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APPLICATION OF THE PRECAUTIONARY APPROACH TO THE MANAGEMENT OF MARINE MAMMALS IN NORTHERN CANADA

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ABSTRACT

Canada is committed to managing its resources using a Precautionary Approach (PA). However, when applying this approach to Arctic marine mammals, the Government of Canada must also respect the land claims agreements it has signed with Canada's Inuit. Under these agreements the co-management boards are responsible for wildlife management within the land claim area. In addition to protecting the rights of hunters to harvest, the land claims agreements also call for the development of management systems that respect the principles of conservation and ensure sustainability of the resource, potentially resulting in a management paradox. We present criteria by which the status of a population can be assessed, and an appropriate PA framework applied. If sufficient data are available to understand the population dynamics of a given stock (i.e., a Data Rich situation), management decisions can be based upon an appropriate population model with quantitatively estimated reference levels. In cases where the population dynamics are poorly understood (i.e., Data Poor), a more conservative approach, referred to as the Potential Biological Removal (PBR) should be used to provide advice on sustainable harvest levels. Generally, only the most recent estimate of abundance is used in the PBR calculation which may ignore other data. We propose that if sufficient data are available to fit a population model, while still not sufficient to be considered Data Rich, the modelled estimate of current abundance can be used for a more robust PBR estimate. We also review guidelines for the choice of the recovery factor which is part of the PBR calculation. The apparent management paradox can be addressed within the context of a Management Procedure or Management Strategy Evaluation where Indigenous Knowledge and Western Science can contribute to setting management objectives, decision rules and appropriate time-frames that can be evaluated within a simulation environment.

Keywords: marine mammals, management, land claim, data rich, data poor, harvesting, harvest rights, conservation

INTRODUCTION

The goal of fisheries management is to achieve an acceptable trade-off between social, political and economic goals while ensuring the conservation of the resource (Punt et al., 2014). Much of fisheries science and management has developed within the context of single-stock, large-scale and commodity-driven fisheries, where the goal has been to manage most stocks for maximum sustainable yield (MSY). Initially set as a target that could be exceeded, MSY has evolved over time to serve as a limit to be avoided (Mace, 2001; Frid et al., 2023). The collapse of several major fisheries late in the 20th century, which were linked to uncertainties in fisheries science and the difficulties with implementing management measures, helped reach agreement on several international instruments stipulating that the Precautionary Approach (PA) should be applied to management of fisheries (Hilborn et al., 2001). These large fisheries failures also contributed to an increased awareness of stochastic processes and the ecosystem effects of fishing, which led to calls for an ecosystem approach to fisheries management (Mace, 2001; Mangel & Levin, 2005). Fisheries managers have been relatively successful in developing and implementing PA measures. However, the continued focus on maximizing the long-term commercial catch of single species and the challenges of developing quantitative, multi-species models have hindered the development of broader management frameworks to sustain healthy ecosystems and resource use that balance costs and benefits for ecological, economic, and social well-being (Mace, 2001; Mangel & Levin, 2005; Frid et al., 2023).

In Canada, the conservation, and management of marine mammals falls under the Fisheries Act. The Act is administered by the Federal Department of Fisheries and Oceans Canada (DFO) under the Minister of Fisheries and Oceans (Fisheries Act, 1985). As a signatory to the United Nations Convention on the Law of the Sea (UNCLOS), Canada has committed to applying a PA to the management of its resources, which is to maintain or restore populations of harvested species at or above levels which can produce the maximum sustainable yield (Convention on the Law of the Sea, 1982). To meet this goal, Canada amended its Fisheries Act to enable the Minister to set a Limit Reference Point and implement measures to maintain a stock above that point (Fisheries Act, 1985). As a signatory to the 1992 Rio Declaration on Environment and Development, Canada was an early supporter of the PA, but it was not until the early 2000s, that the DFO first implemented a PA framework for the management of a commercial fishery, with the Atlantic Seal Management Strategy (ASMS) to manage commercial seal harvesting (Hammill & Stenson, 2003, 2007). More recently, PA components of the ASMS such as reference levels and measures of uncertainty, have been applied to Inuit subsistence harvests in the Canadian Arctic in the provision of science advice (see e.g., Doniol-Valcroze et al., 2015, for High Arctic narwhal; Marcoux & Hammill, 2016, Cumberland Sound beluga; Ferguson et al.,2021, for Eastern Canada-West Greenland bowhead whale; Department of Fisheries and Oceans Canada [DFO], 2018, for Western Hudson Bay beluga).

While the Fisheries Act (1985) outlines conservation objectives, it also states that the rights of the Indigenous peoples of Canada must be respected, including harvesting rights as recognized and affirmed by the Canadian Constitution. The Fisheries Act also states that, in the course of any decision, the Minister must consider Indigenous knowledge, community knowledge, cooperation with a co-management body established under a land claims agreement, social, economic and cultural factors in the management of fisheries (Fisheries Act, 1985). The modern land claims agreements the federal government has signed with Inuit and First Nations affect many aspects of ownership over lands, economic issues and, different forms of self-government and wildlife management. Since the signing of the original James Bay and Northern Quebec Agreement (1975), there has been a change in legal obligations, from a requirement to consult with the designated wildlife body, to the delegation of responsibility for wildlife management directly to co-management boards (henceforth Board(s)). Decisions by Boards, or the Minister, to restrict Inuit harvesting may only do so to the extent necessary for conservation, allocation of the resource or safety (Hammill et al., 2017). While conservation is often identified as an objective in management decisions, other factors such as minimum needs by a community for a resource, which are inconsistent with the conservation objective in conventional fisheries, may influence the decision for some allowable take. In the absence of co-management decisions that consider the PA, this would appear to create a management paradox. At the same time, there is increasing international interest in northern marine mammals in light of climate change. This, combined with the absence of a clear management framework suggest that wildlife management in northern Canada will be increasingly the focus of international interest, which will put added pressure on the co-management system (e.g., Dale & Armitage, 2011; Lovecraft & Meek, 2011; Suluk & Blakney, 2008; Weber et al., 2015; Hammill et al., 2017).

Changes in the legal environment and the failure of fisheries science to develop and implement ecosystem approaches to fisheries management are motivating the development of alternative, more inclusive approaches that include a wider range of preferred management objectives (Adams et al., 2021; Damiano et al., 2022; Silver et al., 2022). Indigenous knowledge systems (IKS) offer a more holistic approach to the management of subsistence harvesting in the Canadian Arctic. Indigenous knowledge systems can be defined as the broader political, legal, economic, and cultural systems that enable the continued generation and renewal of Indigenous Peoples to ensure their well-being (McGregor, 2021). Indigenous knowledge systems are often considered synonymous or closely related to the term, Traditional Ecological Knowledge (TEK), which is defined by Berkes et al. (2000) "as a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (p. 1252). In contrast to the MSY focus on maximizing exploitation, IKS aims to maximize food security, by taking only what is needed, community sharing, minimizing waste, having respect for the animals and supporting other ecosystem components (Adams et al., 2021; Breton-Honeyman et al., 2021). The development and implementation of management frameworks does not mean that one knowledge system should be prioritized over another. Instead, a more inclusive approach unifying both knowledge systems ("two-eyed seeing" according to Reid et al., 2021), is more likely to reduce uncertainty and to provide other benefits as well such as improving social acceptance (Nonkes et al., 2021).

In this paper, we explore potential approaches to the management of marine mammals subject to subsistence harvests in northern Canada that are covered by two very similar agreements, the Nunavut Land Claim Agreement (NLCA) (1993) and the Nunavik Inuit Land Claim Agreement (NILCA) (2006). We propose a mechanism by which a PA-compliant framework could be developed for the consistent management of northern marine mammals while respecting both domestic land claims legislation and international obligations. We also present examples of how this framework could be applied to the management of marine mammal stocks that are harvested in Canada.

THE PRECAUTIONARY APPROACH

Scientists provide harvest advice to managers based on the best available information on the status of the population under consideration. However, because of environmental stochasticity, incomplete information, required assumptions and imprecise parameter estimates, the advice is associated with varying degrees of uncertainty. A key component of a PA framework is the establishment of decision rules for the management of a stock which are defined in advance for pre-determined reference levels and which are more cautious when information is less certain. These reference points can mark a transition point between desirable and undesirable states as defined by the conservation objectives identified for the stock (e.g., Curtis et al., 2015; Hammill & Stenson, 2007; Hammill et al., 2017).

Many PA frameworks share common features. The objective is to manage the population above a lower limit, referred to as a Limit Reference Level (LRL), to avoid causing significant harm to the resource. Under the Fish Stock Provisions of the revised Canadian Fisheries Act, the Minister is legally required to identify LRLs and to promote the sustainability of major fish stocks (Department of Fisheries and Oceans Canada [DFO], 2021). Determination of the LRL must consider uncertainty in both the abundance metric and the reference point estimate (Department of Fisheries and Oceans Canada [DFO], 2021). This results in a second objective, to manage the resource as far away as possible from the Limit Reference Level. To do this a second reference level may be established and is usually referred to as a Precautionary Reference Level (PRL; Figure 1, Table 1; Curtis et al., 2015; Department of Agriculture, Fisheries and Forestry [DAFF], 2018; Department of Fisheries and Oceans Canada [DFO], 2006, 2009; Hammill & Stenson, 2007; Ministry of Fisheries, 2008; Moore et al., 2013; Marentette et al., 2021). The PRL represents a specified level of practical and effective resource use over the long term to maintain the stock above the LRL in order to be consistent with promoting stock sustainability (Department of Fisheries and Oceans Canada [DFO], 2021). The two reference levels create three zones, referred to as Healthy,

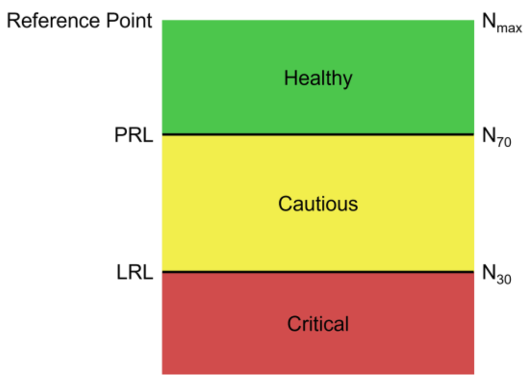

Figure 1. A generalized PA framework for fisheries showing the Precautionary Reference Level (PRL) and Limit Reference Level (LRL) (modified after Department of Fisheries and Oceans Canada [DFO], 2009). Under the Atlantic Seal Management Strategy (ASMS), the PRL and LRL are set at 70% (N_{70}) and 30% (N_{30}) of the maximum population abundance observed or estimated (N_{max}; Hammill & Stenson, 2007).

Cautious and Critical zones (Figure 1). Ideally, the stock will remain above the PRL (i.e., Healthy Zone). For a stock falling below the PRL, harvesting should be progressively reduced to avoid reaching the LRL and timelines established to identify when the resource will recover.

The timelines for recovery may vary. For example, under the United States Magnuson-Stevens Fishery Conservation Act (2007) stocks must recover above MSY within 10 years (McQuaw et al., 2021); in Canada, recovery within one and a half to two generations is recommended (Department of Fisheries and Oceans Canada [DFO], 2009), but longer time frames might be envisioned. For example, the International Union for the Conservation of Nature (IUCN) and the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) use a timeframe of three generations when evaluating changes in status, while catch levels set using the Potential Biological Removal approach are expected to have a high probability of recovery over a timeframe of 100 years (Committee on the Status of Endangered Wildlife in Canada [COSEWIC], 2024; Wade, 1998). The management objectives will also affect timelines. For example, long-term sustainability for future generations among some First-Nation communities may consider seven generations (Reid et al., 2021). However, it is important to note that in multi-species fisheries promoting the rapid recovery of one species may limit the exploitation of others if strict bycatch rules are in place (e.g., McQuaw et al., 2021). Alternatively, closure of a fishery for rebuilding of a stock may transfer unsustainable fishing pressure to alternative stocks which are also important food resources (e.g., perhaps closure of beluga harvesting may increase fishing pressure on local Arctic char).

Our knowledge of the abundance, population trends, removals and vital rates of individual populations (or stocks) varies greatly. Therefore, some PA frameworks have also identified conditions for populations considered as 'Data Poor' or 'Data Rich'. When we have a poor understanding of stock status (i.e., Data Poor), the advice should be more cautious or risk adverse. In cases where there is more information related to estimates of abundance, demographic rates, stock discreteness and threats, then the stock might be considered Data Rich meaning that a higher level of risk tolerance may be acceptable (e.g., Department of Fisheries and Oceans Canada [DFO], 2006, 2013; Hammill & Stenson, 2007; Lassen et al., 2014; Ministry of Fisheries, 2008). In reality, the amount of information available to evaluate a stock may vary such that stocks lie along a continuum between the Data Poor and Data Rich categories (e.g., Lassen et al., 2014; Anderson et al., 2021).

Data Rich

The ASMS defines Data Rich criteria for commercially hunted seals including harp (*Pagophilus groenlandicus*), and grey (*Halichoerus grypus*) seals. Under the ASMS, Data Rich stocks have three or more estimates of abundance within a 15-year period, with the last estimate not older than five years old, and information obtained within the last five years on mortality and/or fecundity which can be used to determine sustainable levels of exploitation (Stenson et al., 2012). This definition has been adopted by the joint NAMMCO/NAFO/ICES working group on harp and hooded seals (WGHARP) to provide advice on sustainable removals for these species in the northeast Atlantic, although they have added the requirement that the estimates of abundance be relatively precise, i.e., CV<0.3 (International Council for the Exploration of the Sea [ICES], 2006).

While the Data Rich criteria may be appropriate for some stocks, the criteria may need revision for management of all harvested marine mammals in Canada (Stenson et al., 2012). Guidelines that could be used to evaluate whether a stock should be considered as Data Rich or Data Poor could include questions that examine our understanding of the stock composition, abundance and demographic information, the reliability of catch statistics, and whether the stock dynamics can be described (Table 2). The basic criterion for Data Rich is that there are enough data to understand the dynamics of the population and how removals or changes in the ecosystem may impact it (points 1 to 4 in Table 2). Initially, these guidelines might act as qualitative measures to evaluate our understanding of stock dynamics and abundance. As time goes on, additional guidelines could be added to better assign stocks more clearly to the Data Poor or Data Rich categories.

Another criterion (point 5 in Table 2) is that the dynamics of the stock can be described using a population model that provides a reasonable fit to the data and which is relatively robust to the assumptions that have been used to develop the model. The type of model and its complexity will depend on the amount of data available, which could range from a simple deterministic surplus production model to a stochastic age-structure model (e.g., Hammill et al., 2015; Pella & Tomlinson, 1969; Tinker et al., 2023; Wade, 1998).

The LRL represents a point where the resource is considered to have suffered serious harm. In some PA frameworks, removals would stop if a population declined to the LRL while, in others, minimum levels of removals are still permitted. There is no clear consensus on how to set the reference levels but common ways to set the LRL have been as a proportion of the pre-exploitation abundance, as a proportion of the estimated environmental carrying capacity (K), or as a proportion of the largest population observed (Table 1). For marine mammal populations, where recovery from the LRL may be measured in decades, complete closure would lead to a more rapid recovery, however, among Inuit or other harvesting communities,

Table 1. Reference levels for some common precautionary approach frameworks. ASMS is the Atlantic Seal Management Strategy. PRL is the Precautionary Reference Level, LRL is the Limit Reference Level. Risk Level is the probability that the resource status is above PRL or LRL. ND is not defined. N_{Max} is the largest population observed or estimated, MSY is maximum sustainable yield, MNPL is maximum net productivity level. N is number, B is biomass and N_0/ B_0 refer to levels prior to the start of commercial harvesting. MMPA is Marine Mammal Protection Act.

Framework	PRL	PRL Risk Level	LRL	LRL Risk Level	Target Level	Reference
Canada (ASMS)	$0.7N_{Max}$	0.8	$0.3N_{Max}$	0.95		Hammill & Stenson, 2007
Canada (DFO-MSY)	0.8[1]MSY	ND	$0.4N_{MSY}$	ND		Department of Fisheries and Oceans Canada [DFO], 2006
New Zealand	higher of: $0.5N_{MSY}$ or 0.2 N_0	0.9	0.25 higher of N_{MSY} or $0.1N_0$	0.98		Ministry of Fisheries, 2008
United States (MMPA)	N_{MNPL}	0.95	ND[2]	ND		National Marine Fisheries Service [NMFS], 2016, 2023
United States (Fisheries)	B_{MSY}		$0.5B_{MSY}$	ND		Magnuson-Stevens Fishery Conservation Act, 2007; McIlgorm, 2013
International Whaling Commission (Commercial Harvest)			$0.54N_0$	0.59		Butterworth & Best, 1994; International Whaling Commission [IWC], 1994
International Whaling Commission (Subsistence Harvest)			$0.23N_0$	0.59		Butterworth & Best, 1994; International Whaling Commission [IWC], 1994
Australia	B_{MSY} or $0.4B_0$	0.9	$0.5B_{MSY}$ or 0.2 B_0		>$1.2B_{MSY}$	Department of Agriculture, Fisheries and Forestry [DAFF], 2018; McIlgorm, 2013

[1] Default value (Department of Fisheries and Oceans Canada [DFO], 2009), but other approaches possible, e.g., ASMS

[2] No limit reference point is defined, but recovery above the PRL should occur within 100 years.

minimal harvest levels may be preferred for cultural reasons and to preserve crucial harvest skills during the recovery phase. Under these circumstances the LRL could be considered as the population level that provides the minimum level of community needs, assuming that it is biologically sustainable. Various levels have been identified for the PRL and it may be considered as a target or threshold reference point to be achieved (perhaps as a recovery target), but the underlying considerations when setting the PRL is to minimize the risk of falling below the LRL (Department of Agriculture, Fisheries and Forestry [DAFF], 2018; Hammill & Stenson, 2007; Ministry of Fisheries, 2008).

In addition to harp and grey seals, a number of northern stocks in Canada have been considered to be Data Rich based upon a series of abundance estimates, information on the history of removals, the fit of the population model to the data and the robustness of the model to the assumptions that have been made. These include eastern Hudson Bay beluga and Cumberland Sound beluga (Department of Fisheries and Oceans Canada [DFO], 2019, 2020).

Data Poor

If information on the abundance or dynamics of the stock are limited, our ability to predict the consequences of a given level of removals is more restricted. For Data Poor stocks, the uncertainty associated with the status of the resource and the effects of particular management actions increases and, therefore, an even more risk-adverse approach is needed. Assuming it is possible to obtain an estimate of abundance, it seems reasonable to use the highly-conservative Potential Biological Removal (PBR) approach first developed in the United States (Wade, 1998). The management objective of PBR is that there is a 95% probability that the population will be above its maximum net productivity level (MNPL, which is roughly equivalent to MSY in concept) after 100 years (Wade, 1998).

The PBR is estimated as: $PBR = N_{min} \cdot 0.5 \cdot R_{max} \cdot F_R$

Where, N_{min} is the minimum population size (calculated as the 20-percentile of the log-normal distribution around the abundance estimate); R_{max} is the maximum rate of population increase; F_R is a recovery factor, between 0.1 and 1.0 (Wade, 1998). The strength of PBR is that it only requires a single

Table 2. Factors to consider determining if a population is Data Rich or Data Poor as outlined by Hammill et al. (2017).

1.	**Stock composition**	In any management framework it is important to have an understanding of the unit being managed. Is there certainty in stock composition/identification? Are there data to support stock delineation, stock composition of the harvest? Is uncertainty in stock composition incorporated into the stock assessment.
2.	**Abundance**	What information is available on abundance? Is this information limited to a single survey, or is there a time series of abundance estimates? Are these estimates clumped together or spread out over time. For example, for a population of seals in Atlantic Canada to be considered as data rich, three or more abundance estimates must be available from the last 15 years, with the last estimate ≤5 years old. The quality of the estimates should also be considered. Are all of the estimates considered 'reliable'? Are they reasonably precise (e.g. CV < 30%)? If different methods or approaches were used to assess abundance, are they comparable? Is the entire stock assessed or does the assessment cover only a portion of the stock (e.g., specific age group)?
3.	**Demographic data**	Are there other demographic data available that can be used to provide insight into stock dynamics (e.g. survival and mortality rates, reproductive rates, trends in mean age/sex composition of the harvest)?
4.	**Removals**	Are there reliable statistics on harvest, bycatch or other anthropogenic sources of mortality? Can removals be allocated according to stock composition? Are the data obtained from independent observers?
5.	**Population model**	Can a population model be fitted to the abundance data and removal data (e.g. surplus production, age or stage-structured models) that provides an acceptable description of the population dynamics? Is there a reasonable estimate of historical abundance? Does the model provide a reasonable fit to the data? Does model fit and behaviour appear reasonable (e.g. are there signs of autocorrelation, convergence, cross-correlation)? Is the model robust to the assumptions that have been used?

abundance estimate to calculate an acceptable level of removals and that it does not require an estimate of carrying capacity. In cases where several abundance estimates are available, the PBR can be calculated following a tiered approach that uses the most recent abundance estimate, a weighted mean of two or more estimates, if the available estimates are within the last eight years, or an average weighted by time and precision, where more recent estimates are given more weight than older estimates (Brandon et al., 2017). Based upon their simulation study, Brandon et al. (2017) noted that averaging multiple estimates may impact the way N_{min} should be calculated to meet the objectives of PBR and recommended that a complete management evaluation strategy (MSE) be carried out to test the implications of the different approaches. They also found that under most scenarios the PBR objective is met unless the harvest is directed towards females or the estimate of the R_{max} used is overestimated.

Increased research efforts in the Canadian Arctic have allowed us to obtain a series of abundance estimates for some stocks that provide us with information on current abundance although there is insufficient data to consider these stocks as Data Rich. However, it may be possible to construct population models that provide consistent estimates of current abundance that are robust to the differing model assumptions (e.g., Hudson Bay-Davis Strait walrus, Foxe Basin walrus; Department of Fisheries and Oceans Canada [DFO], 2015, 2016a). In such cases, PBR can be calculated directly from the model estimate of abundance. This has the advantage of using more of the available data and avoids the problem of widely varying estimates of PBR that can result from using the most recent survey estimates alone, particularly in the case where individual estimates are imprecise.

Recovery Factor (F_R)

The F_R is defined as being between 0.1 and 1.0 and is considered as an additional safety factor to account for uncertainties associated with our understanding of the stock (Wade, 1998). The F_R may be chosen on a case-by-case basis depending upon the level of potential errors or biases affecting the estimate of the base PBR (Richard & Abraham, 2013). However, having some general criteria for the choice of the recovery factor would provide some consistency and reduce the need for potentially arbitrary decisions regarding the level which should be used for each assessment. Some guidelines have been developed for setting F_R, but these remain very jurisdiction-specific (Table 3; Wade, 1998; National Marine Fisheries Service [NMFS], 2016, 2023). Under the United States Marine Mammal Protection Act (2019), the default for F_R is 0.5, except in the case of stocks of unknown status that are known to be increasing, or stocks that are not known to be decreasing taken primarily by aboriginal subsistence hunters. These stocks could have higher F_R values, up to and including 1.0, provided there have not been recent increases in the levels of takes (Table 3; National Marine Fisheries Service [NMFS], 2023).

In the United Kingdom, criteria for F_R have been developed based on a matrix approach that evaluates the level of confidence in the abundance estimate and the understanding of trend and demography (Boyd et al., 2010). In the case of differing levels of confidence, the most precautionary is selected. Beginning with abundance, a high level of confidence is associated with the understanding that the population is closed, population estimates are designed to evaluate

Table 3. Criteria for recovery factors (F_R) in the United States under the Marine Mammal Protection Act (MMPA; Marine Mammal Protection Act [MMPA], 2019; National Marine Fisheries Service [NMFS], 2016), in the United Kingdom (Boyd et al., 2010) and proposed guidelines for use in Canada (Department of Fisheries and Oceans Canada [DFO], 2018). MNPL is the Maximum Net Productivity Level, the number of animals which will result in the maximum productivity of the population (Wade, 1998), which would be equivalent to maximum sustainable yield (MSY). For the United Kingdom, the guidelines assign F_R based on confidence (High, Intermediate or Low) in estimates of abundance (N) and demography (R).

F_R	United States MMPA	United Kingdom	Canada
1	Above MNPL, unknown status but increasing or not known to be decreasing; taken by aboriginal hunters, provided no recent increases in takes	Confidence in the estimates of both N and R is High	Population appears to be abundant; increasing or stable;
0.75		Confidence in either the N or R factor is Intermediate while the other is High	Population appears to be Abundant but limited data; trend unknown but not considered to be declining;
0.5	Depleted, threatened, unknown status & CV of mortality ≤30%	Confidence in both the N and R factors are Intermediate	Population appears to be abundant, but trend is declining or unknown if declining;
0.4 to 0.48	For above, but if CV of mortality >30%		
0.25 (0.2-0.3)		Confidence in one of the factors is High or Intermediate but the other factor is Low	Population is considered to be small; trend appears to be increasing or stable.
0.1	Endangered	Confidence in both the N and R factors is Low	Population is considered to be small, declining or unknown trend.

uncertainty within the assessment framework, or abundance estimates are direct counts. An Intermediate level of confidence is assigned if the population is only partially closed (<10 immigration/emigration per year) or if the uncertainty estimate is a post-hoc estimate from multiple serial counts. A low level of confidence occurs when the population is completely open, or there is no information about population boundaries, there is no measure of uncertainty associated with the abundance estimates or less than two estimates are available. On the side of demographic traits, a high level of confidence is assigned if direct measurement of demography allows estimation of R_{max} or in an open or partially open populations potential adjacent source populations are present. Intermediate confidence is assigned if there is population decline, but there is evidence from the population or an adjacent one, that general life-history traits still apply. A low confidence rating is assigned if no information for the population is available and the assessment relies on life history information from the taxonomic group; in open or partially open populations, the presence of an adjacent potential sink population; presence of undefined, non-specific causes of mortality or reduced productivity that compromise resilience.

Brandon et al. (2017) suggested that when choosing a value for F_R the estimated rate of change in abundance and its standard error should also be considered. Management priorities for recovery (e.g., listing under the Canadian Species at Risk Act or IUCN Red List) may also warrant a reduced F_R. Simulations in the development of the PBR identified an explicit recovery period of 100 years (Wade, 1998) which suggests that a lower recovery factor may be considered for long lived species when using the default R_{max} (Richard & Abraham, 2013).

We have previously identified potential criteria to set the F_R (Table 3; Department of Fisheries and Oceans Canada [DFO], 2018) that are based on the general status and trend of the stock. These criteria for F_R have been used to estimate the PBR for several stocks in Canada, but the recent application of this approach to Atlantic harbour seals, which are abundant but only have a single range-wide survey highlighted that the guidelines do not apply to all situations and remain a work in progress. However, they do provide a starting point for the selection of F_R that can be used in the context of the approach we have presented here. It must be remembered that while in many jurisdictions, PBR is applied to all marine mammals (e.g., National Marine Fisheries Service [NMFS], 2016, 2023), it is only used to provide advice for populations considered to be Data Poor in Canada and, therefore, by definition, all are considered to have a level of uncertainty in some or all of the factors listed in Table 2. Within this context, Indigenous Knowledge could contribute to reducing uncertainty with respect to movements, discreteness, abundance and threats.

One way to improve the selection of F_R used previously in Canada would be to clarify the categories for abundance, perhaps setting limits to separate Abundant, Intermediate and Small populations. Additional factors might include whether stock structure is known and whether demographic information is available for the population being evaluated, or whether it is assumed, from other populations. Time to recovery, management priorities, long living species and level of uncertainty in the data may also be important factors to consider.

Management Procedure or Management Strategy Evaluation

Traditionally stock assessment advice has consisted of a 'best assessment' of the resource, an evaluation of model uncertainty, and recommendations for a management action based on applying a harvest control rule. This approach is gradually being supplemented by management-oriented approaches that evaluate the performance of management objectives within a simulation environment. In its simplest form a management procedure (MP), also called a Management Strategy Evaluation (MSE), uses model simulations to evaluate if the management objectives are still likely to be achieved under reasonable levels of uncertainty in either model assumptions or the data (Wade, 1998; Butterworth, 2007). It has evolved over time into an approach to evaluate management performance that includes a wider range of policy options and fishery objectives and differing levels of data richness within a closed loop simulation environment (Anderson et al., 2021). The main features of a MP have been reviewed by Punt et al. (2016) and Anderson et al. (2021). We summarize relevant points here:

1. Definition the decision context.

Defining the decision context sets the stage for the MSE process. Management Strategy Evaluations are very resource and time intensive to undertake. The decision to undertake a full MSE or a less intensive simulation approach will depend on the clarity of management objectives and the level of stakeholder involvement in the management process (Walter III et al., 2023). At this stage a clear understanding of what the management plan aims to achieve (the balance between needs and conservation objectives), how it will do so (e.g., quota or non-quota limitations), and the governance structure needed for management plan acceptance and compliance which will have a major impact on the overall plan's success (Armitage et al., 2019; Nonkes et al., 2023).

2. Selection of objectives and performance metrics

Clear management and fishery objectives, and the performance metrics that measure them must be identified (Anderson et al., 2021). Are the objectives to support a commercial fishery that aims to maximize yield (MSY) and/or subsistence harvests that may consider food security, being able to harvest without traveling far from home, or supporting other ecosystem components (e.g., bears; Adams, 2021)? What is the time frame: short term within the context of the United States Magnuson Stevens Fishery Conservation Act (2007; 10 years), or long term over several decades to ensure sustainability for future generations (Reid et al., 2021)? Is recovery to be rapid, or can alternative benefits be achieved by following a slower recovery path (McQuaw et al., 2021)? Identifying objectives can require extensive consultations among the various parties involved.

3. Selection of uncertainties/specification of operating models.

Here a set of models that describe the biological properties of the resource are developed. Often more than one model is needed to evaluate the contribution of different sources of uncertainty.

4. Identification of candidate management procedures.

At this stage several management procedures may have been identified. A screening process helps to eliminate unnecessary MPs, but the thinning criteria should not be too strict, since alternative MPs may be more informative at a later stage.

5. Simulation of the application of the management procedures.

Once the operating models and the Management Procedures are fully specified, the simulations can be undertaken. The simulations provide feedback between the operating models and the management procedure, where the models provide data, which generates a management action over the projection period. Many simulations must be completed to generate performance metrics that can be calculated with adequate precision (Punt et al., 2016; Anderson et al., 2021).

6. Presentation of results and selection of management procedure

Selection of the final management procedure will involve addressing trade offs. Although this may be a subjective process, it may also be possible to rank the different management procedures based on the performance metrics. In cases where several MPs are retained it is the role of Managers or the Boards, with inputs from all stakeholders (i.e., fishers, Inuit hunters, Scientists, Non-governmental organizations).

DISCUSSION

We have presented a general framework for providing advice for commercial and subsistence harvests of marine mammals in Canada. The flexibility of this approach and how it can be applied will depend upon the management objectives and the various levels of data available. While stocks are often considered to be either Data Rich or Data Poor, this is really a continuum that represents how well we understand the dynamics of a stock or population (Anderson et al., 2021). Based upon a series of indicators related to stock identification, abundance indices, removals data, demographic information, type of model used in the assessment and model performance, it is possible to define limits for stocks that can be considered as Data Rich or stocks that might be considered as more data limited (i.e., Data Poor). In the case of marine mammals, where a relatively cautious approach has already been developed for populations with limited data, the PBR can be estimated directly from a single abundance estimate, with appropriate recovery factors. However, when estimating PBR it is ideal to incorporate the additional data in situations where multiple abundance estimates are available (e.g., using a tiered approach in Brandon et al., 2017). Another possibility is to fit a simple model (similar to that used in the PBR simulation tests), that incorporates other biological information in addition to the survey data, and using the model estimates of abundance to calculate PBR. This approach may also offer interesting insights into population trends. Building on this, as even more information is gathered, a population can move from the Data Poor classification to the Data Rich category. Cumberland Sound beluga was assessed as Data Poor in 2016 but with an additional survey, was re-evaluated as Data Rich in 2019 and advice was provided using a population model (Department of Fisheries and Oceans Canada [DFO], 2016b, 2019). Our approach can also be used to evaluate removals of non-harvested species that may be subjected to unintentional takes (e.g., by-catch). It will allow us to better manage incidental catches in our fisheries and conform to requirements under the United States Marine Mammal Protection Act (2019) which can limit or prohibit the importation of fish products if the 'take' of marine mammals in the fishery are considered to be unsustainable (Office of the

Federal Register, National Archives and Records Administration, 2016).

We introduced this note stating that the revisions to the Fisheries Act (1985) and modern land claims agreements appear to create a management paradox in trying to resolve the question of harvest rights versus conservation. On the surface, they would appear to be. While the harvest and consumption of wildlife are integral to the livelihood, culture, and nutritional status of the Inuit of northern Canada (Kenny & Chan, 2017), the concern for long term sustainability and a broader focus on preserving ecosystem components (e.g., Adams et al., 2021) are more amenable to western concerns for the development of sustainability and ecosystem management. The land claim agreements provide a governance structure for the management of subsistence harvesting in the north that could via a Management Procedure approach balance harvesting rights and priorities with the protection of the renewable resource economy (principles of conservation). The framework presented here shares broad similarities to other frameworks, which reflects the common scientific concepts upon which they are based, but even within the international context (e.g., International Whaling Commission [IWC]) there is recognition that subsistence harvests may differ from normal commercial harvest objectives (Tables 1 and 4; Butterworth & Best, 1994; National Marine Fisheries Service [NMFS], 2016, 2023). Globally, there has been recognition that not one size fits all, resulting in a movement towards management-oriented approaches to stock assessment and adaptive fisheries management that can evaluate alternative management procedures via simulation (Punt al., 2016; Berkes et al., 2000; Anderson et al., 2021; Marentette et al., 2021; McQuaw et al., 2021; Damiano et al., 2022). The development and evaluation of the Management Procedure provides an opportunity to include hunters directly in the development of the particular management framework and to identify and test the performance of different management approaches taking into account Indigenous Knowledge systems (i.e., “two-eyed seeing” according to Reid et al., 2021), quantitative developed reference limits associated with MSY and/or more diverse management objectives.

ADHERENCE TO ANIMAL WELFARE PROTOCOLS

The research presented in this article has been done in accordance with the institutional and national laws and protocols for animal welfare that are applicable in the jurisdictions where the work was conducted.

AUTHOR CONTRIBUTION STATEMENT

M. Hammill: Conceptualization, Writing – original draft, Writing- review and editing; **G. Stenson:** Conceptualization, Writing – original draft, Writing- review and editing; **T. Doniol-Valcroze:** Writing- reviewing and editing; **S. Lang:** Writing-reviewing and editing.

REFERENCES

Adams, M. S., Connors, B., Levi, T., Shaw, D., Walkins, J., Rogers, S., & Darimont, C. (2021). Local Values and Data Empower Culturally Guided Ecosystem-Based Fisheries Management of the Wuikinuxv Bear–Salmon–Human System. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 13*, 362–378. https://doi.org/10.1002/mcf2.10171

Anderson, S. C., Forrest, R. E., Huynh, Q. C., & Keppel, E. A. (2021). *A management procedure framework for groundfish in British Columbia* (Document No. 2021/007). Department of Fisheries and Oceans Canada, Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/41026913.pdf

Armitage, D. R., Okamoto, D. K., Silver, J. J., Francis T. B., Levin, P. S., Punt, A. E., … & Woodruff, J. (2019). Integrating governance and quantitative evaluation of resource management strategies to improve social and ecological outcomes. *Bioscience, 69,* 523–532. https://doi.org/10.1093/biosci/biz059

Berkes, F., Colding, C., & Folke C. (2000). Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications, 10*, 1251-1262. https://doi.org/10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2

Biddlecombe, B. A., & Watt, C. A. (2022). *Estimated population abundance and probability of population decline for Northern Hudson Bay narwhal* (Monodon monoceros) (Research Document No. 2022/019). Canadian Science Advisory Secretariat Science Research. https://publications.gc.ca/collections/collection_2022/mpo-dfo/fs70-5/Fs70-5-2022-019-eng.pdf

Boyd, I. L., Thompson, D. & Lonergan, M. (2010*).* Potential biological removal as a method for setting the impact limits for UK marine mammal populations (Briefing paper no. 10/8). In *SCOS Main Advice 2010 – Scientific advice on matters related to the Management of seal Populations: 2010.* Special Committee on Seals – SCOS, University of St Andrews. https://www.smru.st-andrews.ac.uk/files/2016/08/SCOS-2010.pdf

Brandon, J. R., Punt, A. E., Moreno, P., & Reeves, R. R. (2017). Toward a tier system approach for calculating limits on human-caused mortality of marine mammals. *ICES Journal of Marine Science, 74,* 877–887. https://doi.org/10.1093/icesjms/fsw202

Breton-Honeyman, K., Huntington, H. P., Basterfield, M., Campbell, K., Dicker, J., Gray, T., … & Zdor, E. (2021). Beluga whale stewardship and collaborative research practices among Indigenous peoples in the Arctic. *Polar Research, 40,* 5522, http://dx.doi.org/10.33265/polar.v40.5522.

Butterworth, D. S. (2007). Why a management procedure approach? Some positives and negatives. *ICES Journal of Marine Science, 64,* 613–617. https://doi.org/10.1093/icesjms/fsm003

Butterworth, D. S., & Best, P. B. (1994). The origins of the choice of 54% of carrying capacity as the protection level for baleen whale stocks and the implications thereof for management procedures. *Reports of the International Whaling Commission, 44*, 491–497.

Committee on the Status of Endangered Wildlife in Canada [COSEWIC] (2024). https://www.cosewic.ca/index.php/en/

Convention on the Law of the Sea, 1833 U.N.T.S. 397 (1982). https://treaties.un.org/doc/Publication/UNTS/Volume%201833/volume-1833-A-31363-English.pdf

Curtis, K. A., Moore, J., Boyd, C., Dillingham, P. W., Lewison, R. L., Taylor, B. L. & James, K. C. (2015). Managing catch of marine megafauna: Guidelines for setting limit reference points. *Marine Policy, 6*, 249–263. https://doi.org/10.1016/j.marpol.2015.07.002

Dale, A., & Armitage, D. (2011). Marine mammal co-management in Canada’s Arctic: Knowledge co-production for learning and adaptive capacity. *Marine Policy, 35,* 440–449. https://doi.org/10.1016/j.marpol.2010.10.019

Damiano, M., Wager, B., Rocco, A., Shertzer, K.W., Murray, G.D., & Cao, J. (2021). Integrating information from semi-structured interviews into management strategy evaluation: A case study for southeast United states marine fisheries. *Frontiers in Marine Science, 9,* 1063260. https://doi.org/10.3389/fmars.2022.1063260

Department of Agriculture, Fisheries and Forestry (DAFF) (2018). *Commonwealth fisheries harvest strategy policy. Policy and Guidelines.* https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/fisheries/domestic/hsp.pdf

Department of Fisheries and Oceans Canada (DFO) (2006). *A Harvest Strategy Compliant with the Precautionary Approach* (Report 2006/023). Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/322464.pdf

Department of Fisheries and Oceans Canada (DFO) (2009). A Fishery Decision-Making Framework Incorporating the Precautionary Approach [Framework]. http://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/precaution-eng.htm

Department of Fisheries and Oceans Canada (DFO) (2013). *Proceedings of the National Workshop for Technical Expertise in Stock Assessment (TESA): Maximum Sustainable Yield (MSY) Reference Points and the Precautionary Approach when productivity varies* (Report 2012/055). Canadian Science Advisory Secretariat. https://publications.gc.ca/collections/collection_2013/mpo-dfo/Fs70-4-2012-055-eng.pdf

Department of Fisheries and Oceans Canada (DFO) (2015). *Estimate of abundance and total allowable removals for Hudson Bay-Davis Strait and South and East Hudson Bay Atlantic walrus (*Odobenus rosmarus rosmarus*) stocks* (Report 2015/063). Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/4057491x.pdf

Department of Fisheries and Oceans Canada (DFO) (2016a). *Estimate of abundance and total allowable removals for Atlantic walrus (*Odobenus rosmarus rosmarus*) in Foxe Basin* (Report 2016/007). Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/365442.pdf

Department of Fisheries and Oceans Canada (DFO) (2016b). *Status of beluga (*Delphinapterus leucas*) in Cumberland Sound, Nunavut* (Report 2016/037). Canadian Science Advisory Secretariat. https://publications.gc.ca/collections/collection_2016/mpo-dfo/Fs70-6-2016-037-eng.pdf

Department of Fisheries and Oceans Canada (DFO) (2018). *Harvest advice for eastern and western Hudson Bay beluga (*Delphinapterus leucas*)* (Report 2018/008). Canadian Science Advisory Secretariat. https://publications.gc.ca/collections/collection_2018/mpo-dfo/fs70-6/Fs70-6-2018-008-eng.pdf

Department of Fisheries and Oceans Canada (DFO) (2019). *Sustainable harvest advice for Cumberland Sound beluga based on the 2017 aerial survey and modelled abundance estimates* (Report 2019/024). Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/4081841x.pdf

Department of Fisheries and Oceans Canada (DFO) (2020). *2020 Harvest advice for eastern Hudson Bay beluga (*Delphinapterus leucas*)* (Report 2020/031). Canadian Science Advisory Secretariat. https://publications.gc.ca/collections/collection_2020/mpo-dfo/fs70-6/Fs70-6-2020-031-eng.pdf

Department of Fisheries and Oceans Canada (DFO) (2021). *Science advice for precautionary approach harvest strategies under the fish stocks provision* (Report 2021/004). Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40965715.pdf

Department of Fisheries and Oceans Canada (DFO) (2023). *Eastern Beaufort Sea Beluga (*Delphinapterus leucas*) Population Abundance Estimate in 2019* (Report 2023/047). Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/41220699.pdf

Doniol-Valcroze, T., Gosselin, J.-F., Pike, D., Lawson, J., Asselin, N., Hedges, K., & Ferguson, S. H. (2015). *Abundance estimates of narwhal stocks in the Canadian High Arctic in 2013* (Research Document 2015/060). Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/362110.pdf

Ferguson, S. H., Higdon, J. W., Hall, P. A., Hansen, R., & Doniol-Valcroze, T. (2021). Developing a Precautionary Management Approach for the Eastern Canada-West Greenland population of Bowhead Whales (*Balaena mysticetus*). *Frontiers in Marine Science, 8,* 709989 https://doi.org/10.3389/fmars.2021.709989

Fisheries Act, R.S.C., c.F-14 [Canada] (1985). https://laws.justice.gc.ca/eng/acts/f-14/page-2.html#h-1175547

Frid, A., Wilson, K. L., Walkus, J., Forrest, R. E., & Reid, M. (2023). Re-imagining the precautionary approach to make collaborative fisheries management inclusive of Indigenous Knowledge Systems. *Fish and Fisheries, 24,* 940–958. https://doi.org/10.1111/faf.12778

Hammill, M. O., Rossi, S. P., Mosnier, A., den Heyer, C. E., Bowen, W. D., & Stenson, G. B. (2023a). *Grey Seal Abundance in Canadian Waters and Harvest Advice* (Research Document 2023/053). Canadian Science Advisory Secretariat. https://www.dfo-mpo.gc.ca/csas-sccs/Publications/ResDocs-DocRech/2023/2023_053-eng.html

Hammill, M. O., St-Pierre, A. P., Mosnier, A., Parent, G. J., & Gosselin, J.-F. (2023b). *Total Abundance and Harvest Impacts on Eastern Hudson Bay and James Bay Beluga 2015–2022* (Research Document 2023/066). Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/41219235.pdf

Hammill, M.O., & Stenson, G. B. (2003). *Application of the Precautionary Approach and Conservation Reference Points to the management of Atlantic seals: A Discussion Paper* (Research Document, 2003/067). Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/277448.pdf

Hammill, M. O., & Stenson, G. B. (2007). Application of the Precautionary Approach and Conservation Reference Points to the management of Atlantic seals. *ICES Journal of Marine Science, 64,* 702–706. https://doi.org/10.1093/icesjms/fsm037

Hammill, M. O., Stenson, G. B., & Doniol-Valcroze, T. (2017). A management framework for Nunavik beluga (Research Document 2017/060). Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/4064411x.pdf

Hammill, M. O., Stenson, G. B., Doniol-Valcroze, T., & Mosnier, A. (2015). Conservation of northwest Atlantic harp seals: Past success, future uncertainty? *Biological Conservation, 192,* 181–191. http://dx.doi.org/10.1016/j.biocon.2015.09.016

Hammill, M. O., Stenson, G. B., Mosnier, A., & Doniol-Valcroze, T. (2021). *Trends in abundance of harp seals,* Pagophilus groenlandicus*, in the Northwest Atlantic, 1952-2019* (Research Document 2021/006). Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40958899.pdf

Hilborn, R., Maguire, J.-J., Parma, A. M., & Rosenberg, A. A. (2001). The precautionary approach and risk management: can they increase the probability of successes in fisheries management. Canadian. *Journal of Fisheries and Aquatic Science, 58,* 99–107.

International Council for the Exploration of the Sea (ICES) (2006) *Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP)* (Report ICES CM 2006/ACFM:32). *ICES Expert Group reports*. https://doi.org/10.17895/ices.pub.19267802.v1

International Whaling Commission (IWC) (1994). *Forty-Fourth report of the International Whaling Commission* (Annual Report 1994). https://archive.iwc.int/pages/view.php?ref=48&k=#Header

James Bay and Northern Quebec Agreement (JBNQA) (1975). https://www.cngov.ca/wp-content/uploads/2018/03/01-_james_bay_and_northern_quebec_agreement__consolidated_to_september_13__2013_-1.pdf

Kenny, T.-A., & Chan, H. M. (2017). Estimating wildlife harvest based on reported consumption by Inuit in the Canadian Arctic. *Arctic, 70*, 1–12. https://doi.org/10.14430/arctic4625

Lassen, H., Kelly, C., & Sissenwine, M. (2014). ICES advisory framework 1977–2012: from Fmax to precautionary approach and beyond. *ICES Journal of Marine Science, 71*, 166–172. https://doi.org/10.1093/icesjms/fst146

Lovecraft, A. L., & Meek, C. L. (2011). The human dimensions of marine mammal management in a time of rapid change: comparing policies in Canada, Finland and the United States. *Marine Policy, 35,* 427–429. https://doi.org/10.1016/j.marpol.2010.10.022

Mace, P. M. (2001). A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. *Fish and Fisheries, 2,* 2–32. https://doi.org/10.1046/j.1467-2979.2001.00033.x

Magnuson-Stevens Fishery Conservation Act, P. L. 109–479 [United States] (2007). https://www.govinfo.gov/content/pkg/PLAW-109publ479/pdf/PLAW-109publ479.pdf

Mangel, M., & Levin, P. S. (2005). Regime, phase and paradigm shifts: making community ecology the basic science for fisheries. *Philosophical Transactions of the Royal Society Biological Sciences, 360,* 95–105. https://doi.org/10.1098/rstb.2004.1571

Marcoux, M., & Hammill, M. O. (2016). *Model estimates of Cumberland Sound beluga (*Delphinapterus leucas*) population size and total allowable removals* (Research Document 2016/077). Canadian Science Advisory Secretariat Science. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40573850.pdf

Marcoux, M., Montsion, L. M., Dunn, J. B., Ferguson, S., & Matthews, C. J. D. (2019). *Estimate of the abundance of the Eclipse Sound narwhal (*Monodon monoceros*) summer stock from the 2016 photographic aerial survey* (Research Document 2019/028). Canadian Science Advisory Secretariat. https://publications.gc.ca/collections/collection_2019/mpo-dfo/fs70-5/Fs70-5-2019-028-eng.pdf

Marentette, J. R., Kronlund, A. R., & Cogliati, K. M. (2021). *Specification of Precautionary Approach Reference Points and Harvest Control Rules in Domestically Managed and Assessed Key Harvested Stocks in Canada* (Research Document, 2021/057). Canadian Science Advisory Secretariat. https://publications.gc.ca/collections/collection_2021/mpo-dfo/fs70-5/Fs70-5-2021-057-eng.pdf

Marine Mammal Protection Act (MMPA) [United States] (2019) https://www.mmc.gov/about-the-commission/our-mission/marine-mammal-protection-act/

McGregor, D. (2021). Indigenous knowledge Systems in Environmental Governance in Canada. *Kula, 5(1),* 1–10. https://doi.org/10.18357/kula.148

McQuaw, K., Punt, A.E., & Hilborn, R. (2021). Evaluating alternative rebuilding plans for mixed stock fisheries. *Fisheries Research, 240.* https://doi.org/10.1016/j.fishres.2021.105984

McIlgorm, A. (2013). *Literature study and review of international best practice, fisheries harvest strategy policy approaches. A report to the Department of Agriculture Fisheries and Forestry (DAFF).* ANCORS, University of Wollongong. https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/fisheries/domestic/harvest-strategy-policy/ancors.pdf

Ministry of Fisheries [New Zealand] (2008). *Harvest Strategy Standard for New Zealand Fisheries. Ministry of Fisheries New Zealand.* https://www.mpi.govt.nz/dmsdocument/728-Harvest-Strategy-Standard-for-New-Zealand-Fisheries

Moore, J. E., Curtis, K. A., Lewison, R. L., Dillingham, D. P., Cope, J. M., Fordham, S. V., ... & Zhou, S. (2013). Evaluating sustainability of fisheries bycatch mortality for marine megafauna: a review of conservation reference points for data-limited populations. *Environmental Conservation, 40,* 329–344 https://doi.org/10.1017/S037689291300012X

National Marine Fisheries Service (NMFS) (2016). *Guidelines for the preparing stock assessment reports pursuant to the 1994 amendments to the Marine Mammal Protection Act* (Instruction 02-204-01). https://media.fisheries.noaa.gov/dam-migration/guidelines_for_preparing_stock_assessment_reports_2016_revision_gamms_iii_opr2.pdf

National Marine Fisheries Service (NMFS) (2023). *Guidelines for the preparing stock assessment reports pursuant to the 1994 amendments to the Marine Mammal Protection Act* (Instruction 02-204-01). https://www.fisheries.noaa.gov/s3/2023-05/02-204-01-Final-GAMMS-IV-Revisions-clean-1-kdr.pdf

Nonkes, C., Duncan, A. T., Lauzon, R., Ryan, K., Reid, A. J., Cooke, S. J., & Young. N. (2021). Two-eyed seeing: Developing perspective and wisdom on sea lamprey in the Laurentian Great Lakes. *Journal of Great Lakes Research, 49,* S148–S159. https://doi.org/10.1016/j.jglr.2023.03.001

Nunavut Land Claim Agreement Act (NLCA), S.C., c. 29 (1993). https://laws-lois.justice.gc.ca/eng/acts/n-28.7/

Nunavik Inuit Land Claim Agreement (NILCA) (2006). https://www.rcaanc-cirnac.gc.ca/eng/1320425236476/1551119558759

Office of the Federal Register, National Archives and Records Administration [United States] (2016). *81 FR 54390 - Fish and Fish Product Import Provisions of the Marine Mammal Protection Act*. Office of the Federal Register, National Archives and Records Administration. https://www.govinfo.gov/app/details/FR-2016-08-15/2016-19158Fmange

Pella, J. J., & Thomlinson, P. K. (1969). A generalized stock production model. *Bulletin of the Inter-American Tropical Tuna Commission, 13,* 420–496.

Punt, A. E., Butterworth, D. S., de Moor, C. L. De Oliveira, J. A. A., & Haddon, M. (2016). Management strategy evaluation: best practices. *Fish and Fisheries, 17,* 303–334. https://doi.org/10.1111/faf.12104

Punt, A. E., Smith, A. D. M., Smith, D. C., Tuck, G. N., & Klaer, N. L. (2014). Selecting relative abundance proxies for BMSY and BMEY. *ICES Journal of Marine Science, 71(3),* 469–483. https://doi.org/10.1093/icesj ms/fst162

Reid, A. J, Eckert, L. E., Lane, J-F, Young, N., Hinch, S. G., Darimont, C. T., ... & Marshal A. (2021). "Two-eyed Seeing": An Indigenous framework to transform fisheries research and management. *Fish and Fisheries, 22,* 243–261. https://doi.org/10.1111/faf.12516

Richard, Y., & Abraham, E. R. (2013). *Application of Potential Biological Removal methods to seabird populations* (Report no. 108). New Zealand Aquatic Environment and Biodiversity, Ministry of Primary Industries [New Zealand]. https://www.ccsbt.org/en/system/files/resource/en/51f607b8d433c/ERSWG10_info07_NZ_App_potencial_biological_risk.pdf

Silver, J. J., Okamoto, D. K., Armitage, D., Alexander, S. M., Atleo, C., Burt, J. M., … & Stoll, J. S. (2022). Fish, People, and Systems of Power: Understanding and Disrupting Feedback between Colonialism and Fisheries Science. *American Naturalist, 200,* 168–180. https://doi.org/10.1086/720152

Stenson, G. B., Hammill, M., Ferguson, S., Stewart, R. & Doniol-Valcroze, T. (2012). *Applying the Precautionary Approach to Marine Mammal Harvests in Canada* (Research Document 2012/107). Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/347895.pdf

Suluk, T. K., & Blakeny, S. L. (2008). Land claims and resistance to the management of harvester activities in Nunavut. *Arctic, 61 (5),* 62–70. https://doi.org/10.14430/arctic102

Tinker, M. T., Stenson, G. B., Mosnier, A. & Hammill, M. O. (2023). *Estimating abundance of Northwest Atlantic harp seal using a Bayesian modelling approach* (Research Document 2023/068). Canadian Science Advisory Secretariat Science. https://publications.gc.ca/collections/collection_2023/mpo-dfo/fs70-5/Fs70-5-2023-068-eng.pdf

Wade, P. (1998). Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. *Marine Mammal Science, 14,* 1–37. https://doi.org/10.1111/j.1748-7692.1998.tb00688.x

Walter III, J. F., Peterson, C. D., Marshall, K., Deroba, J.J., Gaichas, S. Williams, B.C., … & Ahrens, R. (2023). When to conduct, and when not to conduct, management strategy evaluations. *2012Journal of Marine Science. 80,* 719–727 https://doi.org/10.1093/icesjms/fsad031

Watt, C. A., Marcoux, M., Hammill, M. O., Montsion, L., Hornby, C., Charry, B., … & Matthews, C. J. D. (2021). *Abundance and total allowable landed catch estimates from the 2017 aerial survey of the Cumberland Sound beluga (*Delphinapterus leucas*) population* (Research Document 2021/050). Canadian Science Advisory Secretariat. https://publications.gc.ca/collections/collection_2021/mpo-dfo/fs70-5/Fs70-5-2021-050-eng.pdf

Weber, D. S., Mandler, T., Dyck, M., Van Coeverden De Groot, P. J., Lee, D. S., and Clark, D. A. (2015). Unexpected and undesired conservation outcomes of wildlife trade bans-An emerging problem for stakeholders. *Global Ecology and Conservation 3,* 389–400. https://doi.org/10.1016/j.gecco.2015.01.006