluate sustainability.

2.2.1. Limits (*B* and *F*) Constrain "Sustainable" Stock States

In theory, stocks may be sustained over a wide range of abundance and harvest levels (Shelton and Sinclair 2008). This creates a challenge for the development and evaluation of management measures for sustainable fisheries – what states are acceptable?

A stock may be reduced to the point that catches are much lower than they might otherwise be, but such low catches could be maintained indefinitely and are therefore technically "sustainable" in the sense of maintained over time. Sainsbury 2008 argued that managing with an objective of *sustainability* alone, with sustainability meaning 'can be continued indefinitely', is a weak and inadequate standard. In other words, under assumptions of equilibrium, for almost every level of fishing mortality, there would be a corresponding stock biomass that could be "sustained" on average but with very different ecological and economic outcomes (Sainsbury 2008, Shelton and Sinclair 2008).

An exception would be fishing mortality rates that result in stock extinction (sometimes expressed as F_{crash}, or $F_{extinction}$ (F_{ext}); Figure 2a). Thus, a "*classical*" view of sustainability, derived from deterministic production models around the 1970s, is primarily related to constraints on fishing mortality (Quinn and Collie 2005).

The advent of limits for both biomass and fishing mortality in the 1980s supported what Quinn and Collie (2005) termed a "*neoclassical*" view of sustainability. This recognized the importance of depensatory and stochastic processes in stock capacity to recover from low levels, as well as stock assessment uncertainty, and thus narrowed the range of acceptable stock states to avoid levels associated with reproductive impairment (Figure 2b). The "*neoclassical*" view of sustainability was later augmented by the identification of F_{MSY} as a limit fishing rate and *not* a target, as in the precautionary approach (Mace 2001) leading to the "*modern*" view, encapsulated in UNFSA 1995. In this view, levels capable of producing MSY were identified as a management goal for target species and avoiding reproductive impairment was identified as a goal for non-target species; Figure 2c,d). Eventually other axes including socio-economic, habitat or ecosystem considerations were introduced, consistent with the "*postmodern*" view of what sustainability entails (Quinn and Collie 2005). Intermediate states between limits and targets for both *F* and *B* are assigned cautionary values, that may be perceived as either sustainable or unsustainable depending on the perspective of the viewer (Quinn and Collie 2005; Figure 2c,d), or perhaps depending on the goals of a given jurisdiction or organization (Hilborn et al. 2015).

Limits (for *F* and *B*) have thus been generally recognized as necessary to define what stock states can be considered sustainable (Figure 2b-d), consistent with the precautionary approach,

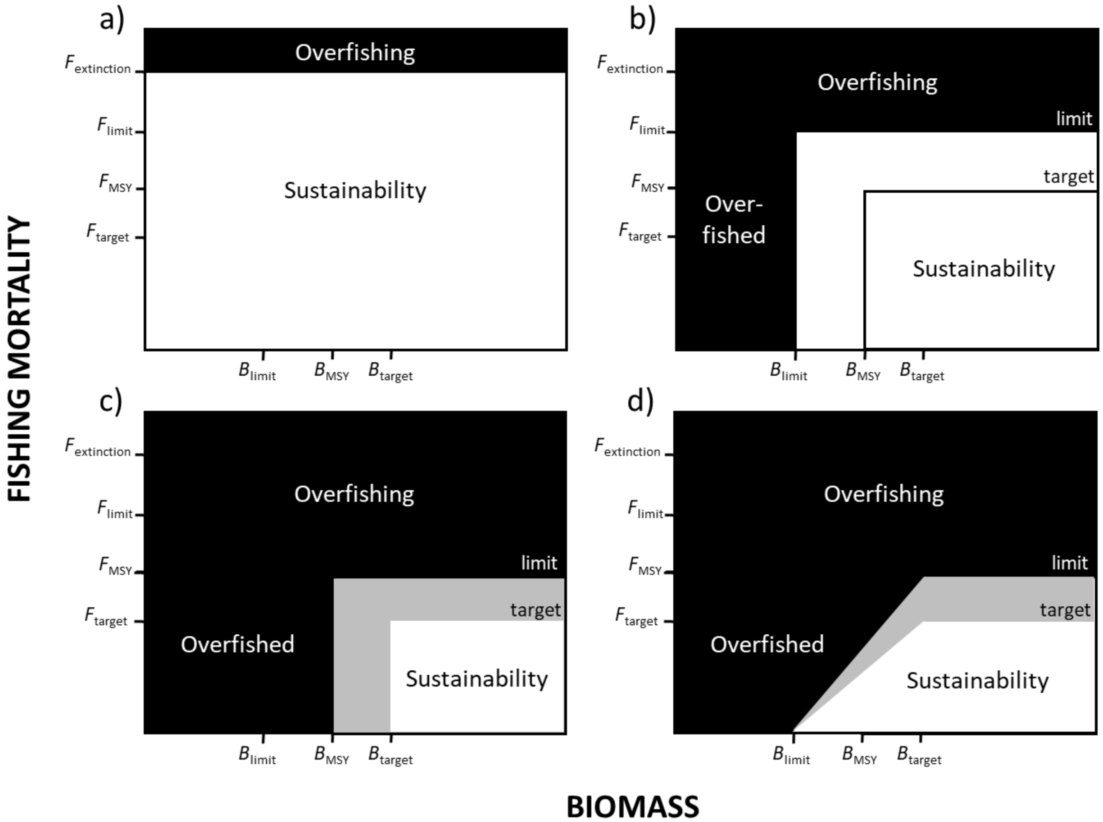

Figure 2: The evolution of the concept of sustainability in fisheries, adapted from Quinn and Collie (2005). The horizontal axis in all cases represents equilibrium biomass (B), and the vertical axis represents the corresponding equilibrium fishing mortality (F). Black areas are considered unsustainable, and white areas sustainable. Grey areas indicate what Quinn and Collie term "cautionary" states, which may be considered either sustainable or unsustainable depending on the viewer. Panel a) shows the "classical" (< 1970s) understanding of sustainability is bounded only by fishing mortality leading to stock extinction ($F_{extinction}$); for every lower F there would be a corresponding equilibrium B. In panel b) the "neoclassical" (1980s) view of sustainability introduced new limits in both B and F, recognizing the need to avoid states of reproductive impairment from occurring. The "modern" (1990s) view of sustainability (panel c) reconceptualized B and F corresponding to maximum sustainable yield (MSY) as limits, not targets. In panel d) the modern view of sustainability is shown with a harvest control rule (HCR) similar to the "MSY control rule" of Restrepo et al. (1998), adjusting both limits and targeted fishing pressures in relation to stock biomass. Postmodern views of sustainability acknowledge other axes apart from biological considerations, and other biological or ecological elements, not visualized here.

and it is common practice to consider stock status on both the *F*- and *B*-axes together (Garcia et al. 2018). It is important, however, to note a few caveats. First, not all organizations are aligned on the values underlying sustainability objectives for *F* and *B*; for example, the International Commission for the Exploration of the Seas (ICES 2019), and the European Union's Common Fisheries Policy (Regulation (EU) No 1380/2013), continue to view F_{MSY} as a target. Second, while management by reference points forms the basis of precautionary approaches to fisheries management worldwide, reference points and stock status relative to them can form a distraction from procedure-oriented approaches to fisheries management. Procedure-oriented approaches (e.g., de la Mare 1998; Punt et al. 2016) focus on whether candidate management measures will acceptably achieve objectives, and less on the stock status relative to reference points at any given moment. This is accomplished by evaluation of whether management options are likely to produce desired outcomes over time, usually via simulation methods. The distraction arises by excessive dependence on current stock status, which appears deceptively easy to communicate but is actually difficult to quantify accurately given the many uncertainties associated with stock assessment (Hilborn 2002).

Reliance on determining status relative to reference points can also encourage “over-simplistic” views that reference points mark abrupt changes in risks, for example, “that a population is in extreme peril anywhere on one side of the limit reference point and is totally safe anywhere on the other side” (Sainsbury 2008). Abrupt thresholds can exist in population responses to harvesting and other factors, but this is often not the case, and transitions in risk with changes in stock status are generally considered on a continuum, with some degree of uncertainty. Procedure-oriented approaches are being implemented in practice in several Canadian fisheries (e.g., DFO 2020a; DFO 2020b; DFO 2020c), and have been proposed as best practice for both data-rich and data-limited species (Punt et al. 2016; DFO 2021). Implementation of the FSP, like the PA, should necessarily be able to accommodate procedure-oriented approaches when determining whether management is consistent with the FSP.

2.2.2. Management Objectives with Targets Operationalize Sustainability

Limits help define acceptable stock states, but “stock sustainability” alone is not enough to achieve fisheries sustainability – other considerations are needed. First, considerations of only ecological objectives of fisheries sustainability (that is, in the absence of objectives for benefits from resource use) would push decision-making 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, Figure 3). At the very least, stock sustainability is promoted by reducing fishing. Such conclusions are unhelpful from a resource management perspective where socio-economic and cultural outcomes of fisheries remain important in addition to conservation outcomes:

> “It might be appropriate to consider the approach of simply fishing less if the only standard of sustainability were the status of the exploited stocks and the ecosystems in which they occur. Neither of those conditions, however, is true. Fisheries are conducted in order to provide economic returns from market sales, livelihoods to those participating in the activity, and above all, food for people. Sustainability must be found for all the outcomes—ecological, economic and social. Aside from rare and exceptional circumstances usually associated with histories of severe overfishing, merely reducing fishing would have unsustainable social and economic outcomes even if the targeted fish stocks increased.” (Rice 2017)

Since a broad range of stock sizes can be maintained in theory, in the sense of “continuing indefinitely,” stock sizes reduced to low levels (but above those levels associated with serious harm) could support only low levels of fishing on an ongoing basis or risk further decline. However, low levels of fishing impact social, cultural and economic outcomes of interest to decision-makers. As noted in previous sections, sustainable stocks are necessary but do not fully define sustainable fisheries.

Elements of the ecological axis of sustainability are rationalized against other axes of sustainability by establishing targets and the management measures intended to attain them. Identification of non-biological targets, and the uncertainty associated with achieving those targets, provides the basis for evaluating trade-offs among outcomes related to the stock conservation and benefits. This provides for sustainable use of the resource consistent with the PA Policy intent for non-limit thresholds and targets (e.g., USR if applicable, or TRP; Figure 1) which are to consider “productivity objectives for the stock, broader biological considerations and social and economic objectives for the fishery” DFO (2009).

2.2.3. Acceptable Risks to Sustainability of Stocks

We suggested above that *stock* sustainability is a gradient (MF 2011, Sainsbury 2008), maximized at unfished biomass ($B = B_0$, $F = 0$), and widely recognized to be generally minimized at levels consistent with reproductive impairment (*serious harm* in the PA Policy). Under that premise, how much stock is required to be (biologically) “sustainable” enough while still acceptably meeting other management objectives? In other words, what probability of having an unsustainable stock status ($F > F_{\text{lim}}$, $B < B_{\text{lim}}$) is considered acceptable?

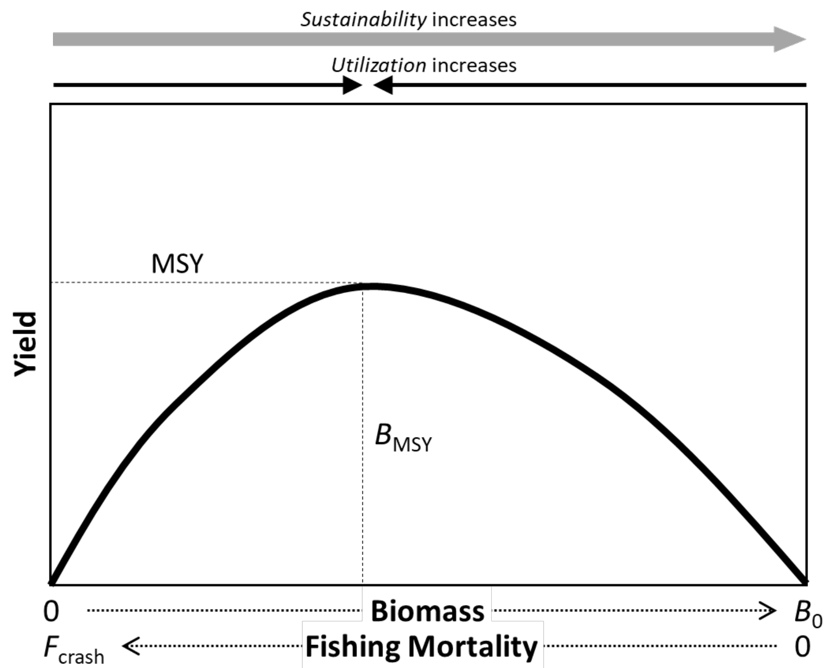

Figure 3: In New Zealand’s Harvest Strategy Standard guidelines, rationalizing the concept of “sustainable use” requires consideration of not only the potential for stocks to be sustained (a potential that generally increases with stock biomass (B) up to a maximum at unfished levels, B_0), but also where the potential for resource use, here shown as yield, reaches its maximum (maximum sustainable yield or MSY). B_{MSY} = biomass that produces MSY under theoretical equilibrium conditions. Adapted from New Zealand Ministry of Fisheries (MF 2011).

Managing risks, including acceptable risks to stock sustainability, is a value-based process. It is informed but not determined by scientific risk assessment (Peterman 2004, Gregory et al. 2012) and is therefore beyond Science remit to define. It requires making trade-offs among management outcomes related to different and often opposing objectives, not all of which can be reliably measured. In Canada, decision-making is guided by “society’s chosen level of protection against risk” (PCO 2003). Where possible, the chosen level of risk is established through domestic policy instruments such as legislation and international agreements, advanced with public involvement of those most affected by decisions. What is considered acceptable risk may evolve over time as society’s tolerances and chosen level of protection vary with new or emerging risks and scientific knowledge (PCO 2003).

Acceptable risks to stock sustainability vary with jurisdictions according to their interests and values along multiple axes of fisheries sustainability, impacting not only the implementation of management measures but also the selection of management targets (reviewed in Marentette and Kronlund 2020). Some jurisdictions specify in policies or guidance the level of risk considered acceptable when designing harvest strategies, particularly with respect to breaching stock limits to undesirable states. For example:

- For Australian Commonwealth-managed fisheries, no greater than a 10% (1-in-10 year) probability of breaching stock limit reference points (DAWR 2018a); and
- For stocks where advice is provided by ICES, management plans with no greater than a 5% probability (1 in 20 scenarios) of breaching limits in each and every year (and some considerations for short-lived species where fluctuations may exceed this naturally; ICES 2019).

Targets that represent desirable stock and fishery states, on the other hand, are often set to be achieved "on average" (UNFSA 1995), e.g., with 50% probability (1 in 2 scenarios) over some specified time period, indicating that fluctuations around targets are acceptable.

2.2.4. Acceptable Stock States Vary by Jurisdiction

Many jurisdictions and organizations have developed precautionary strategies that categorize stock status in ways that simplify evaluation and reporting, including Canada (Figure 4a, Marentette and Kronlund 2020) – although as discussed earlier, reference points such as limits (and therefore stock status categories) rarely if ever mark significant or abrupt changes in actual risk (Sainsbury 2008) and therefore can be misleading. There is also no clear consensus or precise estimates of suitable thresholds for defining status of stocks (Ye 2011) across jurisdictions. As a result, the diverse and somewhat arbitrary nature of value judgements around stock status and resulting categories can complicate the compilation of international statistics for reporting stock status (Ye 2011). Variation in reporting of stock status across different areas can even complicate reporting within a given nation (e.g., Australia; Flood et al. 2016).

Sometimes organizations focus primarily or even solely on evaluating performance via estimates of (current or projected) stock abundance (i.e., B to the exclusion of F). The FAO, for example, considers estimated stock abundance below $0.4B_0$ (~$0.8B_{MSY}$), or various other proxies, to be *overexploited* with respect to achieving a target of maximum sustainable yield, and *overexploited* in terms of spawning potential if below $0.2B_0$ (~$0.4B_{MSY}$; Garcia et al. 2018, Ye 2011). Taking into consideration that "pretty good yield" (Hilborn 2010) can be obtained over a range of stock sizes, the FAO has classed stocks within 0.8 to $1.2B_{MSY}$ as acceptably achieving its target for a sustainability indicator 14.4.1 ("*fully fished*", Ye 2011; double-headed arrow in Figure 4b). However, most jurisdictions, including Canada, evaluate both biomass and fishing mortality (or their proxies) when reporting stock status. This is done in various configurations generally consistent with the "*neoclassical*" and "*modern*" views of sustainability illustrated by Quinn and Collie (2005, Figure 2c, d).

Side-by-side comparisons of stock status schemes from around the world show similarities, but also highlight the arbitrary nature of status classifications (Figure 5). The proposed indicator to meet Aichi Biodiversity Target 6A, for example, expands upon FAO Sustainability Indicator 14.4.1 to identify stock states acceptably within constraints of MSY-based reference points using both B and F axes (Garcia and Rice 2020, grey double-lined rectangle in Figure 4b).

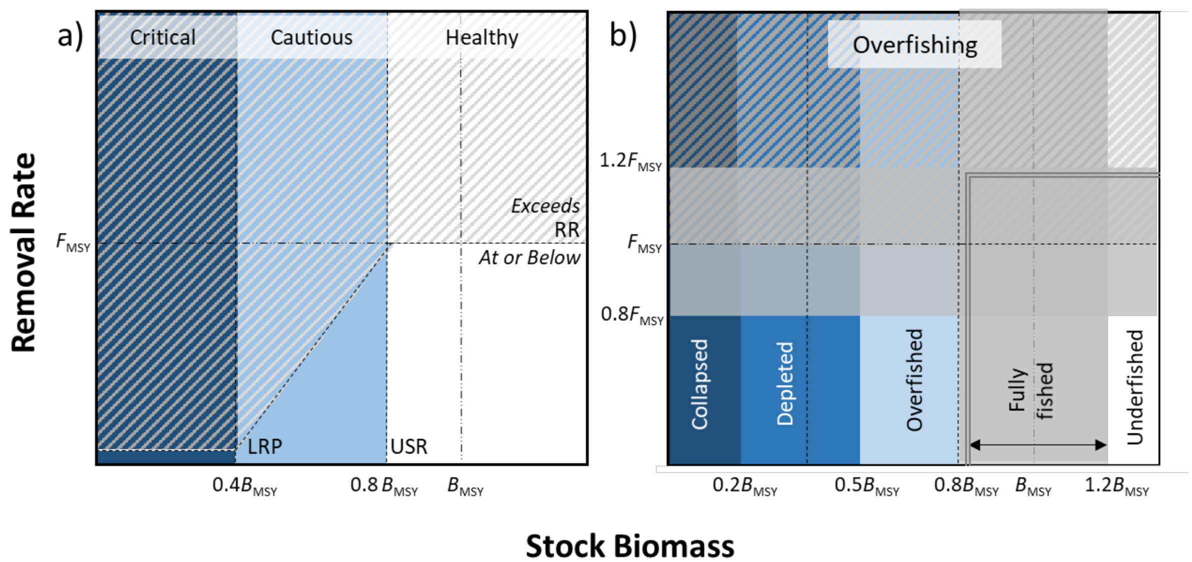

Figure 4: A comparison of a) stock status zones for the Canadian PA Policy, graphed with its provisional default[1] reference points (LRP, USR, RR) with b) stock status labels used for various international performance measures that assess fisheries sustainability (redrawn from Garcia and Rice 2020). In panel b), the grey double-lined rectangle encompasses stock states that meet the minimum requirements for Aichi Biodiversity Target 6A, while the double-headed arrow indicates the stock biomass that would correspond to a stock status of "fully exploited" (or "fully fished"), employed in FAO Sustainability Indicator 14.4.1.

Australia classifies stocks primarily by status in reference to limits; stocks are called "*sustainable"* if the stock is above a B_{lim}, but fished below an F_{lim} (Stewardson et al. 2018; Figure 5b). Some Australian categories (such as "*environmentally-limited*") are also used but not reflected in their diagram of stock states. Similarly, New Zealand's Harvest Strategy Standard focuses on stock states representing breached limits in both biomass and fishing mortality (MF 2011; Figure 5d). Traditional "Kobe" plots (Maunder and Aires-da-Silva 2011), widely used in many states and Regional Fisheries Management Organizations, treat both F_{MSY} and B_{MSY} as limits to undesirable stock states (Figure 5f). The precautionary frameworks of NAFO (2004) and ICES (2019), on the other hand, use buffers or precautionary reference points to nuance the range of acceptable stock states. This is accomplished by adding a zone of "*caution*" or "*increased risk*" between desirable and undesirable stock states on one or both axes, generally representing the boundary where stocks have greater than 5-20% probability of breaching limits in either the *F* or *B* axes (Figure 5c, e). Such zones are comparable to the grey cautionary zones that may be perceived as either sustainable or unsustainable by different viewers (Quinn and Collie 2005, Figure 2) and somewhat like the Cautious Zone of the Canadian framework (Figure 5a), although with important differences as discussed in Section 2.3.3.

Finally, although most of the evaluation schemes described above consider only current stock status, temporal considerations can also be important. NOAA's National Standard Guidelines 1 (NOAA 2018) consider stocks with projected breaches of stock size limits within two years as

[1] 'Default' is understood to be in the sense of a pre-selected, non-mandatory option when no more specific reference point is chosen.

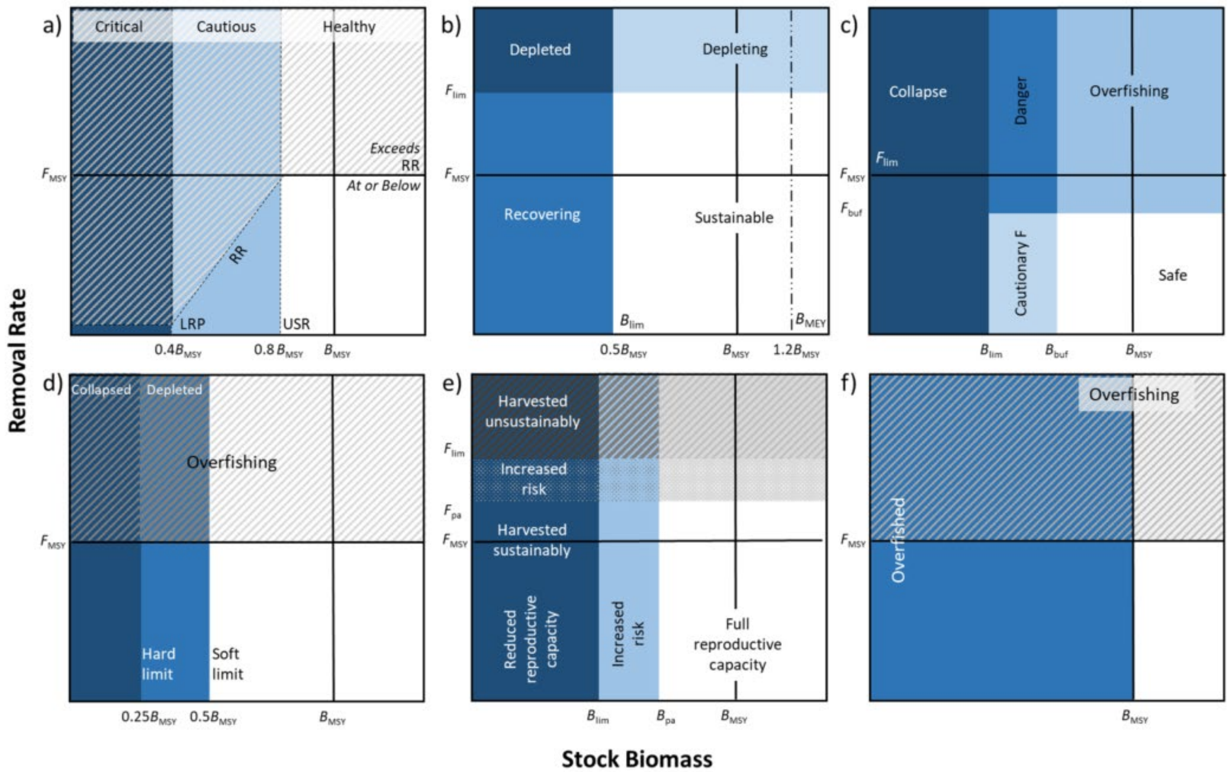

Figure 5: Stock status categories used in precautionary or risk-based fisheries management frameworks for a) Canada, b) Australia, c) NAFO, d) New Zealand, e) ICES, and f) a generalized Kobe plot used in many international contexts. Comparisons highlight similarities but also the somewhat arbitrary nature of value judgements inherent in such status categories. Placement of each jurisdiction's reference points and labels relative to either F_{MSY} or B_{MSY} (including provisional or default values, where given) are specified. Provisional default values for Canadian reference points (LRP as $0.4B_{MSY}$, USR as $0.8B_{MSY}$, and three-part RR declining linearly from F_{MSY}) are presented in panel a) Other jurisdictions also specify default values of reference points (e.g., a B_{lim} of $0.5B_{MSY}$ (or $0.2\ B_0$[2]); Australia, New Zealand and B_{MSY} of the generalized Kobe plot). Otherwise, placement of other reference points should be considered relative.

"*approaching an overfished condition*." The Marine Stewardship Council (MSC) certification process evaluates performance indicators (PIs) relative to stock status (PI 1.1.1), stock rebuilding (PI 1.1.2), harvest strategies (PI 1.2.1), harvest control rules (HCRs) and other tools (PI 1.2.2), information/monitoring (PI 1.2.3), and assessment (PI 1.2.4) used under Principle 1 ("Sustainable Target Fish Stocks"; MSC 2018a). MSC awards higher scores towards certification when stocks that are above their point of reproductive impairment (PRI) can be shown to have trends in biomass where biomass is $0.9B_{MSY}$ or higher over time periods of one generation time, and/or which have trends suggesting this level (or higher) will be maintained in the future (MSC 2018a, 2018b).

[2] An assumption that $B_{MSY} = 0.5B_0$ is predicated on the assumption that fish mature and become vulnerable to fisheries at the same age, amongst other assumptions. In many cases the yield curve (e.g., Figure 3) may be asymmetrical and other assumptions may be made (e.g., $B_{MSY} = 0.4B_0$)

2.2.5. Acceptable Stock States Reflect Management Values

The stock status categories in the subset of international jurisdictions examined here reflect a range of objectives and priorities. The FAO sustainability indicator 14.4.1, Aichi Biodiversity Target 6 (both shown in Figure 4b) and the generalized Kobe plot (shown in Figure 5f) all deem a stock status deviating from some defined range of capacity to produce at least a target of maximum sustainable yield as unacceptable. There is, however, allowance for varying extents of deviation from this target. The minimum stock size threshold or MSST of the United States, below which stocks are defined as overfished and which cannot be lower than $0.5B_{\mathrm{MSY}}$, is also defined as a stock size below which the capacity to produce MSY is "*jeopardized*" (NOAA 2018). Precautionary frameworks in Canada, Australia, New Zealand, ICES and NAFO, however, as well as the Marine Stewardship Council, all evaluate biomass consistent with impaired reproductive capacity as unacceptable. Some, including Canada, also use intermediate/cautionary zones representing states of heightened risk and/or reduced tolerance for further stock decline. Some jurisdictions (Australia, ICES) match limits in fishing mortality to limits in biomass, thus treating F_{MSY} (or F_{MEY}) as a target. Others (Canada, New Zealand) consider F_{MSY} as a limit as per the UNFSA (1995). This latter practice simultaneously implies that B_{MSY} should be the corresponding biomass limit (Maunder 2013); however limiting biomass levels are usually indicated to be less than B_{MSY} (Marentette and Kronlund 2020). The diversity in sustainability reporting schemes reflects differences in sustainable fisheries management criteria across international contexts. Some evaluation frameworks emphasize achieving maximum sustainable yield, some focus on avoiding states of impaired reproductive capacity, and others strive for a mix of both. The differences across organizations and jurisdictions are also reflected in varying and sometimes conflicting usage of terms such as "*overfished*" and "*overfishing*" that may reflect the values applied to stocks and fisheries.

2.3. STOCK STATES AND SUSTAINABILITY IN CANADA

Section Key Points:

- Stock states in Canada 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).
- Canada reports on "fishery status" (status on the fishing mortality or *F*-axis) for major fish stocks via the Canadian Environmental Sustainability Indicators (CESI) program. There, stocks are "*sustainably harvested*" if they are fished at, or below, their RR (or are otherwise harvested at approved levels), and "*overharvested*" if they are not.
- On the biomass (*B)* axis, the Critical Zone (bounded by 0 and the LRP) defines undesirable levels of stock abundance where serious harm may be incurred. The Cautious Zone (bounded by the LRP and USR) and Healthy Zone (stock levels above the USR) serve to differentiate zones where different types of management action may occur.
- Stock states in the Healthy Zone are generally treated as desirable by Canada but the USR is not explicitly defined as a boundary to acceptably sustainable stock states.
- In the context of the PA Policy the primary role of the USR is as an OCP (e.g., as an element of a HCR), where the USR delineates the biomass level where the removal rate is reduced, with the intent to preserve a specified risk of breaching a limit. In that role, the preferred choice of the USR as an OCP also depends on other OCPs and the target removal rate since all will affect whether limits are avoided, on average.

- The PA Policy also states that the USR can be a (threshold or target) reference point determined by productivity objectives for the stock, broader biological considerations, and social-economic objectives for the fishery.
- For the purposes of evaluating fish stocks under the FSP, a composite performance measure of fisheries sustainability could be developed. This would use the elements of the PA Policy, and evaluate whether a stock exceeds the LRP and falls below the RR, and whether the harvest strategy contains management measures that perform acceptably. Performance would be with respect to achieving objectives respecting limits, other thresholds and targets (e.g., USR, TRP) over desirable time frames. This would include rebuilding above the LRP if breaches occur.
- Other axes (such as socio-economic or cultural outcomes), other biological elements (such as age or size structure of the stock), and other ecosystem axis elements (such as biodiversity, trophic level, or habitat considerations) may also be incorporated into fisheries management objectives and could be included in evaluating fisheries sustainability.

In this section, the definition and use of stock states in Canada is explored in more detail. The section concludes with an examination of how stock states in the PA Policy can be integrated into performance measures of fisheries sustainability.

The Canadian PA Policy discriminates between "*stock status*" related to biomass (or a proxy) and "*fishery status*" related to fishing mortality rate ("removal" or "harvest" or "fishing mortality" rate, or a proxy) (Annex 1B of DFO 2009). Both attributes are properties of the stock population and fishery dynamics (i.e., how much of the stock is present, and how quickly it is being removed). We refer to the stock status and fishery status dimensions as the *B*-axis and *F*-axis, respectively. The PA Policy provides guidance for characterizing stock status and fishing mortality rate into three and two zones, respectively. In order of increasing biomass relative to reference points (i.e., status) along the *B*-axis, the management labels Critical, Cautious and Healthy are applied, delineated by the LRP and USR (Figure 1; DFO 2004b). The *F*-axis is divided into two categories depending on whether the fishing mortality rate exceeds, or is at or below, the RR limit fishing mortality (Figure 1). Both stock and fishery status are tracked and reported by DFO's annual *Sustainability Survey for Fisheries* (DFO 2019c).

2.3.1. "Fishery Status" is Used to Report Sustainability

Stock states on the *F*-axis that either exceed, or are less than or equal to, the RR are included in reporting (e.g., DFO 2019c). One avenue by which Canada reports on fishery status for major fish stocks relative to the RR is the Canadian Environmental Sustainability Indicators (CESI) program, led by Environment and Climate Change Canada (ECCC), which reports on sustainable fish harvests (ECCC 2020a) as well as the (stock) status of major fish stocks (ECCC 2020b). For the CESI Sustainable Fish Harvests indicator, stocks are considered to meet the requirements of the indicator if they are at, or below, their RR, or are otherwise harvested at approved levels. Stocks where the fishing mortality rate exceeds the RR are termed "*overharvested*." The RR is there defined as "a harvest rate that is estimated to be biologically sustainable, based on an analytical assessment of historical stock productivity data," (ECCC 2020a). This definition thereby admits a wide range of fishing mortality rates with corresponding biomass and harvest implications that could be 'sustained'. The PA Policy does not contain or define terms such as *overharvesting* or *biologically sustainable*. Rather, it prescribes that, to comply with the UNFSA, the RR must be less than or equal to F_{MSY} (or a proxy) and states that the RR is a maximum acceptable rate (i.e., a limit fishing rate; Shelton and Sinclair 2008). In general, the ECCC indicators are part of a federal sustainability reporting scheme, and are not currently used in the development of science advice for Canadian fish stocks.

2.3.2. Stock Status below the LRP Represents Unacceptable Risk of Serious Harm

Stocks at a level below their LRPs (i.e., the Critical Zone) are considered at unacceptable risk of impaired reproductive capacity or other serious harm (Section 2.1.2; Shelton and Rice 2002). The PA Policy Critical Zone is analogous to stock states bounded by many similar types of limits identified worldwide (Sainsbury 2008), and the LRP serves specific policy and now legislative functions in Canada (FSP ss 6.1(2), 6.2). This is a stock state that other jurisdictions might refer to as being “depleted” and/or “collapsed” (Section 2.2.4), or a state of being “recruitment-overfished” (Froese and Proelss 2012).

2.3.3. Classifying Stock Status Relative to the USR or TRP Requires Trade-offs Among Management Outcomes

It is widely accepted that claims of stock sustainability cannot be supported for stocks that have breached the LRP and are at risk of serious harm. However, stocks at levels above a LRP might be claimed to be biologically sustainable *provided* an appropriate process for scientific assessment and management is in place.

The PA Policy specifies two additional status-based reference points in addition to the LRP; the USR and an optional TRP, where LRP < USR ≤ TRP (Figure 1). Two segments of the RR apply to stock levels above the LRP, where trade-offs in management outcomes are apparent. Under the PA Policy, it is here that “biological/ecosystem and social/economic considerations change in relative priority… thus, management actions are expected to have a different basis in each zone”; DFO 2004b, also see Table 1 of the PA Policy).

The USR is a somewhat ill-defined reference point. It is not explicitly defined as a boundary to acceptably sustainable stock states, although the management actions in the PA Policy generally treat stock states above the USR 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 (2004b) noted that “this is the desired state for sustainable fisheries.”

While the use of a TRP is commonly understood as a level about which a stock is intended to fluctuate, the USR must be carefully described in a stock-specific harvest strategy. This is because there are several possible roles assigned to the USR (OCP, threshold, target; Table 2), which cannot be achieved simultaneously. As an OCP, the USR represents the stock status level below which fishing mortality must be reduced from the target level, i.e., a level where management action is changed. This role is frequently represented in a HCR of the form shown in Figure 6, where there is a lower and upper OCP positioned on the stock biomass axis and some target removal rate below the limit RR on the Removal Rate axis (Figure 1). In this depiction, the USR corresponds to the upper OCP and must be positioned so there is sufficient time to allow feedback effects to correct stock decline and avoid a LRP breach. However, the OCPs and target removal rate do not act independently. The effect of positioning the USR depends on the values of the lower OCP and target removal rate. This role of the USR, as an OCP, is given priority in the PA Policy (Table 2, DFO 2009).

The PA Policy also states that the USR can be a (target) reference point determined by productivity objectives for the stock, broader biological considerations and social-economic objectives for the fishery (Table 2, Figure 1). There are no prescribed targets (only the optional TRP) in either the PA Policy or in the FSP. This situation is unlike other jurisdictions, which may have either legislative or policy mandates regarding management objectives to achieve targets such as maximum sustainable yield (MF 2008, ICES 2019), maximum economic yield (DAWR 2018a), or optimal yield (NOAA 2018). However, provisional defaults for reference points in the PA Policy (LRP = 0.4B_{MSY}, USR = 0.8B_{MSY}, RR ≤ F_{MSY}) are based on the theory of maximum sustainable yield (MSY), suggesting that a biomass level above 0.8B_{MSY}, say B_{MSY}, can be viewed as an *implicit* (unspoken) target of the provisional values provided in the policy (Figure 6). (Paradoxically, however, avoiding fishing mortality above a limit of F_{MSY} implies B_{MSY} is a limit, not a target. The Marine Stewardship Council, for example, recognizes and accepts implied limits/targets in harvest strategies (MSC 2018a, 2018b).

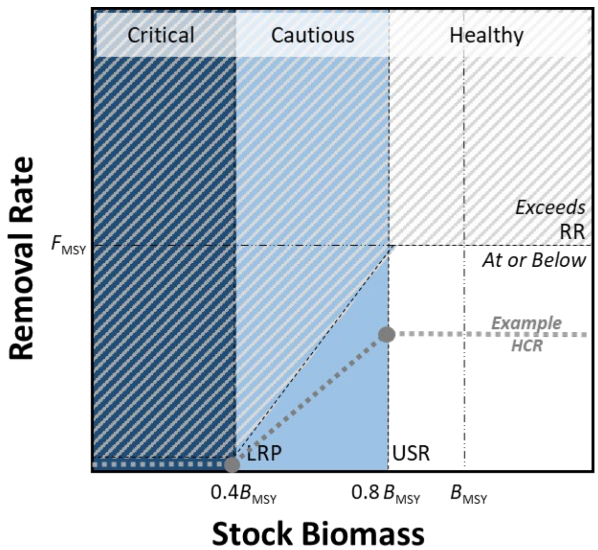

Figure 6: An example harvest control rule (HCR), shown as a grey dashed line, incorporated in the typical framework of the PA Policy, shown with default values for the LRP and USR and the provisional RR. Operational control points (OCPs) are shown on the HCR as grey circles.

There are no explicit mandatory risk tolerances specified for breaching limits in the PA Policy. Instead, the policy suggests that the acceptable risk of a LRP breach is “low” or 5—25% (based on interpretation of Table 1 of the PA Policy, and the provisional risk table provided in Annex 2 of the policy). Unlike jurisdictions such as ICES or Australia, this means there is no prescriptive guidance for how close the USR could be set to the LRP while maintaining acceptable risks of breaching the LRP. There is also no specification of what inherent acceptable risks of being below the LRP are conferred by the provisional USR value of 0.8B_{MSY}. Rather, the PA Policy (Table 1 of DFO 2009) provides generalized criteria including probabilities for preventable decline that become more restrictive with decreasing stock status (on the *B*-axis) and recent negative stock trajectories (Marentette and Kronlund 2020).

A USR set to 0.8B_{MSY} would also incidentally correspond to the lower boundary of stock states considered “fully fished” in the sense of the capacity to produce MSY for FAO sustainability indicator 14.4.1. However, stock states that could produce yields close to MSY may vary much more widely than 0.8 to 1.2 B_{MSY}. In fact, biomass may fluctuate naturally down to levels associated with assumptions of recruitment impairment in some jurisdictions (e.g., 0.5B_{MSY}; Garcia and Rice 2020, Ye 2011), making the choice of 0.8B_{MSY} somewhat arbitrary (Ye 2011). Despite similarities to the FAO indicator 14.4.1, the USR is not identified as fulfilling an analogous role in the PA Policy and the basis on which a provisional default value of 0.8B_{MSY} was selected (i.e., what it was intended to achieve) is not clear. In fact, the USR’s competing

Table 2: PA Policy references to the Upper Stock Reference (USR) and comments on policy intent.

Role	PA Policy (DFO 2009)	Comments on Intent
Operational Control Point (OCP)	"First, in accordance with SAR 2006-023 the USR is the stock level threshold below which removals **must** be progressively reduced in order to avoid reaching the LRP. For this reason, under this framework, the USR, at minimum, **must** be set at an appropriate distance above the LRP to provide sufficient opportunity for the management system to recognize a declining stock status and sufficient time for management actions to have effect." [**emphasis** added]	A reduction in removals (catch) at a stock status level is a management action. The goal of avoiding the LRP means that a reduction in removals needs to be large enough to reduce the *fishing mortality* as abundance declines, a reduction in removals may not reduce *F* for a declining stock. A reduction in fishing mortality to avoid breaching a LRP as the stock declines is policy intent. A reduction in fishing mortality must occur in advance of stock status reaching the LRP to allow for uncertainty in status estimation and lags in stock and fishery response to management actions.
	"… it is essential that while socio-economic factors may influence the location of the USR, these factors **must** not diminish **its minimum function in guiding management of the risk of approaching the LRP**. [**emphasis** added]	The "USR" is serving as a control point in this context, but this statement neglects the interacting effects of other components of the management procedure, i.e., the USR as an OCP does not act in isolation to produce desired management outcomes but interacts with the target harvest rate and stock assessment method.
Reference Point	"… the USR **can** be a target reference point (TRP) determined by productivity objectives for the stock, broader biological considerations and social and economic objectives for the fishery." [**emphasis** added]	The PA Policy admits the possible use of the USR and a TRP ≥ USR as reference points. A TRP is generally specified as a target stock status level about which a stock fluctuates, i.e., the stock is above the TRP 50% of the time, on average. When both a USR and TRP are specified, the probability of achieving the USR must be greater than that of achieving the TRP over the same time horizon. In the absence of a TRP, the USR can be a TRP. If the USR is embedded in a measurable objective by adding the certainty of achieving the USR over a specified time frame, this function is likely to conflict with the PA Policy intent to position the USR to avoid a LRP breach. Thus, the two roles ascribed to the USR in policy cannot be achieved simultaneously.
	The USR is the upper inflection point of the RR where the *limit removal rate* is reduced with declining stock status.	The "USR" is implicit in the definition of the RR, but factors cited to guide the position of the USR in this role conflict with its primary use as an OCP.

roles as OCP to control risks of approaching limits, or as default target in the absence of a separate TRP, would be inconsistent with an interpretation derived from close international analogs described above (which would be a point to take management action when stocks deviate unacceptably from another target altogether, such as B_{MSY}).

An historical review provides some useful perspective on the USR. In 2004, DFO fisheries management proposed a draft framework for the PA Policy that introduced the three stock status zones labelled Critical, Cautious and Healthy separated by two reference points (DFO 2004b). This concept was adopted in the formulation of the PA Policy with the LRP separating the Critical and Cautious Zones and the USR separating the Cautious and Healthy Zones (DFO 2006, 2009). The zone labels have now become a commonly used basis for reporting Canadian "sustainability indicators" like those in other jurisdictions (e.g., Sustainability Survey, CESD 2016), often associated with colour-coding such as red, amber and green (e.g., DFO 2006, Stauffer et al. 2019). However, the compactness and the discreteness of this categorization belies important aspects of claims of stock and fisheries sustainability in Canada and elsewhere.

First, as noted above, stock status is a continuous metric and changes in stock states that imply an abrupt change in risk to the stock are unlikely to occur at zone boundaries; the state of the stock is not markedly different on either side of any given reference point. This characteristic is also true of stock status labels elsewhere such as "overfished" and "not overfished" where B_{MSY} is commonly adopted as the threshold (Froese and Proelss 2012, Hilborn and Stokes 2010).

Second, the primary role of the USR as an OCP aimed at avoiding a LRP breach means that the USR could be positioned at a wide range of status levels, depending on a definition of acceptable risk, and the choice of lower control point and target fishing mortality. In this role, understanding the USR as the boundary for characterizing stock states as "Cautious" or "Healthy" would be confusing if not inappropriate because stock "health" would be defined by the configuration of management measures, not by some desired stock status attribute.

Third, fishery sustainability, and therefore stock sustainability, is also a function of "fishery status" (relative to a limit removal rate such as F_{MSY}) and persistence of desired states over time. Finally, while stock status in a single attribute like biomass is one possible metric of stock health, it is not diagnostic of what may be meant by an objective for achieving or maintaining "stock health" which may also depend on demographics, spatial distribution, genetic diversity, and the ability of a stock to return to desired states when perturbed.

The PA Cautious Zone is therefore not quite analogous to "buffer" zones used in other jurisdictions. Such buffer zones are used to identify stock states that begin to approach limits within a specified level of probability (e.g., > 5-20%; delineated by F_{buf} and B_{buf} of NAFO 2004, or F_{pa} and B_{pa} of ICES 2017, 2019). When implemented, these buffers or precautionary reference points create a "cautionary F" zone (NAFO 2004); or "increased risk" zones (ICES 2017, 2019), regardless of whether management action is adjusted at that point or not (as can occur, for example, when MSY $B_{trigger}$ is set to equal B_{pa}; ICES 2017). The PA USR is sometimes arbitrarily set as "twice the LRP," (Marentette et al. 2021) presumably because of the 0.4 and 0.8 multipliers in the PA Policy guidance for LRP and USR choices. However, the USR is not defined in policy as a value that should be derived from the LRP while taking into account assessment uncertainty, in contrast to B_{buf} or B_{pa}.

Similarly, the Healthy Zone is not analogous to stock states fluctuating at levels deemed capable of producing MSY (cp. "fully" or "under"-exploited states; Garcia and Rice 2020). The concept of the PA Healthy Zone may have originated from a desire for stocks to fluctuate around B_{MSY}. In early discussions, DFO (2004b) noted that "the Healthy-Cautious boundary was better defined as a tool for responding to the beginning of reduction in stock production than as a tool for managing the risk of biomass falling below" the LRP, and explored several methods for estimating the USR as an OCP. A provisional default USR value of $0.8B_{MSY}$ suggests a common origin with OCPs in the "MSY control rule" of the United States' National Standard Guidelines 1 (cB_{MSY}, where *c* is proportional to natural mortality (*M*) for the species, Restrepo et al. 1998) and the default HCR provided for the New Zealand Ministry of Fisheries' Harvest Strategy Standard (MF 2011). The HCRs in both those jurisdictions are intended to achieve a target of B_{MSY} while accounting for natural stock fluctuations around B_{MSY}, presumed to be proportional to *M*. This is conceptually and functionally similar to the use of MSY $B_{trigger}$ in ICES' advice rule (ICES 2019). However, it should be noted that except for cB_{MSY} (proposed by Restrepo et al. 1998 as a default limit reference point on the *B*-axis), these international analogies are not used to define stock status zones.

Thus the USR, in its role as delineator of the Cautious and Healthy Zones, serves to differentiate stock states that merit different types of management actions to achieve various objectives for a fishery, representing combined consideration of (and therefore trade-offs among) conservation, social and economic outcomes.

2.3.3.1. Acceptability of Stock States Near the LRP or Above the RR

Although the Cautious Zone does not carry connotations of unacceptable status in the same manner as the Critical Zone, its existence could be interpreted as implying an abrupt transition to increased risk. In fact, the PA Policy recognizes risks to stocks as occurring over a gradient, with risk increasing as stocks decline, i.e., tolerance for decline decreases as stock status declines. For example, there is reference to "establishing increasingly stringent management actions and increasingly lower tolerances for preventable decline" for stocks low in either the Cautious or Healthy zones, and especially as stocks approach the LRP. Also, rebuilding plans should be initiated for stocks past the "*mid-point*" of the Cautious zone (DFO 2009), though it is unclear how this may occur in practice.

As discussed above (Section 2.2.1), stocks below biomass limits like the LRP would be widely recognized as inconsistent with claims of biological sustainability, regardless of fishing mortality (Quinn and Collie 2005). The same is not true for stocks above limits but below targets, particularly if fishing mortality rates remain below limits and the probability of breaching biomass or fishing mortality limits remain within acceptable levels. However, risks to stock sustainability, not to mention risks to other axes of sustainability, become asymmetrical as stock abundance declines. Stocks that have declined below target levels may be considered acceptably sustainable, but may be increasingly less capable of supporting targeted fisheries or ecosystems capable of supporting other desirable management objectives related to other axes of sustainability. For example, a stock well below its target may be at risk of producing significantly less than maximum long-term yields, even if it can still support lesser catches indefinitely (Sainsbury 2008). As stocks continue to decline below targets, they are at progressively higher risk of breaching the LRP due to potentially compromised recruitment and the effects of positive assessment errors. This results in reduced time for effective management responses and less management maneuvering room to trade-off catches against stock growth (Rice 2011, Kronlund et al. 2021).

Transient periods of fishing mortality above limits (overfishing) may not pose an immediate risk of stock decline to levels consistent with serious harm and may provide harvest opportunities during periods of above average recruitment. However, persistent overfishing will on average lead to stock decline as well as potentially increasing the difficulty of implementing catch reductions when needed, due to pressure from fisheries that have grown economically dependent on higher-than-average yields.

2.3.4. Evaluating Elements of Sustainability under the Precautionary Approach

Shelton and Sinclair (2008) argued for sustainability performance conditions based on the then-developing Canadian PA Policy "… to be consistent with societal objectives…" and "… in accordance with Canadian fisheries policy and international agreements …". They proposed the following criteria:

- Stock is in the Healthy Zone and $F < F_{MSY}$; or
- Stock is in the Cautious Zone, F low enough to rebuild to Healthy Zone with high probability in an acceptably short period of time [not defined].

In other words, criteria to evaluate sustainability, using the elements of the PA Policy, would consider whether:

a. stock abundance exceeds the LRP,
b. stock fishing mortality rate is below the RR, 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 a fishing mortality rate that is acceptably less than the RR.

The criteria (a-c), with a) and b) shown graphically in Figure 7, could also apply in the context of s 6.1 of the *Fisheries Act* when viewed through the lens of the same policy. However, an additional criterion is needed to anticipate that a stock can decline below its LRP despite management efforts to the contrary, and that rebuilding is integral to a harvest (management) strategy:

d. the harvest strategy contains management measures that perform acceptably with respect to rebuilding a stock above its LRP to management at target levels.

While (d) applies in the context of s 6.2 of the *Fisheries Act* (Table 1), it is a necessary though not sufficient condition to promote sustainable outcomes.

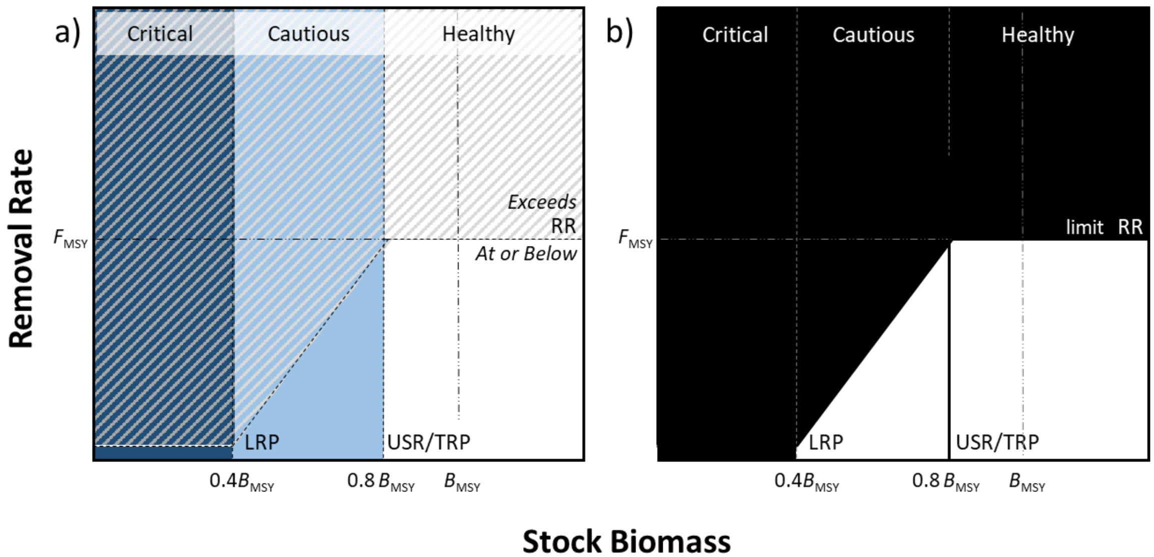

Figure 7: A comparison of a) stock status zones for the Canadian PA Policy, graphed with its default reference points (LRP, USR, RR) with b) acceptable stock states proposed by Shelton and Sinclair (2008) as part of performance measures for evaluating fisheries sustainability under the PA Policy. In 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.

2.4. EVALUATING TIME, OTHER BIOLOGICAL ELEMENTS, OR OTHER AXES OF SUSTAINABILITY

The discussion so far has focused on how Canada and other jurisdictions differ in their conceptions of sustainability and how it should be evaluated from a largely ecological and single-species perspective. This is often the most well-developed form of performance reporting (Flood et al. 2016) and it receives considerable focus in fisheries-specific legislation. It remains important, however, to consider harvest strategies in their entirety when evaluating sustainability, rather than focusing exclusively on individual components such as reference points and stock status relative to them. Reference points such as limits can attract significant attention (Hilborn 2002), especially biomass-based reference points, even when fishing mortality-based reference points and potential lost yield are more pertinent to management (Hilborn 2019). As already noted, limits and targets along either the *F*- or *B*-axes of status determination do not function in isolation. They are embedded in management objectives that constrain the choice of acceptable management measures, including measures that do not directly target *F*. Demonstrating that such objectives and management measures exist, and function acceptably (as proposed by Shelton and Sinclair 2008) must also account for the temporal aspects of biological sustainability (i.e., whether acceptable stock states can be expected to persist in the future under current or proposed management measures). Procedure-oriented approaches to providing advice (e.g., de la Mare 1998; Punt et al., 2016) described in Section 2.2.1, which focus more on whether management measures will acceptably achieve objectives, and less on the stock status relative to reference points, should be considered in the design of management strategies under the FSP, just as they are under the precautionary approach.

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 length or age composition of the stock, 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. However, the same need to fully specify objectives that embed reference points applies to such performance measures to incorporate them into decision-making (Fletcher et al. 2005).

The FAO develops and evaluates multiple indicators related to sustainable fisheries (FAO 2020). Garcia and Rice (2020) propose additional metrics for evaluating Aichi Biodiversity Target 6, including ones targeting recovery plans, threatened species and vulnerable ecosystems. The Marine Stewardship Council not only assesses stocks/fisheries seeking eco-certification against indicators under Principle 1 ("Sustainable Target Fish Stocks"), but also against numerous indicators for Principles 2 ("Environmental impact of fishing"), with categories of primary, secondary and endangered, threatened or protected species, habitats, and ecosystems; and Principle 3 ("Effective management"), with categories under governance and policy, and other details of the management system specific to the fishery.

Similarly, DFO's *Sustainability Survey for Fisheries* (DFO 2019c) is a reporting system that captures many performance measures relevant to Canadian fisheries. These include bycatch, interactions with species at risk, and further elaboration of management measures implemented for major fish stocks. Several of these topics relate to other fisheries polices under the SFF (DFO 2019a). However, the focus of this paper has emphasized biological, single-species fisheries management elements tracked in the Survey that are most pertinent to the PA Policy in particular, as these appear most strongly related to the text of the FSP.

Methods for setting objectives related to broader population, fishery and ecosystem objectives are not nearly as well-established internationally or domestically as biomass or fishing mortality objectives (e.g., ecosystem health, integrity, resilience, etc.; Garcia and Rice 2020), and will be associated with additional levels of uncertainty. This remains a major gap in the fisheries literature, legislation and policy worldwide and would require substantial new research to establish methods and frameworks to establish objectives and performance metrics. Socio-economic and cultural axes of sustainability will merit further investigation by other Sectors.

2.5. IMPLEMENTATION CHALLENGES AND ADAPTATIONS

Section Key Points:

- Departmental guidance as to how management objectives and measures could be expressed or evaluated as acceptable under either s 6.1(1) or s 6.1(2) would help guide analyses performed by the Science Sector in support of implementing the FSP, as only one set of provisional default reference points is provided in the PA Policy.
- Given the multiple possible interpretations of the USR, science guidelines can focus on the roles of limit, other threshold and target reference points in general, and address how these may be expressed, on both the *F*- and *B*-axes (or suitable proxies). Science guidelines can also distinguish OCPs in HCRs from reference points in objectives, and show how HCRs can be evaluated quantitatively to improve performance with respect to objectives.
- The function of the USR (e.g., as OCP, a threshold to the “healthy” stock status zone, or a target) is value-based and not within the purview of the Science Sector to define.
- Clear statement of the intended function(s) of the USR in stock-specific contexts would help the Science Sector to provide support to fisheries management in identifying management measures.
- Departmental guidance will be needed to reconcile status on the *F*-axis with limits, targets, the definition of the RR, the distinction between RRs and HCRs, and define specific requirements for segmenting the RR when necessary to do so. The Science Sector can report on stock status relative to F_{MSY} or suitable proxies when available, consistent with international definitions of the term “overfishing”, and/or to RRs where they have been defined.
- Further scientific work may be required to understand how reference points for major fish stocks developed under different policies correspond to those in the PA Policy, including suitable alternatives appropriate to a range of life histories, such as Pacific salmon.

Some aspects of the implementation of the FSP and PA Policy pose challenges for implementation that would benefit from further Departmental guidance to better support the Science Sector in contributing to the implementation of the FSP, and facilitate the development of national operational guidelines for science.

2.5.1. One Set of Provisional Defaults

The PA Policy describes a decision-making framework comprising limit, other threshold and/or target reference points, a harvest strategy with HCRs, and the need to take into account uncertainty and risk. One provisional default configuration is provided when stock-specific reference points are not available, with values for the LRP, USR and RR maximum of $0.4B_{MSY}$, $0.8B_{MSY}$, and F_{MSY}, respectively. However, these levels are not binding, and “actual reference points for a stock may use other metrics and be set lower or higher than these references but should be demonstrably appropriate for the stock and be consistent with the intent of the PA” (DFO 2009).

The PA Policy predates the FSP by 10 years, and thus neither it, nor the FSP, contain information about what may be suitable for consideration under either s 6.1(1) or s 6.1(2). While such elements of objectives are not determined by the Science Sector, the Science Sector may be asked to help operationalize management objectives given reference points, risk tolerances, and time frames. In this role fisheries scientists can help render objectives measurable and design performance measures that quantify how well a given suite of management measures might perform with respect to the management objectives (e.g., DFO 2021).

Thus, guidelines describing how management objectives (inclusive of reference points, time frames and risks) provided to the Science Sector could be expressed and evaluated quantitatively would help to standardize analyses performed by the Sector. Departmental guidance on specific requirements for objectives and measures considered suitable under either s 6.1(1) or s 6.1(2) would help further shape science analyses and supporting guidelines.

2.5.2. Multiple Roles for the Upper Stock Reference

As noted above (Section 2.3.3), the USR can be assigned the role of a OCP to manage the risk of breaching the LRP and/or the role of a threshold or target reference point, among other things. The provisional default $0.8B_{MSY}$ value of USR in the PA Policy appears to be widely implemented. Nearly two thirds (65%) (Marentette et al. 2021) of all domestically implemented USRs have been set to levels that correspond to $0.8B_{MSY}$ (or 0.8 of a proxy). Additionally, although the "minimum function" of the USR is to guide "management of the risk of approaching the LRP" (DFO 2009), the USR is often but not always used as an OCP in HCRs. All risk-based HCRs (n = 18), and just over half of status-based HCRs (n = 19 of 25; 59%)[3] that have been established for domestically managed and assessed major fish stocks used USRs as OCPs to trigger a change in management action. However, only 49 of 86 stocks with USRs had HCRs in the first place. TRPs are not tracked by the Sustainability Survey (DFO 2019c), so it is not clear how many major fish stocks have TRPs separate from USRs. Consequently, the full suite of intended role(s) of the USR in stock-specific applications may not always be clear. These results do suggest, however, that for a number of stocks the role of USR as the threshold to a desired or "healthy" state (the Healthy Zone in Figure 1), may have taken precedence over the USR's primary role as an OCP, a risk-management tool to avoid LRP breaches.

The importance of multiple conjoined roles for the USR is that any change in management objectives (including targets and risk tolerances) would entail simultaneously shifting thresholds or targets, associated implicit risks, and control points for both management measures and the RR (and the Cautious-Healthy boundary), because all of those functions intersect with the USR. Conjoined shifts would also result in generally narrower Cautious Zones and broader Healthy Zones for stocks managed to lower versus higher thresholds or targets, with potentially different implicit risk tolerances for breaching the LRP and/or the RR as a result in ways that are not necessarily consistent with management measures that would define a sustainable fisheries system.

Individual functions currently associated with the USR could conceivably also be adjusted separately, such that TRPs could be set separately from the USR and enabling OCPs for management measures or the RR to be set where considered necessary to meet management objectives, in ways that can meet PA Policy intent. TRPs separate from USRs are permitted under the PA Policy. Similarly, it is possible that the Healthy-Cautious boundary could be set independently, reflective of multiple biological and socio-economic considerations. While any rationale for the role of the USR would be value-based, and not within the purview of the Science Sector to define, we note that Science has a role to play in defining how the multiple roles may interact and can provide advice on how they may be disentangled in order to meet objectives and PA Policy intent.

Given the multiple functions of the USR and the uncertain extent to which functions assigned to the USR can be separated, science guidelines can focus on the roles of limit, other threshold and target reference points in general, and address how these may be expressed, on both the

F- and *B*-axes (or suitable proxies). Science guidelines can also distinguish and address OCPs in HCRs, and advise on how HCRs with various OCPs can be evaluated quantitatively with respect to objectives concerning reference points (limits, other thresholds and targets). Clear indication of the intended function(s) of the USR in a particular stock-specific context would also be useful to enabling the Science Sector to provide support to fisheries management in identifying management measures expected to meet specified objectives for that stock.

2.5.3. A Segmented Removal Reference

Canada's RR is commonly illustrated, and also reported in DFO's Sustainability Survey, as a series of three segments, one per stock status zone; it is not a HCR despite the resemblance to common depictions (Figure 1; DFO 2019c). This shape is dissimilar to many *F*-based (or proxy) limits in most other jurisdictions reviewed here, but may be derived in part from the "MSY control rule" of Restrepo et al. 1998, which despite its name was developed as a limit reference point for fishing mortality, and below which an "optimum yield control rule" (HCR) is placed that would be used to set catch limits (Figure 8). Similarly, segmented F_{lim} structures could be found in early (but not current) versions of the Australian and NAFO precautionary approach frameworks (NAFO 2004, Australian Government, Department of Agriculture, Fisheries and Forestry [DAFF] 2007, DAWR 2018b). The "MSY control rule" or similar versions continue to be used in some jurisdictions of the United States, such as the 40:10 control rule used by the Pacific Fisheries Management Council (Hilborn 2002). Other Councils in the United States, however, appear to prefer single values, such as F_{MSY}, its proxies, or alternatives, to define overfishing limits (e.g., NRC 2014).

A provisional (p) segmented "harvest decision rule" (HCR) is provided by the PA Policy (overlapping with the RR) as follows:

- Healthy zone : $F_p < F_{MSY}$
- Cautious zone : $F_p < F_{MSY}$ x ((Biomass – 40% B_{MSY}) / (80% B_{MSY} − 40% B_{MSY}))
- Critical zone : $F_p = 0$

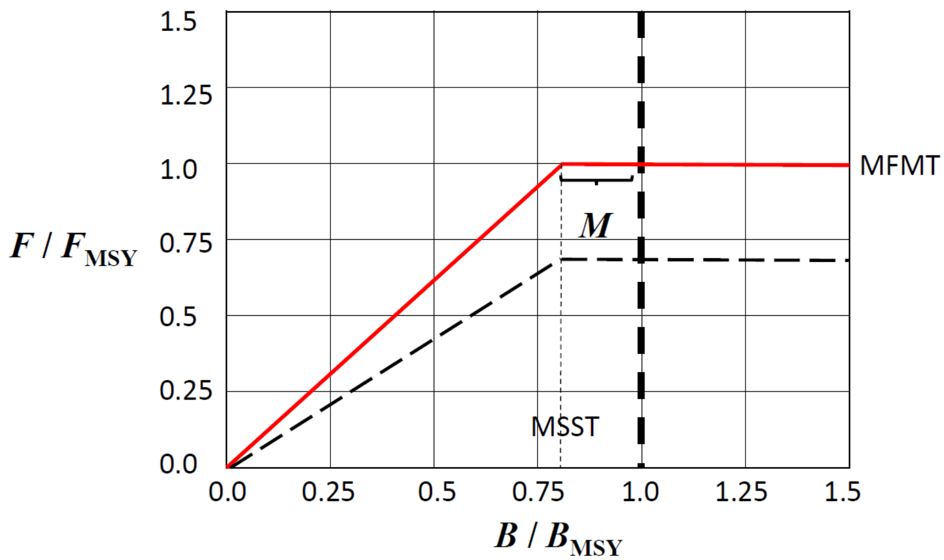

Figure 8: The *MSY-control rule of Restrepo et al. (1998). The MSST is the minimum stock size threshold and MFMT is the maximum fishing mortality threshold. Limits to the fishing mortality rate are indicated by the red solid line. Both the limit and the target fishing mortality rate (optimum yield control rule [HCR], dashed line) are adjusted downwards beginning at a threshold biomass level set as a reduction from* B_{MSY} *in proportion to natural mortality,* M*. Adapted from Restrepo et al. (1998) and Restrepo and Powers (1999), reproduced from Kronlund et al. 2021.*

There are potentially two misinterpretations that can arise from the provisional HCR suggested in the PA Policy:

1. As discussed in Section 2.6.2 it may be falsely concluded that the OCPs in the HCR must match the LRP and USR reference points and the target fishing mortality should be F_{MSY}; and
2. It may be incorrectly concluded that the provisional HCR, when applied to a real fishery system, would on average result in a realized fishing mortality less than F_{MSY} and a biomass above the LRP with the desired probabilities.

The provisional HCR configuration is not a requirement; the PA Policy only states a reduction in removals (as, for example, through a HCR), not a reduction in RR, with declining stock states: “In the Cautious zone, the adjustment of the Removal reference does not have to follow a linear relationship as shown in the diagram but a progressive reduction in **removals** [i.e., rates] is required” (emphasis added; DFO 2009). For example, a number of stock assessments in Canada present advice in terms of decision tables that report probabilities of breaching thresholds such as the LRP, USR and/or RR under a range of catch levels. It is then the role of fisheries managers to make a catch decision based on consistency with the PA Policy and socio-economic and other considerations.

General solutions for choosing the form of the HCR require management measures (i.e., the HCR) to be clearly separated from the reference points (LRP, USR and RR), which are typically embedded in management objectives. The OCPs and the target fishing mortality, as management tactics, must not be constrained to match reference points, as multiple configurations could produce management outcomes that satisfy any imperative objectives (Miller and Shelton 2010) and also provide acceptable trade-offs among other outcomes. Note that the realized outcomes are also a function of other components of the overall *management procedure* (the stock and fishery monitoring data, the method used to assess the stock, any additional management measures or meta-rules along with the HCR). All the components of a management procedure interact to produce effects on the fishery system.

Overall, the conjunction of the provisional HCR with the RR is paralleled with the widespread equating of the limit fishing mortality rate (RR) with fishing mortality targets in practice (found in 77% of domestically managed and assessed stocks and subunits with at least one reported RR segment; Marentette et al. 2021), a pattern also identified by DFO (2016a). This is often expressed by equating RRs to HCRs, with the result that not all RRs have a declining removal rate slope below the USR. RRs for the 58 domestically assessed and managed stocks or subunits that are reported to have at least two RR segments have almost always accomplished this by equating RRs with HCRs or to other management measures such as TACs (i.e., by setting fishing mortality limits to equal targets; n = 55, 95%; Marentette et al. 2021). Equating targets and limits in the form of a single RR could increase the likelihood of exceeding the RR, but may not connote “overfishing” as it is recognized internationally ($F > F_{MSY}$, Froese and Proelss 2012). No Sector has clear responsibility indicated in the PA Policy for setting the RR, nor were specifications for segmenting RRs developed (DFO 2005b, 2016a). Around a third of domestically managed and assessed major fish stocks have “complete” (three-segmented) RRs. 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.

A comparison with international examples suggests that limit fishing mortality rates need not be segmented and that a linear configuration of the RR (Figure 7c) could also form part of a harvest strategy that meets policy intent. Science guidelines can focus on the characterization of stock status relative to 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). Additional Departmental guidance would be needed to reconcile *F* parameters (and status on the *F*-axis) with limits, targets, and segmentation of the RR, in accordance with the PA Policy.

2.5.4. Stocks Managed and Assessed Under Other Policies

The Canadian PA Policy is a national policy; however among Canada’s major fish stocks are many that are also managed under other policies that have their own terminology or requirements for the elements of precautionary harvest strategies. Of the 177 major fish stocks listed on the 2018 Sustainability Survey (DFO 2019c), 18 are Pacific and Atlantic salmonids managed under either the Wild Salmon Policy (DFO 2005a) or the Wild Atlantic Salmon Conservation Policy (newly revised, DFO 2018b). A further 19 stocks are managed under transboundary arrangements, or in other international contexts such as Regional Fisheries Management Organizations. Many of these stocks may eventually be prescribed under the FSP. This creates a challenge, for example, for Pacific salmon stocks which use upper and lower *benchmarks* instead of USRs and LRPs in their precautionary frameworks. Benchmarks share similarities to but are not synonymous with either PA Policy reference point. *Upper benchmarks* represent levels expected to provide MSY on an average annual basis, while *lower benchmarks* represent stock abundance levels sufficiently high enough that a substantial buffer is in place against levels that could lead to populations being considered at risk of extinction (Holt and Irvine 2013). Further elaboration may be required to understand how reference points under different policies correspond to those in the PA Policy, including suitable alternatives appropriate to a range of life histories or stock structures.

3. CONCLUSIONS AND SCIENCE RECOMMENDATIONS

Section Key Points:

- The need to consider socio-economic and cultural axes indicates that ensuring sustainability of stocks and fisheries is not solely dependent on biological considerations identified by the Science Sector.
- 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*.”
- Risk management, including acceptable risks to stock sustainability, is a value-based process. It is informed but not determined by scientific risk assessment and is therefore beyond Science remit to define. In the absence of clearly-defined value-based objectives for resource use or tolerance for risk to the stock, the threshold cannot be defined more specifically.
- Stock levels alone do not necessarily determine the sustainability of the management strategy as a whole. A pragmatic definition of *fisheries sustainability* is that it is a process that conveys the *ability* to maintain a specified level of practical and effective use of a fisheries resource over the long-term.
- Stock status is also deceptively easy to communicate, but is difficult to quantify accurately. Procedure-oriented approaches to fisheries management support sustainable fisheries by focusing instead on whether candidate management measures will acceptably achieve objectives, and less on the stock status relative to reference points at any given moment. This is accomplished by evaluation of whether management options are likely to produce desired outcomes over time, usually via simulation methods.
- Target reference points, other thresholds, USRs, and the acceptable risks associated with failing to either achieve targets or avoid limits over specified time frames are captured in fisheries management objectives. They reflect value-based goals and cannot be established via scientific means alone.
- 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), are not within the Science Sector’s remit.
- However, the Science Sector can support the evaluation of management measures, including alternatives and/or status quo measures, relative to meeting fisheries management objectives for stock conservation and specified use.
- Consistent with the PA Policy, the Science Sector identifies LRPs, and evaluates stock status against *B*- and *F*-based reference points whether based on MSY, MSY proxies, or alternatives.
- The Science Sector also 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 impacts.
- Science requirements for the implementation of s 6.1 can be interpreted, in part, as characterization of stock status. Science can also provide 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 other levels that maintain stocks above the LRP (s 6.1.2).

The following considerations represent the recommended approaches for the Science Sector to incorporate into science guidelines aimed at supporting the implementation of the FSP and PA Policy.

3.1. CONSIDERATIONS FOR SECTION 6.1

To assist with structuring science advice in support of ss 6.1(1) and 6.1(2) of the FSP, a pragmatic definition of what constitutes "*a level necessary to promote sustainability of the stock*" is suggested as "*a threshold representing specified level of practical and effective resource use that can be achieved over the long-term.*" In the absence of value-based objectives for resource use or tolerance for risk to the stock, the threshold cannot be specified any further.

3.1.1. Section 6.1(1)

Using the components of the PA Policy (DFO 2009), conditions consistent with promoting sustainability of the stock could encompass:

- Fully specified *measureable objectives* (indicated by identifying outcomes related to limits and targets, the desired certainty of achieving the outcomes, and a time frame for evaluation);
- A state of not being at unacceptable risk of serious harm (maintaining stock states above a LRP);
- A state of not overfishing evidenced by fishing mortality or harvest rate states below F_{MSY} (or proxy), or removal rates below a RR if one has been established; and
- A means of evaluating whether states consistent with sustainability are likely to persist over the long-term (and where a rationale for a "long-term" time frame is given) via:
  - Investment in stock and fishery monitoring data for use in assessments to determine stock and fishery status;
  - Feedback management systems, inclusive of HCRs, that adjust fishing pressure in response to the assessments and in particular restrict fishing pressure when it is too high.
  - Performance metrics related to objectives that provide a means of determining how well specified objectives are being met.

Data- and model-poor stocks present a challenge to classical management by reference points as embodied by the PA Policy. For the purposes of this paper, we follow Restrepo and Powers (1999) who defined such stocks as those "without reliable estimates of MSY-related quantities, 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". Following Dowling et al. (2015), evaluable conditions consistent with promoting sustainability in these situations could comprise:

- Defined measurable objectives, possibly based in empirical indicators (and under what biological characteristics these will hold);
- Assessment of the stock (trend assessment or other biological characteristics);
- Feedback management systems with triggers that can be 'reasonably assumed' to achieve objectives. Such triggers may include changes in spatial distribution or spawning locations,

trends in spawner abundance, changes to catch composition or fishing locations, etc.), and which have been evaluated retrospectively and/or prospectively[3,4];

- Triggers can impact harvest and monitoring (such as invoking increased data collection);
- Plan for reducing data- and model- poverty via acquisition of needed stock and fishery monitoring data and analyses.

A weight-of-evidence approach to evaluate sustainability for data-poor stocks could take into account available information as to current status (incorporating evidence from a range of empirical indices, risk assessments, fisheries-independent surveys, trends, stock assessments and simulations; Larcrombe et al. 2015). Further guidance would be necessary to align such an approach with the Fish Stocks provisions.

3.1.2. Considerations for Section 6.1(2)

As described above (Section 2.1.2), s 6.1(1) and s 6.1(2) of the FSP suggest the establishment of different target(s) for fish stocks. Although the Science Sector does not determine the socio-economic or cultural objectives that may inform decisions under s 6.1(1) versus s 6.1(2), there is a science role in helping to evaluate the trade-offs incurred against conservation outcomes when considering measures intended to meet objectives under either section of the *Act*.

3.2. ROLE OF SCIENCE IN EVALUATING SUSTAINABILITY

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 conservation 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 where feasible (de la Mare 1998). Trade-offs may result in a desired 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 profitability through higher catch per unit effort at an increased level of biomass, or to provide needed ecosystem services for dependent predators.

Consistent with the PA Policy, the Science Sector has a leading role in identifying and estimating LRPs, and in evaluating stock status against *B* and *F*-based reference points. The reference points may be based on MSY (or proxies) as implied by the PA Policy, or by a choice of reference points that *"… should be demonstrably appropriate for the stock and be consistent with the intent of the PA*" (DFO 2009). The Science Sector also contributes to the evaluation of other elements pertinent to the biological (or ecological) axis of sustainability. This will include conducting risk assessments for habitat and ecosystem impacts and supporting evaluation of management processes in light of those impacts (e.g., Pitcher et al. 2013).

Estimating F_{MSY}, B_{MSY} or proxies for either, and identification of the LRP are all science activities. Unlike other jurisdictions, Canada has no explicit domestic obligations to adopt biological reference points based on the concept of maximum sustainable yield or any other

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[3] Anderson, S.C., Forrest, R.E., Huynh, Q.C., Keppel, E.A. A management procedure framework for groundfish in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. In prep.

[4] Haggarty, D.R., Huynh, Q.C., Forrest, R.E., Anderson, S.C., Bresch, M.J., Keppel, E.A. Evaluation of potential rebuilding strategies for Inside Yelloweye Rockfish (*Sebastes ruberrimus*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. In prep.

basis, although defaults on that basis are provided and, under the PA Policy, the RR must not exceed F_{MSY}. 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 strong role in terms of communicating the performance of fishery management systems.

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APPENDIX A: GLOSSARY

Terminology here adopted or adapted from DAWR (2018b), MF (2011) and NOAA (2018).

Abundance Index: A quantitative measure of fish density or abundance, usually as a time series of (relative) values. An abundance index can be specific to an area or to a segment of the **stock** (e.g., mature fish), or it can refer to abundance stock-wide; the index can reflect abundance in numbers or in weight (**biomass**).

B_0: Virgin biomass, unfished biomass. This is the theoretical **carrying capacity** of the **recruited** or **vulnerable** or **spawning biomass** of a fish **stock**. In some cases, it refers to the average **biomass** of the **stock** in the years before fishing started. More generally, it is the average over recent years of the biomass that theoretically would have occurred if the stock had never been fished. B_0 is often estimated from stock assessment modelling and various percentages of it (e.g. 40% B_0 or 0.4B_0) are used as **biological reference points (BRPs)** to assess the relative status of a **stock**.

$B_{Current}$: Current (spawning) **biomass** in the year of the assessment but may be beginning of year, mid-year, or end of year depending on assessment model.

Biological Reference Point (BRP): A benchmark against which the **biomass** or abundance of the **stock,** or the **fishing mortality rate** (or **exploitation rate**), can be measured in order to determine **stock status**. These reference points can be **targets**, **thresholds** or **limits** depending on their intended use.

Biomass: Biomass refers to the size of the **stock** in units of weight. Often, biomass refers to only one part of the **stock** (e.g., **spawning biomass, vulnerable biomass** or **recruited biomass**, the latter two of which are essentially equivalent).

B_{MSY}: The average **stock biomass** that results from taking an average catch of **MSY** under various types of harvest strategies. Often expressed in terms of spawning **biomass**, but may also be expressed as **recruited** or **vulnerable biomass.**

B_{REF}: A reference average biomass usually treated as a management target.

Catch (*C*): The total weight (or sometimes number) of fish caught by fishing operations including both retained (landed) and released fish (sometimes called discards).

CPUE: Catch per unit effort is the quantity of fish caught with one standard unit of fishing effort; e.g., the number of fish taken per 1000 hooks per day or the weight of fish taken per hour of trawling. CPUE is often assumed to be a relative **abundance index**, i.e., proportional to the portion of the stock biomass (or numbers) vulnerable to the gear.

Depleted: Stocks that are below some limit are deemed to be **depleted**. Stocks can become **depleted** through **overfishing**, or environmental factors, or a combination of the two.

Discards: The portion of the catch thrown away at sea (called releases in some fisheries).

Equilibrium: A theoretical model state that arises when the **fishing mortality**, **exploitation pattern** and other fishery or **stock** characteristics (growth, natural mortality, **recruitment**) do not change from year to year.

Exploitable biomass: Refers to that portion of a **stock's biomass** that is available to the fishery. Also called the **recruited biomass** or **vulnerable biomass**.

Exploitation rate (*U*): The *proportion* of the **recruited** or **vulnerable biomass** that is caught during a certain period, usually a fishing year. Note $U=1-e^{-F}$.

***F*:** The **fishing intensity** or **fishing mortality rate** is that part of the total mortality rate applying to a fish **stock** that is caused by fishing. Usually expressed as an instantaneous rate.

Feed-forward: the modification or control of a process, such as **exploitation rate**, using its anticipated results or effects. May occur in the form of a **Harvest Control Rule.**

Feedback: the modification or control of a process, such as **exploitation rate**, by its results or effects. See **Harvest Control Rule.**

Fishing intensity: A general term that encompasses the related concepts of **fishing mortality** and **exploitation rate**.

Fishing mortality (*F*): That part of the total mortality rate applying to a fish **stock** that is caused by fishing. **Natural mortality (*M*)** is the other component **of total mortality (*Z*).** Usually expressed as instantaneous rates as opposed to annual **exploitation rates**. Note F=-ln(1-U).

Fishing year: Varies by stock. For example, the fishing year for most Pacific groundfish starts on February 21 and ends the following February 20. Often shortened to terms like the 2015/16 fishing year.

F_{MAX}: The **fishing mortality rate** that maximizes **equilibrium yield per recruit**. **F_{MAX}** is a **fishing mortality** level that defines **growth overfishing**. In general, F_{MAX} is different from **F_{MSY}** (the **fishing mortality** that maximizes **sustainable yield**), and is always greater than or equal to **F_{MSY}**, depending on the **stock-recruitment relationship**.

F_{MEY}: The fishing mortality corresponding to the maximum (**sustainable**) economic yield. Not often used in Canada.

F_{MSY}: The **fishing mortality rate** that, if applied constantly, would result in an average catch corresponding to the **Maximum Sustainable Yield** (**MSY**) and an average biomass corresponding to **B_{MSY}**. Usually expressed as an instantaneous rate.

F_{REF}: The **fishing mortality** that is associated with an average biomass of **B_{REF}**.

Harvest Control Rule (HCR): A pre-determined plan that adjusts fishing activity according to the biological and economic conditions of the **stock** and/or fishery (as defined by **indicators** from monitoring or assessment). Also called **Harvest Decision Rules**, HCRs can be **feedback, feed-forward**, or constant in nature. HCRs are a key **tactical** element of a **harvest strategy**.

Harvest Decision Rule: See **Harvest Control Rule**.

Harvest rate: see **exploitation rate.**

Harvest Strategy: For the purpose of the PA Framework, a **harvest strategy** specifies **target** and **limit reference points,** a statement of risk**,** and management actions (**tactics**) associated with achieving the **targets** and avoiding the **limits**. More generally, a **harvest strategy** is a decision framework designed to pursue defined biological, ecological, social and/or economic **objectives** for fish **stocks** in a given fishery. Key elements include: **objectives**, **performance measures**, reference points, acceptable levels of risk, a monitoring strategy, an assessment and **harvest control rules**. Also called a management strategy.

Index: Same as an **abundance index**.

Indicator: A measurement that provides information on the state of some item of interest; e.g., a single **stock**, or more broadly, major fish stocks worldwide. **Stock status** indicators may include estimates of **biomass**, **fishing mortality** or **exploitation rate**, or suitable **proxies** for these. See **metric, performance measure** and **abundance index**.

Limit: a **biomass** or fishing mortality **reference point** that should be avoided with high probability.

Limit Reference Point: the name of the **biomass limit** in Canadian **harvest strategies** that also often serves as an **operational control point**.

***M*:** The (instantaneous) **natural mortality rate** is that part of the total mortality rate applying to a fish **stock** that is caused by predation and other natural events.

Management Procedure (MP): an algorithm for managing a fishery, consisting of a combination of data collection, assessment method, and harvest control rule. Different MPs may be evaluated based on their performance relative to measurable objectives as part of a Management Strategy Evaluation.

Management Strategy: See **harvest strategy.**

Metric: An alternative term for **indicator**, and sometimes used in the evaluation of management procedures (see also **performance measure**).

MEY: maximum economic yield, the catch or effort level for a fishery that allows net economic returns to be maximized. In this context, "maximized" equates to the largest positive difference between total revenue and total cost of fishing.

Model: A set of equations that represents the population dynamics of a fish stock (and associated fisheries), a hypothesis about the population dynamics of a fish stock (and associated fisheries).

MSY: Maximum sustainable yield is the largest long-term average catch or yield that can be taken from a **stock** under prevailing ecological and environmental conditions, and the current selectivity patterns exhibited by the fishery.

MSY reference points: MSY references points include B_{MSY}, F_{MSY} and **MSY** itself; analytical and conceptual **proxies** for each of these quantities may be calculated.

Natural mortality (rate) or *M*: That part of the total mortality rate applying to a fish **stock** that is caused by predation and other natural events. Usually expressed as an instantaneous rate.

Objective: Measurable objectives consist of a specified **target** or **limit,** a period of time, and a desired probability or acceptable risk level. Sometimes described as SMART: specific, measurable, achievable, relevant and time-bound.

Operational control point: a value of an **indicator** or other input variable that acts as a trigger for a change in management actions, as for example in a **Harvest Control Rule**.

Optimum Yield (OY): Under the *Magnuson-Stevens Act* of the United States of America, this is "the amount of fish that will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities and taking into account the protection of marine ecosystems; that is prescribed on the basis of the **MSY** from the fishery, as reduced by any relevant economic, social, or ecological factor; and, in the case of an overfished fishery, that provides for rebuilding to a level consistent with producing the **MSY** in such fishery."

Overexploitation: A situation where observed **exploitation** (or **fishing mortality**) rates are higher than **limits**. Another term for **overfishing**.

Overfishing: A situation where observed **fishing mortality** (or **exploitation**) rates are higher than **limits**. Internationally, overfishing is commonly defined to represent $F > F_{MSY}$.

Performance Measure: A measure that provides information on management procedure performance relative to an **objective**, often expressed as an **indicator** in relation to a **reference point**. Sometimes called a performance **metric**.

Population: A group of fish of one species that shares common ecological and genetic features. The **stocks** defined for the purposes of **stock assessment** and management do not necessarily coincide with self-contained populations.

Population dynamics: In general, refers to the biological and fishing processes that result in changes in fish **stock** abundance over time.

Projection or forecast: Predictions about trends in stock size and fishery dynamics in the future. Projections are made to address "what-if" questions of relevance to management. Short-term (1–5 years) projections are typically used in support of decision-making. Longer term projections become much more uncertain in terms of absolute quantities, because the results are strongly dependent on **recruitment,** which is very difficult to predict. For this reason, long-term projections are more useful for evaluating overall management strategies than for making short-term decisions.

Proxy: A surrogate for another value, such as B_{MSY}, F_{MSY} or **MSY,** that has been demonstrated to approximate one of these metrics through theoretical or empirical studies.

Recruitment: The addition of new individuals to the fished component of a **stock**. This is determined by the size and age at which fish are first caught.

Recruitment-overfished: A situation in which the rate of fishing is, or has been, such that annual **recruitment** to the exploitable **stock** has become significantly reduced. The situation is characterized by a greatly reduced **spawning stock**, a decreasing proportion of older fish in the catch, and generally very low recruitment year after year. If prolonged, exploitation rates associated with recruitment-overfishing can lead to stock collapse, particularly under unfavourable environmental conditions.

Reference Point: A benchmark against which the biomass or abundance of the **stock** or the **fishing mortality rate** (or **exploitation rate**) can be measured in order to determine its **status**. These reference points can be targets, thresholds or limits depending on their intended use.

Removal Reference: the name of the **fishing mortality limit** in Canadian **harvest strategies**.

Spawning stock biomass (SSB): The total weight of sexually mature fish in the **stock**. This quantity depends on the abundance of **year classes**, the **exploitation** pattern, the rate of growth, both fishing and **natural mortality rates**, the onset of sexual maturity, and environmental conditions. Same as **mature biomass**. Often refers to females only.

Stock: The term has different meanings. It may be defined with reference to units for the purpose of fisheries management. On the other hand, a biological stock is a population of a given species that forms a reproductive unit and spawns little if at all with other units. However, there are many uncertainties in defining spatial and temporal geographical boundaries for such biological units that are compatible with established data collection systems. For this reason, the term "stock" is often synonymous with an assessment / management unit, even if there is migration or mixing of some components of the assessment/management unit between areas.

Stock assessment: The analysis of available data to determine stock status, usually through application of statistical and mathematical tools to relevant data in order to obtain a quantitative understanding of the **status** of the **stock** relative to defined management benchmarks or **reference points.**

Stock-recruitment relationship: An equation describing how the expected number of recruits to a stock varies as the **spawning biomass** changes. The most frequently used stock-recruitment relationship is the asymptotic Beverton-Holt equation, in which the expected number of recruits changes very slowly at high levels of spawning biomass.

Stock status: Refers to a determination made, on the basis of **stock assessment** results, about the current condition of the **stock**. Stock status is often expressed relative to management benchmarks and **biological reference points** such as B_{MSY} or F_{MSY} or **proxies**. For example, the current biomass may be said to be above or below B_{MSY} or to be at some percentage of B_0. Similarly, fishing mortality may be above or below F_{MSY} or a **proxy**.

Strategy: a plan of actions designed to achieve a major or overall goal or aim. Strategies inform the selection of **tactics** used to achieve measurable **objectives** in support of the overall plan goal.

TAC: Total Allowable Catch is the sum of the catches from all sources. In some cases it may refer to only the Total Allowable Commercial Catch (**TACC**).

Tactic: the specific measures or actions taken to achieve a particular **objective**, as part of a **strategy.**

Target: Generally, a **biomass**, **fishing mortality** or **exploitation rate** level that management actions are designed to achieve with a specified level of probability

Threshold: Generally, a **biomass**, **fishing mortality** or **exploitation rate** level or **reference point** that management actions are designed to achieve with a specified level of probability (usually >50%). Thresholds may also be used for reporting **stock status**. A **limit** is a specific type of threshold. In some jurisdictions, non-limit thresholds may be termed buffers, triggers or precautionary reference points.

U_{MSY}**:** The **exploitation rate** associated with the maximum sustainable yield. Usually expressed as an annual proportion.

Upper Stock Reference: the name of the **biomass threshold, target** and/or **operational control point** in Canadian **harvest strategies**.

U_{MSY}**:** The **exploitation rate** associated with the maximum sustainable yield. Usually expressed as an annual proportion.

Yield: Catch expressed in terms of weight.

APPENDIX B: DEFINING SUSTAINABILITY

DEFINITIONS

Canadian (including DFO) definitions of sustainable use and development, sustainability and sustainable fisheries appear below:

- "**Sustainable development.** Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. It implies a specific commitment to the management of coastal regions and resources in an environmentally responsible manner that defines and acknowledges risk." (DFO 2004a);
- "**Principle 3: Sustainable Use**. Resource management decisions will consider biological, social, and economic consequences, reflect best science including Aboriginal Traditional Knowledge (ATK), and maintain the potential for future generations to meet their needs and aspirations." (DFO 2005a);
- "**Sustainability** means the capacity of a thing, action, activity, or process to be maintained indefinitely. (durabilité)." (*Federal Sustainable Development Act* 2008);
- "**Sustainable development** means development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (développement durable)." (*Federal Sustainable Development A*ct 2008);
- "**Sustainability** comes from taking a long-term view of things… On a general level, measures to ensure sustainability protect future stock abundance and thus enable fisheries to realize economic gains over the longer term." (DFO 2013a);
- "**Sustainability** means a species can survive and meet the needs of their present population without weakening the chances of future generations to meet their own needs. Sustainability reflects the capacity to thrive over the long term." (DFO 2018a);
- "**Sustainable fisheries** means the harvesting and farming of fish stocks in a manner that meets the needs of the present without compromising the ability of future generations to meet their own needs." (DFO 2018a, DFO 2019b).

These definitions are similar to those found in other jurisdictions and the scientific literature, a subset of which are provided below:

- "**Ecologically sustainable development (ESD)**: Using, conserving and enhancing the community's resources so that ecological processes are maintained, and the total quality of life, now and in the future, can be increased. Principles of ecologically sustainable development (as per the *Fisheries Management Act 1991*):
  - decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equity considerations;
  - if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation;
  - the principle of inter-generational equity - that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations;
  - the conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making;
  - improved valuation, pricing and incentive mechanisms should be promoted." (Australian Government, Department of Water Resources [DAWR] 2018a);

- "**Sustainable harvesting** of all stocks over the long term must still be ensured (avoiding approaching limit reference points)." (DAWR 2018a);
- "**Sustainability**: Ability to persist in the long-term. Often used as a "short hand" for sustainable development." (Food and Agriculture Organization of the United Nations [FAO]; Cochrane and Garcia 2009; FAO 2020a);
- **"Indicator 14.4.1 - Proportion of fish stocks within biologically sustainable levels.** This indicator measures the sustainability of the world's marine capture fisheries by their abundance. A fish stock of which abundance is at or greater than the level, that can produce the maximum sustainable yield (MSY[2]) is classified as biologically sustainable. In contrast, when abundance falls below the MSY level, the stock is considered biologically unsustainable. The indicator will measure progress towards SDG Target 14.4." (FAO 2020b);
- **"'Sustainability**' is defined in CBD (Art. 2) as "the use of components of biodiversity in a way and at a rate that does not lead to long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations". It requires a balance between its ecological, economic, social and governance dimensions. [Aichi Biodiversity] Target 6 refers only to the ecological (biodiversity) dimension (e.g., stocks, species, habitats, ecosystems)". … "The clear implication for reporting on Target 6 is that sustainably harvested stocks include fully fished stocks (with $B = B_{MSY}$ and $F = F_{MSY}$ on average)[5] and underfished stocks (with $B > B_{MSY}$ and $F < F_{MSY}$)…. "Stocks can be considered 'sustainably managed' if biomass is above B_{MSY} or an appropriate surrogate or fluctuating around B_{MSY} with appropriate precautionary management in place to ensure that the exploitation rate decreases well before risk of impaired productivity increases." (Garcia and Rice 2020);
- "**Principle 1: Sustainable target fish stocks.** A fishery must be conducted in a manner that does not lead to over-fishing or depletion of the exploited populations and, for those populations that are depleted, the fishery must be conducted in a manner that demonstrably leads to their recovery." (Marine Stewardship Council 2018a);
- "**Sustainability**: Pertains to the ability of a fish stock to persist in the long-term. Because fish populations exhibit natural variability, it is not possible to keep all stock and fishery attributes at a constant level simultaneously, thus sustainable fishing does not imply that the fishery and stock will persist in a constant equilibrium state. Because of natural variability, even if F_{MSY} could be achieved exactly each year, catches and stock biomass will oscillate around their average MSY and B_{MSY} levels, respectively. In a more general sense, sustainability refers to providing for the needs of the present generation while not compromising the ability of future generations to meet theirs." (New Zealand Ministry of Fisheries [MF] 2011);
- "**Maximum sustainable yield:** is the largest long-term average catch or yield that can be taken from a stock under prevailing ecological and environmental conditions. It is the maximum use that a renewable resource can sustain without impairing its renewability through natural growth and reproduction." (MF 2011);
- "**Sustainable yield**: the average catch that can be removed from a stock over an indefinite period without causing a further reduction in the biomass of the stock. This could be either a

[5] See Appendix A for a glossary of technical terms.

constant yield from year to year, or a yield that fluctuates in response to changes in abundance." (MF 2011);

- "**Sustainable stock**. The agreed national reporting framework for the status of key Australian fish stocks reports defines the term 'sustainable stock' as follows: Stock for which biomass (or biomass proxy) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (that is, not recruitment overfished) and for which fishing pressure is adequately controlled to avoid the stock becoming recruitment overfished." (Stewardson et al. 2018);
- "**Sustainable development** is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (United Nations [UN] 1987).

ELEMENTS

The properties of sustainability identified by the Canadian Commissioner for the Environment and Sustainable Development (CESD 2011) are paraphrased below:

1. Environmental

- Harvest of target species within conservation limits;
- Ecological limits for fishery and other parts of ecosystem based on scientific evidence, including a precautionary approach; and such limits are respected for target and non-target species;
- No long-term degradation of the ecosystem where fishery operates; and
- Adjustments of harvest limits if external factors affect stock health.

2. Economic

- Economically competitive and profitable fishery, able to innovate in response to external changes;
- Capacity of fleet is in line with stock's ability to sustain fishing pressure; and
- Long-term subsidies are not provided.

3. Social

- Clearly defined governance at local, national and international levels;
- Respected rights of Indigenous peoples;
- Access to fishery is equitable, predictable and promotes conservation;
- Fishery contributes to sustaining communities that depend on it; and
- Fishery is able to innovate in response to social changes.

4. Organizational

- Well-defined mandates and lines of accountability;
- Resources available to conduct research, monitor, and ensure compliance, as well as innovate in response to changing circumstances;
- Decisions based on scientific information and predictable criteria, involve stakeholders and openly communicated; and

- Effective mechanisms for making trade-offs between competing objectives.

DFO's schema for the sustainable management of Canadian fisheries covers the following five key areas (DFO 2019b):

1. **Planning** documented by management plans that report on fish stock biology and status, objectives for the fishery, catch levels intended to promote "stock health", allocation to resource users, management tactics, and enforcement measures;
2. **Science activities** to generate peer-reviewed advice that uses the most recent advice to provide information on fish biology, migration, abundance, and relevant biological and environmental factors;
3. **Managing Environmental Impacts** to consider fishing effects on the target species, coincidentally caught species, dependent predators, habitat, and unique marine environments;
4. **Enforcement** that employs methods such as at-sea observers, electronic monitoring of fishing activity and catch, and dockside validation of landings; and
5. **Performance Review** using the Sustainability Survey, review of management plans, and independent review of DFO programs via the Office of the Auditor General (e.g., CESD 2011, 2016).