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Considerations for the design of rebuilding strategies for Canadian fish stocks

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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

Rebuilding plans are required by law under the new Fish Stocks provisions of the revised *Fisheries Act* for major fish stocks prescribed under regulations that have declined to, or below, their limit reference point. The provisions state that the biology of the fish and environmental conditions facing the stock will be taken into consideration in the design of rebuilding strategies. Rebuilding strategies inform the development of rebuilding plans and should be regarded as integral to overall management (harvest) strategies. Science activities focus on the development and evaluation of management strategies in response to stated objectives, including rebuilding.

Viewing a rebuilding strategy as separate from the overall management strategy can lead to the deferral of actions intended to prevent stock decline. Failure to plan rebuilding measures before they are needed can create hard-to-resolve conflicts with measures intended to provide opportunities for resource use. Increased likelihood that rebuilding is achieved depends on planning the transition from rebuilding to target outcomes within a management strategy.

Like many other jurisdictions, Canada advocates management by reference points. Our review of international fisheries agreements highlights key elements that produced Canadian fisheries policy related to the Precautionary Approach. Interpretation of policy must distinguish between objectives that embed biological reference points related to abundance or fishing mortality, and the management measures intended to provide acceptable stock and fishery outcomes. As management by reference points can be challenging when there is data- or model-poverty, rebuilding strategies for such stocks should prioritize increasing information needed to adapt the rebuilding plan while preserving policy intent to avoid or correct undesirable stock states.

We review obligations for recovery strategies under the *Species at Risk Act* and an eco-certification standard to evaluate where common information demands exist that could lead to efficiencies in providing advice. Existing Canadian rebuilding plans are reviewed to identify information needed to support rebuilding considerations in light of proposed regulations to support the Fish Stocks provisions.

We discuss components of rebuilding strategies needed to meet proposed regulations. These include determining when rebuilding is needed, identifying the rebuilt state, and specifying a time period over which to implement a rebuilding plan. One science role is consistent communication of the plausible range of stock scenarios during the lifespan of the plan to inform expectations of decision-makers and resource users. Plan success can be enhanced by allowing for adaptation during the rebuilding period as new data, updated analyses, and revised objectives are considered.

We suggest principles for developing national science guidelines for rebuilding fish stocks. Guidelines are intended to clarify expectations for, and to encourage, consistent science practices. We advocate a structured decision-making approach to developing feasible rebuilding strategies, identifying possible scenarios and eliciting objectives from resource users and decision-makers. The process can be used for data-poor contexts and maps directly into quantitative approaches such as management strategy evaluation. Finally, we provide a recommended list of elements for rebuilding strategies that should be reflected in science guidelines.

1. INTRODUCTION

Key Points:

- The revised *Fisheries Act* includes new Fish Stocks provisions that introduced legal obligations to manage major fish stocks at levels necessary to promote sustainability, avoid limit reference points, and implement plans to rebuild stocks that have declined to, or below, a limit reference point, all while taking into account the biology of the fish and environmental conditions facing the stock.
- Most fisheries jurisdictions rely on a suite of policies, standards, procedures and guidelines to support the implementation of legislative requirements.
- Considerations needed to develop science guidelines for rebuilding Canadian fish stocks are identified in this document. To support this goal, the paper aims to:
  - Describe the international, legal, and regulatory context under which scientific advice for rebuilding strategies must be provided as a result of the revised *Fisheries Act*;
  - Identify key issues related to Fishery Decision-making Framework Incorporating the Precautionary Approach policy (PA Policy) interpretation and implementation that require national science coordination;
  - Provide perspectives on specific topics required to produce scientific advice to support guidelines for rebuilding strategies, including linkages to eco-certification and species at risk contexts;
  - Review current rebuilding plans developed by DFO with respect to alignment with proposed regulations for the Fish Stocks provisions; and
  - Propose a set of scientific principles for rebuilding strategies and the role of science that can be applied nationally.
- A precautionary approach to fisheries includes management strategies that anticipate periods of stock decline to low levels, and the need to pre-specify actions intended to arrest a decline before a rebuilding plan must be implemented.
- Rebuilding strategies should be regarded as integral to management strategies. Viewing a rebuilding strategy as separate from the overall management (harvest) strategy can lead to deferral of actions needed to prevent stock decline to limiting thresholds and delays rebuilding. Failure to plan measures intended to rebuild stocks before they are needed can create conflicts with measures intended to provide opportunities for dependent fisheries that are hard to resolve. Specific stock rebuilding objectives may be given priority as part of the management strategy depending on stock status, and will affect the design of management measures.
- A management strategy, inclusive of a rebuilding strategy, is distinct from a management plan, rebuilding plan, regulations, or other documents that defines the conditions and rules under which a fishery will operate, as well as the accountability of resource users.
- The Science Sector role in developing rebuilding strategies relates to:
  - identifying biological limits to harvest;
  - helping to translate legal and policy intent as well as the goals of decision-makers and resource users into measurable objectives; and
  - evaluating consequences of management choice to outcomes of interest represented by stated goals or objectives.

1.1. CONTEXT

Amendments to the Canadian *Fisheries Act* (*Fisheries Act* R.S.C., 1985, c. F-14. As amended by Bill C-68, June 21 2019) were enacted when Bill C-68 received Royal Assent on June 21, 2019. The amendments include new Fish Stocks provisions (Section 6) that introduced legal obligations to manage stocks at levels necessary to promote sustainability, avoid limit reference points, and institute plans to rebuild fish stocks that have declined to, or below, a limit reference point, all while taking into account the biology of the fish and environmental conditions facing the stock. The legislation applies to stocks that are prescribed under regulations. This document describes scientific considerations for the development of rebuilding strategies. Rebuilding *strategies* help to inform rebuilding *plans* that must meet legal obligations under the revised *Fisheries Act*, and policy intent described by the Sustainable Fisheries Framework (SFF). Of particular relevance are Canada's Fishery Decision-making Framework Incorporating the Precautionary Approach policy (DFO 2009) and the Fisheries and Oceans Canada (DFO 2013a) policy guidance for rebuilding fish stocks above limit reference points. Note that we refer to the DFO (2009) policy as the PA Policy, and use the term "PA Framework" to indicate a stock-specific application of the PA Policy.

The Fish Stocks provisions and PA Policy mean that fisheries management actions must promote (be aimed at) biological sustainability and long-term benefits to resource users (sustainable use). Two means of achieving these goals are suggested by the legal context and policy intent. The first means is a reactive approach: develop rebuilding strategies and implement plans in response to low stock levels as described by DFO (2013a). A second, proactive approach is to design management strategies to avoid thresholds to undesirable stock and fishery states (limits) and to promote achieving desirable states (targets). The latter approach views rebuilding strategies as integral to management strategies and requires first acknowledging that the risk of bad stock and fishery outcomes exists, and second, planning for them before they happen. Considering rebuilding to be integral to overall management strategies also offers alignment with the legal obligations of the Fish Stock provisions to maintain fish stocks at or above levels that promote sustainability, and PA Policy intent to invoke rebuilding plans in a timely manner when required.

Regardless of the means, there are expectations to exercise due diligence in meeting PA Policy intent to avoid limits and achieve targets, and to adopt best fisheries science and management practices (e.g., FAO 1995a, Sainsbury 2008). Such expectations imply that the performance of existing, or proposed, management measures should be evaluated to ensure poorly performing measures are eliminated from consideration. The role of science in designing rebuilding strategies has two components of scientific investigation and advice provision. The first component is related to identifying limits to stock productivity and optimal yield. A specific choice of management measures may also hinge on socio-economic and cultural goals in addition to biological considerations; however, the responsibility for identifying such goals lies outside the remit of science. The second component pertains to evaluating the effectiveness of management measures intended to rebuild depleted stocks. Fisheries scientists can support decision-makers by evaluating the expected consequences of management choices (i.e., management measures and risk tolerances) that lead to trade-offs between stock preservation, socio-economic and cultural outcomes. Scientists have this role because scientific data and methods are very likely to be used for such investigations (de la Mare 1998).

Most fisheries jurisdictions rely on legal instruments analogous to the Canadian *Fisheries Act* that may be supported by policies, procedures, standards and/or guidelines:

1. *Policies* are formal statements produced and supported by senior management (government) that describe how the government plans to conduct its work. This work includes addressing legislative requirements and should reflect objectives;
2. *Standards* are mandatory actions or rules that give formal policies support and direction. Standards must be enforced;
3. *Procedures* are detailed step by step instructions to achieve a given goal or mandate; essentially a “cookbook” for repeatable processes; and
4. *Guidelines* are recommendations to users when specific standards do not apply. Guidelines are designed to streamline certain processes according to best practices. By nature, they are open to interpretation and do not need to be followed to the letter.

Operational guidelines have been produced by various fisheries jurisdictions including Australia (DAWR 2018), New Zealand (MF 2011) and the United States (NOAA 2018) to support their respective laws and fisheries policies (Table 1). Guidelines identify design principles and processes that should be applied when developing a management strategy for a specific stock and fishery. Guidelines should be structured around principles that can be followed regardless of whether a stock is data-poor or data-rich, the status of the stock, or the choice of methods used for monitoring and assessment of stock status. Details of management objectives, stock and fishery monitoring data, the assessment methodology, and measures intended to achieve the objectives will differ with the context, but to the extent practicable the same design principles should be followed and consistent practices for communicating uncertainty and risk applied. Regardless of the specifics of the situation, policy intent should be preserved as much as possible. Canada has few examples of guidelines to support the PA Policy, with the exception of scientific practices documented in an advisory process that occurred in 2012 (DFO 2016a) and the policy guidance for rebuilding stocks above a limit reference point (DFO 2013a).

The Ecosystems and Oceans Science Sector (“Science Sector”) of Fisheries and Oceans Canada (DFO) will be developing national guidelines for a variety of fisheries science topics to support obligations of the revised *Fisheries Act*. One goal of national operational guidelines is to clarify expectations to DFO fisheries scientists and collaborators. A second goal is to harmonize approaches to reduce the occurrence of unnecessary disparity in practices that can undermine scientific credibility. Several jurisdictions, notably the United States (US, Restrepo et al. 1998) and Australia (Sainsbury 2008) have proposed “best practices” for supporting legal and policy obligations. We adopt the definition of *best practice* provided by Sainsbury (2008), namely:

> “The ‘best’ practice concept is based on the best practice that has been demonstrated through use, and recognizes that views of what is ‘best’ will continuously improve with experience. Best practice is not an absolute or fixed entity, or a guarantee of adequacy. It is based on experience to date and it is expected to evolve over time.”

The key elements of this definition are that the practice must be *demonstrated through use*, and that best practice is *expected to evolve over time*. As per this definition of best practices, national operational guidelines for Canadian fisheries science would be expected to be updated periodically over time as experience with their application accumulates and international practice evolves.

While consistency of approach is a desired attribute for science advice, adaptation will be needed to meet the circumstances of individual stocks and fisheries. Topics for scientific guidelines may include approaches to data-poor stocks and fisheries, management strategy evaluation, and the subject of this paper, rebuilding strategies for depleted fish stocks. Although there are clear linkages among the topics, they are separated for logistical reasons so that guidelines related to specific priorities can be advanced.

Table 1. Applicable policies and guidelines for rebuilding fisheries in various jurisdictions.

Country	Document
Canada	
Policy	<u>*Sustainable Fisheries Framework*</u>
	A Fishery Decision-Making Framework Incorporating the Precautionary Approach (DFO 2009)
Guidelines	*Guidance for the development of rebuilding plans under the Precautionary Approach Framework: Growing stocks out of the critical zone* (DFO 2013a)
Australia	
Policy	*Commonwealth Fisheries Harvest Strategy Policy* (Australian Government, Department of Agriculture and Water Resources [DAWR] 2018a)
Guidelines	*Guidelines for the Implementation of the Commonwealth Fisheries Harvest Strategy Policy* (DAWR 2018b)
ICES	
Policy	The *ICES Advice Basis* (*1.2 Advice Basis*; ICES 2018)
NAFO	
Policy	*NAFO Precautionary Approach Framework* (NAFO 2004; NAFO, 2019a), further explored online as *Risk Based Management Strategies* (NAFO 2019b)
New Zealand	
Standards	*Harvest Strategy Standard for New Zealand Fisheries* (New Zealand Government, Ministry of Fisheries [MF] 2008)
Guidelines	*Operational Guidelines for New Zealand's Harvest Strategy Standard* (MF 2011)
United States	
Standards	*National Standard Guidelines* (NOAA 2018a), particularly *National Standard 1 - Optimum Yield.*
Guidelines	*Technical Guidance on the use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act* (Restrepo et al.1998), and *Implementing A Next Generation Stock Assessment Enterprise. An Update to the NOAA Fisheries Stock Assessment Improvement Plan* (Lynch et al. 2018)

1.2. THE REBUILDING DILEMMA

A call for rebuilding implies that a fish stock exists in a state where abundance, or some other attribute important to stock preservation and fisheries sustainability, needs to be enhanced. Most national harvest policies focus on taking action to rebuild a stock from an undesirable state of depletion, usually in relation to a benchmark abundance (biomass) threshold, or limit reference point (LRP). Such reference points may be established with the aim of preventing a state of irreversible, or only slowly reversible *serious harm* (FAO 1995a, Shelton and Rice 2002, United Nations 1995, "UNFSA"). However, LRPs really represent biological thresholds of last resort and as such should be avoided. Requirements for stock rebuilding are likely to result in scientific advice that implies severe constraints on fishing at a time when resource users are already likely to be experiencing reduction, or loss, of socio-economic and cultural benefits. Fishery managers are expected to implement and enforce management measures that may not appear to be effective, or may not yield results for many years, at a time when their maneuvering room to trade-off the rate of stock increase and yield has evaporated. A lucky recruitment event may create additional challenges, as resource users demand increased harvest opportunities at a time when it is not certain that stock recovery has been assured. Such considerations led MacCall (1993) to characterize stock rebuilding as a "treacherous" area of fishery science research, and an even worse area for fishery managers, so it would seem that the best rebuilding plan is one that is never needed. This is why the precautionary approach to fisheries (FAO 1995a) advocated proactive management strategies that anticipate periods of stock decline to low levels, and the need to pre-specify actions intended to arrest a decline before the likely severe restrictions under a rebuilding plan must be implemented.

Rebuilding is typically initiated when a stock is reduced to an undesirable state by various combinations of fishing mortality, habitat degradation or other deleterious environmental conditions. Rebuilding strategies intended to recover stocks are often presented as separate from management strategies. Invoking mechanisms for rebuilding a stock in isolation of the overall management strategy can lead to:

1. Deferral of action until thresholds to serious or irreversible harm are breached; or
2. Conflict between rebuilding measures and those measures intended to provide harvest opportunities, such that recovery efforts are thwarted or delays in rebuilding to target levels are incurred.

In fact, separation of rebuilding scenarios from the overall management strategy design is not helpful to achieving sustainable outcomes for a stock and dependent fisheries. First, the management strategy should aim to avoid getting to a situation where rebuilding is needed. However, a stock can decline despite this intent; such a situation should be anticipated and revisited as a stock approaches limits so that current, rather than average, conditions are considered. Under a precautionary approach to managing fisheries, a rebuilding strategy should therefore be considered integral to the design of a management strategy.

Specific rebuilding objectives may be given priority as part of the management strategy as status declines towards limits. These objectives may affect the selection of management measures in two ways. First, the measures in place as the stock declines are not necessarily those applied when rebuilding; new, or more severe management measures intended to encourage stock rebuilding may be needed. For example, an imperative to rebuild a stock as quickly as possible may mean an existing harvest control rule is adjusted by altering operational control points (OCPs; Cox et al. 2013) and/or the target fishing mortality. This could be a pre-planned action based on prior simulation testing, or an adaptation of pre-specified actions should they prove ineffective. Second, additional resources for monitoring and stock assessment may be required to improve understanding of the stock response to external drivers and management actions. Ideally, such objectives and supporting actions are identified prior to the need for stock rebuilding so that decision-makers and resource users can anticipate the restrictions that are likely to be imposed as limiting thresholds are approached or breached.

Regardless of the rebuilding framework, there is a complex interaction between:

1. Choosing reference points used as benchmarks to judge stock and fishery states;
2. Defining outcomes that indicate the need for rebuilding (an overfished condition) and a rebuilt state (rebuilding target);

3. Choosing desired risk tolerances for avoiding an overfished condition, or assuring that the rebuilt state is achieved;
4. The choice of stock assessment method and treatment of the various types of uncertainty (e.g., process, observation, estimation, implementation and institutional) (Francis and Shotton 1997);
5. Selecting the time period within which to achieve rebuilding outcomes;
6. Planning how the sequence of catches will vary over the rebuilding time period; and
7. Transitioning from rebuilding to target outcomes, with the restoration of sustainable benefits to resource users.

This interaction requires viewing fisheries as systems, and as much as possible evaluating their likely performance as a whole rather than in part. Anticipated outcomes cannot be judged on the basis of the performance of any one component in the absence of the other components of the system (de la Mare 1998).

1.3. WHAT'S IN THIS DOCUMENT?

Considerations needed to develop science guidelines for rebuilding Canadian fish stocks are identified in this document. To support this goal, the paper aims to

1. Describe the international, legal, and regulatory context under which scientific advice for rebuilding strategies must be provided as a result of the revised *Fisheries Act*;
2. Identify key issues related to PA Policy interpretation and implementation that require national science coordination;
3. Review the current situation for rebuilding plans developed by DFO with respect to alignment with proposed regulations;
4. Provide perspectives on specific topics that are required to produce scientific advice to support guidelines for rebuilding strategies, including linkages to eco-certification and the *Species at Risk Act* (*Species at Risk Act*, SC 2002); and
5. Propose a set of scientific principles for rebuilding strategies and the role of the Science Sector that can be applied nationally.

This document is intended to provide context for related documents that provide advice on scientific approaches to designing rebuilding strategies and communicating scientific advice; these documents will be used to develop science guidelines for rebuilding Canadian fish stocks. This document is organized into five sections and supporting appendices, with establishment of document intent and terminology comprising Section 1 (this section).

Section 2 of the document reviews the key elements of international agreements that have shaped fisheries policies and guidelines worldwide, including the topic of rebuilding strategies. We describe the new Fish Stocks provisions established in June 2019 under the revised *Fisheries Act* and the linkages between the provisions and elements of the PA Policy. We identify questions and linked issues raised by proposed regulations that affect science activities initiated under Section 6.2 of the provisions (requirement for a rebuilding plan). However, we note that many of the issues have broader implications for the science role in the development of management strategies, regardless of a rebuilding mandate. We provide information on the interplay of the Canadian *Species at Risk Act* and *Fisheries Act*, focusing on a comparison of Recovery Potential Assessments and rebuilding plans.

Review of the PA Policy in Section 3 is focussed on those elements that may be subject to varying interpretations; we propose interpretations of these elements with the aim of increasing the consistency of science advice to support the policy. We summarize the 2013 policy guidance for rebuilding stocks from levels below a limit reference point (DFO 2013a) and review current Canadian rebuilding plans. All eight of these plans were developed prior to the coming into force of the Fish Stocks provisions, and some plans were developed prior the DFO PA Policy (2013a). We report how the need for rebuilding was determined, approaches for determining rebuilding timelines, methods for tracking progress and challenges common to the plans. This information is compared to the requirements of proposed regulations for rebuilding plans to identify elements needed for science guidelines.

Section 4 provides a brief treatment of perspectives on rebuilding strategies, touching on key topics that have emerged in more thorough examinations of the rebuilding dilemma (e.g., see the extensive work of NRC 2014; Garcia et al. 2018). These perspectives focus on identifying when rebuilding is needed, setting rebuilding objectives that include targets and timelines, and transitioning to desired stock and fishery states such that benefits to resource users are restored. A rebuilding plan can only define how surplus production is allocated to stock growth when it occurs, but does not guarantee that there will be sufficient production to meet specified objectives. Therefore we discuss managing expectations, evaluating progress, and deciding what actions will be taken at interim stages during the lifetime of a rebuilding plan that may depend on rebuilding progress. To support the discussion we draw material from a cross-jurisdictional review of applicable policies and guidelines across six international fisheries jurisdictions or agencies (Marentette and Kronlund 2020). The policies and guidelines examined for the review are listed in Table 1. We conclude the section by reviewing the key elements of an eco-certification standard for fisheries with respect to rebuilding stocks.

We conclude with Section 5 by outlining principles and proposing the science components of rebuilding strategies. The rationale for the principles is described, and we suggest a scenario planning method for approaching the rebuilding dilemma from a structured decision-making perspective. The document concludes with a listing of key issues and recommendations for the elements needed in scientific guidelines for rebuilding.

In reviewing both domestic and international policies we followed the following conventions for interpretation of terms. The use of *must* is interpreted as expressing obligation or an unavoidable requirement. *Must* is widely used to express obligation and has long been recognized as being capable of creating legislative requirements, supplanting the use of *shall*. The use of *should* is interpreted as indicating a recommendation or desirable goal. The verb forms *can*, *could*, *may*, and *might* were interpreted as expressing possibility, both in legislation and in policy. They do not necessarily express the same kind or degree of possibility and could, in certain contexts, lead to ambiguity (Department of Justice 2020).

We use the term *management procedure* to mean the stock and fishery monitoring data, assessment method (model-based or empirical) and harvest decision rules plus any meta rules that modify a catch or effort limit. Although the term is drawn from Management Strategy Evaluation (MSE, see Butterworth 2007; de la Mare 1998), its usage here does not imply a requirement for MSE in developing rebuilding strategies (see below). Instead, we use the term management procedure for two reasons. First, as a collective term for options that are under management control. Second, to emphasize that the efficacy of management actions depends on the interaction of the components of a management procedure, not a single component like the harvest decision (or control) rule. Finally we use the term *biomass*, but mean it to include *abundance* where species are recorded as numbers, or proxies that are proportional to stock size.

Each section and some sub-sections begin with a bulleted list of key points listed in a light-grey shaded text box. Sections conclude with a summary sub-section that lists recommended elements for science guidelines using a dark-grey shaded text box. We use Times New Roman font for mathematical notation to avoid ambiguities in symbols and subscripts. Italics are used to add emphasis; where we have added emphasis in quotations a bold font is used.

1.4. TERMINOLOGY

1.4.1. Rebuilding strategy or management strategy?

We first review how various jurisdictions define a management strategy before refining a definition to integrate rebuilding. We note that the terms "management strategy" and "harvest strategy" are often used interchangeably, but some jurisdictions distinguish the two terms. For example, Australia defined a "harvest strategy" as follows:

> "A decision framework designed to pursue defined biological and economic objectives for commercial fish stocks in a given fishery (also known as a management procedure). Key elements include: operational objectives, performance indicators, reference points acceptable levels of risk, a monitoring strategy, an assessment and harvest control rules." (DAWR 2018)
>
> "A harvest strategy is a framework that specifies pre-determined management actions in a fishery for a defined species (at the stock or management unit level) necessary to achieve the agreed ecological, economic, and/or social management objectives." (Sloan et al. 2014).

New Zealand (MF 2011) cites two uses of "harvest strategy" that are found internationally:

> "The simplest one is that the harvest strategy specifies target and limit reference points and management actions associated with achieving the targets and avoiding the limits. This is sometimes referred to as the harvest control rule."
>
> "The more comprehensive definition takes a systems approach that links together a stock assessment process and management and monitoring controls, along with associated performance measures."

The New Zealand government considers the simpler definition to be a *harvest strategy* while the latter is considered to define a *management strategy*. The United States (Blackhart et al. 2005) provided the following definition of "management strategy" which is much more explicit in the identification of harvest control tactics and allocation:

> "The strategy adopted by the management authority to reach established management goals. In addition to the objectives, it includes choices regarding all or some of the following: access rights and allocation of resources to stakeholders, controls on inputs (e.g., fishing capacity, gear regulations), outputs (e.g., quotas, minimum size at landing), and fishing operations (e.g., calendar, closed areas, season)."

In addition, the following comment is added to the definitions:

> "The management strategy may also include control laws establishing formally the course of management actions in relation to stock or fishery indicators. A precautionary management strategy takes uncertainty into account in order to reduce the probability of negative outcomes."

One element common to the various definitions is the separation of management objectives from the measures (tactics) intended to achieve the objectives. A second element in Australian, US and the more comprehensive New Zealand definition is the view of fisheries as integrated management systems. All definitions imply negative outcomes for the stock and fishery are anticipated in the design of the management strategy, i.e., “avoiding limits” and reducing “the probability of negative outcomes”. Finally, none of the definitions reference a *management plan*, and so separate the strategy from the implementation of an operational management plan.

We favor a concise definition of a management strategy provided by Sloan et al. (2014) and propose a modification to include requirements of FAO (1995a) and the PA Policy to consider uncertainty in the choice of strategy:

> A fishery management strategy is a pre-determined framework that specifies management objectives and the management actions applied to a stock (or stock management unit) necessary to achieve them. A precautionary management strategy takes uncertainty into account in order to reduce the likelihood of negative consequences and promote the achievement of desired management outcomes over the full range of plausible stock conditions.

Thus, the proposed definition includes situations where rebuilding objectives and measures may come to bear, regarding rebuilding as integral to the management strategy. These situations include the need to apply measures intended to prevent a stock from becoming depleted below threshold levels where serious, irreversible, or only slowly reversible harm may be incurred, rather than deferring such measures until limits are breached (DFO 2009, United Nations 1995).

We additionally adopt the practice of distinguishing between a *management strategy* and a *management plan*, *rebuilding plan* or other document that defines the conditions and rules under which a fishery will operate, as well as the accountability of resource users. For stocks determined to have breached a limit reference point, the PA Policy states that “a rebuilding plan must be in place with the aim of having a high probability of the stock growing out of the Critical zone within a reasonable timeframe”, and additionally that plan development should be initiated in advance of needing one. The latter guidance is intended to ensure a plan is ready for implementation if the LRP is breached, with the suggestion that plans be prepared when stock biomass is at the half-way point between the LRP and USR. Management strategies, inclusive of rebuilding strategies, are implemented via the yearly Integrated Fishery Management Plans for Canadian stocks managed by DFO (of which rebuilding plans may constitute a part). The roles and responsibilities of the Science Sector relate mainly to development and evaluation of the management strategy in response to stated goals or objectives, although science advice may inform various elements of the adopted management (rebuilding) plan.

While we refer to a management strategy or rebuilding strategy we avoid the use of *recovery strategy* due to a specific meaning under the *Species At Risk Act (Species at Risk Act*, SC 2002, c 29):

> **“recovery strategy** means a recovery strategy included in the public registry under subsection 43(2), and includes any amendment to it included in the public registry under section 45.”

1.4.2. Recovery or rebuilding?

Some authors have maintained that the terms *recovery* and *rebuild* are distinct, despite their often interchangeable use in the literature. The former has been interpreted as a “straightforward” increase in stock biomass, while the latter is interpreted to imply additional criteria such as restoration of age structure, evolutionary mechanisms, genetic diversity and behavioral traits (Murawski 2010, Garcia et al. 2018). However important the additional criteria considered to be part of rebuilding may be, it might be more difficult to obtain agreement on their undesirable and desirable states. This in turn means that there may be challenges to identifying the management actions required to avoid or achieve those states. For example, while directional changes in age structure could be valued and measurable, it may be challenging to obtain agreement on reference points that represent a “desirable” or conversely a “limit” age structure without a complex consideration of stock depletion, recruitment patterns, changes to natural mortality and selectivity. Similarly, stocks that have been fished for long periods of time prior to a collapse may not have adequate data to characterize complex demographics that existed at the outset of fishing that could define a desired state. This is not to imply that demographic aspects of a stock are unimportant (e.g., the Wild Salmon Policy goal to maintain genetic diversity of salmon stocks by preservation of Conservation Units, DFO 2005a), but only to make the point that motivating management action using demographics may require a compelling argument for a poor future prognosis. This may be possible in situations where there are sufficiently informative data to support stock projections that indicate persistent decline or lack of recovery as a result of prevailing fisheries selectivity, age structure, and expected recruitment patterns.

Consequently, focus is most often placed on stock biomass and fishing mortality rates since decision-makers are more likely to act based on low biomass than on, for example, age composition data that appear truncated. In Canada, fishing mortality rates have received less attention than biomass levels as decision points. This is despite the observation that persistent overfishing (fishing rates above a limiting threshold) is a condition typically coincident with stock decline (see NRC 2014) as well as limit fishing rates being a foundational element of international fishery agreements and policies in various jurisdictions (see Section 2).

Often rebuilding strategies have adopted criteria to provide some assurance a rebuilt target has been attained, usually by requiring rebuilding to an optimal state such as those defined by maximum sustainable yield (MSY) with 50% probability (e.g., United States). Rebuilding policy in New Zealand, for example, considers a stock to have been fully rebuilt when it can be demonstrated that there is at least a 70% probability that the target has been achieved and there is at least a 90% probability (P.M. Mace, pers. comm., January 14, 2020) that the stock is above the New Zealand “soft limit”. The use of a probability level of 70% for achieving the target instead of 50% is intended to provide some assurance that rebuilding plans are not ended too soon. It may, in addition, allow time for demographic characteristics like an age structure truncated by fishing pressure to resolve (MF 2008).

We use both recovery and rebuilding, but tend to the use of *rebuilding*, and suggest that specific applications rely on unambiguous statement of objectives related to limits and targets to define their intended meaning, regardless of the stock attribute of interest.

1.4.3. Overfished and overfishing

Characterizing the status of depleted fish stocks and describing prospects for their rebuilding requires consideration of both abundance (biomass) and mortality under management control, i.e., fishing pressure. Most fisheries jurisdictions consider both the abundance (biomass) and fishing mortality axes in their policies; many use the terms *overfished* and *overfishing* to describe stock states. Fisheries jurisdictions like Australia (DAWR 2018ab), New Zealand (MF 2008, 2011), the United States (NOAA 2009, 2018), and the fisheries science literature apply the terms in both policy and status determination. The terms are also used in various international fisheries agreements (see Section 2.1) although Canada has not adopted the terms. Revisions to the Canadian *Fisheries Act* that explicitly include a limit reference point in law, and requirements for rebuilding, means that characterizing states relative to both abundance (biomass) and fishing mortality limits are needed as much as the management labels described in the PA Policy (i.e., Critical, Cautious, Healthy). Use of overfishing and overfished terminology has been proposed in Canada, for example in framework development for incorporating climate change considerations into stock assessment (DFO 2019a).

There is, however, no internationally agreed convention for the terminology (de Souza et al. 2018; Froese and Proelss 2012). The operational definitions can vary substantially due to the choice of theoretical limit reference points (e.g., MSY-based or proxies) or data-based triggers in data-poor fisheries. Definitions may also vary in their treatment of uncertainty in the criteria used to make a determination of overfished or overfishing. For example, the National Standards Guidelines 1 (NSG1, NOAA 2009, 2018) of the United States *Magnuson-Stevens Fisheries Conservation and Management Act* (MSFSMA, commonly referred to as the Magnuson-Stevens Act or MSA) emphasizes limits and targets, with the minimum stock size threshold (MSST) and maximum fishing mortality threshold (MFMT) used as limits to define overfished and overfishing status, respectively. Specifically, the NSG1 aim to prevent overfishing, defined as a fishing mortality rate greater than that corresponding to maximum sustainable yield (NOAA 2009; 2018). The New Zealand Harvest Strategy Standard (MF 2011), sets F_{MSY} as a target to be achieved rather than a limit to be avoided, but paradoxically considers overfishing to occur when F_{MSY} is exceeded on average. Overfishing may also be used in the context of growth overfishing, recruitment overfishing, and can be applied to other types of overfishing (Garcia et al. 2018, Mace 1998).

Regardless of the specifics of the jurisdictional context, overfishing is a situation where the fishing mortality (or exploitation) rate is higher than a limiting threshold level. Usually the threshold level is a biological limit reference point such as F_{MSY}, so that the ratio of fishing mortality F to F_{MSY} can be used to indicate overfishing, i.e., $F / F_{\mathrm{MSY}} > 1$, or more generally $F / F_{\mathrm{lim}} > 1$, where the subscript lim indicates limit. For the case of F_{MSY}, persistent overfishing leads to stock decline below an optimal level, although not necessarily stock collapse depending on the fishing rate and stock status. For example, it is possible that stocks above target biomass levels can be subject to transient overfishing to take advantage of large year classes without causing immediate conservation concern, provided management can curb the development of persistently high overfishing. In the Canadian context, the PA Policy defines a fishing mortality reference point called the Removal Reference and elaborates that “To comply with the UNF[S]A, the Removal reference must be less than or equal to the removal rate associated with maximum sustainable yield.” Therefore, the Removal Reference is a limit fishing rate under the PA Policy (Shelton and Sinclair 2008), suggesting overfishing could be defined in Canada as a state where the fishing mortality rate is determined to exceed a limit such as F_{MSY} or proxy.

The term overfished usually refers to an abundance metric such as biomass, or numbers, of fish in a population or stock being below some identified limit or threshold. Like overfishing the specific definition of overfished varies widely in practice, but the ratio of biomass, B, to biomass at maximum sustainable yield, $B_{\mathrm{MSY},}$ is commonly used to define overfished conditions. According to FAO (2018), a ratio of $B / B_{\mathrm{MSY}} < 1$ represents an overfished stock having abundance lower than the level that can produce MSY, while the USA typically declares a stock overfished when B / MSST < 1, where the MSST is between 0.5 and 1*B_{MSY} (NOAA 2018).

The potentially smaller ratio used in the US compared to that used by FAO or other jurisdictions is justified on the basis that fish stocks naturally fluctuate around B_{MSY} in the absence of fishing, so that intervention in the downswing of a natural cycle is unneeded (Restrepo and Powers 1999). The FAO uses $0.4B_0$, where B_0 is the unfished (spawning) biomass as a threshold for overfished, based loosely on an argument derived from the Schaefer model that suggests “fully exploited” is in the range of 40-60 percent of the unfished biomass (Ye 2011). The reference point $0.4B_0$ is often considered a proxy for B_{MSY}. Canada has not adopted the term overfished. In the absence of stock-specific information, the PA Policy contains guidance to adopt a default level of $0.4B_{\mathrm{MSY}}$ for an LRP and a default level of $0.8B_{\mathrm{MSY}}$ where reductions in fishing mortality should be initiated as a stock declines. However, adoption of the default reference points is not mandatory and if adopted they can be revised when stock-specific alternatives are determined. The choice of $0.4B_{\mathrm{MSY}}$ would be a lower threshold for overfished than adopted by the USA or by FAO. However, the PA Policy intended the LRP to serve as a threshold to serious harm, which is interpreted as recruitment overfishing in Canada (Shelton and Rice 2002). A overfished level of $0.8B_{\mathrm{MSY}}$ would fall into the range adopted by the USA.

Hilborn and Stokes (2010) commented further on the NOAA context in light of the *Magnuson-Stevens Act*, where overfishing is interpreted in terms of lost yield. They recommended a lost-yield threshold of 80% corresponding to a threshold of $0.5B_{\mathrm{MSY}}$ for stocks with stock-recruitment steepness greater than 0.5, and higher for stocks where steepness is less than 0.5. This recommendation was based on an argument that yield at $0.5B_{\mathrm{MSY}}$ ranges from about 83-93% of MSY for steepness values of 0.5 to 0.9. They noted, however, that the yield curve is generally relatively flat in the region of B_{MSY}, so that there could also be little loss by maintaining the stock above B_{MSY}. The implied advantages of stock levels greater than B_{MSY} would be more time to react to a declining trend and hence more maneuvering room for fishery managers, and an additional possible benefit of meeting needed ecosystem services.

The terms overfishing and overfished can be used in combination to describe the current state of a stock, which lead to the development of the *Kobe plot* (Figure 1, Maunder and Aires-da-Silva, 2011). Thus, a stock can be described as *not experiencing overfishing*, and *not in an overfished state*. Conversely, the stock may be *overfished* and *experiencing overfishing*. Or the stock can be *overfished*, but *not experiencing overfishing*. This static characterization can be coupled with some indication of current trajectory. For example, a stock may be determined as *not overfished and not approaching an overfished condition; overfishing is not occurring*. Within the Canadian PA Policy terminology, the analogous statement could be: *the stock is above the target reference point (TRP) and stock biomass has a stable or increasing trend; the fishing mortality rate is less than the Removal Reference*. This description has meaning in a Canadian context but would not be broadly understood elsewhere. Note that “approaching an overfished condition” is defined under NSG1 in the United States (NOAA 2018) as a stock, or stock complex, when it is *projected* that there will be more than a 50 percent chance that the biomass of the stock, or stock complex, declining below the MSST within two years. Canada has not formally recommended nor adopted the use of projected states to determine whether limits are likely to be breached.

In Canadian practice, there is a tendency to rely on the current estimate of status to indicate stock decline below a limit reference point, although there is no agreed standard for making the determination. The use of projected states, where possible, would be consistent with the PA Policy intent to begin development of a rebuilding strategy and plan “in advance to ensure the plan is ready to come into effect … if a stock has declined and reached the LRP.” It should be noted that the PA Policy does identify a harvest decision (control) rule as a required element. The rule is intended to reduce fishing mortality as a limit is approached to mitigate the risk of a limit breach to accommodate the decline in the Removal Reference as the LRP is approached (DFO 2009). The reduction in target fishing mortality is one means of pre-specifying measures to encourage stock growth *before* an imperative for a rebuilding plan that may severely curtail or close a fishery.

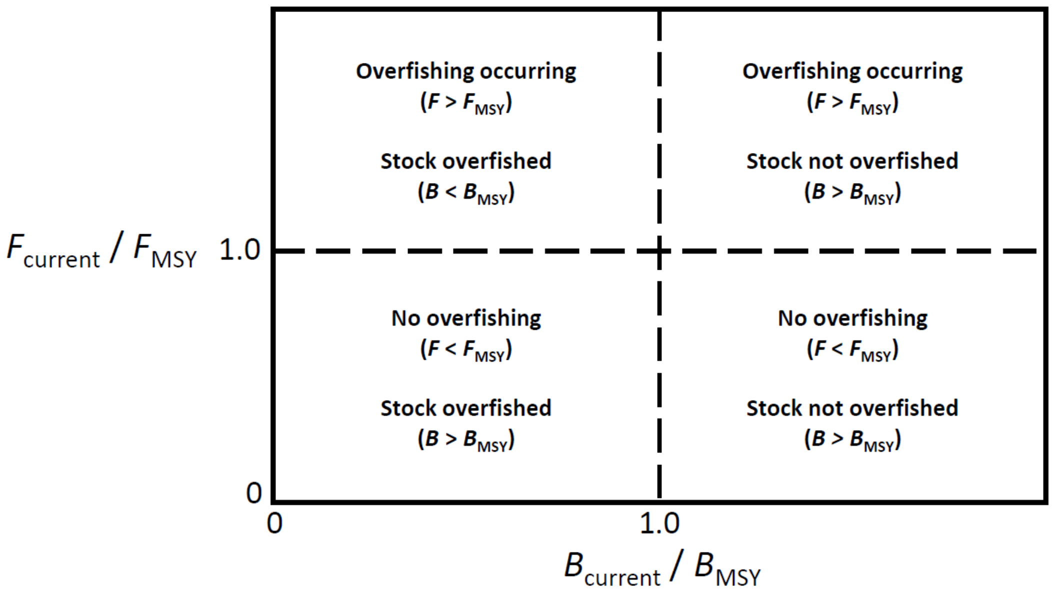

Figure 1. Kobe plot illustrating the characterization of stock states along the stock status and fishing pressure axes. This figure was developed at the first joint meeting of the tuna Regional Fisheries Management Organizations in Kobe, Japan in 2007. This Kobe plot represents a reference point framework based on MSY, but can be applied generally to proxies, theoretical or empirical. Adapted from Maunder and Aires-da-Silva (2011).

Froese and Proelss (2012) proposed the following definitions in their review of eco-certification standards:

> "Overfishing: A fishery is overfishing and a stock is subject to overfishing and overfishing is ongoing if removals (landings plus discards plus other human-induced mortality) from the stock are higher than those that would allow the stock to grow to and maintain a size that can produce the maximum sustainable yield. Technically, overfishing means that fishing mortality F is larger than F_{MSY}.
>
> Overfished: A stock is overfished if fishing has reduced the stock to a size below the level that can produce the maximum sustainable yield. Technically overfished means that the stock biomass is below B_{MSY}.
>
> Recruitment-overfished: An overfished stock is recruitment-overfished if fishing has resulted in a stock size where the number of reproductive adults is reduced to a level where below-average production of offspring becomes more frequent. Technically this means that the stock is smaller than 40-50% of B_{MSY}, the biomass that can produce MSY."

Thus, the definitions of Froese and Proelss (2012) allow statements to the effect that *overfishing is ongoing, the stock is overfished and approaching a recruitment-overfished state*. This refinement of *overfished* to include *recruitment-overfished* partially addresses a concern of Hilborn and Stokes (2010) who noted the irony in establishing high thresholds for overfished and overfishing and then using those thresholds to evaluate performance. High thresholds might give the public a perception that "overfished" stocks must not be producing near maximum sustainable yield, which is not the case. The rationale for most jurisdictions in establishing thresholds for overfishing is derived from concern about lost yield (Hilborn and Stokes 2010), and desires to avoid incurring serious harm (e.g., recruitment-overfishing). Thus, Hilborn and Stokes (2010) recommended that fisheries jurisdictions distinguish between stocks that are losing yield due to overfishing, and those stocks depleted to the extent that there is unacceptable risk of serious harm, ecological losses, or loss of benefits to resource users.

Various jurisdictions have adopted schemes similar to Figure 1, with different threshold choices and labels (e.g., Figure 2) but all are similar in intent. A disadvantage is the problem cited above; technical definitions of overfished such as $B < B_{MSY}$ can give the perception that a stock is being unsustainably managed, or significant yield is being lost when in fact the lost yield may be acceptably small. This has led some jurisdictions to combine state, stock trajectory, and management conditions in characterizing status (e.g., Table 2). For example, a "recovering stock" under the Australian FRDC (2018) scheme is overfished, but overfishing is not occurring based on evidence that F is sufficiently low that recovery is taking place under appropriate management. Note that the change in status labels to eliminate overfished and not overfished in favor of terms such as "depleted", "recovering" (Figure 2, Table 2) allows the inclusion of non-fishing drivers of stock status such as climate change effects or habitat loss.

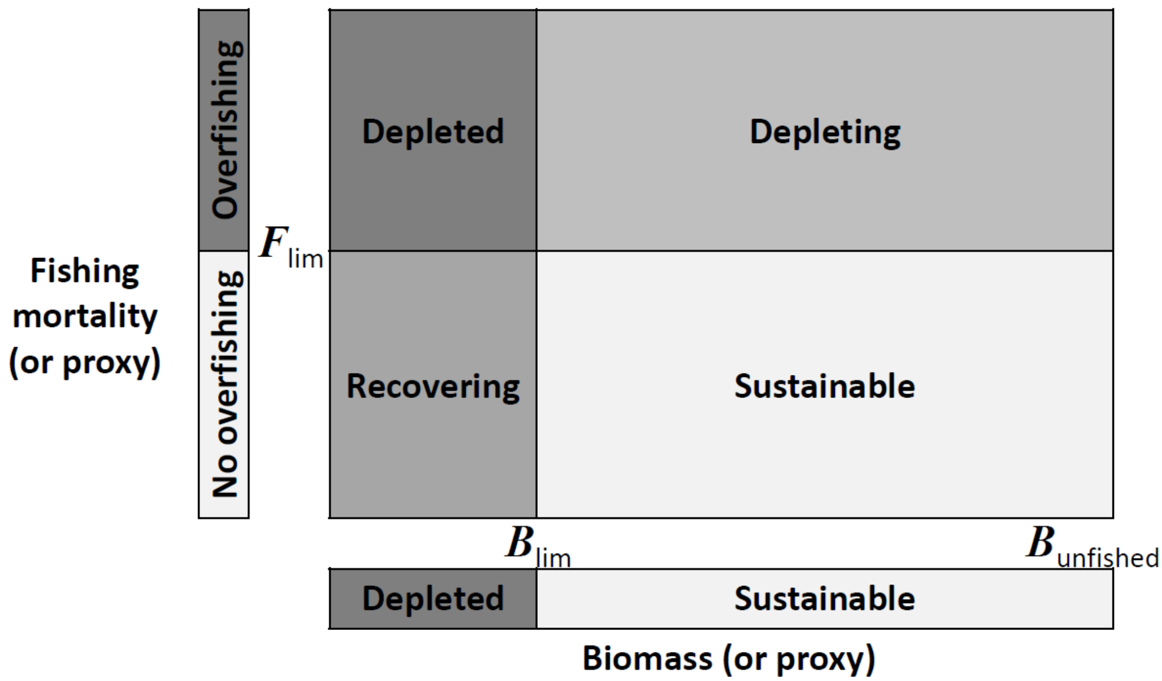

Figure 2. Status related to biomass or proxy and fishing mortality or proxy. This diagram modified from (FRDC 2018). For explanation of the status labels refer to Table 2.

Table 2. Status descriptions and associated management conditions consistent with stock labels in Australian stock status reporting (FRDC 2018).

Label	Status	Description	Management Condition
Sustainable	Not overfished and no overfishing is occurring.	Biomass (or proxy) is at a level where recruitment is not impaired (on average) and fishing mortality (or proxy) is controlled to avoid the stock becoming recruitment impaired (on average).	Appropriate management is in place.

Label	Status	Description	Management Condition
Depleting	Not overfished and overfishing is occurring.	Biomass (or proxy) is not yet depleted below a limit, and recruitment is not yet impaired. Fishing mortality (or proxy) is above a limit and moving the stock in the direction of a limit biomass.	Management is needed to reduce fishing mortality and to avoid biomass becoming depleted.
Recovering	Overfished and no overfishing is occurring.	Biomass (or proxy) is depleted and recruitment may be impaired, but stock recovery is occurring.	Appropriate management is in place, and there is evidence that the biomass is recovering.
Depleted	Overfished and overfishing.	Biomass (or proxy) has been reduced through catch and/or non-fishing effects, such that recruitment is impaired. Current management is not adequate to recover the stock, or adequate management measures have been put in place but have not yet resulted in measurable improvements.	Management is needed to recover this stock; if adequate management measures are already in place, more time may be required for them to take effect.
Undefined	-	Insufficient information to determine status, or status determination unreliable.	Data to assess stock status needed.
Negligible	-	Catches are so low as to be considered negligible and insufficient information exists to determine stock status.	Assessment will not be conducted unless catches and information increase.

Flood et al. (2014) provided a similar scheme to that shown in Table 2 and Figure 2 with five categories that included both status and fishing mortality metrics where recovering and depleting stocks are both classed as “transitional”, but are distinguished by the implementation of management to promote recovery:

1. Sustainable stock: Stock for which biomass (or biomass proxy) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (i.e. not recruitment overfished) and for which fishing pressure is adequately controlled to avoid the stock becoming recruitment overfished. Appropriate management is in place;
2. Transitional – recovering stock: Biomass is recruitment overfished, but management measures are in place to promote recovery and recovery is occurring. Appropriate management is in place;
3. Transitional – depleting stock: Biomass is not yet overfished, but fishing pressure is moving the stock in the direction of becoming recruitment overfished. Management measures are needed to reduce the fishing pressure to ensure the biomass does not deplete to an overfished state [meaning recruitment overfished];
4. Overfished stock: Spawning stock biomass has been reduced through catch, so that average recruitment levels are significantly reduced (i.e. recruitment overfished). Current

management is not adequate to recover the stock or adequate management measures have been put in place but have not yet resulted in measurable improvements;

5. Environmentally limited: Spawning stock biomass has been reduced to the point where average recruitment levels are significantly reduced, primarily as a result of substantial environmental changes / impacts or disease outbreaks (i.e., the stock is not recruitment overfished). Fisheries management has responded appropriately to the environmental change in productivity;
6. Undefined stock: Not enough information exists to determine stock status. Data are required to assess stock status.

The criteria for determining whether stock status is overfished, or overfishing is occurring, may vary depending on the modelling context. All parameters like F and B are uncertain, so their joint probability distribution (where available) is germane to making the determination of a given state. For example, how much of the probability distribution of F / F_{lim} needs to be greater than 1 to conclude overfishing is occurring? Specifically for rebuilding contexts, how much of the probability distribution of B / B_{lim} needs to be below 1 to declare the stock is likely to be recruitment-overfished? Of course there will be cases where the joint distribution of key parameters is not available such as in data-poor contexts and deterministic criteria may have to be adopted in such situations, i.e., crossing some threshold determines the characterization without consideration of probability. In addition, a weight-of-evidence approach may be needed that encompass considerations both of the totality of evidence (evaluating the combined contributions of individual studies which by themselves may be insufficient) and typically expert judgement-assigned weights for each line of evidence in the composite (Health Canada 2018).

Most commonly the terms overfished (and more finely resolved states as in Table 2) and overfishing are applied to characterize current stock status, i.e., a static characterization. However, the concepts can also be applied to prospective evaluation of management strategies where performance measures could quantify the number of years that overfishing occurs when applying a candidate management procedure, or the number of years that the stock is overfished, or various combinations of the two states as discussed above. This usage integrates the risk of incurring overfishing, or an overfished state, over time when designing a rebuilding strategy (de la Mare 1998). This also means that the length of the time horizon used in the projection affects the determination of what is acceptable.

We propose that guidelines for rebuilding and general stock characterization should consider the following practices:

1. Introduce “overfishing” and categories of “overfished” (e.g., depleted, recovering), to address both the abundance (biomass) and fishing mortality axes of status;
2. “Overfishing” could be defined in a Canadian context as a state where the fishing mortality rate is determined to exceed a limit, F_{lim}, e.g., F_{MSY} or proxy;
3. “(Recruitment) overfished” could be defined in a Canadian context as a state where the biomass is determined to be below a limiting threshold, i.e., the LRP, but see (4);
4. Distinguish between stocks that are losing yield due to overfishing (but above a limit), and those stocks depleted to the extent that there is unacceptable risk of “serious harm” (e.g., recruitment overfishing), ecological losses, or loss of benefits to resource users; and
5. Further qualify status by reporting stock trajectory (e.g., “approaching a recruitment-overfished condition”) and management conditions (e.g., “a rebuilding plan is in place, with prescribed timelines”).

Regardless of whether "overfished" and "overfishing" types of terminology are defined and adopted for a Canadian context, we suggest the following:

1. Report the fishing mortality status relative to the limit fishing mortality rate, e.g., the probability (or qualitative likelihood, IPCC 2007) that $F / F_{\mathrm{lim}} > 1$;
2. Report the abundance or proxy status relative to the LRP, i.e., the probability (or qualitative likelihood, IPCC 2007) that $B / B_{\mathrm{lim}} < 1$;
3. Distinguish between stocks that are losing yield, and those stocks depleted to the extent that there is unacceptable risk of "serious harm" (e.g., recruitment overfishing, ecological losses, or loss of benefits to resource users); and
4. Further qualify status by reporting stock trajectory (e.g., "approaching a limit reference point") and management conditions (e.g., "a rebuilding plan is in place, with prescribed timelines").
5. Define criteria to determine when a limit has been breached, inclusive of situations where a probabilistic determination can be made, only a deterministic determination is possible, and when a weight-of-evidence approach must be used.

2. INTERNATIONAL AGREEMENTS, THE FISHERIES ACT AND REGULATIONS

2.1. INTERNATIONAL AGREEMENTS

Key Points:

- Principle 15 of the Rio Declaration was the first to identify a *precautionary approach* to be applied by signatory States. Where there is possible serious or irreversible harm, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.
- Article 61 of the 1982 United Nations Convention on the Law of the Sea (UNCLOS) prescribes two fishery management objectives, including objectives for rebuilding: (a) maintaining or **restoring** stocks to levels that produce *maximum sustainable yield* (Article 61); and (b) *optimum utilization* of allowable catches, such that all the allowable catch is taken and stocks are not under-exploited (Article 62). UNCLOS also mentions two types of adverse effects (**over-exploitation**, and **levels at which reproduction may become seriously threatened**) that are to be generally avoided [**emphasis** added].
- The 1995 UNFSA treaty concretely linked the precautionary approach to avoidance (of limits), with the achievement of specific fisheries management objectives represented by targets in the design of management measures via Articles 5 and 6.
  - Annex II prescribes that fishery management strategies shall ensure that the risk of exceeding limit reference points is very low, and rebuilding actions should be taken to initiate stock recovery if a stock falls below a limit reference point or is at risk of falling below such a reference point.
  - Annex II, Section 7 states that for overfished stocks, B_{MSY} can serve as a rebuilding target.
  - Annex II F_{MSY} is a minimum standard limit fishing mortality reference point. For stocks that are not overfished, F_{MSY} is not to be exceeded.
  - Article 6, Section 7 states that if a natural phenomenon has a significant adverse impact on the status of straddling fish stocks, or highly migratory fish stocks,

conservation and management measures shall be adopted on an emergency basis to ensure that fishing activity does not exacerbate such adverse impact.
    - For cases where reference points are absent or the stock is data-poor, Annex II of UNFSA states that interim [“provisional”] reference points shall be set and may be established by analogy to similar and better-known stocks. The interim reference points are to be revised as information becomes available.
- The 1995 FAO voluntary *Code of Conduct for Responsible Fisheries* for the first time identifies the overriding fisheries management objective as **long-term sustainable use**, and that states should determine stock specific target reference points and actions to be taken if they are exceeded, and stock-specific limit reference points and the action to be taken if they are exceeded. When **a limit reference point is approached**, measures should be taken **to ensure that it will not be exceeded** [**emphasis** added].

We reviewed the development of policies, standards, and guidelines around the application of the precautionary approach in fisheries management, including in cases of rebuilding (Appendix A). The evolution of precautionary fisheries management links two separate but related ideas from a series of international treaties over the course of the second half of the twentieth century. The first, and perhaps most important of these, is the concept of avoiding potential adverse effects; the second is the concept of achieving fisheries management objectives, which are often linked to maximum sustainable yield (MSY). In particular, international agreements and documentations identify the importance of both *optimum utilization* and stock levels capable of producing MSY as fisheries management objectives, highlighting the latter as a potential rebuilding target. They indicate that management measures, including those in support of rebuilding, should be deliberately designed to achieve desired outcomes. The need for both *limit and target reference points*, even if only interim or “provisional,” is identified as well as the need for *management actions* to be taken when, or to prevent, reference points being exceeded. The *Code for Responsible Fishing* (FAO 1995b) which followed the UNFSA (United Nations 1995) brings in some novel language: for example, the overriding fisheries management objective is identified for the first time as *long-term sustainable use.* Article 7.2.2 (2-4) of the Code (FAO 1995b) infers that management objectives around sustainable use include ecosystem and socio-economic considerations as well as biological considerations related to optimal productivity. These concepts are reflected in the terms of various international agreements and documents of the Food and Agriculture Organization (FAO) of the United Nations reviewed in Appendix A and summarized as key points above.

2.2. FISH STOCKS PROVISIONS OF THE CANADIAN *FISHERIES ACT*

Key Points:

- The revised *Fisheries Act* includes new Fish Stocks provisions that introduced legal obligations to manage major fish stocks at or above levels necessary to promote sustainability, avoid limit reference points, and/or institute plans to rebuild fish stocks, all while considering the biology of the fish and environmental conditions facing the stock.
- Language in the Fish Stocks provisions requires interpretation in order to operationalize science activities.
- There is a critical need to define each stock, or stock management unit, such that the scientific rationale for a single associated limit reference point can be supported.

- Key criteria need to be addressed in scientific guidelines for rebuilding strategies, such as those needed to conclude a limit reference point has been breached, a rebuilt state achieved, and appropriate methods for calculating rebuilding time frames.
- As is the case for management strategies in general, rebuilding strategies initiated under the Fish Stocks provisions will be required to demonstrate evidence that the biology of the fish and environmental conditions facing the stock have been taken into consideration.

Sections 6.1 - 6.3 of the revised *Fisheries Act* (Figure 3) refer to the need for measures that maintain major fish stocks at, or above, the level necessary to promote the sustainability of the stock (s 6.1(1)), or the setting of a limit reference point along with measures to maintain the stock above that level (s 6.1(2)). A nuance of interpretation is that a stock perceived to be maintained at sustainable levels under s 6.1(1) will not have to demonstrate avoidance of a limit reference point (as it is only mentioned under s 6.1(2)). However, the omission of a limit reference point would not be consistent with full implementation of the PA Policy. The text of the new Fish Stocks provisions raises a number of questions related to stock rebuilding that will need resolution in guidelines, namely:

1. The PA Policy identifies both a status-based limit reference point and a fishing mortality rate limit reference point (PA Policy, see “three-zone diagram”, Figure 4). The Fish Stocks provisions imply an abundance-based LRP or proxy is intended (“maintain the fish stock above that point”). Are limits under s 6.1(2) restricted to abundance (biomass)-based reference points or proxies? Are limit fishing rate reference points considered to meet the legal intent, or reference points defined by metrics other than biomass and fishing rate as per the PA Policy? Will a limit fishing rate (i.e., Removal Reference, DFO 2009) be necessary to complete full PA Policy alignment before a stock can be prescribed under regulations?
2. If a “one stock, one limit reference point” approach is required, how are situations resolved where a suite of possible stock and fishery outcomes are used to determine thresholds to a state consistent with “serious harm” (e.g., low biomass, truncation of age structure, contraction of range distribution, loss of benefits to resource users)? Can multiple thresholds to serious harm be combined to constitute a condition where a limit is perceived to have been exceeded (e.g., Holt et al. 2009 for Pacific Salmon)? Where there are multiple limits, how is the one limit intended to meet regulations selected? Under what conditions, if any, is it defensible to associate a single limit reference point with an aggregate of biological stocks? Each stock could differ in stock dynamics and thus different biological limit reference points may apply.
3. What is a “level necessary to promote sustainability of the stock” under s 6.1(1)?
4. What criterion determines that a limit reference point has been breached thus triggering the need for a rebuilding plan under s 6.2(1))? What evidence is needed to establish a stock has met a rebuilt target in order to prescribe the stock under s 6.1?
5. How can legal obligations and PA Policy intent be preserved where data and/or methods are lacking or inadequate for providing reference point estimates?
6. Given that a rebuilding strategy is integral to a management strategy, how are conflicts between objectives prioritized when transitioning below, or above, a limit reference point, respectively? What steps need to be taken to ensure that management measures applied as the stock transitions above the LRP do not thwart the achievement of stock rebuilding objectives?

7. What does it mean to take “into account the biology of the fish and the environmental conditions affecting the stock” under ss 6.1-6.2? What evidence is required to demonstrate that these conditions have been considered?

Operational guidance for science activities will be needed to inform solutions to these questions, and in particular to match the specification of future rebuilding plans with requirements under regulations. Under s 6.3 of the amended *Fisheries Act*, the new Fish Stocks provisions will apply only to stocks “prescribed by regulations”, and will not apply to any other fish stocks. Note that we avoid the use of the term “listing” to avoid confusion with the listing process under the *Species at Risk Act*. The process of prescribing a stock means the Minister is informed how the stock-specific implementation of PA Policy elements (Table 3) supports ss 6.1 - 6.2 as required. Under s 6.2(2) the Minister can consider an amendment of the rebuilding plan or prescribed time period for rebuilding due to socio-economic reasons. It is presumed that the list of stocks prescribed according to s 6.3 will be made publicly available, as for species listed under the *Species at Risk Act*, and that the names and definitions of stocks may be difficult to alter thereafter. The latter stipulation raises the critical need to ensure the definition of a stock proposed for prescribing and choice of associated limit reference point can be defended in the development of a (rebuilding) management strategy.

The PA Policy identifies specific elements that comprise a “precautionary” harvest decision-making framework (Table 3). Alignment with DFO’s PA Policy requires reference points and determination of status relative to those reference points (PA1), the application of harvest decision (control) rules (PA2), and risk evaluation while considering uncertainty (PA3) (Table 3). Evaluating the performance of the management system (*PA4*) is not required (“*…*should be considered…”) despite being a critical step in defending claims of precautionary management and fisheries sustainability. Achieving PA Frameworks that provide a literal application of the PA Policy will be difficult for many data-poor and/or model-poor stocks where, for example, reference points and stock status cannot be reliably estimated. Preserving policy intent to avoid bad outcomes and achieve desired outcomes for stocks (and dependent fisheries) will require guidelines that accommodate the range of situations encountered along the continuum of data and model poverty from poor to rich (Bentley 2015, Bentley and Stokes 2009).

Fish Stocks

Measures to maintain fish stocks

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

Limit reference point

(2) If the Minister is of the opinion that it is not feasible or appropriate, for cultural reasons or because of adverse socio-economic impacts, to implement the measures referred to in subsection (1), the Minister shall set a limit reference point and implement measures to maintain the fish stock above that point, taking into account the biology of the fish and the environmental conditions affecting the stock.

Publication of decision

(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.

2012, c. 19, s. 135; 2019, c. 14, s. 9.

Plan to rebuild

6.2 (1) If a major fish stock has declined to or below its limit reference point, the Minister shall develop a plan to rebuild the stock above that point in the affected area, taking into account the biology of the fish and the environmental conditions affecting the stock, and implement it within the period provided for in the plan.

Amendment

(2) If the Minister is of the opinion that such a plan could result in adverse socio-economic or cultural impacts, the Minister may amend the plan or the implementation period in order to mitigate those impacts while minimizing further decline of the fish stock.

Endangered or threatened species

(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

(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

(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.

2019, c. 14, s. 9.

Regulations

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

Stocks de poissons

Mesures pour maintenir les stocks de poissons

6.1 (1) Dans sa gestion des pêches, le ministre met en œuvre des mesures pour maintenir les grands stocks de poissons au moins au niveau nécessaire pour favoriser la durabilité des stocks, en tenant compte de la biologie du poisson et des conditions du milieu qui touchent les stocks.

Point de référence limite

(2) S'il estime qu'il n'est pas possible ou qu'il n'est pas indiqué, en raison de facteurs culturels ou de répercussions socioéconomiques négatives, de mettre en œuvre les mesures visées au paragraphe (1), le ministre établit un point de référence limite et met en œuvre des mesures pour maintenir le stock de poissons au-dessus de ce point, en tenant compte de la biologie du poisson et des conditions du milieu qui touchent le stock.

Publication de la décision

(3) S'il établit un point de référence limite au titre du paragraphe (2), le ministre publie sa décision motivée, dans un délai raisonnable, sur le site Internet du ministère des Pêches et des Océans.

2012, ch. 19, art. 135; 2019, ch. 14, art. 9.

Plan de rétablissement

6.2 (1) Si un grand stock de poissons a diminué jusqu'au point de référence limite pour ce stock ou se situe sous cette limite, le ministre élabore un plan visant à rétablir le stock au-dessus de ce point de référence dans la zone touchée, en tenant compte de la biologie du poisson et des conditions du milieu qui touchent le stock, et met en œuvre ce plan dans la période qui y est prévue.

Modification

(2) S'il estime que le plan pourrait entraîner des répercussions socioéconomiques ou culturelles négatives, le ministre peut le modifier ou en modifier la période de mise en œuvre afin d'atténuer ces répercussions et de minimiser le déclin du stock de poissons.

Espèce menacée ou en voie de disparition

(3) Le paragraphe (1) ne s'applique pas si le stock de poissons touché est une espèce en voie de disparition ou une espèce menacée aux termes de la *Loi sur les espèces en péril* ou si la mise en œuvre de mesures de gestion internationales par le Canada ne le permet pas.

Publication de la décision

(4) S'il modifie le plan mis en œuvre en vertu du paragraphe (2) ou décide de ne pas en élaborer un en application du paragraphe (3), le ministre publie, dans un délai raisonnable, sa décision motivée sur le site Internet du ministère des Pêches et des Océans.

Mesures de restauration

(5) Dans sa gestion des pêches, s'il est d'avis que la perte ou la dégradation de l'habitat du poisson du stock concerné a joué un rôle dans le déclin du stock, le ministre tient compte de l'existence de mesures destinées à restaurer cet habitat.

2019, ch. 14, art. 9.

Règlements

6.3 Les grands stocks de poissons visés par les articles 6.1 et 6.2 sont prévus par règlement.

Figure 3. Fish Stock Provisions of the new Fisheries Act, June 21, 2019 (accessed July 22, 2019).

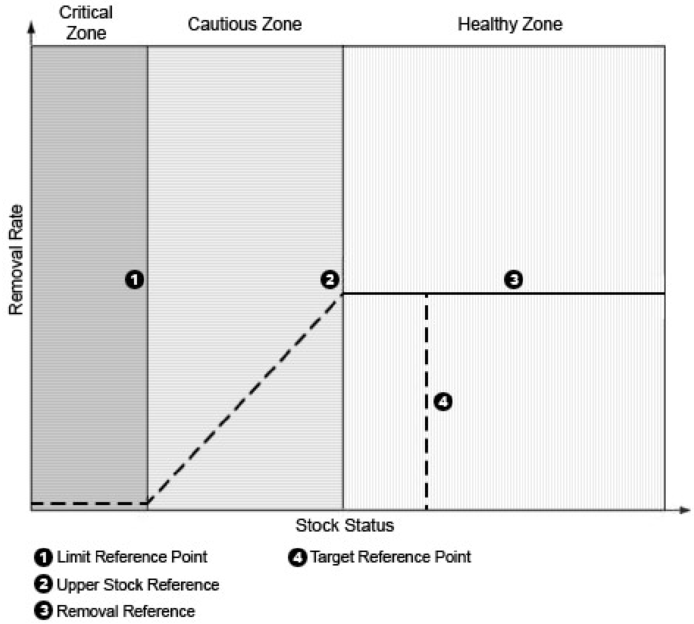

Figure 4. Diagram showing reference points and status zones for the PA Policy. The limit reference point, upper stock reference, and target reference point are status-based, however, the predominate role in choosing the upper stock reference is to avoid a limit reference point breach. The removal reference prescribes a fishing mortality limit that is reduced with declining stock status.

Table 3. List of PA Policy (DFO 2009) elements needed to complete a stock-specific PA Framework. Element PA4 is an expectation, not a requirement of PA Policy implementation but is key to providing evidence that the management system is performing acceptably. ***Emphasis*** *added in table.*

Element	Description
PA1	Limit and upper stock status reference points that delineate Critical, Cautious and Healthy zones and a limit fishing mortality rate. The biomass-based reference points are called the Limit Reference Point (LRP, Critical-Cautious boundary) and Upper Stock Reference (USR, Cautious-Healthy boundary). The policy also includes a Removal Reference defined as the maximum acceptable removal rate for the stock and allows for a separate Target Reference Point (TRP).
PA2	A harvest strategy and **harvest decision rules** (HDRs, more commonly referred to as harvest control rules, HCRs).
PA3	The need to take into account **uncertainty** and **risk** when developing reference points and developing and implementing control rules.
PA4	An expectation to **evaluate the performance** of the management system against the objectives specified by the harvest strategy. "The various components of the framework for a fishery (i.e., the reference points, removal references and decision rules) **should be explicit enough to allow assessment or evaluation of the performance of the framework**. Such an assessment or evaluation **should** be considered on a regular basis and it would normally take place after there is sufficient experience with the framework to conduct a proper evaluation of its performance (a period of 6 - 10 years might provide enough time to gain appropriate experience with the framework)." (DFO 2009)."

2.3. PROPOSED REBUILDING REGULATIONS

Key Points:

- Proposed regulations to support the Fish Stocks provisions will delineate the minimum requirements for rebuilding plans initiated under s 6.2 of the *Fisheries Act*.
- The alignment of stock-specific PA Frameworks with the PA Policy will meet many of the requirements under regulations.
- Proposed regulations to support rebuilding plans under the Fish Stocks provisions require resolution to specific elements. These include the criteria that determine, for example, when a limit reference point is breached, how to deal with "false positive" declarations of a limit breach, rebuilding time frames, identification of feasible management procedures, and evaluation of rebuilding performance. Scientific guidelines that describe scientific activities related to these criteria are required.
- A potential barrier to communicating both the intent and progress of rebuilding strategies is a common misconception that rebuilding is a "slow and steady" process and that the rebuilding plan has failed if specified time-bound milestones are not met.
- A rebuilding strategy and plan can create the conditions where surplus production can be directed towards increasing stock biomass, but does not ensure that there will be sufficient surplus production to do so.
- The dominating factors that lead to the need for rebuilding may not be the same factors that are currently inhibiting stock growth; thus the relative roles of environmental and human-induced decline may change over time and with the status of the stock.
- Management actions to be taken during the period required to develop an acceptable rebuilding strategy and implement a rebuilding plan are not specified in policy or proposed regulations.
- A rebuilding strategy may include requirements for augmented data collection and additional analyses to reduce data- and model-poverty.
- Roles and responsibilities of the Science Sector in developing rebuilding strategies aligned with the PA Policy are not fully specified in policy and need to be clarified in scientific guidelines.

Regulations are anticipated that support the Fish Stocks provisions, including those applicable to stock rebuilding under s 6.2(1) of the amended *Fisheries Act.* Proposed regulations may consider the topics listed in Table 4.

Proposed regulations may also indicate that a rebuilding plan for a prescribed stock must be put in place within a prescribed time period (e.g., 24 months after Section 6.2(1) of the *Fisheries Act* is triggered). In addition, under Section 6.2(2) there are provisions by which the Minister may extend the time line of Section 6.2(1) for the following reasons:

- To collect and provide scientific information necessary to develop a rebuilding plan;
- To provide additional time to seek feedback on the rebuilding plan from Indigenous peoples; and
- To discuss with other jurisdictions the management measures for a shared stock.

Table 4. Topics proposed for inclusion in regulations aimed at supporting the Fish Stocks provisions and the linkage to PA Policy (DFO 2009) elements listed in Table 3.

Id	Topic	Relevant PA Element
(a)	Description of the stock status and stock trends	**PA1**. The LRP is specified in law under s 6.1(2). The LRP, USR and RR (fishing mortality limit) are required to characterize stock status with respect to abundance (biomass) and fishing mortality or proxies.
(b)	Reasons for the stock's decline	May be reflected in the choice of past management options under **PA2** (e.g., leading to overfishing) and whether management measures were evaluated as to efficacy given various types of structural or parameter uncertainty under **PA3** (e.g., assessment errors, relative roles of environmental conditions and fishing).
(c)	Measurable objectives aimed at rebuilding the stock	Under management by reference points, which are embedded in objectives, **PA1** identifies the limiting states to be avoided (e.g., spawning biomass less than a limit biomass, fishing mortality less than the limit fishing rate). Also, **PA1** identifies the target states to be achieved (e.g., spawning biomass of at least biomass at maximum sustainable yield). Where possible, both the tolerance (probability) for avoiding a limit or achieving a target state and a time frame for evaluation are needed to form fully specified measurable objectives.
(d)	Timelines for achieving the objectives	Should be specified under (c) as part of a measurable objective. The PA Policy cites the time for a cohort to recruit to the spawning biomass and contribute to rebuilding the productive capacity of the stock. A timeframe of 1.5-2 fish generations for achieving a state above the LRP is suggested although longer periods are admitted for long-lived species. Generation time does not incorporate the productivity and current depletion of a stock, which both affect rebuilding timelines.
(e)	Desired rebuilding target	Required for meeting legal obligations of the Fish Stocks provisions to prescribe a stock under 6.1(1) or 6.1(2) rather than under Section 6.2(2). Section 6.2(2) indicates that the rebuilding target is above the LRP in the area affected, which must correspond to a "stock" to be associated with an LRP.
(f)	Management measures aimed at achieving the objectives	Supplied by **PA3** if a harvest control rule is inclusive of data and an "assessment" of stock trajectory in specifying a catch (effort) limit, or other measures that adjust catch downwards in response to perceived stock decline, and vice-versa.
(g)	Method to track progress to achieve the rebuilding plan's objectives	Requires optional element ***PA4*** and must include the ability to utilize both retrospective and prospective evaluation (FAO 1995a).
(h)	An approach to review the objectives, and an adjustment of these if the objectives are not being achieved.	Specified under the PA Policy in the evaluation of a management strategy under ***PA4***, but would also include "interim" objectives, or milestones, related to rebuilding as well as objectives related to economic and socio-cultural outcomes.

What is not clear, however, is the management actions to be taken during the period required to develop an acceptable rebuilding strategy and implement a rebuilding plan. Continuing with status-quo management measures after a need for rebuilding is determined can increase the likelihood of incurring “serious harm”, or lead to deepening states of “serious harm” as a stock lingers near or below limits (see Shelton and Rice (1992) for a discussion of “serious harm” for Canadian fish stocks). Conversely, stock biomass can incorrectly be determined to lie below an LRP, in which case invoking a rebuilding plan unnecessarily increases hardship to resource users due to reduced or lost harvest benefits. Thus, the case of how to handle false positives, as well as the case where stocks are correctly determined to be fluctuating around the LRP, needs consideration.

For stocks that suffer data-poverty, achieving sufficient data for reliable status determination using a conventional “best” stock assessment model approach may require many years, again creating a period of uncertainty. In those cases, the determination that rebuilding is needed is unlikely to be based on PA Policy theoretical reference points (e.g., MSY-based reference points or analogs) which typically require large amounts of informative data to estimate. Data-poor frameworks are needed where precautionary steps include data acquisition as part of the rebuilding strategy, and a rebuilding plan where management adaptation can occur as new information accumulates. For example, changes to indicators based on available data for data-poor situations (e.g., fleet distribution and fishery footprint, catch, species composition of the catch, etc.) may be explicitly tied to requirements for increased data collection if fishing activities are to continue (e.g., Dowling et al. 2015).

Each of the proposed topics (a-h) in Table 4 suggests one or more questions that will need resolution for science activities to fully proceed. Some questions cannot be addressed by science because of a need for legal interpretation, policy guidance or a management choice to allow advancement of scientific activities (Table 5). For example, determination of stock status involves the estimation of limit and target reference points. While science has a role and responsibility in estimating the biological limits to harvest (see the PA Policy), choice of risk tolerances and the desired target levels for a stock and fishery are not within the Science Sector remit. A solely science-based approach can only determine theoretically optimal levels of harvest subject to specific assumptions about stock dynamics, although these may serve as useful benchmark outputs when alternative management options are ranked. However, resource management decisions cannot be strictly science-based (Gregory et al. 2012); managers and resource users would legitimately object to relying only on achieving science-defined outcomes which ignore fundamental trade-off outcomes related to:

- values-based economic and socio-cultural considerations;
- acceptable levels of risk relative to avoiding adverse impacts and achieving targets; and
- the priority placed on biological stock preservation.

Although the Science Sector does not determine acceptable risk tolerance relative to a specific outcome, it can adopt and provide guidance on defensible practices for describing and communicating risk to decision-makers (e.g., the practices of the Intergovernmental Panel on Climate Change, IPCC 2007).

Proposed regulations (Table 4) that support Section 6.2(1) of the Fish Stocks provisions may require that the stock has been clearly defined, and that the limit reference point used to determine status can be defensibly associated with that stock, i.e., a rationale exists to support the LRP selection. This is a non-trivial task when attempting to identify an LRP prior to the occurrence of obvious serious harm (e.g., see Kronlund et al. 2018). Documenting the reasons for stock decline may be challenging, and the relative roles of fishing and environmental causes of decline may evolve over time. For example, fishing may have initiated stock decline to a state where environmental factors can now act to maintain a compromised stock state even if fishing pressure is reduced. The reverse is also true; environmental drivers may create conditions where fishing at a level deemed “sustainable” in the past now precludes stock recovery by taking available surplus production in the form of catch. Consequently, attribution of stock depletion to environmental factors should not be taken as an indication that fishing mortality has little or no effect, without evidence that is the case.

Resolving the relative roles of factors contributing to stock decline over time, both in the past and future, may be difficult, again requiring potentially large amounts of informative data. Thus, proposed rebuilding strategies may need to account for alternative hypotheses that govern the stock trajectory and identify management actions that do not depend on a single “best” interpretation of stock conditions and rebuilding potential. This is a challenging area of research for fisheries science since the determination of status depends both on the choice of reference points (e.g., are equilibrium or time-varying reference points adopted?) and the choice of plausible hypotheses to explain stock and fishery dynamics which can have large effects on the estimated value of a given reference point.

A rebuilding time frame may be required under regulations, but the actions to be taken when rebuilding objectives are not achieved are not specified. Roles and responsibilities for each of topics (a-h) listed in Table 4 are not specified, nor are acceptable methods for tracking progress. The process for adjustments to the strategy following periodic review of stock status and rebuilding progress is not specified. Closing these process gaps will, in part, require information from science activities, which highlights the need for advice on operational guidelines.

Each of the proposed regulations raises questions listed in Table 5. Addressing the questions may require technical analyses, or potentially create irresolvable uncertainties that must be accommodated in decision-making. For example, under possible regulations that would require tracking rebuilding progress, the exact recovery trajectory of a stock cannot be known in advance. A potential barrier to communicating both the intent, and progress, of rebuilding strategies is a common misconception that rebuilding is a “slow and steady” process. A stock subject to a rebuilding plan may show no evidence of recovery within the rebuilding time frame, or may benefit from a fortuitous recruitment event early in the rebuilding time period. The patience of managers and resource users may therefore be severely tested when rebuilding does not progress as anticipated or if the stock undergoes alternating periods of apparent recovery and setbacks.

Stock prognosis expected under alternative rebuilding strategies is often characterized using a simulation approach to construct possible futures; usually a large number of iterations are conducted to capture stochasticity. Rebuilding plans could set milestones based on the median of thousands of simulated stock trajectories, a practice which can appear to suggest a smooth and steady trajectory. However, the simulated trajectories underlying the distribution almost certainly won’t mimic the median trend and can represent a range of trend fluctuations that differ widely in timing and magnitude. Stock forecasts that assume average recruitment levels over the forecast period can be misleading given possibly impaired stock dynamics. Thus, fishery scientists have a role in helping to communicate realistic expectations for stock rebuilding in two ways. First, by identifying those management actions that are unlikely to produce desired rebuilding outcomes. Second, scientists can indicate that projections of rebuilding performance over a range of possible stock conditions are a means of ranking which management options might be preferred, rather than serving as a prediction of future stock status.

The rebuilding phase of a management strategy is limited to creating the conditions where surplus production can be directed towards increasing stock biomass, and does not ensure that there will be surplus production that meets specified biomass milestones. This reality raises the question of how to define success in rebuilding, and whether not meeting interim or final goals within the rebuilding time period is a failure or an opportunity to learn, re-investigate, and adapt the rebuilding strategy. Operational science guidelines for rebuilding Canadian fish stocks will need to consider each of the issues described in Table 5, and recommend approaches for their resolution.

*Table 5. Proposed regulations, related questions, and issues that require resolution for compliance. Questions and issues in **bold italics** font need resolution to complete scientific contributions to rebuilding strategies, but are drawn from law, policy or management choice rather than by purview of science.*

ID	Proposed Regulatory Item	Question(s)	Issues
(a)	Description of the stock status and stock trends	What is the stock definition? ***How is stock status assigned*?** e.g., estimates of abundance (biomass) and/or fishing mortality in relation to benchmarks (Pacific Salmon) or reference points, or for “data-poor” contexts in relation to empirical triggers ***When does a stock require rebuilding*?**	Metrics of stock state (e.g., abundance, biomass, age structure, spatial occupancy, fishing mortality, etc.) Limit and ***target*** reference points, associated uncertainty, and ***risk tolerance*** Rationale for associating reference points with stock definition, particularly LRPs Falsely declaring a stock below LRP (a false positive or “false alarm”, Type I error) Failing to correctly declare a stock below LRP (false negative or “a miss”, Type II error: due to retrospective errors, change in assessment model) Volatility of changes to status assignment (e.g., annual changes to overfished determination) Data poverty precludes reliable reference point and status estimation Non-stationarity in stock dynamics
(b)	Reasons for the stock’s decline	How is stock trend characterized? What is the evidence that preventable factors (e.g., fishing, habitat loss) led to stock decline or are impeding recovery? What is the evidence to support a regime shift, or directional ecosystem change, as a factor in stock decline or an impediment to stock recovery?	Metrics and methodology for trend evaluation (trend indicator, time period, uncertainty) Methodology and rationale for partitioning total mortality into natural and fishing mortality, possibly representing alternative forms of structural uncertainty Plausibility of hypotheses to explain stock trajectory in relation to preventable and/or ecosystem factors (related to the risk of discounting one possible explanation of system behavior in favour of another) Distinguishing factors that led to decline from factors that impede recovery; they may be the same or different (e.g., predator pit arises at low abundance, fishing mortality increases with stock decline)
(c)	Measurable objectives aimed at rebuilding the stock	What are good rebuilding objectives? ***What are imperative rebuilding objectives?*** ***What is the order of priority of objectives?***	Rendering rebuilding objectives measurable Metrics of management outcomes (e.g., status, yield, volatility) to match objectives Limit and ***target*** reference points, associated uncertainty, ***risk tolerance*** False positives and negatives in declaring rebuilding required, or rebuilding achieved Data poverty precludes reliable reference point and status estimation Non-stationarity in stock dynamics

ID	Proposed Regulatory Item	Question(s)	Issues
(c)	Timelines for achieving the objectives; a component of objectives in (c)	***What is the rebuilding time frame?***	Generation time calculation ***Default rebuilding time frames*** Plausible hypotheses for stock response to rebuilding measures that may include a schedule of removals or habitat restoration Time to rebuild to ***target*** in absence of removals Time to rebuild to target under status quo and, when available, alternative management actions Time to rebuild to target under alternative plausible hypotheses about stock response to preventable and/or ecosystem factors Projections may show the stock does not recover within default rebuilding time frames
(d)	Desired rebuilt target; an outcome specified in objectives (c)	***What is the desired rebuilt state such that Section 6.2(1) of the Fisheries Act no longer applies?***	Metrics to characterize rebuilt state, uncertainty, ***risk tolerance*** Evidence that the harvest strategy has a high probability of avoiding an LRP breach once Section 6.2(1) no longer applies
(e)	Management measures aimed at achieving the objectives.	What are ***feasible*** sets of alternative management measures (i.e., management procedures)? What are the specific input and/or output controls? Can the management procedure(s), inclusive of the harvest control rule be codified so that it can be evaluated retrospectively or prospectively? What is the evidence that the management measures are likely to lead to acceptable future stock and fishery outcomes? How should environmental conditions facing the stock (ecosystem factors) be considered? How should habitat restoration measures be considered?	Input/output controls Projection of dynamic, and possibly non-stationary, processes: recruitment, natural mortality, selectivity, etc. Sources of error: process, observation, assessment, implementation (management controllability) Evidence that proposed management procedures are likely to produce ***an acceptable trade-off of management outcomes*** relative to the ***priority of objectives*** Prospective and retrospective evaluation Explicit mechanisms for ecosystem factors or mimicking plausible effects, direct inclusion of ecosystem factors in management procedures or tuning management procedures to compensate for ecosystem factors, risks of including ecosystem factors when regime shifts or directional changes cannot be accurately detected Plausible hypotheses for stock response to habitat restoration measures
(f)	Method to track progress to achieve the rebuilding plan objectives.	What “milestone” objectives are appropriate during the rebuilding time-frame? ***What actions are taken if desired rebuilding outcomes are not achieved in the time-frame?***	Plausible hypotheses for stock response to rebuilding measures that may include specifying a schedule of removals or habitat restoration measures Characterizing and communicating possible stock response to rebuilding strategy (rebuilding is rarely a slow and steady process)

ID	Proposed Regulatory Item	Question(s)	Issues
(g)	An approach to review the objectives, and an adjustment of these if the objectives are not being achieved.	How should rebuilding strategy performance be evaluated? ***What actions are taken if desired rebuilding "progress milestones" and rebuilding objectives are not achieved in the time-frame?*** ***When are timelines "reset"?***	Methods for evaluating performance of existing rebuilding strategy Retrospective evaluation of existing rebuilding strategy Evidence to support adaptations to management measures based on retrospective performance and new information Accommodation of updated rebuilding objectives in performance evaluation Prospective evaluation of existing and alternative rebuilding strategies to illustrate likely consequences of management adaptation Standardized reporting of rebuilding strategy performance

2.4. *SPECIES AT RISK ACT* AND RECOVERY STRATEGIES

Key Points:

- The purpose of the *Species at Risk Act* (SARA) is to protect and recover listed wildlife species (Designatable Units), which are not synonymous with fish stocks.
- Unlike the typical evaluation of stock status relative to a biomass limit reference point, designation of species as Endangered or Threatened often includes temporal considerations of the rate of recent or projected decline in recent (or forecasted) years, or spatial considerations of species' distribution and range.
- Under SARA, listed Threatened or Endangered Species receive Recovery Strategies and Action Plans, while listed Special Concern species receive Management Plans. Unlisted species may be subjected to alternative management approaches including Rebuilding Plans.
- DFO guidance indicates that the main role and responsibility of the DFO Science Sector in support of listing decisions and recovery document development is science advice in the form of Recovery Potential Assessments (RPAs).
- Tasks to be conducted in the development of RPAs include assessments of status, recent trajectories, habitat requirements, sources of mortality, performing forecasts or simulated projections, and a comparison of various management options with respect to achieving recovery targets.
- These activities share some similarities to tasks that would be performed in providing science advice in support of rebuilding strategies under the *Fisheries Act*, indicating that it may be possible to minimize some redundancies in advice provided for both processes.

2.4.1. Listing Under the *Species At Risk Act*

The goal of the *Species at Risk Act* (SARA) is to protect and recover wildlife species (Designatable Units of biological species) that are deemed to be at risk of extinction in Canada. Individual Designatable Units are frequently spatially larger, or at least defined differently, than stocks defined in a fisheries context that generally involves consideration of both biological and management perspectives. Designatable Units "should be discrete and evolutionarily significant units of the taxonomic species, where 'significant' means that the unit is important to the evolutionary legacy of the species as a whole and if lost would likely not be replaced through natural dispersion" (COSEWIC 2017). Fish stocks, on the other hand, could be reproductively distinct units, but given uncertainties in defining spatio-temporal boundaries of stocks and the pragmatic needs of management, "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" (MF 2008).

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is the scientific committee that assesses the status of species at risk in Canada. COSEWIC members and the COSEWIC Species Specialist Sub-Committees prioritize species for assessment within the COSEWIC remit. All Designatable Units for species assessed by COSEWIC as 'at risk', must undergo a listing decision by the Government of Canada to decide whether or not to list the species on Schedule 1 of SARA. If the Government makes a decision to list a species as Endangered, Threatened or Extirpated on Schedule 1 of SARA, DFO must develop a Recovery Strategy and Action Plan for the species and protect its critical habitat. If a species is listed on Schedule 1 as Special Concern, a Management Plan must be developed.

If the Government makes a decision against listing the species under SARA, the DFO Listing Policy (DFO 2016b) states DFO must provide a compelling rationale that addresses an alternative management approach in the absence of listing, and the expected outcome for the species under the approach. This can include management under an Integrated Fisheries Management or Rebuilding Plan under the *Fisheries Act*. DFO must also provide and implement a work plan for an unlisted species if the Department will undertake incremental activities to support management actions.

2.4.2. SARA Recovery Strategy

The *Species at Risk Act* requires a Recovery Strategy and subsequent Action Plan be developed for all listed Threatened, Endangered or Extirpated species. Recovery of a species at risk under SARA is interpreted to mean: "A return to a state in which the risk of extinction or extirpation is within the normal range of variability for the species, as indicated in part by its population and distribution characteristics. This is informed by the species' natural condition in Canada, which is defined as its condition prior to the significant impact of human activities which led to the species being listed under SARA" (proposed Policy on Recovery and Survival, Government of Canada 2016).

The current guidance for implementing SARA states the DFO Science Sector may explore different management scenarios corresponding to a range of possible expected outcomes or goals of the Recovery Strategy for a listed species. These scenarios may be similar to what is explored in developing rebuilding strategies. Such outcomes shall include:

1. improving the species status to the COSEWIC designation of Special Concern, but also may include improving status to the designation of Not at Risk;
2. ensuring species survival through on-going management; and
3. significantly reducing the probability of extinction or extirpation (DFO 2011).

SARA requires that the Recovery Strategy includes a statement of the population and distribution objectives that will assist the recovery and survival of the species. Consequently, delineating potential population and distribution objectives is a key step for science. Such objectives directly influence the extent and kinds of actions required for the conservation and recovery of the species, and the protection of its critical habitat. Population and distribution objectives will also have an indirect impact on the types and magnitude of the socio-economic consequences to be incurred following a decision to list a species under SARA.

2.4.3. SARA Management Plan

As noted above, a Management Plan for listed Special Concern species is distinct from the Recovery Strategy and Action Plan for listed Threatened, Endangered or Extirpated species. A Management Plan usually sets out the management objective of maintaining the current population and distribution, setting out broad strategies and conservation measures needed to achieve the objective. The term *recovery* is not used in SARA in reference to species of Special Concern. Recovery targets are not identified.

2.4.4. Recovery Potential Assessment (RPA)

DFO developed the Recovery Potential Assessment (RPA) science advisory process to support decision-making for SARA listing decisions and Recovery Strategies. This peer-reviewed process provides science advice for listing decisions and Recovery Strategy documents. RPAs are generally only completed for species assessed by COSEWIC as Threatened or Endangered.

To support decision-making, information is provided in the RPA about a species' biology, habitat requirements, threats to the survival or recovery of the species, and population and distribution objectives. Science information and advice, in conjunction with information on possible management measures, are used in the development of the economic analyses aimed at supporting a decision whether to list a species under SARA, and for the development of Recovery Strategies and Action Plans. Science advice for establishing recovery targets was first developed in 2005 (DFO 2005b), and revised in 2011 (DFO 2011). A revised protocol for conducting RPAs was published in 2007 (DFO 2007a) and an updated Best Practices for Preparing Recovery Potential Assessments and an associated Terms of Reference template for RPAs was issued internally in 2014.

2.4.5. Determining When Recovery is Needed

The major assessment step in identifying a need for recovery action occurs with a status assignment by COSEWIC of Threatened or Endangered using criteria based on categories from the International Union of Conservation of Nature (IUCN) Red List (COSEWIC 2018). The criteria usually used for assessing marine fish is abundance, but there is a temporal aspect to abundance indicators that feeds into status assignment by COSEWIC, which is unlike the typical means by which fish stock status may be assigned relative to an LRP under the PA Policy. For example, wildlife species can be assigned to categories of Endangered or Threatened based on the extent to which declines in the total number of observed, estimated, inferred or suspected mature individuals have occurred over the last (or will occur over projections of) 10 years or three generations, whichever is the longer (COSEWIC criteria A). The criteria A threshold for Threatened is a greater than 30% decline and the threshold for Endangered is a greater than 50% decline. If numbers of mature individuals are already small and declining, the extent of further decline can be evaluated over 5 years or two generations, whichever is longer. For extremely small populations (e.g., 1000 individuals or less), absolute abundance can be used. In terms of other criteria, the distribution or range of the species is also taken into account. These include indicators of current extent as well as range fragmentation, fluctuations, and continuing decline of the extent or quality of the range.

Under COSEWIC, Designated Units of species that do not meet Threatened or Endangered criteria may be considered as Special Concern using the following guidelines: the abundance of the species is at levels where persistence is increasingly threatened by stochastic events, the species may become Threatened if negative factors are not reversed or managed, the species is near to Threatened, or would be Threatened but for the presence of "rescue effects" from other sub-populations (COSEWIC 2018).

Apart from COSEWIC, the IUCN Red List guidelines note that taxa subject to fisheries may show declines in population size as a result of intentional management action, and such taxa could potentially meet the criteria for Threatened status based on the rate or the extent of decline. However, such declines might or might not reflect extinction risk, particularly if the goal of the fishery is to achieve maximum sustainable yield, which may require fishing biomass down to much less than 50% of the unfished biomass to maximize surplus production. Note that declines are not measured from the original, unexploited status of a species; IUCN criteria constrain assessments to within the last three generations which may be well after the time when fishery removals became significant. This may limit the rates at which sustainably managed fish species are designated as Threatened since fishing down of biomass occurred prior to a three generation window (IUCN 2019).

2.4.6. Identifying Recovery Targets

Recovery targets linked to an overall recovery outcome are essential to support decisions on listing, establishing recovery objectives, and developing Recovery Strategies to identify appropriate recovery and management measures. As such, estimating population and distribution targets is a task (Element 12) in the Terms of Reference template for RPAs. The developing PA Policy was used as initial guidance for developing recovery targets for Recovery Strategies (DFO 2005b). Of sixteen traits considered to be possible bases for recovery targets, two (abundance and total range occupied) emerged as preferred for targets. Recovery Strategies that set recovery targets to the "cautious-healthy" boundary of the developing PA Policy, later known as the Upper Stock Reference, were "expected to result in stocks not assessed as Threatened or Endangered by COSEWIC". However, there was not considered to be a compelling scientific reason to choose between the "cautious-healthy" or "critical-cautious" boundaries, the latter boundary now known as the LRP (DFO 2005b, 2009a). Later guidance indicated that information about the life history of the species and its historical status can provide a starting point for identifying realistic recovery targets, and associated timescales to achieve those targets, based on abundance and distribution (DFO 2011).

2.4.7. Selecting Time Periods for Recovery

According to DFO (2007a), "three generations are often identified as the target for time to recovery because this interval is an assessment standard for COSEWIC and is used in many publications on conservation biology. However, the various possible trajectories until recovery targets are reached, if feasible, are vital for consultations, social and economic evaluations, and planning by Recovery Teams, and should be a product of RPAs whenever possible." This stipulation implies that forecasts or simulation projections are an expected output of RPAs, and indeed guidance has been provided for such outputs (Shelton et al. 2007).

2.4.8. Recovery Objectives

Recovery objectives, including population and distribution objectives, are developed in support of an overall recovery goal for the species (i.e., a desired final outcome such as improving COSEWIC status to Special Concern, or to "not at risk"). Even higher up the objectives gradient could be rebuilding the population to either historical levels, or to where it can sustain "sizeable harvesting activities" (DFO 2011). Initial guidance suggested that goals for abundance (in the context of historical population size), a population growth rate or level of surplus production, an age composition, and an abundance-weighted description of range would be a reasonable suite of attributes to address in Recovery Strategies. Ultimately abundance and total range occupied emerged as preferred attributes (DFO 2005b).

Given the best available information and to the extent possible, population and distribution objectives should be SMART (specific, measurable, achievable, relevant and results-focused, and time-bound; DFO 2011), similar to current policy guidance for rebuilding objectives (DFO 2013a). In this regard, it is desirable to specify a specific target or range, for the population size and distribution. Nonetheless, there may be situations where recovery goals to Special Concern or greater status cannot be feasibly achieved. In these situations, only survival or a significant reduction in the probability of extinction/extirpation can be sought as goals in tested management scenarios (DFO 2011).

In some cases, it may be easier to first identify possible management measures and model their impacts on population trajectories and then assess if proposed measures will lead to recovery (e.g., when the reason for 'at risk' status is essentially based on large population decline). In other cases it may be more convenient to identify recovery thresholds in terms of distribution and abundance and then assess the potential of specific management measures in achieving these thresholds (e.g., for species with a small extent of occurrence or small population size).

2.4.9. Management Options for Recovery

Guidance for RPAs indicates that "inventories" of possible management actions should be acquired in advance from other DFO sectors, industries, stakeholders and public interest groups. Such inventories should include alternatives and mitigation measures proposed by science that may warrant consideration (DFO 2011). Actions that both reduce mortality, and increase productivity, can be the basis for management options in Recovery Strategies. The ideal end product would be risk-based advice as to how the expected mortality of the species would vary among the different management options, including an option of status quo (no change in management).

In 2012, additional guidance was issued by DFO for the development of management scenarios to support listing decisions (DFO 2012a). Scenario development is to be led by the Species At Risk Regional Manager, with appropriate consultation with other DFO sectors as required. Scenarios will draw from information presented in the RPA. Completion of the RPA is the main Science role and responsibility in this guidance (DFO 2012a); however, science may also be asked to conduct a biological analysis of specific management scenarios after the completion of the RPA.

2.4.10. Habitat Considerations

Under the Fish Stocks provisions, Section 6.2(5) notes that for stocks requiring rebuilding plans, "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." Existing guidance for RPAs in documenting habitat requirements and threats to habitat (e.g., DFO 2007b), while designed to meet the requirements of SARA, may also provide some useful bases for developing relevant guidance for similar science advisory requests to support some rebuilding plans under the Fish Stocks provisions.

2.4.11. *Species at Risk Act* or *Fisheries Act*?

If a prescribed stock is subject to Section 6.2 of the Fish Stocks provisions and is also listed as Threatened or Endangered under SARA, Section 6.2(3) is expected to be triggered. In this case it will not be necessary to develop a rebuilding plan under the *Fisheries Act*. The sole recovery planning documents would be the SARA Recovery Strategy and Action Plan. There is currently one species, Cumberland Sound Beluga, on the list of major fish stocks on DFO's Sustainability Survey for Fisheries that is listed as Threatened or Endangered under SARA and would be expected to trigger an exemption from a rebuilding plan. A Recovery Strategy is in the process of being developed for that stock.

If a species or stock is listed under SARA as Special Concern, a Management Plan will be required and if also prescribed under the *Fisheries Act*, depending on the status of the stock, a rebuilding plan may also be necessary. Currently there are four stocks on the 179 list of major stocks that have been listed as Special Concern; Yelloweye Rockfish (inside population), Yelloweye Rockfish (outside population), Longspine Thornyhead and the Blackspotted-Rougheye Rockfish sibling species complex.

There may be cases where science advice for a SARA listing decision as Endangered or Threatened, and science advice for a rebuilding plan are required in the same timeframe. In these circumstances, it may be beneficial to seek efficiencies in coordinating the processes and producing outputs needed to meet requirements for proposed regulations supporting the Fish Stocks provisions and science advice on listing decisions and recovery documents under the SARA. Some similarities in science advice provided to support either process are identified in Table 6. The table compares RPA tasks outlined in the Terms of Reference for an RPA template (consistent with DFO 2007a) and the potential topics for proposed regulations to list major fish stocks for rebuilding plans under the Fish Stocks provisions[1].

[1] DFO. 2018. Proposed regulation to list major fish stocks and describe requirements for stock rebuilding plans.

Table 6. A comparison of topics proposed for inclusion in regulations aimed at rebuilding plans in support of the Fish Stocks provisions and Science tasks to be performed in generating a Recovery Potential Assessment (RPA) as outlined in templates issued in 2014 and consistent with DFO (2007a). While RPAs emphasize advice elements tailored to meet the specific requirements of the Species at Risk Act*, the similarities with rebuilding plan topics suggest that it may be possible to minimize redundancies when both RPAs and science advice in support of rebuilding plans are required simultaneously.*

Id	Topic	Related RPA Task
a	Description of the stock status and stock trends.	**Element 1:** Summarize the biology of the wildlife species. **Element 2:** Evaluate the recent species trajectory for abundance, distribution and number of populations. **Element 3:** Estimate the current or recent life-history parameters for the wildlife species.
b	Reasons for the stock's decline.	**Element 4:** Describe the habitat properties that the wildlife species needs for successful completion of all life-history stages. Describe the function(s), feature(s), and attribute(s) of the habitat, and quantify by how much the biological function(s) that specific habitat feature(s) provides varies with the state or amount of habitat, including carrying capacity limits, if any. **Element 5:** Provide information on the spatial extent of the areas wildlife species' distribution that are likely to have these habitat properties. **Element 6:** Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc. **Element 8:** Assess and prioritize the threats to the survival and recovery of the wildlife species. **Element 9:** Identify the activities most likely to threaten (i.e., damage or destroy) the habitat properties identified in elements 4-5 and provide information on the extent and consequences of these activities. **Element 10:** Assess any natural factors that will limit the survival and recovery of the wildlife species. **Element 11:** Discuss the potential ecological impacts of the threats identified in element 8 to the target species and other co-occurring species. List the possible benefits and disadvantages to the target species and other co-occurring species that may occur if the threats are abated. Identify existing monitoring efforts for the target species and other co-occurring species associated with each of the threats, and identify any knowledge gaps. **Element 14:** Provide advice on the degree to which the supply of suitable habitat meets the demands of the species both at present and when the species reaches the potential recovery target(s) identified in element 12.
c	Measurable objectives aimed at rebuilding the stock.	**Element 12:** Propose candidate abundance and distribution target(s) for recovery. **Element 15:** Assess the probability that the potential recovery target(s) can be achieved under current rates of population dynamics parameters, and how that probability would vary with different mortality (especially lower) and productivity (especially higher) parameters.
d	Timelines for achieving the objectives.	**Element 13:** Project expected population trajectories over a scientifically reasonable time frame (minimum of 10 years), and trajectories over time to the potential recovery target(s), given current population dynamics parameters.
e	Desired rebuilding target.	**Element 12:** Propose candidate abundance and distribution target(s) for recovery.

<table>
<tr><th>Id</th><th>Topic</th><th>Related RPA Task</th></tr>
<tr><td>f</td><td>Management measured aimed at achieving the objectives</td><td>Element 16: Develop an inventory of feasible mitigation measures and reasonable alternatives to the activities that are threats to the species and its habitat (as identified in elements 8 and 10).
Element 17: Develop an inventory of activities that could increase the productivity or survivorship parameters (as identified in elements 3 and 15).
Element 18: If current habitat supply may be insufficient to achieve recovery targets (see element 14), provide advice on the feasibility of restoring the habitat to higher values. Advice must be provided in the context of all available options for achieving abundance and distribution targets.
Element 19: Estimate the reduction in mortality rate expected by each of the mitigation measures or alternatives in element 16 and the increase in productivity or survivorship associated with each measure in element 17.
Element 20: Project expected population trajectory (and uncertainties) over a scientifically reasonable time frame and to the time of reaching recovery targets, given mortality rates and productivities associated with the specific measures identified for exploration in element 19. Include those that provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.
Element 21: Recommend parameter values for population productivity and starting mortality rates and, where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts in support of the listing process.
Element 22: Evaluate maximum human-induced mortality and habitat destruction that the species can sustain without jeopardizing its survival or recovery.</td></tr>
<tr><td>g</td><td>Method to track progress to achieve the rebuilding plan’s objective.</td><td rowspan="2">“The obligation under section 46 of SARA to report on progress toward meeting recovery strategy objectives every five years requires that objectives be stated in a manner that is conducive to doing this.” (DFO 2011)</td></tr>
<tr><td>h</td><td>An approach to review the objectives, and an adjustment of these if the objectives are not being achieved.</td></tr>
</table>

3. PRECAUTIONARY APPROACH POLICY

Key Points:

- Canada, like many other fisheries jurisdictions, advocates precautionary approach management by reference points, with the policy intent of avoiding limits (thresholds to deleterious stock and fishery states) and achieving targets (desirable stock and fishery states).
- “Fisheries management science” takes a systems approach by considering the reference points and associated objectives, data and models, and harvest control rules in their entirety rather than as a collection of independent components.
- The information demands of management by reference points presents challenges to implementation, particularly as data- and model-poverty increase.
- Reference points are used to define limit or target states, but are not operationally useful per se until they are embedded in objectives against which the efficacy of management measures, including those focused on rebuilding, can be evaluated.
- Objectives that include reference points should clearly specify how time should be interpreted, e.g., does a 90% probability of avoiding a limit breach mean a 1-in-10 year chance of a breach, or a 90% probability in each and every year?
- Guidance is needed on the use of current or projected stock states when determining status relative to a limit reference point, as well as the criteria for determining an LRP breach.
- The choice of probability in objectives may vary depending on whether current status is being evaluated, or a management procedure is being designed to avoid an LRP breach or to meet time-prescribed rebuilding objectives. Guidelines should include a description of how these cases are different and the implications of risk tolerance choice as a stock transitions from rebuilding to target outcomes.
- Reference points based on historical stock states may be more easily understood by fishery managers and resource users who may relate to their experience but not to abstract constructs like MSY or B_0-based (unfished biomass) reference points. Limits and targets based on (relative) historical stock levels could preserve the intent of most fisheries policies to avoid select thresholds of overfished states, and to prevent lost yield by overfishing.
- Any decision to introduce time-varying reference points into rebuilding strategies should be supported by evidence derived from feedback simulations to eliminate poorly performing choices and to provide some assurance that desired outcomes can reasonably be expected.
- The Upper Stock Reference (USR) is assigned a dual role in policy as both a target and as an operational control point where the intended fishing mortality is adjusted. A solution to the conflict of roles would be to prioritize the role of the USR as an operational control point as per PA Policy guidance and distinguish reference points from harvest control rules (HCRs).
- The Removal Reference (RR) is limit fishing rate distinct from the HCR that specifies a target fishing rate. It may not be necessary to have a segmented RR to preserve PA Policy intent. Management procedures that include HCRs should be designed such that limits are avoided and targets achieved with acceptable risk tolerance, which is likely to require a reduction in target fishing mortality as limits are approached.

- The effectiveness of a given HCR cannot be determined in isolation of the other components of the management procedure; the application of untested management procedures may result in outcomes that do not meet management objectives acceptably.
- "Preventable decline" is interpreted to mean causes of decline induced by human activities (e.g., fishing or habitat disturbance) or those causes that can be mitigated by humans (e.g., natural habitat erosion that can be mitigated).
- A literal interpretation of "no tolerance" for decline for stocks below an LRP means zero probability of preventable activities that contribute to stock decline. Thus, zero fishing mortality management procedures should be include in analyses to serve as benchmarks for comparison with alternative procedures.
- In the absence of policy-based criteria, science has no role in the determination of the "lowest possible level" until constraints are provided in the form of measurable rebuilding objectives. Objectives comprised of rebuilt targets, time-frames, and acceptable risks act to constrain the sequence of catches that provide acceptable outcomes.
- To account for "removals from all sources," there should be explicit accounting for plausible direction and magnitude of bias in catch estimates, e.g., model sensitivity cases or simulation scenarios that illustrate consequences of catch assumptions.
- The PA Policy is not explicit on multi-stock fisheries; science guidance will be needed for inherently multi-species fisheries such as Pacific salmon and groundfishes, and will arise more frequently where EBFM is applied.

3.1. MANAGEMENT BY REFERENCE POINTS

Canada, like many other fisheries jurisdictions, advocates precautionary approach management by reference points in policy; the policy intent is to avoid limits (thresholds to deleterious stock and fishery states) and achieve targets (desirable stock and fishery states). Usually the desire to maintain a stock near target levels is associated with avoiding loss of long-term yield. Most reference point-based management strategies are founded on maximum sustainable yield (MSY) concepts, either explicitly or implicitly in law or policy (see Marentette and Kronlund 2020). For example, although Canada does not require application of MSY-based reference points in legislation or policy, the PA Policy cites the use of B_{MSY} and F_{MSY} or their proxies, as a basis for reference point choices in the absence of stock-specific information. Biomass-based reference points of $0.4B_{\mathrm{MSY}}$ and $0.8B_{\mathrm{MSY}}$ are suggested as guidance for the Limit Reference Point (LRP) and upper stock reference (USR), respectively. The PA Policy also includes a limit fishing mortality rate reference called the Removal Reference (RR), which "must be less than or equal to the removal rate associated with maximum sustainable yield" for alignment with the UNFSA (UN Nations 1995).

Fishery policies world-wide may give the impression that concepts like MSY provide clear measurable benchmarks to guide decision-making. In fact, they are theoretical quantities that provide a useful tool for exploring limits to harvest and optimal yield under specific assumptions. Those limits and optima may vary over time depending on the state of the stock and environmental factors (and for MSY, fishery selectivity) in a potentially hard-to-estimate manner. The choice of specific thresholds may depend on the experience of fisheries scientists and managers, particularly when selecting proxies for data- and model-poor stocks and fisheries. Estimation of MSY-based reference points usually requires large amounts of informative data, and their effects on management outputs are not independent of other elements of a management strategy. This is one reason why "fisheries management science" (Lane and

Stephenson 1995; Stephenson and Lane 1995, de la Mare 1998) should take a systems approach by considering the reference points and associated objectives, data and models, and harvest control rules in their entirety rather than as a collection of independent components. It is a challenging exercise to specify the suite of components in a management strategy such that there is a reasonable expectation of meeting stock and fishery objectives; acceptable solutions require trade-offs of management outcomes related to conflicting objectives (Restrepo et al. 1998). The relative weights placed on these objectives constrain the available management options and therefore fundamentally affect rebuilding of depleted fish stocks or prevent the need for rebuilding actions in the first place. This is true regardless of whether the weights are formally expressed, ad hoc, or cryptic.

Reference points are used to define limit or target states, but are not operationally useful per se until they are embedded in objectives against which the efficacy of management measures can be evaluated (Rosenburg and Restrepo 1996). Characterizing stock states relative to reference points requires a statement of the criteria used to make the determination. For example, judging whether biomass has breached a limit reference point in the current year, or is likely to fall below the limit in the near future, requires a statement of the tolerance for biomass less than the LRP. The tolerance is usually expressed as a probability, which helps to render the goal to avoid an LRP breach operationally useful by making it measurable. Reference points embedded in measurable objectives help to reduce the set of acceptable management options so that the policy intent can be preserved.

For example, to say the limit reference point is “0.4 of the spawning biomass at maximum sustained yield ($0.4B_{\mathrm{MSY}}$)” says nothing about the management actions needed to maintain a stock above the LRP. An objective that states “spawning biomass should be greater than, or equal to, the limit reference point of $0.4B_{\mathrm{MSY}}$ with 90% probability in each of the next 20 years” represents a fully-specified constraint on acceptable management options. Those management options that meet a high priority measurable objective can be retained; those that do not can be eliminated from further consideration. Meeting such an objective may require taking action to reduce fishing mortality, or completely cease directed fishing, prior to breaching the limit reference point since the actual status of the stock is uncertain (as is the estimate of the LRP). For this reason, the levels at which fishing mortality is adjusted are called operational control points (“take action”) to clearly distinguish them from reference points which are to be avoided or achieved (Cox et al. 2013).

Various fisheries jurisdictions specify measurable objectives in policy or guidelines. The Australian harvest strategy (DAWR 2018) specifies minimum standards for reference points as follows:

- A target biomass reference point, B_{targ}, equal to or greater than B_{MEY}, the biomass at maximum economic yield. A proxy of $1.2B_{\mathrm{MSY}}$ is used when B_{MEY} cannot be determined;
- A limit biomass B_{lim}, (or proxy) equal to or greater than $0.5B_{\mathrm{MSY}}$ (or proxy);
- A limit fishing mortality rate, F_{lim} less than or equal to F_{MSY} (or proxy); and
- A target fishing mortality F_{targ} (or proxy) at the level required to maintain the stock at B_{targ}.

These statements alone say nothing about the desired certainty of avoiding the limit and target reference points, or over what time period the performance of the management system relative to reference points should be evaluated. However, the Australian guidelines clarify risk tolerance for an LRP breach by clarifying that the stock should avoid falling below the LRP at least 90% of the time, to be interpreted as a 1-in-10-year chance that $B < B_{\mathrm{lim}}$. This criterion is key for evaluating proposed management procedures using model forecasts or closed-loop projections. The criterion for determining whether a stock has rebuilt to above the LRP is different in Australian guidelines, requiring a "*reasonable level of certainty*" defined by the stock being at or above the LRP with a 75% probability based on the most recent assessment, i.e., in the terminal year of the assessment (DAWR 2018). The probability value was derived from the IPCC (2007) standard of "likely" (a 66 to 90% probability) and the 75% probability is close to the mid-point of the range. Similarly, if a stock is *expected* (implying projected) to decline below $B_{\lim}$ with a probability of 50% or greater, then targeted fishing is ceased (Ryans 2007).

The New Zealand harvest policy standard and guidelines (MF 2008, 2011) provide three default criteria for rebuilding that do not have precise analogs in Canadian law or policy:

1. The need for rebuilding is flagged when there is at least a 50% probability that stock biomass is below the "soft limit" of $0.5B_{\mathrm{MSY}}$ or $0.2B_0$, whichever is higher;
2. The stock is considered rebuilt when there is at least a 70% probability of exceeding the target biomass defined with respect to MSY-values, or their proxies, possibly modified by other considerations. In addition, there should be at least a 90% probability of exceeding the soft limit (P. Mace, pers. comm.); and
3. The rebuilding timeframe is defined as $T_{\min}$ to $2T_{\min}$, where $T_{\min}$ is the theoretical number of years required to rebuild a stock to the target reference point in the absence of fishing.

In the case of a simulation-derived management procedure, the New Zealand policy suggests that management procedures should perform such that:

1. The probability of achieving the MSY-compatible target or better is at least 50%;
2. The probability of breaching the soft limit does not exceed 10%; and
3. The probability of breaching the hard limit (the maximum of $0.25B_{\mathrm{MSY}}$ or $0.1B_0$) does not exceed 2%.

Although the specifics of policy related to reference points, timelines, and risk tolerance expressed as probabilities may differ, DFO could create an analogous scheme adapted from the New Zealand practice to provide more guidance to the Science Sector in the design of management strategies.

The information demands of management by reference points presents challenges to implementation, particularly as data- and model-poverty increase. Estimation of MSY or unfished biomass (B_0) based reference points (or proxies) is often possible for so-called "data-rich" stocks and fisheries, but the reliability of those estimates can degrade rapidly as data poverty increases. Furthermore, a focus on reference point estimation, which requires specific assumptions about dynamic processes such as recruitment, growth, natural mortality, and fishery selectivity, can communicate an overstated impression of the accuracy with which stock status can be assessed. The reality is that any assessment model and assumptions required for the calculation of reference points and stock status are strictly hypotheses about uncertain stock and fishery dynamics; the actual structural dynamics of the stock and fishery cannot be known with certainty. This may be especially true of cases where rebuilding is mandated, typically at low stock biomass, where the usual compensatory assumptions on stock and recruitment may not hold. This situation is exacerbated where there are few data to the point where reference points and therefore stock status cannot be reliably determined (Dowling et al. 2015). Yet, a fishery management decision will be made annually for "data-poor" stocks and fisheries, even if it is the potentially risk-prone decision of status quo.

Our observation is that there are differences in practice when defining stock-specific PA Frameworks due to varying interpretations of the PA Policy and its integration with other policies under the SFF. In the sections below we discuss challenges to PA Policy interpretation and implementation to highlight the need for their resolution before science guidelines are developed. We focus on the Limit Reference Point, the Upper Stock Reference, and the Removal Reference (Figure 4). We also describe the need to separate management tactics such as the harvest control rule from reference points, and reinforce that the performance of the management system depends on the interaction of its component parts. Finally, we comment on two aspects of the PA Policy that have been subject to various interpretations or lack definitions in science advice, namely the *tolerance for preventable decline* and *lowest possible level of removals* when the stock is perceived to lie below the LRP.

3.2. LIMIT REFERENCE POINT

The LRP is the only reference point cited in the new Fish Stocks provisions. If stock biomass is determined to have breached the LRP for a prescribed stock, a legal requirement for a rebuilding plan is invoked under s 6.2(1). In Canada, like many other jurisdictions, LRPs are viewed as thresholds to “serious harm”. For example, the PA Policy states “*…* the LRP represents the stock status below which serious harm is occurring to the stock. At this stock status level, there may also be resultant impacts to the ecosystem, associated species and a long-term loss of fishing opportunities*.*” This statement establishes three considerations related to serious harm (Kronlund et al. 2018):

1. Serious harm applies not only to the stock of interest, but also to dependent species (e.g., predators) and other ecosystem resources (e.g., habitat);
2. An 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); and
3. Long-term loss of benefits to resource users should be avoided.

In another example, the New Zealand harvest strategy (MF 2008) states that "Limits (both 'soft' and 'hard') should be set well above extinction thresholds – rather, they should act as upper bounds on the zone where depensation may occur". Thus, serious harm is intended to represent deleterious states that occur well before those states that could result in stock extinction.

The DFO PA Framework is partially based on the FAO (1995a) definition of the Precautionary Approach that states:

> “19. Management according to the precautionary approach exercises prudent foresight to avoid unacceptable or undesirable situations, taking into account that changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to change in the environment and human values”. Sainsbury (2008) states that LRPs “… are set primarily on biological grounds to protect the stock from serious, slowly reversible or irreversible fishing impacts.”

These statements, and consideration (3) above, suggest that states of serious harm need not be restricted to irreversible states, and include states that are only slowly reversible. Failure to prevent states of serious harm could lead to problems such as prolonged loss of harvest opportunities, inability to meet international or domestic policy obligations, stock collapse, loss of genetic diversity, shrinkage of the species’ spatial range, or collateral effects on dependent species.

Recruitment overfishing as limits

Although avoiding serious harm is cited as the basis for biologically-based LRPs, practical experience shows that it is difficult to uniquely define states of serious harm until they become quite severe, which is precisely the outcome to be avoided (Hilborn and Walters 1992). In Canada and other jurisdictions, recruitment overfishing is generally agreed to constitute serious harm (Myers et al. 1994; Shelton and Rice 2002). Recruitment overfishing is loosely defined as the state when spawning biomass becomes so small that recruitment declines markedly and, on average, recruitment in a given year is insufficient for the population to replace itself. In practice, identifying the stock size where this occurs is challenging due to annual variability in recruitment and insufficiently informative data. Meta-analyses have been employed in some cases to relate overfishing thresholds to life-history traits and other proxies (e.g., Mace and Sissenwine 1993; Myers et al. 1994; Punt 2000). Growth overfishing occurs when yield per recruit declines below some maximum because high fishing mortality during the rapid growth phase results in loss of the fishery yield that would otherwise be accrued through additional growth. Shelton and Rice (2002) concluded that growth overfishing did not constitute serious or irreversible harm.

Non-stationarity considerations

Sainsbury (2008) concluded for target species that the best practice LRP for biomass is the greatest of three quantities (or proxies thereof):

1. B_{LRP}, the biomass below which average recruitment declines or stock dynamics are highly uncertain (i.e., consistent with the concept of recruitment overfishing);
2. The maximum of either $0.3B_{\mathrm{unfished}}$, where B_{unfished} is the expected biomass that the stock would return to in the absence of fishing, or 0.2 of the median long-term unfished biomass; and
3. The biomass from which rebuilding to the target reference point could be achieved in a period that provides for human intergenerational equity (20-30 years).

The unfished biomass, B_{unfished}, (distinct from B_0, the unfished equilibrium biomass) is a dynamic, time-varying estimate provided by model calculations based on the expected stock dynamics in the absence of a fishery. Sainsbury (2008) noted that the equilibrium unfished spawning biomass (B_0) is commonly used as a proxy for B_{unfished} but is vulnerable to violations of equilibrium assumptions (for example if productivity changes). However, the time-varying $0.3B_{\mathrm{unfished}}$ level could occur at very low levels of absolute abundance during periods of low productivity when the consequences of low abundance could be magnified (Perälä and Kuparinen 2015). Thus an LRP such as $0.3B_{\mathrm{unfished}}$ may not be assured to represent a precautionary limit consistent with the PA Policy intent to avoid serious harm. The PA Policy guidance indicates a default LRP of $0.4B_{\mathrm{MSY}}$, which is similar to the proposed criteria for recruitment overfished (0.4-0.5 B_{MSY}) suggested by Froese and Proelss (2012).

Uncertainty needs to be admitted in keeping with PA Policy element PA3 (Table 3). Allowing greater complexity into stock assessment models is unlikely to advance improvements to management outcomes under a single best assessment model approach because biological reference points (BRPs) derived from over-parameterized stock assessment models are already highly uncertain and difficult to defend. For example, non-stationarity in productivity and carrying capacity (Walters 1986) affects both estimation of BRPs and possibly the management procedures put in place to avoid limits and achieve targets (Haltuch et al. 2008). Consequences of non-stationarity to fish population productivity are not well understood, but may result in:

1. Implied changes in BRPs such as B_0 and B_{MSY} that depend on natural mortality, maturity-at-age, growth, or interactions with predatory or competing species;

2. Over- or under-estimation of stock size when time-varying processes are assumed to be stationary in stock assessment models; and
3. Bias in estimates of stock status and fishing rate control points in HCRs that trigger management actions (Haltuch et al. 2008).

However, there is risk of overfishing if changes to reference points are mistimed, e.g., Szuwalski and Punt (2013), which suggests that seeking management actions robust to plausible effects of non-stationarity in reference points may be preferred over attempting to predict future changes in the factors that drive underlying processes (see King et al. 2015). The PA Policy acknowledges the challenges of time-varying productivity but states that:

> "as a general rule the only circumstances when reference points should be estimated using only information from a period of low productivity is when there is no expectation that the conditions consistent with higher productivity will ever recur naturally or be achievable through management."

However, a contrary view suggests that it may be desirable to adjust reference points in accordance with changes in productivity attributed to regime shifts or other factors that are not expected to reverse in the *short or medium term*s (DFO 2013a). Regardless, we recommend any decision to introduce time-varying reference points into rebuilding strategies should be supported by evidence that provides some assurance that desired rebuilding outcomes could reasonably be expected. In particular, evidence should be sought to show time-varying (limit) reference points have low risk of falling to biomass levels where depensatory effects could emerge. Such evidence could be derived *a priori* from feedback simulations that illustrate the consequences of allowing continuous, or punctuated, changes in reference points over time. This evaluation should be coupled with the identification of exceptional circumstances that could cause re-examination of the reference point choices and adopted management measures.

Depensation

Kronlund et al. (2018) commented that although research has focused on recruitment overfishing as an indicator of serious harm, the emergence of Allee, or depensatory, effects can also be considered to represent serious harm. Allee effects occur when the compensatory response of fish populations to low abundance is compromised (positive density dependence). Sustainable fisheries are based on the assumption that the per capita rate of population increase at low abundance will increase as density-dependent constraints on production are removed (negative density dependence, Nicholson 1933). Allee effects arise when the per capita rate of population increase actually *decreases* as abundance declines (e.g., Courchamp et al 1999).

Kronlund et al. (2018) noted that Allee effects have received little attention in the context of LRPs given various meta-analyses that showed little evidence for depensation in fish stock-recruit relationships (e.g., Hilborn et al. 2014; Liermann and Hilborn 1997; Myers et al. 1995). However, recent work on fish populations at low abundance has suggested that Allee effects can arise from both low reproductive success and predation in small populations (Gascoigne and Lipcius 2004; Hutchings 2014, 2015; Hutchings and Rangeley 2011; Keith and Hutchings 2012; Swain and Benoît 2015). In the case of predation, the mortality per predator increases as prey abundance decreases which can produce demographic Allee effects (e.g., due to a type II functional response of predators to prey). These "emergent" Allee effects can also result when mortality due to predation that is sustainable at high prey abundance, becomes unsustainable with declining prey abundance (Hutchings 2014; Hutchings and Rangeley 2011). Strong evidence of predation-driven Allee effects has been provided for many northwest Atlantic groundfish populations, some of which are expected to decline to extirpation under current conditions, even in the absence of fishing (e.g., Swain and Benoît 2015, 2017; Swain and Chouinard 2008; Swain et al. 2016).

Summary of Limits

Regardless of the challenges posed by identifying states of serious harm such as recruitment overfishing or Allee effects, LRPs related to biomass and fishing rates can be categorized in three classes:

1. Model-based LRPs fixed at equilibrium levels (e.g., fractions of B_0, B_{MSY}, F_{MSY}, and yield-per-recruit reference points);
2. Model-based LRPs that dynamically track changes in productivity over time such as those based on B_{unfished}; and
3. Historical LRPs derived from (model-estimated) biomass levels agreed to represent undesirable states (e.g., Hilborn and Stokes 2010, Forrest et al. 2018).

While reference points derived from unfished biomass, MSY and proxies have become the standard in fisheries (Garcia et al. 2018) they are often difficult to estimate. Major uncertainties associated with structural assumptions can mean that multiple alternative models and data weightings are considered in the reconstruction of stock trajectory, which can have large effects on the estimates of theoretical reference points.

For stocks with a historical record, Hilborn and Stokes (2010) argued that it is often known when the stocks were abundant, and for overfished stocks it would be desirable to rebuild to those levels. To avoid some of the difficulties cited above, they proposed replacing quantities derived from theoretical reference points with quantities derived from historical stock states for management decision-making. Their proposal appeared to focus on operational control points based on historical stock size (derived from models), but there is no reason why such considerations could not also be applied to reference points used in management objectives (see Forrest et al. 2018 for example applications to Pacific groundfishes). Two advantages were cited. First, estimates of historical stock sizes tend to scale in absolute value with model assumptions, but the temporal order of fluctuations tends to be maintained such that the low and high abundance years remain the same regardless of assumptions. These low and high biomass estimates may be more easily understood by fishery managers and resource users who could relate to their experience but not abstract constructs like MSY or B_0-based reference points. Second, limits and targets based on (relative) historical stock levels could preserve the intent of most fisheries policies to avoid overfished states, and to prevent lost yield by overfishing (Hilborn and Stokes 2010).

3.3. UPPER STOCK REFERENCE

The term Upper Stock Reference (USR) appears in DFO (2006):

> “The Upper stock reference point is the stock level threshold below which the removal rate is reduced. As such it applies to exploited populations. This reference point is determined by productivity objectives for the fishery. These objectives will vary among species and fisheries and include biological, social and economic factors.”

By 2009, two roles are assigned the USR in the PA Policy as follows:

> “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. Secondly, 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. A TRP is a required element under UNFA and in the FAO guidance on the application of the PA, as well as eco-certification standards based on it, such as those of the Marine Stewardship Council and may also be desirable in other situations."
>
> "In practice, the threshold point below which removals must be reduced to avoid serious harm (USR) can be different than the TRP. However, 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. In either case, the USR would be developed by fishery managers informed by consultations with the fishery and other interests, with advice and input from Science."

There are potentially three difficulties created by this description:

1. The two roles assigned to the USR cannot be achieved simultaneously, in general. The USR is first assigned a "*minimum function*" role as an operational control point (OCP) that is adjusted to preserve a specified risk tolerance for an LRP breach. Second, it is to serve a target reference point role that reflects biological, economic and socio-cultural goals. The reason both roles cannot be achieved simultaneously is that adjusting the USR as a control point changes any objective that embeds the USR as a target reference point. Furthermore, the role of the USR as an OCP is properly defined as a component of a harvest control rule, not a component of stock and fishery objectives that relate to reference points (i.e., avoid limits and achieve targets);
2. The PA Policy suggests there *must* be a TRP ("a required element under UNFA and in FAO guidance on the PA") and suggests that the USR can be the same or different than the TRP. If the latter, then different risk tolerances and possibly time periods are implied for achieving the USR and TRP when both are treated as reference points. Targets are typically selected such that the probability of being greater than the target should be 50%, on average; and
3. The USR is to be developed by fisheries managers, with input from Science (DFO 2009). This sets up conflict between the need to avoid an LRP breach and the need to provide outcomes related to economic and socio-cultural goals. Such conflict is expected between objectives that embed an LRP and TRP, respectively, but the USR could be operationally redundant if similar goals are applied to both the USR and TRP.

Canadian technical guidelines (DFO 2016a) recognized the dual duties ascribed to the USR and indicated a preference for viewing the USR as an operational control point in keeping with its primary role. A solution to the conflict is to define a target reference point and distinguish reference points from harvest control rules that contain OCPs (Cox et al. 2008; Cox et al. 2013) (see Section 3.5). Specifically, OCPs in HCRs should be selected to provide acceptable trade-offs of stock preservation, economic and socio-cultural outcomes, without being fettered by a requirement to be set to the same values as the reference points used in objectives. The USR could be assigned a role similar to the New Zealand *soft limit* (MF 2008).

It is unclear, however, how this solution affects the role of the USR as a threshold for delineating the PA Policy Cautious and Healthy zones, which along with the Critical Zone, were originally proposed as management (not biologically-based) zone labels (DFO 2004). The upper control point of a harvest control rule cannot be used to delineate the zones, since rules with a very low fishing mortality could allow the upper OCP to be set be very close to the LRP and still meet the risk tolerance for avoiding a breach, i.e., the Cautious zone would be extremely narrow. Conversely, a high target fishing mortality rate may require the upper control point to be set near or above target levels to avoid biomass levels less than the LRP, i.e., the Cautious zone extends above target levels. Furthermore, harvest control rules may vary widely in form and some may lack an upper control point, yet still be able to provide acceptable risk tolerances for breaching limits, and achieving desired states.

The evolution of the USR in Canadian policy and applications may be traced back to the development of Precautionary Approach fisheries policies occurring internationally in the mid- to late-1990s. Parallel concepts are found in, for example, technical guidelines for the implementation of the National Standards Guidelines 1 (NSG1, Restrepo et al. 1998) to support the *Magnuson-Stevens Act* in the USA. Restrepo et al. (1998) advocated that both the overfished (biomass scale) and overfishing (fishing mortality scale) dimensions should be considered in precautionary management strategies and proposed a segmented control rule (Figure 5), or “MSY-control rule” to support legal intent. The NSG1 suggested that a limit reference biomass (minimum stock size threshold, MSST) should be selected as the largest of $0.5B_{\mathrm{MSY}}$, or the lowest biomass from which that target reference point, B_{MSY}, will be reached in 10 years if fishing at the maximum fishing mortality threshold (MFMT). The default control rule uses MSY-based reference points or proxies, in alignment with the enshrinement of MSY in the Magnuson-Stevens Act. The rule is of the form:

$$
\begin{aligned}
F(B) &= \frac{F_{MSY}B}{cB_{MSY}} \qquad for\ B \le cB_{MSY} \\
F(B) &= F_{MSY} \qquad for\ B \ge cB_{MSY}
\end{aligned},
$$

where $c = \max\left(1-M, 0.5\right)$ and M is the natural mortality rate. Thus, the MSST for species with $M \geq 0.5$ would be $0.5B_{\mathrm{MSY}}$ and for a species with M=0.2, MSST=$0.8B_{\mathrm{MSY}}$. Restrepo and Powers (1999) commented that the intent of the rule is “to fix a maximum F equal to F_{MSY} when the stock is ‘healthy’ and to reduce this maximum in proportion to B when it is not.” However, the fishing mortality rate is allowed to remain at F_{MSY} when the stock is below B_{MSY} in proportion to M, under the assumption that a stock fished at F_{MSY} would be expected to fluctuate around B_{MSY} in proportion to M. They argued that intervention by adjusting the harvest rate would be unnecessary within the range of fluctuations and by implication would improve catch stability. The rationale provided was to avoid false declarations of an overfished state due to annual oscillations in abundance. However, using this approach as the technical basis for the USR conflates the role of the control rule as a tactical measure for achieving B_{MSY}, as intended by Restrepo and Powers (1999), with reference points related to determining overfishing and overfished states. It is unknown whether the reference to stock ‘health’ in Restrepo and Powers (1999) is related to the genesis of the “Healthy Zone” label in the PA Policy.

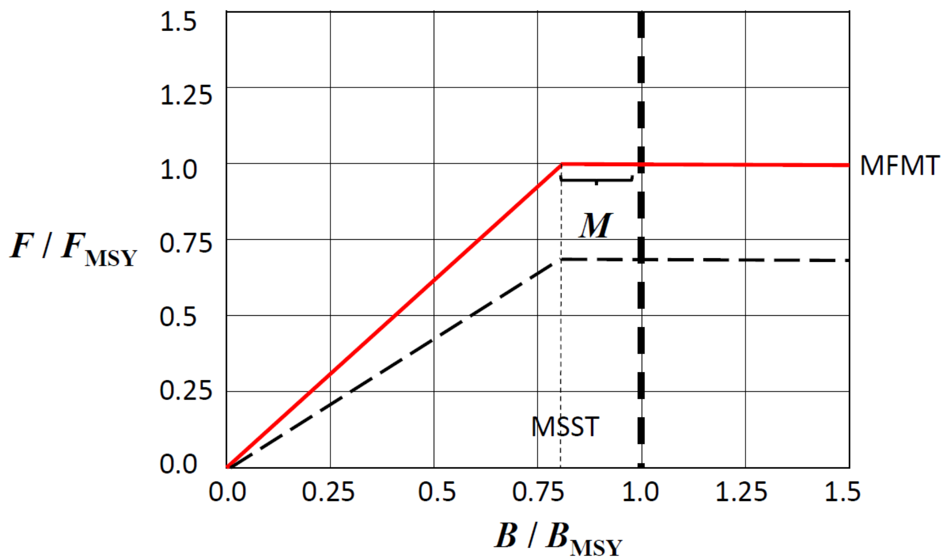

Figure 5. The MSY-control rule of Restrepo et al. (1998). The MSST is the minimum stock size threshold and MFMT is the maximum fishing mortality threshold. Limits to the fishing mortality rate are indicated by the red solid line. The target mortality rate (optimum yield control rule, dashed line) is 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).

3.4. REMOVAL REFERENCE

The United Nations Fish Stocks Agreement (UNFSA, UN 1995), to which Canada is signatory, states "For stocks which are not overfished, fishery management strategies shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield" (Annex II UNFSA 1995). The Removal Reference (Figure 4) is defined by the PA Policy as "the maximum acceptable removal rate for the stock…". The PA Policy goes on to state that "To comply with the UNF[S]A, the Removal reference must be less than or equal to the removal rate associated with maximum sustainable yield." Thus, the Removal Reference is a limit fishing rate, rather than a target, that must not exceed F_{MSY} or suitable proxy (Kronlund et al. 2014; Shelton and Sinclair 2008). However, this single-species perspective is problematic for multi-species fisheries where some stocks may have to be subject to overfishing ($F>F_{MSY}$) to allow access to other stocks at target harvest rates.

Under equilibrium conditions, fishing at F_{MSY} would produce the biomass at maximum sustainable yield (B_{MSY}) which implies B_{MSY} is also a limit biomass level. However, B_{MSY} is commonly regarded as a target level (e.g., United Nations 2002). In fact, the fishing mortality rate that would produce maximum sustainable yield, F_{MSY}, is, by definition, a valid limit reference point for *growth* overfishing (Mace 2001). Generally, the fishing mortality threshold for recruitment overfishing is understood to be around double the growth overfishing threshold (Goodyear 1993; Mace 1994; 2001; Restrepo et al. 1998; but see Cook et al. 1997; NAFO 2003; Punt 2000 for studies showing that fishing mortality thresholds for growth and recruitment overfishing may be closer together for less productive species). One recommendation from Gulland (1971) is that fish stocks should be managed to avoid growth overfishing, as this should also prevent recruitment overfishing.

Regardless, the best practice limit reference point for fishing mortality recommended by Sainsbury (2008) is F_{MSY}, the long-term fishing mortality that produces maximum sustainable yield. A suggested acceptable proxy is $F_{50\%}$, the fishing mortality that gives a 50% reduction in the spawning biomass per recruit (SBR) on the basis that for most species, $F_{50\%}$ would provide more than 80% of MSY while depleting spawning biomass to no more than about 30% of the unfished level (Sainsbury 2008).

The diagram representing the PA Policy elements (Figure 4) shows the RR being reduced as status declines to the LRP. However, the basis for determining a decline, linear or otherwise, in the limit fishing rate as the LRP is approached is not clear, unlike the basis for a single limit fishing rate derived from F_{MSY} or proxy. In fact, it is not clear that it is even necessary to do so since a management procedure that includes an HCR should be designed so there is a reasonable expectation of achieving the policy intent: avoid an LRP breach and achieve the desired target reference point, on average. In fact, an HCR with a precautionary ramp (Figure 6) achieves the effect of reducing the limit fishing rate from max(RR).

3.5. DISTINGUISHING REFERENCE POINTS AND CONTROL POINTS

The purpose of reference points is to separate the objectives in which they appear from the tactics (such as an HCR) applied to achieve the objectives (Cox et al. 2013; Restrepo et al. 1998). The PA Policy describes a provisional harvest control rule based on the default LRP, USR and RR:

$$
\begin{aligned}
&F_p < F_{\mathrm{MSY}}, && B > 0.8B_{\mathrm{MSY}};\\
&F_p < F_{\mathrm{MSY}}\frac{\left(B-0.5B_{\mathrm{MSY}}\right)}{\left(0.8B_{\mathrm{MSY}}-0.4B_{\mathrm{MSY}}\right)}, && 0.4B_{\mathrm{MSY}} \le B \le 0.8B_{\mathrm{MSY}};\\
&F_p = 0, && B < 0.4B_{\mathrm{MSY}}.
\end{aligned}
$$

However, there is no guarantee that setting the operational control points in an HCR to the reference points (LRP, USR) and fishing mortality to a limiting rate (RR) will provide acceptable outcomes, or even achieve the policy intent of avoiding LRP and RR breaches with a specified certainty. Uncertain stock and fishery dynamics mean that adjustments to the HCR are needed to meet risk-based objectives related to limit and target states. For example, setting the target harvest rate at the RR is likely to result in realized fishing mortality rates that unacceptably exceed the fishing mortality limit in uncertain systems, i.e., overfishing. Setting the target fishing mortality rate lower than F_{MSY} is likely to be necessary. It may also be necessary to reduce to removal rate to the lowest level possible *before* reaching the LRP to avoid a breach due to uncertainty in the estimates of both the LRP and stock status (Figure 6). The exact design of the HCR will depend on the interaction of the assessment method, OCPs and target fishing mortality with respect to providing an acceptable tradeoff of management outcomes.

The RR and provisional HCR have in some cases been conflated due to the coincidence of the reference points and operational control points (Figure 6). A segmented control rule with a “precautionary” ramp implies there is some declining fishing mortality limit that is not exceeded, on average. The segmented nature of the provisional HCR is analogous to Restrepo et al. (1998), who established the “MSY-control rule” as a typical limit, or MFMT (maximum fishing mortality threshold), and a separate target “OY [optimum yield] control rule” with which to set harvest levels (Figure 5). The separate OY control rule is in recognition of the need for catch targets that are below limits, since setting catches at limits (MSY in the *Magnuson-Stevens Act*) could create a high probability of persistently exceeding the limit. Thus, Restrepo et al. (1998) argued for setting fishing mortality targets below limits (e.g., $F_{\mathrm{target}} < F_{\mathrm{MSY}}$) to accommodate uncertainty and other management objectives.

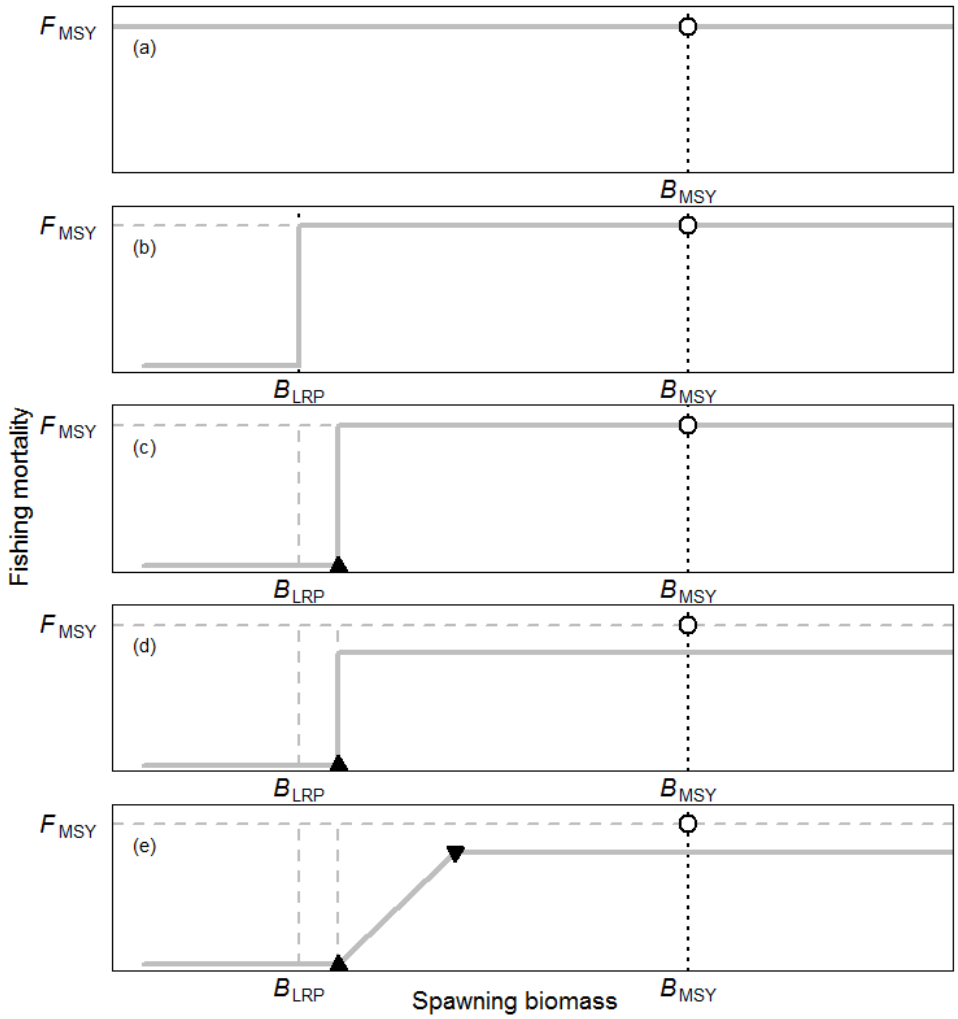

Figure 6. Distinguishing BRPs and operational control points (OCPs) in the design of a DFO PA Framework harvest control rule (HCR). International and domestic fisheries policy state that F_{MSY} is a limit fishing mortality rate and a biomass level of at least B_{MSY} is desirable. Fishing at F_{MSY} produces B_{MSY} under deterministic equilibrium conditions (thick grey line, panel a). Uncertain stock and fishery dynamics mean that adjustments to the HCR are needed to encourage desirable states and avoid deleterious states (panels b-e). A biomass-based limit at B_{LRP} is positioned above level where serious harm is a possibility and fishing mortality is set to 0 below this level (panel b). An OCP (black triangle) indicates where fishing is curtailed in order to avoid reaching B_{LRP} with high probability (panel c). A high probability of avoiding fishing mortalities exceeding F_{MSY} is ensured by specifying a target fishing mortality lower than F_{MSY} (panel d). Finally, fishing mortality is reduced below a second biomass-based OCP (inverted black triangle) to increase the likelihood of avoiding a fishery closure as B_{LRP} is approached (panel e). Note that the reference points B_{LRP} and F_{MSY} are unaffected by changes to the OCPs in the HCR and therefore management objectives do not change (modified from Cox et al. 2013).

3.6. INTERACTION OF DATA, ASSESSMENT METHOD AND HCR

The harvest control rule (HCR) is a component of a management procedure, i.e., a fully-specified set of data, analyses and management measures used to determine a catch or effort limit. Typically the HCR uses the outputs of a stock assessment to translate an estimate of current status (relative biomass or numbers) into a target harvest rate and subsequently a catch limit. Canada has suggested including a “precautionary” ramp in the PA Policy provisional HCR that progressively decreases the intended harvest rate as perceived stock status declines, ultimately setting the rate to the lowest level possible. The purpose of the ramped reduction of the removal rate is to avoid closing the fishery and to encourage stock growth (Figure 6).

However, the effectiveness of a given HCR cannot be determined in isolation of the other components of the management procedure applied to the fisheries system (de la Mare 1998). This is because the components of a management procedure interact in ways that cannot be predicted in advance due to assessment errors and lags in system dynamics; performance must be examined within a reasonable facsimile of the system where the procedure is intended for application, i.e., a simulation. A fundamental challenge is determining what choice of HCR design, coupled with an assessment method, produces acceptable trade-offs among management outcomes. Nevertheless, a common misconception is that simply applying a “precautionary” HCR will produce an acceptable set of outcomes relevant to sustainability objectives; typically “tuning” of the entire management procedure inclusive of the HCR will be required to meet the desired management outcomes, on average.

A general examination of the PA Policy default reference points and provisional HCR was conducted by Shelton (2017). Depleted fish stocks with three different life history types and various combinations of recruitment and measurement errors were simulated. Reference points were assumed known exactly and the magnitude of errors was characterized as “moderate”. The procedure included the provisional HCR with operational control points set to the known LRP and USR values, in accordance with the PA Policy. There was no assessment model fit to simulated data; true spawning biomass with multiplicative lognormal errors added was input to the HCR. Simulation outcomes showed that:

1. Fish stocks below the LRP should rebuild to above the USR with a probability of at least 78% regardless of life history;
2. Time to rebuild above the USR was up to twice as long compared to scenarios with zero fishing;
3. The simulated procedure was not effective in ensuring a low probability (there interpreted as <10%) of the population returning to levels below the USR;
4. The simulated procedure was not able to maintain fishing mortality below F_{MSY} when below the USR; and
5. Variability in annual catch increased with increasing process and observation errors to a maximum CV=0.6.

The simulation study was by the author’s admission optimistic, most critically missing the effects of assessment errors and lags which would be likely to degrade performance. The PA Policy suggests there should be a high probability (75-95%) of avoiding an LRP breach; assessment errors could easily change result (1) such that the PA Policy “high probability” criterion could not be achieved. Forrest et al. (2018) conducted stock-specific simulation analyses which included the default MSY reference points for two Pacific groundfish species. Overestimation of spawning biomass was present in all management procedures under all operating model scenarios which led to overharvesting, particularly for those procedures where OCPs were based on Spawning Potential Ratio (SPR) or MSY. For Pacific Cod (*Gadus microcephalus*), neither the MSY nor SPR-based MPs were successful in maintaining median biomass above “true” target B_{MSY} value determined by the operating model. This result emphasized the risk of untested application of procedures that incorporate theoretical reference points and use them as OCPs in the HCR. Bias in estimates of such OCPs coupled with positive assessment bias could lead to overharvesting. Similar difficulties have been encountered when testing “general” management procedures, particularly as data-poverty increases (e.g., Dowling et al. 2018).

Forrest et al. (2018) found management procedures based on historical reference points exhibited good conservation performance, catch performance was lower, particularly in the short-term. This suggests that tuning of management procedures may be inevitable to achieve an acceptable level of desired conservation, socio-economic and cultural outcomes.

3.7. NO TOLERANCE FOR PREVENTABLE DECLINE

The PA Policy refers to imperatives, i.e., *must*, when a stock is in the critical zone:

> "In the critical zone, management actions **must** promote stock growth and removals from all sources **must** be kept to the lowest possible level until the stock has cleared this zone. There **should** be **no tolerance for preventable decline**." [**emphasis** added, note mixed usage of *must* and *should*].

The requirement in policy is to adopt management measures that promote stock growth and reduce removals to the lowest possible level while the stock is perceived to be below a status-based limit reference point. The verb *should* in reference to *preventable decline* is interpreted here as being expected or recommended, and admits possibility. Points of interpretation here relate to rationalizing the use of *must* with respect to management actions to promote growth and *should* in relation to tolerance for preventable decline, as well as determining what is considered the lowest possible level of removals.

In the case of *preventable decline* we interpret preventable causes to mean those induced by human activities (e.g., fishing or habitat disturbance) or those causes that can be mitigated by humans (e.g., natural habitat erosion that can be mitigated). *No tolerance* literally means zero probability of human-induced (preventable) activities that contribute to decline, although as noted this tolerance is associated with *should*, admitting possibility. Note that a fish stock at any level of abundance could decline in the absence of human activities due to natural fluctuations, i.e., decline is not preventable by management actions but could be exacerbated by them. Therefore, case specific examination of future stock dynamics under scenarios with zero removals provide benchmarks and a guide to reasonable expectations for the performance of management options that specify catch sequences under a rebuilding mandate.

The policy guidance in Table 1 of the PA Policy states:

> "Management actions **must** promote stock growth. Removals from all sources **must** be kept to the lowest possible level until the stock has cleared the Critical Zone. A rebuilding plan **must** be in place with the aim of having a high probability of the stock growing out of the Critical zone within a reasonable time." [**emphasis** added]

The *reasonable time* to achieve a level above an LRP is indicated in policy to be 1.5 to 2 fish generations, with allowance for variance in life history (e.g., for long-lived species which may require more time). Note that the text does not state 1.5 to 2 generations to achieve a rebuilt target above the LRP, but only implies stock increase to above the LRP (e.g., possibly a 50% chance or greater of biomass greater than the LRP). This is a significantly different goal than say the NSG1 standards in the US, where the rebuilt target is taken to be B_{MSY} (or proxy) to be achieved in 10 years, or 10 years plus one generation if the time to the rebuilt target in the absence of fishing is more than 10 years (NOAA 2018).

High probability is defined in Annex Table B (noted as a draft table) of the PA Policy as 75-95%. This range allows a 3-in-4 chance of achieving at least the LRP within the specified time, up to a 19-in-20 chance. In other words, there is a 1-in-4 chance of remaining below the LRP within the specified time period to a 1-in-20 chance, a five-fold difference. The range in risk tolerance for remaining below the LRP correspondingly admits a large range of trade-offs between meeting rebuilding outcomes and yield for proposed catch sequences, but the policy does not provide guidance for a specific risk tolerance.

The phrase *removals from all sources* also requires some consideration in light of the variable quality of catch estimates. Some catches may be well-monitored with high confidence in the estimates, while other removals may be poorly known (e.g., fish released at sea), or out of domestic management control, e.g., the case of trans-boundary stocks. Where catches are poorly known there should be explicit accounting for plausible direction and magnitude of bias in catch estimates, which can be accomplished via assessment model sensitivity cases or different scenarios for simulation experiments.

Four jurisdictions in our review discuss non-target catches in guidance and policies for rebuilding (Table 7). All four noted the importance of accounting for all removals from a stock, including bycatch in other fisheries, in developing rebuilding plans. The policy implications, however, appear to differ. Three jurisdictions (Canada, New Zealand and the United States) noted that flexibility in rebuilding objectives may be needed to accommodate the needs of multi-stock fisheries where catches of the rebuilding stock may be considered unavoidable. Note that we use the term multi-stock to mean different species or different stocks of the same species. In particular, American guidelines indicate acceptable risks of breaching limits for selected stocks in multi-species fisheries, which may be subject to overfishing, may be as high as a 1-in-2 chance. However, it is unclear how this risk tolerance might translate into provisions of rebuilding plans for such stocks. In contrast, Australian policy and guidelines indicate that target reference points for individual stocks in a multi-stock fishery may vary in order to achieve *fishery-level* biomass at maximum economic yield, B_{MEY}. However, all Australian stocks are subject to an acceptable risk of breaching limits of 10% (a 1-in-10 year chance) and so stock-specific TACs may need to be reduced regardless of whether they occur in a multi-stock fishery.

An example of an operational objective for decline tolerance and matching performance statistic is illustrated by Sablefish (*Anoplopoma fimbria*) on the west coast of Canada (Cox and Kronlund 2009, Cox et al. 2011, DFO 2020a). The objective specifies that when female spawning stock biomass is between $0.4B_{\mathrm{MSY}}$ and $0.8B_{\mathrm{MSY}}$, limit the probability of decline over the next 10 years from very low (5%) at $0.4B_{\mathrm{MSY}}$ to moderate (50%) at $0.8B_{\mathrm{MSY}}$. At intermediate stock status levels, define the tolerance for decline by linearly interpolating between these probabilities. Thus, feasible management procedures must meet this priority constraint to be considered against subsequent objectives. The approach could be extended when stock levels are below an LRP and the tolerance for decline configured appropriate to the context.

This suggests default science advice for rebuilding should include, where possible:

1. A zero fishing mortality management procedure for each hypothesis under consideration to estimate T_{min} and to serve as a benchmark for comparison with alternative procedures that specify a catch sequence under rebuilding;
2. Related to (1), an evaluation of the probability of biomass increase to the LRP and TRP (default to B_{MSY} or proxy), respectively, at T_{rebuild} (or specified milestones) under a zero fishing mortality procedure;
3. A decline tolerance objective and performance statistic where possible, given specified risk tolerance and time period for evaluation;
4. A “perfect information” scenario that assumes both stock size estimation and management implementation is without error over the rebuilding time frame to serve as a benchmark;
5. Explicit accounting for catch estimate quality (e.g., plausible direction and magnitude of catch estimation bias).

Table 7. An overview of cross-jurisdictional standards, policies and guidelines relating to determining targeted and non-targeted removals.

Country	Policy or Guidelines
Canada	A key requirement of the PA Policy is that total removals from all fisheries should be taken into account.[1] All IUU (illegal, unreported and unregulated) catches should be eliminated or minimized, where possible.[2] Rebuilding of stocks in a mixed-stock or multi-species fishery may limit harvesting opportunities on healthy stocks. An "adaptive and ecosystem-based" approach may help to "balance objectives for rebuilding depleted stocks with the maintenance of fishing opportunities directed at healthy stocks."[2]
Australia	"Incidental mortality on overfished stocks should be constrained as much as possible…" to allow rebuilding in the specified timeframe.[3] This may include reducing TACs for other stocks.[4] Uncontrollable sources of mortality (e.g., other jurisdictions) should be taken into account.[3]
New Zealand	Unavoidable bycatch is one factor that may go into establishing rebuilding timeframes.[8]
United States	The term ***overfishing*** is defined as "…whenever a stock or stock complex is subjected to a level of fishing mortality or total catch that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis…"[9] and **catch** as "…the total quantity of fish… taken in commercial, recreational, subsistence, tribal, and other fisheries…"[9] indicating that all coincident removals need to be considered. In mixed-stock fisheries, overfishing may be permitted on certain stocks, so long as the risk of the stocks being below the MSST is not more than 50%.[9]

[1]DFO (2009) policy, [2]DFO (2013a) guidelines, [3]DAWR (2018a) policy, [4]DAWR (2018b) guidelines, [5]ICES (2018) advice basis, [6]NAFO (2004), [7]MF (2008) policy, [8]MF (2011) guidelines, [9]NOAA (2018), [10]Restrepo et al (1998).

3.8. THE LOWEST POSSIBLE LEVEL OF REMOVALS

The PA Policy refers to additional imperatives related to the level of removals when a stock is below an LRP:

> "… management actions **must** promote stock growth and removals by all human sources **must** be kept to **the lowest possible level**."
>
> "Flexibility in management measures is limited in the critical zone given that when the stock has reached this zone, priority **must** be to keep all sources of mortality at **the lowest possible level** to get the stock out of the critical zone within a reasonable timeframe, according to the rebuilding plan."
>
> "In the critical zone, management actions **must** promote stock growth and removals from all sources must be kept to **the lowest possible level** until the stock has cleared this zone. There **should** be no tolerance for preventable decline." [note mixed usage of *must* and *should*].

A literal interpretation of "the lowest possible level" that can be attributed to fisheries is zero removals. However, the policy direction is open ended on this matter as there are no criteria provided to determine the what constitutes the lowest possible level. Science has no role in this determination until the question is rendered scientifically usable, i.e., by qualifying the lowest possible level relative to a measurable objective. For example, the USA mandates rebuilding to levels consistent with the production of MSY in a period of time "as short as possible" as exists under the *Magnuson-Stevens Act*. This mandate is operationalized using a maximum time-constraint: if the population can be rebuilt within 10 years ($T_{min} \leq 10$) then the maximum time, T_{max}, is 10 years. If it is determined the stock cannot be rebuilt within 10 years then one of three amendments is available:

- T_{max} is 10 years plus one fish generation;
- T_{max} is the amount of time the stock is expected to take to rebuild to B_{MSY} if fished at 75 percent of its Maximum Fishing Mortality Threshold (MFMT), the level of fishing mortality on an annual basis, above which overfishing is occurring; or
- T_{max} is T_{min} multiplied by two.

Under a constraint imposed by specifying T_{max}, any sequence of catches expected to compromise rebuilding outcomes by exceeding the time specified would not be deemed consistent with guidelines for implementing the *MSA*.

Science could legitimately be asked to estimate the level of removals from all sources that could be accommodated and still attain rebuilding outcomes, if the desired certainty and time period for achieving the outcomes are specified. Addressing this request would additionally require specifying the catch sequence. The sequence of catches might be specified directly, or via a management procedure that generates a sequence of catches based on accruing stock and fishery monitoring data. In the latter case, decision-makers may in fact consider a range of candidate management procedures that “met” any imperative rebuilding objectives in simulations, but vary in the trade-offs of management outcomes after having met those objectives. In fact, it is more correct to state that candidate management procedures are those that could not be rejected due to a failure to meet the imperative rebuilding objectives.

Desired rebuilding outcomes may include both attaining specified target state, as well as growing the stock above the LRP. Objectives associated with achieving the former may differ in time frame and level of certainty. For example, there may be a very high probability associated with achieving biomass levels greater than the LRP. This is because time spent lingering at biomass levels near or below limiting thresholds increases the likelihood that serious, and possibly irreversible, harm might occur or worsen due to assessment errors and ignorance about stock dynamics at low biomass. Experience with rebuilding plans in the United States is that early reduction of fishing mortality is consistent with successful rebuilding outcomes; deferring reductions in fishing mortality lowers the success rate (NRC 2014).

Any choice of a catch sequence invokes a trade-off between stock growth potential and yield regardless of stock status. A general approach to responding to calls for rebuilding is to examine the trade-offs incurred by alternative management actions. As noted above, policy considerations mean the trade-off space for decision-makers is severely reduced as biological limits are approached and breached. Regardless, any evaluation of a management strategy inclusive of considerations related to rebuilding performance, should incorporate the following cases as benchmarks, whenever possible:

1. A zero fishing mortality management procedure for each hypothesis under consideration to estimate T_{min} and to serve as benchmarks for comparison with alternative catch sequences;
2. A “perfect information” scenario that assumes both stock size estimation and management implementation is without error over the rebuilding time frame; and
3. Explicit accounting for catch estimate quality (e.g., plausible direction and magnitude of catch estimation bias).

3.9. 2013 REBUILDING POLICY GUIDANCE

In 2013, DFO produced *Guidance for Developing Rebuilding Plans Under the Precautionary Approach* (DFO 2013a). This document was developed as an extension of the *Fishery Decision-making Framework Incorporating the Precautionary Approach* (DFO 2009), both subsidiary components of the Sustainable Fisheries Framework. The DFO (2013a) rebuilding policy guidance is currently under policy review in light of the revised *Fisheries Act*.

The 2013 rebuilding guidance document is oriented at policy elements, and thus does not provide detailed technical guidance to inform rebuilding plans. However, the following statements from DFO (2013a) could help to align rebuilding plans with the requirements of proposed regulations to support the Fish Stocks provisions:

- When a stock has reached the Critical Zone, a rebuilding plan must be in place with the aim of having a high probability of the stock growing out of the Critical Zone (above the LRP) within a reasonable timeframe;
- The goal of any rebuilding process is to grow stocks up through the Cautious Zone and ultimately into the Healthy Zone (where possible), as defined by the PA Framework [meaning a stock-specific application of the PA Policy];
- Rebuilding plans should define SMART (Specific, Measurable, Attainable, Relevant and Timely) objectives and take into account the overall feasibility of rebuilding;
- Overall rebuilding success should be defined in a broader ecological context and entail restoring a stock to its “normal” or “near normal” life history characteristics (e.g., restoring age structure, size and age-at-maturity, genetic diversity, behavioural traits, distribution) and ecological function (e.g. restoring predator/prey relationships), to the extent possible;
- Factors such as predator-prey relationships and competition within and between species should be considered in developing rebuilding objectives for any particular stock;
- Ideally, a reasonable timeframe [for rebuilding out of the Critical Zone] would normally represent the time for a cohort to recruit to the spawning biomass and then contribute to rebuilding the productive capacity of the stock. This period will vary among species. For many species it will correspond to a period of 1.5 – 2 generations, although it may be longer;
- The specific life history characteristics of the stock in question should be considered in developing a rebuilding strategy, as not all species should be expected to respond in the same manner to specific management measures;
- The influence of environmental conditions on rebuilding success should be considered and incorporated into efforts to rebuild depleted stocks. Rebuilding efforts should be approached within an ecosystem context to the extent possible;
- The feasibility of rebuilding a stock to its historical condition should be considered in developing overall objectives for the stock in question;
- Uncertainty and risks associated with science advice and management actions should be clearly communicated to fishery interests;
- Harvest decision rules should not allow for increases in allowable removals based upon short-term trends in stock growth;
- Clear performance criteria should be outlined in the rebuilding plan, and explicitly linked to the objectives and associated milestones, as well as management measures. Reviews should be completed on a regular basis (e.g., maximum 3 year intervals), with timelines determined by the management team based on the specifics of the stock in question; and

- Reviews should be conducted at regular enough intervals such that the rebuilding plan can be adapted when performance does not meet expectations (e.g., more rapid rebuilding than predicted, or conversely a lack of stock response to rebuilding measures, or continued stock decline).

3.10. REVIEW OF EXISTING REBUILDING PLANS

Key Points:

- We reviewed eight existing rebuilding plans for Canadian fisheries in the context of both existing policy and guidelines for rebuilding and elements of anticipated regulations to support the Fish Stocks provisions.
- Criteria for determining that the LRP has been breached will become increasingly important, and should be well-documented in a consistent manner.
- Measurable objectives with an associated timeline and probability will be required to provide science advice to identify rebuilding strategies that have a reasonable prospect of success, or to evaluate progress over the period of application of a rebuilding plan.
- Rebuilding plans sometimes included measurable objectives and one plan contained a method for tracking progress relative to final rebuilding outcomes or interim milestones.
- A measurable rebuilt state or target could be required under proposed rebuilding regulations. Existing rebuilding plans lack a specific, measurable rebuilt state or target.
- In cases where it is difficult to accurately predict rebuilding time due to low productivity and high natural mortality, it remains important to specify a rebuilding time to avoid inertia in taking feasible actions intended to prevent further deterioration of stock status and promote growth should conditions change.
- Existing plans generally did not include a specified time interval or mechanism for reviewing or updating rebuilding plans, as would be required under regulations.
- The variation in rebuilding plan alignment with future proposed rebuilding regulations could be addressed through the use of guidelines and other tools aimed at increased standardization of rebuilding strategy and plan development.

We reviewed eight rebuilding plans for Canadian fisheries with respect to PA Policy requirements, the DFO (2013a) rebuilding plan guidelines and elements of proposed regulations (described in Section 2.3) to support the Fish Stocks provisions. The review results are described in detail in Appendix B. The following rebuilding plans were reviewed:

- Bocaccio (*Sebastes paucispinis*): Rebuilding plan in DFO (2019b), first full stock assessment using population modelling in 2008 (Stanley et al. 2009);
- Yelloweye Rockfish (*Sebastes ruberrimus*) – Inside: Rebuilding plan in DFO (2019b), first assessed as a single stock in 2011 (Yamanaka et al. 2012);
- Yelloweye Rockfish (*Sebastes ruberrimus*) – Outside: Rebuilding plan in DFO (2019b), first assessed as a single stock in 2015 (Yamanaka et al. 2018);
- Atlantic Cod (*Gadus morhua*) 4X5Y: Rebuilding plan in DFO (2017a);
- Northern Gulf Cod (*Gadus morhua*) 3Pn 4RS: Rebuilding plan in DFO (2013b); the LRP of 200,000 t was adopted at a workshop in 2002, and at this time the biomass was estimated

to be below that level, the LRP was updated in 2011. The rebuilding plan was developed in 2013.

- Atlantic Cod (*Gadus morhua*) 5Z: Rebuilding plan in DFO (2018b); the LRP of 21,000 t was adopted in 2010, and at this time the biomass was estimated to be 9,260 t. The rebuilding plan was developed in 2018 using information from the 2018 Transboundary Resource Assessment Committee (TRAC) assessment (Andrushchenko et al. 2018).
- Yellowtail Flounder (*Limanda ferruginea*) 5Z: Rebuilding plan in DFO (2018c), the last reference point estimated for this stock was B_{MSY} = 43,200 t, and at this time biomass was estimated to be 869 t (TRAC 2018). The rebuilding plan was developed in 2018 using information from the 2018 TRAC assessment (Legault and McCurdy 2018); and
- Northern Shrimp (*Pandalus borealis*) SFA 6: Rebuilding plan in DFO (2018a), the 2016 stock assessment report noted that the female spawning stock biomass (SSB) index was close to the LRP (DFO 2016c). The 2017 stock assessment estimated the female SSB index to be below the LRP with greater than 99% probability (DFO 2017b).

The goal of this review was to examine the current status of rebuilding plans produced by DFO for consistency of approach, and to identify gaps between current practice and new legal obligations under the amended *Fisheries Act* and possible supporting regulations.

A common feature of several existing rebuilding plans was a statement of a low likelihood of stock rebuilding in the near future, even in the absence of fishing pressure. This view was variously attributed to poor environmental conditions, poor stock status and/or episodic recruitment. In the case of Yellowtail Flounder 5Z, a transboundary stock co-managed with the US, it was stated that any further actions taken by Canada are unlikely to greatly impact the rebuilding of this stock as a result of extra-jurisdictional fishing mortality, i.e., management controllability is potentially weakened. This affects the provision of science advice, because it adds a requirement to evaluate the effects of implementation errors in ranking the relative performance of management options. Similar challenges will be faced for rebuilding plan development for domestic stocks where catches from one or more sources are poorly known.

Many rebuilding plans were based on stock assessments that took place 5-10 years before the rebuilding plan was developed. Advice for rebuilding guidelines could reasonably recommend that assessments be updated in the development of rebuilding strategies for such cases. Data poverty, to varying extents, is likely to remain a common challenge, requiring consideration of rebuilding strategies that preserve policy intent by setting triggers to curtail fishing when changes in available (fishery-dependent) data occur, coupled with requirements for enhanced data collection (Dowling et al. 2015).

Closely-related stocks may generally have similar rebuilding plans, but this was not always the case. For example, the rebuilding times for Yelloweye Rockfish - Inside and Outside stocks are markedly different at 80 and 15 years, respectively. This may be possible if the rebuilding time calculation included consideration of the stock depletion (e.g., T_{min}) and a rebuilding times were selected from a specified interval (e.g., $T_{\mathrm{min}} < T_{\mathrm{rebuild}} < 2^*T_{\mathrm{min}}$) in the formulation of rebuilding objectives. The desired level of probability chosen for rebuilding objectives also varied widely across rebuilding plans, generally falling outside the recommended “draft” PA Policy range of what is considered “high probability” (i.e., 75-95%). In cases where it was not recommended to follow all aspects of the 2013 rebuilding guidance (DFO 2013a), due to stock biology or external factors, these reasons were not clearly provided (e.g., considerations of trade-offs among management outcomes related to objectives).

There was a general trend towards an increased level of detail and information in more recently completed rebuilding plans; this increased detail is likely in response to recent audits and to facilitate greater alignment with the elements of proposed regulations to support rebuilding under the Fish Stocks provisions. The biggest gap between existing rebuilding plans and future potential rebuilding regulations appeared to be a description of an evaluation of the feasibility of rebuilding, and discussion of factors influencing rebuilding success. This inconsistency among plans is likely due in part to their development over time since 2009, well before the revised *Fisheries Act* and associated regulations were conceived. However, most of the disparities could be addressed in future though the use of guidelines and other tools facilitating the standardization of rebuilding advice development and presentation. Developing strategies to align Departmental guidance with new legislative and regulatory requirements should further improve the consistency rebuilding plans across Canada.

4. CRITERIA FOR REBUILDING GUIDELINES

Key Points:

- Prior definition of what constitutes a stock in need of rebuilding and what constitutes a rebuilt stock are commonly cited in the fisheries literature as attributes of a successful rebuilding plan.
- Situations that result in calls to rebuild depleted fish stocks represent a loss of flexibility in management decisions as the ability to trade-off rate of stock growth with harvest opportunities becomes restricted by imperative conservation objectives.
- Approaches to rebuilding strategies can be divided into two categories, *rebuilding via a schedule of biomass targets* and *rebuilding via procedural control*.
- Ideally, rebuilding objectives and supporting measures are identified prior to the need for stock rebuilding so that decision-makers and resource users can anticipate the restrictions that are likely to be imposed as limiting thresholds are approached or breached.
- The dominating factors that lead to the need for rebuilding may not be the same factors that are inhibiting stock growth, thus the relative roles of environmental and human-induced decline may change over time and with the status of the stock.
- If target objectives do not exist, then effectively the outcomes that represent avoiding a limit and achieving a target are the same, which may mean a stock is more likely to linger in the vicinity of limiting levels, possibly increasing the likelihood of serious harm and loss of yield.
- Uncertainty can lead to false positive (Type I errors) determinations that a stock has breached a limit reference point, when in fact it has not. Reasons for false positives can include revised estimates of stock abundance, whether due to updated data and/or changes in an assessment model, changes in the estimated values of reference points, or changes in the method for statistical inference selected by the analyst (NRC 2014).
- Once the need for rebuilding is determined, easily understood performance metrics and immediate action to reduce fishing mortality may be required to increase the likelihood of rebuilding plan adoption and success.
- Once the need for rebuilding is determined, immediate action on fishing mortality reduction may be needed while the rebuilding strategy and supporting management measures are being identified and evaluated (e.g., during a two-year period allowed for implementing a rebuilding plan for stocks prescribed under Section 6.2(1) of the revised *Fisheries Act*).
- Rebuilding strategies and plans can fail when, among other issues, there is no plan for adaptation to new scientific information, updated stock assessments, or revised rebuilding

scenarios. A procedural approach that pre-specifies management responses to a variety of scenarios may be helpful to avoid early abandonment of a rebuilding plan.

- There remains a need to accommodate data- and model-poverty since the information demands of MSY (or proxy) reference points are not achievable in a cost-effective manner for all stocks and time is required to accrue stock abundance indexing series.

4.1. DETERMINING WHEN REBUILDING IS NEEDED

Prior definition of what constitutes a stock in need of rebuilding and what constitutes a rebuilt stock was cited as an attribute of a successful rebuilding plan by Murawski (2010). This may not be as straight-forward as first appears, since the criteria depends on specifying acceptable risk tolerance, the ability to quantify uncertainty in the estimate of stock biomass and reference points, and the natural variability of stock abundance. Rice (2011) commented that advisory frameworks try to maintain a low probability that advice will lead to management error, but errors may still occur, and their nature matters. He distinguished unnecessary management interventions ("false alarms") from situations where intervention was warranted but not taken ("a miss"), and noted the inherent trade-offs that occur when trying to minimize one type of error at the expense of an increase in the other type.

A false alarm resulting from incorrectly determining an LRP breach, or alternatively suffering a miss, is exactly the situation that could be faced for declining and depleted stocks. For example, invoking a rebuilding plan based on incorrect determination of a limit reference point breach, that was actually a change in stock distribution (a false alarm) potentially causes unnecessary loss of benefits. In contrast, if the management response had been a modest reduction in catch (a miss) while additional information is gathered, then then there may have been little long-term impact on stock dynamics and benefits to resource users. Regardless of the cause, transitions across limits in either direction potentially create a problem when stock status can be estimated as $B < B_{\text{lim}}$ one year, but updated estimates the following year can indicate $B > B_{\text{lim}}$. This situation can occur if the stock is actually fluctuating around B_{lim}, or because of stock assessment errors, or due to changes in data and model assumptions used to make a status determination.

NRC (2014) found a high probability of classifying stocks as overfished and requiring rebuilding plans in the US when later assessments indicate that the stocks were not below the Minimum Stock Size Threshold (MSST, a limit reference point). Thus, consideration of the disruptive and potentially costly effects of crossing thresholds linked to legislative or policy actions is required. Small deviations in estimated status around the limit that cause rebuilding plans to be invoked or suspended will be disruptive and likely erode support for rebuilding. On the other hand, a stock with status lingering near an LRP is an undesirable condition. This "boundary effect" suggests the need for policy or guidelines so that once initiated, rebuilding plans are not prematurely suspended. Nor should rebuilding plans be so inflexible that new understanding of the management system, updated data, and re-assessment cannot inform adaptation of the rebuilding strategy and plan.

Review of legislative requirements and policies such as the *Magnuson-Stevens Act* in the United States of America (USA), the New Zealand *Fisheries Act*, and the Canadian *Fisheries Act* indicate reliance on reference points to invoke rebuilding requirements, i.e., status relative to the LRP. Some jurisdictions tie their legislative provisions to maximum sustainable yield (USA, New Zealand), and most national policies or guidelines use the MSY concept in discussing reference points, including limits (Table 8). Although MSY is not mentioned in Canadian law, the DFO PA Policy states that the reference removal rate from all sources of fishing mortality should not exceed F_{MSY}, i.e., F_{MSY} is a limit fishing mortality rate (Kronlund et al. 2014; Shelton and

Sinclair 2008). Similarly, default reference points of $0.4B_{\mathrm{MSY}}$ and $0.8B_{\mathrm{MSY}}$ are recommended for the LRP and USR, respectively. Thus, the concept of MSY is implicit in the PA Policy, although not required.

In a cross-jurisdictional review (Marentette and Kronlund 2020, Table 8), five jurisdictions pointed to a triggering value that marked a change in stock status, based on stock abundance, biomass or related proxies that specifically indicated the need for a rebuilding plan. Four of these jurisdictions, including Canada, indicated that rebuilding plans are needed when stock abundance (biomass) is below a limit reference point (LRP, also referred to variously as B_{lim}, "soft limit" (New Zealand), or MSST (US). Two jurisdictions, including Canada, referred to the need for action to promote rebuilding (but not a rebuilding plan) when stocks decline below a threshold, or operational control point (the USR of Canada), and MSY B_{trigger} of ICES). For example, the PA Policy states:

> "The development of a rebuilding plan **should** be initiated enough in advance to ensure the plan is ready to come into effect at the boundary of the Critical and Cautious zones if a stock has declined and reached the LRP… In some cases, a plan **could** be initiated when the stock declined past the mid-point of the Cautious zone. If a stock is already in the critical zone, a rebuilding plan **must** be developed and implemented on a priority basis." [**emphasis** added]

The policy guidance to initiate a plan when the stock declines past the mid-point between the LRP and USR has analogous intent to actions triggered at the "soft limit" of the New Zealand harvest policy. The policy direction to implement a rebuilding plan following an LRP breach is now supported in law by s 6.2(1) of the Canadian *Fisheries Act*. However, in some contexts there may be a number of criteria that are used to determine status, i.e., no one single metric is used to trigger a limit breach. Instead, a combination of factors that use information on current abundances, trends in abundance over time, distribution of spawners, and fishing mortality relative to stock productivity may be employed (e.g., Pacific salmon, Holt et al. 2009). Thus, an LRP may be a composite threshold rather than a biomass-based threshold.

The determination of status requires more than estimation of a biomass or fishing mortality limit alone:

- In accommodating uncertainty the (joint) probability distribution of the biomass or fishing mortality metric and reference point estimate needs to be considered (where possible) to determine the probability that the limit has been breached;
- The risk tolerance for a breach needs to be specified; and
- Time needs to be considered as the determination could be based on the current estimate of status, or the projected status of the stock at some future time, or status averaged over several years.

For example, the NSG1 for the *Magnuson-Stevens Act* states that status determination is often based on MSY or proxies; when usable estimates of such reference points are not available then alternatives can be adopted that promote sustainability of the stock (i.e., preserve policy intent). Specifically the NSG1 states:

1. Exceeding the MFMT (limit fishing mortality rate) for a period of 1 year constitutes overfishing;
2. Catch exceeding the OFL (overfishing limit) for 1 year constitutes overfishing, or
3. A fishery Council may utilize a multi-year approach to determine overfishing status based on a period of no more than 3 years. A rationale for adopting a multi-year approach should be

specified such as when stock abundance fluctuations are high and assessments are not timely enough to forecast such changes. However, the multi-year approach cannot be used to specify future catch limits at levels that do not prevent overfishing.

The NSG1 indicate that a stock is considered overfished under two conditions. First, when spawning biomass, or other measures of reproductive potential, falls below its minimum stock size threshold (MSST). We assume that where a probability can be estimated, a 50% or greater probability of a MSST breach is part of the criteria to determine an overfished state. We conclude this based on the second condition, where a stock or stock complex is considered overfished if it is approaching a state where it will decline below the MSST within two years, with greater than 50% probability (note the use of projected status). Presumably if the stock has not been assessed within two years and a new assessment results in a greater than 50% chance the stock is below the MSST, then rebuilding is mandated.

The NSG1 also consider whether environmental drivers have contributed to the determination that a stock is below the MSST. If it can be determined that environmental change caused the breach without affecting long-term reproductive potential, fishing mortality must be constrained to allow rebuilding within a specified time frame. If however, long-term reproductive potential has been affected by environmental, ecosystem or habitat changes then one or more components used to make the status determination must be re-specified. This stipulation may or may not result in a reduction in fishing mortality. This approach does not alleviate the problem of determining the relative contributions of environment and fishing to stock decline, or the need for evaluating the opportunity for restoration of long-term reproductive potential.

The discussion above raises a number of questions related to the determination of an LRP breach, which leads to a legal requirement for a rebuilding plan under the Fish Stocks provisions:

1. Should a breach be declared based on the probability of stock biomass being below an LRP based on terminal year of assessment, the projected status relative to the LRP (anticipating an LRP breach), or a scheme where if either method indicates a breach rebuilding is initiated?
2. Should the duration (number of years) the stock is below the LRP be considered in a determination that rebuilding is required in addition to the distribution of biomass below the LRP (probability)? Or, is proximity to the LRP sufficient rationale for initiating a rebuilding plan regardless of whether the stock appears to be fluctuating around the LRP or has only briefly breached the LRP?
3. What is the practice for determining an LRP breach if a probability statement is unavailable?
4. How shall “false positives” be treated when subsequent assessment indicates that stock biomass is no longer below the LRP prior to the initiation of the rebuilding plan, e.g., within the two-year period for plan implementation under s 6.2(1) of the Fish Stocks provisions?
5. What is the practice when a change in model assumptions or types of data used to inform the status determination result in revised reference point estimates that change the determination? For example, adding previously unavailable age-structured data to a stock assessment can change the shape of the production function and thus the relative positions of reference points and the estimated stock depletion; and
6. What is the practice when an error in the stock assessment is discovered that results in a change in the status determination?

Some of the questions (1-6) can be addressed in part by providing science guidelines; some aspects of the recommended practices may require policy development (e.g., the fate of the rebuilding plan under a false positive determination is not Science Sector remit, only the updated determination).

Table 8. An overview of cross-jurisdictional standards, policies and guidelines relating to determining when rebuilding is needed.

Country	Policy or Guidelines
Canada	Rebuilding plans are needed when a stock is below its **LRP**, although plans should be developed as stock approaches LRP.[1] Management measures for stocks below the **USR** "…should promote stock rebuilding to the Healthy Zone."[1]
Australia	Rebuilding strategies are needed when a stock is ***overfished*** (when the **median biomass** or other agreed-upon indicator is below its biomass **limit reference point**).[3]
ICES	Stocks that fall below the operational control point **MSY** $\boldsymbol{B}_{\mathbf{trigger}}$, under the ICES MSY Advice Rule, initiate changes in fishing mortality to rebuild to *"…levels capable of producing MSY."*[5] Stocks below B_{lim} require advice to achieve rebuilding to above B_{lim} in the short term.
New Zealand	Stocks are to be rebuilt when they are below "…a level that can produce the maximum sustainable yield."[7] Management action to increase stocks below B_{MSY} is required in general.[8] Rebuilding plans are required when there is a greater than **50% probability** that the stock is below the **soft limit** (by default, the higher of 0.5*B_{MSY} or 0.2*B_0).[7,8] Such stocks are termed ***depleted.***[7] Stocks depleted below the **hard limit** (by default, the higher of 0.25*B_{MSY} or 0.1*B_0)[7,8] are termed ***collapsed.***[7]
United States	Action is required when a stock is ***overfished*** (below its minimum stock size threshold, **MSST**), or is approaching that state (a more than 50% chance of declining below the MSST within two years).[9] MSST is a limit reference point and should be between 0.5*B_{MSY}, and B_{MSY}. [9] The precise value of the MSST selected for the stock may depend on productivity (governed by M).[10]

[1]DFO (2009) policy, [2]DFO (2013a) guidelines, [3]DAWR (2018a) policy, [4]DAWR (2018b) guidelines, [5]ICES (2018) advice basis, [6]NAFO (2004), [7]MF (2008) policy, [8]MF(2011) guidelines, [9]NOAA (2018), [10]Restrepo et al (1998).

4.2. IDENTIFYING THE REQUIRED REBUILT STATE

The context within which a rebuilt state is specified fundamentally affects perspectives on its purpose. For example, the rebuilt target may be the target biomass level defined in law or policy (e.g., B_{MSY} in the US and New Zealand). Defining too low a rebuilt target to signify "rebuilding" is no longer needed and management "as usual" can resume may thwart rebuilding efforts. This challenge can be mitigated by viewing rebuilding as integral to a management strategy that anticipates bad outcomes can occur and plans in advance for transitions back to harvests at target levels. At the same time, meeting legislative requirements under the Fish Stocks provisions means that a mechanism is needed for determining s 6.2 no longer applies.

The focus of the Fish Stocks provisions is on a single LRP, expected to be defined in terms of a stock status metrics such as biomass (abundance or proxies). Therefore a rebuilt state will be expected to be defined in terms of the same metric. However, other metrics of stock condition may be important and may need to be rebuilt, e.g., number of age classes (older fish tend to be larger and make bigger egg contributions), distribution of age classes, or fish size in commercial or recreational fisheries. Similarly, spatial distribution may be important in relation to contractions in species range, geographic shifts in distribution, or abandonment of spawning locations (e.g., herrings, salmonids). Adverse conditions represented by specific levels of all of these metrics may lead to decreases in carrying capacity and productivity, and consequently slower recovery. Regardless of the stock metric selected to represent a rebuilt state, the utility of the choice depends on whether performance measures related to that state can be reliably estimated, how they vary naturally, and how often an unfished stock might reach the proposed rebuilt state (MacCall 1993).

The same considerations that apply to criteria for declaring a limit reference point breach apply to determining a stock is rebuilt, although the risk tolerance and time period under consideration may vary. Two jurisdictions (Canada and Australia) indicated that rebuilding plans are complete when the stock has rebuilt to above the limit reference point, but noted rebuilding to higher levels might continue under other fisheries management plans (Table 9). For example, Australian guidelines suggest the stock is considered rebuilt when the stock is at, or above, the limit reference point with a reasonable level of certainty defined as at least 75% probability, in its most recent assessment. The tolerance of 75% was selected as the midpoint of the IPCC (2007) standard for "likely" (66-90%). Two other jurisdictions indicated that rebuilding is achieved when the target level (typically B_{MSY} or proxy) is achieved (New Zealand, United States). In New Zealand, stocks are considered rebuilt when they have an acceptable (at least a 70% probability) that the target has been achieved, as well as a 90% probability that the soft limit has been achieved. Applying at a 75% probability criteria for exceeding the LRP (Australia) and 70% probability for exceeding the target reference point (New Zealand) may be motivated by wanting a better than 1-in-2 chance that the stock is considered rebuilt, but also to allow more time for other stock characteristics to be recovered, such as age structure. Conversely, the US declares a rebuilt state when stock biomass has at least a 50% probability (a 1-in-2 chance) of having reached B_{MSY}, or proxy.

Table 9. An overview of cross-jurisdictional standards, policies and guidelines relating to the definition of a rebuilt state.

Country	Policy or Guidelines
Canada	Rebuilding plans are no longer required when a stock is above the LRP, although longer term objectives may involve rebuilding to levels above other reference points under the PA Policy (e.g., USR).[2] Policy does not indicate criteria for determining when the stock is considered to be above the LRP.
Australia	Rebuilding strategies must be developed to rebuild stocks to "*levels that ensure long-term sustainability and productivity.*"[3] In practice, this means **above the LRP** with a reasonable level of certainty defined as a 75% probability that stock is at, or above, the limit reference point in its most recent assessment. The tolerance of 75% was selected as the midpoint in the IPCC (2007) standard for "likely" (66-90%).[4]
New Zealand	Stocks are considered rebuilt when they have an ***acceptable*** likelihood (at least a 70% probability) **that the *target* has been achieved**, as well as a 90% probability (P. Mace, pers. comm., January 14, 2020) that the soft limit has been achieved.[7] Targets are set at B_{MSY} (or proxy), or better. If a fishery has been closed as a result of a breach of a hard limit (e.g., $0.1B_0$ or $0.25B_{\mathrm{MSY}}$), then the closure may continue until the stock has rebuilt to at least the soft limit with 70% probability.[8]

Country	Policy or Guidelines
United States	Stocks are rebuilt when they have at least a 50% probability **of having reached B_{MSY}**.[9] ***Targets*** (like B_{MSY}) should not be exceeded with more than 50% probability, or on average.[10] Proxies may be used for data-moderate to data-poor situations (e.g., yield per recruit, spawning potential ratio or catch per unit effort, historical average catches).[10]

[1]DFO (2009) policy, [2]DFO (2013a) guidelines, [3]DAWR (2018a) policy, [4]DAWR (2018b) guidelines, [5]ICES (2018) advice basis, [6]NAFO (2004), [7]MF (2008) policy, [8]MF (2011) guidelines, [9]NOAA (2018), [10]Restrepo et al (1998).

4.3. SELECTING THE TIME PERIOD FOR REBUILDING

Time to a rebuilt state depends on biological considerations such as current stock status, year-class effects, and the productivity of the stock. Management considerations include the relative priority of biological rebuilding and socio-economic objectives that define the rebuilding target, the homogeneity of resource users (determining the degree of conflict in objectives), and the degree of management controllability (Powers 2003). The rebuilding period should be sufficiently long to allow an acceptable likelihood that the metrics of rebuilding performance exceed thresholds, i.e., there is reasonable assurance that the stock and fishery can transition to target levels. Conversely, if the time period is too long then a stock may linger near levels where “serious harm” may be incurred before fishing mortality is reduced sufficiently to allow any surplus production to contribute to stock increase. Persistence at depleted states is likely to increase the risk of incurring further stock deterioration. Also, as the length of the rebuilding period increases, scientific advice may become uninformative due to very uncertain future stock dynamics (Powers 2003), although this problem can be mitigated by a schedule of progress evaluation and adaptation as new data and analyses accrue.

There is no agreed-upon international standard practice for determining the rebuilding time frame. All six jurisdictions we reviewed mentioned the need for a rebuilding timeframe, although only four provided guidance for specifying timeframes (Table 10). Rebuilding time periods based either wholly, or in part, on estimated generation time were used by three jurisdictions (Canada, Australia, and the United States). The T_{min} calculation was used as the primary basis for estimating rebuilding timeframes in Australia, New Zealand, and the United States. The minimum rebuilding time T_{min} is defined as the expected time to reach the rebuilt state, say biomass $B_{rebuild}$, in the absence of fishing mortality (New Zealand, USA) or directed commercial fishing (Australia). Four jurisdictions also indicated the need to consider trade-offs in establishing timeframes, particularly in evaluating socio-economic impacts or other costs borne by fishery participants. New Zealand and the US have chosen to specify minimum (T_{min}) and maximum (T_{max}) rebuilding times to bound the trade-offs between the rebuilding schedule and objectives that capture socio-economic and cultural goals when selecting a desired time to reach a rebuilt state ($T_{rebuild}$). However, the two jurisdictions differ in their standards. For example, New Zealand has chosen to specify a rebuilding period between T_{min} and no more than $T_{max} = 2T_{min}$, where the maximum time allows accommodation for socio-economic considerations. In contrast, the US follows the standard of defining T_{max} as 10 years if the stock can be rebuilt in 10 years or less, else 10 years plus one fish generation.

However the US practice can lead to discontinuities in rebuilding periods between similar stocks (e.g., see Benson et al. 2016; NRC 2014; Patrick and Cope 2014). Patrick and Cope (2014) suggested that this issue could be resolved by focusing on a fishing mortality-based approach to rebuilding (as opposed to a schedule of biomass targets), which was also recommended in NRC (2014) report on US rebuilding plans. NRC (2014) noted that rebuilding plans that focus more on meeting selected fishing mortality targets than on exact schedules for attaining biomass targets may be more robust to assessment uncertainties, natural variability, and ecosystem consideration, and may have lower social and economic impacts.

There are three issues related to the calculation of $T_{\min}$. First, $T_{\min}$ is an estimated parameter and has a probability distribution like any other derived parameter from a stock assessment model, thus the estimate is associated with statistical uncertainty. Second, it may not be possible to calculate $T_{\min}$ in the absence of a population dynamics model. In such cases approaches using multiples of generation time may be considered at the expense of ignoring stock depletion and productivity, although it is not clear generation time is a good indicator of rebuilding time. Finally, it may be that the estimate of $T_{\min}$ is so large that it is beyond the practical limits of forecasts or closed-loop projections. In such situations, multiple of generation time can be considered or the maximum time feasible for calculations. One goal is to allow sufficient time so that short-term transient effects in the modelled stock response from status quo management to a rebuilding strategy can be at least somewhat resolved. Another goal may be to acknowledge human intergenerational equity inherent in widely used definitions of sustainability.

The use of different methods for identifying a time frame will create a lack of risk equivalency in rebuilding objectives. For example, consider where a rebuilding time frame is based on $T_{\min}$ for one stock, but a second similar stock is limited to an ad hoc choice of two generations. Specifying the same probability of achieving the rebuilt state for the two situations would not lead to risk equivalent outcomes (stock status, yield) for the stocks, all other factors being equal, since current depletion is not incorporated into the time frame for the second stock. Nevertheless, $T_{\min}$ will not be available for all stocks so a rebuilding time frame based on generation time could be agreed upon to avoid deferring implementation of a rebuilding plan while data- or model-poverty is resolved.

The method by which generation time is calculated is, somewhat surprisingly, infrequently documented as mathematical equations in assessments. Instead, textual descriptions that may have ambiguous interpretations are common. Three approaches are outlined by the Guidelines for Using the IUCN Red List Categories and Criteria, Version 11 (February 2014), with the average age of parents in the population demanding the most data (e.g., a survivorship function) and equivalent to a method described by Seber (1982), and see also Caswell (1997). The other two methods cited by IUCN are approximations that may serve under specific assumptions. The Pacific Fishery Management Council uses the following description of generation time for Pacific Hake, *Merluccius productus*, and Petrale Sole, *Eopsetta jordani*:

> "mean generation time is defined as the mean age of the net maternity function (i.e., the product of the survivorship and fecundity-at-age). When growth and/or natural mortality are changing over time, survivorship and fecundity at-age are based on recent estimates to reflect current conditions." (NCR 2014).

This description again matches the approach described by Seber (1982), but allows for non-stationarity.

Currently, DFO does not have analogs to $T_{\min}$, $T_{\max}$, and T_{rebuild} in either policy or guidelines. There is no mandate to rebuild to levels consistent with the production of MSY in a period of time "as short as possible" as exists under the *Magnuson-Stevens Act* (*The Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. 1801 - 1891(d)) (2014)*) or other time-constrained outcomes, and no guidance on how trade-offs are to be prioritized within a rebuilding time period. In addition, undefined approaches to calculating the rebuilding period, including the generation time calculation, are likely to result in disparate standards in rebuilding strategies.

Regardless, adoption of standardized practices for estimating a default rebuilding time period is needed to help promote consistency among stock contexts. Those practices should incorporate:

1. An estimate of the minimum time to a rebuilt state ($T_{\min}$) in consideration of the current stock depletion, generation time, and productivity, where possible;
2. Defined methods of calculating generation time (i.e., specific equations) depending on available data support where multiples of generation time are applied; and
3. Communication of the trade-offs incurred by establishing a maximum time vs. a minimum time in consideration of socio-economic and cultural objectives.

Table 10. An overview of cross-jurisdictional standards, policies and guidelines relating to the development of rebuilding time periods.

Country	**Policy or Guidelines** [***emphasis*** added]
Canada	A ***reasonable timeframe***, defined as the time for a cohort to recruit to spawning biomass, is provisionally given as 1.5 to 2 generations. Longer times than 1.5 to 2 generations would be required for situations where life history characteristics imply reduced potential for growth, unfavourable productivity regimes, and severe depletion.[2] Flexibility in setting ***longer timeframes*** may also be desired for socio-economic considerations. [2]
Australia	Timeframes for rebuilding should be defined within the range of $T_{\min}$ to 2 * $T_{\min}$. Here $T_{\min}$ is defined as the minimum rebuilding time in the absence of commercial fishing. In data-poor stocks where $T_{\min}$ cannot be calculated, the lesser of either the average age of a reproductively mature animal in an unexploited population ***[mean generation time] plus 10 years***, or ***3*mean generation time***. ***Longer timeframes*** may be justifiable after a cost-benefit analysis of alternative trajectories, which may include the apportionment of costs across stakeholders.[4] Timeframes should take into account productivity, recruitment, stock-recruitment relationships, and the severity of depletion.[3] Significant related environmental impacts should be documented, whether positive or negative.[4]
ICES	Reference is made to rebuilding spawning stock biomass above $B_{\lim}$ in the ***short term***, where “short-term” is not defined
NAFO	It is the responsibility of the Fisheries Commission to “specify ***time horizons*** for stock rebuilding,” but no further details are provided.[6]
New Zealand	Timeframes for rebuilding should be defined within the range of $T_{\min}$ to 2 * $T_{\min}$. Here, $T_{\min}$ is defined as the minimum rebuilding time in the absence of fishing, and takes into account the biology of the fish, extent of depletion, and prevailing environmental conditions.[7] ***Longer timeframes*** may reflect social, economic and cultural factors associated with fishing sectors that use the stock.[8]

Country	Policy or Guidelines [***emphasis*** added]
United States	Rebuilding time (T_{target}) shall be ***as short as possible***, taking into account the status and biology of the fish, socio-economic considerations, international organization recommendations, and ecosystem considerations. [9] Life history characteristics affect rebuilding plan development (such as productivity and recruitment), and affect timeframes. A link to generation time is important; a default way to calculate generation time is recommended as Goodyear (1995). Accounting for future recruitment uncertainty is important.[10] T_{target} shall not exceed $T_{\max}$ (the maximum time to rebuild to B_{MSY}). If $T_{\min}$ is 10 years or less, then $T_{\max}$ is 10 years; else If $T_{\min}$ exceeds 10 years, then $T_{\max}$ is either (a) $T_{\min}$ plus one generation time (average length of time between an individual being born and the birth of its offspring), (b) the time for the stock to rebuild to B_{MSY} if fished at 0.75 * MFMT, or (c) 2 * $T_{\min}$, where MFMT is the maximum fishing mortality threshold (often F_{MSY} or proxy). $T_{\min}$ is calculated as the time to rebuild to B_{MSY} in the absence of any fishing mortality with 50% probability, where it is possible to calculate.[9]

[1]DFO (2009) policy, [2]DFO (2013a) guidelines, [3]DAWR (2018a) policy, [4]DAWR (2018b) guidelines, [5]ICES (2018) advice basis, [6]NAFO (2004), [7]MF (2008) policy, [8]MF (2011) guidelines, [9]NOAA (2018), [10]Restrepo et al (1998).

4.4. REBUILDING OBJECTIVES: LINKING OUTCOMES, RISK, AND TIME

Under management by reference point policies, goals related to limit and (rebuilding) target reference points should be embedded in measurable objectives. For example, the PA Policy suggests a default LRP of B_{LRP}=0.4B_{MSY}, or 40% of the spawning biomass (B) at maximum sustainable yield (MSY). A measurable objective that embeds the LRP could be stated as “avoid spawning biomass levels lower than 0.4B_{MSY} with 95% probability over the next 20 years (i.e., a 1-in-20 year chance of an LRP breach)”. A fully specified measurable objective must have three components:

1. An outcome of interest, such as a limit to be avoided or a target to be achieved (e.g., $B >$ 0.4B_{MSY});
2. A desired probability (e.g., 95% probability) of achieving the outcome (1); and
3. A time-frame (e.g., 20 years) over which to measure performance with respect to achieving (1) and (2).

The addition of components (2-3) renders outcomes, such as stock status relative to reference points, operationally useful for making a strategic choice of specific management measures from alternatives. As suggested above, the time frame for measurement in a rebuilding context could be related to $T_{\min}$ or multiples of the expected generation time of the species if $T_{\min}$ cannot be calculated. The “high” probability of avoiding biomass levels less than B_{LRP} in the example is based on guidance on risk tolerance provided by the PA Policy. Often, objectives structured around LRPs are considered imperative (Miller and Shelton 2010) and must be satisfied for a given management option to be retained for consideration.

The degree to which measurable objectives are satisfied can be captured as statistics that quantify (a) state, (b) duration, or (c) probability performance measures. For example, suppose B_{rebuild} is some target biomass level considered to be consistent with a rebuilt stock. Then, as an example, the variables of interest for an objective can be:

a) the spawning biomass state (e.g., B / B_{rebuild}) achievable for a specified time period and specified probability (e.g., what spawning biomass level relative to B_{rebuild} can be achieved in 2 generations with 70% certainty?);

b) the expected duration to achieve B_{rebuild} for a specified probability (e.g., how many years will it take to achieve B_{rebuild} with 70% certainty?); or

c) the probability of reaching B_{rebuild} for a specified time period (e.g., how certain is achieving a spawning biomass of at least B_{rebuild} in 2 generations?).

Performance measures are statistics that quantify how well a measurable objective is being met. Every objective has at least one matching performance measure. The example objective described above puts emphasis on the probability because satisfying the objective requires finding a management option that *avoids biomass less than* $0.4B_{\text{MSY}}$ with at least 95% probability over 20 years, i.e., a 19-in-20 years' chance of stock biomass above the LRP. Any management option that led to more than a 5% probability (greater than 1-in-20 years) of breaching the $0.4B_{\text{MSY}}$ level would be discarded from consideration if deemed imperative.

Four jurisdictions reviewed (Table 11) specified a desired level of confidence in achieving a rebuilt state over acceptable timeframes, ranging from at least a 75% probability that the limit reference point had been exceeded ("high probability," Canada; and "reasonable level of certainty," Australia), to a 70% probability that a B_{MSY}-compatible target had been achieved ("acceptable probability", New Zealand). Australian guidelines noted that ceasing overfishing is a rebuilding objective, although no guidance was given for desired probabilities or timelines.

Two jurisdictions (Canada and the United States) mention the use of establishing milestones as a way to track progress towards achieving objectives (Table 11). Canadian guidance described milestones as very short-term objectives (with targets, timeframes and probabilities) that may be useful when a primary objective to rebuild above the LRP appears infeasible. American guidelines described milestones more broadly, as tools with which to measure progress during the implementation of a rebuilding plan.

Time is a key aspect of all management strategies, but attracts particular scrutiny in situations where rebuilding is mandated. Risk tolerances are often used as a static calculation to quantify current stock status relative to a reference point. For example, the probability of the stock biomass being below an LRP in the terminal year of a stock assessment. However, in developing a rebuilding strategy such static calculations do not take into account that the calculation is likely to be repeated at intervals over the lifespan of a rebuilding plan, and that more information about the stock and fishery will be acquired during that period. Actual risk in rebuilding contexts is different than the calculated static "risk" used to characterize current status; improved risk assessment takes into account how catches are planned to vary over the rebuilding time period, the types and quality of data that will become available, and how often the risk calculation is updated (de la Mare 1998). Thus, evaluating the expected efficacy of a rebuilding strategy would involve calculating the likelihood that proposed management measures can satisfy any imperative rebuilding objectives and provide for acceptable trade-offs of other stock and fishery outcomes over the lifespan of the plan. These calculations require a high level of quantitative analysis, and will not be possible in all situations.

Table 11. An overview of cross-jurisdictional standards, policies and guidelines relating to the development of rebuilding objectives.

Country	Policy or Guidelines [*emphasis* added]
Canada	In the short-term, rebuilding plans must aim to have a ***high probability*** (provisionally **75% to 95%**) of the stock rebuilding above the LRP within a ***reasonable timeframe***. [2] ***Milestones*** (specific, measurable targets that represent interim steps for the rebuilding stock) may be used to help achieve the short-term objective over very short time periods (e.g., 3-5 years).[2] Short-term objectives and milestones should have three components: a target, desired time, acceptable probability level for achieving the target. [2] In the long-term, beyond the life of the rebuilding plan, objectives can include growing stock above USR or to TRP.[2]
Australia	The objectives are to cease ***overfishing*** (defined as either a removal rate that is likely to result in the stock becoming overfished, or that will prevent recovery in accordance with its rebuilding strategy[3])**,** and to rebuild the stock above its limit reference point with a ***reasonable level of certainty*** (at least ***75% probability***) within the established timeframe.[4] Objectives should be clearly specified, including targets and timeframes.[4]
ICES	ICES uses MSY as a "broad conceptual objective."[5] It can be inferred that there is an objective to provide advice to rebuild stocks above B_{lim} within the short term.
New Zealand	Rebuilding plans should contain rebuilding targets, expected timeframes for rebuilding, and a minimum ***acceptable*** probability of achieving rebuilding.[7,8] The minimum standard is a ***70% probability*** that the stock will be ***above the target*** at the end of the timeframe, set between $\boldsymbol{T_{\min}}$ **to 2*** $\boldsymbol{T_{\min}}$.[7] A 70% probability helps to ensure that rebuilding plans are not abandoned too soon and helps to ensure that age structure as well as biomass is rebuilt.[7,8] Probabilities should be higher where information is very uncertain, or when multiple sectors have interests in the fishery.[8] Rebuilding plans should also ensure that stocks do not decline below levels that triggered the need for a plan in the first place.[7]
United States	Default rebuilding objectives were proposed in technical guidelines to be as follows, to achieve a ***50% probability of achieving*** $\boldsymbol{B_{\text{MSY}}}$ within $\boldsymbol{T_{\text{target}}}$ **years**, and a ***90% probability of achieving*** $\boldsymbol{B_{\text{MSY}}}$ in $\boldsymbol{T_{\max}}$ ***years.*** [10] Rebuilding plans should include quantifiable ***milestones*** to measure progress during plan implementation, and flag issues that may require adjustments to the plan.[10]

[1]DFO (2009) policy, [2]DFO (2013a) guidelines, [3]DAWR (2018a) policy, [4]DAWR (2018b) guidelines, [5]ICES (2018) advice basis, [6]NAFO (2004), [7]MF (2008) policy, [8]MF (2011) guidelines, [9]NOAA (2018), [10]Restrepo et al (1998).

4.5. PLANNING HOW CATCHES WILL VARY OVER THE REBUILDING TIME PERIOD

Approaches to rebuilding strategies can be divided into two categories, first "*rebuilding via a schedule of biomass targets*" and second, "*rebuilding via procedural control*". The adoption of management by reference points in most jurisdictions has led to emphasis on rebuilding by a schedule of biomass targets. That is, the goal is to achieve a specified biomass level within a time-constrained period. Although hard time limits can create leverage points for criticism when targets are not met, advocates of such an approach argue that a time-constrained strategy discourages inaction or deferral of rebuilding measures which has been a primary motivation for time-constrained rebuilding plans in the United States (Patrick and Cope 2014).

However, experience shows that biomass is difficult to estimate accurately due to structural uncertainty in stock dynamics and stock assessment errors. Furthermore, biomass is subject to natural variability and environmental factors (Patrick and Cope 2014) that cannot be controlled by fisheries management actions (i.e., recruitment leading to surplus production that allows for stock growth). This variability, in concert with non-zero risks of failing to achieve targets even under perfect implementation can lead to situations where rebuilding timelines are not met, testing both management and resource user patience for continued restrictions on the target or coincident species (MacCall 1993). Fixating on biomass increases may additionally distract from improvements to management controllability aimed at effective limitation of fishing mortality, or mitigating other impediments to rebuilding such as degraded habitat.

The alternative is to control fishing mortality to achieve *rebuilding by procedural control*, i.e., application of a management procedure consisting of stock and fishery monitoring data, an assessment method and a harvest control rule (e.g., Benson et al. 2016, Restrepo et al. 1998, Restrepo and Powers 1999, NRC 2014). Such approaches have been demonstrated to be effective at managing fisheries over a wide range of stock sizes (Benson et al. 2016, NRC 2014), and thus can be applied regardless of status or mandated rebuilding. The emphasis on rebuilding by a schedule of biomass in most fisheries policies, rather than controls on fishing mortality, may be because low biomass is an undesirable state that can be expressed in “natural units” of tons or numbers of fish. Thus, biomass limits can be expressed in readily understood units that decision-makers are willing to cite in support of fishing restrictions. Conversely, a high fishing mortality rate (F) cannot be related to natural units and may not cause immediate collapse or low biomass, depending on current stock status and the period over which a high fishing rate is incurred. Yet, controlling fishing mortality is a key determinant of rebuilding success.

Powers (2003) argued that the distinction between a schedule of biomass and procedural control is artificial, that they are readily transformed from one view to the other. He suggested discussions with decision-makers should be focused on questions related to legal imperatives and policy intent, short- and long-term constraints to stock rebuilding, and determining what feasible reductions in catch can be implemented over agreed-upon rebuilding periods. Here, feasibility reflects socio-economic considerations that can include both desires for increased rebuilding priority and/or harvest opportunity (Punt and Ralston 2007). The design of procedural control measures is essentially a process of eliminating management options that are unlikely to meet legislative and policy requirements, and identifying trajectories of catches over time that reflect biological and management constraints. The fishing mortality rate is used in concert with the biomass level to supply much more information about the required actions necessary for rebuilding, or for implementing measures intended to avoid a rebuilding scenario from (re)occurring.

For data-poor stocks where analytical assessments may be unreliable or unavailable, empirical rebuilding strategies that rely on input controls to reduce fishing mortality may be more effective and defensible than strategies based on annual catch limits and biomass targets (NRC 2014). Spatial management may offer a solution, but it is difficult to assess the contribution of spatial measures to rebuilding (NRC 2014).

4.6. TRANSITIONING TO TARGET OUTCOMES

Although a rebuilding strategy must identify a rebuilt state, or more generally a target state, debate about the desired target levels are inevitable. At a minimum, a rebuilt state would likely be required to manage a stock under s 6.1 rather than s 6.2, i.e., remove the requirement for a rebuilding plan. As more data are collected, recruitment fluctuates, and the fishery changes in response to management measures, so will estimates of current stock status relative to updated estimates of biomass and fishing mortality rate reference points. The changing debate about target levels is not as important in the short term as initiating rebuilding actions when the stock is overfished or approaching an overfished level, e.g., bringing fishing mortality below F_{lim}, implementing other measures to encourage stock growth, initiating needed data collection or analyses, and beginning discussions with resource users to identify where maneuvering room can be preserved for management decisions.

However, the situation is exacerbated in the absence of objectives that can be used to end the rebuilding component of a management strategy and transition to harvests at target levels. Determining that a stock is no longer overfished and overfishing is not occurring is an expected condition to support claims of a sustainable fishery. It is usually possible to apply legal context and fisheries policy to guide the choice of an objective related to avoiding limits, but agreed-upon target objectives are more difficult to identify as socio-economic and cultural values receive increased weight in decision-making. If target objectives do not exist, then effectively the outcomes that represent avoiding a limit and achieving a target are the same, meaning that the stock is more likely to linger in the vicinity of undesirable states. Thus Powers (2003) argued that the primary goal of decision-makers should be to avoid an overfished status and then manage towards optimum yield, or we suggest at least “pretty good yield” (defined as 80% of the maximum sustainable yield, Hilborn 2010). Note that Hilborn (2010) concluded that “pretty good yield” can be obtained at a broad range of stock sizes (e.g., 20%-50% of unfished for stocks with stock-recruitment steepness greater than 0.7). He further concluded that that stock sizes higher than the range of 35-40% of the unfished level should be considered desirable to meet expectations for more intact ecosystems as a fishery goal, and that stock sizes of 50% result in little long-term loss of yield. For example, 80% of maximum sustainable yield may be possible at stock sizes greater than 50% of the unfished level.

Our review of international practices indicated that three jurisdictions discussed the transition from rebuilding plans to other plans or harvest strategies (Table 12). Both Canadian and Australian guidance indicates that once rebuilding of the stock above the limit reference point has been achieved, stocks may be managed under other plans that include continued rebuilding to some other desired state (e.g., above the USR for Canada; to the target reference point for Australia). Technical guidance for the American National Standard Guidelines 1 was more specific, suggesting that rebuilding plans could be segmented or phased, allowing step-wise transitions from the initiation of rebuilding to more optimal management regimes as the stock approaches a B_{MSY} target.

Our primary emphasis is that rebuilding is integral to a management strategy. Declaring a stock rebuilt is needed for regulatory purposes, but the transition from a depleted state where rebuilding is required to target levels is achieved via a continuum of measures defined in a management strategy.

Table 12. An overview of cross-jurisdictional standards, policies and guidelines relating to the transition to target outcomes.

Country	Policy or Guidelines [**emphasis** added]
Canada	Rebuilding objectives may carry over. Achieving long-term rebuilding objectives to **continue growing stocks to and above the USR and/or TRP** may be contained in rebuilding plans, but will **rely on long-term fisheries plans** such as Integrated Fisheries Management Plans (IFMPs).[2] Management actions for stocks that have rebuilt above the LRP but below the USR (Cautious Zone) should either "promote stock growth to the Healthy Zone [above USR] within a reasonable timeframe", "encourage stock growth in the short term", or at least "arrest declines" depending on recent stock trajectories.[1]
Australia	Once a stock is deemed recovered (at or above LRP with 75% probability), targeted fishing may recommence with a harvest strategy, likely with reduced catch levels, that **continues to rebuild the stock towards the target**, and will maintain biomass above the limit reference point 90% of the time (1-in-10 year chance).[4] "The **target reference point** for key commercial fish stocks is the stock biomass required to produce maximum economic yield from the fishery (B_{MEY});" however targets for individual stocks in a multi-species fishery may vary to enable fishery level MEY to be achieved.[3]
ICES	It can be inferred that as stocks rebuild above B_{lim}, ICES' advice rules continue to apply. For example, for stocks below MSY $B_{trigger}$ but above c, (B_{lim}) the advice rule indicates that F should increase proportionally to SSB back to F_{MSY}; in other words, $F = F_{MSY}$ * SSB/MSY $B_{trigger}$. Precautionary fisheries management plans are those evaluated through MSY to have a maximum probability of the SSB < B_{lim} of 5% **each year** (with suitable adjustments for short-lived stocks with > 5% risk of breaching B_{lim} under unfished conditions).[5]
New Zealand	It can be inferred that once stocks are considered rebuilt (>70% probability of being above the target and 90% probability of being above the soft limit), then **stocks may be transitioned to other plans**, with harvest strategies that meet acceptable probabilities of (continuing to exceed) the target of 50% or greater.[7,8]
United States	Technical guidelines indicate that rebuilding may be performed in segmented phases, from initiation to supporting a transition to optimal management near the target of B_{MSY}.[10]

[1]DFO (2009) policy, [2]DFO (2013a) guidelines, [3]DAWR (2018a) policy, [4]DAWR (2018b) guidelines, [5]ICES (2018) advice basis, [6]NAFO (2004), [7]MF (2008) policy, [8]MF (2011) guidelines, [9]NOAA (2018), [10]Restrepo et al (1998).

4.7. MANAGEMENT CONTROLLABILITY

Management controllability is also termed implementation error, or the difference between the intended management actions and their actual application. For example, if catch estimates are imprecise, then there is no guarantee that the sequence of catches advised under a rebuilding strategy will actually be implemented as planned. Four jurisdictions we reviewed cite non-targeted catches (i.e., bycatch) in guidance and policies for rebuilding (Table 12). All four noted the importance of accounting for all removals from the stock, including bycatch that occurs in other fisheries, in developing rebuilding plans. The policy implications, however, appear to differ. Three jurisdictions (Canada, New Zealand and the United States) noted that flexibility in rebuilding objectives may be needed to accommodate the needs of multi-stock fisheries where catches of the rebuilding stock are unavoidable. In particular, American guidelines indicate acceptable risks of breaching limits for selected stocks in multi-species fisheries, which may be subject to overfishing, may be as high as a 1-in-2 chance. However, it is unclear how this guideline might affect the efficacy of rebuilding plans for such stocks. In contrast, Australian policy and guidelines indicate that individual target reference points for stocks in a multi-stock fishery may vary in order to achieve fishery-level biomass at maximum economic yield, B_{MEY}. Regardless, all stocks are subject to objectives with respect to exceeding limit reference points with 90% probability (a 9-in-10 year chance) over a specified time period, meaning that catches in other fisheries under Australian jurisdiction may need to be reduced.

Table 13. An overview of cross-jurisdictional standards, policies and guidelines relating coincident (incidental) catches.

Country	Policy or Guidelines [*emphasis* added]
Canada	A key requirement of the PA Policy is that ***total removals from all fisheries*** should be taken into account.[1] All IUU (illegal, unreported and unregulated) catches should be eliminated or minimized, where possible. [2] Rebuilding of stocks in a mixed-stock or multi-species fishery ***may limit harvesting opportunities on healthy stocks***. An “adaptive and ecosystem-based” approach may help to “balance objectives for rebuilding depleted stocks with the maintenance of fishing opportunities directed at healthy stocks.” [2]
Australia	“Incidental mortality on overfished stocks should be constrained as much as possible” to allow rebuilding in the specified timeframe.[3] This may include reducing TACs for other stocks.[4] Uncontrollable sources of mortality (e.g., other jurisdictions) should be taken into account.[3]
New Zealand	Unavoidable bycatch is one factor that may go into establishing rebuilding timeframes.[8]
United States	The term ***overfishing*** is defined as “whenever a stock or stock complex is subjected to a level of fishing mortality or total catch that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis,”[9] and ***catch*** as “the total quantity of fish… taken in commercial, recreational, subsistence, tribal, and other fisheries,”[9] indicating that all coincident removals need to be considered. ***In mixed-stock fisheries, overfishing may be permitted on certain stocks***, so long as the risk of the stocks being below the MSST is not more than 50%.[9]

[1]DFO (2009) policy, [2]DFO (2013a) guidelines, [3]DAWR (2018a) policy, [4]DAWR (2018b) guidelines, [5]ICES (2018) advice basis, [6]NAFO (2004), [7]MF (2008) policy, [8]MF (2011) guidelines, [9]NOAA (2018), [10]Restrepo et al (1998).

4.8. MANAGING REBUILDING EXPECTATIONS

Most jurisdictions cite an imperative to rebuild depleted fish stocks, and to also take into account socio-economic and cultural considerations in developing a rebuilding strategy. There are few examples of socio-economic reviews of the consequences of rebuilding or non-biological outcomes, in part because these data are usually insufficient (NRC 2014). Such reviews could help refine objectives and rebuilding measures, particularly allowing improved quantification of “consequence” in risk determination. Regardless, approaches to planning the implied trade-offs vary both in specificity and emphasis among jurisdictions. National guidelines tend to focus on attaining specified abundance (biomass) targets despite experience that biomass is difficult to estimate accurately due to structural uncertainty in stock dynamics and stock assessment errors.

Failing to meet rebuilding timelines can also pose the opposite dilemma when evaluating rebuilding performance. Updated analyses incorporating new data or different assumptions can result in a situation where the original basis for a rebuilding plan is no longer valid. This possibility was highlighted by a recent evaluation (DFO 2020b) of Yelloweye Rockfish (Outside stock) on the west coast of Canada. In this case the addition of age-composition data not available for a previous assessment (Yamanaka et al. 2018) led to a change in the assessment method from a surplus production to an age-structured model. The result was that all age-structured operating model scenarios considered in a closed-loop simulation analysis characterized the stock as being above the LRP in each scenario. In contrast, the previous surplus production assessment model estimated that stock status was well below the LRP. An LRP of $0.4B_{\mathrm{MSY}}$ was adopted for both analyses, but because the production function and scale of the age-structured models was different than that of the surplus production model, the estimate of status changed.

As noted previously, a common perception may be that rebuilding is a slow gradual process, which poses problems when recruitment is characterized as “cyclical”, “irregular”, “episodic” or “spasmodic”. Often a “steady state” is represented by random variability about a stock and recruitment curve when forecasting rebuilding times. Cyclical stock dynamics can cause false positive and false negatives with respect to the determination of depleted and rebuilt status as assessment models lag the underlying biomass trajectory. Knowledge of environmental factors or correlates is of little help unless future environmental states can be predicted. The problem of changing regimes is of particular relevance to managing expectations for the detection of overfishing and for rebuilding stocks. For example, a systematic change in biological productivity and hence theoretical reference levels can mean a fishing mortality rate (and catches) that can be sustained without depletion of a stock during a period of high productivity may cause overfishing when a less productive period is encountered (MacCall 1993, Szuwalski and Punt 2013). Analysts should provide decision-makers with reasonable expectations by adopting a formal approach to hypothesizing alternative scenarios for uncertain stock and fishery dynamics, and evaluating the expected consequences of alternative rebuilding catch trajectories (MacCall 1993).

Three jurisdictions reviewed, including Canada, spoke to regular review and evaluation of rebuilding plan performance (Table 14). Canada recommended that the time between reviews should not exceed three years, while the United States noted that review periods should not exceed two years. Australia suggested that harvest strategies in general should be reviewed every five years, or more frequently under exceptional circumstances. These circumstances may include when there is new information (data or understanding) that significantly affects the assessment of the stock, indications that the harvest strategy is ineffective, or unexpected external stock drivers.

Table 14. An overview of cross-jurisdictional standards, policies and guidelines relating to evaluation of rebuilding performance.

Country	Policy or Guidelines [**emphasis** added]
Canada	Performance review is separate from regular and continuous monitoring of the stock.[2] Plans must be associated with “*appropriate monitoring and assessment*” to confirm success.[1] Plans should be reviewed on a regular basis (e.g., **maximum every 3 years**), with timelines based on the specifics of the stock. Reviews should be frequent enough to detect failures (prolonged declines, stagnant growth) and enable changes to be made.[2]

Country	Policy or Guidelines [**emphasis** added]
Australia	Performance monitoring is conducted with the use of established performance measures.[4] Harvest strategies in general, but not necessarily rebuilding strategies, are to be reviewed **every five years**, or more frequently under some circumstances or pre-established triggers. These include: lack of MSE testing, missed risk factors in MSE, marked changes in stocks occur, new information substantially affects the understanding of the fishery or performance indicators, external drivers have unexpectedly increased, or performance measures indicate ineffective strategies.[4]
United States	Rebuilding plans shall be reviewed *"…at routine intervals that may not exceed **two years** to determine whether the plans have resulted in adequate progress toward ending overfishing and rebuilding affected fish stocks."*[9]

[1]DFO (2009) policy, [2]DFO (2013a) guidelines, [3]DAWR (2018a) policy, [4]DAWR (2018b) guidelines, [5]ICES (2018) advice basis, [6]NAFO (2004), [7]MF (2008) policy, [8]MF (2011) guidelines, [9]NOAA (2018), [10]Restrepo et al (1998).

A key issue is what happens when planned rebuilding outcomes are not met within the rebuilding time period. Four jurisdictions, including Canada, note that rebuilding plans may be revised if evaluations indicate a lack of rebuilding, or inadequate progress to meet desired outcomes in specified timelines (Table 14). Canadian policy notes that in the event of "failure", rebuilding plan provisions must become mandatory. New Zealand policy notes that more restrictive plans may need to be implemented, while Australian policy notes that more permissive timelines may be merited if further examination shows that rebuilding is likely to be affected by environmental factors. The US mandates reviewing rebuilding plans at intervals no longer than two years for adequate progress towards ending overfishing and rebuilding stocks (*Magnuson-Stevens Act*, section 30(e)(7)). Inadequate progress may be concluded if the fishing mortality specified for rebuilding is exceeded, the operational issue causing the overage is not corrected, and any biological consequences to the stock not addressed when known. A lack of progress may also be determined when rebuilding expectations are changed as a result of new or unexpected information about stock status. Under such conditions, additional management measures may be recommended and a new rebuilding plan must be developed within two years if the stock is under Council management. If a stock or stock complex has not rebuilt by $T_{\max}$, then the fishing mortality rate should be maintained at its current $\underline{F}_{\text{rebuild}}$ or 75 percent of the MFMT (limit fishing rate), whichever is less, until the stock is rebuilt or the fishing mortality rate is changed as a result of a finding that adequate progress is not being made (NOAA 2018).

Benson et al. (2016), like Punt and Ralston (2007), point out that time constraints can be modified based on socio-economic considerations including those that may involve mixed stock fisheries (NRC 2014). They recommend flexibility in rebuilding strategies, suggesting it might be better to consider "adaptation" to updated perceptions of stock status and productivity, changing fishery behavior and market conditions, and revised objectives related to a suite of stock preservation, economic, and socio-cultural outcomes. Thus, if rebuilding targets are not met at agreed upon milestones or within prescribed rebuilding time periods, then the plan should only be deemed a failure if there is no adaptation to modify the strategy based on the evolving conditions. This need for adaptation may be particularly important for long-lived species that rely on infrequent, large recruitment events for stock growth, as simulation analyses may not provide much guidance as to expected rebuilding time. However, simulation does allow planning how surplus production should be utilized when it occurs. Simulation outputs can also be used to communicate that rebuilding such stocks is a management exercise in patience, restraint, and limiting by-catch in related fisheries (MacCall 1993).

Data-poor fisheries pose a challenging situation for rebuilding. For example, the Marine Stewardship Council (MSC 2018a) makes the following comments with respect to HCRs and data-poor fisheries:

> "HCRs are often applied on a frequent basis, such as with the annual setting of TACs or effort restrictions. Such HCRs respond dynamically to the monitoring data from the fishery with regular adjustments to input/output type management measures. In data-poor fisheries which are managed without such input/output controls, **management may comprise only technical measures such as size limits, gear restrictions, closed seasons and closed areas**. In these cases, the specific terms of the technical measures are usually set and fixed for a relatively long period of time (several years), **based on occasional strategic stock assessments**, that are shown to deliver defined target and/or limit reference points. Such an arrangement may be regarded as equivalent to a dynamic HCR operating over a longer time scale in cases where **some indicators are monitored to confirm that the HCRs are delivering the intended targets for the stock**." [**emphasis** added]

For data-poor fisheries it is acknowledged that policies that advocate management by reference points by estimating biomass and setting an appropriate harvest rate are not always possible. The approach advocated by Dowling et al. (2015) relies on a suite of management actions such as those listed by MSC and establishes control rules and indicators so that when triggers are breached data collection is mandated. Such approaches essentially try to avoid disaster while efforts are made to overcome data and model poverty. Even when management measures are selected through simulation-evaluation processes such as MSE, claims of robustness in rebuilding strategies should be tempered. Simulation-evaluation is a process of eliminating the management measures that are unlikely to perform acceptably, based on the premise that measures that perform poorly in simulation testing are unlikely to work well in a real application. Thus, a process of elimination is followed in hopes that those management measures that are not rejected can at a minimum help to prevent stock deterioration while data accrue.

Table 15. An overview of cross-jurisdictional standards, policies and guidelines relating to revision of rebuilding strategies.

Country	Policy or Guidelines
Canada	If evaluation fails to demonstrate that rebuilding is occurring, rebuilding plans must contain a provision that application of rebuilding measures is mandatory.[1] Reviews should be frequent enough to detect failures (prolonged declines, stagnant growth) and enable changes to be made.[2]
Australia	If there is no credible evidence that rebuilding is occurring, or that it will occur in the specified timeframe, the strategy will be reviewed to identify reasons, changes made in "… a timely manner…" and results made public.[3] For example, if rebuilding is affected by environmental factors, the strategy and timeframe may need to be revised.[4]
New Zealand	If the initial rebuilding plan is under- or over-achieved, it may need to be revised before the rebuilding timeframe has elapsed to create a more restrictive or lenient plan.[8]
United States	Reviews may reveal inadequate progress toward ending overfishing and rebuilding. This may be because F is above F_{rebuild} and other management measures are not correcting for this, or new information has been uncovered about the stock.[9] Revising timeframes is not necessary unless inadequate progress is being made.[9] Plans may be discontinued if it was determined the stock was never overfished in the first place, even if the stock has not achieved B_{MSY}.[9]

Country	Policy or Guidelines
	If a stock has not rebuilt by the established timeframe, then F should be maintained at $F_{rebuild}$, or 0.75*MFMT, whichever is less, until the stock is rebuilt or $F_{rebuild}$ is revised.[9]

[1]DFO (2009) policy, [2]DFO (2013a) guidelines, [3]DAWR (2018a) policy, [4]DAWR (2018b) guidelines, [5]ICES (2018) advice basis, [6]NAFO (2004), [7]MF (2008) policy, [8]MF (2011) guidelines, [9]NOAA (2018), [10]Restrepo et al (1998).

4.9. SUCCESSFUL STRATEGIES AND IMPEDIMENTS

Ingredients for Success

Murawski (2010) collated several characteristics of successful rebuilding plans:

1. Well-defined objectives, inclusive of defined time periods for achieving desired outcomes;
2. Easily understood performance metrics such as biomass, catch, effort, indices of abundance, catch per unit effort, expected time to milestones, and fishing mortality (Butterworth 2008; Mace 2004). It should be noted that (instantaneous) mortality rates such as *F* and *M* (natural mortality) are perhaps not a natural metric to persons unfamiliar with fisheries management science;
3. For most rebuilding strategies, substantial and measurable reductions in fishing mortality at the outset, rather than small incremental changes, requiring effective and rapidly implemented management controls on fishing mortality;
4. An open process inclusive of resource users and the public, and political decision-makers (Powers 2003); and
5. Consistent, scientifically credible, and public evaluation of progress (note the evaluation could be extended to non-biological collateral effects of implementing a rebuilding strategy);

Subsequently, Milazzo (2012) also concluded that case studies and the scientific literature both strongly suggest that rebuilding success requires reduction of fishing mortality early in the rebuilding period. This finding is supported by Sherzer and Prager (2007) who examined the effectiveness of early and decisive reductions of fishing mortality and concluded that action should be taken as soon as possible and not delayed.

Murawski (2010) further cited a requirement for consistent definition of reference points and criteria for determining rebuilding, preferably before the need for developing a rebuilding strategy is apparent. Murawski (2010) described three classes of reference points:

1. “directional advice” using so-called “traffic-light” approaches,
2. hybrid approaches that use quantitative but heuristically determined reference points for biomass and fishing mortality rate (e.g., ICES approach where for example the spawning biomass below which recruitment is impaired, B_{lim}, is often quantified by the inspection of recruitment time-series for obvious points where the probability of good recruitment diminishes significantly suggesting the possility of stock collapse, see Cadrin and Pastoors 2008), and
3. MSY-based advice that links fishing mortality and biomass through production models or stock-recruitment dynamics.

These approaches describe a hierarchy of increasing prescription in methods, but in doing so imply an increasing degree of certainty in status determination and rebuilding projections.

Calls for specified rebuilding time periods in policies and guidelines around the world likely resulted from deferral of rebuilding measures under more qualitative approaches to management by reference points (NRC 2014). There remains a need to accommodate data- and model-poverty since the information demands of MSY (or proxy) reference points are not acheivable in a cost-effective manner over all stocks. This has implications for meeting the legal and regulatory obligations anticipated under the Fish Stocks provisions, where it may only be possible to meet PA Policy *intent* rather than expectations for management by MSY-based reference points or their proxies. Here, procedural approaches that rely on testing the relative perfomance of management options against a range of possible hypotheses expressed as mathematical models may be considered (Punt et al. 2016). Such simulation-based approaches do not require selection of a single "best" model, but rather the selection of a rebuilding procedure that is robust to the uncertain stock and fishery dynamics (in the sense that rebuilding performance remains acceptable despite ignorance of the true dynamics). As noted earlier, this expectation may need to be tempered in cases of data poverty until adquate data accrue to mitigate at least the dominant uncertainties. In addition, entertaining alternative hypotheses for stock and fishery dynamics means that there is no single set of reference points; each alternative hypothesis has its own set of reference points and the relative weighting of the alternatives must be considered. This contrasts with the "best assessment model" approach where there is a single set of reference points predicated on the assumptions of that model despite alternatives being similarly plausible.

The extensive review of US rebuilding strategies and plans documented by NRC (2014) provided the following findings:

1. A lower likelihood of determining a stock has breached limits and requires rebuilding could result from harvest control rules that promptly, but gradually, reduce fishing mortality as stock size declines below the target level of B_{MSY};
2. In general, fishing mortality reference points seem to be more robust to uncertain stock and fishery dynamics than biomass reference points regardless of context;
3. Rebuilding strategies that focus on meeting selected fishing mortality targets rather than on a schedule of biomass targets may be more robust to assessment errors, natural variability and ecosystem considerations, and may have improved socio-economic outcomes. This conclusion was derived in consideration of the following points:
   a. Stock rebuilding rate depends on factors outside management control such as environmental conditions or climate change;
   b. A rebuilding strategy that maintains reduced fishing mortality for a period beyond fish generation time may allow for restoration of age structure or population complexity and is less dependent on environmental conditions than scheduled biomass targets; and
   c. When rebuilding does not progress as expected, keeping fishing mortality lower than F_{MSY} may forgo less yield and have fewer economic and social consequences than more severe controls that aim to meet scheduled biomass targets.
4. For states of data poverty where reference points and biomass cannot be estimated reliably and therefore catch limits based on a "biomass times harvest rate" calculation cannot be established, empirical rules that reduce fishing mortality via input controls may be more effective than strategies based on catch limits and B_{MSY} targets;
5. Reviews of socio-economic impacts of rebuilding are rare, but may inform trade-off choices in a better manner because the costs of rebuilding and loss of benefits that result as limits are approached would be made more explicit, i.e., an improved estimate of consequence in the risk evaluation which may actually increase support for management procedures that avoid the need for rebuilding.

Although the findings of the National Research Council (NRC 2014) appear to favor rebuilding through control of fishing mortality via harvest control rules, there is a risk of ignoring the finding that early and rapid reduction of fishing mortality is a key element of successful rebuilding plans (e.g., Murawski 2010). Once the need for rebuilding is established, immediate action to (further) reduce fishing mortality may be required to increase the likelihood of rebuilding success while a rebuilding strategy and plan are developed. Such action may be required to avoid deepening or entering a state of serious harm while rebuilding procedures, inclusive of HCRs, are being identified and evaluated (e.g., during the two year period allowed for implementing a rebuilding plan for stocks prescribed under Section 6.2 of the revised *Fisheries Act*).

As noted by Powers (2003) the distinction between scheduled biomass targets and procedural control of fishing mortality using a harvest control rule is somewhat artificial, and one can be translated or tuned to the other to give similar results. Some quantity of biomass may legitimately be a desired outcome to define a rebuilt state, and under the Fish Stocks provisions is a required criterion for declaring whether Section 6.2(1) applies. The specification of biomass targets restricts the decision space for fishing mortality, the reduction of F provides a different, and probably overlapping decision space that is not constrained by biomass targets. The difference lies in expected time periods to attain a rebuilt state and the effects on the management outcome such as the catch sequence and catch volatility. Perhaps the biggest benefit of procedural control of fishing mortality is the establishment of negative feedback control, which is suggested as a component of sustainable fisheries management systems by Hilborn et al. (2015). However, if early reduction of fishing mortality is associated with successful rebuilding outcomes, the actions to be taken during the period required to identify a rebuilding strategy and implement a rebuilding plan may be critical. In particular, if status quo management has produced the need to consider rebuilding, can the status quo persist during the period of 2 or more years before a rebuilding plan is implemented under Section 6.2(1) without the risk of further stock deterioration?

The issues are then:

1. Clarity in objectives with relation to any legislative context and policy goals (imperatives), and the order of priority of imperative and other objectives;
2. Risk tolerance for lingering near limiting biological thresholds, “the ignorance zone” where stock dynamics are highly uncertain and it is unclear whether compensatory assumptions hold;
3. Pre-agreed-upon processes for adaptation of the rebuilding strategy at specified conditions, including when (interim) rebuilding objectives are not met, new information is accrued, or updated analyses are available; and
4. Recommended actions during the period of rebuilding strategy development prior to adoption of the rebuilding plan.

Impediments to success

Regardless of the approach to management by reference points, when rebuilding strategies are at least partially successful they will be subject to scrutiny when additional data or analyses indicate that benchmarks of success should be increased or decreased. For example, a change of reference point estimates from models may mean longer than expected rebuilding times to achieve rebuilt targets with the specified risk tolerances; or conversely, conditions supporting higher productivity and thus lower thresholds for limits. Varying degrees of data- or model-poverty may mean that estimation of reference points is unreliable, or that stock status is highly uncertain, which can make it difficult to link the characterization of a stock as needing rebuilding to potentially punitive management measures. Similarly, unambiguous determinations of rebuilding progress can erode both scientific and management credibility, noting the general tendency for resource users and the public to expect rapid rebuilding success. Murawski (2010) noted that the latter may be partially due to optimistic forecasts of future stock states based on assumed future recruitment events. We note that this latter issue may be mitigated to some extent by adopting a strategic approach to developing alternative perspectives on future stock dynamics. Rebuilding expectations can be tempered by evaluating proposed management procedures for their robustness against uncertainty in past and future stock-recruitment dynamics, which is arguably one of the most difficult problems in fisheries science.

MacCall (1993), Powers (2003), and Murawski (2010) noted the likelihood of pressure for decision-makers to increase catches at the potential risk of incomplete rebuilding, particularly for chronically depleted stocks if the target levels are near, or even above, previously observed historical maxima. There may also be the belief that stocks are unlikely to return to former levels even in the absence of fishing mortality, as can happen in the face of deleterious environmental factors, or because the collective experience of resource users does not extend backward to the time when a stock was at a higher biomass level. Faced with arguments about the rebuilt target based on theoretical quantities that are hard to understand by many, and seem unconnected to recent experience, there may be pressure to adopt too narrow a view of rebuilding potential. Here again, a procedural approach that pre-specifies management responses to a variety of combinations of future stock dynamics and achievement of fishing mortality targets may be helpful to avoiding early abandonment of a rebuilding plan. Evaluation of a range of possible scenarios can capture short- to mid-term economic or access costs due to alternative measures to illustrate trade-offs with stock conservation. A key step here is to institute the afore-mentioned adaptation of the rebuilding plan at specified periods or when new information becomes available.

Along with concerns about management controllability of fishing mortality (e.g., uncontrolled bycatch in other fisheries, poor estimates of directed catch), multi-species fishery problems were noted by Murawski (2010) as being particularly vexing since the differential rate of rebuilding among component stocks may mean that relatively minor stocks control access to more abundant target stocks. However, this dilemma has no broadly adopted best practices internationally.

4.10. ECO-CERTIFICATION STANDARDS

Key Points:

- In the Marine Stewardship Council Standard, and in contrast to some fisheries jurisdictions, “rebuilding” refers only to stocks that are already above limits, but are rebuilding to desired targets. Stocks below a point of recruitment impairment (limit) do not pass MSC requirements even if a recovery plan is implemented for the particular jurisdiction.
- MSC employs a weight of evidence approach. Higher scores are provided when there is either evidence of rebuilding, or rebuilding on schedule is considered likely/highly likely (70/80%) based on simulation modelling, exploitation rates (probability of F being below F_{MSY}), or previous rebuilding strategy performance.
- MSC requires evaluation of rebuilding strategies when stocks are less than 80% likely to be above their respective point of recruitment impairment, and are not fluctuating around a MSY- compatible target.
- MSC does not require rebuilding strategies to be evaluated once a stock is fluctuating around a MSY-compatible target, that target represents the rebuilt state. The highest scores are allocated by the MSC to units of assessment where there is a high degree of certainty

(>95%) that the stock has been fluctuating around this level, or has been above this level, in recent years.

- Exploitation rates appear to be a key performance measure for MSC in reviewing rebuilding strategies, with higher scores being assigned where it can be shown that F is likely (> 70%) or highly likely (>80%) to be below F_{MSY}.

4.10.1. Context

The Marine Stewardship Council's (MSC) Fisheries Standard (MSC 2018a), and the accompanying guidance (MSC 2018b), were reviewed to further inform international perspectives on rebuilding expectations and performance measures.

The MSC Fisheries Standard is based on three core principles: sustainable target fish stocks, environmental impact of fishing, and effective management. Principle 1 (Sustainable Target Fish Stocks), suited to single-species management considerations, is evaluated based on both outcomes and harvest strategies. Outcomes for Principle 1 are evaluated in turn based on up to two performance indicators: Stock Status (PI 1.1.1) and where relevant Stock Rebuilding (PI 1.1.2). Harvest strategies for Principle 1 are evaluated based on four performance indicators: the Harvest Strategy (PI 1.2.1), Harvest Control Rules and Tools (PI 1.2.2), Information and Monitoring (PI 1.2.3), and Assessment of Stock Status (PI 1.2.4; MSC 2018a).

4.10.2. Rebuilding trigger

In the MSC Standard, and in contrast to some fisheries jurisdictions, "rebuilding" refers only to stocks that are already above limits but are rebuilding to desired targets. Under the Stock Status indicator (PI 1.1.1), stocks in units of assessment seeking certification should be "at a level which maintains high productivity and has low probability of recruitment overfishing" (MSC 2018a). In order to achieve a minimum passing score under Stock Status, stocks must at least be likely (>70%) to be above the point of recruitment impairment (PRI), or at least were so within the past year (MSC 2018b). This requirement with respect to the PRI is analogous to a requirement to be above biomass limit reference points in many jurisdictions. Stocks below this level do not pass MSC requirements even if a recovery plan is implemented for the particular jurisdiction (MSC 2018b).

If the stock is likely (at least 70%) above the PRI, but not highly likely (at least 80%), and also "fluctuating around a level consistent with MSY" (MSC 2018a), then a second performance indicator for rebuilding may be evaluated for fisheries units of assessment seeking certification. Thus, MSC requires evaluation of rebuilding strategies when stocks are less than 80% likely to be above their respective PRI and are not fluctuating around a MSY - compatible target.

The reference points used for evaluating stock status should be "consistent with ecosystem productivity" and adjustments to reference points can be made "consistent with … natural environmental fluctuations," although they should not be adjusted as a result of human-induced impacts such as habitat loss or pollution (MSC 2018a).

If a stock is identified as a "key Low Trophic Level" (LTL) stock, MSC requirements are somewhat different than for other stocks. For key LTL stocks, evaluation of rebuilding strategies would be required where stocks are "likely" (>70%) but not "highly likely" (>80%) to be above the point where "serious ecosystem impacts" could occur, and when the stock cannot be shown to be fluctuating around levels "consistent with ecosystem needs."

Points where "serious ecosystem impacts would occur" for key LTL stocks would be expected to be higher than the PRI, and potentially determined analytically from ecosystem models, but should not be less than 20% of B_0, the unfished biomass. Levels “consistent with ecosystem needs” are by default considered to be 75% of B_0, although lower values could be used if supported by ecosystem modelling or empirical data.

4.10.3. Rebuilt state

As rebuilding strategies no longer need to be evaluated once a stock is fluctuating around a MSY-compatible target, that target represents the rebuilt state (or, for key LTL stocks, levels consistent with ecosystem needs). The highest scores are allocated by the MSC to units of assessment where there is a high degree of certainty (>95%) that the stock has been fluctuating around this level, or has been above this level, in recent years (timeframe unspecified but examples are provided to illustrate how to construct a rationale for a specific choice, MSC 2018a). MSC also permits the evaluation of stock status by fishing mortality rate alone; for such stocks, F must have “been low enough for long enough to ensure the required biomass levels are likely to be met.” (MSC 2018a).

4.10.4. Rebuilding timeframe

MSC reviews rebuilding strategies for stocks with respect to rebuilding to targets, with lower scores given for units that establish timeframes for rebuilding stocks as the lesser of 20 years or two generation times (or, if two generation times is less than five years, then five years), and higher scores given to units where the timeframe does not exceed one generation time.

4.10.5. Rebuilding objectives

The Harvest Strategies indicator (PI 1.2.1) in general is evaluated by MSC against an overall objective of achieving a high likelihood (80%) of stocks being above the PRI (or level of serious ecosystem impacts for key LTL stocks), and of fluctuating around MSY-compatible targets (or levels consistent with ecosystem needs, for key LTL stocks; MSC 2018a). In conjunction with the requirements of the Rebuilding Strategies indicator (PI 1.1.2), the timeframe for achieving these desired states with the stated probability in rebuilding stocks could range from less than one, to two generation times, with a maximum of 20 years.

The guidance further notes that reference points may only be implicitly present in objectives or harvest control rule design, and not explicitly stated in clear management objectives (although such would merit higher scores):

> “If a management strategy is based solely around a target reference point, the HCR, when combined with the target reference point should ensure that the stock remains well above the PRI and ensure that the exploitation rate is reduced as this point is approached. This is an implied limit reference point.
>
> Equally, a management strategy based solely around a limit reference point should imply that there is a target reference point close to or at B_{MSY} (or some other measure or surrogate that maintains the stock at high productivity), and at a level that is well above the limit reference point.” (MSC 2018b)

4.10.6. Performance measures

Apart from estimates of biomass or abundance in relation to reference points, exploitation rates appear to be a key performance measure for MSC review of rebuilding strategies (PI 1.1.2), with higher scores being assigned where it can be shown that F is likely (> 70%) or highly likely (>80%) to be below F_{MSY} (MSC 2018a). Alternatively, “clear evidence of rebuilding”, showing increases in the stock in at least the past two years, may be used (MSC 2018b).

Information and monitoring (PI 1.2.3) standards show increasingly higher scores are allocated where stock abundance and removals are monitored, with one or more indicators monitored to support the harvest control rule (MSC 2018a). It can be inferred that performance measures for abundance, removals and other indicators would also be considered in evaluating rebuilding strategies under PI 1.1.2.

MSC (2018b) suggests that evidence to demonstrate rebuilding is occurring should be achieved within the normal maximum five year duration of certification However, this may be problematic for long-lived species with recruitment dynamics that produce infrequent but large year classes where there may be little ability to predict a substantial recruitment in a five year period and little ability to detect the recruitment event until years later when fish can be selected by survey gear or fisheries.

4.10.7. Development of management procedures

The MSC standard refers specifically to rebuilding or recovery *strategies*, not formal plans which may have binding legislative requirements (MSC 2018b). While rebuilding strategy development is not specifically addressed, the MSC Standard in general scores harvest strategy design under indicator PI 1.2.1. Lower passing scores are given for strategies that can be expected to meet overall stock management objectives, and increasingly higher scores given for strategies responsive to the state of the stock, with elements that work together toward achieving objectives and are explicitly designed to do so, i.e., such as those designed via simulation-evaluation. The evidence on which harvest strategy evaluation can be based ranges from, at minimum, prior experience, plausible argument, “testing” via structured logical arguments and analysis, through to full “evaluation” including testing for robustness to uncertainty (MSC 2018a).

At minimum, harvest control rules under indicator PI 1.2.2 may be “generally understood” to be in place, or are at least available for implementation to reduce exploitation as stocks approach the PRI. Design aimed at avoiding limits is a minimum standard; design aimed at achieving targets allows for higher scores (MSC 2018b). Specifically, higher scores are allocated to units of assessment with harvest control rules in place that can be expected to achieve desired targets, take into account a wide range of uncertainties (including ecological roles), can be shown to be robust to main uncertainties, and are supported by tools where evidence clearly shows efficacy in achieving desired exploitation rates (MSC 2018a).

4.10.8. Evaluation of rebuilding plans

MSC reviews candidate assessment units for certification to determine whether there is, at minimum, monitoring in place to evaluate the efficacy of the rebuilding strategy being implemented for a stock that cannot yet meet desirable stock states under indicator PI 1.1.1 (with respect to being able to complete rebuilding in the specified timeframe; MSC 2018a).

Higher scores are provided when there is either evidence of rebuilding, or rebuilding on schedule is considered likely/highly likely (70/80%) based on simulation modelling, exploitation rates (probability of F being below F_{MSY}), or previous rebuilding strategy performance (MSC 2018a).

4.10.9. Revising rebuilding plans

Harvest strategies in general are candidates for high scores when they are not only periodically reviewed, but also improved as needed (MSC 2018a). However, no specific guidance is given for timing of reviews or the need for improvements.

4.10.10. Coincident catches

The MSC Standard speaks to several forms of coincident species catch considerations. First would be the removals from each component within a multi-stock fishery. Multiple species or stocks within a fishery may either be treated as individual units of assessment, or as separately scored elements within a single unit, each evaluated against the minimum scoring criteria for stock status – i.e., avoiding limits and achieving targets (PI 1.1.1, MSC 2018a). The Standard indicates further that "overall target reference points should be consistent with the intent of the [performance indicator], and maintain the high productivity of the stock complex" (MSC 2018a). This consideration is germane to species such as Pacific Salmon or invertebrate stocks where stock structure is complex, data support for decisions is low for fine-scale spatial management, or stock structure is suspected but not demonstrated. In the case of stocks managed based on indicator stocks, "MSC requires that there is a good basis for expecting that none of the component stocks are reduced below their limit reference point" (MSC 2018b).

Continuing with accounting for targeted catches, harvest strategies should at least account for removals by the unit of assessment, with higher scores possible when there is "good information on all other fishery removals from the stock" (PI 1.2.3, MSC 2018a). Increasingly higher scores are possible for harvest strategies that at least review the potential efficacy of measures to minimize unwanted catches (PI 1.2.1, MSC 2018a). The unit of assessment should be "free" of illegal, unreported and unregulated (IUU) catches (MSC 2018b).

MSC's Standards Principle 2 (Environmental Impact of Fishing) further addresses desired outcomes, management and information requirements for non-target primary species (PI 2.1), secondary species (PI 2.2), and endangered, threatened or protected (ETP) species (PI 2.3), among others. Primary species are those not included in the unit of assessment, but where management objectives and measures are in place with respect to avoiding limits and achieving targets (i.e., non-target but otherwise important fish stocks caught as bycatch; MSC 2018a). Secondary species may not have such measures in place. At minimum, primary and secondary species should be likely (at least 70%) to be above their PRI or other biologically based limits, with strategies in place to maintain them in that condition. If they are below their PRI, harvest strategies for the unit of assessment should not hinder rebuilding of such stocks (MSC 2018a). For ETP species, measures must be in place that at least minimize mortality, in addition to not hindering their recovery.

4.10.11. Transitioning to target stock and fishery outcomes

The criteria against which units of assessment are evaluated changes with stock status and stocks that can meet minimum stock status requirements under indicator PI 1.1.1 no longer need to be evaluated for rebuilding strategies under indicator PI 1.1.2. However, there is no specific information in the MSC standards for transitioning among different management plans.

5. DISCUSSION

Key Points:

- Rebuilding strategies should adopt key principles to suit legislative context and preserve policy intent, demonstrate an acceptable standard of fisheries science and rebuilding performance evaluation, and define precautionary strategies that include pragmatic and unambiguous management measures.
- There is a need to describe approaches for data-poor and data-moderate stocks and fisheries, as well as data-rich scenarios, that preserve the PA Policy intent.

- Management systems should impose feedback control to provide an explicit and consistent mechanism to reduce harvest when abundance is perceived to decline and increase it when it is perceived to increase.
- Exceptional circumstances should be pre-specified to allow for adaptation of a rebuilding strategy, including cessation of the existing strategy in light of new data, updated analyses or revised objectives that may result in a revised status determination and prognosis. Exceptional circumstances also may include unexpected departures from expected performance relative to timelines, unanticipated stock and fishery monitoring data, or loss of data sources.
- Guidance is required regarding the criteria used to determine when to review rebuilding objectives and the criteria for determining when an objective should be adjusted.
- The Science Sector role relates to identifying biological limits to harvest, stock status, and evaluating consequences of choice to management outcomes of interest.
- Scenario planning, as “thought experiments” for group learning, reframing perceptions and preserving uncertainty in advice when it is irreducible, may be useful procedures for developing rebuilding strategies as well as a means of identifying socio-economic and cultural goals.

5.1. PRINCIPLES FOR REBUILDING STRATEGIES

Scientific guidelines for designing rebuilding strategies should follow key principles:

1. Consistency with legislative context and policy intent;
2. Demonstration of an acceptable standard of fisheries science and methods for evaluation of management system performance;
3. Conformity with a definition of precautionary strategies by including:
    a. measurable objectives for limit and target states, and matching performance measures;
    b. feedback control in (rebuilding) management procedures;
    c. a means of assessment and performance evaluation that consider both reducible and irreducible uncertainties; and
    d. an adaptive response to new information and updated analyses;
4. Pragmatic and unambiguous management measures so there is a high likelihood of successful rebuilding plan implementation (distinct from performance evaluation in 3c); and
5. Cost effectiveness, meaning that trade-offs between the likely efficacy of the strategy and costs are identified for a range of management options, including those options with increased data collection.

Expanded discussion of these key principles is provided in the following sections.

5.1.1. Legislative context and policy intent

Overarching international agreements were reviewed in Section 2.1 and Appendix A; the Fish Stocks provisions of the revised *Fisheries Act* and proposed regulations for rebuilding were reviewed in Sections 2.2 and 2.3, respectively. The PA Policy intent is to avoid limit reference points and achieve threshold or target reference points related to desirable stock states. Limits are deleterious states consistent with serious, irreversible or only slowly reversible harm to fish stocks, dependent species and their ecosystems. Targets relate to the policy intent that aims to avoid loss of economic and socio-cultural benefits, which implies a desire to promote maintaining stocks at, or above, levels that provide those benefits over the long-term, consistent with Section 6.1(1) of the revised *Fisheries Act*.

The PA Policy is predicated on reference points related to maximum sustainable yield, but admits theoretical proxies or empirical quantities as an accommodation for increasing data- and model-poverty. A harvest control rule (HCR) is a required PA Policy element; an HCR is typically represented as the fishing mortality rate to be applied over the entire range of stock status (biomass or abundance) as in the PA Policy provisional HCR. However the PA Policy intent to reduce the rate of removals as biomass declines to a limit may be accomplished via a range of input or output controls that are demonstrably appropriate to the context.

As noted in Section 3.1, data and model poverty present a substantial challenge to fisheries policies similar to the PA Policy, since it may not always be possible to reliably determine reference points, stock status and overfishing relative to a limit fishing rate. All these quantities imply some knowledge of stock abundance and exploitation rate that cannot be estimated in extreme states of data and model poverty, and perhaps only poorly estimated in data-moderate cases (Dowling et al. 2015). This situation may occur because no abundance times series is available, key quantities are poorly estimated (natural mortality, growth, selectivity, stock-recruit parameters, etc.), or a population dynamics model is unavailable due to time poverty (i.e., a lack of analytical resources). For such stocks, the collection of data and development of quantitative analyses may not be cost-effective, and approaches other than “estimate abundance and apply a sustainable harvest rate” must be considered (e.g., input controls such as spatial measures, gear restrictions, size limits, etc.). The gap between the policy desire for management by reference points and data- and model-poverty for quantitative assessment of a stock can foster inaction on the basis that “there is no model-based assessment”, “the reference points are unreliable”, or “stock depletion is poorly known, or not at all”. Regardless, the expectation to provide advice on precautionary fisheries management based on legal context, policy, and public scrutiny may persist despite states of data- or model-poverty.

In such situations, there is a need to reconcile the provision of science advice to support management of data-poor stocks and fisheries with the PA Policy, as has been attempted for the Commonwealth Harvest Strategy Policy in Australia (e.g., Smith et al. 2009, Dowling et al. 2015). There has been noteworthy activity to develop “data-limited methods” (e.g., Carruthers et al. (2014), see papers in Thorson et al. (2015) and software for implementing a procedural approach to data-poor fisheries (e.g., DLMTools, Carruthers and Hordyk 2018). Yet, there is no substitute for data (Dowling et al. 2015). At some point, the ability to construct hypotheses, borrow data from similar stocks, and identify feasible management actions that can be justified on the basis of stochastic feedback simulations breaks down. Thus, coupling changes in available indicators with augmented requirements for data collection or analyses of available data represents a precautionary element of rebuilding strategies for data-poor stocks.

5.1.2. Standard of practice

Defensible fisheries science should meet current standards of acceptable scientific practice, requiring a systematic approach to defining objectives, investing in stock and fishery monitoring data, and responding to the results of new information and analyses. Acceptable practice is defined by prevailing international and domestic scientific methods and decision-making frameworks documented in fisheries agreements, policies, and guidelines, the scientific literature, and by peer-review of science advice. Effective fisheries management systems, including those applied to rebuilding depleted fish stocks, rely on integration of science and management practice in a logical decision-making process that includes at least three basic steps (Goodwin and Wright 1991; Starfield 1997):

1. A lucid statement of the objective(s); *what are we trying to achieve*?
2. A defined a set of measures for evaluating the degree to which the objective(s) have been met; *how well does a set of management actions perform with respect to what we are trying to achieve*?, and
3. A procedure for ranking alternative options in terms of these measures; *what is the priority of the (rebuilding) objectives quantified by the measures*?.

Science can inform the rebuilding strategy component of a fisheries management process, but the policy choice for resource management decisions is also based on values and thus cannot be solely science-based. Structured decision-making (SDM, Gregory et al. 2012) is a repeatable process for finding solutions to values-based resource management problems (see also Lane and Stephenson 1995; Stephenson and Lane 1995). It includes the key step of evaluating anticipated outcomes of management choice subject to uncertainty (Figure 7) which is consistent with element *PA4* of the PA Policy (performance evaluation; Table 3) if outcomes are examined prospectively using techniques such as closed-loop feedback simulations.

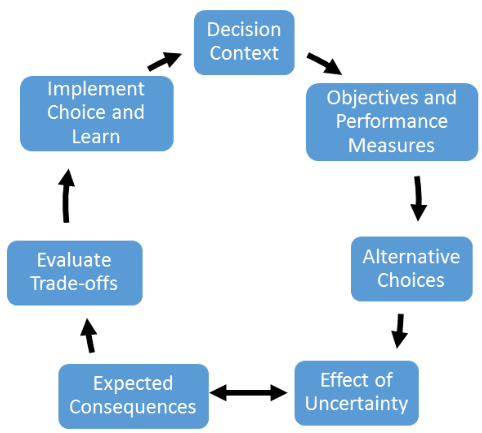

Figure 7. Diagram of a 7-step SDM process. Decision context articulates what decision is to be made, how the decision is made, who makes the decision, and when the decision is needed. Alternative choices describe feasible management actions. The effect of uncertainty on expected consequences often requires repeated examination (double headed arrow), and the entire process is iterative allowing for learning as new data are gathered, or objectives evolve over time (clockwise progression of arrows).

5.1.3. Precautionary strategies

Precaution

Restrepo et al. (1998) pointed out that the term “precautionary” should be used with care by fisheries scientists in the provision of advice (see also commentary on science advice in Hutchings and Stenseth 2016; Rice 2011). Precaution in science advice is exercised by risk-qualified statements about desired stock and fishery outcomes and the identification of management actions that are likely to achieve those outcomes; precaution is not defined by recommending “conservative reference points” or, following the example of Restrepo et al. (1998), by promoting the use of a low quantile of the distribution of F_{MSY} as the best estimate of F_{MSY}. The role of science in providing advice on management strategies in general, inclusive of stock and fishery rebuilding, can be strengthened by peer review of advice by experts from a range of disciplines. That review process should itself include a feedback system such that subsequent iterations of rebuilding strategy development can be shown to have responded to the peer-review and the resulting evolution of science advice over time (either by accommodating the review outcomes or providing a rationale for why suggested actions are not appropriate). This includes advice on biological outcomes, as well as risk-based communication of trade-offs between biological, socio-economic, and cultural outcomes (Rice 2011). We would add consistency (standardization) of communication of management strategies (inclusive of rebuilding considerations) as an additional means of strengthening the impact of peer-reviewed science advice.

The use of precaution in management strategies is consistent with sustainability considerations. A basic definition of sustainable fisheries includes the following attributes (Hilborn et al. 2015):

a) Specific objectives for fishing pressure and abundance (which implies objectives about utilization of abundance);

b) Monitoring of fishing pressure and abundance;

c) Assessments to determine if targets are being met according to pre-determined performance metrics;

d) Feedback management systems that adjust fishing pressure in response to the assessments and in particular restrict fishing pressure when it is too high; and

e) Enforcement systems to assure compliance with regulations.

These same attributes for sustainable fisheries were also largely identified by Sainsbury (2005). Including attributes (a-e) helps to define a sustainable fisheries process as the ability to 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 integrity (e.g., no impairment of recruitment or other states considered to represent serious harm), socio-economic and cultural outcomes, and that these objectives are measurable whenever possible. Defending a claim of fisheries sustainability means that the management (rebuilding) strategy, i.e., objectives (a) plus the actions needed to achieve the objectives (b-e) meets a defined standard of acceptable scientific and management practice. Scientific defensibility of a specific choice of data, stock assessment method, and harvest control rule (b-d) requires a systematic approach to defining objectives, investing in stock and fishery monitoring data, and reacting to the results of new information and analyses in order to take corrective actions that promote acceptable outcomes.

Feedback

Attribute (d), which specifies that management systems should impose feedback control, is perhaps the operational step of highest importance. Feedback links management actions with future stock states. Unless there is an explicit and consistent control mechanism to reduce harvest when abundance is perceived to decline and increase it when it is perceived to increase, then the system can rapidly assume undesirable states (e.g., persistent overfishing, or under-utilization, stock decline to thresholds of serious harm).

Adaptation

Prior-testing of proposed rebuilding options in simulation is part of a precautionary approach to eliminating bad management options; it may not be possible to conduct such simulations prior to the requirement to implement a rebuilding plan. Instead simulation-evaluation of the expected efficacy of management measures may be a proposed milestone deliverable of a rebuilding plan. Regardless of the amount of pre-testing of proposed management measures, there is still a requirement for flexibility in design of the strategy. This flexibility is not meant to apply to interpreting analyses or models or to variation in the application of the selected rebuilding plan.

Exceptional circumstances, a term often used in a MSE context, can be pre-specified and applied regardless of whether simulations are conducted. This consideration defines conditions that trigger review of a rebuilding plan and even cessation and revision of the existing plan if it is found to be performing poorly. Unexpected departures from expected performance relative to timelines, unanticipated behavior in stock and fishery monitoring data, and updated analyses that alter perception of stock status or prognosis all represent possible exceptional circumstances. The key idea is to use such occurrences to address deficiencies in the strategy and implementation, not as an off-ramp to lapse requirements to meet agreed-upon rebuilding and management strategy objectives. Failure of rebuilding strategies result from the inability to adapt to updated knowledge, previously unidentified uncertainties, and new results. In addition to an exceptional circumstances protocol, most rebuilding strategies would be subject to regular review on an interval of 3-5 years depending on context, and likely more frequently earlier in the life-span of the plan. However, there is a need to specify guidance on:

1. The criteria that should be used to determine when to review rebuilding objectives and system performance relative to objectives;
2. The criteria for determining when an objective should be adjusted;
3. The elements of a plan subject to evaluation at each review. For example, one would not expect stock recovery to materialize in the first few years of a rebuilding plan for a long-lived species with late maturity, but review could focus on progress towards reducing fishing mortality to desired levels and implementation errors.

Assessment and performance evaluation

Status determination by comparison of estimated biomass with quantitative reference points is not always possible and a *weight of evidence* approach may be required. A common component of risk assessment and risk management, weight of evidence approaches encompass considerations both of the *totality* of evidence (evaluating the combined contributions of individual studies which by themselves may be insufficient), and the typically expert judgement-assigned *weights* for each line of evidence in the composite. A line of evidence may consist of one or more study or indicator (Health Canada 2018).

For such situations, a weight of evidence approach might involve the following steps (modeled after Health Canada 2018):

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

Performance evaluation of management strategies may be retrospective or prospective. Reliance on retrospective evaluation alone (as cited in the PA Policy) is more risk-prone than undertaking prospective evaluation (FAO 1995a, Kronlund et al. 2014a,b). Although the former approach may be the only practical option in the short-term despite its limitations, retrospective evaluation is mostly diagnostic of realized historical performance under a single assumed hypothesis for the fisheries system. It is possible to consider “retrospective” performance of alternative management actions empirically by considering what decisions would have been made in the past, if those actions had been applied to the data and assessment available at the time. This is at best an approximation of what might have happened under an alternative management choice since the trajectory of the stock and subsequent management decisions are dependent on the sequence of management choices over time. Feedback effects imposed by proposed management choices may have produced a far different trajectory and current stock state than actually realized, had they been applied to the real system.

The “best practice” approach to designing management strategies is simulation-based testing of management options against a range of plausible hypotheses for uncertain stock and fishery dynamics (Punt et al. 2016). When there is full involvement of decision-makers and resource users to engage in identifying objectives, identifying feasible management procedures, and evaluating trade-offs among management outcomes the method is commonly known as Management Strategy Evaluation (MSE). The simulations attempt to represent the relative performance of management options in a reasonable facsimile of the actual system in which the options are to be applied. The idea is not to find the “right management procedure” but to reject those that fail to meet stock-specific rebuilding and target objectives. However, all we can say is that the rejected procedures failed to acceptably meet stock-specific objectives under simulated conditions, and therefore are unlikely to work in actual application. We cannot say that procedures that survived elimination are guaranteed to work, which links back to the need for adaptation described previously.

Prospective evaluation via simulation can be motivated on risk considerations. The PA Policy is a risk-based fisheries management policy wherein science is charged with risk evaluation and fisheries managers with risk mitigation via their choice of management actions. Avoiding undesirable outcomes such as the need for rebuilding is focused on the risk of a stock falling below some threshold level or limit. Risk is typically stated as a probability of the outcome, without a link to the consequences of such an event. However, this is a static calculation that does not integrate the time-dependent effects of the realized catch sequence, repeated risk calculations over time, the acquisition of new data, and possible applications of updated assessment methods as understanding of stock and fishery dynamics evolves over time (de la Mare 1998). Risk integrated over time using a forecast (or better a closed-loop feedback projection) and captured in performance measures provides a basis for rejecting management options from consideration on the basis that they are unlikely to work in practice.

Simulation approaches can also be motivated by their application to data-poor or data-moderate stocks and fisheries by not requiring a single set of reference points or the true biomass to be “known”. Each hypothesis for uncertain stock and fishery dynamics is a mathematical model that includes reference points and an accounting of stock biomass over time consistent with the hypothesis. However, the actual reference points are unknown, since the alternative hypotheses may provide a similarly plausible explanation of currently observed data but with quite different estimates of reference points and biomass. More data may help resolve status and scale, but often accumulating data can result in increased structural uncertainty as more information reveals additional hypotheses to explain the fisheries system (Mace 2001). Thus, seeking management options that are robust to uncertainty is part of developing a precautionary strategy.

Pragmatic and unambiguous

Rebuilding strategies should be unambiguous so that they are reproducible. Reproducibility means the steps leading to selection of the strategy are documented and could be repeated, and that implementation of the strategy is the same regardless of who is charged with specifying the rebuilding plan. In addition, participants involved in completing the rebuilding plan should have a common interpretation of the objectives and the management measures proposed to meet the objectives. Acceptance of rebuilding measures depends on the understanding of resource users and key decision-makers. Empirical approaches (population model-free methods that use survey-based indices or even commercial indices as inputs to harvest control rules) to a rebuilding procedure may have enhanced potential for support by resource users. However, their selection should be supported by evidence of their likely efficacy via feedback simulation analyses (e.g., Butterworth and Punt 1999) that includes investigation of their dependence on the assumed functional link between the index and stock abundance.

5.1.4. Cost-effectiveness

Costs of management strategies can be viewed from two perspectives, the first related to implementation. Implementation costs include the expenses associated with ongoing data collection (e.g., surveys, fish ageing, tag release-recovery programs) and analyses to support application of the management procedure inclusive of an HCR. Also included are the costs of implementing the rebuilding plan such as catch and compliance monitoring. Such considerations may inform the choice of a preferred management procedure where expected stock and fishery outcomes from feasible procedures are not markedly different in terms of rebuilding progress, or a performance-cost trade-off is necessary.

A second way to view costs would result from decisions that delay implementation of a rebuilding plan, which may incur further stock degradation and possible loss of any remaining benefits to resource users. Where full agreement cannot be obtained on a rebuilding strategy and plan (e.g., identification of a rebuilt state) measures should nevertheless be identified for implementation in the short-term while agreement is sought. Although science does not make the trade-off choice between costs and expected stock and fishery outcomes, it has a role in helping to quantify and portray those trade-offs. The Australian Government (DAWR 2018) includes such considerations in guidelines for implementing its Commonwealth fisheries policy.

5.2. SCIENCE ROLE IN DEVELOPING REBUILDING STRATEGIES

The role of science in developing rebuilding strategies encompasses all the aspects required to develop management strategies in general. The FAO Technical Guidelines on the Precautionary Approach to Capture Fisheries and Species Introductions (FAO 1995a) summarized the main issues for fisheries research with respect to precaution in the use of fisheries resources [**emphasis** added to items with an inherent science role]:

1. Provide **data and analyses of relevance to fisheries management** that are accurate and complete;
2. Monitor fisheries;
3. Develop **operational and measurable objectives that are related to limits and targets** using criteria that are scientifically usable (**can be evaluated** using quantifiable metrics) and **relevant to management**;
4. Incorporate **uncertainty** into assessments and management;
5. Provide **scientific evaluation of the consequences** of management actions;

6. Incorporate **biological** and socio-economic **elements** into advice;
7. Address **reversibility and irreversibility in ecosystems**;
8. Conduct **research on which management processes and decision structures work best**;
9. Conduct work that is multi-disciplinary in nature to include environmental, economic and social sciences and **addresses decision-making processes** within the management institution; and
10. Define implementation guidelines.

Issues 1, 3-5 and 8 above speak to the role of science in supporting a decision-culture approach oriented towards the evaluation of the consequences of alternative management options. This is not exclusive of the requirement for study of biological and broader environmental considerations (e.g., issues 6, 7, and 9), but changes the entry point to the problem, from calls for more study to the need to support a (usually annual) decision. A decision will be made, even the decision of "no change" to the status quo, regardless of the amount of study or understanding of the biological and socio-economic system (Gregory et al. 2012).

The extent to which each of these issues is addressed, and the responsible party, may vary among jurisdictions. For example, in Canada the responsibility for monitoring fishery-dependent data (e.g., catch whether retained or released) generally lies with fisheries management, while collection of stock monitoring data is generally conducted by science. Also, the meaning of terms like "develop" in (3) above does not imbue "science" with decision-making authority for management actions. Rather, this refers to the process by which, for example, aspirational goals are translated into measurable objectives that can be evaluated to determine the realized or likely future performance of management actions. Another area where practice may differ from the FAO technical guidelines is related to guideline (3) where, in particular, targets may be the responsibility of fisheries management guided in some jurisdictions by legal context. For example in Canada the PA Policy identifies that target reference points (USR when applicable and TRP) are "*…* developed by fishery managers informed by consultations with the fishery and other interests, with advice and input from Science". Here, the advice from science would presumably be related to identifying MSY or proxy reference points, and in ensuring that the "*…*minimum function [of the USR] in guiding management of the risk of approaching the LRP" is not diminished. In New Zealand (Table 16) targets *"…*will be set by fisheries managers based on estimates of MSY-compatible reference points, but modified by relevant factors."

The identification of operational objectives related to the stock and fishery goals depends on collaboration between scientists, decision-makers and resource users. Although scientists do not set policy, they have a role in providing advice in the formulation of policy and an interest in how the policy is expressed in operational terms. This is because scientists have a responsibility to give advice to decision-makers on options that are likely to meet policy intent and objectives for the specific stock context. The form of operational objectives depends on both the data and the scientific methods used to measure their success. Furthermore, open discussion of the interaction between science and policy is the best way to define the boundary between them so that policy is not presented as science and vice-versa (de la Mare 1998, Rice 2011).

As an example of how the science role is demarcated in an international jurisdiction, New Zealand outlined roles and responsibilities for Science working groups (SWGs) and fisheries management (The Ministry) that closely represents the necessary interactions required to design management procedures subject to specified objectives (Table 16). The "Rebuilding plans" section in Table 16 reflects the process steps (1-4) for which SWGs are responsible; these steps are similar to elements proposed for regulations to support the Fish Stocks provisions (Table 4). For example, in step (1) determining whether a limit threshold is breached relates to element (a: *description of status and stock trends*) of the proposed regulations. Identifying a rebuilding timeframe by estimation of T_{min}, also in step (1), relates to element (d: *timelines for achieving objectives*) of proposed regulations. Step (3), illustrating trade-offs of outcomes that result from alternative management actions provides strategic choice and can be linked to elements (c: *measurable objectives*, e: *rebuilding target*, f: *management measures*). Conducting ongoing evaluation of progress towards satisfying rebuilding objectives in step (4) can be linked to combined elements (g: *method to track progress*, h: *periodic review of the rebuilding strategy*).

Table 16. Roles and responsibilities of Science Working Groups (SWGs) and Fisheries Managers with respect to targets, limits and rebuilding fish stocks (taken from Ministry of Fisheries 2011). Note that New Zealand has enshrined MSY in law. The New Zealand harvest policy includes three status-based reference points: a hard limit, a soft limit, and a target. Default values are provided as well as probabilities for avoiding or attaining reference points, and time horizons for rebuilding contexts are specified.

The following requirements are subject to the existence of sufficient information.

Targets

1. SWGs will be asked to provide their best estimate, or range of estimates, of B_{MSY}, F_{MSY}, MSY, or relevant proxies for each of these.
2. Targets will be set by fisheries managers based on estimates of MSY-compatible reference points, but modified by relevant factors.
3. SWGs will define and report on performance measures related to these targets; these assessments will be reported via annual Fisheries Assessment Plenaries and other mechanisms.
4. SWGs will determine whether or not overfishing is occurring, where overfishing is deemed to occur when the average fishing mortality or exploitation rate (or other measure of fishing intensity) has exceeded F_{MSY} or an appropriate proxy.

Limits

1. SWGs will estimate the probability that current and/or projected biomass is below either the soft or the hard limit.
2. If the probability that a stock is below the soft limit exceeds 50%, the stock will be determined to be depleted and SWGs may be requested to develop a formal, time constrained rebuilding plan.
3. If the probability that a stock is below the hard limit exceeds 50%, the stock will be determined to be collapsed and SWGs may be requested to investigate the implications of closing target fisheries and/or curtailing or closing fisheries that incidentally catch the species concerned.
4. If the probability that either limit has been breached exceeds 50%, the Ministry will provide advice to the Minister on a range of management actions that may include a formal, time-constrained rebuilding plan or closure of target fisheries and curtailment or closure of fisheries that incidentally catch the species concerned.

Rebuilding plans

1. SWGs will estimate the probability that current and/or projected biomass is below ½ B_{MSY} or 20% B_0, whichever is higher. If this probability is greater than or equal to 50%, SWGs should calculate T_{min}.
2. SWGs will work with fisheries managers to define and evaluate alternative rebuilding plans that will rebuild the stock back to the target with a 70% probability within a timeframe ranging from T_{min} to 2 * T_{min}. This is likely to be an iterative process.
3. The Ministry will provide advice to the Minister on a range of rebuilding plans that satisfy the T_{min} to 2 * T_{min} time constraint (or an alternative that can be adequately justified), and the specified probability levels.
4. Once a rebuilding plan has been implemented, SWGs will regularly evaluate and report on the performance of the rebuilding plans.
5. The Ministry will provide advice to the Minister on appropriate TACs to achieve the rebuilding plan.

5.3. PROCESS FOR DEVELOPING REBUILDING STRATEGIES

Key steps for developing rebuilding strategies can be outlined as follows:

1. Define the stock and fishery(ies) to which the rebuilding strategy applies;
2. Identify relevant legislative constraints and policy objectives;
3. Develop stock preservation and fishery management objectives by specifying limit and target reference points, the desired certainty of achieving stock states defined by the reference points, and the timeframes for evaluation;
4. Determine stock status relative to limits and targets, and other considerations for the fishery;
5. Evaluate the robustness of any existing strategy, and that of alternative rebuilding strategies, to identify the sequence of catches that acceptably satisfy objectives; and
6. Establish a mechanism for periodic review of rebuilding progress, including the transition from rebuilding to target levels.

Rebuilding strategies imply a need to estimate what the likely future consequences of management choice are to stock and fishery outcomes. Ideally, the future prognosis of the stock state can be quantified using forecasts or closed-loop projections with appropriate considerations of uncertainty. Even if quantitative simulations cannot be done at the outset of developing a rebuilding strategy, a structured process can be followed. For example, “scenario planning” is a technique for describing the future in stories as though written by people in the future (attributed to Herman Kahn who worked with the RAND Corporation during the 1950s, e.g., see Kahn 1965). The approach is intended to encourage group planning, problem identification and accommodating uncertainty where it cannot be resolved. It is a precursor to what is now called structured decision-making (e.g., Gregory et al. 2012) that can serve to organize an approach to the rebuilding dilemma, regardless of whether there is capacity for pursuing quantitative projections of future stock and fishery states. Many of the steps in scenario planning can be considered part of defining the “decision context” in structured decision-making. The decision context articulates what decision is to be made, how the decision is made, who makes the decision, when the decision is needed and when the decision should be re-evaluated and updated.

Scenario planning is a “thought experiment” process for group learning, reframing perceptions and preserving uncertainty when it is irreducible, i.e., uncertainty that cannot be resolved, or is cost-prohibitive to reduce. This may allow engagement of knowledgeable participants in the decision process who might otherwise be excluded by a purely analytical approach, and can help to articulate societal issues. The method entertains multiple futures rather than trying to predict "the" future, which is the basis of management strategy evaluation in fisheries. For example, the "best assessment model" approach (Butterworth 2007) tries both to reconstruct the uncertain past and predict the more uncertain future; failure to do either task accurately may have contributed to the need for rebuilding fisheries in some situations. Scenarios for rebuilding fish stocks should not be taken as though they predict a fixed future; their purpose is to bound possible consequences in a way that permits learning and adaption over time. The scenarios can then be used to inform quantitative forecasts or simulation projections used to evaluate a rebuilding strategy, and may help to improve the understanding of decision-makers and resource users in more long-term consequences of management choice. The steps in scenario planning for a stock rebuilding context might be structured as follows:

1. *Define the key question(s) to be answered and decisions to be made.* If the question is limited to a very small number of changes then more formalized methods may be superior.
2. *Set the time period and scope of the planning exercise.* Consider how quickly the changes in stock status have happened, and the degree to which factors believed to contribute to a decline can be controlled.
3. *Identify major interested parties.* Decide who is affected and has an interest in possible outcomes of a rebuilding plan. Try to identify how these interests have changed over time and may change in the future.
4. *Document basic trends and identify potential driving forces.* This includes stock dynamics, environmental drivers, fishing activities as well as economic, political, technological, legal, and societal trends. Evaluate the degree to which trends affect the problem definition. Describe each trend, how and why it will affect the interested parties. This can be "brainstorming" to identify all potential trends before they are assessed to detect possible group think or confirmation bias.
5. *Identify key uncertainties.* Sketch the driving forces on two axes, assessing each force on an uncertainty (or predictability) scale and an importance scale. The axes can be qualitative. Unimportant driving forces can be discarded. Important driving forces that have relatively low uncertainty or are relatively predictable can be included in any scenario. Therefore such driving forces should not be used to distinguish between scenarios. Look for redundancies between driving forces and eliminate any impossible scenarios (e.g., catch sequences that apply higher fishing mortality than those that led to stock depletion in the first place). However there is value in retaining a status quo scenario as basis for comparing the relative effects of alternative choices.
6. *Determine whether driving forces can be grouped, and reduce the number of forces to a minimum (e.g., 2-3).* This step makes it easier to visualize likely effects.
7. *Identify the extremes.* Identify the range of the possible outcomes of the most important driving forces and check the extremes for consistency and plausibility. Three key points should be assessed:
   a. Time period: are the trends compatible within the time period in question?
   b. Internal consistency: do the driving forces describe uncertainties that can construct plausible scenarios?
   c. Are any interested parties positioned far from their preferred outcomes? To what extent can they influence the outcomes by actions, or by prioritizing their objectives?
8. *Define the scenarios, trying the maintain a small number of scenarios e.g., (2-4).* The current status quo scenario does not have to lie in the middle of other scenarios. One approach can

be to create all “positive” elements into one scenario and all “negative” elements (relative to the current situation) in another scenario and refine. Avoid the purely best case and purely worst case (but retain zero catch scenarios for relative comparisons and the unfortunate circumstance where it is the only scenario that meets objectives acceptably).

9. *Document the scenarios.* Construct a narrative as to what happens in the future and the reasons for the proposed outcomes. Give each scenario a descriptive, “sticky” name (Heath and Heath 2007) for ease of reference.
10. *Assess the scenarios.* Are they relevant for the goal? Are they internally consistent? Do they represent relatively stable outcome situations?
11. *Identify research needs.* Based on the scenarios, assess where more information is needed. The information gap(s) may be biological, or related to the positions of interested parties. When the latter, obtain more information on the motivations of stakeholders, possible changes in markets, possible innovations (e.g., gear changes) that may occur in the industry and so on.
12. *Develop quantitative methods.* If possible, develop models to help quantify consequences of the various scenarios, such as future recruitment patterns, changes in gear selectivity, relative effects of environmental and fishery factors, bias in catch estimation, etc. This step may be infeasible in some contexts, but mimicking the hypothesized system could give some sense of the value of collecting additional stock and fishery monitoring data.
13. *Converge towards identifying management options.* Retrace the steps above in an iterative process until scenarios are reached which address the fundamental issues of identifying measures that might provide successful rebuilding strategies, including those that include additional data acquisition where needed. Try to rank the options by various factors related to objectives, respecting the order of priority of objectives and any imperative objectives dictated by law, policy or agreement.

5.4. RECOMMENDATIONS FOR GUIDELINES DEVELOPMENT

Rebuilding strategies are integral to management strategies, and under the Fish Stocks provisions, rebuilding plans will be required for major fish stocks prescribed under regulations once it is determined they have breached a limit reference point. Proposed regulations that determine the requirements of Canadian rebuilding plans are intended to support obligations particularly under Section 6.2(1) of the revised *Fisheries Act*.

We emphasize the view that recovery or rebuilding should be viewed as integral to a management strategy, and should not be thought of as a “set aside” to be applied when undesirable states are encountered. The PA Policy states that rebuilding plans should be initiated as the limit reference point is approached and should be ready to implement as soon as the stock declines below its LRP (DFO 2009). This statement means that changes in fisheries management measures should not be delayed until the LRP is breached; to do so would not be consistent with an objective to avoid limits. For example, Table 1 of the PA Policy indicates that for stocks declining toward the LRP within the Cautious Zone, “…management actions must arrest declines in the short term or immediately if low in the zone. Risk tolerance for preventable decline – very low / low”. Furthermore, the limit fishing mortality rate (Removal Reference) is intended to be reduced as status declines towards the LRP. Even if a reduction in the limit fishing rate is not fully specified, policy intent can be preserved using a harvest control rule and/or other measures to implement a reduction in target fishing mortality from some maximum (less than the limit fishing rate) as the LRP is approached. These changes in management actions from target to limit levels are in large part why rebuilding should be regarded as integral to the overall management strategy, not a reactive change in fisheries management because a theoretical or empirical threshold is perceived to have been reached or passed.

The following elements and advice should be included in scientific guidelines for rebuilding strategies (note the relevant proposed regulations or legislative topics are identified in *italics*):

Management strategies and rebuilding:

1. Define rebuilding strategies as integral to management strategies. Seek to specify measures intended to rebuild a stock to target levels prior to a limit reference point breach and to promote seamless transitions to target levels when rebuilding from low abundance.

Status, Criteria for Exceeding Limits, and Terminology:

2. Specify how stock abundance (biomass) and fishing mortality are characterized and the stock trend (*if a major fish stock has declined to or below its limit reference point and description of stock status and trends*):
   - 2.1. Report the abundance or proxy status relative to the LRP, i.e., the probability (or qualitative likelihood, IPCC 2007) that $B / B_{\text{lim}} < 1$;
   - 2.2. Report the fishing mortality status relative to the limit fishing mortality rate, e.g., the probability (or qualitative likelihood, IPCC 2007) that $F / F_{\text{lim}} > 1$;
   - 2.3. Define criteria to determine when a limit has been breached for situations where a probabilistic determination can be made, only a deterministic determination is possible, and when a weight of evidence approach must be used;
   - 2.4. Define criteria for handling:
     - 2.4.1. False positive determinations of a limit breach;
     - 2.4.2. Stocks fluctuating around a limit;
     - 2.4.3. Changes in status determination due to new data and assumptions in updated analyses;
     - 2.4.4. An error in status determination (e.g., a data or assessment error).
   - 2.5. Guidance is needed on whether determination of a limit reference point breach should be based on projected stock states (where possible), or current stock states, or accumulating persistent low stock states over time;
   - 2.6. Distinguish between stocks that are losing yield, and those stocks depleted to the extent that there is unacceptable risk of “serious harm” (e.g., recruitment overfishing, ecological losses, or loss of benefits to resource users);
     - 2.6.1. Introduce terminology for categories of “overfished” (e.g., recruitment overfished, depleted, recovering, etc.), to address the abundance (biomass) axis of status;
     - 2.6.2. Introduce terminology for “overfishing” which could be defined in a Canadian context as a state where the fishing mortality rate is determined to exceed a limit, F_{lim}, e.g., F_{MSY} or proxy;
   - 2.7 Further characterize status by reporting stock trends or trajectories (e.g., criteria for “approaching a limit reference point” based on projection, or “decreasing, stable, increasing” trend characterization).

Reasons for stock decline:

3. Identify or propose reasons for the stocks' decline historically and factors likely to affect future stock prognosis (*taking into account the biology of the fish and the environmental conditions affecting the stock and reasons for the stocks' decline*):
    3.1. Describe potential drivers of trends (e.g., "reasons for the stock's decline," including anthropogenic, biological, habitat and environmental conditions),
    3.2. Distinguish time-dependent changes in the relative importance of anthropogenic and environmental factors (e.g., distinguishing where necessary what caused the decline and what is currently keeping the stock at a low level or is likely to do so in future);
    3.3. Characterize the management conditions at the time of status determination (e.g., "a rebuilding plan is in place, with prescribed timelines").

Management objectives and rebuilding:

4. Defined (rebuilding) management objectives for the stock and fishery related to reference points, or benchmarks (*a plan to rebuild the stock above that point, minimizing further decline of the fish stock; measurable objectives aimed at rebuilding the stock, timelines for achieving the objectives, desired rebuilt target, an outcome specified in objectives*):
    4.1. Define interim objectives that allow evaluation of rebuilding progress and create process steps to allow adaptation of the rebuilding strategy using new information and updated analyses, and allow for revisions to objectives if appropriate;
    4.2. Revised objectives for avoiding a limit reference point breach may be required for application when the stock grows above the LRP in the course of the rebuilding plan given a breach has occurred;
    4.3. Define what default stock states could be used to characterize a rebuilt state and the criteria for determine the rebuild state has been achieved (given the desired risk tolerance); additional alternative rebuilt states may be specified by decision-makers (this to distinguish between ss 6.1 and 6.2 of the Fish Stocks provisions);
    4.4. Specify that any decision to introduce time-varying reference points into rebuilding strategies should be supported by evidence derived from feedback simulations to provide some assurance that desired outcomes can reasonably be expected (e.g., reference points are not adjusted downwards to levels where policy intent is unlikely to be preserved, or there is possibility that an assumption of compensatory stock-recruit response dynamics may not hold based on evidence or analogy to similar stocks);
    4.5. Include a decline tolerance objective and performance statistic, where possible, given a specified risk tolerance and time period for evaluation.

Timeframes:

5. Describe methods for the calculation of rebuilding timeframes that may vary depend on available data and model support (*timelines for achieving the objectives*):
    5.1. An estimate of the minimum time to a rebuilt state in consideration of the current stock depletion, generation time, and productivity to the extent possible (i.e., $T_{\min}$);
    5.2. Defined methods of calculating generation time (i.e., specific equations) depending on available data support (e.g., when $T_{\min}$ cannot be calculated, multiples of generation time could be used); and

5.3. Communicate the trade-offs incurred by selecting a target rebuilding time, i.e., by demonstrating how choosing a time longer than $T_{\min}$ affects biological outcomes vs. socio-economic and cultural trade-offs.

Stating objectives, risk and communication:

6. A statement of acceptable levels of risk in the context of the time period for meeting objectives, noting that context-specific specification of risk tolerance is guided by policy and fishery management choice (*measurable objectives aimed at rebuilding the stock*):

6.1. Objectives that include reference points should clearly specify how time should be interpreted, e.g., does a 90% probability of avoiding a limit breach mean a 1-in-10 year chance of a breach, or 90% in each and every year?

6.2. The choice of probability in objectives may vary depending on whether current status is being evaluated, or a management strategy is being designed to meet time-prescribed rebuilding objectives. Guidelines should include a description of how these cases are different and the implications of risk tolerance choice as a stock transitions from rebuilding to target outcomes.

6.3. Adopt and provide guidance on defensible practices for describing and communicating risk to decision-makers.

Uncertainty:

7. Describe various methods by which key uncertainties affecting science advice can be identified and quantified given the state of data and model poverty (*in the management of fisheries; taking into account the biology of the fish and the environmental conditions affecting the stock*):

7.1. Uncertainties include those associated with stock status, biology, environmental conditions facing the stock, habitat, potential drivers (or reasons) for the stock's decline, and implementation error (uncertainties in fishing mortality or total removals);

7.2. Uncertainties can be irreducible, which means that rebuilding measures should be selected based on their robustness to unknown stock and fishery dynamics;

7.3. Uncertainties can be reducible, in which case the rebuilding strategy should include provisions for collecting the data needed, or conducting the analyses required, to resolve those uncertainties.

Performance measures:

8. Measures of stock and fishery performance related to the objectives (*method to track progress to achieve the rebuilding plan objectives*), including:

8.1. The spawning biomass <u>state</u> achievable for a specified time period and specified probability (e.g., what spawning biomass level can be achieved in 2 generations with 50% certainty?);

8.2. The expected <u>duration</u> to achieve B_{rebuild} for a specified probability (e.g., how many years will it take to achieve the B_{rebuild} state with 70% certainty?); or

8.3. The <u>probability</u> of reaching B_{rebuild} for a specified time period (e.g., how certain is a spawning biomass of at least B_{rebuild} in 2 generations?);

8.4. Use of natural numbers when possible in performance measures (years to rebuilt target, catch, number of years of fishery closure, etc.).

Components of sustainable fisheries systems:

9. Management procedures intended to meet stock and fishery objectives under the rebuilding strategy and achieve transition to target outcomes (*management measures aimed at achieving the objectives*);

   9.1. Stock and fishery monitoring needed to collect data required to evaluate performance;

   9.2. Assessments, inclusive of model-based and empirical approaches, to determine if targets are being met according to the pre-determined performance measures;

   9.3. Feedback management systems including harvest control rules and any meta-rules that adjust fishing pressure in response to the assessments. In particular the feedback should reduce fishing mortality when the stock is perceived to decline and increase it when the stock is perceived to increase, subject to meeting any imperative objectives and providing acceptable trade-offs of outcomes related to other objectives;

      9.3.1. The purpose of reference points is to separate objectives from the tactics employed to achieve the objectives. As such the configuration of a harvest control rule should not be constrained to align with, or even include, the reference points used to define objectives. The purpose of a management procedure (tactics) is to acceptably avoid limits and achieve targets;

      9.3.2. For states of data poverty where reference points and biomass cannot be estimated reliably, and therefore catch limits based on a “biomass times harvest rate” calculation established, empirical rules that reduce fishing mortality via input controls may be more effective than strategies based on catch limits and B_{MSY} targets.

Evaluation of rebuilding strategies:

10. Describe a means of conducting evaluation of stock and fishery performance of existing or proposed management strategies relative to objectives appropriate to the state of data or model poverty (*method to track progress to achieve the rebuilding plan objectives*):

    10.1. Proposed rebuilding strategies may need to account for alternative hypotheses that govern the stock trajectory and identify management actions that do not depend on a single “best” interpretation of stock conditions and rebuilding potential. Attribution of stock depletion to environmental factors should not be taken as an indication that fishing mortality has little, or no effect, without evidence that is the case;

    10.2. Describe how to show trade-offs in management outcomes that result from choice of alternative management procedures, including the choice of data collected:

       10.2.1. Trade-offs include possible costs (e.g., persistent or worsening stock and fishery states) and benefits (e.g., stock growth in support of attaining desired stock states, shorter rebuilding times, and restoration of benefits to resource users), and how they vary in response to enhanced data collection (value of information);

    10.3. Where possible, a zero fishing mortality management procedure is needed for each hypothesis under consideration to serve as a benchmark for comparison with alternative procedures and to estimate $T_{\min}$;

    10.4. Related to (10.3), an evaluation of the probability of biomass increase to the LRP and TRP (default to B_{MSY} or proxy), respectively, at T_{rebuild} (or specified milestones) under a zero fishing mortality procedure;

10.5. Where possible, a “perfect information” scenario that assumes both stock size estimation and management implementation is without error over the rebuilding time frame to serve as a benchmark;

10.6. Data-poor frameworks are needed where precautionary steps include data acquisition as part of the rebuilding strategy.

Catch monitoring (targeted and bycatch):

11. Illustrate the value of enforcement systems to provide reliable catch monitoring and implementation of rebuilding strategies as intended by showing the loss of performance due to imprecise data or implementation errors (*in the management of fisheries*):

    11.1. Explicit accounting for catch estimate quality (e.g., plausible direction and magnitude of catch estimation bias).

Interim measures:

12. Identify possible management actions to be taken during the interim period required to identify an acceptable rebuilding strategy and implement a rebuilding plan after an LRP breach invokes s 6.2(1). Such actions should be consistent with the PA Policy intent, noting that reviews of rebuilding performance identify early reduction of fishing mortality as a key feature of successful plans.

Adaptation of rebuilding strategies:

13. Adaptation of rebuilding strategies (*an approach to review the objectives, and an adjustment of these if the objectives are not being achieved*):

    13.1. Advice on determining how frequently the rebuilding strategy should be evaluated for progress which may vary according to:

        13.1.1. Time-prescribed interim objectives agreed to in the development of the rebuilding plan;

        13.1.2. Life history (short-lived fish may require more frequent progress evaluation than long-lived species);

        13.1.3. Schedule of anticipated data collection or availability of new data or analytical resources for updating assessments or simulations;

    13.2. Exceptional circumstances such as unexpected data, or new understanding of the stock and fishery.

    13.3. Specify that not meeting interim or overall rebuilding objectives is not failure; failure is failing to adapt to new data, altered system understanding, updated analyses, or revised objectives. It is to be expected that a rebuilding prognosis will in general evolve from initial expectations through the lifespan of the plan.

Roles and responsibilities:

14. Roles and responsibilities of various contributors to the development of rebuilding strategies and plans, including provisional terms of reference for science advisory requests.

    14.1. Science has a role in helping to set realistic expectations for stock rebuilding by identifying those management actions unlikely to produce desired rebuilding outcomes over a range of possible stock conditions and adapting the selected rebuilding strategy based on the stock response observed over time.

Efficiency in developing rebuilding strategies:

15. Identify items for alignment and efficiencies with related processes, such as terms of reference (and roles and responsibilities) for science advice needed for stocks meriting both rebuilding strategies under the Fish Stocks provisions and recovery potential assessments under SARA.

Consistency of communication:

16. Describe a consistent communication format for science advice on rebuilding strategies.

Elements 2-10 are exactly the same as those needed for defining fisheries sustainability as a process that involves specifying values-based objectives for resource utilization, and the acceptable degree of risk incurred by a management choice (Hilborn et al. 2015). Furthermore, most elements related to actions when the stock is below the LRP are already in existing Canadian policy guidance for rebuilding stocks above an LRP (DFO 2013a).

To make the above elements concrete in operational guidelines, each would require further elaboration to expand these general perspectives and principles, as well as tangible recommendations for science advice providers to apply. This step would consist of specifics such as identifying default risk levels drawn from policy guidance, specific methods of calculating generation times for rebuilding timeframes, or a rebuilt level based on optimizing yield (e.g., B_{MSY} or proxy) to which decision-makers could add alternatives for evaluation. Recommendations in guidelines may include specific process steps or templates to follow, hypotheses or questions to consider, methods (e.g., how should recruitment be projected in forecasts and simulation), and default outputs to routinely produce (e.g., trade-off plots of key performance statistics tied to management objectives). In some cases, a generalized description of methods, approaches or means by which to address each item may also be provided. Such generalizations recognize that methods are continuously evolving, international best practices may not be fully delineated in some instances, and there is a need to accommodate stocks across the continuum of data- and model-poverty from poor to rich.

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8. APPENDIX A INTERNATIONAL AGREEMENTS

8.1. CONCEPTS

The development of policies, standards and guidelines around the application of the precautionary approach in fisheries management marries two separate but related ideas from a series of international treaties over the course of the second half of the twentieth century. The first, and perhaps most important of these, is the concept of avoiding potential adverse effects. The second is the concept of achieving fisheries management objectives, which are often linked to maximum sustainable yield (MSY). Objectives include identifying targets including those related to rebuilding fish stocks. The United Nations “Fish Stocks Agreement” (UNFSA) developed in 1995 (UN 1995) was followed by the *Code of Conduct for Responsible Fisheries*, which was adopted on 31 October 1995 (FAO 1995b) and combined the concepts of avoiding limits and achieving targets.

8.2. AVOIDING ADVERSE EFFECTS

The *precautionary principle* was first outlined in the United Nations’ 1982 World Charter for Nature, although it was not identified as such by name. Principle 11(b) stipulates that:

> “Activities which are likely to pose a significant risk to nature shall be preceded by an exhaustive examination; their **proponents shall demonstrate** that expected benefits outweigh potential damage to nature, and where potential adverse effects are not fully understood, the **activities should not proceed**.” [**emphasis** added]

This statement captures two important prescriptive concepts about information requirements for risk-based decision-making. First, there is a reversal of the burden of proof such that the onus is on a proponent to show that benefits of an activity outweigh potential adverse effects. Second, there is the concept that sufficient uncertainty concerning adverse impacts can justify preventing an activity to proceed.

Evolution of these ideas is evident in subsequent treaty texts. In 1992, the United Nations Conference on Environment and Development (UNCED) in Rio adopted a non-binding policy statement declaring 27 principles. Principle 15 of the Rio Declaration identified for the first time a *precautionary approach* (as opposed to *principle*) to be applied by signatory States:

> “In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, **lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation**.” [**emphasis** added]

Here, the approach lessens prescriptive restrictions on risk-based decision-making in two ways. First, there is a recognition that the capacity to apply the approach will vary among States, potentially giving them flexibility to determine individual decision-making thresholds unique to their jurisdiction (“according to their capabilities”) and economic needs (“cost-effective measures”). Second, the presence of sufficient uncertainty concerning adverse impacts is only described as providing no impediment to decision-makers taking preventative management measures. There is no longer a prescriptive requirement to cease or prevent the activity associated with the potential adverse impacts.

8.3. ACHIEVING (REBUILDING) TARGETS

The 1982 United Nations Convention on the Law of the Sea (UNCLOS) gave coastal states jurisdiction over the natural resources contained in surrounding waters within 200 nautical miles of each state's baseline, an area known as the Exclusive Economic Zone (EEZ). Importantly, the authorities granted by UNCLOS to coastal states in the EEZ were limited by stipulations under Articles 61 and 62 described below.

Article 61 prescribes a fishery management objective of MSY to be achieved, but also mentions two types of adverse effects (over-exploitation, and levels at which reproduction may become seriously threatened) that are to be generally avoided, either for harvested species, or dependent or associated species:

> "2. The coastal State, taking into account the best scientific evidence available to it, **shall ensure through proper conservation and management measures** that the maintenance of the living resources in the exclusive economic zone is **not endangered by over-exploitation**…;
>
> 3. **Such measures shall also be designed to maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield**, as qualified by relevant environmental and economic factors...;
>
> 4. In taking such measures the coastal State shall take into consideration the effects on species associated with or dependent upon harvested species with **a view to maintaining or restoring populations of such associated or dependent species above levels at which their reproduction may become seriously threatened**." [**emphasis** added].

Article 61 (3, 4) contains the first mention of rebuilding objectives, with respect to two rebuilt target states. The first is for dependent or associated species, to above levels where reproduction is seriously impaired (implying a limit); and the second is for harvested species, to levels that can produce MSY (implying a target). Article 61(4) also introduces aspects of ecosystem considerations by reference to species' associations or dependencies.

Article 62 suggests a second fishery management objective to be achieved:

> "1. The coastal State shall **promote the objective of optimum utilization** of the living resources in the exclusive economic zone without prejudice to article 61.;
>
> 2. The coastal State shall determine its capacity to harvest the living resources of the exclusive economic zone. Where the **coastal State does not have the capacity to harvest the entire allowable catch**, it shall, through agreements or other arrangements and pursuant to the terms, conditions, laws and regulations referred to in paragraph 4, give other States **access to the surplus of the allowable catch**, having particular regard to the provisions of articles 69 and 70, especially in relation to the developing States mentioned therein." [**emphasis** added].

Similar stipulations for management measures on living resources in the high seas (outside of the EEZ), or those that straddled EEZs, are identified in Article 119. For shared fish stocks, UNCLOS exhorts coastal states to cooperate directly or through appropriate regional or international organizations with a view to ensuring conservation and promoting the objective of optimum utilization. Thus, UNCLOS identifies three fisheries management objectives:

1. maintaining or restoring harvested stocks to levels that produce *maximum sustainable yield* (MSY);
2. avoiding *over-exploitation* of all living resources; and
3. achieving *optimum utilization* of living resources, such that all the allowable catch is taken and stocks are not under-exploited.

Objective (3) is important to the goal of fluctuating around desired target levels to avoid under-utilization of the allowable catch, rather than the specifying the desired target level which is inferred to be at least levels that produce MSY by objective (1). However, this does not seem to preclude a target state defined by various axes of sustainability including, for example, ecosystem services or profitability considerations subject to restoration of depleted stocks to levels that produce MSY (e.g., maximum economic yield as per DAWR (2018)).

8.4. COMBINING OBJECTIVES: THE UNFSA AND THE FAO CODE OF CONDUCT

After UNCLOS formally came into effect in 1994, the United Nations "Fish Stocks Agreement" (UNFSA) was developed in 1995, to come into effect in 2001. The UNFSA was specifically designed to address the conservation and management of straddling and highly migratory fish stocks on the high seas. It also helped lay more specific groundwork for the regional and international organizations to manage shared fish stocks.

The 1995 UNFSA treaty appears to be the first to concretely link the precautionary approach to avoidance of undesirable states with the achievement of specific fisheries management objectives. This link is accomplished in the design of management measures via Articles 5 and 6. Article 5 (General Principles) noted that in order to conserve and manage shared fish stocks, coastal states shall, among other things:

> "(a) adopt measures to ensure **long-term sustainability** of straddling fish stocks and highly migratory fish stocks and **promote the objective of their optimum utilization**;
>
> (b) ensure that such measures are based on the best scientific evidence available and are **designed to maintain or restore stocks at levels capable of producing maximum sustainable yield**, as qualified by relevant environmental and economic factors, including the special requirements of developing States, and taking into account fishing patterns, the interdependence of stocks and any generally recommended international minimum standards, whether subregional, regional or global;
>
> (c) **apply the precautionary approach** in accordance with article 6;
>
> (e) adopt, where necessary, conservation and management measures for **species belonging to the same ecosystem or associated with or dependent upon the target stocks**, with a view to maintaining or restoring populations of such species above **levels at which their reproduction may become seriously threatened**;
>
> (h) take measures to prevent or eliminate **overfishing** and excess fishing capacity and to ensure that **levels of fishing effort do not exceed those commensurate with the sustainable use** of fishery resources" [**emphasis** added]

Article 6 (Application of the Precautionary Approach) reiterated and expanded upon the wording of the 1992 Rio Declaration, incorporating a prescribed decrease in risk tolerance with increasing uncertainty:

> "2. States **shall be more cautious when information is uncertain, unreliable or inadequate**. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures." [**emphasis** added]

Article 6 formally identified the need for fisheries *reference points* and management actions that vary depending on the stock status relative to the reference points:

> "3. In implementing the precautionary approach, States shall: … b) apply the guidelines set out in Annex II and determine, on the basis of the best scientific information available, **stock-specific reference points and the action to be taken if they are exceeded**; (c) **take into account, inter alia, uncertainties** relating to the size and productivity of the stocks, reference points, stock condition in relation to such reference points, levels and distribution of fishing mortality and the impact of fishing activities on non-target and associated or dependent species, as well as existing and predicted oceanic, environmental and socio-economic conditions; and
>
> 4. States shall take measures to ensure that, **when reference points are approached, they will not be exceeded**. In the event that they are exceeded, States shall, without delay, take the action determined under paragraph 3 (b) to restore the stocks." [**emphasis** added]

Note that principle in Article 6.4 was reiterated by the 2012 report of the Royal Society of Canada (Hutchings et al. 2019). Article 6 further described the need to regularly review and revise management measures over time, as new information comes to light on fish stocks:

> "5. Where the status of target stocks or non-target or associated or dependent species is of concern, States shall subject such stocks and species to **enhanced monitoring** in order **to review their status and the efficacy of conservation and management measures**. They shall **revise those measures regularly in the light of new information**.
>
> 6. For new or exploratory fisheries, States shall adopt as soon as possible cautious conservation and management measures, including, inter alia, catch limits and effort limits. Such measures shall **remain in force until there are sufficient data** to allow assessment of the impact of the fisheries on the long-term sustainability of the stocks, whereupon conservation and management measures based on that assessment shall be implemented. The latter measures shall, if appropriate, allow for the gradual development of the fisheries." [**emphasis** added].

Finally, Article 6 explicitly alters earlier prescribed fishery management objectives related to MSY in the event of natural phenomena exerting adverse impacts. Under such conditions, fishery objectives are to instead ensure that fishing does not worsen adverse impacts:

> "7. If a **natural phenomenon has a significant adverse impact** on the status of straddling fish stocks or highly migratory fish stocks, States shall adopt **conservation and management measures on an emergency basis to ensure that fishing activity does not exacerbate such adverse impact**. States shall also adopt such measures on an emergency basis where fishing activity presents **a serious threat to the sustainability of such stocks**. Measures taken on an emergency basis shall be temporary and shall be based on the best scientific evidence available." [**emphasis** added]

Annex II of the UNFSA prescriptively intertwines the ideas of avoidance and achievement in the form of twin "precautionary" reference points and establishes a rebuilding target in the following Articles:

"1. A **precautionary reference point is an estimated value** derived through an agreed scientific procedure, which **corresponds to the state of the resource and of the fishery**, and which can be used as a guide for fisheries management.

2. **Two types of precautionary reference points should be used**: conservation, or **limit**, reference points and management, or **target**, reference points. **Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield. Target reference points are intended to meet management objectives.**

3. Precautionary reference points should be **stock-specific** to account, inter alia, for the reproductive capacity, the resilience of each stock and the characteristics of fisheries exploiting the stock, as well as other sources of mortality and major sources of uncertainty.

4. **Management strategies shall seek to maintain or restore populations of harvested stocks, and where necessary associated or dependent species, at levels consistent with previously agreed precautionary reference points**. Such reference points shall be used to **trigger pre-agreed** conservation and management **action**. Management strategies shall include measures which can be implemented **when precautionary reference points are approached**.

5. **Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low**. If a stock falls below a limit reference point or is at risk of falling below such a reference point, conservation and management action should be initiated to facilitate stock recovery. **Fishery management strategies shall ensure that target reference points are not exceeded on average**.

6. When information for determining reference points for a fishery is poor or absent, provisional reference points shall be set. **Provisional reference points may be established by analogy to similar and better-known stocks**. In such situations, the fishery shall be subject to enhanced monitoring so as to enable **revision of provisional reference points as improved information becomes available**.

7. **The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points**. For stocks which are not overfished, fishery management strategies **shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield**, and that the biomass does not fall below a predefined threshold. **For overfished stocks, the biomass which would produce maximum sustainable yield can serve as a rebuilding target."** [**emphasis** added]

In summary, the 1995 UNFSA, particularly Annex II, prescribes the following considerations.

1. Two types of reference points are specified to manage fisheries: limits and targets:
    a. The use of the verb "trigger" in Article 4 at first suggests that reference points are intended to be used as operational control points (OCPs) where action is taken. However, the following phrases implies their interpretation as reference points to be avoided or achieved:
        - "when precautionary reference points are approached" (Annex II, 4);

- "ensure that the risk of exceeding limit reference point is very low" (Annex II, 5);
- "ensure that target reference points are not exceeded on average" (Annex II, 5);
- "shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield, and that the biomass does not fall below a predefined threshold" (Annex II, 7).

Thus, Article 4 is interpreted to mean that the desired certainty of avoiding or achieving reference points is used to guide the choice of "triggers" (OCPs) where management actions occur. There is no restriction on the number of OCPs needed, particularly under Article 5 which references management measures to ensure that when the stock "approaches" the reference points they are not exceeded;

b. Limit reference points are intended to provide the bounds of "safe biological limits" defined as those within which the stock can produce maximum sustainable yield in Annex II (2). Thus, an LRP that is positioned at a threshold to serious harm (e.g., recruitment overfished) may not actually meet the original intent of the UNFSA for harvested stocks, although it might for other dependent or associated species (where measures must maintain or restore such stocks "above levels at which their reproduction may become seriously threatened"; Article (5e)). The intent of Article (2) for harvested stocks may be served more closely by limits that bound the range of natural stock fluctuations around B_{MSY} as was the approach of Restrepo et al. (1998) and similar to FAO's sustainability indicator 14.4.1 (Ye 2011). Similarly, the "pretty good yield" concept of Hilborn (2010) suggests that at least 80% of MSY could be attained by stock sizes of 20-50% of the unfished stock size and that little loss of yield occurs at 50% of the unfished stock size.

c. Reference points are intended to be stock-specific. However, interim [provisional] reference points should be set in the absence of stock-specific values, including for data-limited stocks, until more information becomes available (Article 6). This allows for the use of default proxies, arguments by analogy with similar stocks (e.g., Kronlund et al. 2018), or the "Robin-Hooding" (borrowing of information from data-rich stocks for use with data-poor stocks, Punt et al. 2001) of reference points from similar but better-known stocks.

2. For limit (conservation) reference points:

   a. Management strategies must, in general, be designed to ensure the risk of exceeding limits is very low;

   b. If a stock falls below a limit, or is at risk of doing so, then management actions should facilitate stock recovery to B_{MSY}, it is later stated (see target section below); and

   c. F_{MSY} is a minimum standard limit fishing mortality reference point. For stocks that are not overfished F_{MSY} is not to be exceeded. However, it is important to note that the corresponding biomass B_{MSY} is identified as a target, not a limit (this is paradoxical, unless it is interpreted as an interim target applying only to that subset of stocks that are depleted; see Richards and Maguire 1998; Shelton and Sinclair 2008; Maunder 2013).

3. For target (management) reference points:

   a. Management strategies should be designed to ensure targets are not exceeded on average (linking to the objective of *optimum utilization*, management must ensure that there is no unused surplus production); and

   b. B_{MSY} can serve as a rebuilding target reference point for stocks that are overfished (see Annex II, 7).

Subsequent to the UNFSA, The Food and Agriculture Organization of the United Nations (FAO) completed the development a voluntary *Code of Conduct for Responsible Fisheries*, which was adopted on 31 October 1995 (FAO 1995b). In particular, Article 7 (Fisheries Management) in the Code reiterated the UNFSA position on the precautionary approach:

> "7.1.1 States and all those engaged in fisheries management should, through an appropriate policy, legal and institutional framework, adopt **measures for the long-term conservation and sustainable use** of fisheries resources. Conservation and management measures, whether at local, national, subregional or regional levels, should be based on the best scientific evidence available and be designed to ensure the **long-term sustainability of fishery resources** at levels which promote the objective of their optimum utilization and maintain their availability for present and future generations; short term considerations should not compromise these objectives.
>
> 7.2.1 Recognizing that long-term sustainable use of fisheries resources is the overriding objective of conservation and management, States and subregional or regional fisheries management organizations and arrangements should, inter alia, **adopt appropriate measures, based on the best scientific evidence available, which are designed to maintain or restore stocks at levels capable of producing maximum sustainable yield, as qualified by relevant environmental and economic factors,** including the special requirements of developing countries.
>
> 7.2.2 Such measures should provide inter alia that:
>
> 1. excess fishing capacity is avoided and exploitation of the stocks remains economically viable;
> 2. the economic conditions under which fishing industries operate promote responsible fisheries;
> 3. the interests of fishers, including those engaged in subsistence, small-scale and artisanal fisheries, are taken into account;
> 4. biodiversity of aquatic habitats and ecosystems is conserved and endangered species are protected;
> 5. **depleted stocks are allowed to recover or, where appropriate, are actively restored;**
> 6. adverse environmental impacts on the resources from human activities are assessed and, where appropriate, corrected; and
> 7. pollution, waste, discards, catch by lost or abandoned gear, catch of non-target species, both fish and non- fish species, and impacts on associated or dependent species are minimized, through measures including, to the extent practicable, the development and use of selective, environmentally safe and cost-effective fishing gear and techniques.
>
> 7.2.3 States **should assess the impacts of environmental factors on target stocks and species belonging to the same ecosystem or associated with or dependent upon the target stocks, and assess the relationship among the populations in the ecosystem.**
>
> 7.5.1 States should apply **the precautionary approach** widely to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment. The absence of adequate scientific

information should not be used as a reason for postponing or failing to take conservation and management measures.

7.5.2 In implementing the precautionary approach, States should take into account, inter alia, uncertainties relating to the size and productivity of the stocks, reference points, stock condition in relation to such reference points, **levels and distribution of fishing mortality and the impact of fishing activities, including discards, on non-target and associated or dependent species, as well as environmental and socio-economic conditions**.

7.5.3 States and subregional or regional fisheries management organizations and arrangements should, on the basis of the best scientific evidence available, inter alia, determine:

1. **stock specific target reference points**, and, at the same time, the action to be taken if they are exceeded; and
2. **stock-specific limit reference points**, and, at the same time, the action to be taken if they are exceeded; when a limit reference point is approached, measures should be taken to ensure that it will not be exceeded." [**emphasis** added]

Here again are highlighted the importance of both *optimum utilization* and stock levels capable of producing MSY as fisheries management objectives, towards which management measures including rebuilding should be designed; the need for both *limit and target reference points*; and the need for *management actions* to be taken when, or to prevent, reference points being exceeded. The Code also brings in some novel language: for example, the overriding fisheries management objective is identified for the first time as *long-term sustainable use.* Article 7.2.2 (2-4) infer that management objectives around sustainable use include ecosystem and socio-economic considerations as well as biological considerations related to optimal productivity.

9. APPENDIX B REVIEW OF CANADIAN FISH STOCK REBUILDING PLANS

9.1. CONTEXT

We reviewed eight rebuilding plans for Canadian fisheries with respect to PA Policy requirements, the DFO (2013a) rebuilding plan guidelines, and elements of proposed regulations (described in Section 2.3) to support the Fish Stocks provisions. We also included a reference related to the first time that the stock was determined to be below its LRP and when the rebuilding plan was developed. The following rebuilding plans and supporting documents were reviewed:

- Bocaccio (*Sebastes paucispinis*): Rebuilding plan in DFO (2019b), first full stock assessment using population modelling in 2008 (Stanley et al. 2009);
- Yelloweye Rockfish (*Sebastes ruberrimus*) – Inside: Rebuilding plan in DFO (2019b), first assessed as a single stock in 2011 (Yamanaka et al. 2012);
- Yelloweye Rockfish (*Sebastes ruberrimus*) – Outside: Rebuilding plan in DFO (2019b), first assessed as a single stock in 2015 (Yamanaka et al. 2018);
- Atlantic Cod (*Gadus morhua*) 4X5Y: Rebuilding plan in DFO (2017a);
- Northern Gulf Cod (*Gadus morhua*) 3Pn 4RS: Rebuilding plan in DFO (2013b); the LRP of 200,000 t was adopted at a workshop in 2002, and at this time the biomass was estimated

to be below that level, the LRP was updated in 2011. The rebuilding plan was developed in 2013.

- Atlantic Cod (*Gadus morhua*) 5Z: Rebuilding plan in DFO (2018b); the LRP of 21,000 t was adopted in 2010, and at this time the biomass was estimated to be 9,260 t. The rebuilding plan was developed in 2018 using information from the 2018 TRAC assessment (Andrushchenko et al. 2018).
- Yellowtail Flounder (*Limanda ferruginea*) 5Z: Rebuilding plan in DFO 2018c), the last reference point estimated for this stock was B_{MSY} = 43,200 t, and at this time biomass was estimated to be 869 t (TRAC 2018). The rebuilding plan was developed in 2018 using information from the 2018 TRAC assessment (Legault and McCurdy 2018); and
- Northern Shrimp (*Pandalus borealis*) SFA 6: Rebuilding plan in DFO (2018a), the 2016 stock assessment report noted that the female spawning stock biomass (SSB) index was close to the LRP (DFO 2016c). The 2017 stock assessment estimated the female SSB index to be below the LRP with greater than 99% probability (DFO 2017b).

The goal of this review was to examine existing rebuilding plans produced by DFO for consistency of approach, and to identify gaps between current practice and new legal obligations under the amended *Fisheries Act* and possible supporting regulations. When reviewing plans, we looked for information related to the proposed regulations and attempted to determine whether the questions associated with each proposed regulation listed in Table 17 were addressed. There was no expectation that existing rebuilding plans would align closely with the proposed rebuilding regulations, since these plans were established well before the drafting of proposed regulations following the amendment of the *Fisheries Act* in June 2019. Policy guidance on rebuilding stocks above the LRP was available in DFO (2013a) for most of the existing plans. Furthermore, updated stock status information developed since the most recent version of the rebuilding plans is not included (e.g., DFO 2020b for Yelloweye Rockfish – Outside stock). Finally, we compare our review to those issues highlighted by a recent review of rebuilding plans undertaken by Oceana Canada (2018).

Table 17. Proposed regulations to support rebuilding under the Fish Stocks provisions and questions used to identify information needed for supporting evidence.

Proposed regulations	Questions used to identify supporting information
(a) Description of stock status and trends	Is the stock defined? Biological evidence for stock definition or administrative definition based on management areas? What is the LRP? Basis for LRP choice: theoretical based on stock-specific analysis, empirical based on historical biomass, policy-based, or by analogy with similar stocks? Are criteria for determining an LRP breach stated?
(b) Reasons for stock's decline	Reasons for stock decline? Targeted and non-targeted catch identified? Habitat loss identified? Environmental factors identified, relative importance compared to fishing evaluated?

Proposed regulations	Questions used to identify supporting information
(c) Measurable objectives	Objectives specified? Are the objectives measurable, i.e., state, probability and time period?
(d) Timelines for achieving the objectives	Method for choosing rebuilding time period described, including definition of generation time (method may depend on data support)?
(e) Desired rebuilt target	When is the stock considered rebuilt, i.e., what is the rebuilt target and the criteria for determining the target has been achieved?
(f) Management measures aimed at achieving the objectives.	Is a management procedure identified, i.e., stock and fishery monitoring data, assessment method, HCR, other measures, and meta-rules?
(g) Method to track progress to achieve the rebuilding plan objectives.	Is each objective associated with a performance statistic that can be calculated with available data? How is rebuilding performance/progress evaluated relative to the rebuilt target and any interim milestones? Have coincidentally caught species been considered? For example, the rebuilding stock may be bycatch in another fishery, or the fishery on the rebuilding stock may intercept other species of concern.
(h) An approach to review the objectives, and an adjustment of these if the objectives are not being achieved.	Under what circumstances would the rebuilding strategy and plan be revisited and possibly revised? Are exceptional circumstances defined that would trigger a review?

9.2. STOCK STATUS, TRENDS AND REASONS FOR DECLINE

Most (five of eight) existing rebuilding plans contained an overview of the biology of the fish, the history of the fishery, and potential reasons for stock decline. In others, such as the rebuilding plans for Bocaccio, Yelloweye Rockfish - Inside and Yelloweye Rockfish - Outside stocks, the reader is referred to stock assessment documents for detailed descriptions of biology and distribution, habitat requirements, and stock scenarios. The rebuilding plan for Northern Gulf Cod 3Pn-4RS did mention possible bycatch in other fisheries. However, some rebuilding plans for stocks that are caught as part of a mixed-species fishery, or stocks that are caught as bycatch, did not include this information in the description of sources of mortality.

We determined whether a limit reference point was identified (e.g., LRP=0.4B_{MSY}) along with the most recent estimate of that reference point available at the time the plan was implemented (e.g., LRP_{2018}=10,000 t or B / B_{LRP}=0.76, etc.). We also determined whether a basis for reference point choice was provided (Table 18). The criteria, or reasons, used to determine that the stock had fallen below its LRP were also noted when provided; such information will be key for future rebuilding plans, as the criteria for an LRP breach will be the basis for determining whether the stock is prescribed under Section 6.2 of the Fish Stocks provisions (item (a), Table 17). While it may not be necessary to summarize all available information on life history and fishery context in rebuilding plans, those factors believed to have contributed to stock decline or those that influence rebuilding prospects were also noted when provided (Table 19). This was done in order to assess alignment with various items of proposed regulations (items (a)-(b), Table 17).

Table 18. Status determination: Limit Reference Point (LRP), basis of LRP, and criteria used to determine an LRP breach.

Stock	LRP	LRP Basis	Criteria to determine LRP breached
Bocaccio	$0.4B_{MSY}$ Estimated by Bayesian surplus production model	PA Policy guidance of $0.4B_{MSY}$	Median estimate of B_{2012}/B_{MSY} (the ratio of current stock size to that at maximum sustainable yield) is 7.0%, with 90% confidence limits of 2.9-18.2%. 99% probability of spawning biomass less than $0.4B_{MSY}$.
Yelloweye Rockfish – Inside	$0.4B_{MSY} = 0.2B_0$ Estimated using surplus production model, B_{MSY} is at $0.5B_0$, hence $0.4B_{MSY} = 0.2B_0$	PA Policy guidance of $0.4B_{MSY}$	Median initial stock biomass in 1918 (B_{1918}) is estimated at 6,466 t (CV 0.40). Estimate of stock biomass in 2009 is at 780 t which is 12% of B_{1918}. Median B_{2009}/B_{MSY} is 0.215 (CV 0.4), with a probability that $B_{2009} > 0.4B_{MSY}$ of 4.8%. i.e., 95.2% probability that stock biomass is below LRP.
Yelloweye Rockfish – Outside	$0.4B_{MSY} = 0.2B_0$ Estimated using surplus production model, B_{MSY} is at $0.5B_0$, hence $0.4B_{MSY} = 0.2B_0$	PA Policy guidance of $0.4B_{MSY}$	Median initial biomass 1918 (B_{1918}) is 21,955 t (90% credibility interval 13,747 – 37,694 t). Estimate of stock biomass in 2014 is 18% of the unfished biomass B_{1918}. Median B_{2014}/B_{MSY} is 0.36 [90% CI: 0.227 – 0.604] 63% probability that stock status is below the LRP.
Atlantic Cod 4X5Y	LRP = $B_{50/90}$. i.e., the spawning biomass corresponding to the intersection of the 50th percentile of the recruitment observations and the replacement line for which 10% of the stock-recruitment points are above the line. The 2018 estimate of $B_{50/90}$ = 22,193 t. Previous 2011 LRP = 24,000 t based on Beverton-Holt stock recruitment model.	Estimated based on identifying biomass threshold below which recruitment is likely to be poor.	Stock status evaluated using VPA model. Estimated 4X5Yb spawning stock biomass has been below the LRP since 2002 and was estimated to be 10,600 t at the beginning of 2009. 2008 mature 3+ spawning stock biomass of 10,600 t (5.2 million individuals) is lowest observed in a time series dating back to 1948.

Stock	LRP	LRP Basis	Criteria to determine LRP breached
Northern Gulf Cod 3Pn 4RS	Calculated as mean of two estimates (HS_{50} and NP_{50}) using SSB and recruitment at age-3 from ADAPT model (Duplisea and Fréchet 2011) LRP estimate is 116,000 t (DFO 2012d) HS_{50} is derived from a “hockey stick” recruitment relationship, i.e., SSB at 50% maximum recruitment NP_{50} is derived from a non-parametric recruitment curve SSB at 50% maximum recruitment	Estimated based on identifying biomass threshold below which recruitment is likely to be poor.	Sequential population analysis (SPA) model. The spawning stock abundance for 2012 and projected to 2014 is well below the LRP. The stock has remained below LRP for the last 23 years. Given the stock's current productivity, the exploitation rates between 1997 and 2011 were too high to allow for any significant rebuilding of this stock, except for 2003 when the second moratorium was in effect.
Atlantic Cod 5Z	No status-based LRP Fishing mortality reference, F_{ref} = 0.11	Fishery reference point based on yield per recruit	Total mortality has remained high and adult biomass has fluctuated at a low level. Current estimate of the 2016 year class from the VPA model is one of the lowest recruitment estimates on record. Estimated adult population biomass at the beginning of 2018 from the VPA model was 9,502 t, which was approximately 20% of the adult biomass at the start of the time series in 1978. Given the extremely low spawning stock biomass (SSB), TRAC advises that management aim to rebuild SSB.
Yellowtail Flounder 5Z	No Precautionary Approach LRP Fishing mortality limit reference, F_{ref} = 0.25 No model, an estimate of the fishing mortality rate can no longer be calculated.	Fishery reference point based on yield per recruit	Declining trend in survey biomass to low levels, despite reductions in catch to historical low amounts, indicates a poor state of the resource. Catch curve analyses (Sinclair 2001 in TRAC 2018) indicated declining but high total mortality rates (total mortality *Z* above 1 for most years). The Transboundary Resources Assessment Committee (TRAC) recommends setting the exploitation rate as low as possible below the upper bound of 6%.

Stock	LRP	LRP Basis	Criteria to determine LRP breached
Northern Shrimp SFA 6	LRP defined as 30% of the geometric mean of female spawning stock biomass index over a productive period (1996–2003)	Based on 30% of a proxy for B_{MSY}	Annual commercial CPUE has demonstrated a declining trend for about the last ten years. Female spawning stock biomass (SSB) index declined from estimated 466,000 t in 2006 to 65,000 t in 2016 which is the lowest in the time series DFO 2016 estimated that Female SSB index was close to the LRP with a 20% probability of being below LRP. DFO 2017b estimated that the female SSB index is currently in the Critical Zone with greater than 99% probability.

Table 19. Stock trend, reasons for decline leading to rebuilding, and ecosystem factors.

Stock	Trend (recent or prognosis)	Reasons for decline	Ecosystem factors
Bocaccio	Severely depleted current status. Moderate probabilities of rebuilding the stock out of the critical zone in the near future.	Description of major source of human-induced mortality: commercial groundfish fisheries. Slow growth, and long generation times.	-
Yelloweye Rockfish – Inside	"Two periods of relative steep decline … during the war years and during the mid-1980s to mid-1990s. The estimated population abundance shows relatively little change since the mid-1990s when catches were very substantially reduced. Stock projections show that the stock will increase over time. The probability that the current biomass in 2009 (B2009) >0.4 B_{MSY} at the end of a 5 year horizon is low (< 14%) for all harvest policies." (Yamanaka et al. 2012)	Description of major source of human-induced mortality: Pacific Halibut and Rockfish Outside Fisheries (general statement about Yelloweye Rockfish that does not distinguish between Inside and Outside stocks), recreational catch. Slow growing, low productivity, and have long generation times.	-

Stock	Trend (recent or prognosis)	Reasons for decline	Ecosystem factors
Yelloweye Rockfish – Outside	Very substantial decline estimated from the 1980s. Moderate probabilities of rebuilding the stock out of the critical zone in the near future.	Description of major source of human-induced mortality: Pacific Halibut and Rockfish Outside fisheries (general statement about Yelloweye Rockfish that does not distinguish between Inside and Outside stocks), recreational catch. Slow growing, low productivity, and have long generation times.	-
Atlantic Cod 4X5Y	"Despite decreases in fishing mortality, productivity of the stock remains low and short-term projections show a high probability that SSB will decrease from 2019 and 2020 even in the absence of fishing, if the current productivity conditions persist" (DFO 2017a)	Truncated age structure. Description of major potential threats to survival and recovery including natural mortality (including seal predation), fishing above F_{REF}, discards and bycatch. Natural mortality very high with unknown cause: "Unless natural mortality is reduced there is a very low probability of this stock recovering to the Cautious Zone over the next 10 years." (DFO 2017a)	"Warming temperature trends along the Scotian Shelf and in the Bay of Fundy are expected to continue contributing to the recent shifts in the distribution of the cod stock." (DFO 2017a)
Northern Gulf Cod 3Pn 4RS	Population collapse through the 1980's and early 1990's. Some info on recent (~20 year) stock history including biomass for fish aged 3+ years, natural mortality, TAC, catch and exploitation rate.	Description of high natural mortality and high fishing mortality in 1990s.	-

Stock	Trend (recent or prognosis)	Reasons for decline	Ecosystem factors
Atlantic Cod 5Z	"Survey biomass indices decreased for all three surveys and recruitment has been poor for the last 25 years." (Andrushchenko et al. 2018)	Majority caught as bycatch, description of several other non-groundfish fisheries resulting in discards. Truncated age structure. Description of high natural mortality and possible causes. "High total mortality, low weights at age in the population, and poor recruitment have contributed to the lack of rebuilding for eastern Georges Bank Cod." (TRAC 2018 *in* DFO 2018b)	2016 climate vulnerability assessment concluded very high potential for a change in species distribution and very high certainty that climate change will have a negative directional effect. (Hare et al. 2016 *in* DFO 2018b) Also 2017 NOAA risk analysis which concluded that increasing mean fall bottom temperatures, increasing sea surface temperatures, decreasing cool thermal habitats, and species distribution changes are expected to have a negative impact on Georges Bank Atlantic Cod. (NOAA 2017 *in* DFO 2018b)
Yellowtail Flounder 5Z	Declining trend in survey biomass to low levels, despite reductions in catch to historical low amounts.	"Recent catch … is low relative to the biomass estimated from the surveys but the total mortality rate (Z) remains high … indicating other sources of mortality are contributing to the decline." (TRAC 2018 *in* DFO 2018c) Elevated natural mortality and constricted age range . Indication of depensation in recent years. Description of other non-groundfish fisheries resulting in discards.	2016 climate vulnerability assessment concluded very high potential for a change in species distribution and very high certainty that climate change will have a negative directional effect. (Hare et al. 2016 *in* DFO 2018b) Also 2017 NOAA risk analysis which concluded that increasing mean fall bottom temperatures, increasing sea surface temperatures, decreasing cool thermal habitats, and species distribution changes are expected to have a negative impact of Georges Bank Yellowtail Flounder. (NOAA 2017 *in* DFO 2018b)

Stock	Trend (recent or prognosis)	Reasons for decline	Ecosystem factors
Northern Shrimp SFA 6	“Given the current and anticipated environmental and ecosystem conditions, it is acknowledged that rebuilding shrimp in SFA 6 may not be possible in the short-medium term.” (DFO 2018a)	Description of unfavourable environmental conditions and predation. “The decline in shrimp production has been associated with environmental forcing, increasing biomass of predatory fishes and commercial fishing.” (DFO 2018a) Description of small fishery removals relative to removals by predators	Some discussion of inter-species effects including removals by predators compared to fishery removals, and importance of shrimp as a prey item for several species including Atlantic Cod. “Rebuilding objectives for shrimp should take into consideration rebuilding objectives for other species (e.g. groundfish).” (DFO 2018a)

9.3. OBJECTIVES

Rebuilding plans sometimes included measurable objectives (defined as an outcome or state, probability of achieving the state, and a time period), a component of the DFO (2013a) policy guidance and an item to be required under anticipated future regulations (item (c), Table 17). Rebuilding plans also sometimes included more general or aspirational rebuilding goals. For example, four of eight rebuilding plans specified a rebuilding time period and three of eight specified the desired probability of achieving the desired building outcomes (Table 20). A lack of measurable objectives and matching performance measures poses challenges to identifying rebuilding strategies that have a reasonable prospect of success, or to enable an evaluation of progress over the period of application of a rebuilding plan. Rebuilding plans for Bocaccio, Yelloweye Rockfish - Inside, and Yelloweye Rockfish - Outside all included measurable objectives with an associated timeline and probability, but varied in their phrasing of objectives in the context of policy guidance (DFO 2013a). The PA Policy, for example, suggests that a “reasonable time frame” for growing the stock above the LRP can be 1.5 to 2 fish generations (or longer, depending on the severity of depletion of the stock, or other factors; DFO 2013a), and that there should be a high probability of rebuilding above the LRP (i.e., 75-95%) in that timeframe. For example, Yelloweye Rockfish – Outside indicated a time period of 15 years and 57% probability of growing out of the Critical zone, while Yelloweye Rockfish – Inside indicated a time period of 80 years and 56% probability of growing out of the Critical zone.

Table 20. Measurable objectives, time period and rebuilt target.

Stock	Measurable objectives	Time period	Rebuilt target and criteria
Bocaccio	Objectives include state, probability and timeline. Probability of 65% and rebuilding time of 3 generations	Three generations. Generation time estimated to be 20.4 years based on the mean age of mature females in an unfished population.	No specific and measurable rebuilt target other than ‘above the LRP’.

Stock	Measurable objectives	Time period	Rebuilt target and criteria
Yelloweye Rockfish – Inside	Objectives include state, probability and timeline. Probability of 56% and rebuilding time (greater than 1.5-2 generations)	80 years. No generation time calculation provided.	No specific and measurable rebuilt target other than 'above the LRP'
Yelloweye Rockfish – Outside	Objectives include state, probability and timeline. Probability of 57% and rebuilding time of one generation.	15 years. "*Average female age at maturity is estimated as 15 years.*" (DFO 2019b)	No specific and measurable rebuilt target other than 'above the LRP'
Atlantic Cod 4X5Y	Primary objective of promoting stock growth out of the critical zone, does not specify a desired probability or time period. Long-term goal to grow the stock out of Critical Zone and into Healthy Zone.	1.5-2 generations estimated to be approximately 11-15 years, however, "given the low productivity and high natural mortality of the 4X5Y Atlantic Cod stock, timelines for rebuilding are difficult to specify." (DFO 2017a)	No specific and measurable rebuilt target other than 'above the LRP'
Northern Gulf Cod 3Pn 4RS	Objectives include a state and time period, but no probability. "*The short term objective is to double the SSB in ten years (i.e., to ~40,000t), commencing 2013, based on the SSB as of January 1, 2012.*" (DFO 2013b)	Estimated to be 8.4, 7.6, or 7.1 years for mean F (ages 7 to 9) of 0, 0.09, and 0.2, respectively.	No specific and measurable rebuilt target other than 'above the LRP'
Atlantic Cod 5Z	Primary objective of promoting stock growth out of the critical zone, does not identify a probability or time period. Long-term goal to grow the stock out of Critical Zone and into Healthy Zone.	1.5-2 generations estimated to be approximately 11-15 years, however, "given the low productivity and high natural mortality of the 5Z Atlantic Cod stock, timelines for rebuilding are difficult to specify." (DFO 2018b)	No specific and measurable rebuilt target other than 'above the LRP'
Yellowtail Flounder 5Z	Primary objective of promoting stock growth out of the critical zone, does not identify a probability or time period. Long-term goal to grow the stock out of Critical Zone and into Healthy Zone.	1.5-2 generations equates to approximately 12-16 years, however, "given the low productivity and high natural mortality of the stock and the lack of response to reduced fishing to date, rebuilding of this stock is not expected unless stock productivity improves." (DFO 2018c)	No specific and measurable rebuilt target other than 'above the LRP'

Stock	Measurable objectives	Time period	Rebuilt target and criteria
Northern Shrimp SFA 6	Draft objectives do not all contain states, probabilities and time periods. Plan specifies short-term objectives within 3 years related to harvest levels and developing population models. Plan contains 2 long-term objectives that are to be implemented once the short-term objective of developing population models is met.	No description of generation time. *"It remains highly unlikely that the stock will be rebuilt to previous levels in the short-medium term due to dominant climate and ecosystem influences."* (DFO 2018a) Good description of planned management approach until a model is available.	No specific and measurable rebuilt target other than 'above the LRP'

9.4. REBUILT STATE OR TARGET

No existing rebuilding plans contained a specific and measurable rebuilt state or target (item (e), Table 17), beyond the goal of growing the stock of interest to a level above the LRP (Table 20). In the case of rebuilding plans for Atlantic Cod 4X5Y, Yellowtail Flounder 5Z, and Atlantic Cod 5Z the long-term goal of growing the stock above both the LRP and the USR is identified in recognition of the DFO (2013a) policy guidance that states "… the goal of any rebuilding process is to grow stocks up through the Cautious Zone and ultimately into the Healthy Zone (where possible) as defined by the PA Framework [Policy]".

Proposed rebuilding regulations may specify a requirement for a rebuilt state or target, that forms the outcome of interest within a measurable objective, for example, to achieve a spawning biomass $B > B_{\text{target}}$ with 50% probability in 10 years. Design of a rebuilding strategy would involve identifying what feasible catch trajectories might have a reasonable expectation of attaining such a rebuilt objective, along with other possibly conflicting objectives likely to be of interest to decision makers. Each such an objective should be linked to a performance measure; for the example above a suitable performance measures is the probability of biomass exceeding the target biomass at year 10 calculated from model forecasts or closed-loop projections. Even if it is unlikely that a stock might grow above the LRP in the short- to mid-term, a rebuilt target should be specified to provide reasonable assurance that there is a smooth transition to management at target levels, should growth occur. This provides a basis for revision and relative comparison as new data acquired during the rebuilding period improves system understanding, objectives are revised and possibly new management options identified.

9.5. REBUILDING TIME

Proposed regulations may require identifying a time period for the rebuilding plan (item (d),Table 17). The rebuilding policy guidelines (DFO 2013a) and PA Policy suggest that a reasonable timeframe for rebuilding above the LRP for many species may correspond to 1.5-2 fish generations, and possibly more for long-lived species (or severely depleted stocks, among other reasons; DFO 2013a). This approach to developing rebuilding time periods has been applied to some extent across existing rebuilding plans, with six of eight plans providing an estimate of generation time for the species of interest (Table 20). Other rebuilding periods are reported in years, without direct citation of generation time. For example, Yelloweye Rockfish - Inside and

Outside plans report rebuilding times of 80 years and 15 years, respectively, which correspond to the length of the projections completed in the stock assessments that were used to derive the rebuilding plan, i.e., the forecast time period was used. Yelloweye Rockfish are estimated to have a generation time of 15 years based on the average female age at maturity (DFO 2015, but see DFO 2019b where an estimate based on Seber's (1982) method is 38 years), meaning the time periods of 80 and 15 years range from five generations to one generation, respectively. For long-lived species such as Yelloweye Rockfish, projections of two or more generations may be of limited relevance to fishery managers and resource users, or may be uninformative due to unknown long-term stock dynamics. However, extended time periods can serve to verify that projections do not contain pathologies, whether transitory effects dampen after a change to the catch sequence under a rebuilding procedure, and in some cases may serve to approximate equilibrium stock and fishery behavior as a benchmark. Some rebuilding plans (three of eight) cited generation time, but further stated that a rebuilding time would be difficult to specify due to low productivity and high natural mortality, i.e., rebuilding success cannot be predicted accurately. Such challenges may be common where open-loop forecasts are conducted, but more may be learned about the conditions necessary for rebuilding, or the value of new types of data, by evaluating scenario-driven close-loop feedback simulations. The latter would be relevant to conditioning expectations for stock rebuilding given current understanding of system dynamics. However, it remains important to:

1. Illustrate the expected consequences of proposed rebuilding measures so that objectives and their relative priority can be re-evaluated;
2. Examine sources of uncertainty to determine what information would improve the information base in a cost-effective manner; and
3. Specify a rebuilding time period even under challenging environmental conditions to avoid inertia in taking those feasible actions intended to prevent further deterioration of stock status and promote growth should conditions change.

9.6. MANAGEMENT MEASURES

All existing rebuilding plans contained management measures (item (f), Table 17) intended to reduce fishing effort and catch. However, the likelihood that these measures will promote achieving rebuilding objectives was not usually provided, nor the rationale for selecting the management measures (Table 21). In some cases, the management measures contained in rebuilding plans were a summary of previously-implemented measures, but it was unclear whether the existing measures had been assessed for their efficacy specifically in the context of rebuilding. One rebuilding plan (Northern Gulf Cod 3Pn 4RS) included increases in total allowable catch during the lifespan of the rebuilding plan. Plans for increases may be feasible for rebuilding, but could be further supported by evaluation of whether rebuilding outcomes are likely to be met under the proposed sequence of catches, or a description of what trade-off outcomes are being accommodated under the rebuilding strategy. The former point about the catch sequence relates to providing criteria for the PA Policy direction on maintaining removals at the "lowest possible level" for stocks below their limit, i.e., what is the likelihood of management objectives being met under proposed catch sequences?

Three of eight plans contained a discussion of possible alternative management measures that could be implemented. Alternative measures in a rebuilding plan could be part of a pre-specified response to exceptional circumstances, if we adhere to the view that a rebuilding plan is what is implemented (i.e., a decision on rebuilding measures has been made). The evidence to support the efficacy of alternative measures in response to exceptional circumstances would ideally be explored when the rebuilding strategy to inform the plan is being developed. Their likely performance should be ranked against the selected measures as well as against a zero fishing mortality benchmark and status quo management.

Table 21. Management measures and methods for evaluating rebuilding progress.

Stock	Management Measures	Evaluation of progress
Bocaccio	Near term plan for stepped reductions of total Bocaccio harvest over 3 years (2013-14 to 2015-16). Groundfish trawl: New TAC, ITP quotas. Groundfish hook and line: new trip limits. Salmon troll: daily limits.	"Current focus for commercial groundfish fisheries will continue to be on annual reviews of performance against the catch reduction targets." (DFO 2019b)
Yelloweye Rockfish – Inside	"The inside population has experienced more significant fishing effort reductions in the early 2000s." (DFO 2019b) Total mortality cap: at 15 t. Rockfish and dogfish fishery: ITQ allocation. Halibut fishery: 200 pound (0.09 tonne) annual limit.	"Current focus for commercial groundfish fisheries will continue to be on annual reviews of performance against the catch reduction targets." (DFO 2019b)
Yelloweye Rockfish – Outside	Stepped reductions of total Yelloweye Rockfish harvest from estimated total catch mortality of 287 mt in 2014 to a mortality cap of 100 mt over 3 years (2016/17 to 2018/19) Recreational daily limits for Yelloweye were reduced in 2016/17 from 3 to 2 in the north and from 2 to 1 in the south.	"Current focus for commercial groundfish fisheries will continue to be on annual reviews of performance against the catch reduction targets." (DFO 2019b)
Atlantic Cod 4X5Y	Reductions in directed fishing (to the level of F_{REF}) and bycatch mortality. TAC decreased by 50% after 2018 update and directed fishery was prohibited. "*Additional restrictions on catches will be implemented beginning in 2019/20 to ensure directed cod fishing is not occurring*" (DFO 2017a) Bycatch policy to be implemented over time. New lobster bycatch program was initiated in Autumn 2018 in LFAs 33, 34 and 35.	"During the time period of this plan (2019) if the stock is not seen to be showing signs of recovery relative to the 2014 levels or F is found to be at a level that impacts rebuilding, these measures will be revisited." (DFO 2017a)

Stock	Management Measures	Evaluation of progress
Northern Gulf Cod 3Pn 4RS	"*Starting in 2013 with SSB below B_{lim} total catch, including all removals, will be limited." "To 1,500 t per annum for a 5-year period*." (DFO 2013b) Plan includes a harvest control rule that would allow for increases in TAC during rebuilding, up to 3,185 t.	"Experience gained from the application of this plan will be reviewed in 2018 (i.e., after five years*).*" (DFO 2013b) "Should the stock appear to be on neither a positive or negative trajectory, harvest controls will be re-evaluated to include recruitment indices in a manner to encourage stock growth according to the short term goal." (DFO 2013b)
Atlantic Cod 5Z	Reductions in directed fishing (to the level of F_{REF}) and bycatch mortality. New bycatch policy to be implemented over time. Gear modification to reduce bycatch since 2009. Seasonal spawning and small-fish closures.	To be reviewed after new advice provided by TRAC in 2021. "If the stock is not seen to be showing signs of recovery based on the TRAC model or F is found to be at a level that impacts rebuilding, revisit management measures." (DFO 2018b) Action plan table included that describes work related to the assessment approach, commercial fishing, recreational fishing, and illegal discarding.
Yellowtail Flounder 5Z	Dockside monitoring program for compliance. New bycatch policy to be implemented over time. Conservation Harvesting Plan (CHP) for the 5Z groundfish fishery. Reduction in estimated bycatch in offshore Scallop fishery since 2005. Gear modification to reduce bycatch since 2009. Seasonal spawning closures and small-fish closures.	"There is an annual scientific assessment for 5Z Yellowtail Flounder through the TRAC, and this Rebuilding Plan will be reviewed and revised as needed following each assessment." (DFO 2018c) Action plan table included that describes work related to reference points, commercial fishing, recreational fishing, bycatch management, illegal discarding, and seasonal distribution.
Northern Shrimp SFA 6	"*Until a model is available, the Department's planned management approach, based on the best available science, is to maintain compliance with the current PA and Harvest Control Rules for the SFA 6 stock in the Critical Zone, which specifies that the exploitation rate shall not exceed 10%."* (DFO 2018a)	"Full Science stock assessment each year for SFA 6. Science to consider assessment results in the context of the rebuilding plan and offer supplementary advice, if possible." (DFO 2018a)

9.7. METHOD FOR TRACKING PROGRESS

One existing rebuilding plan discussed a method for tracking progress relative to final rebuilding outcomes or interim milestones (item (g), Table 17). A misconception that rebuilding is a slow and steady process could give the impression that failure to meet milestones indicates the rebuilding plan is unsuccessful. The key benefit of milestones is to "check in" as understanding of the rebuilding context increases, new data are accrued, analyses updated, and fishery conditions change in response to the rebuilding plan and possible effects on resource utilization (e.g., changing markets). Milestones provide an opportunity for adaptation of the strategy and adjustment of the plan, but are not necessarily signals of rebuilding plan failure if they are not met. What is absent in existing rebuilding plans is a specified time interval and mechanism for updating or confirming the existing plan, as could be required under proposed regulations.

In some cases, such as Northern Shrimp SFA 6, it is stated that rebuilding success within 1.5-2 generations is unlikely. This information is useful and necessary to condition expectations for rebuilding plan performance, highlight the factors that may impede rebuilding, and to provide the basis for interim plan while waiting for environmental conditions to improve.

9.8. EXTERNAL REVIEWS

Challenges faced in the management of Canada's major fish stocks were identified in recent governmental audits (CESD 2011, 2016) and there have been external reviews of fisheries sustainability in Canada. For example, Oceana Canada's *Fishery Audit* report (2018) contained a review of newer rebuilding plans. This review considered four of the following rebuilding plans previously discussed: Atlantic Cod 4X5Y (DFO 2017a), Bocaccio Rockfish (Stanley et al. 2008, DFO 2019b), Yelloweye Rockfish – Inside (DFO 2019b), and Yelloweye Rockfish – Outside (DFO 2019b).

The *Fishery Audit* (Oceana Canada 2018) included some criteria for evaluation that overlapped with the requirements of the proposed regulations (e.g., objectives, management measures, a method for tracking progress), and some suggested comprehensive criteria outside of the scope of the proposed regulations, but which overlap with some components of the DFO (2013a) rebuilding policy guidance (e.g., stock-specific objectives such as target size or age structure). One challenge highlighted was document organization or structure. For example, many criteria for information to be included in the plans for Bocaccio, Yelloweye Rockfish - Inside, and Yelloweye Rockfish - Outside were evaluated as being only partially satisfied because the plans did not contain a specific section for the information in question, although this information may have been noted throughout the document.

Oceana Canada (2018) noted a lack of clarity in reporting details related to the source of timeframes and estimated probabilities of success, or demonstration that management measures will meet objectives. Science guidelines for developing rebuilding strategies could address the organization of science components by ensuring that the proposed regulations (Table 17) are supported and that communication of this information is standardized in advisory documents produced to inform rebuilding plans.

The *Fishery Audit* (Oceana Canada 2018) review also highlighted some positive aspects of existing rebuilding plans, such as the Atlantic Cod 4X5Y rebuilding plan which comprehensively articulates many of the criteria evaluated in the *Audit*. Overall, the 2018 *Fisheries Audit* criteria for reviewing rebuilding plans aligned moderately well with the requirements of the proposed regulation for rebuilding plans, although they were not always aligned with existing DFO policy or guidelines requirements for specific wording or document format and organization.