A Cross-Jurisdictional Review of International Fisheries Policies, Standards and Guidelines: Considerations for a Canadian Science Sector Approach

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A CROSS-JURISDICTIONAL REVIEW OF INTERNATIONAL FISHERIES POLICIES, STANDARDS AND GUIDELINES: CONSIDERATIONS FOR A CANADIAN SCIENCE SECTOR APPROACH

By

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Legislative changes to Canada's *Fisheries Act* via Bill C-68 received Royal Assent on June 21, 2019, creating a new impetus towards the development of national operational guidelines for fisheries science. In this review, policies, standards and guidelines from Canada and five jurisdictions or organizations (Australia, the International Council for the Exploration of the Sea, the Northwest Atlantic Fisheries Organization, New Zealand and the United States) are compared and contrasted. Based on this review, considerations are put forth to inform approaches to updating and expanding existing guidelines for the Science Sector to support implementation of Canada's Precautionary Approach (PA) policy and to meet the requirements of the new legislation.

RÉSUMÉ

Marentette, J.R. and Kronlund, A.R. 2020. A Cross-Jurisdictional Review of International Fisheries Policies, Standards and Guidelines: Considerations for a Canadian Science Sector Approach. Can. Tech. Rep. Fish. Aquat. Sci. 3342: xiii + 169 p.

Les modifications apportées à la *Loi sur les pêches* du Canada par l'entremise du projet de loi C-68 ont reçu la sanction royale le 21 juin 2019, donnant un nouvel élan à l'élaboration de lignes directrices opérationnelles nationales pour les sciences halieutiques. Dans le présent examen, les politiques, les normes et les lignes directrices du Canada et de cinq administrations ou organisations (Australie, Conseil international pour l'exploration de la mer, Organisation des pêches de l'Atlantique Nord-Ouest, Nouvelle-Zélande et États-Unis) sont comparées et mises en contraste. À la lumière de cet examen, des recommandations sont formulées afin d'éclairer les approches visant à mettre à jour et à élargir les lignes directrices actuelles du Secteur des sciences pour appuyer la mise en œuvre de la politique canadienne de l'approche de précaution (AP) et pour répondre aux exigences de la nouvelle loi.

ACRONYMS

***Note**: Identification of reference points as* F *or* B *does not imply that proxies are not applied by the relevant jurisdiction.*

ABC: Acceptable biological catch (NOAA)

ACL: Annual catch limit (NOAA)

B_0: Unfished equilibrium biomass (all jurisdictions)

B_{buf}: Biomass buffer reference point (NAFO)

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

B_{pa}: Biomass precautionary approach reference point (ICES), functionally equivalent to MSY $B_{escapement}$ or MSY $B_{trigger}$

B_{mgt}: Biomass reference point in a management plan (ICES)

B_{MSY}: Biomass associated with the production of maximum sustainable yield (all jurisdictions)

B_{targ}: Biomass target reference point (Australia)

DAFF: Department of Agriculture, Fisheries and Forestry (Australia)

DAWR: Department of Agriculture and Water Resources (Australia)

DFO: Fisheries and Oceans Canada (Canada)

F_{buf}: Fishing mortality rate buffer reference point (NAFO)

F_{cap}: fishing mortality rate limit reference point used to provide advice for short-lived Category 1 and 2 stocks when biomass is high (ICES)

F_{lim}: Common name for fishing mortality rate limit reference point (Australia, ICES, NAFO)

F_{MSY}: Fishing mortality associated with the production of maximum sustainable yield (all jurisdictions)

FAO: Food and Agriculture Organization of the United Nations

F_{pa}: Fishing mortality precautionary reference point (ICES)

FRDC: Fisheries Research Development Corporation (Australia)

FSSI: Fish Stock Sustainability Index (NOAA)

***F_{targ}*:** Fishing mortality target reference point (Australia)

Hard Limit: Limit reference point, based in biomass or proxies (New Zealand)

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

HS Policy: Refers to Australia's Harvest Strategy Policy (DAWR 2018a)

HS Standard: Refers to New Zealand's Harvest Strategy Standard (MF 2008)

ICES: International Council for the Exploration of the Sea

LRP: Limit reference point, based in biomass (Canada)

MF: Ministry of Fisheries (New Zealand)

MFMT: maximum fishing mortality threshold (used to determine if stock is undergoing overfishing; NOAA)

MSST: minimum stock size threshold (used to determine if stock is overfished; NOAA)

MSY: maximum sustainable yield (all jurisdictions)

MSY $B_{escapement}$: the minimum stock size that should remain in the sea every year to ensure future recruitment of short-lived species where recruitment is highly variable. It is functionally equivalent to B_{pa} (ICES)

MSY $B_{trigger}$: is the parameter in the ICES MSY framework which triggers advice on a reduced fishing mortality relative to F_{MSY}. It is functionally equivalent to B_{pa} (ICES)

NAFO: Northwest Atlantic Fisheries Organization

NS Guidelines: Refers to the National Standard Guidelines of the *Magnuson-Stevens Act* of the United States (NOAA 2018a)

NOAA: National Oceanic and Atmospheric Administration (United States)

OCP: Operational control point, a level of an input to a harvest control rule (e.g., estimated biomass or abundance, indexing survey value) where management action is taken (e.g., a reduction in harvest rate).

OFL: Overfishing limit

PA Policy: Refers to Canada's national precautionary approach policy (DFO 2009a)

PAF: Refers to NAFO's precautionary approach framework (NAFO 2004a)

RCC: Risk-Catch-Cost tradeoff (Australia)

RFMO: Regional fisheries management organization, e.g., NAFO

RR: Removal reference (Canada)

SDC: Status determination criteria (some of the reference points of the United States), including MFMT, MSST and OFL (NOAA)

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

Soft Limit: threshold reference point, based in biomass or proxies (New Zealand)

SSC: Scientific and Statistical Committee, part of fisheries councils in the United States (NOAA)

Target: Target reference point, based in biomass or proxies (New Zealand)

TRP: Target reference point (Canada)

UNCLOS: United Nations Convention on the Law of the Sea

UNFSA: United Nations Fish Stocks Agreement

USR: Upper stock reference (Canada)

WSP: Refers to Canada’s Wild Salmon Policy (DFO 2005a)

INTRODUCTION

Science advice in support of fisheries management decision-making generally reflects the requirements outlined in fisheries harvest policies applicable to a given jurisdiction (i.e., a nation, state, or regional fisheries management organization). Policy requirements reflect relevant legislation and regulations, and changes in legal instruments may trigger a need to revisit policies to ensure science advice continues to reflect the needs of decision-makers in meeting legislative requirements. In turn, associated technical guidance provides direction as to how science advice consistent with policy is formulated. Guidance may relate to the process of determining what advice is needed by resource managers and users, and when that advice is required, as well as mandatory components including reference points, status determination, and communication of uncertainty and risks. The latter may be particularly important for those stock and fishery objectives regarded as being imperative (*sensu* Miller and Shelton 2010).

Legislative changes to fisheries management in Canada were enacted in June 2019 when Bill C-68 received Royal Assent. In early 2018, the Government of Canada tabled Bill C-68, "An Act to amend the *Fisheries Act* and other Acts in consequence," which received Royal Assent on June 21, 2019. The new text in the *Act* includes provisions (*Considerations* (section 2), and *Fish Stocks* (section 6); see Appendix 1) that speak to the application of a precautionary approach and an ecosystem approach, and the sustainability of fisheries. The provisions require implementation of measures to maintain prescribed major fish stocks at or above the level necessary to promote sustainability, or above the limit reference point. For stocks at or below their limit reference point, there is a requirement to implement measures intended to rebuild fish stocks.

Fisheries and Oceans Canada is interpreting the new legislation through its national Precautionary Approach Framework [PA] Policy (Fisheries and Oceans Canada [DFO] 2009a). One of the major components of the DFO Science Sector's plan to address the Fish Stocks provisions is a renewed approach towards the development of national science operational guidelines for the delivery of fisheries management science advice (Lane and Stephenson 1995). In this working paper, we compare and contrast fisheries policies and associated technical guidance from Canada and five other jurisdictions representing three countries with fisheries legislation somewhat similar to the revised *Fisheries Act* (Australia, New Zealand and the United States) and two other fisheries management or science organizations (the International Council for the Exploration of the Sea, ICES, and the Northwest Atlantic Fisheries Organization, NAFO).

This technical report is intended to highlight concepts that may be relevant for an analogous Canadian approach. A renewed approach to Canadian operational science guidelines (i.e., DFO 2016a) for Canada's PA Policy (DFO 2009a, DFO 2013b) may, for example, focus on how consistent presentation of fisheries science advice can provide evidence that legal obligations and policy intent are being met. An expected outcome of a *nationally* consistent approach is an improved ability to evaluate whether management measures (including rebuilding plans) meet the legislative requirements of a revised *Fisheries Act* regardless of the specific stock or region in Canada.

This technical report is broken into sections by topic. In the main body of the report, an overview of cross-jurisdictional similarities and differences on each topic is provided. This analysis is focused on the primary or ‘official’ policies, standards, and guidelines available. Potential difficulties of interpretation are also highlighted. Each section then concludes with remarks under the subtitle of “Considerations for a Canadian Approach,” a discussion which expands upon the overview to develop specific recommendations for consideration in the development of Canadian operational guidelines. All recommendations for a Canadian approach are summarized at the end of the main body of this report. For further reference, full details of the review for each topic and jurisdiction are provided in table format in the Appendices.

This document is not intended to be a detailed review of stock assessment methodology, reference point calculation or harvest control rule (HCR) design. Comprehensive literature exists on those subjects elsewhere (e.g., DFO 2016a, Dowling et al. 2015a, Dowling et al. 2015b, Gabriel and Mace 1999, Newman et al. 2014, Sainsbury 2008, Shelton and Rice 2002, Sloan et al. 2014). Neither is this review intended to be an exhaustive inspection of all existing international guidance for providing fisheries management science advice, nor the extensive body of peer-reviewed and supplementary grey literature or reports available in all jurisdictions for stock assessment practitioners to employ.

DOCUMENTS IN THIS REVIEW

The documents considered in this cross-jurisdictional review are listed in Table 1, with relevant legislative text by country presented in Appendix 1.

***Table 1**: Applicable laws, policies, standards, guidelines and reporting performed for fisheries science in various jurisdictions.*

Country	Document	Abbreviation
Canada		
Law	The *Fisheries Act* (R.S.C., 1985, c. F-14), revised under Bill C-68 (which received Royal Assent on June 21, 2019).	
Policy	*Sustainable Fisheries Framework* (DFO 2018b)	SFF
	A Fishery Decision-Making Framework Incorporating the Precautionary Approach (DFO 2009a)	PA Policy

	Canada's Policy for Conservation of Wild Pacific Salmon, also referred to as the Wild Salmon Policy [WSP] (DFO 2005a)	WSP
	Canada's Policy for Conservation of Wild Atlantic Salmon (DFO 2009b)	
Standards	n/a	
Guidelines	*Guidance for the development of rebuilding plans under the Precautionary Approach Framework: Growing stocks out of the critical zone* (DFO 2013b)	
	Annex 4 of the *Proceedings of the National Peer Review on the Development of Technical Guidelines for the Provision of Scientific Advice on the Various Elements of Fisheries and Oceans Canada Precautionary Approach Framework*, entitled *Current Approaches For The Provision Of Scientific Advice On The Precautionary Approach For Canadian Fish Stocks* (DFO 2016a)	
	Indicators of status and benchmarks for conservation units in Canada's Wild Salmon Policy (Holt et al. 2009); *Evaluation of benchmarks for conservation units in Canada's Wild Salmon Policy: Technical Documentation* (Holt, 2009); *Framework for characterizing Conservation Units of Pacific salmon (*Oncorhynchus *spp.) for implementing the Wild Salmon Policy* (DFO 2009c)	
Reporting	The *Sustainability Survey for Fisheries* website (DFO 2018c)	Sustainability Survey
Australia		
Law	The *Fisheries Management Act* 1991.	
Policy	*Commonwealth Fisheries Harvest Strategy Policy* (Australian Government, Department of Agriculture and Water Resources [DAWR] 2018a)	HS Policy
Standards	n/a	
Guidelines	*Guidelines for the Implementation of the Commonwealth Fisheries Harvest Strategy Policy* (DAWR 2018b)	
Reporting	The *Status of Australian Fish Stocks Reports* website (Fisheries Research Development Corporation [FRDC] 2018).	
ICES		
Law	(n/a) The International Council for the Exploration of the Sea (ICES) is an intergovernmental marine science organization with numerous clients and 20 member countries, including Canada. Relevant international laws and treaties include the *United Nations Convention on the Law of the Sea* (UNCLOS; 1982) and the *United Nations Fish Stocks Agreement* (UNFSA; 1995).	
Policy	The *ICES Advice Basis* (*1.2 Advice Basis*; ICES 2018a)	
Standards	n/a	

Guidelines	Technical guidelines are available via ICES (2019), including: ● 12.1 Advisory process (16 December 2016) ● 12.4.3.1 ICES fisheries management reference points for category 1 and 2 stocks (20 January 2017; ICES 2017) ● 12.4.4 Timeline of ICES advice (16 December 2016) ● 12.4.6 Advice on catches and landings (16 December 2016) ● 12.4.8 Reopening of the advice (16 December 2016) ● 12.4.9 Definitions of stock status (16 December 2016) ● 12.4.10 ICES criteria for defining multi-annual plans as precautionary (16 December 2016; ICES 2016) ● 12.5.1 Handling of late data submission or critically incomplete data (16 December 2016) ● 12.6 Technical Services (16 December 2016) ● 16.1.3 Guidelines for Advice Drafting Groups (29 January 2019) ● 16.4.3.2 ICES reference points for stocks in categories 3 and 4 (13 February 2018; ICES 2018b)	
Reporting	The *Latest Advice* website (ICES 2019)	
NAFO		
Law	The Northwest Atlantic Fisheries Organization (NAFO) is a regional fisheries management organization (RFMO) with 12 contracting parties, of which Canada is one. Relevant international laws and treaties include the United Nations Convention on the Law of the Sea (UNCLOS; 1982) and the United Nations Fish Stocks Agreement (UNFSA; 1995).	
Policy	*NAFO Precautionary Approach Framework* (NAFO 2004a; NAFO, 2019a), further explored online as *Risk Based Management Strategies* (NAFO 2019b)	PAF
Standards	n/a	
Guidelines	n/a	
Reporting	The *Stock Advice* website (NAFO 2019c)	
New Zealand		
Law	The *Fisheries Act* 1996, amended in 2008.	
Policy	n/a	
Standards	*Harvest Strategy Standard for New Zealand Fisheries* (New Zealand Government, Ministry of Fisheries [MF] 2008)	HS Standard

Guidelines	*Operational Guidelines for New Zealand's Harvest Strategy Standard* (MF 2011)	
Reporting	The *Fish Stock Status* website (MF 2019a)	
United States		
Law	The *Magnuson-Stevens Fishery Conservation and Management Act*	
Policy	n/a	
Standards	*National Standard Guidelines* (NOAA 2018a), particularly *National Standard 1 - Optimum Yield.*	NS Guidelines
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)	
Reporting	The *Status of U.S. Fisheries* website (NOAA 2018b).	

WHAT ARE GUIDELINES?

Policy, standards, procedures and guidelines serve distinct purposes within an organization (Table 2). Science Sector does not have a mechanism for enforcing mandatory actions or rules in the provision of advice and specific advisory contexts may have different steps. Thus, the use of guidelines to encourage consistent approaches to meeting legal obligations and policy alignment seems a reasonable choice. As per Table 2, guidelines are intended to be based on best practices, here determined by peer-reviewed fisheries science literature and international convention.

Table 2*: Suggested interpretation of terminology for operational guidance in fisheries science.*

Term	What does it say?	Why
Guideline	**"Try this"**: Provides recommended guidance	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.
Procedure	**"Follow this"**: Establishes proper steps	Procedures are detailed step by step instructions to achieve a given goal or mandate. "Cookbook" for repeatable processes.

Standard	**"Must do this"**: Assigns quantifiable measures	Standards are mandatory actions or rules that give formal policies support and direction. Must be enforced.
Policy	**"Where are we going and why?"**: Identifies issue and scope	Policies are formal statements produced and supported by senior management (government) that describe how the government plans to conduct its work. This includes addressing legislative requirements and should reflect objectives.

In developing guidelines, care should be taken to avoid the use of prescriptive language, particularly in light of the accommodation necessary for a range of stock contexts along a data continuum from data-poor to data-rich. Prescriptive content can be assumed to include the terms "require," "must", "necessary", "mandatory" or assertions such as "harvest control rules contain…" Other types of language, including "should," "may," "could" or items and actions described as "desirable" are to be considered recommendations of varying strength. Prescriptive content would reflect a *standard* ("must do this"; Table 2), and some policies or other guidance are termed standards for this reason (e.g., MF 2008). However, in general *guidelines* might be the more appropriate vehicle for documents intended to support implementation of Canadian fisheries policy.

CONTEXT FOR A CANADIAN APPROACH

Under the *Fisheries Act*, it is anticipated that there may be legal requirements and challenges relating to elements such as management measures, limit reference points and rebuilding plans. Furthermore, the criteria for recommending stocks to prescribe under regulations will be judged in part by the degree of alignment with the PA Policy. Defense of Science Sector advice can be strengthened by consistent and reproducible application of accepted fisheries science practice. Defense of the fisheries management system will be strengthened by providing evidence that recommended management measures, including those specified in rebuilding plans, are likely to provide acceptable outcomes relative to stock and fishery objectives.

In order to match the new legislation, Canadian national operational guidelines for fisheries science should be targeted to providing advice on management measures that:

- Maintain stocks at or above the level necessary to promote sustainability of the stock (6.1(1) of the Fish Stocks provisions)

- Maintain stocks above the limit reference point or LRP (6.1(2))

- Rebuild stocks above the limit reference point (6.2), in a specified time period

Recognizing that methods and techniques for identifying reference points and designing HCRs are continually evolving, particularly for data-poor stocks national operational guidelines for fisheries science could focus on consistent:

- Identification of default objectives in relation to reference points, and performance metrics matching objectives against which management options would be evaluated, either prospectively or retrospectively;

- Science evaluation and reporting of performance (including current stock status in relation to reference points, and incorporating and communicating uncertainty).

Default objectives and associated performance metrics would be aimed to meet the minimum requirements of each Fish Stocks provision; e.g., current, past or projected stock status in relation to the LRP against an objective to maintain stocks at or above the LRP for provision 6.1(2).

It is important to recognize that national operational guidelines development would be a continuation of previous work by DFO. For example, technical guidelines exist for the PA Policy, published as an Annex of a proceedings (DFO 2016a), and associated research documents (Chaput et al. 2013, Kronlund et al. 2014a, Kronlund et al. 2014b, Smith et al. 2012, and Stenson et al. 2012). However, DFO (2016a) identified a number of challenges that could not be resolved at the time of the associated scientific meeting, and most importantly, the Annex guidelines pre-date the most recent changes to the *Fisheries Act*. Thus, the content does not reflect the current international practices of fisheries science which has progressed rapidly in the intervening seven years and does not capture the specific obligations of the new Fish Stocks provisions of the revised *Fisheries Act*.

When the development of Canadian guidelines associated with the PA Policy were first proposed in 2005 by the Science Working Group on the Precautionary Approach (DFO 2005b) a number of recommendations were made. The 2005 recommendations continue to be relevant today, including those advocating for:

- Development of guidelines and tools for best practices in evaluating management strategies and harvest control rules, including
  - Determining the circumstances when reference points should be changed
  - Conducting and using medium and long-term (5 years and longer) projections and simulations for evaluating management strategies

  - Evaluating management strategies in data-poor situations
  - Quantifying and expressing uncertainty
  - Expressing and displaying risk and uncertainty in projections
- Development of guidelines for reviewing and evaluating existing management plans against a list of key elements required for PA compliance
- Development of alternative methods to setting removal references (limit fishing mortality rates) that decrease as stock status declines in the Cautious Zone of the PA framework

CROSS-JURISDICTIONAL COMPARISON

The policies, standards and guidelines for five fisheries jurisdictions (Table 1) were compared and contrasted to determine what might be most relevant for Canadian guidelines on fisheries science advice. While details for each jurisdiction are presented in the appendices, a summary of the review is presented below, divided by topics applicable to the development of operational guidelines (Table 2).

SCOPE OF APPLICATION

The *scope of application* here refers to which fish stocks fall under the relevant policy, standard, or guidelines. Science advice requirements may differ for fish stocks that fall inside vs. outside of the scope. Full details on the Scope of Application are available in Appendix 2.

Not all jurisdictions clearly indicated scope in their policies, standards or guidelines. This may be because the interpretation of legislative obligations for fisheries management vary widely among jurisdictions. In some cases, the policy or guideline might apply to all stocks under a jurisdiction's mandate, and in others, only to certain stocks (e.g., where responsibilities are shared between states or between central and local governments, or depending on the economic value of the fishery).

Canada's PA Policy, for example, is intended to apply primarily to *key harvested stocks* (DFO 2009a) which may be considered to be those tracked on Canada's Sustainability Survey (DFO 2018c). These stocks may be of high cultural, economic or environmental importance, and in future, those *major fish stocks* that will be prescribed by regulation under the Fish Stocks provisions of the revised *Fisheries Act*. Australia, by comparison, uses commercial catch value to differentiate three kinds of fish stocks (*key commercial*, *byproduct* and *bycatch*), and applies different fisheries management objectives to different stock types based on that value (DAWR 2018a, DAWR 2018b). New Zealand separates reporting for *main* and *nominal* fish stocks in its public website (MF 2019a). In the United States, fisheries management performance is only tracked for a select list of particularly important stocks that are included in a *Fish Stock Sustainability Index* (FSSI; NOAA 2018b). However, the National Standard Guidelines are still applied in managing FSSI stocks, non-FSSI stocks, and ecosystem component stocks (non-target stocks neither overfished or undergoing overfishing; NOAA 2019).

Considerations for a Canadian Approach

Under the Fish Stocks provisions of the revised *Fisheries Act*, section 6.3 speaks to the prescription of stocks by regulation, and it is only to these prescribed "major fish stocks" that the Fish Stocks provisions will apply.

At present, the Department has considered the "major fish stocks" in Canada to be those represented on the Sustainability Survey (DFO 2018c). A number of criteria are used to determine whether a stock is suitable for the Sustainability Survey, including economic, cultural and ecosystem value, internationally managed stocks, and depleted stocks that were formerly part of a significant commercial fishery (DFO 2018c). While the survey includes approximately 179 "major fish stocks", not all fish stocks managed by DFO are tracked. In fact, since its inception, the Sustainability Survey has increased the number of stocks tracked every year. Canada has no single list of stocks under federal jurisdiction (Baum and Fuller 2016). In any event, stock names would be expected to evolve over time with changing management regimes, or with evolving understanding of stock biology so that a process for updating the list of major stocks is required to accommodate additions, changes in stock structure and deletions of stocks from the list.

Since the Fish Stocks provisions of the revised *Fisheries Act* do not speak to all fish stocks under DFO's mandate and for which science advice is to be provided, a clear statement is needed to determine when operational guidelines apply to the provision of advice (e.g., to the stocks listed on the Sustainability Survey; to the stocks listed by regulation under the Fish Stocks provisions; to stocks that meet given criteria; etc.).

Apart from operational guidelines, developing a full list of all possible or known fish stocks may also be beneficial. Adopting a categorization scheme similar to that used by Australia or the United States may also be helpful to include in operational guidelines to indicate which stocks are of primary concern and why, and which stocks are considered secondary.

An additional aspect of the Fish Stocks provisions, related to scope, is that for each stock, a single LRP is established, with management measures implemented to maintain stocks above this point as required in section 6.1(2) of the *Act,* or a rebuilding plan to rebuild stocks above this point as required in section 2.

The term “stock” is not easily defined. Some definitions published by various jurisdictions include:

- “*Fish stock* is a population of individuals of a species found in a particular area. The term is used as a unit for fisheries management, such as the Northwest Atlantic Fisheries Organization area 4R herring.” (DFO 2018a)

- “*Stock*: the term has different meanings. Under the [New Zealand] *Fisheries Act*, it is defined with reference to units for the purpose of fisheries management. For the purposes of the Harvest Strategy Standard, a biological stock is a population of a given species that forms a reproductive unit and spawns little if at all with other units. However, there are many uncertainties in defining spatial and temporal geographical boundaries for such biological units that are compatible with established data collection systems. For this reason, the term “stock” is often synonymous with an assessment/management unit, even if there is migration or mixing of some components of the assessment/management unit between areas.” (MF 2008)

- “*Stock (stock structure*): A unit of management (subpopulation) of a particular fish species with common intrinsic population parameters (growth, recruitment, mortality and fishing mortality) and for which extrinsic factors (immigration and emigration) may be ignored. A stock may encompass the whole distribution of a species, in which case the stock and species are in effect the same thing. Or it may be some subset of the distribution of a species, in which case a species would have stock structure and comprise multiple stocks.” (DAWR 2018a)

- “A ‘*stock*’ or ‘*stock complex*’ is a management unit in the sense of the *Magnuson-Stevens Act*’s first definition of the term ‘fishery’: ‘*One or more stocks of fish that can be treated as a unit for purposes of conservation and management and that are identified on the basis of geographic, scientific, technical, recreational, or economic characteristics*.’ Defining a ‘stock’ on a scientific basis is a very difficult task. Many types of information are used to identify stocks: Distribution and movements, population trends, morphological differences, genetic differences, contaminants and natural isotope loads, parasite differences, and oceanographic habitat differences. … When the distribution of fishing effort corresponds spatially with the density of the target species, management errors caused by improper stock definition are likely to be small. … The risks of local depletion leading to range contraction or fragmentation is particularly high for long-lived species with high site fidelity. … In the absence of adequate information on stock structure, a species’ range within an ocean should be divided into stocks that represent useful management units.” (Restrepo et al. 1998)

Scope of Application	Operational guidelines should: **1.1** define the term “stock” with respect to the scale at which limit reference points are established, and provide guidance for taking stock biology and environmental conditions into consideration when identifying limit reference points. **1.2** indicate to what fish stocks the guidance is intended to apply.

SCIENCE ADVICE IN SUPPORT OF FISHERIES MANAGEMENT OBJECTIVES

Statements of overarching objectives may reflect legislative or regulatory requirements related to fisheries management within that state or organizational jurisdiction. Including overarching statements of fisheries policy objectives in standards or guidelines can help to inform the overall nature and requirements of the science advice that is to be generated in support of the policy. These statements may include, for example, the general type of fisheries management objectives to be set for fish stocks within the scope of the policy, against which performance of harvest strategies must be evaluated. Here, fisheries management objectives are intended to be inclusive of those related to stock conservation, economic, and socio-cultural outcomes consistent with sustainable use. Full details on Overarching Objectives are available in Appendix 3.

Canada’s Sustainable Fisheries Framework highlights “conservation and sustainable use” (DFO 2018b), goals that are mirrored in policies in other countries. Similar policies imply that technical guidelines from one jurisdiction may usefully inform those in others. Australia, for example refers to “ecologically sustainable and profitable use” (DAWR 2018a). New Zealand speaks to “providing for utilization… while ensuring sustainability” (MF 2008). National Standard Guidelines of the United States represent “principles that must be followed in any fishery management plan to ensure sustainable and responsible fishery management” (NOAA 2018a). The concept of maximum sustainable yield is highlighted as an overall desired state, or the basis of fisheries management, in some locations but not others: e.g., ICES (ICES 2018a), New Zealand (MF 2008) and the United States (NOAA 2018a).

Apart from overarching objectives, policies, standards or guidelines may indicate that harvest strategies should include specific stock or fishery objectives that are either to be avoided (i.e., concerning limits), or to be achieved (i.e., concerning targets); preferably these include accompanying probabilities related to specific outcomes and timeframes, rendering the objectives measurable. Such objectives are important to note when they occur in law, policy or guidelines, as they provide prescriptive guidance about how science advice is to be structured, in order to best inform the development and evaluation of harvest strategies. Full details on fisheries management objectives are available in Appendix 4.

In Canada, it appears that pre-eminence is given to avoiding limits (undesirable stock states or scenarios) in both the revised *Fisheries Act* and PA Policy, with less emphasis on objectives regarding targets (desired stock states), although both are discussed. The main fisheries management objective would be to "avoid serious harm to the reproductive capacity of the stock" (DFO 2009a), in line with the Canadian Government-wide approach to the use of precaution (PCO 2003), the Food and Agriculture Organization prioritizing limit constraints over targets (FAO 1996), and the science advice on the overall harvest strategy of the PA Policy, which "aims to keep the removal rate moderate when the stock status is healthy, promote rebuilding when stock status is low and ensure a low risk of serious or irreversible harm" (DFO 2006). In Canada, "serious harm" has been equated with recruitment overfishing (e.g., Shelton and Rice 2002) but could include other deleterious stock and fishery states (e.g., Kronlund et al. 2018).

In a similar manner to Canada, other jurisdictions either prioritize objectives concerning limits over targets (albeit indirectly; NAFO 2004a), or at least place them on similar footing. In Australia, a fisheries management objective concerning avoidance of limits is applied to both key commercial and byproduct stocks, while an objective regarding achievement of targets is only applied to key commercial stocks (DAWR 2018a). New Zealand aims to set management measures with both a low chance of breaching limits, and a high probability of achieving targets (MF 2008). National Standard Guidelines 1 of the United States' *Magnuson-Stevens Act* also emphasizes both limits and targets, as the aim is to prevent overfishing (e.g., a fishing mortality rate greater than that at maximum sustainable yield) while achieving optimum yield (NOAA 2018a). While the ICES Advice Basis emphasizes maximum sustainable yield (MSY) as a target, a precautionary approach is also seen as "necessary" (ICES 2018a).

Some jurisdictions also specify additional technical details regarding the formulation of objectives. For example, Australia's HS Policy is explicit that the objective for harvest strategies to avoid limits with 90% probability is to be interpreted as a 1-in-10 year risk of stocks declining below the limit (DAWR 2018b). ICES, on the other hand, interprets a default objective to avoid limits with 95% probability as a 95% probability evaluated in each year (and not as a 1-in-20 year risk; ICES 2018a). That said, it is rare to see jurisdictions provide fully specified objectives in policies, standards and guidelines, consisting of a stock state, probability, and time frame (Table 3).

***Table 3**: A summary of explicitly stated objectives for fisheries management, including rebuilding, that are represented in policies, standards and guidelines across jurisdictions. The focus of each objective is also identified. Here, risk tolerance is used in the sense of tolerance for (acceptability of) negative outcomes, such as breaching limits, declining trajectories, or not achieving targets. Note that in most cases, provided risk tolerances and/or time frames for consideration by decision-makers are considered provisional, with some exceptions (Australia, ICES). B = biomass. Buf = buffer. F = fishing mortality. Lim = limit. LRP = limit reference point. M = natural mortality. MEY = maximum economic yield. MSY = maximum sustainable yield. T = time. T_{min} = minimum time to rebuild to B_{MSY} under F = 0. USR = upper stock reference.*

Jurisdiction	Fisheries Management Objective	Focus	Risk Tolerance	Time Frame
Canada (DFO 2009a)	"[Avoid] serious harm to the reproductive capacity for the stock."	Biomass limit	--[1]	--
	For stocks below the LRP, "management actions must promote stock growth"…"a rebuilding plan must be in place with the aim of having a high probability of growing out of the Critical Zone within a reasonable time frame."	Trajectory, biomass target	Low[2] (for biomass target)	1.5 to 2 generations[3]
	For stocks above the LRP and below the USR with increasing recent trajectories[3], "management actions should promote stock growth to the Healthy Zone within a reasonable time frame" with provisional tolerances for preventable decline.	Trajectory, biomass target	Low to Moderate (if high in zone, for trajectory)[4]	1.5 to 2 generations[3]
	For stocks above the LRP and below the USR with stable recent trajectories, "management actions must encourage stock growth in the short term"[3] with provisional tolerances for preventable decline.	Trajectory	Low to Moderate (if high in zone, for trajectory)[4]	--
	For stocks above the LRP and below the USR with declining recent trajectories,	Trajectory	Very low to low[5]	--

	"management actions must arrest declines in the short term[3] or immediately if low in the zone" with provisional tolerances for preventable decline.			
	For stocks above the USR with increasing recent trajectories, "risk tolerance for preventable decline" is further described as tolerance of "normal stock fluctuations."	Trajectory	High[6]	--
	For stocks above the USR with declining recent trajectories, "management actions should react to a declining trend the approaches the cautious boundary" with adjusted provisional risk tolerances for "preventable decline."	Trajectory	Moderate to neutral[7]	--
	For stocks above the USR, "where economic considerations may prevail, stock reductions resulting from management actions with a low probability of the stock falling to the Critical zone are tolerated because of their reduced impact on the integrity of the stock."	Biomass limit	Low[2]	--
	For stocks above the USR, "harvest rate… not to exceed established maximum" while for stocks above the LRP but below the USR, "harvest rate… should progressively decrease from the established maximum"[8]	Fishing mortality limit	--	--
Australia (DAWR 2018a, 2018b)	"Maintain all commercial fish stocks…above a biomass limit where the risk to the stock is regarded as unacceptable (B_{lim})".	Biomass limit	10%	Over 10 years
	"Maintain key commercial fish stocks, on average, at the	Biomass target	50%[9]	--

	required target biomass to produce maximum economic yield" or B_{MEY}.			
ICES (2018a)	For data-rich stocks, attain "a fishing mortality rate of no more than F_{MSY} while maintaining the stock above B_{lim}."	Fishing mortality limit, biomass limit	95% (for B_{lim})	Each year
NAFO (2004)	For stocks below F_{buf} and above B_{buf}, "select and set fishing mortality from a range of F values" relating to the desired risk tolerance for exceeding F_{lim}.	Fishing mortality limit	Low (for F_{lim})[10]	--
	For stocks with biomass between B_{lim} and B_{buf},, "ensure that there is a very low probability that the biomass will decline below B_{lim}."	Biomass limit	Very Low (for B_{lim})[11]	Foreseeable future[12]
New Zealand (MF 2008)	Harvest strategies with "a high probability of achieving targets, a very low probability of breaching limits, and acceptable probabilities of rebuilding stocks that nevertheless become depleted, in a timely manner."	Biomass limits and targets	--	--
	"…an objective of maintaining the stock at or above, or moving the stock towards or above, a level that can produce the maximum sustainable yield."	Biomass target	--	--
	"Fisheries should be managed to fluctuate around" a MSY-compatible or better target.	Biomass and fishing mortality targets	50%	--
	Harvest strategies should have a probability of breaching the soft limit of no higher than 10%, and of breaching the hard limit of no higher than 2%. Alternatively, a probability of breaching the	Biomass limits	2, 5 or 10%, depending on context	--

	soft limit alone of no higher than 5%.			
	For rebuilding, an objective for at least a 70% probability of achieving the MSY-compatible target or better within the specified timeframe.	Biomass target	30%[13]	T_{min} to $2*T_{min}$
United States (NOAA 2018a, Restrepo et al. 1998)	"Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield (OY) from each fishery."	Fishing mortality limit	50% (for F_{lim})	--
	Guidelines indicate provisional risk tolerances for an objective to rebuild stocks to achieve B_{MSY}.	Biomass target	50% (target time), 10%[13] (maximum time)	T_{target}, T_{max}

[1]PA Policy indicates decisions "should be explicit about the risk of decline associated with a management action" but do not give a provisional risk tolerance for this phrase (DFO 2009a)
[2]"Low" is assumed here as the inverse of 'high," provisionally described as 5-25% (DFO 2009a)
[3]"Recent stock trajectory" and "short term" are not defined, but "reasonable time frame" is provisionally described as 1.5 to 2 generations.
[4]"Low to moderate" applies to "risk tolerance for preventable decline". Low is provisionally 5-25%, and Moderate is 25-50% (DFO 2009a)
[5]"Very low" is provisionally described as < 5%, and "low" as 5-25% (DFO 2009a)
[6]"High" is provisionally described as 75-95% (DFO 2009a)
[7]"Moderate" is provisionally described as 25-50%, and "neutral" as 50% (DFO 2009a)
[8]The wording suggests possible establishment of desired risk tolerances for exceeding "established maximums" in *F*-based reference points, i.e., the removal reference.
[9]50% is the proposed interpretation here for "on average"
[10]"Low" is provisionally given as approximately 20% (NAFO 2004a)
[11]"Very low" is provisionally given as approximately 5-10% (NAFO 2004a)
[12]"Foreseeable future" is provisionally given as 5 to 10 years (NAFO 2004a)
[13] Value is inferred as the provisional risk tolerance (i.e., risk of not achieving the target).

Both Canada and NAFO provide guidance for adjusting risk tolerances of, and the focus of, fisheries management objectives in a way that varies with stock status. Canada's PA Policy (Table 1) is particularly unique in that it emphasizes risk tolerances for objectives around stock trajectories (here, avoiding "preventable decline"), presumably evaluated over relatively short time intervals, instead of primarily for limits and targets.

Considerations for a Canadian Approach

An overarching objective may be most relevant for policy on harvest strategies, but existing policy objectives should be reflected in operational guidelines. The Sustainable Fisheries Framework, as the parent policy of DFO's PA Policy, speaks to "conservation and sustainable use" and this could readily be reiterated in operational guidelines.

Although Canada's PA Policy (DFO 2009a) does not generally stipulate default or baseline fisheries management objectives to which all fisheries must subscribe (with an exception below), the new Fish Stocks provisions of the revised *Fisheries Act* infer several fisheries management goals that will presumably need to be reflected in operational guidelines, translated into measurable objectives wherever possible:

- Measures to maintain fish stocks at or above levels necessary to promote sustainability of the stock (section 6.1(1));
- Measures to maintain fish stocks above the Limit Reference Point (6.1(2)); and
- Measures to rebuild fish stocks above the Limit Reference Point (6.2)).

It is important to preserve the "intent" of the Fish Stocks provisions and the PA Policy in advice given for stocks across the data continuum, even in situations where reference points and stock status cannot be determined reliably due to a paucity of data. In the case of data-poor stocks specifically, the existing PA Policy does provide a recommended fisheries management objective (precautionary management actions should be selected "with the *objective of avoiding serious harm to reproductive capacity of the stock*"; DFO 2009a; emphasis added), as does the supporting science advice ("*ensure a low risk of serious or irreversible harm*," DFO 2006; emphasis added). However, identifying a state of serious harm can be challenging, typically requiring large amounts of informative data, and often not realized until serious harm is incurred (Hilborn and Walters 1992). Regardless, any operational guidelines for science advice should include consideration and recommended methods for stock and fishery contexts considered to be data poor.

The situations in which the complex set of risk tolerances and shifting fisheries management objectives prescribed in Table 1 of the PA Policy are intended to apply (which when summed together comprise a "risk-based rule" which adjusts risk tolerances depending on recent stock trajectory) may also benefit from clarification. A risk-based HCR that completely accounts for all risk tolerances specified in the stock status-dependent objectives implied in Table 1 of the PA Policy actually becomes unwieldy to design (Kronlund et al. 2014a) and may only have been useful to date in qualitative scenarios (DFO 2016a). Simpler feedback management procedures using a HCR produce similar outcomes and are more easily testable in simulation. The broad goals captured in Table 1 of the PA Policy, however, may be useful in guiding fisheries management objectives and thus also harvest strategy development.

Science Advice in Support of Fisheries Management Objectives	Operational guidelines should: **2.1** acknowledge existing Canadian legislative and policy frameworks, objectives and intent **2.2** explicitly present the Fish Stocks provisions in the guidelines, as a framework against which fisheries science advice in general should be couched. **2.3** define the various components of objectives used in science advice (e.g., targets, limits, probabilities, risks and time frames) and identify the role of the Science Sector in support of the development of measureable objectives by fisheries managers. **2.4** prioritize, at minimum, providing advice in support of evaluating management measures against an objective of avoiding limits (i.e., avoiding an undesirable stock state of “serious harm”), and to achieving targets (desired states) when possible to do so. **2.5** preserve the intent of Canadian policy in providing advice in relation to objectives for data-poor stocks. **2.6** clarify the application of the objectives and associated risk tolerances found in Table 1 of the PA Policy in terms of supporting evaluation of harvest strategies.

REFERENCE POINTS

The use of reference points, specifically limits and targets in the context of a precautionary approach, was outlined in Annex II of the United Nations Fish Stocks Agreement (UNFSA; 1995). Different jurisdictions have subsequently evolved their own unique systems of reference points and in some cases nomenclatures, all of which require estimation and reporting in science advice regardless of which agency sector (science or management) is primarily responsible for establishing and/or approving them for adoption. Full details on Reference Points are available in Appendix 5.

Annex II of the 1995 UNFSA specified the identification of limit and target reference points for fisheries. According to the Annex, fishery management strategies must, in general, be designed to ensure the risk of exceeding limits is very low. If a fish stock falls below a limit, or is at risk of doing so, then management actions should facilitate stock recovery (e.g., to B_{MSY}). F_{MSY} is given as a minimum standard limit reference point. For stocks that are not overfished, F_{MSY} is not to be exceeded. However, the corresponding biomass B_{MSY} is identified as a target instead of a limit (which is a contradiction; Kronlund et al.

2014a, Maunder 2013). The Annex further states that management strategies should be designed to ensure [biomass] targets are not exceeded on average (as the UNFSA 1995 also has an objective of *optimum utilization*, where management must ensure that there is no unused surplus production). B_{MSY} can however serve as a target for stocks that are overfished.

Under Annex II, reference points are also intended to be stock-specific. However, provisional reference points should be set for data-poor stocks until more information becomes available. This allows for the use of defaults and proxies employed by many jurisdictions, or the "robin-hooding" of reference points from similar but better-known stocks (Punt et al. 2011).

Table 4: *Brief summary table of reference points versus operational control points for various jurisdictions as described in either policy, standards or guidelines. ACT = annual catch target. B = biomass. Buf = buffer. F = fishing mortality. Lim = limit. LRP = limit reference point. M = natural mortality. MFMT = maximum fishing mortality threshold. MSST = minimum stock size threshold. MSY = maximum sustainable yield. OFL = overfishing limit. OY = optimum yield. RR = removal reference. Targ = target. TRP = target reference point. USR = upper stock reference.*

	Limit		**Target**		**Operational Control Points**	
Jurisdiction	***B***	***F***	***B***	***F***	**B**	***F***
Canada	LRP	RR[1]	TRP, USR	RR[1]	USR	
Australia	B_{lim}	F_{lim}	B_{targ}	F_{targ}		
ICES[2]	B_{lim}	F_{lim}, F_{MSY}, F_{cap}	B_{MSY}		B_{pa} MSY $B_{trigger}$, MSY $B_{escapement}$	F_{pa}
NAFO	B_{lim}	F_{lim}			$B_{buf;}$ B_{tr}[4]	F_{buf}
New Zealand	Hard & soft limits	F_{MSY}[3]	Target	F_{MSY}[3]	Soft limit, Threshold [$(1-M)B_{MSY}$]	
United States	MSST	MFMT (*F*) and OFL (t), "MSY control rule"[5]		OY; "OY control rule" [5]; "ACT control rule"	c B_{MSY} in "MSY control rule" (MFMT), where c = max (1-*M*, 0.5)[5]	

[1] Can be interpreted as both limit and target fishing rate
[2] Alternative limits, targets, OCPs may be management plan-specific (F_{mgt}, B_{mgt})

[3] F_{MSY} is defined in policy as both a limit (when exceeded on average, overfishing is occurring), and a maximum target
[4]B_{tr} is found in an earlier precautionary approach framework developed by NAFO in 1997
[5]Specifications in technical guidelines may no longer reflect current policies or standards

Annex II of UNFSA also gave reference points a dual function. They are described as both operational control points (OCPs) in harvest strategies (in the sense that they "trigger... management action"), as well as components of fisheries management objectives (in the sense that "management strategies shall seek to maintain or restore populations… at levels consistent with" the reference points), although in practice dual functions create paradoxes for implementation (Cox et al. 2013, Kronlund et al. 2014a). For example, in the presence of uncertain stock and fishery dynamics a low probability of breaching a limit may not be maintained on average if management actions are delayed until the limit is reached.

It is conceptually important to separate reference points, which can be roughly divided into categories of limits and targets for use in management objectives, from OCPs, which are points where management actions are taken. Such points are variously termed buffers, soft limits, thresholds, interim thresholds or triggers (Table 4). While reference points and OCPs can coincide, they serve different purposes.

All jurisdictions reviewed here have identified limit reference points in their policy, standards or guidelines as applicable, although there is variation in nomenclature, definition, dual use in harvest strategies as operational control points, default values and acceptable proxies to reference points based on, for example, MSY. ICES, in particular, has a complex reference point nomenclature system supported by guidance that varies depending on the data-richness category of the stock, and which affects the suggested proxies that must be used (ICES 2017, ICES 2018a, ICES 2018b). NOAA's overall nomenclature differs substantially from most other jurisdictions; for example, NOAA uses the term *threshold* to mean *limit*, while in most other regions, *threshold* means a buffer or trigger (Restrepo et al. 1998). NOAA also considers Acceptable Biological Catch (ABC) and Annual Catch Limit (ACL) as among its reference points (NOAA 2018a), although these may be more analogous to outputs of advice or harvest control rules as they may be distinct from the minimum stock size (MSST) and maximum fishing mortality (MFMT) thresholds used as limits to define overfished and overfishing status, respectively. Canada's WSP (DFO 2005a) uses the term *benchmarks* instead of reference points, although the two may be functionally similar. Paradoxically, the WSP operationally uses the term "management reference point" to indicate where action is taken, i.e., an operational control point (Holt and Irvine, 2013). Note that a full overview of all possible acceptable defaults, proxies and methods for calculating various types of reference points across jurisdictions was out of scope for this review.

While most reference points appear to be defined as static values, variable limit fishing mortality rates (where *F* or its proxy changes with stock status) were held in common between Canada's PA Policy (Removal Reference, or RR), an early version of NAFO's PAF (NAFO 2004a), an earlier iteration of Australia's HS Policy (Australian Government, Department of Agriculture, Fisheries and Forestry [DAFF] 2007), and NOAA's former "MSY control rule." In the latter, variable limit fishing rates were established as a recommended default limit control rule to set the MFMT in Restrepo and others (1998). Guidance for Australia's current HS Policy also permits the use of dynamic biomass reference points that can vary from year to year regardless of stock status, when considered superior to equilibrium reference points (DAWR 2018b).

In McIlgorm's (2013) review of international best practices, B_{lim} was noted as having been adopted internationally as the reference point for declaring stocks "overfished," with B_{lim} defined in best practice as 0.5 B_{MSY} or $0.2B_0$. The corresponding "overfishing" reference point was identified as F_{MSY}. McIlgorm (2013) described F_{MSY} as "regarded internationally as a target limit, but not … a reference limit. Countries seek to keep control of *F* within a percentage probability of not exceeding F_{lim}, with 50% being considered by that author to be international best practice. Canada's PA Policy, however, describes maximum fishing mortality rates as a limit "not to be exceeded" suggesting the possibility that desirable risk tolerances for overages may be less than 50% (DFO 2009a).

McIlgorm's (2013) description of F_{MSY} as "target limit" may reflect the fact that some jurisdictions appear to have multiple and potentially incompatible interpretations of reference points. The New Zealand Harvest Strategy Standard for example 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 (MF 2008). Similarly, Canada's RR has also been interpreted both as a limit and a target fishing rate (DFO 2016a), and both meanings may be considered consistent with the PA Policy. More specifically, while the policy indicates that the removal reference is a maximum not to be exceeded (i.e., a limit), fishery status relative to the removal reference can take one of two forms, either "at or below" or "exceeding" the reference (DFO 2009a). Since harvests at the RR are considered equivalent in status to those below the RR, the RR may also be interpreted in practice as a target.

Biomass-based reference points can also be described as serving multiple roles. New Zealand's soft limit serves as an OCP triggering the development of a rebuilding plan, but also as a reference point (as for the limit) with default risk tolerances for allowable breaching, and against which stock status is defined as depleted (MF 2008). Canada's Upper Stock Reference (USR) is assigned roles both as a buffer, and a target in the absence of a separately defined target reference point. When considered as a buffer, it is an OCP analogous with NAFO's B_{buf} (and earlier B_{tr}), ICES' MSY $B_{trigger}$ (or alternatively, B_{pa}), New Zealand's threshold or the unnamed OCP (suggested as a default MSST) of NOAA's former "MSY control rule" used to set MFMT (cB_{MSY}; Restrepo et al. 1998) in the sense that its minimum function is to guide the risk of the stock approaching the LRP (DFO 2009a).

There may also be variation among jurisdictions in how frequently the various reference points or OCPs are used in harvest strategies. The utility of all of the components of NAFO's PA framework, for example, including the associated management actions, is particularly unclear as portions of the suite of reference points have been underutilized. For example, NAFO (2013) concludes that the "…concept of buffer reference points, which is an element in both the original and current versions of the PAF, has never really been implemented in NAFO, and B_{buf} or F_{buf} have not been defined for any NAFO stocks." However, identifying rates of use of all reference points across jurisdictions was beyond the scope of this review.

Considerations for a Canadian Approach

Canada, like most jurisdictions, has developed its own suite of precautionary reference points and acceptable proxies pursuant to the 1995 UNFSA and FAO (1996). In developing operational guidelines for science advice, Canada is expected to need to resolve differences in reference point and harvest strategy nomenclature and delineation for Pacific salmon and other key species such as marine mammals. For example, the *benchmarks* of the WSP (DFO 2005a) are functionally equivalent to reference points for the purposes of management action (Holt and Irving 2013). However, benchmarks are defined for Conservation Units while management may occur at the scale of Management Units that include multiple Conservation Units (DFO 2005a). Many marine mammal species are data-poor, and are managed with a removal reference-based HCR known as Potential Biological Removals (PBRs). This level is not explicitly recognized in Canada's PA Policy. Guidance for additional useful proxies may need to be developed; e.g., for such data-poor marine mammals, it is possible that an LRP could be set as 30% of the maximum population size (if estimable) or assigned based upon IUCN/COSEWIC criteria for a small population (DFO 2016a).

A second task for operational guidelines would be to resolve some of the ongoing technical challenges and interpretation around other reference points and operational control points mandated by the PA Policy (DFO 2009a). One of these items is the USR. While the Canadian LRP is, like most limits, generally well-understood in meaning across jurisdictions (although see the Multi-species Considerations section below), Canada's

USR is assigned a dual function; expressed simply, it is first and foremost an OCP guiding risk management of approaching the LRP, although its positioning can reflect economic objectives for the fishery; and it is also a “stand-in” for a target reference point as required by the UNFSA, in the absence of a defined third reference point explicitly identified as a target. This dual role cannot be achieved simultaneously and leads to confusion about:

1. contributions of science vs. management sectors in setting the USR (DFO 2016a; see section on Roles and Responsibilities below), and
2. interpreting performance of stock status against the USR.

For example, if the USR is intended to serve primarily as an economic target (desired state) for the fishery, then performance might usefully be evaluated along the lines of the target in systems such as that found in New Zealand; i.e., stocks would be expected to fluctuate around the USR with a 50% probability of being above it over some period of time.. However, as the primary purpose of the USR is about avoiding limits (i.e., comparable to a buffer, or the New Zealand soft limit) then the evaluation of performance is relative to the limit reference point, with the USR serving only as point where management actions are adjusted to preserve a low probability of a limit breach. A further complication, particularly for science communication, is that the USR has no overt biological meaning, unlike the LRP which is a threshold to serious or irreversible harm (DFO 2016a). Nonetheless, the USR is used in the PA Policy to demarcate what is termed a Healthy Zone, thus inextricably linking the USR with what may be considered a “healthy” versus “unhealthy” stock on the basis of stock abundance or biomass alone. The conflation of reference point with OCP causes confusion among practitioners and unnecessarily constrains the management options under consideration since it is incorrectly presumed that the HCR cannot be independent of the reference points.

There are also technical challenges in delineating and understanding the RR (*F*-based reference point) separately in all three stock status zones, particularly the Cautious Zone. Unlike most jurisdictions with *F*-based reference points, Canada’s RR is not a single value but is expected to decrease with stock status below the USR through to the LRP. This definition is similar to an early version of NAFO’s PAF (NAFO 2004a), NOAA’s former default ‘MSY Control Rule’ (Restrepo et al. 1998) and an earlier version of F_{lim} in Australia’s first HS Policy (DAFF 2007). Such a design requirement complicates reference point and HCR development and stock status reporting relative to the reference point, and may not in fact be necessary for preserving the policy intent to avoid a breach of status-based limit with high probability, or to avoiding a breach of a limit fishing rate. DFO (2016a) noted that as it is currently described, RR can be considered in three ways: *F* limits, *F* targets, and also (in the case of the diagonal component in the Cautious Zone of the PA Policy) even a HCR in its own right. However, the latter interpretation again conflates reference points (components of management objectives) with the management tactics intended to achieve objectives that incorporate reference points. Recognizing that the need for guidance in setting the RR was also highlighted by DFO (2005b), clarification in operational guidelines may facilitate more consistent reporting of fishery status along the *F* dimension of the Precautionary Approach.

Reference Points	Operational guidelines should: **3.1** reflect current international practices in setting reference points (particularly for limits) and operational control points. **3.2** resolve existing differences between Canadian precautionary approach policies (e.g., regarding salmon). **3.3** accommodate new data-poor reference points useful for some taxonomic groups (e.g., marine mammals). **3.4** address technical aspects of identifying and providing advice regarding the Upper Stock Reference (USR) and Removal Reference (RR).

HARVEST STRATEGIES

A *harvest strategy* sometimes called a *management strategy,* may be generally defined as a complete specification for managing a particular stock, with aspects that fall under the mandate of both science and management. A harvest strategy can be defined to include (a) a data collection or monitoring program, (b), calculation of performance indicators (i.e., via stock assessment), and (c) the use of performance indicators, including status with respect to any reference points, into tactical decision-making via harvest control rules to achieve the fisheries management objectives for that stock (Dowling et al. 2015a, Dowling et al. 2015b). Full details on harvest strategies are available in Appendix 6.

Policies and associated guidance frequently describe the mandatory components of a harvest strategy; identifying these components is an important part of determining the required content of science advice in support of decision-making. Both Australia and New Zealand explicitly consider *scientific activities* (monitoring and assessment) to be part of harvest or management strategies, although New Zealand draws a distinction between a simple harvest strategy (harvest control rule) and the more complex management strategy in which the harvest strategy and associated scientific work are embedded (MF 2008). Australia in particular emphasizes the need to consider risk-catch-cost tradeoffs when making investments in different management measures, including investments in science – in essence, the relative costs and benefits of various options should be taken into consideration before an approach is selected (DAWR 2018a). The role that scientific data collection plays in harvest strategies was also addressed by Restrepo and others

(1998), who noted that "improved knowledge" over time should result in reduced uncertainty and as a result, both higher yields and lower risks of stock depletion. New fisheries, they stated, should aim to gather sufficient information to meet "data-moderate standards" over time. However, note that improved knowledge does not necessarily translate into higher yields and could in fact increase structural uncertainty as more is learned about the fishery system (Mace 2001).

Most jurisdictions tie reference points, either by definitions or figures, to default harvest control rule design as *operational control points* (the "bends" in the rule that trigger a change in management action). In some cases, this may be by design, or simply by lack of illustrating more than one option beyond a single default harvest control rule. A notable exception is the NOAA guidelines for implementing the *Magnuson-Stevens Act* (Restrepo et al. 1998, in their figures 1 and 2). Regardless, this linkage may be limiting or impractical from an analytical point of view and may lead to sub-optimal management outcomes (Cox et al. 2013). Default, but non-prescriptive, harvest control rules are either described in text or illustrated by all jurisdictions reviewed here except for NAFO (2004a), which noted that a less prescriptive framework was desired.

Policies and guidelines for various jurisdictions differ in their approach to providing high-level guidance for developing and evaluating harvest strategies, while at the same time recognizing that it will never be possible to address all possible circumstances facing fisheries managers and stock assessors. Some jurisdictions, particularly ICES, give prominent consideration to the diversity of stocks for which advice on harvest strategies must be provided, both in terms of life history variation (long- and short-lived species) and in terms of data poverty (Categories 1-6). Risk equivalency along the data continuum may be achieved, for example, by the use of tiered and buffered systems (Fulton et al. 2016, ICES 2018a), or by alternative methods that embrace a continuous approach (Bentley 2015). In the former case, care must be taken in choosing the buffers and demonstrating that they provide the desired risk equivalency among tiers. Others focus more on methods of accounting for diverse stock life histories in reference points (e.g., Restrepo et al. 1998) but not necessarily as a component of whole-harvest strategy design. Guidelines for Australia's HS Policy (DAWR 2018b) contained five examples of harvest strategies across a range of taxa and data poverty levels as an aid to technical experts in interpreting options consistent with policy.

Considerations for a Canadian Approach

Many elements of Canada's PA Policy (DFO 2009a) are non-prescriptive about the details or formulation of harvest strategies, possibly in an effort to best accommodate stocks along a data and model continuum. For example, Table 1 of the PA Policy contains a series of generalized management actions that are specifically described per stock status zone, and some of which vary according to recent stock trends. While this scheme is intended to guide the development of HCRs, it may also be used to serve as a decision-making guide for a data-poor ad hoc management approach in the absence of a defined HCR provided guidelines for implementation are developed. Such specifications may continue to be helpful in developing future Canadian guidance for harvest strategies across a data continuum that meet policy intent.

Operational guidelines may also benefit from recognizing that scientific monitoring, and analyst time, are in fact a part of the investment in harvest strategies from a whole-organizational perspective. Australia's policy and guidelines take a pragmatic approach, and recognize that increases in monitoring should be worth the investment in terms of improvements to science advice that confer benefits to the fisheries management system as a whole (DAWR 2018a, DAWR 2018b). A frank consideration of diminishing returns (Mace et al. 2001) when investing in stock monitoring and analysis would help to ensure that scientific resources are used where they are most effective (i.e., when they are most useful to decision-making).

Due consideration must be given to enable the appropriate and flexible provision of advice for all stocks along the data continuum from data-poor to data-rich stocks. Many jurisdictions have begun more recent work exploring options for developing harvest strategies for data-poor stocks (e.g., NOAA; Berkson et al. 2010) that are not yet formally reflected in technical guidelines. Australian practitioners have considered guidelines for stocks at the very data-poor end of the continuum that explicitly ties changes in fishery characteristics to requirements for enhanced data collection (Dowling et al. 2015). The primary goal of operational guidance on harvest strategy formulation should be to ensure that harvest strategies or "PA frameworks" are not so narrowly defined with heavy data requirements that they cannot be applied to even data-moderate stocks. An *uncertainty paradox* should be avoided: "Ironically, it appears that these 'PA frameworks' only require a precautionary approach to managing fisheries that have a relatively informative scientific assessment" (Cadrin and Pastoors 2008). Rather, like the Australian HS Policy, it is recommended harvest control rules should be "designed to pursue" objectives (i.e., preserve the intent) for a given fishery (DAWR 2018a). They should also ensure that reference points (limits and targets) are disentangled from harvest control rule operational control points.

Harvest Strategies	Operational guidelines should: **4.1** define components of harvest strategies, and recognize data collection and assessment as a fundamental part of the broader organizational investments made in developing and evaluating

	harvest strategies. **4.2** accommodate the need to develop harvest strategies across life histories representing a range of taxa and across the data continuum (from “poor” to “rich”), making specific note of objectives and provisions for data poverty already expressed in the PA Policy. This may include providing examples of harvest strategies that meet policy intent where PA Policy elements cannot be closely met.

UNCERTAINTY AND RISK

Policies and associated guidance may provide specific instructions or recommendations as to how uncertainty and risk is to be incorporated into reference points and harvest strategies, directly shaping how science advice is provided. Full details on Uncertainty and Risk are available in Appendix 7.

All jurisdictions recognize that as uncertainty increases, advice or management action becomes more conservative, usually in terms of reductions in fishing mortality intended to preserve a high probability of avoiding biological limits to harvest. Plans to incrementally improve information available for data-poor stocks may reduce risks to the stock and fisheries by better estimating trade-offs for decision-makers, and should be part of new fishery development (Restrepo et al. 1998). NOAA’s recent Stock Assessment Improvement Plan recommends a structured decision-making approach to expanding stock assessments to include other types of information where such information can be shown to improve accuracy and precision of advice (Lynch et al. 2013). Australia, similarly, emphasizes a risk-catch-cost trade-off to ensure that the costs of data collection, assessment and management are taken into account when considering the benefits of additional data in reducing risks (DAWR 2018a).

Apart from plans to improve data, and in order to provide advice in the interim, accommodation of stocks by life history or by data poverty level by tiered, buffered or discounted systems is generally intended to systematically operationalize approaches to incorporating uncertainty and risk equally across stock types (e.g., Australia, ICES, and NOAA), although only Australia formally uses the term *risk equivalency* in the rationale for their approach (DAWR 2018b). Policies and guidance for Canada (DFO 2009a) and NAFO (NOAA 2004a) note that buffers (USR, and B_{buf}/F_{buf} respectively) must be placed at increasing distance from limits with increasing stock uncertainty. Here the buffers are OCPs to be adjusted to preserve the desired risk tolerance, on average.

Although stock-specific risk tolerances are widely recognized as a management prerogative, Canada, NAFO and New Zealand provide default risk tolerance tables (or designations) to assist with calibrating and understanding risk tolerances expressed verbally, assigning specific numeric values or ranges of probability to terms such as "high," "low," etc. All three jurisdictions employ different values for default risk tolerances, however, and only the source of New Zealand's definitions is cited (IPCC 2007).

Australia, ICES and NAFO have established specific risks considered acceptable over timeframes that then comprise default or provisional fisheries management objectives. For Australia, a 10% or less risk of a stock declining below B_{lim} (once in a 10-year period) is considered acceptable. For ICES, a management plan is considered "precautionary" if the strategy results in no greater than a 5% risk of the stock declining below its limit in each and every year of the plan (with suitable provisions for shorter-lived stocks that naturally exceed this probability), For NAFO stocks close to B_{lim} ($B_{buf} > B > B_{lim}$), fishing mortality should ensure a *very low* (e.g., 5-10%) probability of declining below B_{lim} in the *foreseeable future* (e.g., 5-10 years). McIlgorm (2013) claimed that a 50% probability of reaching a target, and 90% probability of avoiding a limit, were international best practice, although it is not clear that this review fully considered specifications by jurisdictions such as ICES (95% probability of avoiding limits) in making this designation.

Considerations for a Canadian Approach

Fisheries management, and the application of the precautionary approach within decision-making is fundamentally concerned with risk management in Canada (PCO 2003) and elsewhere. The Canadian PA Policy already notes that *uncertainty* ("incomplete knowledge about the state of nature") and *risk* ("probability of an outcome multiplied by the level of impact") are some of the primary components of the generalized decision-making framework that need to be taken into account when developing reference points, calculating stock status and implementing harvest decision rules. Uncertainty itself is recognized as comprising scientific and/or implementation uncertainty (DFO 2009a), analogous to the terms of process, observer and implementation error used throughout the fisheries literature.

The "appropriate risk" to consider when using a PA framework was defined as the "probability of and the severity of the impact from management actions on stock productivity," and management decisions "should be explicit about the risk of decline associated with a management action" (DFO 2009a), presumably with reference to stock decline and not yield. In the development of harvest strategies, risk affects three things: "the identification and position of reference points, the changing severity of management actions that are chosen as stock status changes and the tolerance for stock declines" (DFO 2009a). This is particularly in the case of the Upper Stock Reference which has a primary function of guiding risk management of approaching the Limit Reference Point.

When evaluating fisheries management objectives, Canada's PA policy (DFO 2009a) already identifies three risks that should be described, namely:

1) "the probability of and severity of the impact from management actions on stock productivity",
2) "the risk of decline associated with a management action" and
3) the "probability of achieving a target or falling to a certain level."

Such risk delineation could help to form the basis of a recommended technical performance metric (s) useful for performance evaluation of harvest strategies. However, the "severity of impact" is not specified in most advice to fisheries managers so "risk" is typically synonymous with probability. As "probability" is not a natural or well-understood metric by the broader community around fisheries, it may be useful to introduce metrics for severity of consequences, e.g., time to achieve a rebuilt or target level, or reduction in catches incurred at status levels where so-called precautionary harvest rate reductions are implemented compared to catches at target levels.

The revision of Canada's *Fisheries Act* has resulted in Fish Stocks provisions that mandate the implementation of management measures that take into account "the biology of the fish and environmental conditions affecting the stock," not just in developing rebuilding plans, but also in maintaining stocks at sustainable levels and above the limit reference point. Such factors are directly implicated in both scientific and implementation uncertainty already considered as part of Canada's PA Policy.

Operational guidelines that address the quantification and expression of uncertainty and risk will likely need to be specific about three key items. The first is technical guidance on how to account for and communicate uncertainty in science advice, as well as methods to convert uncertainty into risk-based advice in support of harvest strategies. Furthermore, analysts are often asked to identify key uncertainties affecting advice that may be resolved with the acquisition of more data, especially on new or suspected stock dynamics drivers, in order to reduce risks for decision-makers. As such, guidance on "monitoring strategy evaluation" (Piacenza et al. 2019) to justify costs associated with increasing scientific scope (DAWR 2018a, Lynch et al. 2013), as well as guidance on the design and testing of robust harvest strategies (e.g., via MSE and ensemble modelling) to address current uncertainties, may be useful to assist analysts.

The second key item is how to best to accommodate the increasing uncertainty inherent with increasing data poverty in estimating reference points and designing harvest strategies, keeping in mind that harvest strategies for data-poor stocks may look quite different from those of data-rich stocks and may not fall neatly into the mould of the PA Policy. The proposal here is to work towards maintaining, to the extent possible, risk equivalency for decision-makers such that regardless of stock the risk of serious harm would be expressed equally (Fulton et al. 2016). Appropriately calibrated, tiered and buffered systems can help with this goal (e.g., as described by ICES 2018a, DAWR 2018a, Restrepo et al. 1998 or reviewed by DFO 2016b), as described earlier under Harvest Strategies. Such approaches, however, are essentially a categorization of the concepts of a data and model continuum (Bentley 2015) and can lead to choices based on what stock assessment model can be fit, rather than current hypotheses about the underlying stock and fishery dynamics.

The third key item may be to revisit default calibrated risk tolerances, which are currently in draft form in the PA Policy (2009a). Sound advice needs consistent application of defensible default risk tolerance language, and to date the only cited source of risk tolerance table values in the array of jurisdictions considered here is from IPCC (2007), employed in modified form by New Zealand.

Uncertainty and Risk	Operational guidelines should: **5.1** clarify how to account for and communicate uncertainty and risk in science advice, in line with the requirements of the PA Policy, the Fish Stocks provisions, and international best practices, particularly with respect to deleterious stock and fishery states consistent with an interpretation of “serious harm.” **5.2** indicate various methods by which key uncertainties affecting science advice can be identified, and possible costs and benefits (i.e., reduced risks) of improved data collection to reduce uncertainty can be demonstrated. **5.3** give consideration as to methods by which uncertainty and risk could be accommodated a continuum of data availability to preserve, to the extent possible, risk equivalency in science advice across a wide range of stocks. **5.4** provide defensible definitions of risk tolerance terms for use in stock and fishery objectives when evaluating harvest strategies.

ENVIRONMENTAL AND ECOSYSTEM CONDITIONS

The policies and associated guidance of most jurisdictions gave at least some attention to accommodating environmental or ecosystem considerations in developing harvest strategies. Full details on Environmental and Ecosystem Conditions are available in Appendix 8.

Four of six jurisdictions (Canada, ICES, NAFO and New Zealand) explicitly recognized that their policies and standards regarding precautionary approaches to fisheries management were fundamentally concerned with single-species management, in ways that do not necessarily lend themselves readily to inclusion of other considerations. Two of six jurisdictions, however, Canada and Australia, noted existing higher-level government or policy commitments to an ecosystem-based fisheries management approach, of which the relevant precautionary approach harvest policy was considered a part (DAWR 2018a, DFO 2009e).

New Zealand's *Fisheries Act*, similar to Canada's newly revised *Fisheries Act,* contains a requirement to take into consideration environmental conditions, in New Zealand's case for rebuilding. This requirement appears to have been met through the use of T_{min} when calculating rebuilding times (the minimum time to rebuild the stock, given its biology, state of depletion and the prevailing environmental conditions).

Three jurisdictions (Canada, Australia, and the United States) made clear mention of the impact of environmental change on setting reference points, either in policies and standards or in technical guidance. NOAA's NS Guidelines (2018a) explicitly require a change in reference points and harvest strategies to be considered under conditions of long-term environmental change. While recognizing the difficulties and lack of international guidance for addressing environmental change in either setting reference points or designing harvest strategies, Australia's guidelines note the "need" for similar action if changes in conditions were long-term (DAWR 2018b). Technical guidelines for Canada's PA Policy highlighted the diversity of ways in which environmental factors could be incorporated into assessments, and also the challenges in doing so under conditions of environmental change (DFO 2016a). An approach favouring robust harvest control rule design in the face of environmental change was suggested in lieu of changing reference points, particularly where functional relationships between environmental factors and stock dynamics might prove challenging to elucidate or be highly nonlinear (DFO 2016a).

Considerations for a Canadian Approach

The development of operational guidance for Canada that speaks to incorporating environmental and ecosystem considerations in fisheries science builds on a body of extensive earlier and ongoing work, much of which is beyond the scope of this review. As an example, some consideration has been given to determining when reference points might need to change with stock productivity, concluding that:

> "It is appropriate to change reference points when: i) the productivity change is known with high certainty to be due to a regime shift, i.e. when there is an understanding of the mechanisms linking the environmental change with the productivity of the stock, and an understanding of the life history stages that are affected by the regime shift; ii) the change is not believed to be reversible in the short or medium term (e.g. is expected to last at least a decade or a generation – whichever is longer); and iii) there has been a change in the capacity of the environment to support the stock" (DFO 2013c).

Feedback simulation to evaluate hypotheses on stock productivity, and the need to evaluate proposed reference points as part of harvest strategies in light of management objectives, were recommended (DFO 2013c). The recommendation for evaluation is particularly important because, for example, there is potential risk to the stock if the underlying mechanisms governing regimes and the ability to detect regime shifts is not well understood (e.g., Punt et al. 2014).

Canada's *Fisheries Act* has recently been revised and now explicitly contains requirements to implement management measures that take into account "the biology of the fish and environmental conditions affecting the stock," not just in developing rebuilding plans, but also in maintaining stocks at sustainable levels and above the limit reference point. The application of an *ecosystem approach* as well as the *precautionary approach* are now also both identified in the law as things that Ministers may take into consideration when making decisions, and one of the proposed rebuilding plan regulations will include a section on describing reasons for a stock's decline.

While existing technical guidance for Canada's PA Policy (DFO 2016a) addressed some options for incorporating environmental and ecosystem factors into science advice, additional guidance will likely be needed to ensure that the specific requirements of the new Fish Stocks provisions are taken into consideration when providing advice for prescribed major fish stocks.

Environmental and Ecosystem Conditions	Operational guidelines should: **6.1** to the extent possible, outline options for meeting the requirements of the Fish Stocks provisions when it comes to setting and changing reference points, taking into account stock biology and environmental conditions, **6.2** address methods for identifying and modelling key hypothesized drivers in stock dynamics (past, present and future)

	6.3 discuss the evaluation of harvest strategies that takes into account biology and environmental conditions **6.4** make recommendations for evaluating and communicating these factors as components of uncertainty.

REBUILDING STOCKS

The policies or guidance of most jurisdictions speak to at least some extent to the special case of developing management strategies for depleted stocks that need rebuilding. However, as McIlgorm (2013) noted, “there is no international consensus about if and when stock rebuilding plans should commence and over what time period recovery arrangements should be in place.” Full details on Rebuilding Stocks are available in Appendix 9.

<u>When rebuilding is required</u>: In most cases, jurisdictions require rebuilding actions, or at least advise a reduction in fishing mortality (NAFO), when a stock has declined below its biomass-based limit (with nomenclature ranging from LRP in Canada, B_{lim} in Australia, ICES and NAFO, and MSST (minimum stock size threshold) in the United States). An exception is New Zealand, which requires rebuilding plans to be developed for stocks that have declined below a *soft limit* (functioning as an OCP). Canada’s harvest policy does indicate a goal of taking management actions intended to arrest stock decline as stock status decreases towards the LRP (Table 1, DFO 2009a); the primary tactic indicated is a reduction in fishing mortality via a HCR, though other measures are not precluded.

<u>When rebuilding is complete</u>: Here, definitions vary and are less precise. Australia notes that rebuilding is complete when stocks have exceeded B_{lim} with at least 75% probability, while New Zealand indicates that stocks are considered rebuilt when they have exceeded the target with at least 70% probability, where the target is at least B_{MSY} under the HS Standard. Canada’s guidelines indicate that the short-term goal of a rebuilding plan is to rebuild stocks above the LRP, but long-term objectives (beyond the lifespan of a rebuilding plan) “*include growing the stock through the Cautious Zone and into the Healthy Zone*” (DFO 2013b; emphasis added).

<u>Timeframes</u>: While Canada’s policy and rebuilding guidelines indicate rebuilding must occur in a *reasonable timeframe*, a default value for which is given as 1.5-2 generations, flexibility is also provided to accommodate severely depleted stocks, low productivity regimes, and the need to trade off against socio-economic impacts (DFO 2013b). Both Australia and New Zealand indicate that rebuilding is to occur between T_{min} and $2*T_{min}$ (where T_{min} is the time the stock would take to rebuild in the absence of fishing); Australia

further provides flexibility in setting rebuilding timeframes for data-poor stocks, with a method based on generation time. ICES's Advice Basis (2018a) indicates that advice will be given to rebuild the stock above B_{lim} in the "short term," which is not defined and thus perhaps left to clients to specify. The United States sets rebuilding timeframes to be 10 years (if T_{min} < 10 years), or T_{min} plus one generation time, 2*T_{min} or the time to rebuild to B_{MSY} under 0.75*MFMT (maximum fishing mortality threshold; NOAA 2018a).

While not strictly a science advice issue, not all jurisdictions indicate what is to be done in the event that stocks do not rebuild within specified time frames. In the United States, if a stock or stock complex has not rebuilt by its specified maximum time period, then "*F should be maintained at* $F_{rebuild}$ *or 0.75*MFMT (maximum fishing mortality threshold), whichever is less, until the stock is rebuilt or the* $F_{rebuild}$ *is changed as a result of the Secretary finding that adequate progress is not being made*" (NOAA 2018a). In Canada, if evaluation fails to find clear evidence that rebuilding is occurring, rebuilding plans must contain a provision that "*application of the measures is mandatory*" (DFO 2009a), although under the Fish Stocks provisions, the implementation of a rebuilding plan will now be required by law.

Considerations for a Canadian Approach

Rebuilding strategies are a special case of harvest strategies, and under the proposed Fish Stocks provisions, rebuilding plans will be required for prescribed major fish stocks once they are below their LRP. Regulations regarding the requirements of such rebuilding plans are being developed for the Fish Stocks provisions in the revised *Fisheries Act*. These regulations, while still under development, may include a requirement to provide the following:

- description of stock status
- description of stock trends
- description of the reasons for the stock's decline
- measurable objectives aimed at rebuilding the stock with timelines for achieving the objectives (including a rebuilt target)
- management measures aimed at achieving the objectives; and
- a determination as to whether additional scientific information is necessary to develop a rebuilding plan

Anticipatory changes in fisheries management measures may occur before a stock breaches its limit, and therefore be a part of harvest strategies before a specific rebuilding strategy requires development. The PA Policy states that rebuilding plans should be initiated while a stock is still in the Cautious Zone (below the USR), and be ready to implement as soon as the stock declines below its LRP into the Critical Zone (DFO 2009a). This does not mean that changes in fisheries management measures should be delayed until the LRP is breached; Table 1 indicates that for stocks in the Cautious Zone and declining, "…management actions must arrest declines in the short term or immediately if low in the zone. Risk tolerance for preventable decline – very low / low" (DFO 2009a).

In existing DFO guidance to support the development of rebuilding plans, rebuilding objectives in Canada should have three components: a target outcome, acceptable probability of achieving the outcome, and timeframe associated with evaluating whether the outcome has been achieved (DFO 2013b). The PA Policy contains information pertinent for science advice on what might be used to inform objectives for rebuilding strategies. For example, the PA Policy (DFO 2009a) indicates that rebuilding plans are to have the following attributes:

1. Be in place when stocks reach the Critical Zone;
2. Aim to have *"…*a high probability of the stock growing out of the Critical zone within a reasonable timeframe";
3. Include management actions that "…must promote stock growth";
4. Include management actions such that "Removals from all sources must be kept to the lowest possible level until the stock has cleared the Critical Zone*…* "; and
5. "there should be no tolerance for preventable decline" (DFO 2009a).

The PA Policy (DFO 2009a), and rebuilding guidelines (DFO 2013b), indicate that a baseline, provisional or default value for a *reasonable timeframe* is 1.5—2 generations, when rebuilding out of the Critical zone, although timeframes could be longer depending on the biology of the stock or the state of depletion. However, the acceptable methods of calculating generation time are not specified nor does generation time alone reflect the current state of stock depletion which also affects time for stock rebuilding.

Operational guidance will be needed to provide answers to the following questions, and in particular to match the requirements of forthcoming rebuilding plan regulations:

<u>When is rebuilding required?</u> According to section 6.2 of the Fish Stocks provisions, a rebuilding plan must be developed for major fish stocks determined to be below their limit reference point. As most stock status assignments are associated with some uncertainty

(expressed as a probability the stock is below its LRP, where possible), sufficient guidance should be in place to determine when stocks are below their respective LRP across the data continuum. Where a probabilistic statement is not possible, then an agreed upon means of assigning status relative to limits should be recommended.

Why has the stock declined? Rebuilding regulations may require the incorporation of additional evidence attributing the depleted status of the stock to various drivers. Technical guidance should be given as to methods that could be used to support the development and evaluation of various hypotheses of historical and current drivers of stock dynamics in order to facilitate science advice that can meet the regulatory requirements.

When is rebuilding is complete? According to section 6.2 of the Fish Stocks provisions, "…*the Minister shall develop a plan to rebuild the stock to or above [the limit reference point] in the affected area*" and may amend that plan "*…to mitigate [socio-economic or cultural] impacts while minimizing further decline of the fish stock*". Operational guidelines should provide clarity on what stock status, with what level of certainty, would define a rebuilt state in a manner that satisfies the requirements of section 6.2, outlining where considerations are biological and where management choice can be incorporated into advice (e.g., a multi-species context where a deliberate decision may be made to sustain stocks below biologically optimal levels).

What rebuilding timeframes are appropriate? Operational guidelines should provide analysts with sufficient information to assist with calculating rebuilding timeframes that reflect the biology of the fish and the environmental conditions facing the stock.

When is additional scientific information required? Regulations may extend timelines for developing a rebuilding plan in the event that more scientific information needs to be accrued. As discussed in the section on Uncertainty and Risk, scientific information is one component of management strategies and investments can be considered part of a Risk-Catch-Cost trade-off, weighing the benefits of additional information to managers against expenses incurred (DAWR 2018a) and risks of deferring management actions. Additional information may not always improve accuracy and precision of science advice (Lynch et al. 2018, Mace 2001). Guidance will be beneficial for analysts who may need to demonstrate the relative benefits of increased scientific information in improving science advice towards rebuilding plans (i.e., less uncertainty, and reduced risk) versus the costs of delayed rebuilding strategy development (e.g., "monitoring strategy evaluation," Piacenza et al. 2019).

Rebuilding Stocks	Operational guidelines should: **7.1** provide clear technical information on determining when stock status indicates a limit has been breached. **7.2** clarify what stock states characterizes a rebuilt state (in ways that can be incorporated into measurable rebuilding strategy objectives). **7.3** outline methods for the calculation of rebuilding timeframes. **7.4** support development of rebuilding strategies (as a subset of harvest strategies) across the data continuum. **7.5** identify various methods by which key uncertainties affecting science advice can be identified. **7.6** discuss demonstration of possible costs (persistent or worsening stock and fishery states incurred by delayed rebuilding measures) and benefits (i.e., increased biomass and range of management choice, reduced risks to the stock and fishery) of improved data collection.

PERFORMANCE EVALUATION

Some jurisdictions discuss performance or technical evaluation of harvest strategies and stock status. When such requirements or recommendations are present, they directly affect the form and means by which the science advice provided to support decision-makers. Full details on Performance Evaluation are available in Appendix 10.

Management Strategy Evaluation (MSE), or at least simulation, is highlighted as a best-practice decision-making tool for evaluating performance of harvest strategies against objectives in the policies or guidelines of five of six jurisdictions: Australia, Canada, ICES, New Zealand and the United States. To support implementation, at least four jurisdictions provided illustrations of simulation or MSE schematics in technical guidelines or auxiliary reports (ICES, NAFO, New Zealand, NOAA). Restrepo and others (1998) used a simple simulation framework to test the default recommended harvest control rule for the NOAA NS Guidelines in their technical guidelines. ICES provided a summary template to facilitate MSE reporting, while New Zealand recommended that of multiple operating models, only the “base case” or a weighted average be used to assign stock status.

No jurisdiction requires MSE, with several recognizing that its full consultative form is resource-intensive. Canada proposed a “MSE-light” approach to expand the use of simulation-based evaluation to more stocks (DFO 2016a). Australia, which is the only reviewed jurisdiction to require performance evaluation, notes that MSE may be useful way to ensure a "*high probability of achieving objectives*" regarding avoiding limits (which they clearly specified as a 1-in-10-year risk or less) and achieving targets, although the policy acknowledges other risk-based methods may also be used (DAWR 2018a). As of 2013, most stocks in Australia appear to have been evaluated by MSE (Penney et al. 2013), although it is not clear whether "MSE" in this case refers to desktop simulation exercises, or to a consultative structured decision-making process.

Only Canada and Australia recommended timelines for a cycle of harvest strategy review, with Canada's PA Policy suggesting periods of 6-10 years (DFO 2009a), and Australia up to 5 years (with faster reviews in the event of new information or rapid change; DAWR 2018a).

At the other end of the evaluation spectrum, five of six jurisdictions also identified the potential need for expert judgement or expert opinion to assign stock status (Canada, ICES, New Zealand, NOAA) or to develop harvest strategies (Australia) for data-poor stocks. In Australia's case, where the Risk-Catch-Cost tradeoff is part of policy, the need for expert judgement was linked to weighing the costs and benefits associated with increased data collection, particularly for small low-value fisheries (DAWR 2018b).

Considerations for a Canadian Approach

A technical evaluation of management measures may be done retrospectively (by examining past performance in light of what would have been predicted performance given available data), and/or prospectively into the future, via simulation. Both perspectives can used in informing future management choices, albeit in different ways as past performance may not adequately account for performance in the future under uncertain conditions (Kronlund et al. 2014b). Prospective evaluation is key for a precautionary approach (FAO 1995, Restrepo et al. 1998).

Operational guidelines should address the needs of analysts who may participate in full MSE or simulation-based processes by providing guidance on technical aspects (simulation and model development), communicating uncertainty and risk, and reporting of stock status (Kronlund et al. 2014a). Although the PA Policy recommended an implementation period of 6-10 years before review, guidelines should assist analysts in identifying appropriate timelines for evaluation, including circumstances in which earlier review may be required. Consideration should also be given to using simulation testing to evaluate default and provisional reference points and harvest control rules (similar to Shelton 2017), possibly for a variety of life histories or scenarios.

In particular, MSE (simulation) may provide a way to identify management procedures for data-poor stocks and fisheries, where empirical rather than model-based procedures may be the only possible approach. For example, the Potential Biological Removals harvest strategy method applied to many marine mammal stocks was extensively tested via simulation (Wade 1998), and much recent work on a variety of data-poor harvest strategy methods (Carruthers et al. 2014, Dichmont et al. 2016, Dowling et al. 2015a, Fulton et al. 2016, Newman et al. 2014).

Given the costs associated with increased data collection, monitoring and analysis, expert judgement is likely to continue to be applied in some fisheries contexts as a means by which to provide science advice. While no jurisdiction outlined specific guidance for when and how such judgement is to be applied other than in relatively data-poor situations, operational guidelines for Canada could outline some example scenarios, and options for documenting the use of expert judgement, in order to best align with reporting requirements for the Fish Stocks provisions.

Technical Performance Evaluation	Operational guidelines should: **8.1** provide information on conducting and reporting tabular or graphical results of retrospective and prospective performance evaluation, simulation, projection, and management strategy evaluations. **8.2** demonstrate simulation-based evaluations of a range of default or provisional options for reference points and harvest control rules. **8.3** identify circumstances when expert judgement may be useful, what defensible practices to follow, and how to document its application.

REPORTING OF STATUS

Most jurisdictions report fish stock status as a way to track general fisheries management performance (Table 5). Public, or science advisory reports, may use metrics similar to those calculated during technical fisheries management system evaluation or planning, or may instead rely on simplified (condensed) metrics to report stock status in ways. The latter approach allows ready comparisons across potentially hundreds of stocks. Full details on Reporting of Status are available in Appendix 11.

Stock status often represents status in a given year. McIlgorm (2013) notes that stock status reports by nations become a “crude measure of policy success” but inter-country comparisons are complicated by a diversity of definitions of status. This finding may be applicable to regional differences within Canada upon review. Most publicly available status reports rarely include explicit accounting of uncertainty (with New Zealand as an exception; MF 2019a). New Zealand and the United States are the only jurisdictions that appear to regularly report status against fishery targets as well as limits. Canada is the only jurisdiction that does not at least nominally report stock status with respect to fishing mortality (although information on fishery removals in relation to the relevant RR is collected via the Sustainability Survey; DFO 2018c). While NAFO's framework allows for the delineation of 5 stock status zones, several key zones are based on precautionary buffer reference points that have not been identified for NAFO stocks (Brodie et al. 2013). It is unclear from this brief review to what extent the nomenclature of the stock status zones is considered useful in NAFO reporting. In addition to reporting conditions of *overfished* and *overfishing*, relative to the stock and *F*-based reference points MSST and MFMT (OFL) respectively, the United States also tracks whether stocks are approaching an overfished state, and B/B_{MSY} (with points awarded by NOAA towards a stock's score on the Fish Stocks Sustainability Index if B is at least 80% of B_{MSY}; NOAA 2018b).

Table 5: *Brief summary table of stock status as reported for various jurisdictions. B = biomass or suitable proxies; F = fishing mortality or suitable proxies.*

Jurisdiction	Status	Meaning (in brief)
Canada	Healthy zone	B > USR
	Cautious Zone	USR > B > LRP
	Critical Zone	B < LRP
	Uncertain	Stock status is unknown
	At or Below RR	F < RR
	Exceeds RR	F > RR
Australia	Sustainable	$B > B_{lim}$, $F < F_{lim}$
	Recovering	$B < B_{lim}$, $F < F_{lim}$
	Depleting	$B > B_{lim}$, $F > F_{lim}$
	Overfished	$B < B_{lim}$, $F > F_{lim}$
	Environmentally Limited	$B < B_{lim}$ for non-fishing reasons
	Undefined	Status is unknown
	Negligible	Status is unknown but catches very low
ICES	Full Reproductive Capacity	$B > B_{pa}$
	Increased Risk	$B_{pa} > B > B_{lim}$
	Reduced Reproductive Capacity	$B < B_{lim}$
	Harvested Sustainably	$F < F_{pa}$
	Increased Risk	$F_{pa} < F < F_{lim}$
	Harvested Unsustainably	$F > F_{lim}$
	Undefined	No reference points
	Unknown	Status is unknown
NAFO	Safe Zone	$B > B_{buf}$, $F < F_{buf}$
	Overfishing Zone	$B > B_{buf}$, $F > F_{buf}$

	Cautionary *F* Zone	$B_{lim} < B < B_{buf}$, $F < F_{buf}$
	Danger Zone	$B_{lim} < B < B_{buf}$, $F > F_{buf}$
	Collapse Zone	$B < B_{lim}$
New Zealand	Status with respect to Target	(Expressed as %)
	Depleted	*B* < soft limit
	Collapsed	*B* < hard limit
	Overfishing	$F > F_{MSY}$ (3-5 yr running average)
United States	Overfishing	*F* > MFMT
	Not undergoing overfishing	*F* < MFMT
	Overfished	*B* < MSST
	Not overfished	*B* > MSST
	Unknown	Status is unknown (either *B* or *F*)
	B/B_{MSY}	(expressed as value)

Considerations for a Canadian Approach

Operational guidelines should include practices for standardized reporting of performance metrics closely tied to evidence required to support the implementation of Fish Stocks provisions, namely sections 6.1(1), 6.1(2) and 6.2. Evidence may be helpfully presented in a tabular format in Science Advisory documents, similar to other jurisdictions. Standardized reporting may also help to address concerns expressed about accessibility and transparency of Canadian fisheries science and stock assessments (Baum and Fuller, 2016), by providing consistently formatted reporting and possibly reducing the time and translation costs to produce published documents. Standardized approaches also allow consideration of database applications for capturing the source information and flexibly generating reports to serve a variety of audiences.

Like most jurisdictions, public reporting of fish stocks in Canada is focused on indicators of current stock status. Unlike most jurisdictions the highest priority has traditionally been given to status against what could be called "*B*-based" reference points (stock status zone, based on biomass or some abundance proxy) and not "*F*-based" reference points (i.e., RR; although information on this is available in downloadable Excel files of Sustainability Survey data; DFO 2018c). The reasons for a Canadian focus on "*B*-based" reference points could vary. Canada has no name for different levels of "*F*-based" fishery status, apart from noting whether removals are either "at or below" versus "exceeds" the RR (DFO 2009a). Public reporting systems in Australia, New Zealand, ICES and the United States report status against axes of both biomass and fishing mortality, either separately or in combination (and with flexibility for relevant proxies).

Operational guidelines that describe standardized fisheries stock assessment reporting should include stock status determination against both abundance (biomass) and fishing rate (*F* or proxy) reference points, wherever possible, in order to capture the complete suite of PA Policy elements related to reference points.

Public Reporting of Status	Operational guidelines should: **9.1** outline formats for standard reporting of stock and fishery status to facilitate rapid communication of science advice (e.g., Science Advisory Reports), including any accommodations for data-poor stocks. **9.2** reflect status relative to limit, target and other reference points in both biomass and fishing mortality axes, as required under Canada's PA Policy or as outlined in objectives related to the Fish Stocks provisions and subsequent regulations. **9.3** integrate the reporting of stock status with reporting associated uncertainty.

SUSTAINABILITY CONSIDERATIONS

Special notice was taken in this review as to where and how sustainability was either defined or incorporated by the various jurisdictions into management objectives, reference points, performance evaluation and public reporting. Two jurisdictions use the term *sustainability* in stock status reporting. Australia classifies stocks as *sustainable* if the stock is above B_{lim}, but fished below F_{lim} (FRDC, 2019). ICES, on the other hand, considers stocks to be *harvested sustainably* if *F* is below the precautionary *F* reference point (F_{pa}), and unsustainably if *F* is above the limit (F_{lim}); otherwise, the stock is at "increased risk" (ICES 2018a). Full details on Sustainability Consideration are available in Appendix 12.

In contrast, New Zealand's operational guidance (2011) notes that sustainability is a continuum along a stock's biomass axis, with no one metric demarcating the boundary between sustainable and unsustainable. A definition is provided (MF 2011):

> ***"Sustainability****: Pertains to the ability of a fish stock to persist in the long-term. Because fish populations exhibit natural variability, it is not possible to keep all stock and fishery attributes at a constant level simultaneously, thus sustainable fishing does not imply that the fishery and stock will persist in a constant equilibrium state. Because of natural variability, even if F_{MSY} could be achieved exactly each year, catches and stock biomass will oscillate around their average MSY and B_{MSY} levels, respectively. In a more general sense, sustainability refers to providing for - 39 - the*

> *needs of the present generation while not compromising the ability of future generations to meet theirs.”*

Considerations for a Canadian Approach

One of the more challenging aspects for the provision of Canadian science advice under the revised *Fisheries Act* will be evaluating management measures against “*…levels necessary to promote sustainability of the stock…*”. This level is distinct from the Limit Reference Point that forms the basis of section 6.1(1) of the new Fish Stocks provisions. This is not a phrase found in the Canadian PA Policy, although the SSF (of which the PA Policy is a part) is intended to serve as the basis to ensure that “*Canadian fisheries support conservation and sustainable use of resources*” (DFO 2018b).

Canada has adopted a zoned approach that distinguishes between stock status states demarcated by the LRP and USR, with the upper zone named “healthy” without explicit reference to inter-generational sustainability considerations (DFO 2009a).

In their review of the use of the term *sustainability* in fisheries, Shelton and Sinclair (2008) noted that “*…fishing can be considered sustainable over a broad range of use, from very little to the level where the resource is barely viable.*” They argued, in essence, for a sustainability performance metric based on the Canadian PA Policy “*… to be consistent with societal objectives…*” and “*… in accordance with Canadian fisheries policy and international agreements …*” to be as follows:

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

The term *sustainability* has been employed or defined by the Government of Canada in general, and Fisheries and Oceans Canada in particular, in the following ways:

- “*Sustainable development*: Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. It implies a specific commitment to the management of coastal regions and resources in an environmentally responsible manner that defines and acknowledges risk.” (DFO 2004);
- “*Principle 3: Sustainable Use*. Resource management decisions will consider biological, social, and economic consequences, reflect best science including Aboriginal Traditional Knowledge (ATK), and maintain the potential for future generations to meet their needs and aspirations.” (DFO 2005a);

- ***"****Sustainability* means the capacity of a thing, action, activity, or process to be maintained indefinitely. (*durabilité*)" (*Federal Sustainable Development Act* 2008);
- *"Sustainable development* means development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (*développement durable*)" (*Federal Sustainable Development Act* 2008);
- "Sustainability comes from taking a long-term view of things… On a general level, measures to ensure sustainability protect future stock abundance and thus enable fisheries to realize economic gains over the longer term." (DFO 2013a); and
- "Sustainability means a species can survive and meet the needs of their present population without weakening the chances of future generations to meet their own needs. Sustainability reflects the capacity to thrive over the long term." (DFO 2018a).

These definitions are similar to the definition of *sustainability* used by the FAO ("*Ability to persist in the long-term. Often used as a "short hand" for sustainable development*"; Cochrane and Garcia 2009) and the MF (2011).

Several general observations may be made here. First is the importance of time. Sustainability in fisheries implies there is a need to consider what is to be achieved over the long term**.** The FAO's technical guidelines similarly iterated that *"… short-term (1-2y) projections alone are not sufficient for precautionary assessment; timeframes and discount rates appropriate to inter-generational issues should be used*" (FAO, 1996). Second is the importance of continuous access to benefits (most commonly with respect to the needs of resource users, except for DFO, 2018a above which specifies the needs of the species being harvested).

Both of these considerations (long-term timescales, and access to benefits) are consistent with the PA Policy. For example, the PA Policy states that restraint must be exercised through the recovery phase of stocks below the LRP to realize "*long-term sustainable fishery benefits*" and that "*the fishery is a common property resource to be managed for the benefit of all Canadians, consistent with conservation objectives, the constitutional protection afforded Aboriginal and treaty rights, and the relative contributions that various uses of the resource make to Canadian society, including socio-economic benefits to communities*" (DFO 2009a).

A science advice standard that incorporates "sustainability objectives," or performance metrics evaluated over longer periods of time, with suitable flexibility for data-poor situations, would be a departure from the way that fisheries science advice is presently developed and reported in Canada, with its focus on current stock status. However, it is important to note that longer-term objectives and performance metrics would also be in line with the intent of the PA Policy, which notes that assessing the "probability of achieving a target or of a stock falling to a certain level under a specific management approach" is desirable and that management actions should be "explicit about the risk of decline" (DFO 2009a). Since decline needs to be evaluated over a period of time, it seems that time horizons longer than the 1—3 years typically reported by assessment forecasts are also consistent with the policy intent.

Shelton and Sinclair's (2008) definition considers current stock status expressed simultaneously in units of both *B* (biomass) and *F* (fishing mortality; or proxies thereof), qualities shared by some other jurisdictions. However, their definition does not consider a multi-year time horizon. If desired, a fulsome analysis and peer review of the specifics of "sustainability" performance metrics would need to be conducted before a given "sustainability" metric could be endorsed in national operational guidelines and incorporated consistently into science advice. The simple "current status" metrics posed by Shelton and Sinclair (2008) is an example of what could be incorporated into science advice delivery and public reporting of science advice until there is agreement on metrics that apply over longer terms.

Sustainability Considerations	Operational guidelines should: **10.1** provide support for evaluating stock status and harvest strategy performance over the long term consistent with sustainability objectives. **10.2** provide clarity as to what science advice is required to demonstrate compliance with s.6.1(1) of the Fish Stocks provisions (i.e., to maintain stocks at sustainable levels).

MULTI-SPECIES CONSIDERATIONS

Some jurisdictions have made some accommodations for how to handle aggregate stocks or multi-species fisheries in their policies or guidance. Full details on Multi-species Considerations are available in Appendix 13.

Australia, while noting that providing advice at the fishery level for multi-species fisheries is complex, indicates that setting a fishery-level target (maximum economic yield or MEY) may result in some species being harvested more intensively than others (DAWR 2018a). New Zealand's operational guidelines speak to targets regarding "*overall fishing intensity*" on multi-species stocks, but it is unclear how provisions are made for stock status reporting in such scenarios (MF 2011). Similarly, Restrepo and other (1998) discuss setting fishery level optimum yield (OY). NOAA's NS Guidelines indicate that selective overfishing of some components in a multi-stock fishery can occur under some circumstances, with risk tolerance of breaching MSST of up to 50% (NOAA 2018a).

Canada, in both its policy and rebuilding guidelines, notes that the application of harvest control rules may need to be "*tempered*" to limit the effects on other stocks (including the harvesting of healthy stocks impacted by restrictions on stocks in the Critical Zone; DFO 2009a, DFO 2013b), but there is no elucidation of the goals of limiting effects.

Multi-species scenarios affect how stocks are assessed, managed and reported in diverse ways. The United States' National Standard Guidelines, for example, indicates that stocks may be grouped into complexes. Stock complexes may result from several stocks forming a multi-species fishery, multiple species resembling each other so closely catches cannot be easily distinguished, or because there are insufficient data on certain stocks. "*Complexes thus may have one or more indicator stocks with measurable and objective status determination criteria and possibly annual catch limits that can be used to manage and evaluate more data-poor stocks, or have such criteria/limits set for the complex as a whole*" (NOAA 2018a).

Considerations for a Canadian Approach

Canada's PA Policy is fundamentally concerned with single-species management, as are the PA harvest policies of most jurisdictions. Providing advice for multi-species stocks continues to pose technical challenges (DFO 2016a), and operational guidelines should provide more detail about methods to address such scenarios. Greater clarity may be needed on what to provide decision-makers in terms of evaluating trade-offs in multi-species fisheries (i.e., restricting harvests to benefit less abundant stocks, or accepting higher risks to less abundant stocks in order to increase overall harvests across species). At present, it is assumed that all prescribed major fish stocks will need to meet the requirements of the Fish Stocks provisions, meaning that in a multi-stock fishery, management measures must be implemented to maintain all major fish stocks in that fishery at or above sustainable levels, the LRP, or to require a rebuilding plan. This is similar in stance to the Australian HS Policy (DAWR 2018a).

Given that the proposed Fish Stocks provisions require management measures to maintain stocks above their LRP, and rebuilding plans for stocks below their LRP, operational guidance will need to clarify how LRPs are to be set for aggregate stocks in Canada (also discussed in the Scope of Application section above). Such stocks may encompass finfish, shellfish, other invertebrates, and particularly salmonids where biological benchmarks are set at the Conservation Unit level but stocks may be managed (and named, for listing purposes) at another aggregated level. A careful delineation of stock-specific LRPs from management operational control point terminology may be required to ensure that fisheries managers have a clear interpretation of obligations under the new provisions.

Multi-species Considerations	Operational guidelines should: **11.1** assist analysts with technical considerations for providing multi-species fishery advice, including setting reference points and evaluating harvest strategies. **11.2** clarify nomenclature of reference points (most importantly, limits) versus operational control points for all stocks, including aggregate stocks.

VISUAL TOOLS

Most jurisdictions employ visualizations of their policies and guidance directed at scientists, fisheries managers, and other stakeholders including the general public. The intent of the visual presentation is to communicate the relationship between the various elements of a harvest strategy or decision-making framework in relation to stock status, and how performance relative to stock and fishery objectives can be interpreted. Full details on Visual Tools are available in Appendix 14.

A colour combination of red, yellow and green (a “traffic light” approach) appears to be common in many jurisdictions in terms of public reporting (e.g., in ICES, Australia, and NAFO), or PA policy visualization (Canada’s WSP, DFO 2005a; an early version of the Canada’s PA Policy (DFO 2006), although not the final published version (DFO 2009b); and New Zealand (2019a).

The use of limited visual aids per jurisdiction may be beneficial in some respects, but in others may cause confusion. Multiple PA visual tools show either reference points (the removal reference in Canada’s PA Policy, DFO 2009a; *F*-based reference points in the original PA framework of NAFO 2004a) or stock-recruit relationships used to inform reference points (ICES 2018a) that exhibit a classic “broken hockey stick”-like form that look like harvest control rules but are or may not be (or that fuse reference points and operational control points). Restrepo and others (1998) illustrated a diversity of harvest control rule families that may be useful for analysts seeking options for consideration. Australia and New Zealand illustrated reference points (and the meaning of stock performance) separately from harvest control rules, which may be useful in from a science communication perspective and preserves the necessary distinction between reference point and the management tactics used to avoid limit and achieve target states related to reference points.

<u>Considerations for a Canadian Approach</u>

The incorporation of visual aids to understand reference points, harvest control rules and performance evaluation is a critical part of effective operational guidance, particularly in conveying the advice to fisheries managers, stakeholders and the general public. However, the presence of visual tools while helpful, can also create some challenges when it comes to science advice communication. For example, the use of a single illustration of a PA framework (while useful for rapidly conveying an approach) can result in an excessive focus on default values for things like reference points and harvest control rules, falsely conveying that, for example, harvest control rules can only take one shape, or that operational control points in harvest control rules must be tied to reference points (Cox et al. 2013).

Another challenge is the use of discrete colours, particularly ones that are discontinuous such as a “traffic light” scheme (red-yellow-green). While memorable, the use of such colours evokes other meanings (e.g., STOP and GO, or “health” versus “sickness”) and may also foster the impression that there are discrete and abrupt boundaries in biological stock status positioned at reference points. In fact, stock status (and the indices on which status is evaluated) represent a continuum and stock status always has some measure of uncertainty associated with its determination, even though status must be “binned” into categories to facilitate reporting. While Canada’s PA Policy (2009a) formally presents the PA framework in greyscale, it is common to see the original “traffic light” colour scheme of the science advice that was developed in support of the policy (DFO 2006) replicated in the public eye or in other graphs. Furthermore, there is no biological meaning to the placement of the USR as an operational control point, which means that it does not in itself demarcate an abrupt transition between a “healthy” stock from an “unhealthy” stock, despite the use of the term ‘Healthy Zone’ used in the PA Policy (DFO 2016a).

Finally, while it may be preferable for policies to have minimal illustrations for practical reasons, operational guidelines should consider the liberal use of visual tools to address some of these science communication challenges. For example, a range of possible harvest control rule shapes should be illustrated (e.g., Restrepo et al. 1998), instead of one default rule that may be misunderstood as limiting analyst and manager options for other shapes. Figures showing possible harvest control rule designs could also be beneficially separated from figures showing the meaning and relative placement of the different reference points (e.g., as is done in Australia and New Zealand).

Visual Tools	Operational guidelines should: **12.1** include multiple illustrations, including various forms of harvest control rules consistent with PA Policy intent.

	12.2 consider illustrating reference points and performance evaluation separately from harvest control rules. **12.3** consider alternative techniques such as linearly scaled colour schemes that may better convey stock status and uncertainty as a continuum without evoking subjective responses.

ROLES AND RESPONSIBILITIES

Harvest policy implementation is a complex process involving many participants, and as a consequence several jurisdictions have outlined some delineation of roles and responsibilities of the science component (versus management components) in the development of harvest strategies. Both Canada and NAFO provided some guidance as to which parties perform what function in selecting reference points, interpreting risk, etc., while others (Australia, ICES) provide little to no information on these functions in their policies, standards or guidelines. New Zealand provided in its operational guidelines a detailed list of roles and responsibilities without delving into specific procedural details (MF 2011). Full details on Roles and Responsibilities are available in Appendix 15.

Considerations for a Canadian Approach

As noted above, the PA Policy (DFO 2009a) contains some information on roles and responsibilities, but these are not identified for all components of the framework, and also conflict in different portions of the document.

After several years of PA Policy implementation, DFO (2016a) identified a number of areas requiring further resolution for understanding the roles of Science and Fisheries Management. The first of these was with respect to risk delineation. While scientists must describe the shape of risk functions, managers must select risk tolerances and the two roles are difficult if not impossible to separate completely. In the absence of MSE, the production of decision tables was considered a useful option to assist in role separation with respect to risk. However, Shelton and Sinclair (2008) noted that risk plots may be difficult for managers to interpret and simple projections that do not take into account uncertainties may provide risk-based advice of limited value.

The dual role of the USR as both buffer and target also appears to have been the source of some concern around roles and responsibilities in Canadian fisheries (DFO 2016a). If the USR is a target reference point, then the responsibility for setting fishery targets based on socio-economic objectives is clearly a management decision. However if the USR is also a buffer (an OCP set high enough above the LRP to avoid a breach with high probability; DFO 2016a), then scientists have a much larger role in evaluating the consequences of choice of OCP because of the need to evaluate uncertainty and produce risk functions. The precise risk tolerence would still be a management decision. DFO (2016a) concluded in Annex 4 that "*the development of the USR is led by the Fisheries Management sector in cooperation with key fishery interests, with advice and input provided by the Science sector;*" however this explanation lacks additional clarity as it reiterated some of the original text of the 2009 PA Policy and thus did not resolve the conflict between the two roles assigned.

Despite the identification of the RR as potentially being interpreted in three ways, as a limit *F*, a target *F,* and an HCR, DFO (2016a) did not discuss the absence of assigned roles and responsibilities for establishing this component.

DFO (2016a) also noted that for harvest decision rules, and in contrast to wording of the PA Policy, scientists have a role in designing rules that can achieve conservation and yield objectives, and in assessing or evaluating management strategy performance. Science is also involved in identifying conservation objectives and needs to provide input on how scientific data, methods and assessment procedures are combined with harvest decision rules (i.e., rendering the policy operational).

The use of default values and options for reference points and HDRs (in lieu of stock-specific instructions from fisheries managers) may increase the speed and economy by which science advice is provided, but may also result in the perception that science staff are unilaterally responsible for the application of the PA Policy (an approach that does not lead to successful fisheries management; Hilborn et al. 2001, Garcia 1995). Clarifying roles and responsibilities, perhaps with itemized lists (as per MF 2011), terms of reference, or with a stand-alone "Procedures" document that identifies various steps of harvest strategy development, from the request for advice, through advice generation, and ultimately selection of and implementation of harvest strategies by managers, should be a priority for operational guidelines. Clarity may enhance the efficiency and speed at which science advice is provided to decision-makers, and confirm mandates of the sectors involved in implementing the PA Policy.

Roles and Responsibilities	Operational guidelines should: **13.1** demarcate the roles and responsibilities of the Science Sector in developing or supporting the development of harvest strategy components. **13.2** facilitate production of science advice with provisional terms of reference to ensure desired advice components are incorporated.

SUMMARY and RECOMMENDATIONS FOR A CANADIAN APPROACH

Considerations for potential components of operational guidelines for science advice are summarized in Table 6.

Table 6: *Analyses and recommendations for potential Canadian operational guidelines for fisheries science advice, organized by components analyzed in the cross-jurisdictional review.*

Scope of Application	Operational guidelines should: **1.1** define the term "stock" with respect to the scale at which limit reference points are established, and provide guidance for taking stock biology and environmental conditions into consideration when identifying limit reference points. **1.2** indicate to what fish stocks the guidance is intended to apply.
Science Advice in Support of Fisheries Management Objectives	Operational guidelines should: **2.1** acknowledge existing Canadian legislative and policy frameworks, objectives and intent **2.2** explicitly present the Fish Stocks provisions in the guidelines, as a framework against which fisheries science advice in general should be couched. **2.3** define the various components of objectives used in science advice (e.g., targets, limits, probabilities, risks and time frames) and identify the role of the Science Sector in support of the development of measureable objectives by fisheries managers. **2.4** prioritize, at minimum, providing advice in support of evaluating management measures against an objective of avoiding limits (i.e., avoiding an undesirable stock state of "serious harm"), and to achieving targets (desired states) when possible to do so. **2.5** preserve the intent of Canadian policy in providing advice in relation to objectives for data-poor stocks. **2.6** clarify the application of the objectives and associated risk tolerances found in Table 1 of the PA Policy in terms of supporting evaluation of harvest strategies.
Reference Points	Operational guidelines should: **3.1** reflect current international practices in setting reference points (particularly for limits) and operational control points. **3.2** resolve existing differences between Canadian precautionary approach policies (e.g., regarding salmon).

	3.3 accommodate new data-poor reference points useful for some taxonomic groups (e.g., marine mammals). **3.4** address technical aspects of identifying and providing advice regarding the Upper Stock Reference (USR) and Removal Reference (RR).
Harvest Strategies	Operational guidelines should: **4.1** define components of harvest strategies, and recognize data collection and assessment as a fundamental part of the broader organizational investments made in developing and evaluating harvest strategies. **4.2** accommodate the need to develop harvest strategies across life histories representing a range of taxa and across the data continuum (from “poor” to “rich”), making specific note of objectives and provisions for data poverty already expressed in the PA Policy. This may include providing examples of harvest strategies that meet policy intent where PA Policy elements cannot be closely met.
Uncertainty and Risk	Operational guidelines should: **5.1** clarify how to account for and communicate uncertainty and risk in science advice, in line with the requirements of the PA Policy, the Fish Stocks provisions, and international best practices, particularly with respect to deleterious stock and fishery states consistent with an interpretation of “serious harm.” **5.2** indicate various methods by which key uncertainties affecting science advice can be identified, and possible costs and benefits (i.e., reduced risks) of improved data collection to reduce uncertainty can be demonstrated. **5.3** give consideration as to methods by which uncertainty and risk could be accommodated a continuum of data availability to preserve, to the extent possible, risk equivalency in science advice across a wide range of stocks. **5.4** provide defensible definitions of risk tolerance terms for use in stock and fishery objectives when evaluating harvest strategies.
Environmental and Ecosystem Conditions	Operational guidelines should: **6.1** to the extent possible, outline options for meeting the requirements of the Fish Stocks provisions when it comes to setting and changing reference points, taking into account stock biology and environmental conditions, **6.2** address methods for identifying and modelling key hypothesized drivers in stock dynamics (past, present and future)

	6.3 discuss the evaluation of harvest strategies that takes into account biology and environmental conditions **6.4** make recommendations for evaluating and communicating these factors as components of uncertainty.
Rebuilding Stocks	Operational guidelines should: **7.1** provide clear technical information on determining when stock status indicates a limit has been breached. **7.2** clarify what stock states characterizes a rebuilt state (in ways that can be incorporated into measurable rebuilding strategy objectives). **7.3** outline methods for the calculation of rebuilding timeframes. **7.4** support development of rebuilding strategies (as a subset of harvest strategies) across the data continuum. **7.5** identify various methods by which key uncertainties affecting science advice can be identified. **7.6** discuss demonstration of possible costs (persistent or worsening stock and fishery states incurred by delayed rebuilding measures) and benefits (i.e., increased biomass and range of management choice, reduced risks to the stock and fishery) of improved data collection.
Performance Evaluation	Operational guidelines should: **8.1** provide information on conducting and reporting tabular or graphical results of retrospective and prospective performance evaluation, simulation, projection, and management strategy evaluations. **8.2** demonstrate simulation-based evaluations of a range of default or provisional options for reference points and harvest control rules. **8.3** identify circumstances when expert judgement may be useful, what defensible practices to follow, and how to document its application.
Reporting of Status	Operational guidelines should: **9.1** outline formats for standard reporting of stock and fishery status to facilitate rapid communication of science advice (e.g., Science Advisory Reports), including any accommodations for data-poor stocks. **9.2** reflect status relative to limit, target and other reference points in both biomass and fishing mortality axes, as required under Canada's PA Policy or as outlined in objectives related to the Fish

	Stocks provisions and subsequent regulations. **9.3** integrate the reporting of stock status with reporting associated uncertainty.
Sustainability Considerations	Operational guidelines should: **10.1** provide support for evaluating stock status and harvest strategy performance over the long term consistent with sustainability objectives. **10.2** provide clarity as to what science advice is required to demonstrate compliance with s.6.1(1) of the Fish Stocks provisions (i.e., to maintain stocks at sustainable levels).
Multi-species Considerations	Operational guidelines should: **11.1** assist analysts with technical considerations for providing multi-species fishery advice, including setting reference points and evaluating harvest strategies. **11.2** clarify nomenclature of reference points (most importantly, limits) versus operational control points for all stocks, including aggregate stocks.
Visual Tools	Operational guidelines should: **12.1** include multiple illustrations, including various forms of harvest control rules consistent with PA Policy intent. **12.2** consider illustrating reference points and performance evaluation separately from harvest control rules. **12.3** consider alternative techniques such as linearly scaled colour schemes that may better convey stock status and uncertainty as a continuum without evoking subjective responses.
Roles and Responsibilities	Operational guidelines should: **13.1** demarcate the roles and responsibilities of the Science Sector in developing or supporting the development of harvest strategy components. **13.2** facilitate production of science advice with provisional terms of reference to ensure desired advice components are incorporated.

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APPENDICES

Appendix 1 - RELEVANT LEGISLATION (COUNTRIES)

Canada	The primary Canadian legislation is the *Fisheries Act* (R.S.C., 1985, c. F-14), revised under Bill C-68 (Royal Assent, June 21, 2019), shown below. **CONSIDERATIONS** **Considerations for decision making** **2.5** Except as otherwise provided in this *Act*, when making a decision under this Act, the Minister may consider, among other things, **(a)** the application of a precautionary approach and an ecosystem approach; **(b)** the sustainability of fisheries; **(c)** scientific information; **(d)** Indigenous knowledge of the Indigenous peoples of Canada that has been provided to the Minister; **(e)** community knowledge; **(f)** cooperation with any government of a province, any Indigenous governing body and any body — including a co-management body — established under a land claims agreement; **(g)** social, economic and cultural factors in the management of fisheries; **(h)** the preservation or promotion of the independence of licence holders in commercial inshore fisheries; and **(i)** the intersection of sex and gender with other identity factors. **FISH STOCKS** **Measures to maintain fish stocks** **6.1 (1)** In the management of fisheries, the Minister shall implement measures to maintain major fish stocks at or above the level necessary to promote the sustainability of the stock, taking into account the biology of the fish and the environmental conditions affecting the stock. **Limit reference point** **(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.

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, 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.

Regulations

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

Australia	The primary Australian legislation is the *Fisheries Management Act 1991*. Schedule 2 reprints the 1995 UNFSA. **3 Objectives** (1) The following objectives must be pursued by the Minister in the administration of this Act and by AFMA in the performance of its functions: (a) implementing efficient and cost-effective fisheries management on behalf of the Commonwealth; and (b) ensuring that the exploitation of fisheries resources and the carrying on of any related activities are conducted in a manner consistent with the principles of ecologically sustainable development (which include the exercise of the precautionary principle), in particular the need to have regard to the impact of fishing activities on non-target species and the long term sustainability of the marine environment; and (c) maximising the net economic returns to the Australian community from the management of Australian fisheries; and (d) ensuring accountability to the fishing industry and to the Australian community in AFMA's management of fisheries resources; and (e) achieving government targets in relation to the recovery of the costs of AFMA. (2) In addition to the objectives mentioned in subsection (1), or in section 78 of this Act, the Minister, AFMA and Joint Authorities are to have regard to the objectives of: (a) ensuring, through proper conservation and management measures, that the living resources of the AFZ are not endangered by over-exploitation; and (b) achieving the optimum utilisation of the living resources of the AFZ; and (c) ensuring that conservation and management measures in the AFZ and the high seas implement Australia's obligations under international agreements that deal with fish stocks; and (d) to the extent that Australia has obligations: (i) under international law; or (ii) under the Compliance Agreement or any other international agreement; in relation to fishing activities by Australian-flagged boats on the high seas that are additional to the obligations referred

	to in paragraph (c)—ensuring that Australia implements those first-mentioned obligations; and (e) ensuring that the interests of commercial, recreational and Indigenous fishers are taken into account; but must ensure, as far as practicable, that measures adopted in pursuit of those objectives must not be inconsistent with the preservation, conservation and protection of all species of whales. **3A Principles of ecologically sustainable development** The following principles are *principles of ecologically sustainable development*: (a) decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equity considerations; (b) if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation; (c) the principle of inter-generational equity—that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations; (d) the conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making; (e) improved valuation, pricing and incentive mechanisms should be promoted.
New Zealand	The primary New Zealand legislation is the *Fisheries Act* 1996, amended in 2008. **8 Purpose** (1)The purpose of this Act is to provide for the utilisation of fisheries resources while ensuring sustainability. (2)In this Act,— ensuring sustainability means— (a)maintaining the potential of fisheries resources to meet the reasonably foreseeable needs of future generations; and (b)avoiding, remedying, or mitigating any adverse effects of fishing on the aquatic environment

utilisation means conserving, using, enhancing, and developing fisheries resources to enable people to provide for their social, economic, and cultural well-being.

9 Environmental principles

All persons exercising or performing functions, duties, or powers under this Act, in relation to the utilisation of fisheries resources or ensuring sustainability, shall take into account the following environmental principles:

(a)associated or dependent species should be maintained above a level that ensures their long-term viability:

(b)biological diversity of the aquatic environment should be maintained:

(c)habitat of particular significance for fisheries management should be protected.

13 Total allowable catch

(1)Subject to this section, the Minister shall, by notice in the *Gazette*, set in respect of the quota management area relating to each quota management stock a total allowable catch for that stock, and that total allowable catch shall continue to apply in each fishing year for that stock unless varied under this section, or until an alteration of the quota management area for that stock takes effect in accordance with sections 25 and 26.

(2)The Minister shall set a total allowable catch that—

(a)maintains the stock at or above a level that can produce the maximum sustainable yield, having regard to the interdependence of stocks; or

(b)enables the level of any stock whose current level is below that which can produce the maximum sustainable yield to be altered—
(i)in a way and at a rate that will result in the stock being restored to or above a level that can produce the maximum sustainable yield, having regard to the interdependence of stocks; and

	(ii)within a period appropriate to the stock, having regard to the biological characteristics of the stock and any environmental conditions affecting the stock; or (c)enables the level of any stock whose current level is above that which can produce the maximum sustainable yield to be altered in a way and at a rate that will result in the stock moving towards or above a level that can produce the maximum sustainable yield, having regard to the interdependence of stocks. (2A)For the purposes of setting a total allowable catch under this section, if the Minister considers that the current level of the stock or the level of the stock that can produce the maximum sustainable yield is not able to be estimated reliably using the best available information, the Minister must— (a)not use the absence of, or any uncertainty in, that information as a reason for postponing or failing to set a total allowable catch for the stock; and (b)have regard to the interdependence of stocks, the biological characteristics of the stock, and any environmental conditions affecting the stock; and (c)set a total allowable catch— (i)using the best available information; and (ii)that is not inconsistent with the objective of maintaining the stock at or above, or moving the stock towards or above, a level that can produce the maximum sustainable yield. (3)In considering the way in which and rate at which a stock is moved towards or above a level that can produce maximum sustainable yield under subsection (2)(b) or (c), or (2A) (if applicable), the Minister shall have regard to such social, cultural, and economic factors as he or she considers relevant. (4)The Minister may from time to time, by notice in the *Gazette*, vary any total allowable catch set for any quota management stock under this section by increasing or reducing the total allowable catch. When considering any variation, the Minister is to have regard to the matters specified in subsections (2), (2A) (if applicable), and (3). (5)Without limiting subsection (1) or subsection (4), the Minister may

	set or vary any total allowable catch at, or to, zero. (6)Except as provided in subsection (7), every setting or variation of a total allowable catch shall have effect on and from the first day of the next fishing year for the stock concerned. (7)After considering information about the abundance during the current fishing year of any stock listed in Schedule 2, and after having regard to the matters specified in subsections (2), (2A) (if applicable), and (3), the Minister may, by notice in the *Gazette*, increase the total allowable catch for the stock with effect from such date in the fishing year in which the notice is published as may be stated in the notice. (8)If a total allowable catch for any stock has been increased during any fishing year under subsection (7), the total allowable catch for that stock shall, at the close of that fishing year, revert to the total allowable catch that applied to that stock at the beginning of that fishing year; but this subsection does not prevent a variation under subsection (4) of the total allowable catch that applied at the beginning of that fishing year. (9)The Governor-General may from time to time, by Order in Council, omit the name of any stock from Schedule 2 or add to that schedule the name of any stock whose abundance is highly variable from year to year. (10)Subsection (1) does not require the Minister to set an initial total allowable catch for any quota management area and stock unless the Minister also proposes to set or vary a total allowable commercial catch for that area and stock under section 20.
United States	The primary fisheries legislation of the United States is the *Magnuson-Stevens Fishery Conservation and Management Act*. **(b)PURPOSES.**—It is therefore declared to be the purposes of the Congress in this Act— 99-659, 101-627, 102-251 (1)to take immediate action to conserve and manage the fishery resources found off the coasts of the United States, and the anadromous species and Continental Shelf fishery resources of the United States, by exercising (A) sovereign rights for the purposes of exploring, exploiting, conserving, and managing all fish within the

	exclusive economic zone established by Presidential Proclamation 5030, dated March 10, 1983, and (B) exclusive fishery management authority beyond the exclusive economic zone over such anadromous species and Continental Shelf fishery resources[, and fishery resources in the special areas]*; (2)to support and encourage the implementation and enforcement of international fishery agreements for the conservation and management of highly migratory species, and to encourage the negotiation and implementation of additional such agreements as necessary; 104-297 (3)to promote domestic commercial and recreational fishing under sound conservation and management principles, including the promotion of catch and release programs in recreational fishing; (4)to provide for the preparation and implementation, in accordance with national standards, of fishery management plans which will achieve and maintain, on a continuing basis, the optimum yield from each fishery; 101-627 (5) to establish Regional Fishery Management Councils to exercise sound judgment in the stewardship of fishery resources through the preparation, monitoring, and revision of such plans under circumstances (A) which will enable the States, the fishing industry, consumer and environmental organizations, and other interested persons to participate in, and advise on, the establishment and administration of such plans, and (B) which take into account the social and economic needs of the States; 95-354, 96-561, 104-297 (6) to encourage the development by the United States fishing industry of fisheries which are currently underutilized or not utilized by United States fishermen, including bottom fish off Alaska, and to that end, to ensure that optimum yield determinations promote such development in a non-wasteful manner; and 104-297 (7)to promote the protection of essential fish habitat in the review of projects conducted under Federal permits, licenses, or other authorities that affect or have the potential to affect such habitat. **(c) POLICY.**—It is further declared to be the policy of the Congress in this Act— (1)to maintain without change the existing territorial or other ocean jurisdiction of the United States for all purposes other than the conservation and management of fishery resources, as provided for in this Act; (2)to authorize no impediment to, or interference with, recognized legitimate uses of the high seas, except as necessary for the

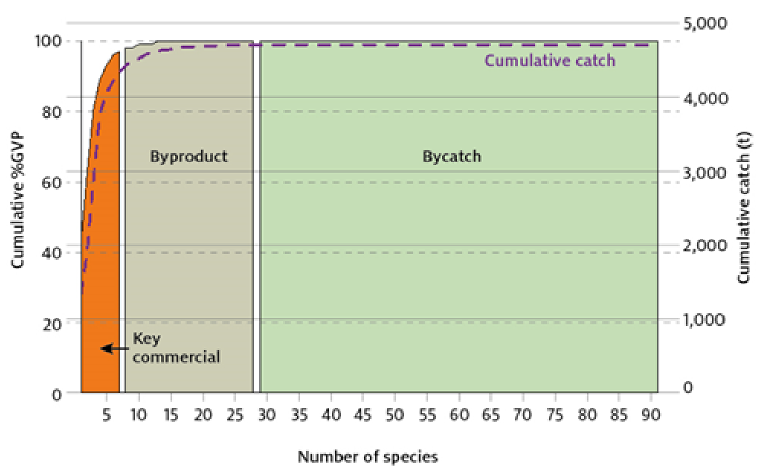
	conservation and management of fishery resources, as provided for in this Act; 101-627, 104-297 (3)to assure that the national fishery conservation and management program utilizes, and is based upon, the best scientific information available; involves, and is responsive to the needs of, interested and affected States and citizens; considers efficiency; draws upon Federal, State, and academic capabilities in carrying out research, administration, management, and enforcement; considers the effects of fishing on immature fish and encourages development of practical measures that minimize bycatch and avoid unnecessary waste of fish; and is workable and effective; (4)to permit foreign fishing consistent with the provisions of this Act; 99-659, 101-627 (5) to support and encourage active United States efforts to obtain internationally acceptable agreements which provide for effective conservation and management of fishery resources, and to secure agreements to regulate fishing by vessels or persons beyond the exclusive economic zones of any nation; 101-627 (6) to foster and maintain the diversity of fisheries in the United States; and 104-297 (7) to ensure that the fishery resources adjacent to a Pacific Insular Area, including resident or migratory stocks within the exclusive economic zone adjacent to such areas, be explored, developed, conserved, and managed for the benefit of the people of such area and of the United States. **SEC. 301. NATIONAL STANDARDS FOR FISHERY 16 U.S.C. 1851 CONSERVATION AND MANAGEMENT** (a) IN GENERAL.—Any fishery management plan prepared, and any regulation promulgated to implement any such plan, pursuant to this title shall be consistent with the following national standards for fishery conservation and management: 98-623 (1)Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry. (2)Conservation and management measures shall be based upon the best scientific information available. (3)To the extent practicable, an individual stock of fish shall be managed as a unit throughout its range, and interrelated stocks of fish shall be managed as a unit or in close coordination. (4)Conservation and management measures shall not discriminate between residents of different States. If it becomes necessary to

	allocate or assign fishing privileges among various United States fishermen, such allocation shall be (A) fair and equitable to all such fishermen; (B) reasonably calculated to promote conservation; and (C) carried out in such manner that no particular individual, corporation, or other entity acquires an excessive share of such privileges. 104-297 (5)Conservation and management measures shall, where practicable, consider efficiency in the utilization of fishery resources; except that no such measure shall have economic allocation as its sole purpose. (6)Conservation and management measures shall take into account and allow for variations among, and contingencies in, fisheries, fishery resources, and catches. (7)Conservation and management measures shall, where practicable, minimize costs and avoid unnecessary duplication. 104-297, 109-479 (8) Conservation and management measures shall, consistent with the conservation requirements of this Act (including the prevention of overfishing and rebuilding of overfished stocks), take into account the importance of fishery resources to fishing communities by utilizing economic and social data that meet the requirements of paragraph (2), in order to (A) provide for the sustained participation of such communities, and (B) to the extent practicable, minimize adverse economic impacts on such communities. 104-297 (9) Conservation and management measures shall, to the extent practicable, (A) minimize bycatch and (B) to the extent bycatch cannot be avoided, minimize the mortality of such bycatch. 104-297 (10) Conservation and management measures shall, to the extent practicable, promote the safety of human life at sea. 97-453 (b) GUIDELINES.—The Secretary shall establish advisory guidelines (which shall not have the force and effect of law), based on the national standards, to assist in the development of fishery management plans.

Appendix 2 - SCOPE OF APPLICATION

<table>
<tr><td>Canada (national)</td><td>At minimum, the Canadian PA Policy "applies to key harvested stocks managed by Fisheries and Oceans Canada. Key harvested stocks are defined as those stocks that are the specific and intended targets of a fishery, whether in a commercial, recreational or subsistence fishery" (DFO 2009a). The Policy may also be applied more broadly to other types of stocks, as needed and when circumstances permit (DFO 2009a).

A primary tool by which Canada tracks and reports on what may be considered "key harvested" fish stocks is via an annual Sustainability Survey for Fisheries (DFO 2018c). In guidance established for completing the 2017 Sustainability Survey, stocks are considered for inclusion in the Survey if they meet one or more of the following criteria (DFO 2018c):
Annual landed value of >$1 million or landings of > ~ 2,000 t at least once in last 5 years
Has an Integrated Fisheries Management Plan (IFMP)
Highly migratory, transboundary, straddling or internationally managed stock
Stocks assessed by the Committee on the Status of Endangered Wildlife in Canada as being threatened, endangered or special concern, and are the targets of directed fisheries or approved as bycatch
Economically or significantly ecologically important to the region (at least one other criterion)
An emerging regional or important recreational or Indigenous food, social and ceremonial fishery
A charismatic or iconic species
A small fishery but seeking eco-certification
A forage species
Currently under moratorium (and at least one other criterion)
The list of major fish stocks to which the revised Fisheries Act will apply, will be a separate list prescribed gradually by regulation (section 6.3).</td></tr>
<tr><td>Canada (WSP)</td><td>Canada's WSP identifies and manages wild salmon in the form of Conservation Units (CUs; DFO, 2005a) which are defined as groups (one or more populations) that are "sufficiently isolated from other groups that, if lost, is very unlikely to recolonize naturally within an acceptable time frame (e.g., a human lifetime or a specified number of salmon generations)." The policy does not specify a set number of CUs, recognizing that delineation of the units will evolve as more information</td></tr>
</table>

	or experience comes to light. Later work (DFO 2009c) established a framework for the identification of CUs and an initial list was published (DFO 2009d). As of 2018, 463 CUs have been identified (DFO 2018d).
Australia	The Australian HS Policy "applies to management of commercial species (***key commercial*** and ***byproduct***) in Commonwealth fisheries managed by [the Australian Fisheries Management Authority]. Non-commercial bycatch species …. are managed under the Bycatch Policy and the *Environment Protection and Biodiversity Conservation Act 1999*" (emphasis added; DAWR 2018a). A figure is used to clearly outline which policies apply to which type of stocks. For stocks managed with other jurisdictions, the Policy indicates that the Australian Government will see to apply and encourage the adoption of this policy in negotiation and implementation of joint or cooperative management schemes. Commercial species are considered to be anything that is landed and sold, and are of two types. ***Key commercial species*** are later defined as "those most relevant to the objective of maximizing net economic returns to the Australian community" and these stocks are more likely to be data-rich because more resources are allocated to their assessment, management and monitoring. ***Byproduct species***, on the other hand, are those that make a lesser contribution to the value of the fishery and information on these species is often limited and management actions may vary depending on data limitations and cost-effectiveness of the actions. The technical guidance (DAWR 2018b) illustrates how the cumulative contribution to the gross value of production was used to differentiate between key commercial, byproduct and ***bycatch*** species (Figure A1, DAWR 2018b).  ***Figure A1:*** *Differentiation between key commercial, byproduct and bycatch species. Reproduced from DAWR 2018b (Fig. 3).*

ICES	ICES provides various forms of advice (such as stock assessments) upon the request of numerous clients including member countries, and in so doing, responds to the legal and policy needs of the client. In addressing requests for advice, ICES staff work with clients to interpret the request and identify what sort of advice ICES can deliver (ICES 2018a). There is no mention in the ICES guidance of rules by which requests for advice can be included or excluded on the basis of stock type alone, so the scope of ICES guidance appears to be determined on a case-by-case basis.
NAFO	As an RFMO, NAFO is responsible for the management of 19 stocks of 11 different species which likely defines the scope of NAFO's PAF.
New Zealand	The New Zealand HS Standard applies to fish stocks enrolled in New Zealand's Quota Management System (QMS; MF 2008), a fisheries management system that has been in place since 1986 to allocate commercial fishery quotas and which has covered an increasing number of species since that time. At present, the QMS has 98 species and 642 fish stocks enrolled (MF 2019b).
United States	NOAA's NS Guidelines are applicable to the development of any fishery management plan (NOAA 2018a) and NOAA fisheries is responsible for marine fisheries in the Exclusive Economic Zone (EEZ; 3 to 200 miles off the coast of the United States; NOAA, 2017). Thus, the scope of the NOAA NS Guidelines is presumed to apply to all U.S. marine fish stocks and stock complexes in the EEZ. Note that fisheries management < 3 miles off the coast is the purview of the applicable state. For primary reporting (but not governance) purposes, the most important domestic commercial and recreational fish stocks and stock complexes are monitored as part of the ***Fish Stock Sustainability Index*** or FSSI; as of 2018, there are 199 such stocks and they account for 85% of total catches (NOAA 2018b). The 2017 report on fish stock status to Congress notes, under the *Additional Report Information*, that fish stocks in the report are grouped as FSSI stocks, non-FSSI stocks, and ecosystem component stocks (NOAA 2019).

Appendix 3 - OVERARCHING OBJECTIVES

Canada (national)	The Canadian PA policy is part of the Sustainable Fisheries Framework (SFF), a broader policy suite that "provides the basis for ensuring that Canadian fisheries support conservation and sustainable use of resources" (DFO 2018b). SFF policies help to achieve three general goals: "keep our fish stocks healthy; protect biodiversity and fisheries habitats [and] make sure our fisheries remain productive." The Canadian PA policy itself, as a subsidiary of the SFF, does not state an independent policy objective. The "paper describes a general decision-making framework for implementing a harvest strategy" (DFO 2009a), comparable to the New Zealand HS Standard. Individual components of the framework, such as reference points, are ascribed purposes and the term "objective" is used specifically to refer to various forms of stock-specific fishery management objectives (see section on Fisheries Management Objectives below).
Canada (WSP)	The overarching goal of Canada's WSP is "to restore and maintain healthy and diverse salmon populations and their habitats for the benefit and enjoyment of the people of Canada in perpetuity" (DFO 2005a). Three objectives are identified: safeguarding the genetic diversity of wild Pacific salmon, maintaining habitat and ecosystem integrity, and manage fisheries for sustainable benefits.
Australia	The objective of the Australian HS Policy is "the ecologically sustainable and profitable use of Australia's commonwealth commercial fisheries resources (where ecological sustainability takes priority) - through implementation of harvest strategies." (DAWR 2018a). According to Australia's *Fisheries Management Act 1991*, the Minister must pursue objectives regarding the implementation of efficient and cost-effective fisheries management, ensuring that exploitation of fisheries resources is consistent with the principles of ecologically sustainable development (including the precautionary approach), and maximizing the net economic returns to the Australian community from the management of Australia's fisheries (s.3). Schedule 2 of the law contains the UNFSA (1995).
ICES	In providing advice services, ICES notes that the context for its advice is set by a range of international agreements and policies, including the 1982 United Nations Convention on the Law of the Sea, the 1992 United Nations Conference on Environment and Development (Rio Declaration), 1992 Convention on Biological Diversity, the 1995 United Nations Fish Stocks Agreement and the Food and Agriculture Organization's Code of Conduct for Responsible Fisheries, and the 2002 Johannesburg Declaration of the World Summit on Sustainable

	Development (ICES 2018a). Advice will also respond to the policy or legal requirements of ICES's clients, whether they are countries or regional fisheries management organizations. ICES's approach to providing advice integrates ecosystem-based management with the objective of achieving ***maximum sustainable yield*** (MSY), and an aim to inform policies for high long-term yields while maintaining productive fish stocks within healthy marine ecosystems (ICES 2018a). MSY as a broad conceptual objective is aimed at achieving the highest yield in the long-term and can be applied to an ecosystem, a community, or a stock.
NAFO	NAFO's PAF is "used for improved protection of resources, and to determine appropriate resource management measures in the absence of sufficient scientific data" (NAFO 2019a). NAFO recognizes that the 1995 UNFSA and the FAO Code of Conduct call for the rebuilding of depleted fish stocks, many Contracting parties require limit reference points and recovery targets, and the RFMO wishes to see "continued recovery and growth of [stocks under moratorium] to ensure long term sustainability and to promote associated economic opportunities" (NAFO 2019b).
New Zealand	New Zealand's HS Standard "establishes a consistent and transparent framework for decision-making to achieve the objective of providing for utilisation of New Zealand's QMS [Quota Management System] species while ensuring sustainability" (MF 2008; c.p. Canada's SFF policy on "conservation and sustainable use"). The term *standard* is used for this document, because a standard is defined as laying out the minimum performance requirements that must be met for a harvest strategy to deemed to be acceptable (MF 2008). Later in the document, it is stated that the objective of the HS Standard is "to provide a consistent and transparent framework for setting fishery and stock targets and limits and associated fisheries management measures, so that there is a high probability of achieving targets, a very low probability of breaching limits, and acceptable probabilities of rebuilding stocks that nevertheless become depleted, in a timely manner," and the document will specify appropriate probabilities for each (MF 2008). The HS Standard reflects New Zealand's *Fisheries Act 1996*, the purpose of which is "to provide for the utilisation of fisheries resources while ensuring sustainability" (s.8). In its Total Allowable Catch provisions (s.13), the *Act* further states that the Minister shall set a total allowable catch (TAC) that maintains the stock at or above a level that can produce MSY, taking into account the interdependence of stocks. TACs shall be set for stocks that are below that level to enable the stock to be restored (rebuilt) to or above that level in an appropriate period

	(taking into account the biological characteristics and any environmental conditions affecting the stock), and TACs for stocks above that level shall be set to enable those stocks to move towards or above that level (i.e., fished down), among other requirements. The provisions also state that relevant social, cultural, and economic factors may be taken into account by the Minister.
United States	The NOAA NS Guidelines represent "principles that must be followed in any fishery management plan to ensure sustainable and responsible fishery management" and are developed to support national standards that are in fact explicitly mandated by the *Magnuson-Stevens Act* (NOAA 2018a). The *Act* has also established MSY as the basis for fisheries management (NOAA 2018a).

Appendix 4 - FISHERY MANAGEMENT OBJECTIVES

Canada (national)	Objectives *per se* are not explicitly mentioned as one of the primary components of the 2009 PA Policy framework, but the document does note that "objectives for desirable resource and fishery outcomes" were an essential part of a risk-based framework proposed in a preceding policy, the Atlantic Fisheries Policy Review (DFO 2004). This 2004 policy outlined among other things a nascent approach called *Objectives-based Management*: "This risk management framework will focus on achieving conservation objectives compatible with sustainable use, by: ● establishing reference points that are linked to key stock and ecosystem indicators, such as the size and productivity of the resource; and, ● implementing resource use strategies in relation to these reference points that will scale levels of use to stock condition in a manner that will avoid undesirable outcomes. "Reference points for fisheries management decisions include targets where benefits sought by resource users can be obtained on a sustainable basis, as well as "limits" beyond which there is unacceptable risk of serious or irreversible harm. The risk management framework will be designed with input from resource users, particularly related to establishing targets for stocks such as long-term sustainable yields and size profiles in the catch. These targets would be the basis for a fisheries management approach anchored in setting and achieving measurable objectives." (DFO 2004) Although not identified as a key component, the need for and utility of fishery management objectives is mentioned throughout the Canadian PA Policy (DFO 2009a), although few specifications are prescribed or recommended. For example, the policy states that rebuilding strategies and rebuilding objectives that "support" a precautionary approach are "crucial" for rebuilding plans. The placement of the Upper Stock Reference point, as a fishery target, can be determined in part by productivity objectives and social and economic objectives for the fishery (although these socio-economic considerations must not diminish the minimum function of this reference point in guiding the risk of approaching the Limit Reference Point). The Upper Stock Reference is described in more detail in the section on Reference Points. The PA Policy specifically states for data-poor stocks where proxy indicators must be used (but possibly reflecting the intent of the policy

	for all stocks), precautionary management actions should be based "***with the objective of avoiding serious harm to reproductive capacity of the stock***" (DFO 2009a). Given that this is the only objective explicitly mentioned in the policy, the primary fishery management objective for Canada's PA Policy could be construed as avoiding limits. The PA Policy notes that the most appropriate risk to consider is that the "probability of and the severity of the impact from management actions on ***stock productivity***," and management decisions "should be explicit about the ***risk of decline*** associated with a management action" (DFO 2009a). The PA Policy indicates this risk is to be taken into account when identifying reference points, and for management, the tolerance for stock declines and the changing severity of management actions with stock status. Thus, in partnership with the draft table of risk tolerance designations in Annex 2b, and the risk tolerances per stock status zone in Table 1 of the PA Policy, this represents "risks of decline" that may be used to set objectives against which performance may be evaluated. Table 1 of the PA Policy (DFO 2009a) indicates that provisional risk tolerances for management actions shift with stock status (three zones). This table is unique among jurisdictions, which generally (if any guidance on risk is specified at all) speak to designing strategies with an overall acceptable risk of breaching limits, or desired probabilities for achieving targets. The complexity of this table also makes it difficult to attempt to operationalize as a full risk-based HCR (DFO 2016a, Kronlund et al. 2014a). In terms of avoiding limits, desirable risk tolerances are only indicated for stocks "in the Healthy zone, where economic considerations may prevail." Here, "stock reductions resulting from management actions with a low probability of the stock falling to the Critical zone are tolerated because of their reduced impact on the integrity of the stock." The PA Policy contains no specific guidance on criteria for determining when limits have been breached or targets achieved when taking uncertainty into account as required by the policy. Such criteria, however, may be specified in quantifiable objectives. With respect to objectives regarding targets, and possibly limits as well, DFO (2016a) noted that timelines [for evaluation] and risk tolerances need to be clearly specified by managers. A draft table of risk tolerance designations is further discussed in Appendix 7 (Uncertainty and Risk).

Australia	The Australian HS Policy emphasizes objectives concerning avoiding limits for all stocks, including those in multi-species fisheries; as well as achieving targets for a subset of the most economically important fish stocks. The HS Policy indicates that harvest strategies will be implemented that "***maintain all commercial fish stocks, including byproduct, above a biomass limit where the risk to the stock is regarded as unacceptable (*** B_{lim} ***), at least 90 per cent of the time***" (DAWR 2018a). The 90% risk criterion is to be interpreted as a 1-in-10year risk, not a "90% each year risk" (DAWR 2018b), in contrast to ICES (below). It is important to note that the objective of avoiding limits applies to both types of fish stocks to which the policy applies (key commercial and byproduct stocks). Australia is unique among jurisdictions in setting fisheries objectives based on ***maximum economic yield*** (MEY), and not maximum sustainable yield (MSY; McIlgorm 2013). The Australian HS Policy also indicates that harvest strategies will "***maintain key commercial fish stocks, on average, at the required target biomass to produce maximum economic yield [MEY] from the fishery***" (DAWR 2018a). However, the objective of achieving targets applies only to key commercial stocks, not byproduct stocks. While not explicitly stated, "on average" may be interpreted provisionally as 50% of the time above or below the target. The Australian HS Policy notes that it may be necessary to manage individual stocks in multi-species fisheries to different targets in order to achieve MEY at the level of the fishery. However, sustainable harvesting "must still be ensured (avoiding approaching limit reference points)" (DAWR 2018a). Here sustainability is explicitly linked with avoiding B_{lim}. However, the policy is mute on the time horizon over which alignment with the policy intent is to be evaluated.
ICES	The ICES Advice Basis document focuses on targets to be achieved with limits implicitly addressed. ICES employs ***MSY*** as a "***broad conceptual objective***" (ICES 2018a). MSY is aimed at achieving the highest yield in the long-term and can be applied to an ecosystem, community, or stock, and MSY is to be maximized as the wanted part of the catch in weight (ICES 2018a). ICES refers to the 1995 UNFSA, in that a precautionary approach is considered necessary, but not sufficient, for achieving MSY; "populations need to be maintained within safe biological limits to make MSY possible." The precautionary approach is further identified as "a necessary boundary to ensure sustainability." The document additionally notes that "limitations on fisheries may be required to

	achieve environmental objectives, especially regarding biodiversity, habitat integrity, and foodwebs" but that these considerations will not be included in the provision of science advice on fishing opportunities (ICES 2018a); such considerations may, however affect the ability to utilize fishing opportunities. Harvest advice recommendations are made using the following assumed objectives (ICES 2018a): For **long-lived data-rich Category 1 and 2 stocks**, the MSY approach is based on "attaining a fishing mortality rate of no more than F_{MSY} while ***maintaining the stock above B_{lim} with at least 95% probability***" (each year). The reference points used are F_{MSY} and MSY $B_{trigger}$, where "F_{MSY} is not allowed to be above F_{pa}." SSB is the estimated value at either the beginning of the year to which the advice applies, or at spawning time the year before. Thus, stock advice is mostly based on *projected values.* For **short-lived data-rich Category 1 and 2 stocks,** where future stock size is very sensitive to recruitment, advice is aimed at ensuring the probability of the stock being below B_{lim} in any single year is no more than 5% (as for long-lived stocks). The reference points used are MSY $B_{escapement}$ and F_{cap}; advised catches correspond to the SSB in excess of MSY $B_{escapement}$, but constrained to allow $F \leq F_{cap}$. As assessments may be highly sensitive to incoming recruitment, which cannot be reliably estimated until the data are available, or not at all…. (often just before fishery starts or during fishing), advice will be given on such data when they are available, even after the fishery has opened (ICES 2018a). As mentioned earlier, advice for **increasingly data-poor stocks (i.e., Categories 3-6**) is based on the following performance evaluations: ● Category 3 (trends from survey-based assessment) - advice on recent advised catch (landings) adjusted to change in stock index for (in default settings) the two most recent values, in relation to the three preceding values (i.e., a running average). Other values may be used. ● Category 4 (reliable catch data): catch data are used to evaluate whether stock is fished sustainably or whether a reduction is required. "Decreases and increases in catch are incremental and slow." ● Category 5 and 6 (landings only, or bycatch): advice will be based on recent catch or landings, applying a precautionary buffer. If catches have declined significantly over a period of time, and if this could reflect a reduction in stock size, advice may include zero catch or implementation of a management strategy.

	If a stock status can be determined for stocks in Categories 3 and 4, the stocks are given statuses relative to MSY proxies (one for exploitation, against F_{MSY} proxy; and one for biomass, MSY $B_{trigger}$ proxy). In evaluating multi-year management strategies, ICES considers the risks to maintaining reproductive capacity and the likelihood that high yields are produced in the long term. The following criteria to define precautionary are used: **Long-lived stocks** ● A management strategy is considered ***precautionary*** if, over the simulated period, the maximum probability that SSB < B_{lim} is $\leq$ 5%, where the maximum of the annual probabilities is taken over all years in the plan (i.e., short and long-term). **Short-lived stocks** ● If, under natural conditions of no fishing, the long-term annual probability of SSB < B_{lim} is $\leq$ 5%, the same precautionary criterion used for long-lived stocks, is used. ● Otherwise, the management strategy is precautionary so long as the probability that SSB $\leq$ B_{lim} is < 5% in any year the fishery takes place. In all other years the fishery should be closed.
NAFO	Fisheries management objectives (in the sense of avoiding limits and achieving targets) are obliquely addressed by NAFO. The PAF notes that flexible fishing mortality rates will be selected by fisheries managers, to ***achieve desired management objectives*** for stocks so long as they are above a buffer biomass reference point and below a buffer fishing mortality reference point (i.e., similar to the concepts of *not overfished* and *not overfishing* in the United States; see below). However, the selected management measures are subject to constraints defined by the reference points (i.e., there is an implicit prescribed fishery management objective to avoid breaching limits and buffers that takes precedence over achieving desired states; NAFO 2004a). Provisional risk tolerances also help to inform fisheries management objectives regarding limits and targets. NAFO's PAF divides stock status into 5 zones (see Harvest Strategies section below; NAFO 2004a). In the Safe Zone ($B > B_{buf}$, $F < F_{buf}$), limit reference points should have a *low* (20% or otherwise specified) probability of being exceeded for fishing mortality, and a *very low* (5-10% or otherwise specified) probability of being violated for biomass (NAFO 2004a). In the Cautionary Zone however, (B between B_{lim} and B_{buf}, $F < F_{buf}$), fishing mortality (F) should be low enough to ensure that there is a ***very low (5-***

	10% or otherwise specified) probability that biomass will decline below B_{lim} within the foreseeable future (***5-10 years*** or otherwise specified; NAFO 2005).
New Zealand	An objective of the HS Standard is to provide a framework for setting management measures that have "a ***high probability of achieving targets, a very low probability of breaching limits, and acceptable probabilities of rebuilding stocks that nevertheless become depleted, in a timely manner***" (MF 2008). Note that New Zealand has two types of limit reference points (see Reference Points section below, Appendix 5). In conformity with the 2008 amendments to the New Zealand *Fisheries Act*, the minister must set Total Allowable Catches that are "not inconsistent with ***the objective of maintaining the stock at or above, or moving the stock towards or above, a level that can produce the maximum sustainable yield***" (MF 2008). The essential requirements are to maintain stocks at or above levels that can produce MSY, and to rebuild stocks that are below this level. The HS Standard states that fisheries should be managed to fluctuate around a MSY-compatible or better target, with at least a 50% probability of achieving the target (timeframe unspecified; MF 2008). Management strategies should also be designed so that ***the probability of breaching the soft limit is no higher than 10%, and the probability of breaching the hard limit is no greater than 2%***. Alternatively, ***a probability of breaching the soft limit of 5%*** (and no consideration of the hard limit) would also be considered acceptable (MF 2008). A soft or hard limit will be considered to have been breached when the probability that the stock is below the limit is ***greater than 50%.*** If the intent is to evaluate rebuilding strategies, the minimum standard objective is a 70% probability of achieving the MSY-compatible target or better within the timeframe of T_{min} to 2* T_{min} (New Zealand, 2011).
United States	Dual goals are presented with respect to avoiding undesirable states and achieving desireable outcomes. In the NOAA NS Guidelines, *Standard 1 - Optimum Yield* states that "conservation and management measures shall ***prevent overfishing*** [by means of *an Allowable Biological Catch* or ABC] while ***achieving, on a continuing basis, the optimum yield*** (OY) from each fishery for the U.S. fishing industry" (NOAA 2018a). "In NS1, use of the phrase "achieving, on a continuing basis, the

> OY from each fishery” means: producing, from each stock, stock complex, or fishery, an amount of catch that is, on average, equal to the Council's specified OY; prevents overfishing; maintains the long term average biomass near or above B_{MSY}” (NOAA 2018a).

The American system of five reference points, in which ABC and OY are included, is further discussed in the section on Reference Points (Appendix 5), while overfishing is discussed in the Reporting of Status section (Appendix 11).

The NS Guidelines further notes that the relevant legislation (i.e., the *Magnuson-Stevens Act*) has established MSY as the basis for fisheries management. Fishing must not risk the capacity of the stock to produce MSY, stocks must be rebuilt as needed to a level that can produce MSY, and OY must not exceed MSY (NOAA 2018a). OY, as a target, is also described as a “decisional mechanism” that resolves both conservation and management objectives (similar to how targets may be described in other jurisdictions).

Some information on provisional risk tolerances for decision making is provided, although discretion is left up to individual councils. For example, “The Council's risk policy could be based on an acceptable probability (***at least 50 percent***) that catch equal to the stock's ABC will not result in overfishing, but other appropriate methods can be used” (NOAA 2018a).

An exception to requirements to prevent overfishing is also permitted in some limited circumstances (such as multi-species fisheries). Overfishing may be permitted, so long as the Council considers, among other items, that “***the resulting rate of fishing mortality will not cause any stock or stock complex to fall below its MSST more than 50 percent of the time in the long term***, although it is recognized that persistent overfishing is expected to cause the affected stock to fall below its B_{MSY} more than 50 percent of the time in the long term” (NOAA 2018a).

In terms of defining stock states that meet (or do not meet) objectives, the default definition appears to be a 50% probability. For example, In calculating rebuilding timeframes,

> *“*T_{min} means the amount of time the stock or stock complex is expected to take to rebuild to its MSY biomass level in the absence of any fishing mortality. In this context, the term “expected” means to have at least a ***50 percent probability*** of attaining the B_{MSY}, where such probabilities can be calculated. The starting year for the T_{min} calculation should be the first year that the rebuilding

	plan is expected to be implemented" (NOAA 2018a). Furthermore, stocks are considered to be approaching an overfished condition when there is at least a 50% probability that the stock will decline below its minimum stock size threshold (MSST) in the next two years (NOAA 2018).

Appendix 5 - REFERENCE POINTS

Canada (national)	The Canadian PA Policy outlines three reference points, with an optional fourth (target reference point). The ***Limit Reference Point* (LRP)** is defined there as the stock status below which serious harm is occurring to the stock (DFO 2009a), but above the levels where risk of extinction becomes a concern (DFO 2006). Several approaches for calculating the LRP are in use. In the absence of stock-specific information, a default value for the LRP is given as 40% of the B_{MSY}. In the absence of an estimate of B_{MSY}, the PA Policy indicates that provisional estimates could be calculated as biomass at biomass-per-recruit at $F_{0.1}$ multiplied by the number of recruits on average; average biomass or index over a productive period; or 50% of maximum historical biomass. DFO (2016a) reviewed other options, including model-derived, empirical and data-poor methods and considerations for certain taxonomic groups like salmonids and marine mammals. DFO (2016a) clarified that the LRP is the point below which the risk that the stock will suffer serious harm begins to increase rapidly, as opposed to “is occurring” (with serious harm defined as impaired recruitment, “any change to the biological properties of the stock that make rebuilding cease to be considered rapid and secure”). The ***Upper Stock Reference* (USR)** has two roles: a minimum function in guiding risk management of approaching the LRP (i.e., it is a buffer or operational control point first and foremost, a threshold below which removals must be progressively reduced); but it can also serve as a ***target reference point* (TRP)** in the absence of a separate TRP in accordance with the UNFSA (1995). The USR is determined by productivity objectives for the fishery and include biological, social and economic factors (DFO 2006). While socio-economic factors may influence the placement of the USR, they must not diminish its minimum function in relation to the LRP (DFO 2009a). In the absence of stock-specific information, a default value for the USR is given as 80% of the B_{MSY}. The practice of merging the TRP with a precautionary buffer reference point has been considered acceptable so long as the USR is set far enough above the LRP to accommodate uncertainties in stock status relative to avoiding the limit (Rice, 2009). The two roles of the USR, however, may be difficult to reconcile in practice. DFO (2016a) later clarified that the USR has no defining biological properties itself (thus implying that the “healthy zone” the USR bounds has no defined biological meaning). The USR should be sufficiently high above the LRP that if management aims to keep the stock at or above

	the USR, the risk of the stock falling below the LRP does not exceed allowable risk tolerances (DFO 2016a). It is thus defined relative to the LRP. The TRP was similarly described as needing to be set well within the Healthy Zone so that the probability of the stock falling into the Cautious Zone over a set period of time is moderately low (DFO 2016a). The LRP and USR are used to demarcate stock status zones of Critical, Cautious and Healthy, on the basis of stock biomass or proxies thereof (see Visual Tools section). The third primary Canadian reference point is the ***Removal Reference* (RR)**, the maximum acceptable removal rate, which should progressively decrease as the stock level approaches the Critical zone (DFO 2006); that is, three Removal References, or formulae for adjusting them according to stock status, may be developed for a given stock. To comply with the 1995 UNFSA, RRs must be less than or equal to F_{MSY}. In the absence of an estimate of F_{MSY}, options include $F_{0.1}$, the average F or index of F that did not lead to stock decline over a productive period, or the F equal to M inferred from life history of the species. DFO (2016a) reviewed other options. An alternate definition of RR was later provided as the maximum removal rate that when applied in a risk-neutral fashion, does not imply equilibrium biomass below the USR - thus resolving a conflict between a limit F at F_{MSY} and a target USR at 80% B_{MSY} (DFO 2016a). It is important to note that despite visual similarities, the RR is distinct from a harvest control rule (see Visual Tools section).
Canada (WSP)	For salmon, DFO's WSP identifies not reference points but benchmarks for Conservation Units (CUs) that, like the Canadian PA Policy, delimit three stock status zones (here, termed Green, Amber and Red instead of Healthy, Cautious and Critical; DFO, 2005a). The benchmarks are expressed in units of spawner distribution and abundance, or proxies thereof, and identify "when the biological production status of a CU has changed significantly, but do not prescribe specific restrictions." The ***lower benchmark*** of the WSP corresponds to a level of abundance high enough to ensure there is a substantial buffer between it and any level of abundance that could be considered at risk of extinction by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; DFO, 2005a). The specific risk tolerance in defining this lower benchmark needs to be determined in consultation with Indigenous communities and other stakeholders, and there is no one recommended default metric for the lower benchmark in the WSP. It is thus not exactly analogous to the LRP of the national PA Policy (DFO 2009a).

	The ***higher benchmark*** of the WSP will be placed in order to determine whether harvests are greater or less than the level expected to provide on average the maximum annual catch from a given CU, taking into account the environmental conditions (DFO 2005a).
Australia	***Indicators*** (data such as estimated biomass, fishing mortality, harvest levels, or proxies) provide information on the status of the stock of fishery (DAWR 2018b), and ***reference points*** are defined in the HS Policy as specified levels of indicators used as a basis for managing the stock or fishery (DAWR 2018a). The default illustration provided for a harvest control rule (HCR) indicates that they are also operational control points (although perhaps not necessarily so as the specific form of the HCR depends on the management tools; DAWR 2018b; see Visual Tools section). Dynamic reference points may be set if equilibrium reference points are not appropriate (DAWR 2018b). It is noteworthy that the HS Policy only specifies biomass-based reference points. However, the associated guidance notes that the policy requirements can be met through the use of reference points based on fishing mortality (DAWR 2018b). $\boldsymbol{B_{targ}}$ and $\boldsymbol{F_{targ}}$ represent the desired state of the stock and the desired intensity of fishing. The default value is B_{MEY}; suggested proxies include 0.48*B_0 or 1.2*B_{MSY} and a proxy for B_{MSY} if needed is 0.4*B_0 (or their F equivalents). Other proxies for MEY may be derived through the application of expert judgement to a reliable indicator of stock abundance/biomass (e.g., historical catch or effort levels in data-poor stocks). In multi-species fisheries, the target is fishery-level MEY and target reference points for each stock in the fishery are set with that in mind. Australia is unique in prioritizing B_{MEY} (McIlgorm 2013). $\boldsymbol{B_{lim}}$ and $\boldsymbol{F_{lim}}$ represent situations to be avoided because they represent a point beyond which the risk to the stock is unacceptably high. Note: if the stock is below B_{lim} or the indicator-based limit reference point, the stock is considered *overfished*. If not stock-specific, 0.2*B_0 or other values so long as they are > 0.2*B_0. For less productive stocks, alternatives such as 0.3*B_0 or 0.5*B_{MSY} are recommended. F_{lim} is the point above which the removal rate is considered too high and results in the stock declining below B_{lim}. Although earlier guidance for Australia's HS Policy noted that F_{lim} could not exceed F_{MSY} (DAFF 2007), and further guidance for setting F-based reference points was recommended in an HS Policy review (DAFF 2013), neither that stipulation nor any other is apparent in current guidance (DAWR 2018b). No buffers or other operational control points are prescribed; although

	harvest strategies may include intermediate triggers, or review triggers, intended to detect change and trigger investigation but not necessarily to require an immediate change to fishing activities.
ICES	ICES' Advice Basis and guidance identify the following reference points, used in various combinations depending on the stock (long-lived versus short lived) and data poverty level (category), with the possibility for proxies as needed (Category 1-2 or 3-6; ICES 2017, ICES 2018a, ICES 2018b): ***B*lim** is the stock size below which there is a high risk of impaired recruitment, and is identified for stocks where quantitative information is available. ICES (2017) further elaborates this for Category 1 and 2 stocks as "a deterministic biomass limit below which a stock is considered to have reduced reproductive capacity" and gives its basis as "the biomass below which recruitment reduces with spawning-stock biomass (SSB)." This could be calculated as a "segmented regression change point," the biomass based on the lowest SSB where large recruitment is observed, fractions of B_{MSY} and various other methods depending on the nature of the stock in question (ICES 2017 and ICES 2018b). ***B*MSY** is the average expected biomass if the stock is exploited at F_{MSY}. The MSY advice rule does not explicitly use a B_{MSY} estimate, as this is a notional value around which stock size fluctuates when fishing at F_{MSY} and is strongly dependent on environmental interactions. Additionally, historical stock size trends may not be informative about B_{MSY} due to high *F*s for many years, or substantially different past environmental conditions. ***B*pa** is a precautionary reference point serving as a safety margin, which incorporates uncertainty in ICES stock estimates, and is set when MSY $B_{trigger}$ cannot be estimated. It has a low probability of being below B_{lim}. If the stock is above B_{pa}, the probability of impaired recruitment is expected to be low. ICES (2017) alternatively describes this as a reference point "above which the stock is considered to have full reproductive capacity, having accounted for estimation uncertainty" and is set to the value of SSB which ensures less than 5% probability of being below B_{lim}. **MSY *B*trigger** is the parameter in the ICES MSY framework which triggers advice on a reduced fishing mortality relative to F_{MSY}. It is illustrated in the Advice Basis as being interchangeable with B_{pa} (Figure 1.2.2 of ICES 2018a; see also Figure A32, below). It is considered to be the "lower bound of spawning-stock biomass fluctuations when the stock is fished at F_{MSY}," and is used in the ICES advice rule to trigger a "cautious

	response" (i.e., it is an operational control point similar to the Canadian USR). If insufficient data are available to estimate MSY $B_{trigger}$, the reference point may be set as B_{pa}. ICES (2017) clarifies that MSY $B_{trigger}$ for Category 1 and 2 stocks is the maximum of either B_{pa} or the 5th percentile of SSB when fishing at F_{MSY}. Guidance for more data-poor Category 3 and 4 stocks indicates that MSY $B_{trigger}$ could be set to 0.5 B_{MSY} in a way "consistent with other management systems" such as the United States and the minimum stock size threshold (ICES 2018b). **MSY $B_{escapement}$** is the minimum stock size that should remain in the sea every year to ensure future recruitment of short-lived species where recruitment is highly variable. It is "often equal" to B_{pa}. It is estimated each year to be robust against low SSB and includes a biomass buffer to account for uncertainty in assessments and advice. "**B_{mgmt}**" is used to refer to management plan-specific limits, targets and triggers apart from the ICES advice rules. **F_{cap}** is a limit to exploitation rates used to provide advice for short-lived Category 1 and 2 stocks when biomass is high; it is a cap beyond which F cannot exceed, taking into account the SSB in excess of MSY $B_{escapement}$. As uncertainty scales with stock size, the presence of an F_{cap} results in an increase in escapement biomass with stock size, enabling the maintenance of a high probability of achieving the minimum amount of biomass left to spawn. **F_{lim}** is the fishing mortality which in the long-term will result in an average stock size around B_{lim} (i.e., 50% probability of being above or below B_{lim}; ICES 2017). F_{pa} is a precautionary buffer to avoid that true fishing mortality is above F_{lim}. **F_{MSY}** is estimated as the fishing mortality with a given fishing pattern and current environmental conditions that gives the long-term maximum sustainable yield. ICES also calculates ranges in F_{MSY} values (F_{lower}, F_{upper}) derived to deliver no more than a 5% reduction in long-term yield compared with MSY; F_{upper} is capped so that the probability of SSB < B_{lim} is no greater than 5% in any single year. **F_{pa}** is mentioned in applying the MSY advice rule to long-lived Category 1 and 2 stocks; it must be above F_{MSY}. ICES (2017) describes this as an "exploitation rate reference point below which exploitation is considered to be sustainable, having accounted for estimation uncertainty" and ensures that there is a 5% probability of being above F_{lim}. There is extensive technical guidance available for identifying reference

	points for relatively data-rich stocks (Categories 1 and 2; ICES 2017) and relatively data-poor stocks (Categories 3 and 4; ICES 2018b), but the intent here is not to cover all available alternatives, considerations and acceptable proxies in setting reference points.
NAFO	NAFO's PAF (2004a) identifies the following reference points, which according to the management actions prescribed for each zone, also serve as operational control points (see Harvest Strategies section): **B_{tr}**: a target biomass level identified in the original PAF schematic, but not present in the accepted version (NAFO 2004a). **B_{buf}:** a safety margin required for certain stocks; a stock biomass level above B_{lim} that is required when there is no ability to calculate a probability that the current or projected B < B_{lim}. B_{buf} is to be specified by managers and should satisfy the requirement that there is a very low (i.e., 5-10%) probability that any biomass above B_{buf} will actually be below B_{lim} (which therefore means that B_{buf} shares some similarities with the Canadian USR, in that the USR guides risk management with respect to the LRP). The greater the uncertainty, the greater the buffer should be. A buffer is required to signify the need for more restrictive measures (i.e., it is an operational control point). It should be noted that as of 2013, no B_{buf} or F_{buf} points have been identified for any NAFO stocks (Brodie et al. 2013). **B_{lim}:** A biomass level below which stock productivity is likely to be seriously impaired, that should have a very low probability of being violated. **F_{buf}:** a safety margin required for certain stocks; fishing mortality rate below F_{lim} that is required in the absence of analyses of the probability that $F > F_{lim}$. Like B_{buf}, F_{buf} should be specified by managers and should satisfy the requirement that there is a very low probability that any F below F_{buf} will actually be above F_{lim}. The greater the uncertainty, the greater the buffer should be. A buffer is required to signify the need for more restrictive measures. **F_{lim}:** A fishing mortality rate that should have a low probability of being exceeded. F_{lim} cannot be greater than F_{MSY}. If F_{MSY} cannot be estimated, then an appropriate surrogate may be used. Recommendations regarding the setting of limit reference points were made by a Study Group (NAFO 2004b), including default and possible proxy values. For example, with respect to defaults, "the biomass giving production of 50% of MSY should be considered as an appropriate B_{lim} for stocks assessed using production models. Under the Schaefer

	model this is 30% of B_{MSY}" (NAFO 2004b). Such defaults, however, were not incorporated explicitly into the PAF (NAFO 2004a).
New Zealand	New Zealand's HS Standard has three core reference point elements: a ***target***, around which a fishery or stock should fluctuate; a ***soft limit***, that acts as a buffer or operational control point (where fisheries should be curtailed) and which triggers a requirement for a rebuilding plan, and a ***hard limit*** below which fisheries should be considered for closure. In general, ***limits*** represent "a point at which further reductions in stock size (or proxies) are likely to ultimately lead to an unacceptably high risk of stock collapse and/or a point at which current and future utility values are diminished or compromised. 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, and associated management actions should prevent stocks from falling into such zones" (MF 2011). ***Targets*** should be based on MSY-compatible reference points or better (as a result of considering economic, social, cultural or ecosystem factors; MF 2011). The technical guidance includes a variety of options for calculating B_{MSY} or B_0 proxies, including in relation to stock productivity (MF 2011). A default ***soft limit*** is 0.5* B_{MSY}, or 20% * B_0, whichever is higher—note, this assumes B_{MSY} is around 40% of B_0. Lower levels could be considered in some circumstances, such as stocks with high natural fluctuations or high natural mortality that might be expected to fluctuate below the soft limit more than 10% of the time even when managed to fluctuate around a target. However, rigorous scientific evaluation is needed to justify this. The default ***hard limit*** is 0.25* B_{MSY} or 10% B_0, whichever is higher (these are minimum standards; higher values could be set). The hard limit is the reference point at which closure should be considered for target fisheries; it may also be appropriate to consider closure of fisheries that incidentally catch the species (MF 2008). For new or developing fisheries, F should not exceed F_{MSY}; where this is unknown, it should be assumed to be equivalent to M (MF 2008). Thus, F_{MSY} appears to function as a limit (when it is exceeded on average, overfishing is occurring) but is considered a "maximum target, rather than as a limit to be avoided" (MF 2008). The technical guidance also introduces the concept of a ***threshold***, an operational control point (e.g., at (1-M) B_{MSY}) which acts as a trigger for strengthened management actions to enable the stock to avoid the soft limit and not fall too far below the target (MF 2011; also see Visual Tools

	section below and Figure A36). A threshold thus shares some similarities with the Canadian USR. Linking the trigger point to natural mortality recognizes that stock fluctuations around B_{MSY} will reflect natural mortality, and also that stocks with high natural mortality are also more productive.
United States	In the NOAA NS Guidelines, *Standard 1 - Optimum Yield* collectively refers to the five items below as reference points (NOAA 2018a). **1. SDC (*status determination criteria*)** are measurable and objective factors such as the MFMT, OFL, and MSST, or their proxies that are used to determine if *overfishing* has occurred (i.e., *F*) or if the stock/stock complex is *overfished* (i.e., *B*). The *Magnuson-Stevens Act* defines overfishing as a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce MSY on a continuing basis. ● **MFMT (*maximum fishing mortality threshold*):** *F* above which, on an annual basis, overfishing is occurring. This may be expressed as a single value of *F*, or as a function of spawning biomass or other measure of reproductive potential. Where practicable, all sources of mortality should be included in evaluating stock status with respect to reference points, including bycatch, scientific catches and other activities. ● **OFL (*overfishing limit*)**: annual amount of catch that corresponds to MFMT; numbers or weight of fish. ● **MSST (*minimum stock size threshold*):** the level of biomass below which the capacity of the stock or stock complex to produce MSY has been jeopardized. This should be expressed in terms of biomass or other proxy of reproductive potential, and should be between ½ B_{MSY} and B_{MSY}. It should be informed by the stock life history, the natural fluctuations of the stock, the requirements of internationally-managed stocks and other considerations. While SDCs are often based on MSY or associated proxies, other metrics can be used if data are not available - if so, the Council must provide an analysis as to how the SDC were selected, how they relate to ***stock reproductive potential***, and how they will ***promote sustainability of the stock or stock complex on a long-term basis***. SDC should only be re-specified if environmental changes affect the long-term reproductive potential of the stock. **2. MSY (maximum sustainable yield)** is the largest long-term average catch that can be taken from a stock or stock complex under prevailing conditions, including fisheries technology and distribution among fleets. F_{MSY} is the fishing mortality that over the long term would result in MSY and B_{MSY} (long-term average size of stock or stock complex, typically

	measured as SSB or other measure of reproductive potential). For stock complexes, MSY can be calculated at the indicator stock or whole-complex level. Reasonable proxies may be used if data are insufficient to calculate MSY, B_{MSY} or F_{MSY}, and ecological and environmental information should be taken into account when calculating these values. NS Guidelines 1 recognizes that there are circumstances which may not fit the standard approaches for specifying reference points or management measures, such as Pacific Salmon, where the spawning potential for a stock is spread over a multi-year period, or other stocks where MSY or MSY proxies cannot be used. In such cases, Councils may propose alternative approaches, documenting their rationale in the FMP which will be reviewed for consistency with the *Act*. **3. OY (optimum yield)** is defined in the *Magnuson-Stevens Act* as the amount of fish that will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational fishing and taking into account protection of marine ecosystems. It may be defined at the stock, stock complex, or fishery level; it is a long-term average amount of desired yield. Achieving the OY means producing from the stock/complex/fishery the amount of catch that is on average equal to the OY, prevents overfishing, maintains long-term biomass near or above B_{MSY}, and rebuilds overfished stocks consistent with requirements under the *Act* and the rest of the NS Guidelines. The OY is set based on MSY estimates or proxies, while taking into account various economic, ecological and social factors, all with inherent trade-offs. Uncertainty also plays a role in where OY is set. If estimates of biomass and MFMT are known with a high level of certainty, and if management controls can accurately limit catch, then OY can be set close to MSY. At the fishery level, OY should not exceed the sum of MSY values for each stock or stock complex. **4. ABC (*acceptable biological catch*)** is the total quantity of fish taken in all fisheries (landed and discarded), that corresponds to an ABC control rule that accounts for scientific uncertainty in OFL or elsewhere, and the Council's risk policy. **5. ACL (*annual catch limit*)** is a limit on the total annual catch of any stock or stock complex, which cannot exceed the ABC, that serves as the basis for invoking accountability measures (AMs). The relationship between OFL, ABC and AFL is illustrated in Figure A37 (Visual Tools section), below. Although Restrepo et al. (1998) provide technical guidance for an earlier and now out-of-date version of National Standard Guidelines 1, some additional information on reference points is available. The authors note

	that NOAA nomenclature differs from international practice; *thresholds* correspond to what other jurisdictions call limits, while *interim thresholds* correspond to what other jurisdictions call thresholds and buffers. The guidance further describes a “limit control rule” or “MSY control rule” that was not an operational harvest control rule but a limit reference point used both as MFMT and to set MSST (the value of biomass at which rebuilding to B_{MSY} would take 10 years or less when fishing at MFMT). According to the 1998 guidelines, Councils could set their own MSST, which in turn would modify the slope of the MFMT, but in “no case could the MSST fall below one-half of the MSY level” (Restrepo et al. 1998). In the absence of detailed assessments and consideration of trade-offs by councils, a default “MSY control rule” (MFMT) was recommended that had a constant F of F_{MSY} when biomass exceeded some value (cB_{MSY}, where c = max(1-M,1/2)), and a proportionately declining F when biomass fell below this value. The rationale for setting the inflection point of control rules as cB_{MSY} was that it was considered reasonable to expect a stock fished at F_{MSY} to fluctuate around B_{MSY} in a fashion that was proportional to M (Restrepo et al. 1998). In this way the “MSY control rule” or MFMT described by Restrepo et al. (1998) appears to be directly analogous to the Removal Reference of Canada’s PA Policy (DFO 2005a), and the inflection point of the MFMT (cB_{MSY}) described by Restrepo et al. (1998) as a possible default for the MSST appears to be directly analogous to Canada’s USR. It is important to note that the term “MSY control rule” is no longer used by the National Standard Guidelines, and has been replaced by “ABC control rule” (NOAA 2009; see section on Harvest Strategies). Furthermore, a formal link between MFMT and the concept of a “control rule” appears to have been removed in the intervening years, as the NSG indicate MFMT could represent a single F value (NOAA 2018a). Although not described in any other formal guidelines to date, many stock assessments conducted by NOAA may, for example, derive a single limit F value from MSY: “The limit reference point (typically the fishing rate at maximum sustainable yield (F_{MSY}) or a proxy for it) is generally considered to represent the level at which overfishing occurs” (Shertzer et al. 2008). Methot and others (2014) discuss a limit F as such a single value, noting that OFL is derived from MSY and as a consequence will vary with absolute biomass estimates (F_{MSY} x B), and stating that the ABC control rule set with an acceptable probability (P*) may calculate ABC through such simple means as 0.75*OFL.

Appendix 6 - HARVEST STRATEGIES

Canada (national)	The Canadian PA Policy notes that harvest strategies and harvest decision rules (i.e., harvest control rules or HCRs) are among the three primary components of the generalized decision-making framework (DFO 2009a). A ***harvest rate strategy*** is defined as the approach taken to manage the harvest of a stock, a necessary element of any fishery plan, and essential components of which are pre-agreed harvest decision rules and management actions for each stock status zone (DFO 2009a). Science advice generated in support of the Canadian PA Policy further notes that a harvest strategy compliant with the precautionary approach includes a removal reference for three stock status zones, each delineated by two other reference points: a limit reference point (LRP) and an upper stock reference (USR) treated as operational control points (DFO 2006). A provisional harvest decision rule to guide management in the absence of a pre-agreed harvest rule is given as ● Healthy Zone: $F_p < F_{MSY}$ ● Cautious Zone: $F_p < F_{MSY}$ x (biomass - 40% B_{MSY})/(80% B_{MSY} - 40% B_{MSY}) ● Critical Zone: $F_p = 0$ In addition, a table is provided that describes generalized criteria for management actions, consisting of the general approach to be taken (i.e., the relative weight of conservation versus socio-economic considerations), general harvest rate recommendations, and optional guidance to vary management actions in light of recent stock trajectories (i.e., risk tolerances may vary depending on whether the stock is increasing, stable or declining; Table 1, DFO 2009a). These items are described separately for each stock status zone (Critical, Cautious and Healthy). Actual harvest decision rules should be more precise, however, and contain detailed information on harvest rates and other management measures specified within each stock status zone (DFO 2009a). DFO (2016a) summarized these two rules as a “status-based” and “risk-based” rule, respectively, noting that the risk-based rule reflected in the table is very hard to operationalized quantitatively and appears to have only been qualitatively applied. Inflection points of HCRs (operational control points) should also not be bound to reference points.

	All removals from all types of fishing must be taken into account when the framework is applied (DFO 2009a). In terms of interactions among different stocks (multi-species considerations), the Canadian PA Policy states that the application of harvest decision rules may need to be "tempered to limit effects on other stocks" and that management actions "related to other ecosystem elements may also be considered" depending on the available information (DFO 2009a).
Australia	The Australian HS Policy defines a ***harvest strategy*** as a "decision framework necessary to achieve defined biological and economic objectives for commercial fish stocks in a given fishery." Harvest strategies in this policy contain processes for monitoring (i.e., data collection) and for assessing the biological and economic condition of the stock against fishery-specific reference levels. In common with most policies, pre-determined HCRs are to be defined that control fishing activity according to the condition of the stock and are "designed to pursue" the various objectives for a given fishery (DAWR 2018a). Harvest strategies "will account" for all known sources of fishing mortality (*F*) and "should account" for all known non-fishing sources of mortality (*M*) that cannot be managed or constrained by the Australian Fisheries Management Authority (DAWR 2018a). Data-poor stocks could be accounted for via assessment methods suited for data poverty, and consideration of the increased uncertainty dealt with via MSE or through applying a buffer or discount to the recommended catch from a HCR in order to maintain risk equivalency of science advice generated for these stocks (DAWR 2018a, 2018b). In designing a harvest strategy, the Australian HS Policy states that consideration should be given to the information and administration requirements of potential strategies, as well as the costs and benefits associated with the available options (DAWR 2018b). The Risk-Catch-Cost (RCC) trade-off aims to balance the resource investment required to collect and analyze data and manage the fishery with the level of catch that fishery produces. Finally, when amending or developing a harvest strategy, the process should be based on current scientific and economic information and involve appropriate stakeholder consultation. Australia's illustration of a HCR (Figure A30, Visual Tools section below) ties reference points to operational control points (OCPs; DAWR 2018b). The text further suggests that reference points are OCPs (HCRs reduce fishing pressure as the stock indicator moves towards the limit and away from the target; or increase pressure on a stock above its target), but also notes that harvest strategies may include other sorts of

	triggers and that the specific from of the control rule depends on the management tools being used (DAWR 2018b). Five example harvest strategies are given in the technical guidelines (DAWR 2018b). ***Buffers*** or ***discounts*** may also be used to aim for risk equivalency (e.g., Fulton et al. 2016) in harvest strategies when stocks across a range of data availabilities are assigned to tiers; an example is given in Appendix B of the guidelines (DAWR 2018b).
ICES	As an international marine science organization with many clients operating under disparate legislation or policies, ICES provides limited information on defined harvest strategies. Instead, advice will be provided in accordance with an agreed-upon management plan or strategy by the relevant management authorities for the stock, with the understanding that such plans have been evaluated by ICES to be "precautionary" (ICES 2018a), according to predefined acceptable probabilities of the stock being below B_{lim} (ICES 2016). For medium- to long-lived stocks, a plan is deemed precautionary if the probability of $B < B_{\mathrm{lim}}$ does not exceed 5% in each year of the plan (or if rebuilding, $B > B_{\mathrm{lim}}$ with > 95% probability in some pre-specified year, timeframe not prescribed). For short-lived stocks where $B < B_{\mathrm{lim}}$ exceeds 5% even in conditions of no fishing, the plan should allow for closures in years when $B < B_{\mathrm{lim}}$ > 5% and should overall not result in a doubling of risk that the stock would be below B_{lim} under unfished conditions (ICES 2016) Like some Australian fisheries, ICES has identified a tiered approach to categorizing its science advice (ICES 2018a). Categories 1 and 2 represent fairly data-rich stocks that have quantitative or analytical assessments, with forecasts that may be quantitative or qualitative. These stocks are candidates for the ICES "MSY Approach" unless a suitable management strategy is already agreed-upon. Categories 3-6 are increasingly data-poor, relying on survey trends, catch, landings, or negligible landings data. Some of these stocks may be suitable for adopting proxies to MSY reference points, but otherwise advice is given "based on the precautionary approach" which implies that when stock biomass is so low that reproduction is at significant risk of being impaired, "fisheries management in such situations should be more cautious." The ICES ***MSY advice rule*** is based on fishing mortality (*F*), or in some cases harvest rates (HR). *F* is defined as the instantaneous rate derived from the proportion in numbers of fish in a year class taken by fisheries during one year, and is estimated as the average over ages that dominate in the catches. HR, in turn, is defined as the fraction of a reference biomass or abundance that is caught during a year.

Reference points are described in the section preceding (Appendix 5). For long-lived Category 1 and 2 stocks, F_{MSY} is not allowed to be above F_{pa}, and if spawning stock biomass (SSB) falls below MSY $B_{trigger}$, a "cautious response" is triggered which is to reduce fishing mortality to allow a stock to rebuild to levels capable of producing MSY, proportional to the ratio between SSB and MSY $B_{trigger}$.

- $F = F_{MSY}$ when SSB > MSY $B_{trigger}$
- $F = F_{MSY}$ x SSB/MSY $B_{trigger}$ when SSB < MSY $B_{trigger}$ and > B_{lim}
- If F from the above is insufficient to bring stock > B_{lim} in short term, advice will be based on bringing stock > B_{lim} in short term (undefined), possibly $F = 0$.

For short-lived Category 1 and 2 stocks, advised yearly catches reflect the estimated biomass in excess of MSY $B_{escapement}$, with F not to exceed some value of F_{cap} (ICES 2018a).

For Category 3-6 stocks, with an absence of population estimates, harvest advice aims to ensure that the advised catch is sustainable. All available information should be used and a precautionary approach should be followed (as information becomes increasingly limited, more conservative reference points are used and a larger margin of precaution; ICES, 2018a). To accommodate uncertainty:

- A change limit of +/- 20% is applied in the advice to reference values (e.g., recent average catches), because more noise is anticipated in these values for data-poor stocks.
- Reference points for exploitation (when proxies are available) are on the lower margins of F_{MSY} (e.g., lower range, F0.1)
- A *precautionary buffer* or *precautionary margin* of -20% is applied where it is likely that $F > F_{MSY}$ or when stock status is unknown (and re-evaluated every three years); exceptions apply when expert judgement determines that the stock is not reproductively impaired, and the stock size is increasing or exploitation has been reduced.
- Advice is fixed for a time-frame compatible with a measurable response in the metrics used as the basis for advice.

Advice rules for these increasingly data-poor stocks are based on the following (ICES 2018a):

- Category 3 (trends from survey-based assessment) - advice on recent advised catch (landings) adjusted to change in stock index for (in default settings) the two most recent values, in relation to the three preceding values (i.e., a running average). Other values may be used.
- Category 4 (reliable catch data): catch data are used to evaluate whether stock is fished sustainably or whether a reduction is

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required. “Decreases and increases in catch are incremental and slow.”
● Category 5 and 6 (landings only, or bycatch): advice will be based on recent catch or landings, applying a precautionary buffer. If catches have declined significantly over a period of time, and if this could reflect a reduction in stock size, advice may include zero catch or implementation of a management strategy.
</td>
</tr>
<tr>
<td>NAFO</td>
<td>
NAFO’s PAF (2004a) contains little direct information on harvest strategy specifications. This lack of information may be by design, because the document notes that early versions of the PAF were never formally adopted by the Fisheries Commission, in part because of prescriptive harvest control rules indicating no fishing below B_{lim} or B_{buf} (See Reference Points section for full details).

Instead, management strategies and courses of action are provided for each zone of the PAF as follows:

<table>
<tr><td>Zone 1
(B > B_{buf}, F < F_{buf})</td><td>Safe Zone: Select and set fishing mortality from a range of F values that have a low probability of exceeding F_{lim} in a situation where stock biomass (B) has a very low probability of being below B_{lim}. In this area, target reference points are selected and set by managers based on criteria of their choosing (e.g. stable TACs; socio-economic considerations).</td></tr>
<tr><td>Zone 2
(B > B_{buf}, F > F_{buf})</td><td>Overfishing Zone: Reduce F to below F_{buf}.</td></tr>
<tr><td>Zone 3
(B between B_{lim} and B_{buf}, F < F_{buf})</td><td>Cautionary F Zone: The closer stock biomass (B) is to B_{lim}, the lower F should be below F_{buf} to ensure that there is a very low probability that biomass will decline below B_{lim} within the foreseeable future.</td></tr>
<tr><td>Zone 4
(B between B_{lim} and B_{buf}, F > F_{buf})</td><td>Danger Zone: Reduce F to below F_{buf}. The closer stock biomass (B) is to B_{lim}, the lower F should be below F_{buf} to ensure that there is a very low probability that biomass will decline below B_{lim} within the foreseeable future.</td></tr>
<tr><td>Zone 5
(B< B_{lim})</td><td>Collapse Zone: F should be set as close to zero as possible.</td></tr>
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	Other features of the framework are: There must be a very low probability of management actions resulting in the projected biomass < B_{lim} in the foreseeable future Below B_{lim}, fishing mortality should kept as close to zero as possible F_{lim} should be no higher than F_{MSY} There should be a low probability that the realized fishing mortality will exceed F_{lim} If B_{lim} exists but there is no probability distribution for biomass estimates (current or projected), the Fisheries Commission establishes a buffer zone B_{buf} and F_{buf}, against which biomass and fishing mortality are evaluated ● If biomass is > B_{lim} but < B_{buf}, action is required to reduce F < F_{buf} to ensure there is a very low probability that biomass declines below B_{lim} in the foreseeable future Actual time horizons and acceptable risk levels are specified by managers, but tentative values are given as: ● Low probability = 20% ● Very low probability 5-10% ● Foreseeable future = 5-10 years It is worth noting here that buffer reference points have never been identified for any NAFO stocks (Brodie et al. 2013).
New Zealand	The HS Standard recognizes that ***harvest strategy*** may be defined simply (as target and limit reference points and associated management actions, i.e., a HCR) or more comprehensively as a system that links stock assessment, management and monitoring, including performance measures, and sometimes associated research and enforcement activities (MF 2008). The HS Standard notes that it will use the simple “HCR” definition for harvest strategies, and employ “management strategy” when making reference to the more comprehensive fisheries management system. The three core elements of the HS Standard (target, soft limit, hard limit, and associated management actions) are elaborated in the Reference Points section above (Appendix 5). The HS Standard identifies best practices in relation to setting targets and limits, but does so from a single-species perspective. Other considerations, such as environmental principles, social, economic and cultural factors also play a role in the Minister’s decisions (MF 2008). For new or developing fisheries, F should not exceed F_{MSY} and preference should be given to $F < F_{MSY}$. In general, fishing-down phases

	of fisheries where $F > F_{MSY}$ should not be used as they are not sustainable in the long run (MF 2008).
United States	NOAA's (2018a) NS Guidelines contain a number of provisions as to what precisely is to be incorporated in ***Fishery Management Plans*** (FMPs), that may be broadly interpreted as requirements of harvest strategies. FMPs must contain: 1. MSY and status determination criteria (SDC) 2. Optimum yield (OY) at the stock, stock complex of fishery level and provide the OY specification analysis 3. Allowable biological catch (ABC) control rule 4. Mechanisms for specifying Annual Catch Limits (ACLs) from ABC 5. Accountability measures (AMs), that may include Annual Catch Targets (ACTs) The National Standard guidelines define a ***control rule*** as "a policy for establishing a limit or target catch level that is based on the best scientific information available and is established by the Council in consultation with its" Scientific committee (NOAA 2018a). Earlier technical guidance was a bit more specific, noting that "control rules are pre-agreed plans for making management decisions based on stock size;" and that "a control rule describes a variable over which management has some direct control as a function of some other variable(s) related to the status of the stock" (Restrepo et al. 1998). There is a recognition of including research and monitoring in harvest strategies; the NS Guidelines state that FMPs must contain an assessment and specification of optimum yield (OY), conservation and management measures to achieve this yield, and provisions for collecting information to determine the degree to which the yield is achieved (NOAA 2018a). This is mirrored in earlier technical guidance, which states that "a fishery management strategy is the combination of data collection, stock assessment, control rules and technical measures for implementing harvest controls" (Restrepo et al. 1998). **Allowable biological catch (ABC) control rule**: For stocks and complexes required to have such a rule, the Council must establish one that accounts for both scientific uncertainty in the **overfishing limit (OFL)** and the Council's own risk policy, using a comprehensive analysis to show that the rule prevents overfishing (at least 50% probability; NOAA 2018a). ● The ABC cannot exceed the OFL. ● The rule should consider reducing F as stock size declines below B_{MSY} and as *scientific uncertainty* (see next section) increases.

	• If proxies are used for reference points, proxies can be used for uncertainty as well. • A tiered approach (cp. Australia, ICES) may be used to also help accommodate scientific uncertainty • If the rule recommends large changes in catch (direction unclear, but likely with reference to sudden decreases, the changes may be phased-in over a period of time not to exceed 3 years and so long as catch does not exceed OFL in any year • Unused ACL can also be carried over from year to year, if such underages have occurred as a result of management uncertainty (but perhaps not scientific uncertainty) • ABC should be expressed in terms of catch, but landings may be used as long as bycatch and other mortality are accounted for • **Annual catch limits (ACL)** cannot exceed the ABC, and may be set on an annual or multi-year basis; they may also be divided by sectors (user groups) Sources of fishing mortality that need to be taken into account by the rule include landings, discards, commercial and recreational catch and bycatch in other fisheries. **Accountability measures (AMs)** are management controls (monitoring and management measures) to prevent ACLs from being exceeded, and to correct or mitigate exceedances when they occur. Within the system of AMs, **annual catch targets (ACTs)** from **ACT control rules** are recommended; an ACT is the amount of annual catch that is the management target, and control rules for the ACT account for management uncertainty in controlling the catch at or below the ACL (NOAA 2018a). Exceptions to the requirement to prevent overfishing could apply under certain limited circumstances (e.g., harvesting one stock at optimum levels can result in a second species being overharvested as bycatch or part of a multi-species fishery). A Council may decide to allow this overfishing, after considering the overall benefits, and the risk of the stock of concern falling below its MSST (minimum stock size threshold; i.e., if the stock or stock complex is not overfished; NOAA 2018a). The technical guidance for National Standard 1 (Restrepo et al. 1998) describes earlier and now out-of-date guidelines for establishing what the then-current NSGs required: two different control rules, a *limit* control rule, also called a MSY control rule, and a *target control rule,* called a OY control rule. In 2009 revisions to the National Standards, the MSY control rule was replaced with the ***ABC control rule***, and the OY control rule was replaced with the ***ACT control rule*** (which was made optional for FMPs, as part of the AMs; NOAA 2009).

	According to the 1998 technical guidelines, the MSY control rule was not necessarily used as a HCR but was used as (or to define) limit reference points; that is, the fishing mortality derived from the rule constituted the maximum fishing mortality threshold (MFMT), and it was used to determine the minimum stock size threshold (MSST) where fishing at MFMT would allow recovery to B_{MSY} in at most 10 years. According to the then-current National Standards, harvest levels "may be prescribed on the basis of an OY control rule" which would recommend harvests less than or equal to that derived from the MSY control rule (Restrepo et al. 1998). In essence, the target (OY) control rule was designed to be "safely below" the limit, established by the MSY control rule. It could be established based on a decision-theoretic approach given a specified level of risk aversion (minimizing expected losses), or based on a frequentist approach in given a risk of violating a limit. It was recommended that the OY control rule be developed such that the probability of exceeding the MFMT was no greater than 20-30%, and "certainly smaller than 50%." In the absence of such evaluations, the recommended default OY control rule used values of *F* at 75% of what was specified in the default MSY control rule. The NS Guidelines note the potential use for "reasonable proxies" of MSST, MFMT, and MSY (NOAA 2018a). In the same vein, and recognizing that a range of data-richness was possible across stocks, Restrepo and others (1998) outlined a series of potential proxies for MSY-based reference points in which control rules could be couched. In extremely data-poor conditions, where only CPUE or catch data might be available, the authors provided some suggested options for setting catches and reference points but noted that "there are few options for defining meaningful targets and limits" and that priority should be given to improving the knowledge base for the stock. More recently, a NOAA working group targeting ORCS (only reliable catch stocks) has recommended a tiered approach to recommending ABCs for data-poor stocks, including depletion-based stock reduction analysis, depletion-corrected average catch, the working group's specific approach, or management of the data-poor stock as part of a stock complex (Berkson et al. 2010).

Appendix 7 - UNCERTAINTY AND RISK

Canada (national)	The Canadian PA Policy notes that uncertainty and risk are one of the primary components of the generalized decision-making framework and these need to be taken into account when developing reference points, calculating stock status and implementing harvest decision rules (harvest control rules or HCRs). ***Uncertainty*** is defined as "incomplete knowledge about the state of nature" while ***risk*** is defined as "the probability of an outcome multiplied by the level of impact of the outcome. In the framework, the probability component of risk is managed by establishing increasingly stringent management actions and lower tolerances for preventable decline as the stock moves from the Healthy zone, through the Cautious zone towards the Critical zone. The impact component is managed through the use of reference points" (DFO 2009a). Uncertainty itself may take the form of scientific or implementation uncertainty (DFO 2009a), and the minimum function of the Upper Stock Reference (USR) point is in fact to guide the management of the risk of the stock approaching the Limit Reference Point (LRP); for this purpose it must take the role of an operational control point (OCP). Like other jurisdictions such as NAFO's PAF (2004), the USR as buffer should become more conservative with increasing uncertainty: "The greater the uncertainty about the degree to which the LRP actually reflects a condition associated with serious harm, the further away the USR should be set from the LRP" (DFO 2009a). DFO (2016a) identified six types of uncertainty that should be considered when estimating reference points: process, observation, model, estimation, implementation and institutional uncertainties. Decision tables can be used to represent uncertainty (with various models as columns, and management options as rows). The "appropriate risk" to consider when using a PA framework is defined as the "probability of and the severity of the impact from management actions on stock productivity," and management decisions "should be explicit about the risk of decline associated with a management action" (DFO 2009a). The PA Policy describes this risk for management as being the tolerance for stock declines and the changing severity of specified management actions with stock status (to date incorporated into the west coast's Sablefish MSE and Yelloweye Rockfish Rebuilding Plan, in development). A draft table of risk tolerance designations is presented in Annex 2b, to be partnered with the risk tolerances per stock

	status zone in Table 1 of Annex 1b (see section below on Evaluating Performance). Note that the source of the risk categories is not cited. ● Very high: >95% ● High: 75-95% ● Moderately High: 50-75% ● Neutral: ~50% ● Moderate: 25-50% ● Low: 5-25% ● Very Low: < 5% DFO (2016a) clarified that while scientists describe risk functions, managers select risk tolerances. Risks should be evaluated with management strategy evaluation if possible, but otherwise, decision tables were recommended to enable managers to select desired risk tolerances. Managers should select risk tolerance for approaching the LRP that scientists then use to calculate the USR.
Australia	The Australian HS Policy “establishes a risk-based management approach to developing and implementing harvest strategies in Commonwealth fisheries—that is, more caution is used when uncertainty about stock status increases” (DAWR 2018a). ***Risk*** is to be expressed in two ways, “both an unacceptable risk of recruitment impairment at the stock level and the risk that objectives for both the stock and the fishery will not be achieved (noting the limit reference point cannot be breached)” (DAWR 2018a). The associated policy guidance (DAWR 2018b) indicates that the first way of expressing risk is interpreted as the biological risk, or the risk of breaching the LRP and exposing the stock to an unacceptable risk of recruitment impairment, while the second way is the economic risk, or the risk of not achieving MEY (DAWR 2018b). Neither of these risks can be traded away; the trade-off comes from balancing investment in developing a harvest strategy and the benefits derived from it. Australia’s HS Policy guidance also highlights the importance of maintaining ***risk equivalency*** amongst stocks, and provides guidance for possible use of tiers to assist with this maintenance (DAWR 2018b). Risk equivalency can be defined as the adjustment of harvest advice in concert with increasing uncertainty in a given fishery, such that the harvest advice maintains roughly the same risk (e.g., of breaching the limit reference point) regardless of stock. “In some multi-stock and TAC-managed fisheries globally, assessment and harvest strategy approaches have been placed in tiers that roughly move from data rich to more data limited approaches (Dichmont et al. 2016). In many of these fisheries,

	buffers have been used to offset assessment uncertainty. In this context, buffers take the form of the gap between the assessment or harvest strategy produced recommended management control (for example, RBC) and the final management decision (for example, the TAC). After simulation tests for the SESSF (Fulton et al. 2016), the work of Dowling et al. (2014) on tier systems, and the international tier review (Dichmont et al. 2016), it is recommended that, if tier systems are to be applied, they be based in the first instance on the quantities that can be estimated (such as fishing mortality and biomass) and then on the level of uncertainty in the estimate of that quantity. Appropriate buffers can be used to maintain risk equivalency between tiers."
ICES	***Uncertainty*** is incorporated into the precautionary reference point B_{pa} and its alternates (MSY $B_{escapement}$ and MSY $B_{trigger}$). B_{pa} serves as a safety margin, representing a biomass reference point with low probability of being below B_{lim} (ICES 2018a)**.** For Category 3-6 stocks, with an absence of population estimates, advice is couched under the precautionary approach (as information becomes increasingly limited, more conservative reference points are used and a larger margin of precaution). ● A change limit of +/- 20% is applied in the advice to reference values (e.g., recent average catches), because more noise is anticipated in these values for data-poor stocks. ● Reference points for exploitation (when proxies are available) are on the lower margins of F_{MSY} (e.g., lower range, $F_{0.1}$) ● A *precautionary buffer* or *precautionary margin* of -20% is applied where it is likely that $F > F_{MSY}$ or when stock status is unknown (and re-evaluated every three years); exceptions apply when expert judgement determines that the stock is not reproductively impaired, and the stock size is increasing or exploitation has been reduced. ***Risk tolerances***, while a management prerogative, may be applied as a series of default values; however, these do not appear to be clearly articulated as percentage numbers except in the context of management strategy evaluations (see section on Fisheries Management Objectives, Appendix 4).
NAFO	Buffer reference points are to be set taking into account the uncertainty associated with the stock assessment (more uncertainty, larger buffers; NAFO 2004a). It is the responsibility of the Fisheries Commission (i.e., managers) to specify acceptable levels of risk, e.g., in the calculation of safety margins delineated by F_{buf} and B_{buf}, or in setting security margins

	where risk analyses by the Scientific Council are not possible (NAFO 2004a). In the PAF, provisional risk tolerances for management strategies and courses of action are often linked to references to “low” or “very low” probability, and tentative definitions of those are given as ● Low probability = 20% ● Very low probability 5-10% More information on provisional risk tolerances for decision-making is in Appendix 4 (Fisheries Management Objectives).
New Zealand	Like Australia, the HS Standard recognizes that “targets and limits should be set more conservatively for stocks with lower levels of information or higher levels of uncertainty, due to the higher risks associated with managing such fisheries on a long-term basis to provide for utilisation while ensuring sustainability” (MF 2008). The document further recognizes that data-rich stocks are not necessarily information-rich and this issue will be stock-specific. In its public reporting website (MF 2019a), but not in its operational guidance, New Zealand identifies categories of uncertainty as follows: ● > 99% = Virtually Certain ● > 90% = Very Likely ● > 60% = Likely ● 40 - 60% = About as Likely as Not ● < 40% = Unlikely ● < 10% = Very Unlikely ● < 1% = Exceptionally Unlikely These categories were adapted from IPCC (2007): ● > 99% = Virtually Certain ● >95% = Extremely Likely ● > 90% = Very Likely ● > 66% = Likely ● > 50% = More Likely than Not ● 33 - 66% = About as Likely as Not ● < 33% = Unlikely ● < 10% = Very Unlikely ● < 5% = Extremely Unlikely ● < 1% = Exceptionally Unlikely More information on provisional risk tolerances for decision-making is in Appendix 4 (Fisheries Management Objectives).
United	Two kinds of ***uncertainty*** are recognized by the NS Guidelines (NOAA

States	2018a): ● ***Scientific****:* relating to the stock and its reference points (MFMT, MSST, biomass, OFL), time lags in updating assessments, retrospective revisions, projections, choice of model, longer-term effects of the ecosystem or environment, calculation of rebuilding times, etc. ● ***Management****:* relating to the ability of managers to constrain catch so that ACL is not exceeded, and uncertainty in true catch amounts due to late reporting, misreporting, underreporting, etc. ACT control rules articulate how management uncertainty is accounted for in setting the ACT. NOAA's NS Guidelines recognize that there is a level of uncertainty associated with estimates of MSY, B_{MSY} and F_{MSY}, whether they are estimated directly or with the use of proxies. The degree of uncertainty should be estimated when practicable and this should be taken into account when specifying the allowable biological catch (ABC) control rule (NOAA 2018a)**.** Each Council will have its own risk policy that should address uncertainty such that there is a low risk of breaching limits. Uncertainty plays a role in how far optimal yields are set from maximum sustainable yields, for example. OY can be set close to MSY when there is high certainty that biomass is measured accurately and that management controls accurately limit catch; as certainty decreases, OY should be set at increasing distance from MSY. Acceptable biological catches (ABCs) should be based on a control rule that accounts for scientific uncertainty in the estimate of OFL among other things, and the Council's risk policy (e.g., a 50% probability that the ABC will not result in overfishing; NOAA 2018a). In technical guidelines, Restrepo and others (1998) highlighted the role that increased uncertainty plays in setting targets and limits, in a way that remains consistent with the most recent National Standard Guidelines. "Another common element in the application of the precautionary approach to fisheries management worldwide is the specification of "targets" that are safely below limits. Setting OY at its limit (MSY in the *Magnuson-Stevens Act*) would not normally be precautionary because there could be a high probability of exceeding the limit year after year. Under the precautionary approach, the target should be set below the limit taking uncertainty and other management objectives into consideration." When developing the OY (or target) control rule as distinct from the MSY (or limit) control rule, the technical guidelines suggested two ways in

	which risk could be accounted for: a decision-theoretical approach, minimizing risk quantified as expected losses, or a frequentist approach, setting risk tolerances for violating limits to a desired quantity. Restrepo and others (1998) recommended default risk tolerances of exceeding limits of no greater than 20-30% and “certainly smaller than 50%.” More information on provisional risk tolerances for decision-making is in Appendix 4 (Fisheries Management Objectives).

Appendix 8 – ENVIRONMENTAL AND ECOSYSTEM CONDITIONS

Canada (national)	Canada's Sustainable Fisheries Framework, an overarching policy framework which includes the PA Policy, "forms a foundation for implementing an ***ecosystem approach*** in the management of its fisheries" (DFO 2009e). Canada's PA Policy (DFO 2009a) notes that stocks below the LRP may result in impacts to the ecosystem, including other species, but does not specifically describe or require ecosystem or environmental conditions being reflected in reference points or in evaluating harvest strategies. It does state that "the application of the harvest decision rules in a fishery may need to be tempered to limit effects on other stocks. Management actions related to other ecosystem elements may also be considered when using the decision-making framework based on available information" (DFO 2009a). In technical guidelines (DFO 2016a), it was stated that there are two major classes of ecosystem considerations to take into account, and that other guidance exists for bycatch and habitat impacts: 1. Ensuring sustainability of fishery impacts on non-target species 2. Accounting for impacts of the environment on stock productivity A policy framework for addressing community-level impacts of fishing did not exist at the time of the writing of the technical guidelines, which stated that such a policy would be needed before guidelines on the application of precaution could be developed (DFO 2016a). In terms of harvesting forage fish, the needs of predators should be taken into account and trophodynamic models have an important role in estimating average levels of predation and natural mortality for use in reference points. However, such models are not robust at guiding adjustment of reference points annually, and "it is usually more tractable to address predator needs through a robust harvest decision rule rather than through modelling the predator-prey relationships dynamically" (DFO 2016a). International guidance on harvesting top predators is much more limited, but there is a common concern that not all species can be simultaneously harvested at each stock's F_{MSY}. Concerns for Canada were considered theoretical, however, as most species in foodwebs are not harvested (DFO 2016a). Environmental effects on recruitment, growth and natural mortality can be represented by extra variables and parameters in models, stock-recruitment relationships, and management strategy evaluations (DFO 2016a). Adjusting or revisiting reference points based on functional relationships

	to the environmental conditions facing the stock, however, is likely to be pose challenges as functional relationships are unlikely to be smooth or continuous and relationships may be vulnerable to outliers or error. A more robust alternative would be to account for environmental considerations in the harvest decision rules, not the reference points. Special cases identified for these scenarios included when an environmental impact on recruitment is infrequent but large (i.e., has a low miss rate) and when regime change has been documented. In such cases demonstrable environmental change coupled with a mechanistic understanding of impacts on stocks could be a trigger for re-evaluation (DFO 2016a).
Australia	Agency application of Australia's HS Policy "applies an ***ecosystem-based*** fisheries management approach—that is, it manages the effects of fishing on the broader marine ecosystem. Harvest strategies consider the relationship the species has with others in the food web and the marine environment. This may require a stock or group of stocks to be managed more conservatively" (DAWR 2018a). Operationally, this is supported by spatial and temporal approaches to fisheries management. "Consistent with ecosystem-based fisheries management and the need to consider a fish stock across its full distribution, the impact of any relevant Commonwealth or state marine reserve on the likely abundance and distribution of the stock should be considered when developing harvest strategies for fisheries" (DAWR 2018a). Consideration of a species' role in the ecosystem in setting biomass limit and target reference points, however, is only specifically highlighted in the HS Policy for threatened species. The potential impact of environmental conditions on B_0 is discussed in the implementation guidelines for the HSP, including conditions that represent short-term inter-annual variability, medium-term regime shifts and long-term directional climate change (DAWR 2018b). The guidelines state that environmental conditions can affect the establishment of limit and target reference points, estimates of B_0, rebuilding targets and timeframes, spatial and temporal management measures and "companion species" (community-level or non-target impacts). Monitoring programs affect the ability to detect change, and simulation testing can be used to determine whether significant change may be detected (DAWR 2018b). The guidelines acknowledge that regime shift and changing reference points are less frequently performed in harvest strategy design. While updating proxy reference points has been suggested as an approach, this may be complicated by difficulties with reliable reference point

	estimation. However, the guidelines conclude that reference points will "need to be adjusted" if environmental factors change over the medium- and long-term, assuming that the harvest strategy has only been designed to accommodate inter-annual variation. Modifying harvest strategies to account for undemonstrated environmental change should be avoided; weight-of-evidence approaches supported with monitoring data should be applied to evaluate functional relationships between stock dynamics and environmental variables (DAWR 2018b). Regime shifts should be evaluated against four or more criteria: 1. Observed changes in a stock productivity indicator 2. Confidence in observed data 3. Confidence in life history knowledge 4. Theoretical explanations of how changes are linked to the environment
ICES	ICES Advice Basis (2018a) states that achieving environmental objectives is outside the purview of its MSY-centered approach to providing harvest advice: "Limitations on fisheries may be required to achieve environmental objectives, especially regarding biodiversity, habitat integrity, and foodwebs. This will not affect the catch that can be taken from a stock in accordance with the objectives of MSY and the precautionary approach and will therefore not affect ICES advice on fishing possibilities. However, the limitations may affect the possibilities for the fisheries to fully utilize the advised fishing possibilities. ICES may, if requested, advise on the likely impact of such limitations on the catch but will, as explained, not include such considerations in the advice on fishing opportunities." Environmental conditions are to be taken into consideration when developing reference points. For long-lived category 1 and 2 stocks, ICES calculates F_{MSY} "as the fishing mortality with a given fishing pattern and current environmental conditions that gives the long-term maximum yield" (ICES 2018a). B_{MSY} is not estimated as it "is a notional value around which stock size fluctuates when fishing at F_{MSY}. B_{MSY} strongly depends on the interactions between the fish stock and the environment it lives in, including biological interactions between different species. Historical stock size trends may not be informative about B_{MSY} (e.g. when F has exceeded F_{MSY} for many years or when current ecosystem conditions and spatial stock structure are, or could be, substantially different from those in the past)" (ICES 2018a).

	In providing advice for short-lived category 1 and 2 stocks, ICES (2017) considers that “there can be a large yearly variation in natural mortality because it is largely caused by predation and environmental conditions, by highly-variable recruitment, and by a low age at first capture. … The size of a short-lived fish stock is very sensitive to recruitment because of the few age groups in the natural population.” Elsewhere, ICES (n.d.) also highlights support for an ***ecosystem approach*** to fisheries management via reference points that consider environmental conditions. “Advice on fishing opportunities uses rules, with associated reference points, that reflect policy objectives. The ecosystem approach is integrated into the reference points, which are based on the current state of the ecosystem and updated to reflect any effects of the ecosystem on stock dynamics. Where appropriate, such as with forage fish or cannibalistic fish, estimates of the temporal variation of natural mortality are built into the stock assessments to consider the implications for fish for top predators or density effects on stock dynamics.”
NAFO	NAFO’s (2004a) PAF notes that “Although the proposed PA Framework is focused on ***single species***, ensuring that no individual species is fished harder than the single-species F_{MSY} has frequently been suggested as a first step towards satisfying several important and common ecosystem objectives.” No specific considerations are described regarding the integration of environmental or ecosystem considerations into the application of the PAF.
New Zealand	New Zealand’s HS Standard, like similar policies in other jurisdictions, is “focused on ***single species*** biological considerations and related uncertainties, and includes only limited consideration of economic, social, cultural or ecosystem issues. Although it will form a core basis for the Ministry’s advice to the Minister, other considerations such as environmental principles (section 9) and economic, social, and cultural factors also play a role in the advice to, and decisions by, the Minister” (MF 2008). Nonetheless, New Zealand’s *Fisheries Act* requires that the Minister set total allowable catches that enable stocks below levels capable of producing MSY to be restored to such levels within an appropriate time period “having regard to the biological characteristics of the stock and any environmental conditions affecting the stock.”

	Environmental conditions are therefore explicitly taken into account by the HS Standard when it comes to specifying rates of rebuilding which must take "due account of relevant biological and environmental factors" and permits "flexible rebuilding timeframes" (MF 2008; MF 2011). This is because T_{min}, used to establish baseline potential rebuilding rates in the absence of fishing, is calculated using three considerations: species biology, extent of depletion and the prevailing environmental conditions. Calculations of MSY and therefore any reference points derived from MSY should also take into account prevailing environmental factors affecting the stock. According to the HS Standard, "Maximum sustainable yield is defined in the *Act* as 'the greatest yield that can be achieved over time while maintaining the stock's productive capacity, having regard to the population dynamics of the stock and any environmental factors that influence the stock'" (MF 2008). The HS Standard also explicitly uses the term ***depleted*** instead of ***overfished*** "because stocks can become depleted through a combination of overfishing and environmental factors, and it is usually impossible to separate the two" (MF 2008).
United States	Ecosystem and environmental effects are identified as a key source of scientific uncertainty in the National Standard Guidelines (NOAA 2018a). The National Standard Guidelines further differentiate between short-term and long-term environmental changes with respect to their impacts on setting status determination criteria (SDC), which are types of reference points. Short-term environmental changes, but not long-term ones, can affect stock size without impacting the long-term reproductive potential of the stock. In the event of long-term environmental changes impacting stock reproductive potential, SDCs must be re-specified**,** which may or may not result in reductions to fishing mortality. If man-made environmental changes are partially responsible, Councils should also recommend habitat restoration (NOAA 2018a). Like SDC, MSY is defined as "the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological, environmental conditions and fishery technological characteristics (*e.g.,* gear selectivity), and the distribution of catch among fleets" and should be re-estimated as required under conditions of long-term ecosystem change (NOAA 2018a). If environmental changes cause the stock to drop below its MSST but do not affect its long-term reproductive potential, fishing mortality must be constrained sufficiently to allow rebuilding within an acceptable time

	frame (NOAA 2018a). If the long-term reproductive potential is affected, status determination criteria may need to be re-specified, and fishing mortality may or may not have to be reduced, depending on the stock status in relation to the new criteria (NOAA 2018a). As a special consideration, Restrepo and others (1998) noted that fish stocks undergo natural fluctuations in recruitment that are often linked to environmental factors. They noted that it was important to classify impacts on recruitment as short, medium or long-term and to account for recruitment uncertainty in rebuilding plans. In a recently developed national Stock Assessment Improvement Plan, Lynch and others (2018) recognized that there are stocks in which the addition of ecosystem and/or socioeconomic information may significantly improve accuracy and precision of stock assessments; however, such factors should not be forced into assessments without clear evidence supporting their inclusion. Terms of reference were recommended to be included nationally to ensure attention was paid to ecosystem and socioeconomic considerations.

Appendix 9 - REBUILDING STOCKS

Canada (national)	Table 1 of the PA Policy presents an array of generalized management actions to apply a PA decision-making framework to ***key harvested*** fish stocks (DFO 2009a), and some of these actions speak to rebuilding. For stocks determined to be below a status-based upper stock reference point (USR; i.e., determined to be in the Cautious Zone), it is recommended that harvest rates should progressively decrease from the established limit harvest rate and management measures should promote stock rebuilding to the Healthy Zone. For stocks in the Critical Zone (below the limit reference point or LRP), however, policy language is more prescriptive and the policy emphasis is that conservation considerations should prevail and "management actions cannot be inconsistent with ***secure recovery***." However, the meaning of "secure recovery" is not prescribed. The harvest rate strategy indicates that harvests are to be kept to an absolute minimum; later, the table also describes this as "removal from all sources must be kept to the ***lowest possible level*** until the stock has cleared the Critical Zone" (DFO 2009a). "Management actions must promote stock growth (there should be no tolerance for preventable decline)." A ***rebuilding plan*** must be in place for stocks below the LRP, with the aim of having a high probability of the stock growing out of the Critical Zone within a ***reasonable timeframe*** (i.e., provisionally 1.5—2 generations; DFO 2009a, 2013b). The plan, the policy states, also must include monitoring and assessment of stock status to confirm rebuilding, additional restrictions on catches, and somewhat confusingly, "a provision that application of the measures is mandatory if the evaluation fails to find clear evidence that rebuilding is occurring" (DFO 2009a). The latter stipulation suggests that application of the rebuilding measures is not mandatory under the PA Policy. According to the PA Policy, rebuilding plan development, should be initiated while the stock is in the Cautious Zone (or enough in advance such that the plan is ready to come into effect as the stock breaches the LRP). DFO's 2013 rebuilding plan guidelines distinguish between short and long-term objectives, and clarify that the primary short-term objective of any rebuilding plan is to "promote stock growth out of the Critical Zone (i.e., grow the stock beyond the LRP) by ensuring removals from all fishing sources are kept to the lowest possible level until the stock has cleared this zone. There should be no tolerance for preventable decline.

	This objective remains the same whether the stock is declining, stable or increasing (DFO 2013b). Long-term objectives (which occur outside the lifespan of the rebuilding plan) including growing the stock into the Healthy Zone, taking into account the USR and/or the TRP. More information about short-term objectives is given as follows: **“*Milestones*** may provide a valuable tool in achieving the short-term rebuilding objective. These are specific and measurable targets that represent interim “steps” that can be achieved as the stock grows through and out of the Critical Zone. Milestones may be based on such characteristics as positive stock trajectory, biomass targets, restoration (or progress towards restoration) of desirable stock and/or ecological characteristics, and fishing mortality reductions. Milestones may be achievable over relatively short timeframes (e.g. 3-5 years) when compared to the overall period required to grow the stock above the LRP, and can provide a valuable and measurable indicator to ensure rebuilding is on track as determined through performance reviews (Section 11.0). Indeed, the development of milestones plays a dual role; the process will also assist in determining what indicators can be tracked to measure plan performance. “Short-term objectives, as well as the milestones established to reach them, should be defined to explicitly consider three components: a target, which is preferably quantifiable where possible (e.g. specified biomass goal); a desired time to reach the target (e.g. specified number of years/generations); and an acceptable probability level for reaching the target within the specified timeframe.” (DFO 2013b) Regarding ***timelines*** for rebuilding, the 2013 rebuilding guidelines state the following: “As outlined in the PA Framework, rebuilding plans 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. Ideally, a reasonable timeframe 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. “In some cases, however, the rebuilding of a stock above the LRP may only be possible over a longer timeframe (i.e. greater than 1.5-2

	generations). This would include situations where life history characteristics of the stock in question reduce potential growth rates, when current productivity regimes are not favourable for stock growth, or for stocks that are so severely depleted that growth above the LRP would only be possible over many generations. Recent experience suggests that often there are numerous factors leading to the decline of stocks and the specific causes may not be fully understood. Such uncertainty (see Section 7.7) may influence rebuilding timelines. "Flexibility in setting rebuilding timeframes may also be desirable from a socioeconomic perspective (Section 6.0), as it may be desirable to trade-off the pace of rebuilding in favour of a management approach that results in slower yet positive stock growth with fewer socioeconomic impacts. However, in such circumstances, conservation considerations (e.g. positive stock trajectory) must still remain the primary goal in setting timelines." (DFO 2013b)
Australia	If a stock managed solely by the Australian authorities is *overfished* (below its limit reference point), the HS Policy indicates that "immediate action is required to cease overfishing and rebuild overfished stocks to levels that ensure both long-term sustainability and productivity" (DAWR 2018a). For such stocks, "AFMA must cease targeted fishing and develop a ***rebuilding strategy*** to rebuild the stock above its limit reference point" with a reasonable level of certainty (i.e., a 75% probability the stock is at or above the limit in the most recent assessment; DAWR 2018a, 2018b). ***Overfishing*** is defined as a rate of removals that is likely to result in the stock becoming overfished, or that will prevent overfished stocks from recovering in accordance with its rebuilding strategy (DAWR 2018a). Rebuilding timeframes should be defined within the range of T_{min} and 2* T_{min}, with T_{min} being the time to rebuild in the absence of any commercial fishing in a Commonwealth-managed fishery (or in data-poor stocks, the lesser of either the average age of a reproductively mature animal in an unexploited population [mean generation time] plus 10 years, or three times the mean generation time; DAWR 2018b). Other types of fishing (e.g., recreational) are not mentioned. Longer timeframes may be justifiable after assessing the costs and benefits of alternative recovery trajectories.
ICES	Little specific information on rebuilding is presented in the ICES Advice Basis document (ICES 2018a). The capacity to rebuild stocks is built into general harvest strategy design in ICES, as in many precautionary approach frameworks in other jurisdictions. MSY $B_{trigger}$ is used as an operational control point in the

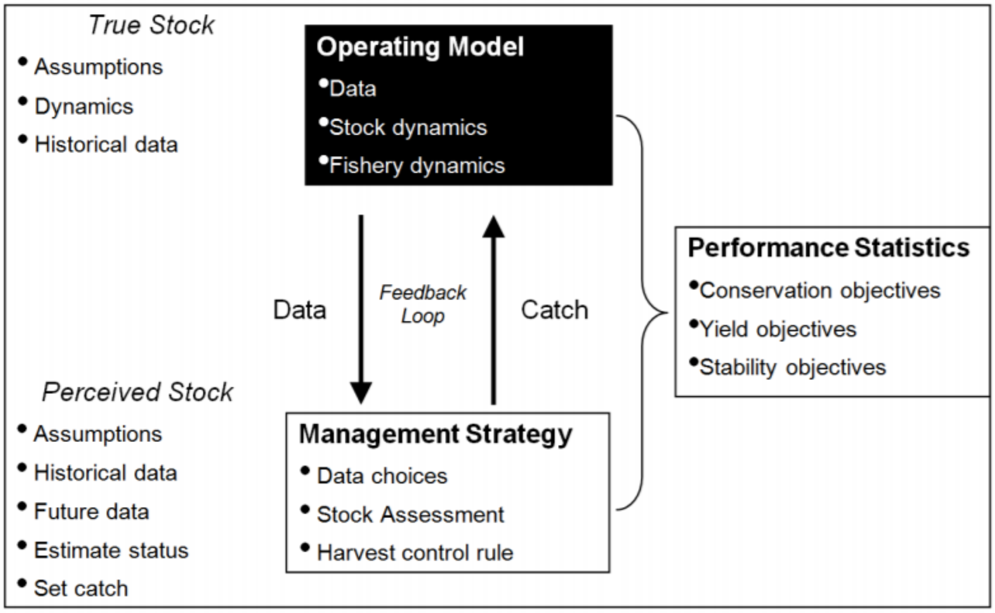
	MSY advice rule initiating a "cautious response", that is, "to reduce fishing mortality to allow a stock to rebuild to levels capable of producing MSY. The reduction in fishing mortality is proportional to the ratio between the size of the spawning–stock and MSY $B_{trigger}$" (ICES 2018a). When the MSY advice rule is applied to long-lived Category 1 and 2 (i.e., data-rich) stocks, if the F from the rule is insufficient to bring a stock above B_{lim} in the short term, advice will be based on bringing SSB > B_{lim} in the short term (including advice of zero catch). The duration of "short term" is not defined. For increasingly data-poor stocks (Categories 3-6), advice is based on available information on catch, landings, etc., and if catches decline significantly over a period of time in a manner that reflects possible reduction in stock size, advice of reduced or zero catch may result.
NAFO	Little information specific to rebuilding is included in NAFO's PAF (2004a). The management strategies and courses of action for Zone 5 (Collapse Zone), when B < B_{lim} regardless of F, indicate that "F should be set as close to zero as possible." Among the roles of the Commission is also to "Specify ***time horizons*** for stock rebuilding and for fishing mortality adjustments to ensure stock recovery and/or avoid stock collapse" (NAFO 2004a). While NAFO has established a working group of fishery Managers and Scientists on Conservation Plans and Rebuilding Strategies (WGFMS-CPRS; NAFO 2019b), no operational guidelines from this group appear to be available at this time.
New Zealand	The HS Standard states that it interprets section 13 of the *Fisheries Act* as a requirement "to maintain stocks at or above a level that can produce the maximum sustainable yield and to rebuild stocks that are below this level, consistent with the purpose of the *Act* of providing for utilisation while ensuring sustainability (section 8)" (MF 2008). A rebuilding plan "consists of the rebuild ***target***, the expected ***timeframe*** for rebuilding and a minimum acceptable ***probability*** of achieving the rebuild, together with a set of management actions that will achieve the desired rebuild….The minimum standard for a rebuilding plan is that 70% of the projected trajectories will result in the achievement of a target based on MSY-compatible reference points or better within the timeframe of T_{min} to 2* T_{min}. This equates to a probability of 70% that the stock will be above the target level at the end of the timeframe" but this probability should be increased where information is highly uncertain or multiple fisheries sectors have significant interests in the fishery (MF 2011).

	According to the HS Standard, stocks require a rebuilding plan when the probability that the stock is below the soft limit is greater than 50%. Stocks should be rebuilt back to at least the target level in a time frame between T_{min} and 2* T_{min}, with an acceptable probability, where T_{min} represents the theoretical time in years for the stock to rebuild to a target in the absence of fishing and is a function of the species biology, extent of depletion, and prevailing environmental conditions. Stocks are considered to be fully rebuilt when there is at least a 70% probability that the target has been achieved and there is at least a 50% probability that the stock is above the soft limit [sic] (MF 2008), and time frames may reflect social, economic and cultural factors associated with the fishing sectors that use the stock (MF 2011). The HS Standard notes that it does not matter whether stocks become depleted through overfishing, unfavourable environmental conditions, or both, because similar management actions to rebuild stocks are required in each of the situations (New Zealand, 2008). Fisheries that have been closed as a result of breaching the hard limit will not be reopened until it can be shown that there is at least a 70% probability that the stock has rebuilt to or above the soft limit (MF 2011). The minimum standard for a rebuilding plan is that 70% of the projected trajectories will result in the achievement of a target based on MSY-compatible reference points or better within the timeframe of T_{min} to 2* T_{min}. This equates to a probability of 70% that the stock will be above the target level at the end of the timeframe. A stock will not be declared to be rebuilt, and therefore absolved from further rebuilding, until it can be determined that there is at least a 70% probability that the target has been achieved.
United States	The Secretary notifies the Council if it is determined that a stock (or stock complex) is undergoing overfishing, is overfished, is approaching an overfished state or inadequate progress has been made in rebuilding a previously identified overfished stock (or in ending overfishing; NOAA 2018a). In the event of overfishing - Councils must immediately work with its SSC or other source of science advice to ensure that the allowable biological catch (ABC) is set appropriately to end overfishing. For overfished stocks or stock complexes, a ***rebuilding ABC*** must be set to reflect the annual catch limit (ACL) that is consistent with the rebuilding plan schedule of fishing mortality rates. In the event of a stock being overfished, or approaching such a state - Councils have two years

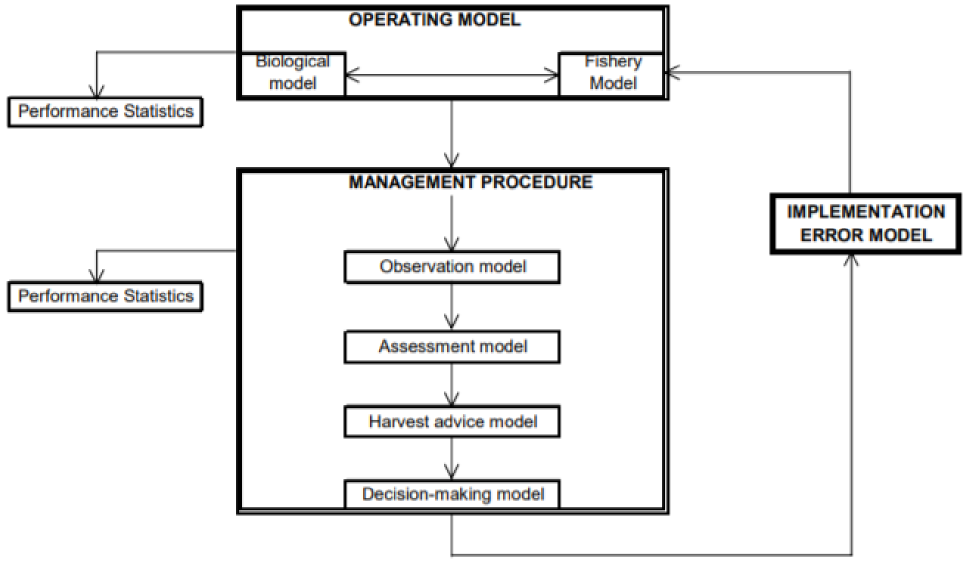
	to develop and implement a Fishery Management Plan (FMP), amend an FMP or propose regulations to address the stock. A time period for rebuilding the stock (***T_{target}***) shall be as short as possible, taking into account the status and biology of the stock, needs of fishing communities, recommendations of international organizations, and interaction of the stock within the marine ecosystem. The time period shall not exceed 10 years, except where stock biology, environmental conditions, or management measures under an international agreement to which the US participates dictates otherwise. T_{target} shall not exceed T_{max}, calculated as follows: ● ***T_{min}*** = the time to rebuild to MSY biomass in absence of any fishing mortality (50% probability of attaining B_{MSY}, where such probabilities can be calculated), starting from the year the rebuilding plan is first implemented. ● ***T_{max}*** = maximum time to rebuild to B_{MSY} ● If T_{min} is 10 years or less, then T_{max} is 10 years ● If T_{min} exceeds 10 years, then T_{max} is either ○ T_{min} plus one generation time (average length of time between an individual being born, and the birth of its offspring) ○ The amount of time the stock is expected to rebuild to B_{MSY} if fished at 0.75*MFMT ○ T_{min} multiplied by 2 If environmental changes cause the stock to drop below its MSST but do not affect its long-term reproductive potential, fishing mortality must be constrained sufficiently to allow rebuilding within an acceptable time frame (NOAA 2018a). If the long-term reproductive potential is affected, status determination criteria may need to be re-specified, and fishing mortality may or may not have to be reduced, depending on the stock status in relation to the new criteria (NOAA 2018a). If a stock or stock complex has not rebuilt by T_{max}, then F should be maintained at $F_{rebuild}$ or 0.75*MFMT (maximum fishing mortality threshold), whichever is less, until the stock is rebuilt or the $F_{rebuild}$ is changed as a result of the Secretary finding that adequate progress is not being made (NOAA 2018a). Restrepo and others (1998) suggested that default rebuilding objectives should be to achieve a 50% or higher probability of achieving B_{MSY} within T_{target} years, and a 90% or higher probablity of achieving B_{MSY} in T_{max} years. They also note that while definitions in the scientific literature for ***generation time*** may vary, a proposed default was based on Goodyear.

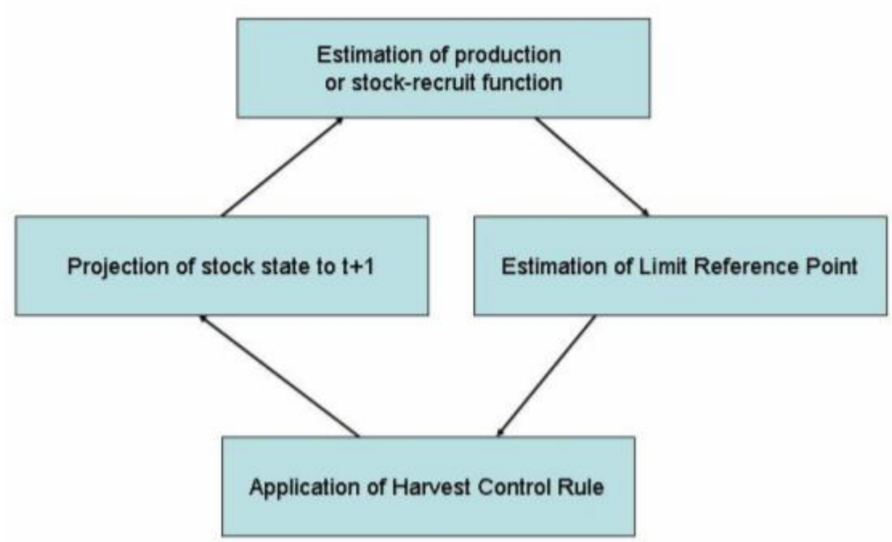
Appendix 10 - PERFORMANCE EVALUATION

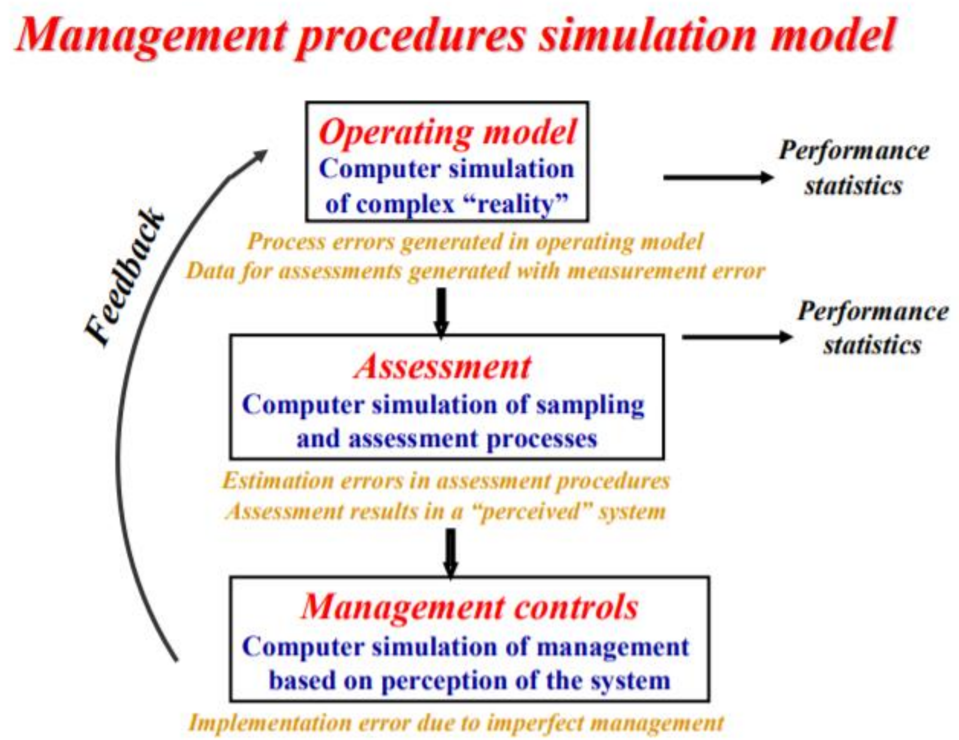
Canada (national)	The Canadian PA Policy is not prescriptive about the formulation of science advice, and so does not specify precisely what is to be used for evaluating harvest strategy performance. Some general recommendations are made in policy, however. For example, “it is desirable that scientific uncertainty be quantified to the extent possible and used to assess the probability of achieving a target or of a stock falling to a certain level under a specific management approach” (DFO 2009a). The recommendations in the PA Policy indicate that whatever their form, the reference points and harvest decision rules “should be explicit enough to allow assessment or evaluation of the performance framework,” which should be considered on a regular basis after there is sufficient experience to conduct a proper (presumably retrospective) evaluation (a time of ***6-10 years*** is suggested, or earlier as required; DFO, 2009a). DFO (2016a) noted that although the PA Policy does not require evaluation, HCRs should be evaluated quantitatively, and preferably with simulation testing. Default or generic HCRs should be also be evaluated, possibly over sets of similar species. ***Management strategy evaluation (MSE)*** was identified as an option for evaluation of potential harvest strategies, but was noted to be resource-intensive in its full consultative form. An “MSE-light” approach could be taken for stocks with generic rules tested, instead of custom options, as a way to accelerate the discussion process. In supporting documentation for DFO (2016a), Kronlund and others (2014b) expanded upon MSE practices (Figure A2). In data-poor situations, “the determination of stock status may rely on ***expert opinion***” (DFO 2016a).

	 ***Figure A2****: A schematic of management strategy evaluation, from Kronlund et al. (2014b, fig. 1).*
Australia	The Australian HS Policy requires technical evaluation of harvest strategies. Harvest strategies "will be formally tested to assess whether they are highly likely to meet the objective of this policy," (DAWR 2018a) and such results should be made publicly available. Recognizing that the HSP outlines formal testing as a requirement, Australia's implementation guidelines cover evaluation in more detail. "Where appropriate, ***management strategy evaluation (MSE)*** or other similar methods "should" be used to develop new or updated harvest strategies to ensure that such strategies have a high probability of achieving policy objectives before they are implemented (DAWR 2018b). The guidelines note that MSE may not be feasible for all stocks due to cost reasons or data deficiency, in which case alternative methods such as risk-based evaluation methods may also be used; these however should be calibrated against more quantitative methods. Despite these constraints, Penney et al. (2013) noted that "most harvest strategies" in Australia have been evaluated through MSE to ensure <10% risk of breaching limits. Regarding avoidance of the limit reference point, the technical guidance specifies that the "90% risk criterion" should be interpreted in evaluation as a 1-in-10 year risk that stocks fall below B_{lim}, not that there is a 90% probability that the stock is above the LRP in each and every year (DAWR 2018b). This interpretation is thus in contrast to ICES, which employs an "each year" approach (ICES 2018a). A similar explanation

	for a corresponding criterion meeting the objective concerning MEY is not given, however, which creates a vagary in policy interpretation. A time period of ***five years*** is established for harvest strategy review, to be shortened in the event of: new information, marked changes in fishery activity or in stock drivers, change in stock status (e.g., below limits) poor performance, etc. (DAWR 2018b). Faster reviews may also be triggered for harvest strategies implemented without formal testing or MSE, or where such evaluation failed to take into account all adequate risks or develop appropriate indicators for use in establishing HCRs. Apart from the use of expert judgement to determine whether stocks are considered key commercial, byproduct or bycatch, ***expert opinion*** was identified as a possible appropriate means by which to identify “sustainable and profitable catch levels or effort controls” for small fisheries, where costs of collecting data may be quite high (DAWR 2018b).
ICES	ICES’ Advice Basis (ICES 2018a) indicates that ***management strategy evaluation (MSE)*** is used to evaluate multiannual plans: “Before using a plan/strategy as basis for the advice, ICES evaluates them relative to their compliance with a precautionary approach regarding risks to maintenance of reproductive capacity, and according to the likelihood that high yields will be produced in the long term. The evaluations also address issues raised by stakeholders and authorities that are contained in a specific management plan, such as stability of yield and risks under specific recruitment regimes.” Plans are evaluated against specific objectives (Fisheries Management Objectives section above) for short- and long-lived stocks (ICES 2018a). To facilitate the completion and communication of MSEs, ICES provides a ***summary template***, to be completed by analysts, to describe the harvest control rule (HCR) and other aspects of the simulation (ICES 2016). Extensive supplementary information on MSE is also available from a Study Group on Management Strategies (ICES 2006), including a section on Standards for Simulation; however, for the purposes of this review the Study Group report was not considered formal guidance for ICES. For comparative purposes with other jurisdictions, however, the MSE framework is presented below (Figure A3).

	 ***Figure A3:*** *A framework for conducting management strategy simulations, reproduced from ICES 2006 (fig. 7.1).* For increasingly data-poor stocks (Category 3-6), ICES Advice Basis (2018a) notes that ***expert judgement*** may be used to determine whether the stock is reproductively impaired, as well as qualitative indicators to describe trends in stock abundance or exploitation rates.
NAFO	Little information specific to the evaluation of performance is given in NAFO's PAF (2004a). There is reference to being able to conduct a "risk analysis" around current and projected biomass or fishing mortality levels; in normal operational considerations the biomass probability distribution would be evaluated against B_{lim} (and same for F). If the probability distribution cannot be calculated, B would be compared against B_{buf} (or F to F_{buf}). The Study Group (SG) on reference points repeatedly noted the importance of ***simulation testing***. In one discussion, it was noted that "applying LRPs that have not been evaluated, either empirically or through simulation analysis, cannot be defended scientifically" (NAFO 2004b). In another, "the SG considered that it was highly desirable to evaluate LRPs and other reference points such as target and buffer reference points, through simulations in which the reference points are linked with HCRs. Such simulations need to take into account uncertainty in estimates of the LRP and in the state of the stock" (NAFO 2004b). A diagram was used to illustrate the proper steps of simulation (Figure A4).

	 ***Figure A4:*** *A diagram of simulation steps, reproduced from NAFO 2004b (Fig. 3.8.5.1).*
New Zealand	The HS Standard does not explicitly state that evaluation is required, but highlights ***management strategy evaluation (MSE)*** as a tool which has gained "international prominence" in recent years, is compatible with the Standard and has been applied to a small number of New Zealand fisheries (MF 2008). MSE is defined as "the process of evaluating alternative management strategies against one or more operating models (simulation models of the real world)" and is deemed "fully compatible" with the HS Standard (MF 2008). The potential role of evaluation is also highlighted elsewhere, e.g., to support the designation of reference points such as soft limits that are lower than recommended defaults (MF 2008). Operational guidelines for the HS Standard went somewhat further in clarifying that "the outcome of an MSE is a TAC that may or may not incorporate MSY-based reference points for a stock; however, this does not necessarily mean that the [MSE] approach is inconsistent or incompatible with the proposed Harvest Strategy Standard. The Harvest Strategy Standard does not constrain MSEs from being adopted" (MF 2011). The process of MSE was illustrated in the guidelines as follows (Figure A5):

	 ***Figure A5:*** *A diagram illustrating the process of management strategy evaluation, reproduced from MF 2011 (Fig. A4).* If multiple models are used, the guidelines recommend choosing a single "base case" or use an overall weighted average to calculate current estimated biomass (MF 2011). In the absence of the quantitative ability to estimate the probability that the current or projected biomass is above or below either the hard or soft limits, ***expert judgement*** may be used (alone or in combination with other methods; MF 2011).
United States	The National Standard Guidelines make few references regarding technical evaluations, beyond noting that some analysis or assessment for key harvest strategy components is essential. For example, optimum yield (OY) ***specification analysis*** is a mandatory component of Fishery Management Plans (FMPs). The assessment of OY included in the FMP should include: "a summary of information utilized in making such specification; an explanation of how the OY specification will produce the greatest benefits to the nation and prevent overfishing and rebuild overfished stocks; and a consideration of the economic, social, and ecological factors relevant to the management of a particular stock, stock complex, or fishery" and should also be reviewed on a continuing basis (NOAA 2018a).

	Councils must also: • provide an analysis of how the status determination criteria (SDC) were chosen for the stock, and explain how they relate to reproductive potential (NOAA 2018a). • establish an ABC control rule "that accounts for scientific uncertainty in the OFL and for the Council's risk policy, and that is based on a comprehensive analysis that shows how the control rule prevents overfishing" (NOAA 2018a) Restrepo and others (1998), in their technical guidelines, propose a general ***simulation framework*** for testing harvest strategies as cohesive collections of data collection, assessment and management measures. The general technique involves simulating a "true" fishery system, observations with error ("perceived" fishery system), and then simulating assessment with the observations. Key to this process are: identifying performance criteria, and understanding tradeoffs between conflicting objectives. Simulation frameworks could be used for several purposes: • to determine how far apart targets (e.g., the OY control rule consistent with the National Standards of the time) need to be set from limits (e.g., the MSY control rule) to achieve management objectives. • To evaluate the benefits from reduced uncertainty (i.e., increased access to scientific information enhancing precision of stock abundance estimates) • To facilitate discussions among managers, scientists, users and the public about tradeoffs and harvest strategy performance as a whole Simulations were used to evaluate the proposed default target (OY control rule) of 75% of *F* at the MSY control rule using a simple deterministic model. The guidelines indicate that simulation tools "could be used" to investigate various issues, but do not indicate that such evaluation is required for each stock. "No single policy can fully address all of the considerations to be encountered in the wide variety of fisheries subject to the [law]" (Restrepo et al. 1998). Restrepo and others (1998) also note that "Determination of the status of biomass relative to B_{MSY} preferably involves quantitative analysis, but in data-poor cases, applicable analytic methods may not be particularly sophisticated and include a variety of stock assessment methods … In

	cases of severe data limitations, qualitative approaches may be necessary, including ***expert opinion and consensus-building methods***."

Appendix 11 – REPORTING OF STATUS

Canada (national)

As noted earlier, public reporting of Canada’s fish stocks is performed through the annual Sustainability Survey for Fisheries (DFO 2018c), currently updated as of 2017. Data available since the 2015 Survey are published online.

The primary reported performance metric for Canada’s key harvested stocks on the Survey is that of ***current stock status*** (i.e., one of four options or zones, Critical, Cautious, Healthy or Uncertain; status is determined in relation to stock status reference points, the LRP and USR; Figure A6).

Fish stocks reported on by the survey: 2017 results

Filter items | Showing 1 to 10 of 179 entries | Show 10 entries

Fish stock	DFO Region	Current status zone for stock
Albacore tuna - North Pacific	Pacific	Healthy Zone
American lobster - LFA 3-14c	Newfoundland and Labrador	Uncertain
American plaice - Southern Gulf of St. Lawrence (4T)	Gulf	Critical Zone
Arctic char - Cambridge Bay	Central and Arctic	Healthy Zone
Arctic char - Cumberland Sound	Central and Arctic	Uncertain
Atlantic Canada dogfish - 4VWNX - 5	Maritimes	Uncertain

Figure A6: *Website visualization of stock status on Canada's Sustainability Survey for Fisheries (DFO 2018c).*

Additional information is reported on the presence/absence of reference points (LRP, USR, RR), rebuilding plans and harvest decision rules, and interactions of stocks with species covered by other Canadian fisheries policies. These include interactions with Species at Risk, and the measures in place associated with retained and released bycatch species (Figure A7).

Precautionary Approach Policy

The results show that reference points and harvest control rules of the Precautionary Approach Policy have been put in place for many, but not all, of the 179 stocks. Highlights of the results for this section include:

- of the 179 stocks:
  - 45% (80 of 179) have upper stock references
  - 59% (105 of 179) have limit reference points
  - 65% (117 of 179) have harvest control rules
  - 50% (90 of 179) have removal references for the status zone the stock is currently in
- of the 18 stocks currently classified as in the critical zone:
  - 4 have a stock rebuilding plan
  - another 7 of 18 stocks have rebuilding plans under development
- of the stocks classified as uncertain:
  - 3 are at levels such that serious harm is likely
  - 19 are at levels such that serious harm is possible

Some of the questions in this section are used to report on indicators in the Canadian Environmental Sustainability Indicators report.

Figure A7: *Website depiction of summary statistics for stock status on Canada's Sustainability Survey for Fisheries (DFO 2018c).*

<table>
<tr>
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<td>The complete details of the Sustainability Survey are available for public download (DFO 2018c), and include more specific information pertaining to management measures, management plans, and scientific information related to reference points and stock status including the processes by which values were generated (peer review, expert judgement, etc.).</td>
</tr>
<tr>
<td>Australia</td>
<td>
The ongoing performance of harvest strategies against its objectives must also be assessed and publicly reported (DAWR 2018b).
As noted earlier, public reporting on Australian fisheries is done via the Status of Australian Fish Stocks Reports website (FRDC 2018).
The website links to a search engine (the Report) to locate information on individual stocks, or to permit browsing over all stocks. Current stock status is defined as one of seven options: Sustainable, Recovering, Depleting, Overfished, Environmentally Limited, Undefined, and Negligible. The thumbnail version of each stock gives the name of the species (common and taxonomic), name of the stock, status with a corresponding colour code, and catch where available (Figure A8).

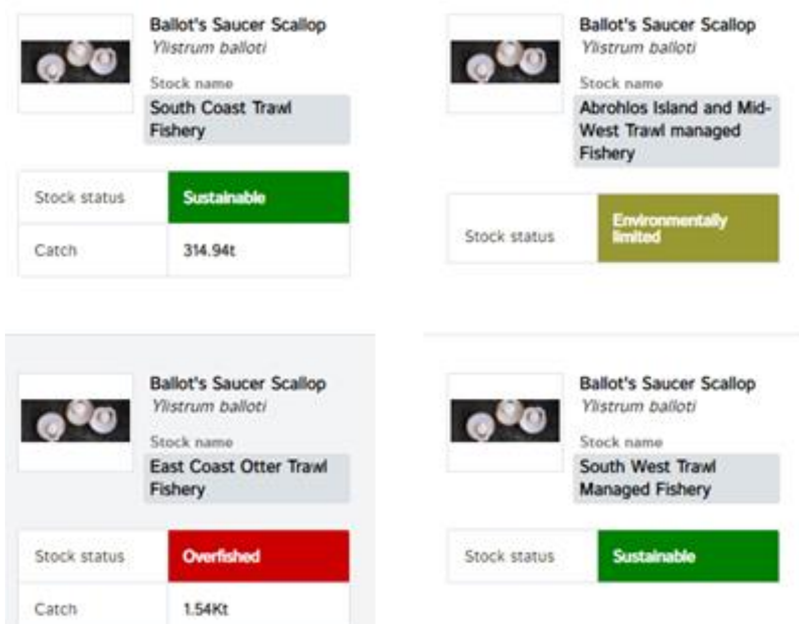

Figure A8: View of the Status of Australian Fish Stocks Reports website (FRDC 2018).
</td>
</tr>
</table>

Data Visualization

Clicking on a particular stock profile leads to a much more detailed, highly visual and interactive website (not PDF) reflecting the most up to date science advice that specifies, among other things: the names of the stock assessors, the status of all stocks of that species and the rationale for those assignments in drop-down sections, interactions with the environment, and an interactive distribution map, navigable tables of fishing gear used and interactive graphics showing catch patterns. Archived stock assessment information from previous years is also provided as links. An example is shown below (Figure A9):

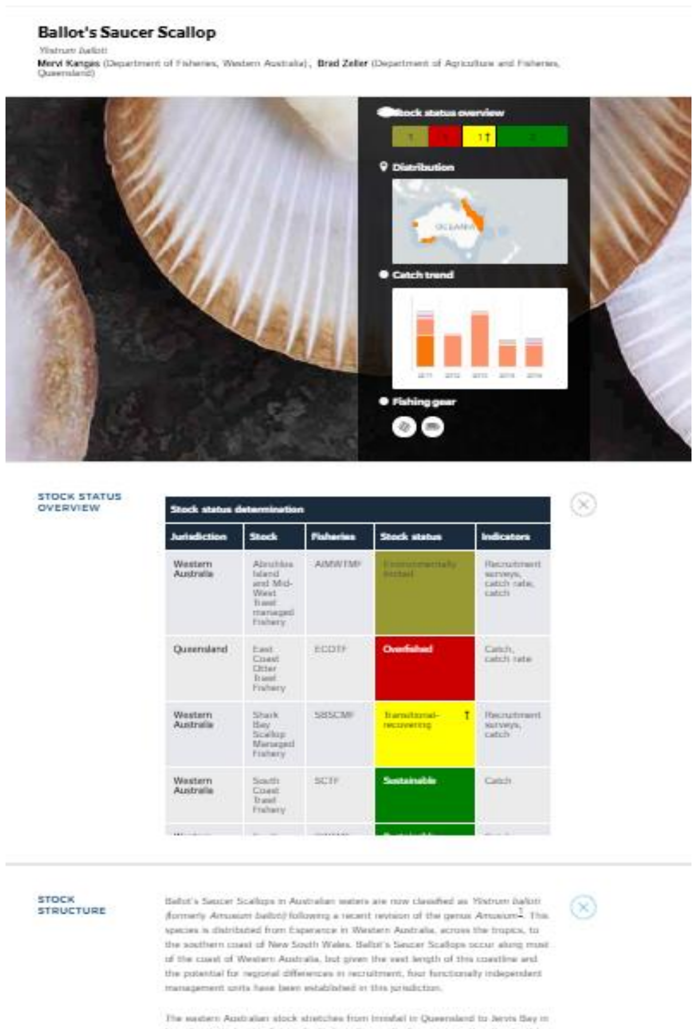

Figure A9: *Example of stock profile from the Status of Australian Fish Stocks Reports website (FRDC 2018).*

Public Performance Metrics

According to the Stock Status Classification System section of the website (available at http://fish.gov.au/Overview/Introduction/Stock-status-classification-system), in order to classify stocks into one of seven categories, the current stock abundance and level of fishing pressure are compared with limit reference points as follows (taken from Table 1 of the website):

Sustainable	*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*
Transitional - Recovering	*Recovering stock—biomass is recruitment overfished, but management measures are in place to promote stock recovery, and recovery is occurring*
Transitional - depleting	*Deteriorating stock—biomass is not yet recruitment overfished, but fishing pressure is too high and moving the stock in the direction of becoming recruitment overfished*
Overfished	*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*
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*
Undefined	*Not enough information exists to determine stock status*

<table>
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<table>
<tr><td>Negligible</td><td>Stocks do not form part of a cross jurisdictional biological stock, catches are so low as to be considered negligible and inadequate information exists to determine stock status</td></tr>
</table>

The relationship between the primary stock status assignments, in relation to the status of the stock considering both types of reference points (F and B-based) is illustrated below (Figure A10):

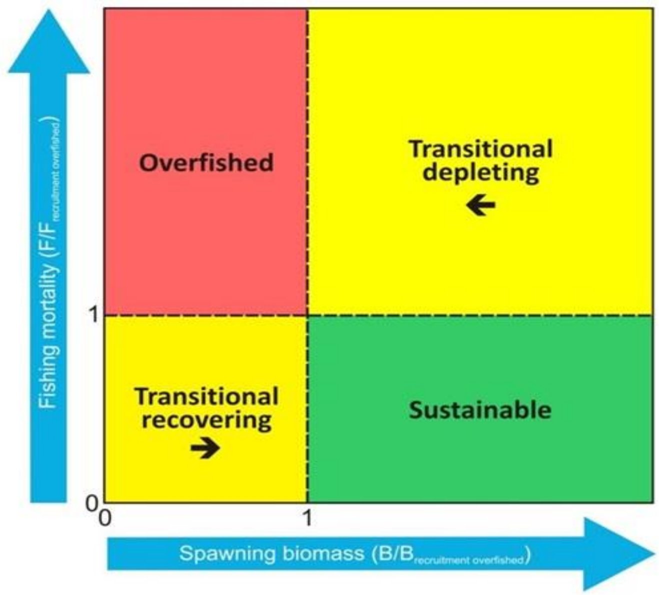


Figure A10: Stock status assignment diagram from the Status of Australian Fish Stocks Reports website (reproduced from FRDC 2018; Fig. 4).

This figure notably does not include environmentally limited stocks (excluded because they “are not below the limit reference point as a result of fishing pressure”), nor does it include undefined or negligible stocks.

<u>Communicating Uncertainty</u>

Uncertainty does not appear to be explicitly taken into account in reporting, nor is it clear how, or whether, it is used in assigning stock status. Rationales for assigning stock status are given in narrative form.
</td>
</tr>
<tr>
<td>ICES</td>
<td>As noted earlier, public information on the science advice produced by ICES is disseminated through the Latest Advice website (ICES 2019).</td>
</tr>
</table>

	Data Visualization Stock advice is given in individual documents, which include graphs of catch, SSB, recruitment, *F*, etc., over time (when available), summary tables of reference point estimates and decision tables at a range of exploitation rates (when available), and a reporting of stock status using icons to indicate the stock and fishery is above/below reference points (e.g., Atlantic Mackerel in 2017; Figure A11). Public Performance Metrics In the ICES Advice Basis document (2018a), a series of pictograms are outlined that are used to visually demonstrate stock status in relation to both fishing pressure (*F*, *F* proxy, *F*/ F_{MSY} or harvest rate) and stock size (SSB, total biomass, *B*/B_{MSY} or abundance/biomass indices; ICES 2018a, Figure A12). The pictograms use both a "traffic light" colour system, and commonly used symbols (checks and Xs) to denote stocks that "pass" or do not "pass" implied stock status performance thresholds.

Stock and exploitation status

Table 1 Mackerel in subareas 1–8 and 14, and in Division 9.a. State of the stock and fishery relative to reference points.

	Fishing pressure					Stock size				
		2014	2015	2016			2015	2016	2017	
Maximum sustainable yield	F_{MSY}	✖	✖	✖	Above	MSY $B_{trigger}$	✔	✔	✔	Above trigger
Precautionary approach	F_{pa},F_{lim}	✔	✔	✔	Harvested sustainably	B_{pa},B_{lim}	✔	✔	✔	Full reproductive capacity
Management plan	F_{MGT}	–	–	–	Not applicable	B_{MGT}	–	–	–	Not applicable

Figure A11: *Example of stock status summary for Atlantic mackerel (reproduced from ICES 2019).*

Table 1.2.1 Pictograms used by ICES to represent the evaluation of the stock status.

Status relative to reference points	Qualitative evaluation	Description
✔	✔	Desirable situation, e.g. fishing pressure is below the relevant reference point or stock size is above the relevant reference point.
o		Status lies between the precautionary (PA) and limit (lim) reference points.
✖	✖	Undesirable situation, e.g. fishing pressure is above the relevant reference point or stock size is below the relevant reference point.
?		Status of the stock is either **Unknown** when neither quantitative assessment nor proxy calculation exist, or **Undefined** when there is an analytical assessment but reference points are undefined.
	↗	Absolute level unknown, but increasing.
	→	Absolute level unknown, but unchanged.
	↘	Absolute level unknown, but decreasing.

Figure A12: *Pictograms used to succinctly communicate stock status, reproduced from ICES (2018a, Table 1.2.1).*

Because of ICES's role in providing advice to clients who may or may not have an established management plan, reporting of stock status is separated by reference points related to the "ICES advice rule reference points" (whether MSY rule, MSY $B_{trigger}$ or proxies; or precautionary approach; B_{pa}, B_{lim} or proxies), and those relative to an existing management plan (which may include Bmgmt targets, limits or triggers).

Communicating Uncertainty

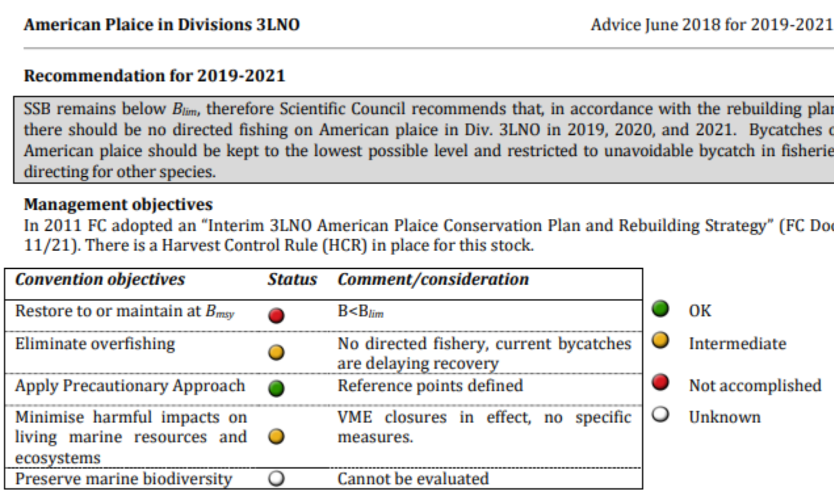
Different symbols are used to denote qualitative versus quantitative evaluations of stock status, the former presumably implying greater uncertainty.

NAFO

Public information on NAFO fisheries in terms of science advice is disseminated through the Stocks Advice website (NAFO 2019c). Public reporting is integrated with the stock advice, and not summarized separately.

Public Performance Metrics

An example of the science advice provided as individual PDFs for a stock is as follows (Figure A13):



American Plaice in Divisions 3LNO Advice June 2018 for 2019-2021

Recommendation for 2019-2021

SSB remains below B_{lim}, therefore Scientific Council recommends that, in accordance with the rebuilding plan, there should be no directed fishing on American plaice in Div. 3LNO in 2019, 2020, and 2021. Bycatches of American plaice should be kept to the lowest possible level and restricted to unavoidable bycatch in fisheries directing for other species.

Management objectives

In 2011 FC adopted an "Interim 3LNO American Plaice Conservation Plan and Rebuilding Strategy" (FC Doc. 11/21). There is a Harvest Control Rule (HCR) in place for this stock.

Convention objectives	*Status*	*Comment/consideration*
Restore to or maintain at B_{msy}	●	$B<B_{lim}$
Eliminate overfishing	●	No directed fishery, current bycatches are delaying recovery
Apply Precautionary Approach	●	Reference points defined
Minimise harmful impacts on living marine resources and ecosystems	●	VME closures in effect, no specific measures.
Preserve marine biodiversity	○	Cannot be evaluated

● OK
● Intermediate
● Not accomplished
○ Unknown

Figure A13: *Example of stock status summary information from NAFO (2019c).*

Here, a simple table is provided for each stock objective, along with a "traffic light" system of colour-coded status indicators, as well as a brief comment explaining the indicator in light of the objective. There is no systematic reporting of stock status against reference points as the reporting requirements of each stock are tailored to the data available for that stocks. There is also no systematic reporting of stocks by zones 1 through 5 in the PA framework.

New Zealand

Public reporting on fisheries performance is achieved through the Fish Stock Status website (MF 2019a) which contains graphics, short descriptions, and links to PDFs and other web pages that show a complete list of both ***main fish stocks*** and their most recent status, as well as a list of all ***nominal fish stocks*** that are of less significance.

Information is provided on the QMS, catches and allowances, and the reference points (target, soft limit and hard limit). ***Sustainability*** appears to be evaluated by stock performance against the soft limit "The soft limit is an important performance measure as it can show potential sustainability issues." Further links are provided to the annual plenary reports (e.g., Fisheries New Zealand, 2018) completed by Fisheries Assessment Working Group meetings that are convened every year, as well as the Harvest Strategy Standard that is used to guide how stock assessments are conducted.

If F_{MSY} or the appropriate proxy is exceeded on average (3-5 year running average), ***overfishing*** will be deemed to be occurring. A stock that is determined to be below the soft limit is termed ***depleted*** and in need of rebuilding. A stock that is determined to be below the hard limit is termed ***collapsed*** (MF 2008).

<u>Data Visualization</u>

New Zealand's public-facing website employs a range of text-focused and graphics-focused content. High-level summary materials are displayed in a simple visual manner as shown below (Figure A14):

Figure A14: *Example of infographics used to summarize stock status across fisheries, reproduced from MF (2019a). Available from 2017-Status-of-New-Zealands-Fish-Stocks-overview-v2.pdf.*

The illustration and meaning of the three reference points employed by the New Zealand are also shown in simple graphical form on the main website (Figure A15):

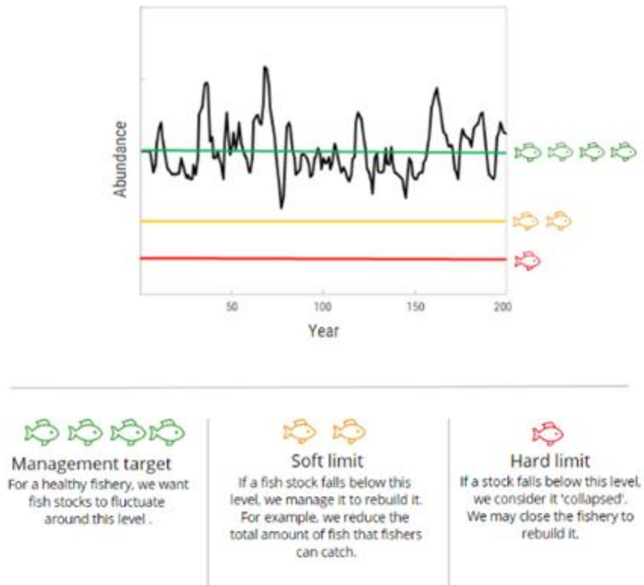


Figure A15: *Illustration of the three reference points employed in the HS Standard, reproduced from MF (2019a).*

Actual stock statuses are reported in a large PDF table (Figure A16):

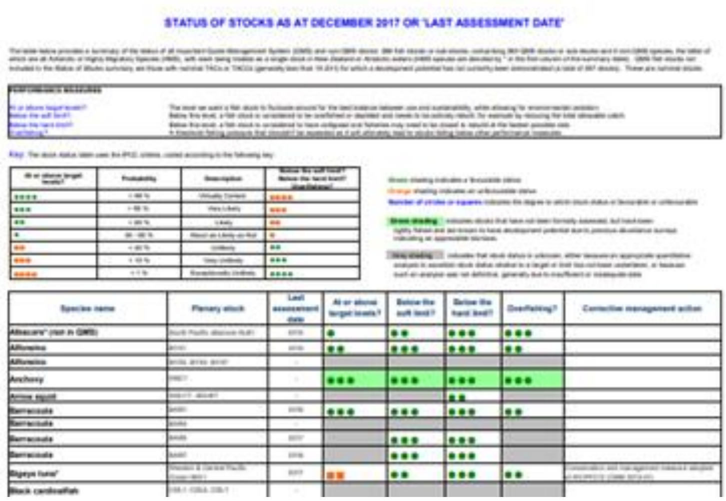

STATUS OF STOCKS AS AT DECEMBER 2017 OR 'LAST ASSESSMENT DATE'

Figure A16: *Example view of full stock status information, stock by stock, reproduced from MF (2019a). Available from Stock-Status-Table-Dec-2017-with-symbols.pdf.*

Public Performance Metrics

New Zealand reports stock status against four performance metrics: whether the stock is at or above target levels, below the soft limit, below the hard limit, and whether it is subject to overfishing (Figure A17).

PERFORMANCE MEASURES	
At or above target levels?	The level we want a fish stock to fluctuate around for the best balance between use and sustainability, while allowing for environmental variation.
Below the soft limit?	Below this level, a fish stock is considered to be overfished or depleted and needs to be actively rebuilt, for example by reducing the total allowable catch.
Below the hard limit?	Below this level, a fish stock is considered to have collapsed and fisheries may need to be closed to rebuild at the fastest possible rate.
Overfishing?	A threshold fishing pressure that shouldn't be exceeded as it will ultimately lead to stocks falling below other performance measures.

Figure A17: *Performance metrics used to assign stock status, reproduced from MF (2019a). Available from Stock-Status-Table-Dec-2017-with-symbols.pdf.*

Communicating Uncertainty

As is shown below, performance is scored using green circles (positive indicators) or orange squares (negative indicators), with the number of either circles or squares being used to denote the certainty of the stock status (threshold probability values of 40-60%, 60%, 90% and 99%). Stocks with unknown status are conveyed by grey rows with no circles or squares (Figure A18).

Key: The stock status table uses the IPCC criteria, coded according to the following key:

At or above target levels?	Probability	Description	Below the soft limit? Below the hard limit? Overfishing?
●●●●	> 99 %	Virtually Certain	■■■■
●●●	> 90 %	Very Likely	■■■
●●	> 60 %	Likely	■■
●	40 - 60 %	About as Likely as Not	■
■■	< 40 %	Unlikely	●●
■■■	< 10 %	Very Unlikely	●●●
■■■■	< 1 %	Exceptionally Unlikely	●●●●

Green shading indicates a favourable status
Orange shading indicates an unfavourable status
Number of circles or squares indicates the degree to which stock status is favourable or unfavourable

Green shading indicates stocks that have not been formally assessed, but have been lightly fished and are known to have development potential due to previous abundance surveys indicating an appreciable biomass.

Grey shading indicates that stock status is unknown, either because an appropriate quantitative analysis to ascertain stock status relative to a target or limit has not been undertaken, or because such an analysis was not definitive, generally due to insufficient or inadequate data.

Species name	Plenary stock	Last assessment date	At or above target levels?	Below the soft limit?	Below the hard limit?	Overfishing?	Corrective management action
Albacore* (not in QMS)	South Pacific albacore ALB1	2015	●	●●	●●●	●●●	-
Alfonsino	BYX1	2010	●●	●●●	●●●	●●	-
Alfonsino	BYX2, BYX3, BYX7	-					-
Anchovy	ANC1	-	●●●	●●●	●●●	●●●	-

Figure A18*: Close-up example view of full stock status information, stock by stock, reproduced from MF (2019a). Available from Stock-Status-Table-Dec-2017-with-symbols.pdf.*

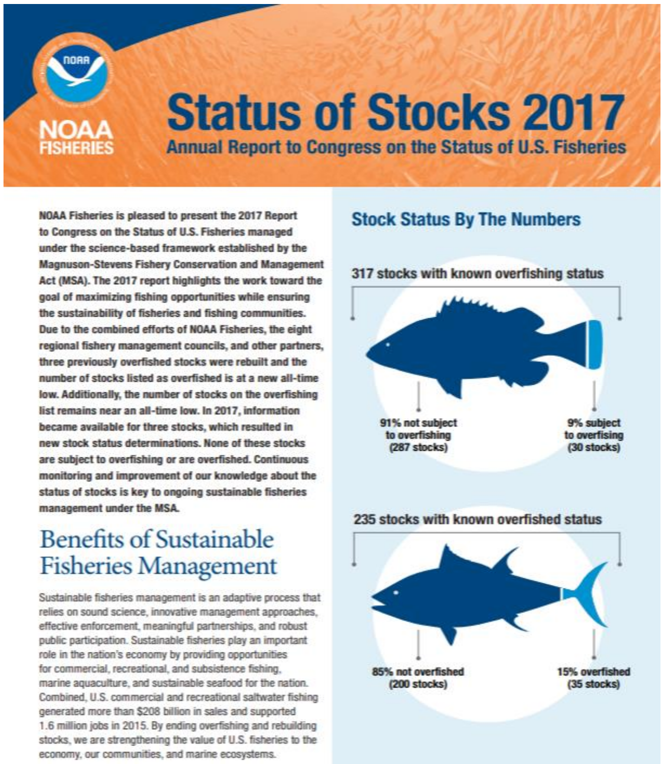
United States

According to NOAA's NS Guidelines, status determination criteria must be measurable and objective - enabling the fisheries management council to monitor the status of the stock (NOAA 2018a).

A stock or stock complex is considered ***overfished*** if the biomass is below the minimum stock size threshold (MSST), and to be subjected to ***overfishing*** if the fishing mortality is above maximum fishing mortality threshold (MFMT) or the catch exceeds the overfishing limit (OFL). The stock or stock complex is ***approaching an overfished condition*** if there is a more than 50% chance the biomass will decline below the MSST in two years (NOAA 2018a).

Councils should specify which method (MFMT or OFL) is to be used to determine overfishing status, which is usually evaluated over time increments of 1 year. In some circumstances, a multi-year approach may be used (of a duration of no more than 3 years); this may be appropriate when there is high uncertainty in *F* calculations of the most recent year, or cases where stock abundance fluctuations are high or assessments not timely enough to make forecasts.

As noted above, public information on fisheries is disseminated on the Status of U.S. Fisheries website (NOAA 2018b), with information reported quarterly (NOAA 2018c) and summarized annually in a report to congress (e.g., the 2017 annual report to Congress shown below; Figure A19).


NOAA FISHERIES

Status of Stocks 2017

Annual Report to Congress on the Status of U.S. Fisheries

NOAA Fisheries is pleased to present the 2017 Report to Congress on the Status of U.S. Fisheries managed under the science-based framework established by the Magnuson-Stevens Fishery Conservation and Management Act (MSA). The 2017 report highlights the work toward the goal of maximizing fishing opportunities while ensuring the sustainability of fisheries and fishing communities. Due to the combined efforts of NOAA Fisheries, the eight regional fishery management councils, and other partners, three previously overfished stocks were rebuilt and the number of stocks listed as overfished is at a new all-time low. Additionally, the number of stocks on the overfishing list remains near an all-time low. In 2017, information became available for three stocks, which resulted in new stock status determinations. None of these stocks are subject to overfishing or are overfished. Continuous monitoring and improvement of our knowledge about the status of stocks is key to ongoing sustainable fisheries management under the MSA.

Benefits of Sustainable Fisheries Management

Sustainable fisheries management is an adaptive process that relies on sound science, innovative management approaches, effective enforcement, meaningful partnerships, and robust public participation. Sustainable fisheries play an important role in the nation's economy by providing opportunities for commercial, recreational, and subsistence fishing, marine aquaculture, and sustainable seafood for the nation. Combined, U.S. commercial and recreational saltwater fishing generated more than $208 billion in sales and supported 1.6 million jobs in 2015. By ending overfishing and rebuilding stocks, we are strengthening the value of U.S. fisheries to the economy, our communities, and marine ecosystems.

Stock Status By The Numbers

317 stocks with known overfishing status

91% not subject to overfishing (287 stocks)

9% subject to overfishing (30 stocks)

235 stocks with known overfished status

85% not overfished (200 stocks)

15% overfished (35 stocks)

Figure A19: *The 2017 annual report to Congress, reproduced from NOAA 2019.*

The annual report briefly summarizes information on two kinds of stock status; status in relation to overfishing (fishing mortality), and status in relation to being overfished (biomass). The short, graphics-heavy document does not distinguish among stocks included in the Fish Stock Sustainability Index (FSSI) or non-FSSI stocks, and places a heavy emphasis on reporting both changes in stock status from the previous year, and rebuilding progress (Figure A20):

OVERFISHING LIST	
Removed	**Added**
Sailfish – Western Atlantic[1] Blue king crab – Pribilof Islands Puerto Rico Wrasses Complex Coho salmon – Puget Sound: Hood Canal[1] Winter flounder – Georges Bank Witch flounder – Northwestern Atlantic Coast (now unknown)	Greater amberjack – Gulf of Mexico Red grouper – Southern Atlantic Coast Coho salmon – Puget Sound: Stillaguamish[1] Shortfin mako – North Atlantic[1] Red hake – Southern Georges Bank / Mid-Atlantic Gray triggerfish – Gulf of Mexico
OVERFISHED LIST	
Removed	**Added**
Yelloweye rockfish – Pacific coast Winter flounder – Georges Bank Gray triggerfish – Gulf of Mexico Red snapper – Gulf of Mexico Pacific ocean perch – Pacific Coast Bluefin tuna – Western Atlantic (now unknown)	Red grouper – Southern Atlantic Coast Shortfin mako – North Atlantic[1] Red hake – Southern Georges Bank / Mid-Atlantic
REBUILT LIST	
Bocaccio – Southern Pacific Coast Darkblotched rockfish – Pacific Coast Pacific ocean perch – Pacific Coast	
FIRST TIME STATUS DETERMINATIONS	
Not Subject to Overfishing	**Not Overfished**
Spiny dogfish – Pacific coast St. Croix Wrasses Complex	Golden king crab – Aleutian Islands

[1] This stock is fished by U.S. and international fleets.

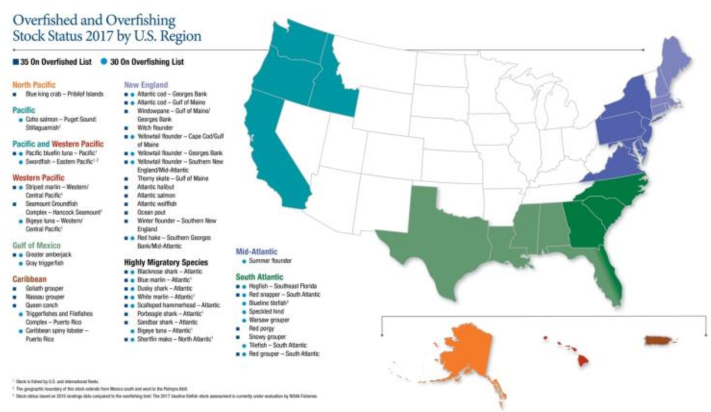


Figure A20: *Inside view of the 2017 annual report to Congress, reproduced from NOAA 2019.*

<u>Data Visualization</u>

Visualizations in quarterly reports focus on maps and stock lists (NOAA 2018c), emphasizing two kinds of stock status and progress in rebuilding (Figure A21):

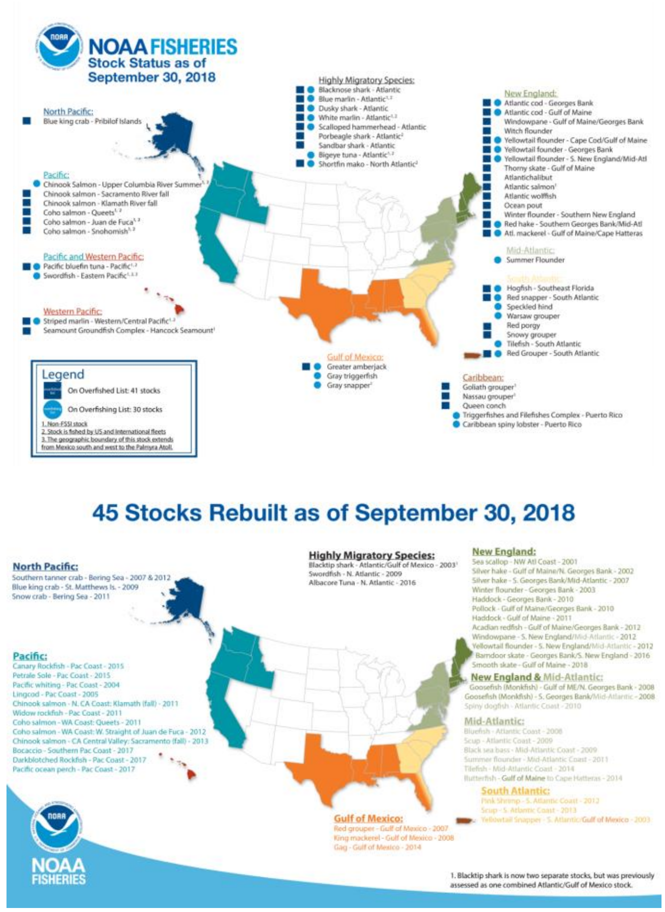


Figure A21: *Example of quarterly report showing stock status and rebuilding progress, reproduced from NOAA 2018c.*

<u>Public Performance Metrics</u>

Quarterly reports focus more on FSSI versus non-FSSI stocks, and also generate the total FSSI score for U.S. fisheries. The FSSI is calculated by assigning each FSSI stock a score (up to 4 points per stock; 1000 points possible; NOAA, 2018b). Higher FSSI scores mean that more stock statuses are known, or statuses have improved.

Weighted criteria points are assigned to each stock as follows:

Criteria	Criteria Points
1. "Overfished" status is known	0.5
2. "Overfishing" status is known.	0.5

3. Overfishing is not occurring (for stocks with known "overfishing" status).	1.0
4. Stock biomass is above the "overfished" level defined for the stock.	1.0
5. Stock biomass is at or above 80% of the biomass that produces maximum sustainable yield (B_{MSY})*	1.0

** Stocks rebuilding from a previously overfished condition are not awarded the fourth point until they reach B_{MSY}, as mandated by the Magnuson-Stevens Act. After they have been fully rebuilt, they may fluctuate within the 80% parameter and retain the score of 4 like the other non-rebuilding stocks. This point is in addition to the point awarded for being above the "overfished" level.*

Sections of the most recently available quarterly update at the time of writing is shown below (NOAA 2018c), emphasizing the FSSI score and stock counts by status (Figure A22):

2018 Quarter 3 Update through September 30, 2018

2018 Quarter 3 Score = 757.5 *(July 1, 2018 to September 30, 2018)*

Overview

The Fish Stock Sustainability Index (FSSI) is a performance measure for the sustainability of 199 U.S. fish stocks[1] selected for their importance to commercial and recreational fisheries. The FSSI will increase as stock status becomes known, overfishing is ended, and stocks increase to the level that provides maximum sustainable yield.

Overview of FSSI stocks through September 30, 2018

Overfishing Status	Number of Stocks	Overfished Status	Number of Stocks
Known Status	180	Known Status	172
Not Subject to Overfishing	158	Not Overfished (includes 1 stock approaching an overfished condition)	142
Subject to Overfishing	22	Overfished	30
Unknown Status	19	Unknown Status	27

Figure A22*: Example of quarterly report showing summarized stock status information, reproduced from NOAA 2018c.*

Quarterly and annual reports also include long tables by stock or stock complex, showing not only stock status but associated information on management actions and rebuilding (NOAA 2018c; Figure A23):

National Marine Fisheries Service - 3rd Quarter 2018 Update
Table A. Summary of Stock Status for FSSI Stocks

Jurisdiction	FMP	Stock	Overfishing? (Is Fishing Mortality above Threshold?)	Overfished? (Is Biomass below Threshold?)	Approaching Overfished	Management Action Required	Rebuilding Program Progress	B/B_{MSY}	Points
CFMC	Queen Conch Resources of Puerto Rico and the United States Virgin Islands	Queen conch - Caribbean	No	Yes	NA	Continue Rebuilding	Year 13 of 15-year plan	<<1	2
CFMC	Reef Fish Fishery of Puerto Rico and the U.S. Virgin Islands	Caribbean Groupers *	No	Unknown	Unknown	NA	NA	not estimated	1.5
CFMC	Reef Fish Fishery of Puerto Rico and the U.S. Virgin Islands	Caribbean Parrotfishes Complex *	No	No	Yes	NA	NA	not estimated	3

***Figure A23**: Example of quarterly report showing information on a stock by stock basis, reproduced from NOAA 2018c.*

The annual report (e.g., NOAA 2019) also includes tables per stock and stock complex with citations to the most recent stock assessment, the last year an assessment or data were available, and precise definitions for each stock when it is to be considered overfished, or overfishing is occurring (with precise values of status determination criteria).

<u>Communicating Uncertainty</u>

There does not appear to be an overt representation of uncertainty around status estimates in the quarterly or annual reports.

Appendix 12 - SUSTAINABILITY CONSIDERATIONS

Canada (national)	The Canadian PA policy is part of the Sustainable Fisheries Framework (SFF) is an umbrella of policies and tools that was introduced by DFO in 2009 following extensive public consultation. The PA Policy provides the basis for ensuring that Canadian fisheries support "***conservation and the sustainable use of resources***" (DFO 2013a, 2018b). The SFF establishes a precautionary approach policy to fisheries science and management and provides a basis for an ecosystem approach to fisheries management. The conservation and sustainable use policies are intended to guide measures to keep fish stocks "healthy" and ensure fisheries remain productive (DFO 2018b). Neither "*sustainability,*" the phrase "*levels necessary to promote sustainability*" found in the revised *Fisheries Act*, nor "*sustainable use*" are unambiguously defined in the text of either the SFF or the PA Policy. Neither have any of those terms been unequivocally equated with "healthy," which is important distinction to make given the characterization of stock status by Critical, Cautious and Healthy zones. Canada has relevant definitions (including for *sustainable use*) located in other related policy and legislative sources, and these are discussed in the main body of the report.
Canada (WSP)	Canada's WSP contains three objectives, one of which is to manage fisheries for ***sustainable benefits*** (DFO 2005a).
Australia	The objective of the Australian HS Policy is "the ***ecologically sustainable and profitable use*** of Australia's commonwealth commercial fisheries resources (where ecological sustainability takes priority) - through implementation of harvest strategies." (DAWR 2018a). Although not included in policy implementation guidelines, public reporting includes the rationale for assigning stock status as one of seven possible options (including "sustainable") is given in the linked website. This framework states that both fish abundance, and fishing pressure, are assessed against the "conceptual reference point of 'recruitment overfished.'" ***Sustainability*** is defined in the reporting framework as: "The status classifications assess whether the current abundance of fish in a stock is sustainable—that is, whether there is a large enough proportion of the original adult stock remaining that the production of juveniles is not significantly reduced." A ***sustainable stock*** is defined as one where the "biomass (or biomass proxy) is at a level sufficient to ensure that, on

<table>
<tr><td></td><td>average, future levels of recruitment are adequate (that is, the stock is not recruitment overfished) and that fishing pressure is adequately controlled to avoid the stock becoming recruitment overfished.”

In essence, it appears as if the “90% risk criterion” or at least B> B_{lim} is met, coupled with an acceptable level of fishing pressure ($F < F_{lim}$), the stock may be classified as “sustainable.”</td></tr>
<tr><td>ICES</td><td>ICES’ Advice Basis states that “ICES advises competent authorities on marine policy and management issues related to the impacts of human activities on marine ecosystems and the sustainable use of living marine resources” (ICES 2018a).

Sustainable use carries long-term implications, that affect the way ICES calculates its advice metrics. For example, “MSY is a long-term average. A management strategy that harvests variable yields in response to the natural variability in stock size will, on average, give yields closer to the long-term MSY than a strategy operating with the maximum constant yield that could be taken sustainably” (ICES 2018a). For increasingly data-poor stocks where the MSY advice rule cannot be applied, ICES applies a precautionary approach with the aim of providing advice as to whether catch levels are sustainable or whether a “reduction in catch is required to achieve sustainability.”

Sustainability also entails avoiding limits. The Advice Basis states, “To ensure that fishing at F_{MSY} is sustainable, F_{MSY} is not allowed to be above F_{pa}. This is appropriate since a precautionary approach is a necessary boundary to ensure sustainability” (ICES 2018a). FP is thus an operational control point.

Finally, ICES uses the term sustainability in performance evaluation and reporting only in the context of fishing mortality, not in terms of stock biomass, and only for stocks with defined PA reference points (ICES 2018a, Figure A24).

<table>
<tr><td rowspan="5">Precautionary approach (F_{PA}, F_{lim})</td><td>$F \leq F_{PA}$</td><td>✔</td><td>Harvested sustainably</td></tr>
<tr><td>$F_{lim} > F > F_{PA}$</td><td>O</td><td>Increased risk</td></tr>
<tr><td>$F \geq F_{lim}$</td><td>✖</td><td>Harvested unsustainably</td></tr>
<tr><td>No reference point [2]</td><td>?</td><td>Undefined</td></tr>
<tr><td>Stock status unknown (even if reference point is defined)</td><td>?</td><td>Unknown</td></tr>
</table>
Figure A24: Use of the term "sustainable" in ICES performance evaluation, reproduced from ICES 2018a, Table 1.2.1.</td></tr>
<tr><td>NAFO</td><td>NAFO’s PAF does not employ the use of the term “sustainable” or</td></tr>
</table>

<table>
<tr><td></td><td>“sustainability” outside of maximum sustainable yield (NAFO 2004a).</td></tr>
<tr><td>New Zealand</td><td>
New Zealand’s HS Standard “establishes a consistent and transparent framework for decision-making to achieve the objective of providing for utilisation of New Zealand’s QMS [Quota Management System] species while ensuring sustainability” (MF 2008).

New Zealand’s operational guidelines illustrate sustainability as a continuum (MF 2011; Figure A25). The guidelines therefore do not set a single metric for what is considered sustainable, but recognize that risks to sustainability occur over a gradient: “Over the long run, utilisation and sustainability act in the same direction for stocks that have been depleted below B_{MSY}. In other words, it is beneficial to maintain stocks near or somewhat above B_{MSY} from both a utilisation and a sustainability perspective. … For relatively small sacrifices in yield, average biomass can be maintained relatively far above B_{MSY} (Appendix II), resulting in reduced sustainability risks.”

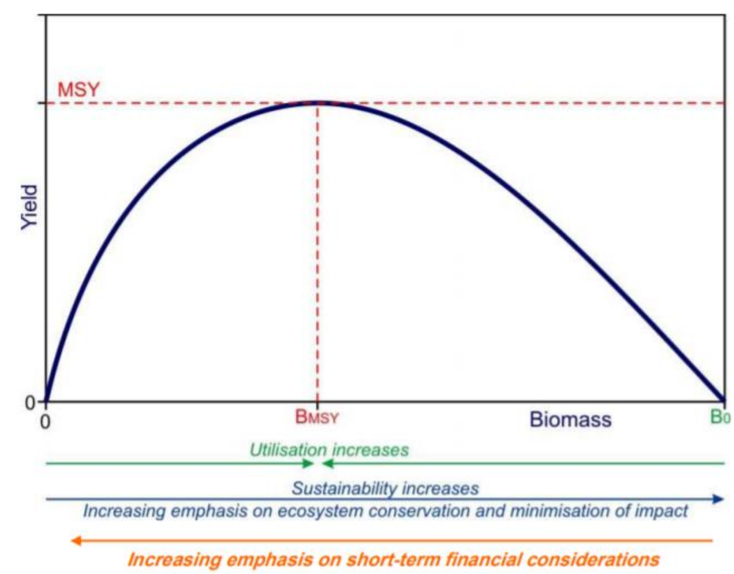


Figure A25: Diagram illustrating concept of sustainability, reproduced from MF (2011, Fig. 1).

The term sustainable is notably not used in New Zealand’s public performance reporting, which instead focuses on four performance metrics (at or above target levels, below soft limit, below hard limit, and overfishing).

The operational guidelines also give these definitions:
</td></tr>
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	“***Sustainability***: Pertains to the ability of a fish stock to persist in the long-term. Because fish populations exhibit natural variability, it is not possible to keep all stock and fishery attributes at a constant level simultaneously, thus sustainable fishing does not imply that the fishery and stock will persist in a constant equilibrium state. Because of natural variability, even if F_{MSY} could be achieved exactly each year, catches and stock biomass will oscillate around their average MSY and B_{MSY} levels, respectively. In a more general sense, sustainability refers to providing for the needs of the present generation while not compromising the ability of future generations to meet theirs. “***Sustainable yield***: the average catch that can be removed from a stock over an indefinite period without causing a further reduction in the biomass of the stock. This could be either a constant yield from year to year, or a yield that fluctuates in response to changes in abundance.” (MF 2011).
United States	As stated above, the NOAA NS Guidelines represent “principles that must be followed in any fishery management plan to ensure sustainable and responsible fishery management” and support national standards mandated by the *Magnuson-Stevens Act* (NOAA 2018a). National Standard 1 of the NS Guidelines does not explicitly define sustainability, nor does it link the term to one of the status determination criteria (SDC) for a stock beyond reference to maximum sustainable yield. The document makes reference to selection of non-MSY proxies for SDC that can be demonstrated to “promote sustainability of the stock” and periodic review of information on stocks within a stock complex to ensure they are “sustainably managed.” According to Restrepo and others (1998), overfished and overfishing are both defined with respect to a stock’s capacity to produce maximum sustainable yield.

Appendix 13- MULTI-SPECIES CONSIDERATIONS

Canada (national)	The Canadian PA policy (DFO 2009a) makes limited references to multi-species fisheries or stocks, or aggregate stocks in general. In terms of interactions among different stocks (multi-species considerations), the Canadian PA Policy states that the application of harvest decision rules may need to be "tempered to limit effects on other stocks" and that management actions "related to other ecosystem elements may also be considered" depending on the available information (DFO 2009a). A subsequent workshop on the PA Policy identified some of the challenges associated with aggregate stocks (e.g., in setting reference points for mixed fisheries), but could not fully address or provide a resolution to the issue (DFO 2016a). In terms of rebuilding, Canada's rebuilding guidelines note that "rebuilding efforts for a depleted stock harvested in a mixed-stock or multispecies fishery may result in reduced fishing opportunities on targeted stocks/species whose populations are healthy. …The challenge of rebuilding stocks in these situations may be tempered by following a management approach that is adaptive and ecosystem-based, which balances the objectives for rebuilding depleted stocks with the maintenance of fishing opportunities directed at healthy stocks." (DFO 2013b)
Australia	The Australian HS Policy, as a second edition, brought more attention to the challenges of developing harvest strategies for multi-species fisheries than the earlier policy could address (DAWR 2018a). More specifically, the revised policy indicated that "managing individual stocks to different target reference points may be necessary to achieve fishery level maximum economic yield" but also that "Sustainable harvesting of all stocks over the long term must still be ensured (avoiding approaching limit reference points)" (DAWR 2018a). The tier system incorporating buffers as a means to aim for risk equivalency in advice is presented as an option for multi-species fisheries in the operational guidance. "In some multi-stock and TAC-managed fisheries globally, assessment and harvest strategy approaches have been placed in tiers that roughly move from data rich to more data limited approaches (Dichmont et al. 2016). In many of these fisheries, buffers have been used to offset assessment uncertainty. In this context, buffers take the form of the gap between the assessment

	or harvest strategy produced recommended management control (for example, RBC) and the final management decision (for example, the TAC). After simulation tests for the SESSF (Fulton et al. 2016), the work of Dowling et al. (2014) on tier systems, and the international tier review (Dichmont et al. 2016), it is recommended that, if tier systems are to be applied, they be based in the first instance on the quantities that can be estimated (such as fishing mortality and biomass) and then on the level of uncertainty in the estimate of that quantity. Appropriate buffers can be used to maintain risk equivalency between tiers." (DAWR 2018b) Identifying a fishery-level maximum economic yield (MEY) for a multi-species fishery presents a number of challenges, and Australia's operational guidance is not prescriptive, but describes a number of considerations for varying levels of analytical complexity (DAWR 2018b).
ICES	According to the Advice Basis, ICES "applies the MSY concept to single stocks as well as to groups of stocks in the context of mixed fisheries, where stocks are caught together in a fishery." ICES has developed a mixed-species model to address concerns that mixed-species fisheries preclude the achievement of single-stock MSY catch advice for all stocks simultaneously (ICES 2018a). ICES' Advice Basis does not provide details regarding how it handles multi-species advice, but Rindorf et al. (2013) has proposed a framework.
NAFO	NAFO's PAF outlines past challenges raised by the Fisheries Commission in applying proposed PA frameworks, including the consideration of multi-species scenarios. In order to address those concerns, the revised and ultimately accepted PAF states: "Although the proposed PA Framework is focused on single species, ensuring that no individual species is fished harder than the single-species F_{MSY} has frequently been suggested as a first step towards satisfying several important and common ecosystem objectives (NRC, 1999; Mace et al. 2001; Sissenwine and Mace, 2003) In addition, two other aspects of multi-species management were considered in the proposed revision of the PA Framework. First, the de-emphasis of B_{MSY} avoids the problem of the impossibility of maintaining all stocks in a multi-species assemblage simultaneously at their respective single-species B_{MSY} levels. Second, by replacing the requirement that fishing mortality be zero when biomass is below B_{lim} with a requirement that fishing mortality to be as close to zero as possible in this situation, there is now

	recognition of the need for a certain amount of flexibility to account for technical interactions that result in unavoidable by-catch of depleted species." (NAFO 2004a)
New Zealand	New Zealand's HS Standard comments on its application to a number of different types of specific cases, but "multi-species" fisheries were not one of them (MF 2008). A few non-prescriptive considerations for multi-species stocks are however incorporated throughout the associated operational guidelines (MF 2011). For example, because multi-species fisheries may not have a single value for a reference point similar to F_{MSY}, "methods have been developed to calculate overall annual "fishing intensity", which can be compared to a reference level in the same metric" and some suggested methods are elaborated upon in further detail. What is not clear, however, is how stocks in multi-species fisheries are evaluated by means of targets, soft and hard limits in public reporting. The reporting notes that "in some cases the assessment unit is smaller than the QMA; thus the number of units for which stock status is assessed does not correspond exactly to QMA stocks", but these stocks do not appear to be clearly flagged (Fish Stock Status website, https://www.mpi.govt.nz/dmsdocument/17653-stock-status-table-for-fish-stocks).
United States	NOAA's *National Standard 1 - Optimum Yield* indicates that stocks may be grouped into complexes for the purposes of conservation and management. This may occur because there are several stocks inextricably part of a multi-species fishery, because two species are so similar they cannot be readily distinguished, or because there are insufficient data on certain stocks. When a stock complex is established, the plan "should provide, to the extent practicable, ***a full and explicit description of the proportional composition of each stock in the stock complex***…Where practicable, the group of stocks should have a similar geographic distribution, life history characteristics, and vulnerabilities to fishing pressure such that the impact of management actions on the stocks is similar" (NOAA 2018a). Complexes are seen as management tools, and thus may have one or more ***indicator stocks* considered representative of the typical vulnerability of the stocks in the complex** with measurable and objective status determination criteria (SDC) and possibly annual catch limits, that can be used to manage and evaluate more data-poor stocks, or have such criteria/limits set for the complex as a whole (NOAA 2018a;

	Berkson et al. 2011). Alternatively, stock complexes may contain: • "Several stocks without an indicator stock (with SDC and an ACL for the complex as a whole), or • "one or more indicator stocks (each of which has SDC and management objectives) with an ACL for the complex as a whole (this situation might be applicable to some salmon species)." The use of indicator stocks does not eliminate the need for consideration of fishing impacts on all stocks in the complex. The NSG1 recommends that "Councils should review the available quantitative or qualitative information (*e.g.,* catch trends, changes in vulnerability, fish health indices, etc.) of stocks within a complex on a regular basis to determine if they are being sustainably managed" (NOAA 2018a). Restrepo and others (1998) noted that unless individual OY levels were specified for each stock in a mixed-stock fishery, the fishery-level OY could be specified in such a way that a few stock components could be overfished. Consequently, reference points and targets should be specified for each stock in a complex where possible, and at minimum, *F* should not exceed MFMT for any individual stock unless excepted by the national standard guidelines. Exceptions to the requirement to prevent overfishing could apply under certain limited circumstances (e.g., harvesting one stock at optimum levels can result in a second species being overharvested as bycatch or part of a multi-species fishery). A Council may decide to allow this overfishing, after considering the overall benefits, and the risk of the stock of concern falling below its MSST (minimum stock size threshold; i.e., if the stock or stock complex is not overfished; NOAA, 2018a).

Appendix 14 - VISUAL TOOLS

Canada (national)

The “traffic light” approach first employed by Canada’s WSP (DFO 2005a) was also used by DFO (2006) in the first official illustration of the accepted national PA framework. The colours emphasize the three stock status zones bounded by the limit reference point (LRP) and upper stock reference (USR), while the use of a second axis allows for the demarcation of the change in removal reference (RR) with stock status as well (Figure A26).

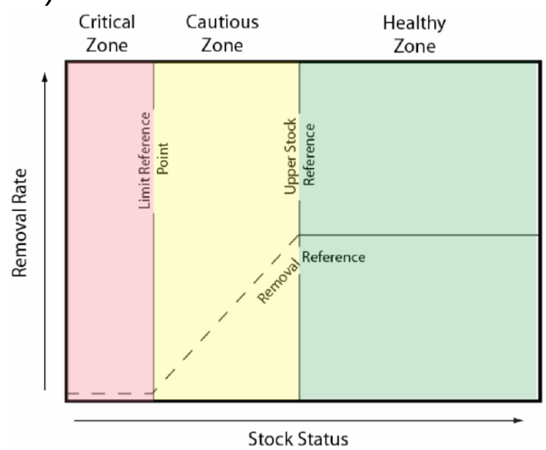


Figure A26: *First illustration of the national PA framework (reproduced from DFO 2006).*

The final policy version of the national PA framework discarded the use of colours present in the science advice document of DFO (2006), and incorporated an optional visualization of an additional reference point, the TRP (DFO 2009a; Figure A27).

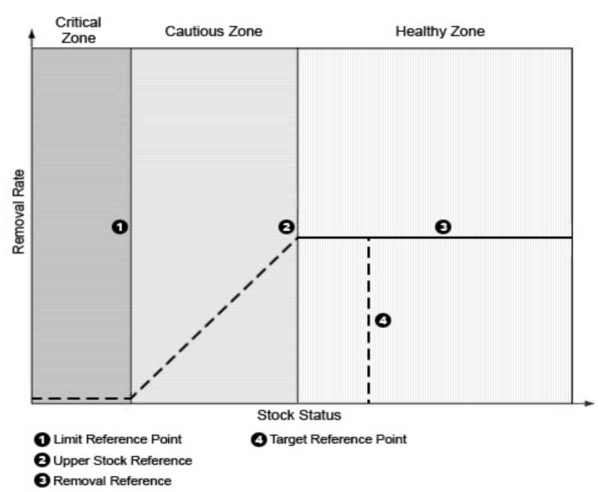
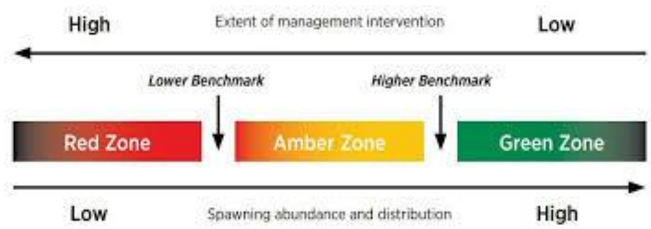
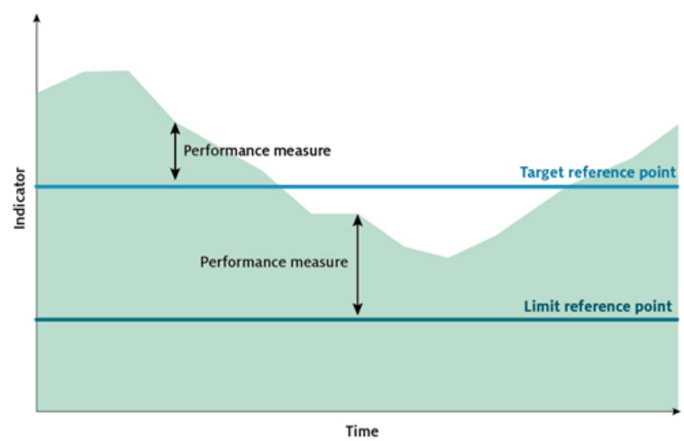


Figure A27*: Final illustration of the national PA framework (reproduced from DFO 2009a).*

	Note that there is no illustration of a harvest decision rule (harvest control rule, or HCR) as separate from the removal reference point (although both might have a hockey-stick like structure).
Canada (WSP)	Canada's WSP employed a simple "traffic-light" approach to visualizing its salmon-centered PA framework, with reference points relative to stock abundance and the "extent of management intervention" illustrated along a single dimension (Figure A28; DFO 2005a). The single stock abundance dimension precludes illustration of a generic harvest control rules, but emphasizes the high-medium-low relationship among the three zones.  ***Figure A28****: Illustration of the PA framework for the Wild Salmon Policy (reproduced from DFO 2005a).*
Australia	Australia's HS Policy Guidelines (DAWR 2018b) employs two separate diagrams to illustrate its concepts. The first image conveys how fisheries performance is evaluated, by contrasting some stock status indicator (such as abundance or catch-per-unit-effort) against both a target and limit reference point (Figure A29):  ***Figure A29:*** *Diagram illustrating harvest strategy evaluation, reproduced form DAWR (2018b, Fig. 1).*

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The second diagram illustrates an example harvest control rule showing the relationship between an indicator, reference points and exploitation rate (DAWR 2018b; Figure A30). Although this diagram, like Canada's PA Policy, ties changes in exploitation rate to reference points as operational control points, it is not clear if this is mandatory; the guidelines state that "the specific form of the control rules will depend on management tools."

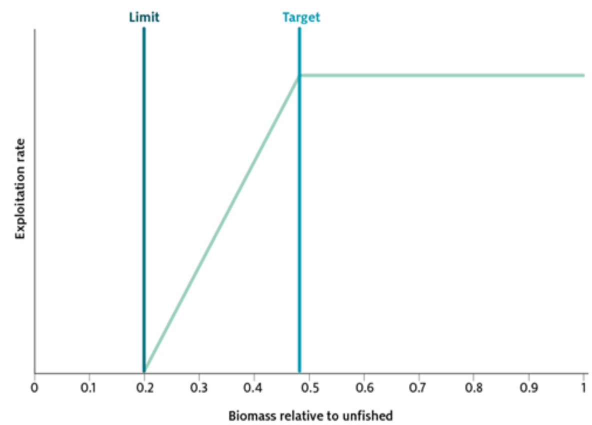

Figure A30: *Diagram illustrating harvest control rule and biomass reference points, reproduced from DAWR (2018b, Fig. 2).*

An earlier version of Australia's HS Policy guidelines also illustrated *F*-based reference points along with biomass ones in showing an example of a HCR (DAFF 2007, Figure A31):

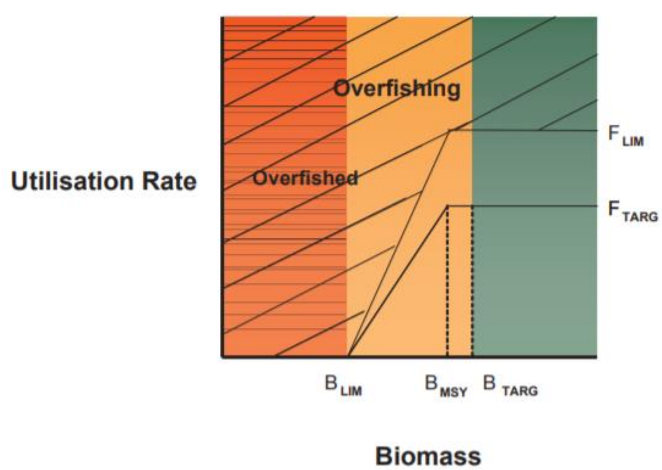

Figure A31: *Diagram illustrating harvest control rule with both F and B-based reference points, reproduced from DAFF (2007, Fig. 2).*
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<td>ICES</td>
<td>The ICES MSY Rule is illustrated below (ICES 2018a, Figure A32).</td>
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Among the jurisdictions here, it is unique in having both dimensions of the visual tool be based on biological characteristics (X-axis of spawning stock biomass, and Y-axis of recruitment), which concretely relates the illustrated reference points to a stock-recruitment relationship and thus the concept of recruitment impairment. Although the “broken hockey stick” linking stock-recruitment to reference points evokes a harvest control rule-rule like shape, F is not included or represented in this diagram.

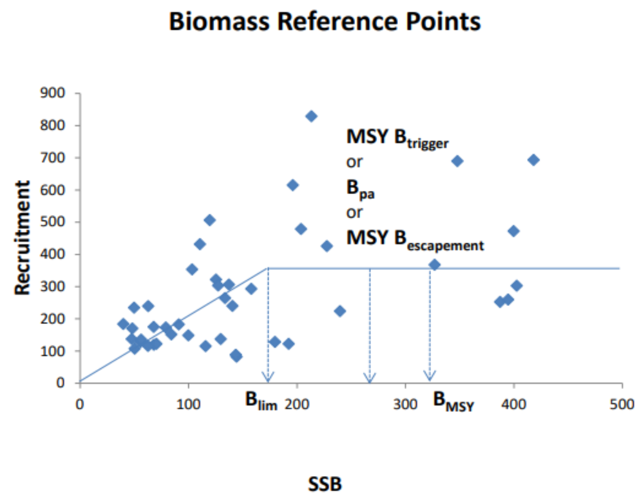

Figure A32: The ICES MSY Rule, reproduced from ICES (2018a, Fig. 1.2.2).
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<td>NAFO</td>
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NAFO’s PAF (2004a) specifies both draft and final visualizations of its precautionary approach framework, and both are included here for interest. The preliminary schematic first proposed in 1997 is show below (Figure A33, NAFO 2004a):

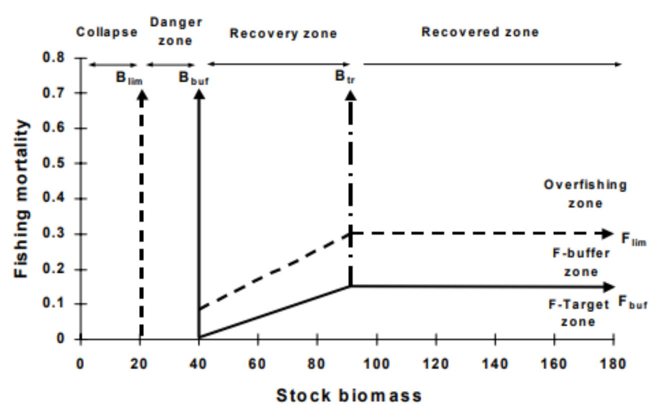

Figure A33: An early draft version of NAFO's PA framework, reproduced from NAFO (2004a, Fig.1).
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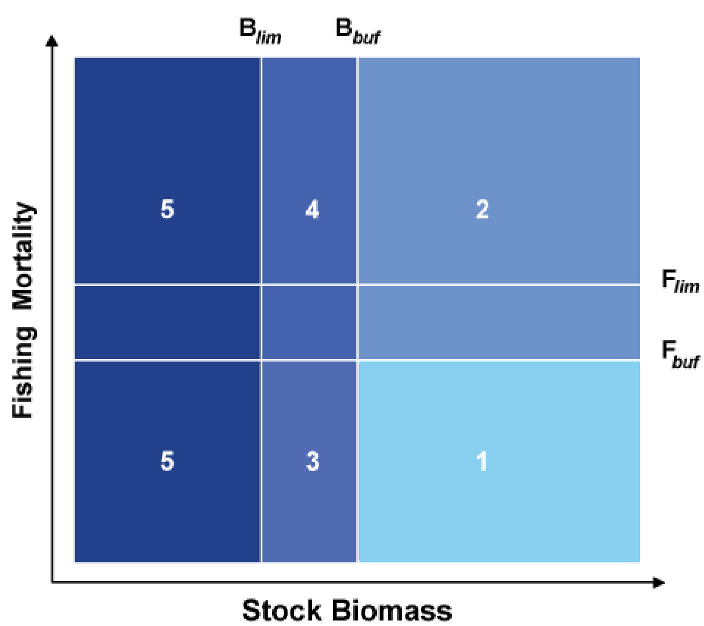
	The draft schematic with its "hockey-stick"-like *F*-based reference points bears some similarities to Canada's national PA framework adopted in 2009 (DFO 2006; DFO, 2009a), but differs in that two hockey-stick-like structures are shown. One is intended to represent a limit fishing rate beyond which overfishing occurs (dashed line), whereas the solid line represents a target fishing rate. Like other jurisdictions, the HCR operational control points are tied to the reference points used to delineate discrete zonal boundaries of stock status. A selected HCR, based on F, would therefore not necessarily match either of the two HCR boundaries illustrated. As the PAF (NAFO 2004a) describes, the above framework was never formally adopted, in part because is prescribed no fishing below B_{lim} or B_{buf}, a fishing mortality limit at F_{MSY}, a linear decrease from B_{target} (B_{tr}) to B_{buf}, no consideration for desirability of stable TACs, and no consideration of multi-species situations. In subsequent discussions, the reference points and visualization tool for NAFO's PAF took the following form (presented in colour in NAFO 2019b, Figure A34):  ***Figure A34:*** *Visualization of NAFO's current PA framework, reproduced from NAFO 2019b.* Here, B_{target} was removed and the emphasis is on five zones of stock status, illustrated with dimensions on two axes (fishing mortality, and biomass). A de-emphasis on B_{MSY} "avoids the problem of the

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<td>impossibility of maintaining all stocks in a multi-species assemblage simultaneously at their respective single-species B_{MSY} levels" (NAFO 2004a). There is no longer a putative HCR in place, simply limits and buffers in zones where changes in F are not prescribed to be of any particular shape.</td>
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<tr>
<td>New Zealand</td>
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The Fish Stocks Status website uses a simple graphic and plain language to convey how fisheries stock status may evolve over time, in relation to the three reference points (Figure A35), much like the Australian guidance (Figure A29).

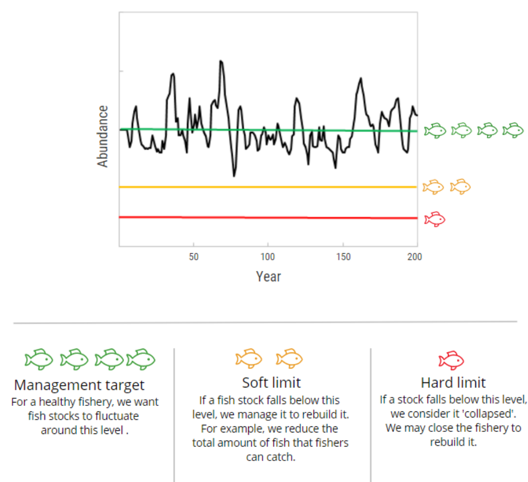

Figure A35: Illustration of the three reference points employed in the HS Standard, reproduced from MF (2019a).

New Zealand's operational guidelines show an example harvest control rule using two different axes (fishing mortality, and catch; Figure A36, MF 2011). Note that the threshold is present as an operational control point distinct from either target or limit reference points; the HCR is illustrated as the special cause where the lower operational control point matches the hard limit reference point.
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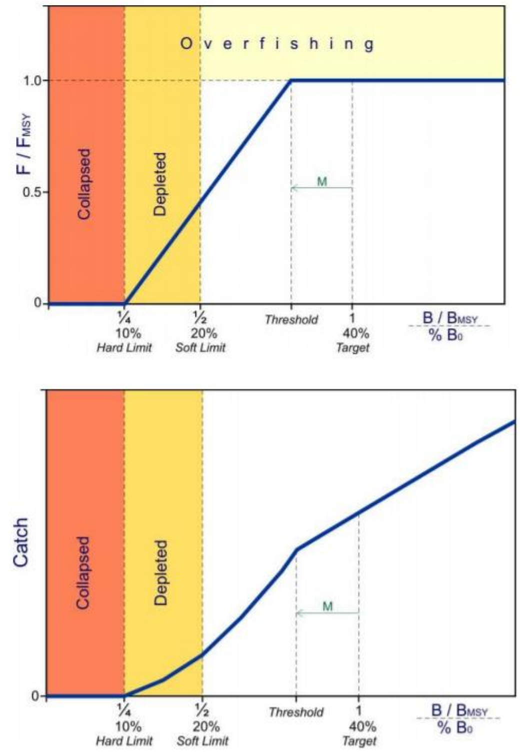

Figure A36: *Illustration of a harvest control rule using two different axes, conveying the difference between F and catch. Reproduced from MF (2011, Fig. 6).*

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United States

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2009 revisions to the NS guidelines were accompanied by this figure (Figure A37, NOAA 2009), outlining the various reference points.

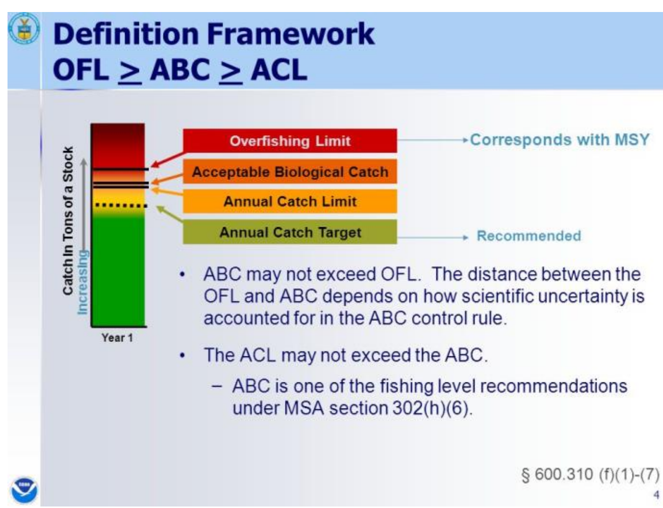

Figure A37: *The relationship between various reference points introduced during the 2009 revisions to the National Standard Guidelines. Reproduced from NOAA (2009).*

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The only overt illustration of what stock status might mean is given in terms of stock rebuilding activities (specifically in relation to stock trajectories from being *overfished* to reaching a target level) is shown below (Figure A38, NOAA 2018b):

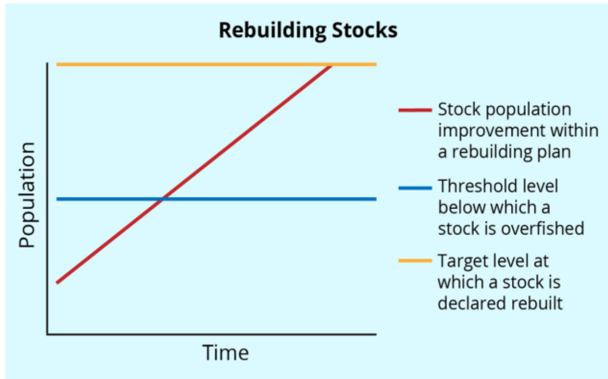

Figure A38: *Illustration of stock rebuilding over time in relation to limits and targets. Reproduced from NOAA (2018b).*

The technical guidance for the NS Guidelines (Restrepo et al. 1998) contains numerous illustrations of harvest control rules, such as families of rules (Figure A39) and a recommended default pair of MSY and OY control rule defaults (Figure A40).

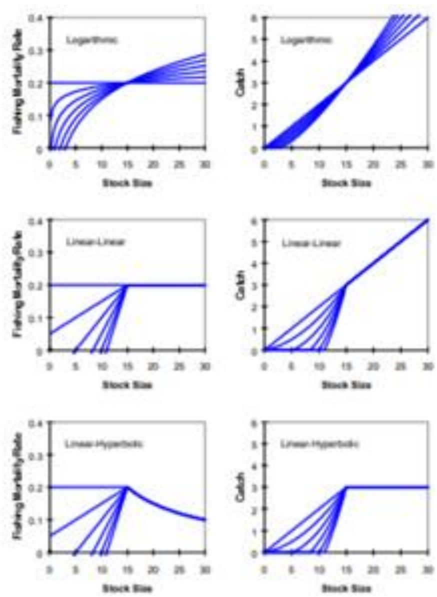

Figure A39: *Families of harvest control rules. Reproduced from Restrepo et al. (1998, Fig. 1).*

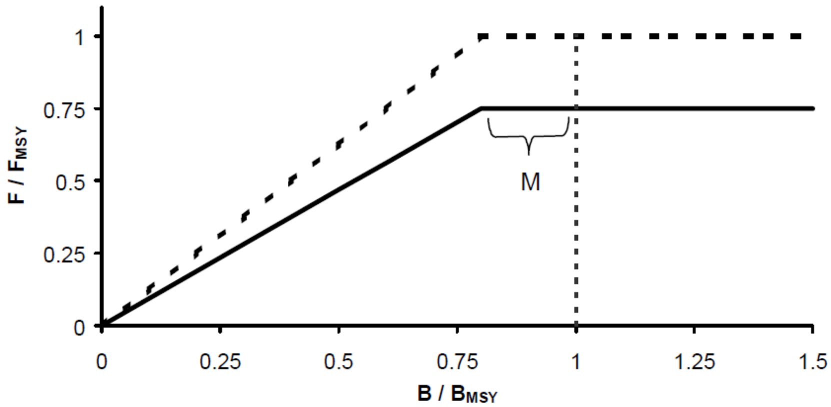

Figure A40: *The limit, or MSY control rule is shown as a dashed line, while target, or OY control rule, is illustrated with a solid line. Reproduced from Restrepo et al. (1998, Fig. 10).*

It is important to note that according to Restrepo et al. (1998), the MSY control rule is intended to serve as a limit, and the OY as a target; and neither terms are reflective of current National Standard Guidelines in the United States (NOAA 2018a).

Restrepo and others (1998) also provided an example of a rebuilding plan control rule that differs from the established target control rule for the fishery in several phases (a – initiate rebuilding with high probability, b – keep rebuilding faster than what would occur under the OY control rule, and c – transition to OY control rule; Figure A41):

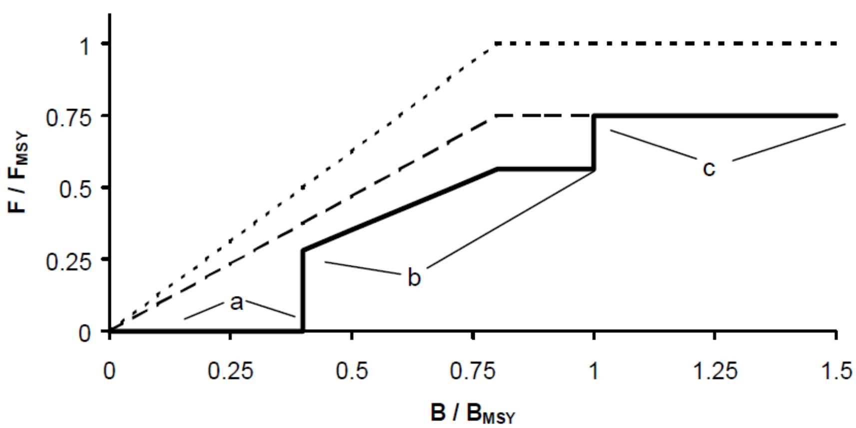

Figure A41: *An illustration of a possible rebuilding plan for a depleted stock, with three phases (a, b and c) representing initiation, acceleration of rebuilding relative to target, and transition to optimal management. Reproduced from Restrepo et al. (1998, Fig.10).*

Appendix 15 - ROLES AND RESPONSIBILITIES

Canada (national)	Policy implementation and regulatory activities for marine fisheries, and some freshwater fisheries under federal jurisdiction, are all performed by the Canadian federal department of Fisheries and Oceans Canada. Canada's PA Policy (DFO 2009a) assigns several roles and responsibilities, namely: ● Limit reference point (LRP): this is based on biological criteria and established by Science through a peer reviewed process. ● Upper stock reference (USR): this would be developed by fishery managers informed by consultations with the fishery and other interests, with advice and input from Science. ● Harvest decision rules (harvest control rules, HCRs): The development of rules is the responsibility of fishery managers and Science's role is to provide advice in support of their development. However, information on roles and responsibilities appears incomplete and possibly conflicting. No information was provided on roles and responsibilities for setting removal references, which are reference points intended to limit fishing rates to avoid stock conditions consistent with serious harm, i.e., a reference point intended to separate objectives (avoid overfishing with high probability) from management actions intended to achieve the objectives. Later on in the document, Science is also assigned a stronger role in the identifications of all reference points than earlier text would indicate; the later text notes that the development and application of a PA framework involves a number of steps "from the determination by science of reference points and stock status in relation to these points, to the development by fisheries management, in collaboration with fishery interests, of a harvest rate strategy including pre-agreed decision rules" (DFO 2009a). This implies Science is responsible for status determination. Later, the PA Policy identifies the need for evaluation, which requires that desired outcomes, the probability for achieving those outcomes (risk), and a time frame for evaluation need to be specified. The PA Policy is mute on which Sector is responsible for the evaluation, but Science has a role since scientific data and methods are required to conduct an evaluation, regardless of whether it is retrospective or prospective. DFO (2016a) noted that the responsibility of setting the USR in light of what it is intended to represent (among multiple possible interpretations) remained an outstanding question. However, discussions did not similarly identify issues with roles and responsibilities for setting RR

	given its three possible interpretations. Risk tolerance levels was firmly identified as a management responsibility.
Australia	In Australia, the Department of Agriculture and Water Resources oversees implementation of the Harvest Strategy Policy, while the Australian Fisheries Management Authority (AFMA) is the regulator responsible for developing, implementing and monitoring harvest strategies (DAWR 2018a). There is no reference in the HS Policy to science versus management roles in generating harvest strategies or their components.
ICES	Unlike other entities reviewed here, ICES as a science-based organization that does not encompass both managers and scientists, but instead provides advice to a wide array of clients who undertake management in their own jurisdictions. As such, the roles and responsibilities for both managers and scientists in generating harvest strategies are not directly addressed by ICES guidance documents. To facilitate the provision of advice, ICES' Advice Basis document (ICES 2018a) outlines default MSY or precautionary rules under which advice will be provided, in lieu of a client-generated management plan that conforms to ICES' precautionary criterion (see section on Evaluating Performance). It is these default rules for advice provision that leads to a larger perceived role for ICES scientists in prescribing harvest levels, as noted elsewhere (e.g., determining at what stock size *F* must start to drop; DFO 2016a). However, these default formulations do not change the fact that the "margin of risk tolerance is a management prerogative" (ICES 2018a) That is not to say that ICES provides no guidance for staff activities; in their technical guidelines (16.1.3 Guidelines for Advice Drafting Groups, for example), details are provided regarding prescribed tasks within teams of people responsible for generating science advice, and the sequence of steps in the advisory process itself is illustrated in Figures 1.2.1 and 1.2.2 of ICES (2018).
NAFO	Table 1 of NAFO's PAF (2004a) identifies separate roles for the Scientific Council and the Fisheries Commission that were developed in early discussions around the establishment of a precautionary approach framework. The table is not especially clear; for example, it is the role of the Scientific Council to "calculate limit reference points," but the role of the Fisheries Commission to "set limit reference points" - the difference in meaning is not clear.

	The table may also be incomplete. In later developments of the PAF, described elsewhere in the PAF (NAFO 2004a) stocks are divided into two categories: stocks where the Scientific Council can conduct "risk analyses" and those where they cannot. If risk analyses are possible, "security margins (F_{buf} and B_{buf}) will be based on the risk levels specified by the Fisheries Commission", presumably meaning that F_{buf} and B_{buf} are calculated by the Scientific Council. If risk analyses are not possible "the Fisheries Commission will specify the security margins", presumably meaning the values of F_{buf} and B_{buf} are set by the Fisheries Commission. However, these activities are not explicitly identified in NAFO's PAF (2004a).
New Zealand	The operational guidelines for the HS Standard outline generally sequential roles and responsibilities for Science Working Groups and fisheries managers in developing targets, limits, rebuilding plans, and fisheries stock status reporting (MF 2011). In brief: Targets: ● Scientists estimate B_{MSY}, F_{MSY}, MSY or relevant proxies ● Fisheries managers set targets based on these values (modified with relevant factors) ● Scientists define and report or performance measures in relation to targets and determine whether or not overfishing is occurring Limits ● Scientists estimate the probability that a stock is below the hard or soft limit ● Scientists may be requested to develop rebuilding plans or to investigate the implications of closing target or incidental fisheries Rebuilding Plans ● Scientists estimate probability stock is below soft and hard limits and calculate T_{min} ● Scientists work iteratively with fisheries managers to define and evaluate alternative rebuilding plans ● Once a plan is in place, scientists evaluate and report on progress Stocks below targets but above limits ● Scientists estimate stock status and confidence intervals (biomass and fishing mortality) ● Scientists work with fisheries managers to define and evaluate the consequences of altering fishing mortality or catch
United	The office of the National Oceanic and Atmospheric Administration -

States	Fisheries, more formally known as the National Marine Fisheries Service or NMFS, a federal agency and a branch of the Department of Commerce, is responsible for fisheries management in the Exclusive Economic Zone of the United States, which extends 200 nautical miles from the coastline (NOAA 2017). Under the 1976 *Magnuson-Stevens Act,* eight Regional Fishery Management councils were established, each with their own scientific and statistical committee (SSC). The NS Guidelines are replete with details about what items must be provided and what actions are taken by councils, SSCs, or the Secretary (NOAA 2018a). For example, the SCC provides its corresponding council with recommendations for ABC and other scientific advice, while Councils establish ABC control rules. It is the Secretary who determines, based on the SDC defined in the FMP, whether overfishing is occurring. It is possible that more detailed information on roles and procedures would be available within each Council's records. In technical guidelines, Restrepo and others (1998) recognized that "specification of MSY control rules, status determination criteria, and precautionary target control rules is a challenging exercise" and "key to this process is communication between managers, scientists, users and the public." However, few specifics were provided.