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Design of Ecological Risk Criteria for the Integrated Management of Canadian Oceans

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Foreword

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

Research documents are produced in the official language in which they are provided to the Secretariat.

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TABLE OF CONTENTS

ABSTRACT

Ecological risk criteria (ERC) are used in Canada and around the world within risk assessment and management frameworks. The purpose of this Research Document is to evaluate and compare ERC risk categories and thresholds for use within the context of DFO's ecosystem-based integrated oceans management (IOM) plan.

In particular, we investigated how DFO's 2006 ERC were aligned with existing categories and thresholds used within other existing frameworks, and the biological significance of each criterion. Within that context, we asked:

1) How realistic is it to compartmentalize spectrums of risk into separate categories and thresholds; and,
2) For nationally applicable ERC, how do we assign risk categories and thresholds that are general enough to be applied across a wide range of situations, geographic locations and scales, timings and human activities, yet specific enough to address complex ecological responses to environmental pressures?

Review of existing ERCs founds a range of appropriate models, with the majority consisting of three or five categories. Both three and five category ERCs generally had a "low" or "negligible" risk category and a "high" or "intolerable" risk category, with 1-3 intermediate categories of increasing risk levels. The number of intermediate categories was based on management outcomes, and perhaps on the accuracy and precision of available data. Thresholds among levels were often context dependent, and based on regional baselines or benchmarks. In some cases (such as certain contaminants, e.g., mercury), however, predefined thresholds were used. Given natural variations, in some cases there was difficulty determining at what point thresholds become too uncertain to be helpful.

Conception de critères de risque écologique pour la gestion intégrée des océans du Canada

RÉSUMÉ

Les critères de risque écologique (CRE) sont utilisés au Canada et partout sur la planète au sein de cadres de gestion et d'évaluation des risques. Le présent document de recherche vise à évaluer et à comparer les catégories et les seuils de risques des CRE utilisés dans le contexte du plan de gestion intégrée des océans (GIO) fondée sur une approche écosystémique du MPO.

Plus précisément, nous avons étudié l'harmonie entre les CRE de 2006 du MPO et les catégories et les seuils existants utilisés dans d'autres cadres, ainsi que l'importance biologique de chaque critère. Dans ce contexte, nous nous sommes posé les questions suivantes :

1) Est-il réaliste de compartimenter les spectres des risques dans des catégories et des seuils distincts;
2) En ce qui concerne les CRE applicables à l'échelle nationale, comment pouvons-nous attribuer des catégories et des seuils de risque suffisamment généraux pour être appliqués à un large éventail de situations, de lieux et d'échelles géographiques, de moments et d'activités humaines tout en étant suffisamment précis pour présenter des réponses écologiques complexes aux pressions environnementales?

L'examen des CRE actuels a permis de déterminer une gamme de modèles adéquats, dont la plupart comportent trois ou cinq catégories. Les CRE comptant trois ou cinq catégories incluaient généralement une catégorie de risque « faible » ou « négligeable » et une catégorie de risque « élevé » ou « intolérable » ainsi qu'une à trois catégories intermédiaires de niveaux de risque croissants. Le nombre de catégories intermédiaires était fondé sur les résultats de gestion et, possiblement, sur l'exactitude et la précision des données disponibles. Les seuils des niveaux dépendaient souvent du contexte et étaient fondés sur des situations ou des points de référence régionaux. Toutefois, dans quelques cas (comme pour certains contaminants, dont le mercure), nous avons utilisé des seuils prédéfinis. En raison de variations naturelles, il a parfois été difficile de déterminer le point où les seuils devenaient trop incertains pour être utiles.

1. CONTEXT OF REPORT ON ECOLOGICAL RISK CRITERIA

The purpose of this report is to investigate and compare the categories and thresholds associated with the Ecological Risk Criteria (ERC) used in Canada and elsewhere within risk assessment and management frameworks in the context of integrated oceans management. In the context of this report, risk management is a methodology for aiding decision-making in ocean management regarding a wide range of human activities or geographic locations. This approach has a defined structure which has been laid out in the context of ecosystem management in Canadian (DFO 2006a) and international policy (Cormier et al. 2013). In a more general sense, risk management can be applied to a wide range of managerial decisions, and its growing acceptance as a critical tool for effective governance has led to its own certification category under the International Organization for Standardization (ISO 31000:2009; see Appendix 1 for list of acronyms). In environmental management the approach relies on a series of steps that identifies and evaluates the risk of a harmful change occurring to the state of the ecosystem if a particular activity is allowed to take place (Figure 1). Isolating the activities, and their associated risk, has multiple benefits including: 1) allowing targeted mitigation actions to be applied to reduce the impacts that are considered likely to cause the most risk of harm; 2) framing policy discussions in a predictive and precautionary manner such that relative changes in policy are determined by corresponding changes in the risk of particular outcomes; 3) setting clear reference points that can be monitored to ensure the state of the ecosystem remains within a preferred state; and 4) improving transparency in policy decisions. In most cases, the measures of risk may very well be continuous functions, such that as the magnitude of the environmental effects of a particular activity increases, the risk of harm to the ecosystem increases in a correspondingly linear or non-linear manner. However, the relationship between risk and activity is rarely known to such a fine degree of detail, and so categories of risk are identified (e.g. Low, Medium and High), and appropriate thresholds between categories are determined to place an activity within a risk category (Figure 2). Thus the risk categories and thresholds collectively make up the ERC and play an integral role in risk management frameworks.

Fisheries and Oceans Canada (DFO) has already developed several sector-based risk management frameworks related to assessing the risk of human activities which impact aspects of aquatic ecosystems (e.g. Fisheries Resource Management, Fisheries Protection, Species at Risk, etc.) and is currently developing ERC for broad use in integrated oceans management. These ERC will assist in determining what activities might be permitted under the *Oceans Act* and *Fisheries Act, and/or Species At Risk Act* within a geographic location. In this report, ERC from a range of regulations, policy and ecological studies are discussed in the context of designing appropriate risk categories and thresholds for oceans management. These ERCs will be applicable in the management of multi-use marine zones such as Ecologically and Biologically Significant Areas (EBSA) and Marine Protected Areas (MPA) and can assist in determining the risk of human activities to the ecosystem. DFO's existing departmental ERC include five risk categories however for a range of reasons a three risk category structure may be desirable given existing sector-based frameworks (See Appendix 2 for ERC frameworks related to DFO policies). This report asks two central questions for each ERC reviewed:

1. How well aligned are these categories or thresholds with DFO's 2006 ERC and is there a more appropriate/practical structure (e.g. a three-level ERC)?
2. For each framework considered, what are the characteristics associated with each of the ERC, and further, what are the characteristics of the boundaries between criteria?

Assigning a particular condition to a risk category would almost always involve site specific information, and potentially even repeated monitoring to determine reference conditions. However, for nationally applicable ERC, the risk categories and thresholds must be general enough to be applied across a wide range of situations, geographic locations, spatial and temporal scales, and human activities. This report offers a brief introduction to the role of ERCs in the process of risk management, followed by a brief introduction of common human activities in Canadian marine waters, and finally a review of ERCs that can address these situations.

ERC IN RISK MANAGEMENT

The impact of human activities on any ecosystem is typically difficult to predict because natural variability, the effectiveness of mitigation strategies, cumulative effects and changes of plan all lead to high uncertainty (Minns and Moore 2003, Moilanen et al 2009). Risk management frameworks address these uncertainties by determining the risk of harmful outcomes under a given set of circumstances, and risk can ultimately be considered as a function of the magnitude of interaction and the sensitivity of the ecosystem component or property (CP) (Figure 1). Depending on the degree of risk associated with a management decision, additional measures (e.g. mitigation, monitoring, regulation) can be taken until the risk to the ecosystem is deemed sufficiently small. This brief introduction to the process is based on the ICES Marine and Coastal Ecosystem Based Risk Management Handbook, which incorporates the ISO 31000:2009 and the World Trade Organization processes (Cormier et al. 2013).

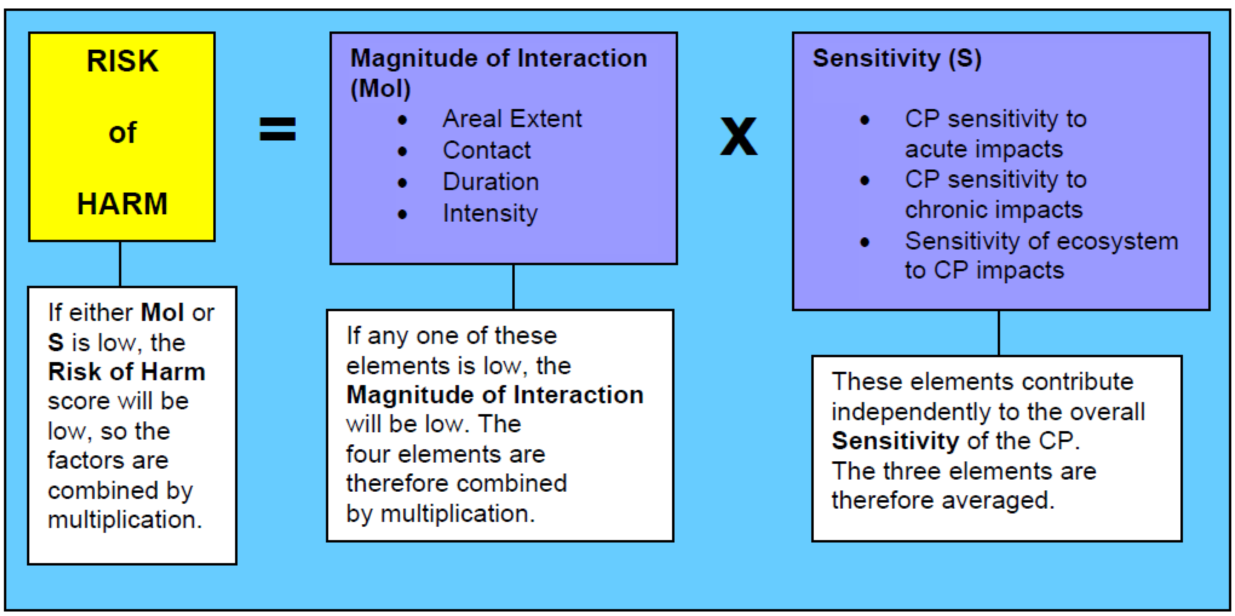

Figure 1. Risk of Harm calculation (Park et al. 2010).

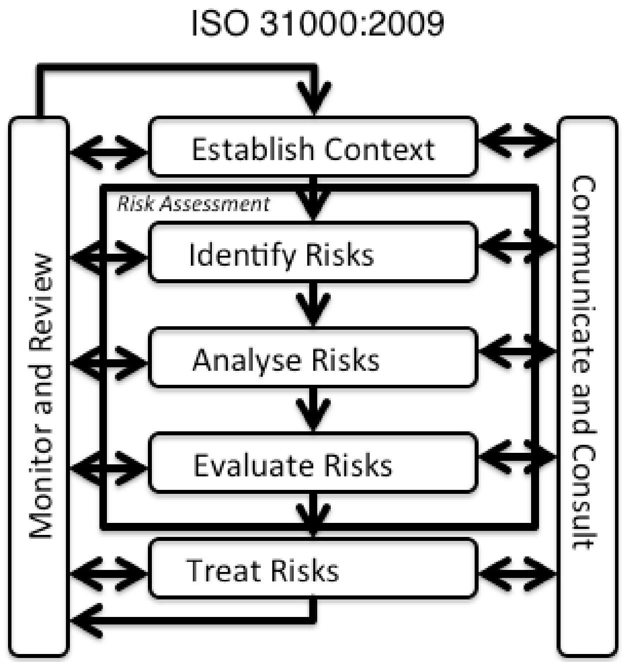

Figure 2. A risk management flow chart as described in the ISO 31000:2009 process.

The first stage of a risk management process typically involves setting the context of the management scenario and identifying the expected hazards that will require mitigation and management (see Figure 2). At this initial stage the ecological and management basis for managing risks must be identified as they relate to potential environmental effects. For example, if a potential environmental effect involves the destruction of fish habitat, the *Fisheries Act* and the Fisheries Protection Program may provide the proper context for managing the risks and mitigating the activities.

Next, the risk assessment stage is used to estimate the magnitude of and likelihood that the activities may cause a particular ecological impact. In this stage the vulnerabilities of the ecosystem and the environmental pressures from the activities are identified and evaluated together. To achieve this end, the assessment stage is further broken down into three steps: risk identification, risk analysis and risk evaluation. The risk identification step is particularly important, because here the spatial zone of influence, frequency, intensity and severity of the activity is described. From here, possibly by using a pathway of effects model, the potential impacts on ecosystem components can be identified and linked to ecosystem effects. If any of the ecosystem components are vulnerable to impact from the activities, the further steps of the risk analysis are prioritized to address those effects. The perceptions of stakeholders are important in the risk assessment processes, as the significance of some of the ecosystem components may be more prominent to the public or industry partners and thus require a different risk management strategy (i.e. more or less conservative). These views are considered when making policy or management decisions, but not in the scientific aspects of the risk assessment (i.e. potential interactions, and their magnitude, between human activities and the ecosystem). Based on the vulnerability profile of the ecosystem components, the risk analysis step estimates the likelihood of an impact based on existing control, mitigation and offsetting measures. Any gaps or inconsistencies at this step are used to determine if additional measures would be appropriate in the risk evaluation step. As such the possible outputs of this third step are:

1. no new measures are needed,
2. existing measures are adequate, and
3. new or enhanced measures should be considered to reduce the risk to the ecosystem.

The first two outputs are quite similar to each other and only require a review and monitoring of the activities, rather than any further management of the risks.

The final stage of the risk management process is risk treatment, which develops and implements the management strategies required by the risk evaluation step to eliminate, control or mitigate the risks of the activities harming the ecosystem. Throughout these three stages important processes occur on the side such as risk communication and environmental monitoring. The communication of the risk management process and results to local stakeholders, relevant management agencies and scientific bodies is critical for proper community engagement and also for prioritizing the activities that will be allowed to proceed in the area. Furthermore, monitoring programs will be required at most stages of the process to ensure that baseline, reference and post-impact data is collected to empirically measure any changes to the ecosystem components over time.

At all three stages, as well as the side processes, the ERC must be considered, and the definition of their categories helps a risk assessor move through the process. A well-defined set of ERC categories is necessary to set the context of the management scenarios in the initial stage of the risk management process, define the vulnerability profiles of the ecosystem components to human activities and consider pathways of effects that should be addressed. At the risk analysis stage ERC are critical to the process because they establish the levels of risk that will be evaluated for a particular activity. It is in this risk evaluation phase that a decision is taken either to accept the risk at its current level or to design and implement additional steps (risk mitigation or risk treatment) to reduce the risk level. For example, a moderate risk of population decline may be deemed acceptable for a widely distributed species of little economic, ecological or social value, whereas the lowest risk category might be required for any species with conservation listings.

The framing of the ERC is thus a necessary process that must occur prior to the risk assessment. In ecosystem and environmental management, the ERC might be framed best by the overarching goal of strategic policy objectives or the mandate of management agencies. Often the goal of environmental management is to sustain, protect or conserve a resource (e.g. a fishery), or alternatively, avoid a particular effect (e.g. contamination). Therefore, it is useful to note that the preferred outcomes of management actions can be used to work backwards towards framing the ERC to ensure these objectives are met. For example, the European Union Good Environmental Status (EU GES) describes a set of outcomes based on 11 descriptors that cover the functioning of the ecosystem. The descriptors read like end goals but include enough detail to note the relevant ecosystem services. An example reads:

“Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographical, and climate conditions.”

In this descriptor, regional species and aquatic habitats are a management priority and can be defined based on their quality, quantity and location. The other 10 descriptors range between ecosystem parameters (e.g. trophic pathways, biodiversity and seabed integrity) and individual pressures from human activities (e.g. noise and pollution). Similarly, the Canadian *Oceans Act* and the Canada Oceans Strategy states that the mandate of these policies is to:

- Promote the understanding of oceans, ocean processes, marine resources and marine ecosystems to foster the sustainable development of the oceans and their resources;
- Hold that conservation, based on an ecosystem approach, is of fundamental importance to maintaining biological diversity and productivity in the marine environment;
- Promote the wide application of the precautionary approach to the conservation, management and exploitation of marine resources in order to protect these resources and preserve the marine environment;
- Recognize that the oceans and their resources offer significant opportunities for economic diversification and the generation of wealth for the benefit of all Canadians, and in particular for coastal communities; and
- Promote the integrated management of oceans and marine resources.

From these statements ERCs provide risk categories that address the sustainability of marine resources including the conservation of marine biodiversity and opportunities for economic development. A further benefit of framing ERCs within the context of current legislation and regulations is that management measures (e.g. gear restrictions, area closures, encounter protocols, by-catch limits, codes of contact and seasonal restrictions, etc.) and regulatory powers are often already in place and well defined. If the individual pressures have a quality that makes their regulation self-evident, then it is possible that they can be used to define the thresholds between the ERC categories (e.g. release of harmful contaminants), but more often it is the expected change to an ecosystem component due to a pressure that must be quantified in some way. For example, the effect of fishing on a stock can be an individual pressure (i.e. the harvest) on an ecosystem component (i.e. a fish population), and the typical management goal is to sustainably harvest the fishery. To achieve this goal stock reference points are developed as targets for precautionary harvests (see Figure 3; DFO 2006b). At stock sizes above the Upper Stock Reference the risk of an unsustainable fishery is very low, but below this threshold, the risk of low recruitment increases and so the overall risk is moderate. At stock sizes below the Limit Reference Point, the fish population is no longer able to replace the harvest rate, and so the risk of population decline is high. The Upper Stock Reference and Limit Reference Point thus provide the thresholds for a three category ERC focused on the changes to a fish stock based on the effects of a fishery (Figure 3). In this scenario, fishery managers can control the removal rate depending on the accepted risk tolerance and know how these rates are likely to impact the stock status.

Fisheries Protection Provisions (FPP; DFO 2013) were implemented in the Fisheries Act to inform decision-making for productivity and sustainability of Canadian Commercial, Recreational, and Aboriginal (CRA) fisheries. A general framework showing the productivity of species considered under CRA was developed (Figure 4) and theoretical response patterns were modeled for a variety of potential stressors (DFO 2013). As outlined in Figure 4, the goals of the FPP framework include identifying reference benchmark and depressed productivity levels across stressor gradients, and identifying the thresholds at which stressors switch from having negligible to moderate impact, and moderate to severe impact, on CRA productivity.

The previous examples from DFO's precautionary approaches to fisheries and EU GES are fairly straight forward, however, impacts to aquatic systems from human activities often have multiple effects on a range of ecosystem services. Sometimes it is easier to group types of effects under broad categories. For example, environmental effects might be designated as a disruption (i.e. short term, small scale, relatively easy to mitigate), alteration (change in habitat or biodiversity with low chance of restoration) or degradation (permanent loss of ecosystem function). Further, types of impacts might be categorized as either operating from inside (i.e.

endogenous) or outside (i.e. exogenous) the ecosystem. In this case the spatial scale of the ecosystem, ecological unit (e.g. the distribution of a particular stock) and management area are important to identify relative to the spatial scale of the impact. While socio-economic or cultural values are not considered when identifying pathways of effects, they do inform what types of changes to the ecosystem would be considered minor versus catastrophic. This final point suggests that decisions regarding the mitigation of impacts will consider ecological characteristics as well as other factors through theory or predictive modelling. In some cases, qualitative or even economic considerations will set the risk tolerance level and related thresholds. Predictive modelling approaches allow estimation of the likelihood of the ecosystem effects, and indicators for mitigation strategies and monitoring can be clearly identified.

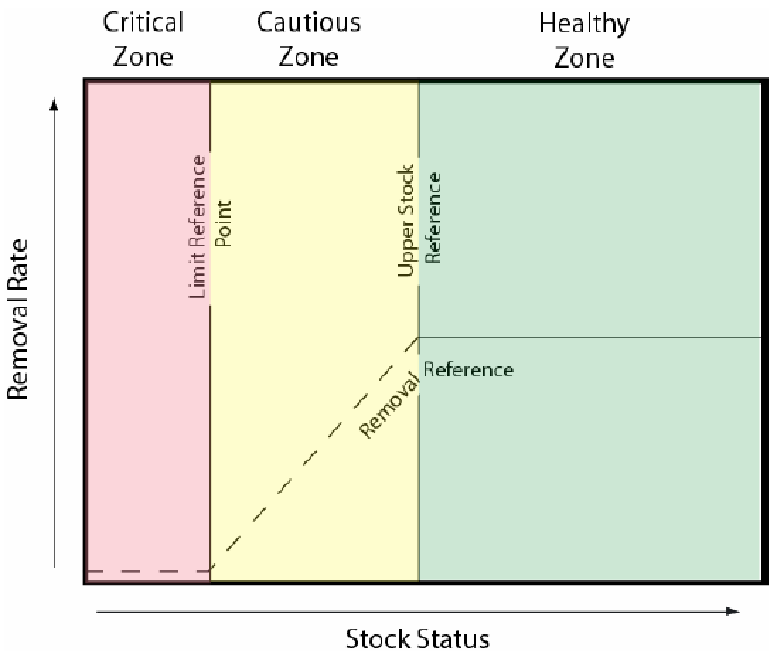

Figure 3. A fisheries management framework that is consistent with a precautionary approach, and identifies three risk categories (Critical, Cautious, and Healthy) and two thresholds (Limit Reference Point and Upper Stock Reference). (Source DFO 2006b)

In an ecological risk assessment framework originally designed for oceans management in Canada's Pacific Region but since expanded to areas of the Arctic, three levels of qualitative to quantitative risk assessment methodologies are described (CSAS 2012). The first level, Qualitative Risk Assessment, is used to provide rapid assessments of vulnerable ecosystem components, and is based entirely on literature reviews, qualitative site-specific descriptions and expert judgment. This rapid approach is suitable for identifying the most common pathways-of-effects from human activities and ranking those impact-environment combinations that require more study. The second level, Semi-quantitative Risk Assessment, is flexible in terms of methodologies, and focusses mainly on assessing the risks to ecosystem components from activities at different ecological and spatial scales. This addresses cumulative impacts, includes the influence of natural variation, and can be used to predict the relative risk to the ecosystem from the loss of particular ecosystem components. The third level, Quantitative Risk Assessment, is the most involved and includes ecological models ranging from stock assessment models, trophic linkages and population viability analyses. Besides the high amount of effort and site-specific data required at this level of risk assessment, it is a challenge to use a methodology that can be equally applied to all the ecosystem components and human activities involved in the management decision. However, the great benefit is that the specific case can be clearly assigned to a particular ERC.

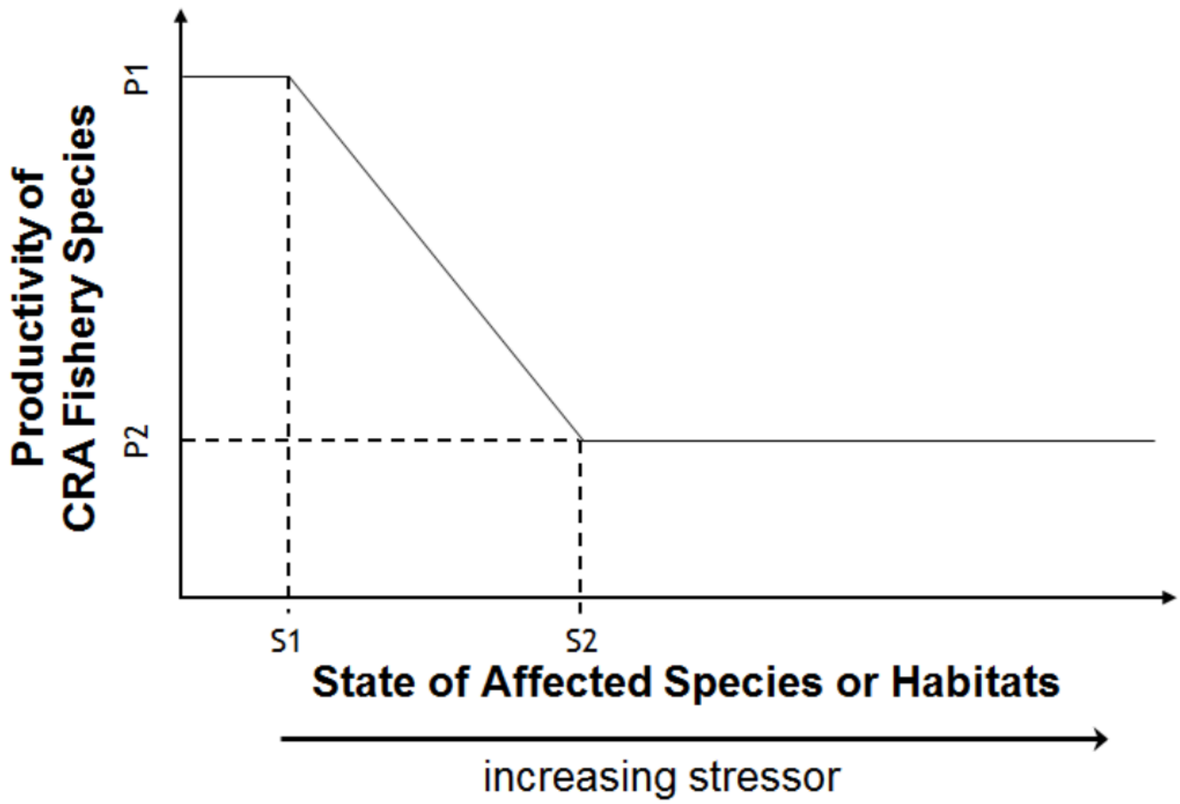

Figure 4. Schematic of the contribution framework from the Fisheries Protection Provisions (FPP) for Commercial, Recreational, and Aboriginal (CRA) fisheries. The y-axis represents productivity measured along a continuum from low (bottom) to high (top). The x-axis represents state along a continuum from good (left) to poor (right), movement along the x-axis represents a change in state of species or habitats as stressors increase. Four reference points are identified: P1 is the benchmark reference productivity of the CRA fishery species; P2 is the depressed productivity of the CRA fishery species under maximum total or cumulative change to the affected species or habitats; S1 is a threshold state to the left of which stressors have little or no impact on fishery productivity (i.e., the upper plateau) and to the right of which productivity declines as state is further reduced; S2 is the threshold where the maximum total or cumulative change is large enough to eliminate the contribution of the affected species or habitats to the ongoing productivity of the CRA fishery species (i.e., the lower plateau). (Source: DFO 2013)

As we have presented here, the role of the ERCs is to not only guide the risk assessment process but also to provide the thresholds between risk categories that will determine what level of risk a particular activity poses to one or more ecosystem components. However, it is important to note how difficult it can be to not only define these boundaries, but also evaluate multiple activities and multiple ecosystem components under one risk assessment. Stephenson and Hartwig (2009) conducted a risk assessment of marine activities on Yukon's North Slope. Figure 5 demonstrates all the pathways of effects from the seven activities, to the eight pressures to the seven ecosystem components and to the seven social economic dependencies on those ecosystem services. It is clear that each activity leads to multiple pressures, which also lead to multiple ecosystem components such that there is a thick web of linkages. In evaluating this entire system, each activity is analyzed based on general risk assessment criteria (i.e. Low, Medium and High), even though the nature of activity and the ecosystem service might be different between activities. To compare all activities their risk level is super-imposed over a generic risk landscape defined by the likelihood of the activity causing an impact and the severity of that impact (Figure 6). The outcome is that the effect of the activities on entire system can be standardized and compared.

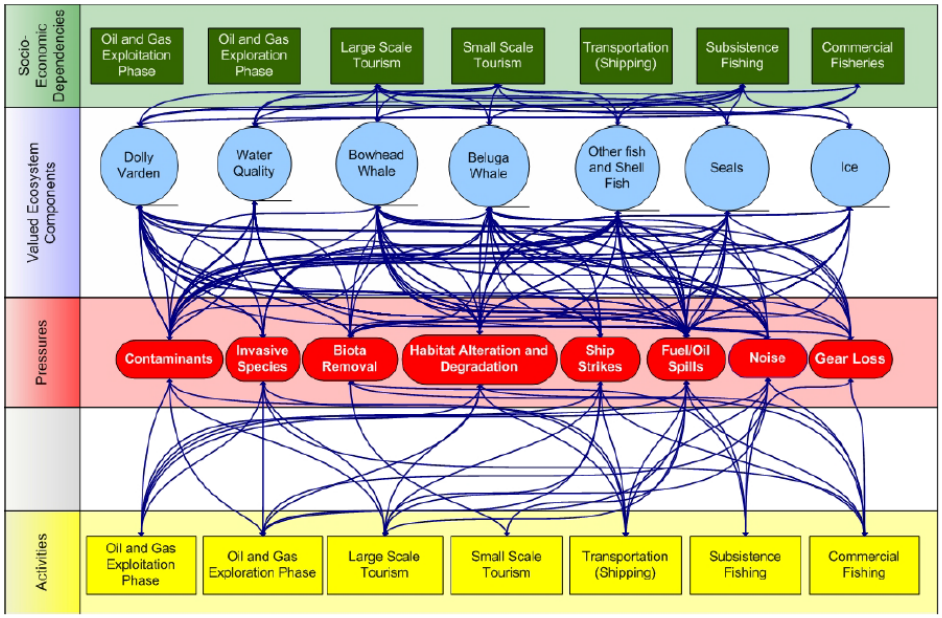

Figure 5. Pathway of effects from a set of proposed activities (Yellow) to environmental pressures (Red) to ecosystem components (Blue) to socio-economic dependencies (Green) in a risk management exercise in Yukon's North Slope marine area. (Source: Stephenson and Hartwig 2009)

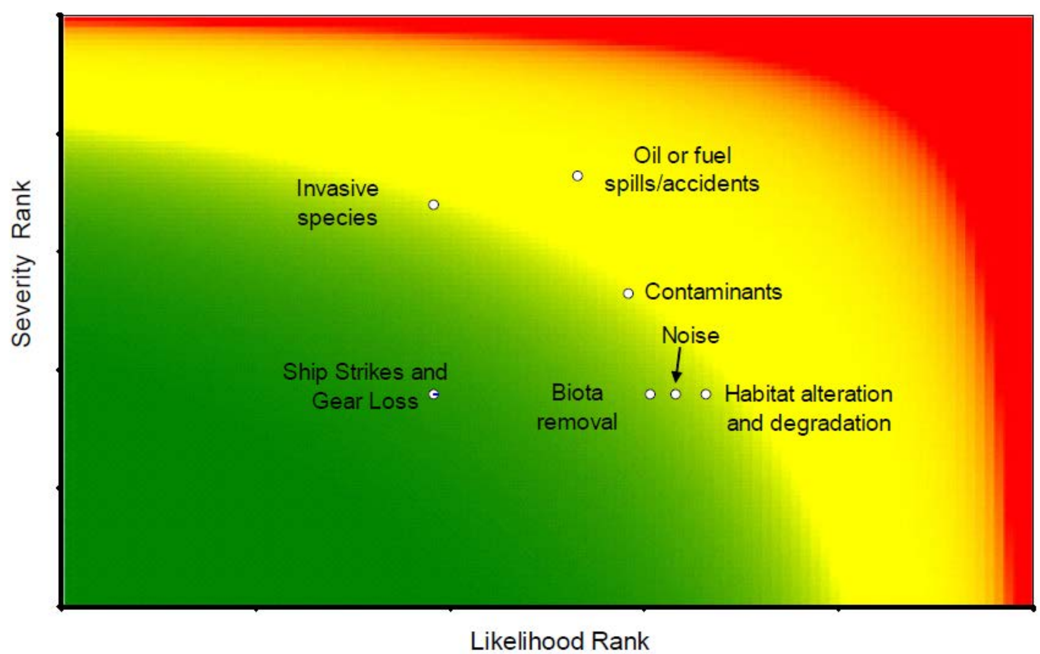

Figure 6. Risk landscape of possible activities in the Yukon's North Slope marine area. (Source: Stephenson and Hartwig 2009)

The ICES Marine and Coastal Ecosystem Based Risk Management Handbook includes Quality Assurance questions that managers should ask when designing a risk assessment framework. Listed here are a few that relate to designing ERC:

- What criteria and classification system was used to define the environmental effects in relation to the ecosystem management outcomes?
- What are the environmental effects that are linked to the ecosystem management outcomes?
- What drivers and pressures can generate the identified environmental effects?
- What is the geographical distribution of the drivers and the zone of influence of the pressures?
- Which organizations have legislations, policies, or programmes that complement the competent authority mandate in managing drivers within the management area?
- In what area are the environmental criteria used to identify significant environmental services and their environmental effects susceptibilities?
- What environmental services depend on the ecosystem management outcomes and occur in the ecological unit?
- What risk criteria are used to characterize the intensity of the drivers and the loads of their pressures occurring in the zone of influence?
- What are the significant pressure loads in the zone of influence?
- What risk criteria are used to identify the risk analysis endpoints in relation to the cause-and-effect pathways?
- What empirical methods are used to complete the environmental vulnerability profile?
- What criteria are used to determine the level of residual risk to identify the significant environmental effect of the ecological unit?
- In the ecological unit, what are the ecosystem components and environmental services that are most at risk to environmental effects as they relate to the drivers and associated pressures found in the zone of influence?

HUMAN ACTIVITIES IN CANADIAN WATERS

A wide range of specific activities are expected to be found across Canada's diverse marine ecosystems, however, for the most part these activities can be grouped into a main set of impacts on a common set of marine habitats. Halpern et al. (2007) conducted an analysis of 874 threat-ecosystem combinations (i.e. 38 activities in 23 ecosystems) to determine the most common activities that have a high risk of impacting marine environments across the globe. The highest threats were found in the most sensitive environments including mangroves, reefs and marshes, and typically involved human activities that had direct effects on aquatic habitat quality and quantity. However, high risks were also found in stable environments in coastal (e.g. hard or soft shelves 30 to 200 m deep) and oceanic (e.g. deep sea-mount, depth between 200 and 2000 m) environments associated with overfishing and climate change. A similar study was conducted in Eastern Canada by Park et al. (2011) in which over 1000 references, interviews with experts and a risk ranking system were used to identify the top 8 high risk human activities on 94 conservation priorities (i.e. ecosystem components, EBSAs, depleted species). Here the top human activities were grouped as fishing, pollution and climate change

(Figure 7) and the most sensitive ecosystem components including habitat structuring (e.g. rockweed, kelp and coral) and exploited fish (e.g. cod, cunner, groundfish) species (Table 1).

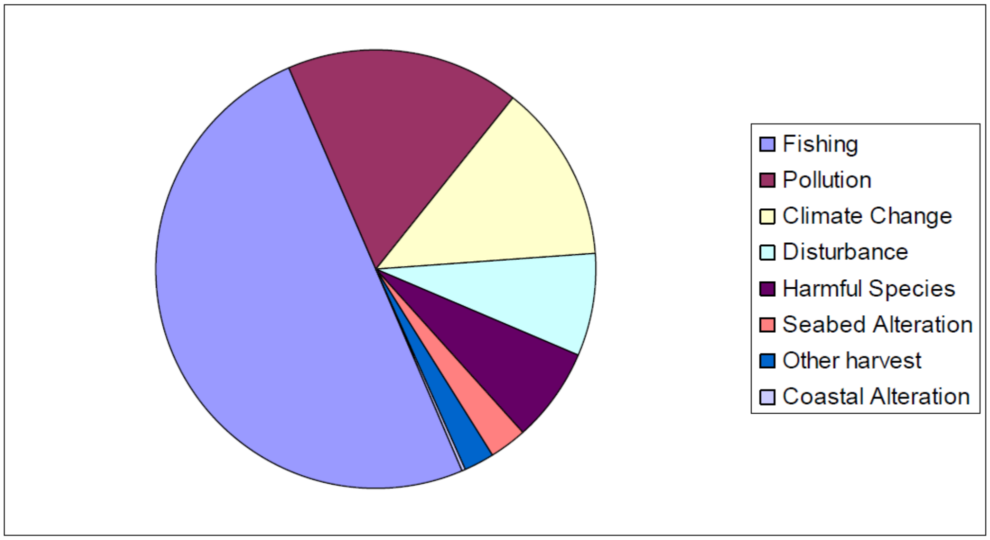

Figure 7. The top eight human activities that may cause risk of harm to ecosystem components in the Placentia Bay- Grand Banks Large Ocean Management Area. (Source: Park et al. 2011)

As mentioned, ERCs are not necessarily limited to scientific studies or expert judgement, and also must address the concerns of stakeholders. In a recent survey of over 10 000 respondents from 10 European nations, the majority of public concerns were with overfishing, pollution and acidification in marine environments (Gelcich et al 2014). These concerns seem to mirror the results from the Park and Halpern studies, and therefore might speak favourably for open communication between environmental managers, scientists and the public. The same survey determined that the public had a high level of trust in academic, non-governmental and government scientists with regards to the state of the ocean, but little in more mainstream news sources or political parties. While in these broad cases public concerns aligned well with scientific findings, in specific cases, the public may be more concerned about cultural value over ecological value. For example, the effects of certain activities on areas with recognized national, community or international significance may over-rule the effects on conservation priorities (Park et al. 2011).

Table 1. Ranking of ecosystem component or property with a high risk of harm from human activities in the Placentia Bay- Grand Banks Large Ocean Management Area. (Source: Table 3 in Park et al. 2010)

Component or Property (CP)	Cumulative Score	Rank
Rockweed and kelp within the PB/GB LOMA	142.3	1
Cod, cunner, plaice, capelin, and other species nursery habitat in the Placentia Bay Extension	119.3	2
Seabird aggregation, feeding, nesting, and refuge in the Placentia Bay Extension	116.9	3
Groundfish biomass in the Southwest Shelf	102.8	4
Atlantic cod migration in the SW Shelf Edge and Slope	101.3	5
Control the spread and abundance of invasive species within the PB/GB LOMA	95.8	6
Large Gorgonian corals (depleted or rare species) within the PB/GB LOMA	95.6	7
Structural habitat provided by coral in the SW Shelf Edge and Slope	94.8	8
Eelgrass in the PB/GB LOMA	92.5	9
Phytoplankton in the PB/GB LOMA	83.9	10
Etc.		

Elliott et al. (2010) presented a typology for grouping hazards in marine environments leading to 12 different groupings which included hazards from natural processes (e.g. climate). These groupings, as well as the results of Halpern et al. (2007), Park et al. (2010, 2011), and Gelcich (2014) are extremely valuable for identifying the types of activities and ecosystem vulnerability profiles that will need to be addressed by ERCs. Elliott et al.'s list comprises:

- Surface hydrological hazards
- Surface physiographic removal – chronic/long term
- Surface physiographic removal – acute/short term
- Climatological hazards – acute/short term
- Climatological hazards – chronic/long term
- Tectonic hazards – acute/short term
- Tectonic hazards – chronic/long term
- Anthropogenic microbial biohazards
- Anthropogenic macrobial biohazards
- Anthropogenic (introduced technological) hazards
- Anthropogenic (extractive technological) hazards
- Anthropogenic (chemical) hazards

In the Placentia Bay – Grand Banks Large Ocean Management Area, Park et al. (2011) listed the characteristics of the human activities and geographic area that informs the ranking of risks:

- Intensity, duration and spatial extent of activities
- Probability, duration, frequency and reversibility of the impact of activities
- Cumulative effects of both anthropogenic activities and natural processes
- Trans-boundary nature of the activities
- Risk to human health and the environment from accidents associated with the activity

- Magnitude and spatial extent of the effects from the activities.

The activities within this region were grouped into broad sections (i.e. fishing, pollution), however, within these groups it is important to list the specific activities estimated to occur (see Table 2), because these will be location specific.

Table 2. Checklist of human activities with groupings and specific activities identified in the Placentia Bay – Grand Banks Large Ocean Management Area (Source: Park et al. 2010, Table 1)

Potentially Harmful Activity (X)			**Potentially Harmful Stressor (X)**		
Fishing	Bottom trawl		Marine pollution	Oil pollution	
	Scallop dredges			Industrial effluent	
	Clam dredges			Fishplant effluent	
	Midwater trawl			Sewage	
	Gillnets (groundfish)			Historic military waste	
	Gillnets (pelagic)			Long range transport of nutrients	
	Long line			Acid rain	
	Scottish seining			Persistant Organic Pollutants (POPs)	
	Purse seining			Eutrophication	
	Cod food fishery			Ghost nets	
	Crab pots			Litter	
	Lobster pots			Other contaminants (specify)	
	Whelk pots		Climate Change	Ice distribution	
Other harvest	Otter trapping			Temperature change	
	Seal hunt			Sea-level rise	
	Seabird hunt			Ocean acidification	
	Seaweed harvest			Current shifts	
Seabed alteration	Anchor drops/drags			Increased storm events	
	Ore spill			Increased UV light	
	Fish offal dumping			Oxygen depletion	
	Finfish aquaculture			Changes in freshwater runoff	
	Dredge spoil			Other (specify)	
	Dredging		Harmful species	Green crab	
	Mining / Oil & gas			*Membranipora*	
	Cables			Golden Star Tunicate	
Coastal alteration	Freshwater diversion			Violet Tunicate	
	Subtidal			Vase Tunicate	
	Intertidal / coastal construction			*Codium fragile*	
	Other (specify)			Clubbed Tunicate	
Disturbance	Vessel traffic			*Didemnum*	
	Ship strikes			Toxic algal blooms	
	Ecotourism			Disease organisms (human waste)	
	Marine construction			Disease organisms (aquaculture waste)	
	Seismic surveys			Other harmful species (specify)	
	Navy sonar		Other		
	Other (specify)				

2. COMPARISON OF ECOLOGICAL RISK CRITERIA

Ecological risks can be categorized in several ways, the most common of which are exceedance of a range or threshold, and categories of increasing risk. The simple threshold approach is to determine whether a given measurement (population size, nutrient loading, etc) exceeds either a predetermined value, or lies outside of the defined range of reference for unaffected populations. This approach can be useful for determining whether there is an effect, but makes no determination of the magnitude of the effect. Most schemes therefore provide between three and five categories of increasing effect size. For determining relative effect, categories range from high or excellent condition to bad or very poor condition, with 1-3 intermediate categories.

Table 3a. Examples of three categories of risk criteria.

Best		Worst
Green	Amber	Red
Low Risk	Medium Risk	High Risk
Fully Supporting	Threatened	Impaired

Table 3b. Examples of five categories of risk criteria.

Best				Worst
Excellent	Good	Fair	Poor	Very Poor
High	Good	Moderate	Poor	Bad

Higher numbers of categories provide greater resolution but functionally provide the same information: factors or areas that are not of concern, those of some concern, and those of great concern. Perhaps the most illuminating illustration of this approach is the “Traffic Light” method employed in the Precautionary Approach for Fisheries (Figure 3a; DFO 2006b) among others with categories of Green (healthy), Yellow (caution), and Red (critical).

Existing DFO corporate risk criteria utilize this approach, identifying five levels of ERCs (see (Table 3b). The categories themselves are thus relatively standard, regardless of the number of categories they identify: no/low risk categories (1), degrees of moderate risk (2,3,4), and high risk (5). The primary differences among programs are the thresholds or boundaries between each category, and these are generally assigned based on predetermined factors, either absolute or relative to a reference condition or reference point.

A review of ERCs from a wide range of sources from both regulatory guidelines and primary literature on environmental monitoring, demonstrated a range of approaches that have been used to define risk categories, or more accurately, define the state of an ecosystem component within a management framework (see Table 4 for criteria categories and Table 5 for thresholds).

From a simple perspective of the number of categories available, there is a wide range from ERCs with only one threshold, and thus only two categories, to those with greater than five (e.g. Index of Biotic Integrity). The single threshold ERCs typically involve a fairly specific measure, and so an actual quantity might be listed as a firm boundary. Here the single threshold boundaries seem appropriate to be a pathway-of-effects tool for larger risk characterizations.

There are several ways in which boundaries and thresholds between each category are determined. In some cases, hybrid approaches may be used:

- Reference point / Site approach in which values differ from reference conditions by a specified degree. Examples include 2 standard deviations, outside normal variability, and confidence intervals. These values therefore vary regionally and are site specific.
- Exceeding a predefined threshold or maximum tolerable difference. Examples include rate of population decline, total maximum daily loads, and contaminant levels in food.
- Qualitative / Subjective / Expert Opinion / Weight of evidence. This approach is less quantitative than other methods, but may be able to incorporate information than cannot otherwise be considered.

The rest of this report examines each of these three boundary conditions with examples to demonstrate the range of options available when designing an ERC.

Table 4. Comparison of Ecological Risk Criteria Categories from regulatory and environmental monitoring sources.

Framework	Very Low	Low	Medium	High	Very High
Effect Size - Chemistry - CSRA		Below SQG		Above SQG (can include degree above SQG)	
Maximum tolerable difference - EEM		Not ecologically significant		Ecologically significant	
Mercury Maximum Limit - EEM		Below	Exceed		
Outside normal range - EEM		Not ecologically significant		Ecologically significant	
Two standard deviations - EEM		Not ecologically significant		Ecologically significant	
Benthic invertebrate density, evenness, richness, diversity - EEM		Significantly lower	Reference/not significant	Significantly higher	
Clean Water Act - Impaired Waters - CWA		Fully supporting beneficial uses	Threatened	Impaired	
Clean Water Act - Total Max. Daily Loads - CWA		Fully supporting beneficial uses	Threatened	Impaired	
Cumulative Rankings -		Low	Medium	High	
Ecological Relevance - CSRA		Low	Medium	High	
Ecological Risk Assessment - EPA		Low	Medium	High	
EPA nutrient guidelines - EPA		Reference	N/A	Impaired	
Fish Condition - EEM		Significantly lower	Reference/not significant	Significantly higher	
Fish Weight-at-age, GSI, LSI, Age - EEM		Significantly lower	Reference/not significant	Significantly higher	
Invasive freshwater fish - expert opinion/literature - FISK		Low risk	Medium risk	High Risk	
Invasive freshwater invertebrates - expert opinion/literature - FI-ISK		Low risk	Medium risk	High Risk	
Invasive marine fish - expert opinion/literature - MFISK		Low risk	Medium risk	High Risk	

Framework	Very Low	Low	Medium	High	Very High
Invasive marine invertebrates - expert opinion, literature - MI-ISK		Low risk	Medium risk	High Risk	
Population decline rates - CITES	Not listed		Appendix II	Appendix I	
Population decline rates - cause not reversible, not understood, or not ceased - COSEWIC	Not listed		Threatened	Endangered	
Traffic Light/Reference Point approach - CSAS-FPP		Green/Low	Yellow/Medium due to high complexity or uncertainty	Red/High	
Effect Size - Community - CSRA	Negligible	Low	Moderate	high	
Effect Size - Toxicity - CSRA	Negligible	Low	Moderate	high	
Population decline rates - cause reversible, understood, ceased - COSEWIC	Not listed	Vulnerable - very low productivity species	Threatened	Endangered	
Reference Condition & Ordination - CABIN	Not stressed	Possibly stressed	Stressed	Severely Stressed	
Biotic Index - EU EPA	High	Good	Moderate	Poor	Bad
Cumulative scoring - expert opinion -	No threat	low threat	medium threat	high threat	very high threat
Ecological Quality (defined by taxa, specific factor) - EU EPA	High	Good	Moderate	Poor	Bad
Ecological Quality Ratio - EU EPA	High	Good	Moderate	Poor	Bad
Index of Biotic Integrity - IBI	Excellent	Good	Fair	Poor	Very Poor
Population decline rates - AFS	Not listed	Vulnerable - very low productivity species	Vulnerable - low productivity species	Vulnerable - medium productivity species	Vulnerable - High productivity species
Population decline rates - cause not reversible, not understood, or not ceased - IUCN	Lowest Risk/Least Concern	Lower Risk/Near Threatened	Vulnerable	Endangered	Critically Endangered
Population decline rates - cause reversible, understood, ceased - IUCN	Lowest Risk/Least Concern	Lower Risk/Near Threatened	Vulnerable	Endangered	Critically Endangered

Table 5. Comparison of Ecological Risk Criteria Thresholds from regulatory and environmental monitoring sources.

Framework	**Very Low-Low**	**Low-Medium**	**Medium-High**	**High-Very High**
Effect Size - Chemistry - CSRA		Sediment Quality Guideline		
Maximum tolerable difference - EEM		Exceeds predefined value		
Mercury Maximum Limit - EEM		0.5 ug/g in fish tissue		
Outside normal range - EEM		within normal variabilty		
Two standard deviations - EEM		2 S.D. from reference		
Benthic invertebrate density, evenness, richness, diversity - EEM		2 S.D. below mean	2 S.D. above mean	
Clean Water Act - Impaired Waters - CWA		Specific threat	75th percentile among regional references	
Clean Water Act - Total Max. Daily Loads - CWA		Specific threat	75th percentile among regional references	
Cumulative Rankings -		not defined	not defined	
Ecological Relevance - CSRA				
Ecological Risk Assessment - EPA		regional	regional	
EPA nutrient guidelines - EPA		75th percentile	25th percentile	
Fish Condition - EEM		10% below mean	10% above mean	
Fish Weight-at-age, GSI, LSI, Age - EEM		25% below mean	25% above mean	
Invasive freshwater fish - expert opinion/literature - FISK		1	19	
Invasive freshwater invertebrates - expert opinion/literature - FI-ISK		1	16	
Invasive marine fish - expert opinion/literature - MFISK		1	6	
Invasive marine invertebrates - expert opinion, literature - MI-ISK		1	6	

Framework	Very Low-Low	Low-Medium	Medium-High	High-Very High
Population decline rates - CITES	≥20 decline rate		≥50	
Population decline rates - cause not reversible, not understood, or not ceased - COSEWIC		≥30 decline rate	≥50	
Traffic Light/Reference Point approach - CSAS-FPP		Small impacts, can be avoided or mitigated; low uncertainty	Large, unavoidable impacts, low uncertainty	
Effect Size - Community - CSRA	10%	20%	50%	
Effect Size - Toxicity - CSRA	10%	20%	50%	
Population decline rates - cause reversible, understood, ceased - COSEWIC		≥50 decline rate	≥70	
Reference Condition & Ordination - CABIN	>90% probability	>99% probability	>99.9% probability	
Biotic Index - EU EPA	>4	4	3	≤2
Cumulative scoring - expert opinion -	1.5	2	2.5	3
Ecological Quality (defined by taxa, specific factor) - EU EPA	regional	regional	regional	regional
Ecological Quality Ratio - EU EPA		0.85	0.75	
Index of Biotic Integrity - IBI	regional	regional	regional	regional
Population decline rates - AFS	≥70 decline rate	≥85	≥95	≥99
Population decline rates - cause not reversible, not understood, or not ceased - IUCN		≥30 decline rate	≥50	≥80
Population decline rates - cause reversible, understood, ceased - IUCN		≥50 decline rate	≥70	≥90

REFERENCE POINT / REFERENCE CONDITION

Most ERCs include some form of reference point or reference condition with which to compare the site or study in question. These can be determined in several ways: temporal reference (what the site was like pre-stressor), geographic (how does the stressed site compare to non-stressed sites), or aspirational (based on desired values). These methods are frequently data and labour intensive, as both stressed and pre-defined / pristine (as above) reference sites must be located and assessed, or a full range of sites must be assessed and then assigned to categories (such as quartiles). An advantage to both of these approaches is that regional differences are accounted for, and thus for instance northern naturally low-nutrient lakes are not compared with southern, naturally high nutrient lakes.

Quartile/Reference Range Approach for Water Quality, and Narrative Biological Criteria (Clean Water Act, USA)

The goal of the Clean Water Act (CWA) of the United States is protection and restoration of water bodies so that they "fully support beneficial uses" (EPA 2014) Beneficial uses include aquatic ecosystems, recreational and commercial fisheries, recreation, industry, and agriculture. To reach this goal, the CWA uses both quantitative physicochemical water quality measurements and narrative biological criteria. The quantitative assessments use a reference range approach to determine whether a water body is impaired. A number of sites in a specified region are sampled biennially for nutrient and contaminant levels. These data are compiled for each variable, and are divided into quartiles. Thresholds or benchmarks are set at the 25th percentile (lower quartile), below which sites are considered to be in reference condition, and 75th percentile (upper quartile), above which sites are considered impaired, for each category. If a site meets these water quality criteria but is at risk from a specific stressor, it may be considered *Threatened*. If a site meets water quality criteria, but fails the more subjective narrative biological criteria, it is still considered *Impaired*. An example of the latter is a stream reach above a dam that may have high water quality, but poor connectivity and fisheries due to the dam.

The quartile approach is consistent with a three-criteria ERC framework. The lowest quartile (25th percentile) can be considered *low risk / reference*, the middle two quartiles (25th – 75th percentiles) is *low-moderate risk*, and the upper quartile (>75th percentile) is *high risk*. One potential concern with this approach is that these definitions by quartile are by their nature arbitrary and do not necessarily align with ecological or biological significance. For these analyses to be statistically as well as ecologically significant, it is also necessary to sample many sites. The addition of the narrative biological criteria and *Threatened* category provide flexibility to take factors other than water quality parameters into account. These categories may thus be best considered as simple two-category thresholds (present/absent, high/low), and can also be considered as more qualitative criteria.

Predetermined Reference Site (EEM, Canada)

Canada's Environmental Effects Monitoring (EEM) Program uses reference sites for comparisons to sites affected by metal mining and pulp and paper mills (Environment Canada 2010; Environment Canada 2012). Reference sites should be geographically, geologically, and biologically similar to the exposure site, but the reference site should not be exposed to the effluent, nor should it be frequented by fish that are exposed to the effluent (Munkittrick 2000). Near-field reference sites (for instance, upstream sites, far-bank of large rivers and lakes, far downstream) generally have the advantage of similar environmental and biological conditions, but effluent may impact further away than thought due wind, tides, and fish movements, and thus may be at risk of effluent exposure. Far-field sites (such as a very long way upstream or downstream, in another river in the same watershed, the next bay over) reduce the risk of migratory species or unknown effluent effects confounding the results, but may differ geologically or have different biological communities. Selection of appropriate sentinel species is therefore vital.

EEM fish surveys compare population and physiological endpoints in sentinel fish species at exposure sites to the same endpoints in the same species at reference sites. The most commonly used effect endpoints are: age (survival), size-at-age (growth rate), relative gonad size (reproductive allocations), and condition factor and relative liver size (energy storage). In all cases, analyses for males and females are separate, and minimum sample sizes (such as 20 adult males and 20 adult females) are required (Environment Canada 2010; Environment Canada 2012).

These endpoints are statistically compared between exposure and reference sites using statistical analyses such as ANOVA and ANCOVA, but these analyses reveal only statistical significance, not biological significance. Statistically significant differences might reveal background differences between populations or be due to slight environmental differences, and thus may not always be due to the effect of the effluent. Critical effect sizes (CES) were therefore developed for each endpoint, and validated through early iterations of EEM cycles. These CES have been selected because they reveal biologically significant differences in these endpoints; it is thus possible that fish populations could differ in a statistically significant way between exposure and references sites, but these results not be biologically significant. The CES identified were ±25% differences from the reference site for age, weight-at-age, relative gonad size, and relative liver size; and ±10% for body condition (Environment Canada 2010; Environment Canada 2012).

These EEM endpoints therefore have two categories of ERC: Low risk (within CES) and High risk (exceed ERC). Although there is not an intermediate ERC of Moderate risk, it may be noted if results are close to the CES. This approach could be modified to include an intermediate ERC, which we shall term SCES (Sub-Critical Effect Size) for a moderate risk level, if managers wished to denote whether populations were in danger of approaching the CES. Further analyses would be required to determine where this SCES should be set for each endpoint.

PREDEFINED THRESHOLDS AND MAXIMUM TOLERABLE DIFFERENCES

Mercury Contamination in Effluent and Fish (EEM, Canada) and Consumption Guidelines (Health Canada)

Environmental Effects Monitoring (EEM) for Metal Mining was implemented to assess the environmental effects of metal mines across Canada (Environment Canada 2012). Many criteria are therefore used, one of which is testing for potentially harmful chemicals and elements such as mercury. High mercury concentrations can cause developmental and health issues in all animals, and can lead to fishery warnings and closures, and can bioaccumulate through the food chain. It can thus be considered a threat to the environment and ecosystem, public health, socioeconomics, and public confidence.

EEM guidelines state that mercury concentrations in the effluent be tested regularly, but if the concentration is <0.10 µg/L in 12 consecutive samples this testing may be discontinued. If effluent mercury levels do exceed 0.10 µg/L, testing of fish mercury levels is required because the mercury may enter the food chain and bioaccumulate in fish, causing consumption advisories. During the fish monitoring cycle of EEM, muscle samples are taken from sentinel species and tested for mercury levels. An “effect on fish tissue” is defined in the EEM guidelines “as measurements of concentrations of total mercury that exceed 0.5 µg/g wet weight in fish tissue taken in an exposure area and that are statistically different from and higher than the measurements of concentrations of total mercury in fish tissue taken in a reference area”(Environment Canada 2012). There are thus two mercury thresholds in the EEM guidelines – an effluent threshold (0.10 µg/L) and a fish tissue threshold (0.5 µg/g). This threshold approach thus does not align well with a three-category ERC framework in that there are only two categories: Low risk (<0.10 µg/L or <0.5 µg/g) and High risk (>0.10 µg/L or >0.5 µg/g).

Health Canada has issued consumption guidelines that recommend maximum levels of fish consumption depending on mercury levels (Health Canada 2008) that can be restated as:

- No/negligible risk, for fish with very low mercury levels. No consumption advisory.
- Moderate risk, for fish with intermediate mercury levels (<0.5 µg/g, or <1.0 µg/g for certain species). The general population should limit consumption to 150g/week; at-risk population (pregnant and breast-feeding women and children) should eat 150 g /month or less).
- High risk, for fish with mercury levels >0.5 µg/g (or 1.0 µg/g). These fish should not be consumed.

Guidelines such as the Guide to Eating Ontario Sportfish (Ontario Ministry of the Environment 2013) are even more explicit, dividing fish consumption into five categories: 8, 4, 2, 1, and 0 meals per month, depending on whether the consumer is in the high-risk population, and depending on size, species, and locality of the fish. The Ontario guidelines, however, do also take other potential contaminants such as PCBs into consideration.

The Health Canada and Ontario Sportfish consumption guidelines thus align well with three-category and five-category ERCs respectively.

Population Decline Rates for Conservation and Management (COSEWIC, Canada, and IUCN, Global)

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2014) and International Union for Conservation of Nature (IUCN 2001) use population decline rates as a major criterion for listing species (Musick 1999; Dulvy et al. 2004). In each of the following instances, the time scale used in the interpretation is at least 10 years or three generations. Vulnerable (IUCN) and Threatened marine fishes (COSEWIC) are characterized by a decline of ≥50% over the defined timescale if the cause is understood, ceased, and reversible, or a decline rate of ≥30% if the cause is either not understood, not ceased, or not reversible. Endangered marine fishes (both IUCN and COSEWIC) are characterized by a decline of ≥70% if the cause is understood, ceased, and reversible, or a decline rate of ≥50% if the cause is either not understood, not ceased, or not reversible. Critically Endangered (IUCN only) have decline rates of 90% if the causes are understood, ceased, and reversible, or a decline rate of ≥80% if the cause is either not understood, not ceased, or not reversible. These categorizations therefore incorporate uncertainty about the causes of decline rates by having more conservative thresholds of decline.

COSEWIC thus include two calculated ERCs, which can be thought of as Moderate Risk (Threatened) and High Risk (Endangered) while IUCN has three, Moderate (Vulnerable), High (Endangered), and Very high (Critically Endangered). The inclusion of a lower ERC defined as being below moderate risk (lowest risk / least concern for IUCN; not listed for COSEWIC) adds a Low Risk category.

COSEWIC designations are also used in Canadian Species at Risk Act (SARA 2014) designations at both the species and population level, and can thus recognize distinct populations that may be at particular risk. Thus, Atlantic salmon are listed as Endangered under COSEWIC, and are broken down into 15 populations whose designations range from Not at Risk to Extinct, and special recommendations can be made for specific populations such as the Inner Bay of Fundy population, listed as Schedule 1 Endangered.

Because species and populations are naturally present at different population sizes and densities, life-history traits differ greatly, and jurisdictional areas may not comprise the entire range of a species, metrics other than population size are needed to determine conservation status of a species. Listing agencies therefore use a number of criteria, including not only population size, but also habitat range and requirements, life-history traits, and changes in population size.

QUALITATIVE, SUBJECTIVE, EXPERT OPINION, WEIGHT OF EVIDENCE

Fish Invasiveness Screening (CEFAS, UK)

The Fish Invasiveness Screening Kit (FISK) was originally developed by the Centre for Environment, Fisheries and Aquaculture Sciences, UK (CEFAS 2014). It functions as a pre-screening toolkit to determine relative invasiveness of any given species of freshwater fish, and has also been adapted for freshwater invertebrates and for marine fish and invertebrates (Copp et al. 2009). Calibrated to specific regions, it relies on expert judgment and literature reviews to answer a series of queries regarding aspects of the organism's ecology, such as thermal tolerances and fecundity, and includes relative uncertainty for each question. Uncertainty in this case is based on existing literature or known facts about each species. One of the primary uses of these toolkits is to assign relative risks of potential aquaculture species to native ecosystems, but it can also be used to assess relative risks of introduced species from factors such as climate change or ballast water from shipping.

There are 49 questions for the fish assessments, and score is thus assigned out of 49. An example question is "Has the species become naturalized where introduced?" and the scorer selects a response from "Yes," "No," or "Uncertain" and a certainty from "Very Uncertain" to "Very Certain." The result of this process is a score with associated confidence based on the number of "Yes" answers, allowing for a relative risk category of *Low Risk* (ex. <1 for marine fishes), *Medium Risk* (1-6), or *High Risk* (>6) to be assigned (CEFAS 2014). Relative risk for each score is reliant on regional calibration. The relative risk categories align well with a three-category ERC framework, although the medium risk category is broad enough and could be split to accommodate a five-category ERC. A precautionary approach would bias the relative risk towards lower scores such that the thresholds were: Low-Medium Risk (3-5), Medium Risk (6-12), and High-Medium Risk (12-19). While these categories are relative, a biological significance can be ascribed to each of the three categories: *Low Risk* - new species will definitely not successfully invade; *Medium Risk* - species may invade, but may not establish, may displace existing species, and/or may be managed with mitigation strategies; and *High Risk* - new species will invade and become entrenched and naturalized while changing community dynamics.

FISK thus allows relative risks to be determined and assigned using preexisting data and expert judgment, and using well defined criteria (*Low*, *Medium* and *High Risk*). Weak or missing data is a potentially major source of uncertainty, particularly for less well studied taxa.

Index of Biotic Integrity (IBI, USA)

The Index of Biotic integrity, originally developed by Karr (1981), was one of the first approaches to look at community-wide responses to stressors. His approach, originally developed for stream fishes, has now been adapted for other systems and taxa including marine and estuarine systems, lakes, large rivers, and for both fish and invertebrates (Karr 1991). A commonality of this approach is that all rely on comparison of relative community composition across a series of sites. General categories are determined based on relative species sensitivity, trophic structure, generalist/specialist, and whether the species is native or invasive.

The highest ranked sites can be designated as reference sites for the purposes of regional calibration. Based on fish communities in US Midwestern streams, Karr designated categories of *Very Poor* (≤23 out of 60), *Poor-Very Poor* (24-27), *Poor* (28-35), *Fair-Poor* (36-38), *Fair* (39-44), *Good-Fair* (45-47), *Good* (48-52), *Excellent-Good* (53-56) and *Excellent* (57-60), with the primary categories being *Very Poor, Poor, Fair, Good,* and *Excellent*). These specific categorical values may vary across habitat types and geographic ranges, but the concept remains consistent throughout. These categories from *Very Poor* to *Excellent* align well with a five category ERC, and could be adapted to a three category ERC depending on how the categories were allocated.

UNCERTAINTY AND CUMULATIVE EFFECTS

Any model is only as good as the data used in the analyses. In ecological and environmental studies, however, it can be challenging or impossible to collect or acquire all of the needed data. Uncertainty can be incorporated and accounted for either in developing a threshold or defining a population or data point. Because the same data series are used to calculate both elements, it is important to incorporate uncertainty only in the threshold or in the population, not in both.

The FISK approach, for instance, accounts for uncertainty by having the expert collating the data rank the uncertainty for each factor on a scale from 1-4. COSEWIC and IUCN incorporate uncertainty by lowering the threshold for each status when the cause of population decline is less certain.

One difficulty in any risk assessment is parsing cumulative effects. Ecosystems are seldom subject to only one effect, and it may be difficult to parse individual effects in a given system. It is important to note that many of these risk factors are inextricably linked, and can apply to multiple categories. For instance, fishing can remove biomass and reduce numbers, alter fish life history traits, open niches to invading species, and alter food webs; and may be exacerbated by factors such as pollution, coastal development, eutrophication, and climate change. Possible cumulative effects of the risk factors should therefore be considered with the understanding that their cumulative effects may be positive, neutral, or negative, as well as non-cumulative, additive, or multiplicative. One goal when selecting a reference site is therefore to select a site that has all of the same effects as the exposure site, *except* for the stressor under investigation.

3. SYNTHESIS AND CONCLUSION

There are many ways in which risks are categorized. All of these categories are bordered by thresholds which may be absolute or relative to reference conditions, and qualitative or quantitative. These categories are consistent in that they have categories that are recognizable as “Negligible or Low Risk” and “High or Extreme Risk” – these may in fact be the only two categories in a two-category ERC, showing whether the level of an environmental stress is exceeded or not exceeded. When additional categories or criteria are added, they fill the gaps between these two endpoints: adding one category for “Moderate Risk” for a three category ERC, or three categories for “Low Risk,” “Moderate Risk,” and “High Risk” giving a five category ERC. Likewise, it is possible to reduce the numbers of categories in an ERC, for instance by combining the categories into one. Despite the superficial disparities among the different ERCs evaluated in this report, the central underlying concepts remain functionally the same thus facilitating adaptation and comparisons across jurisdictional and disciplinary boundaries.

For example, sometimes the high risk categories are close enough in management outcome or practical measures that they could be combined. For example, the Extreme and Very High categories of risk (i.e. 5 and 4) in the existing DFO ERCs for “Environmental / Biological” (DFO 2006b) and “Ecosystem Structure and/or Function” (DFO 2013 draft) list these attributes (note some are nested):

- Elimination (5) vs almost elimination (4) of the ongoing productivity, biodiversity and structure of a particular spatially referenced ecosystem function
- Extinction (5) vs Endangerment (4) of a species
- Permanent loss (5) vs significant damage (4) to fish habitat with little to no chance of recovery
- Limit reference point exceeded (5, 4)
- Erosion of genetic diversity (5, 4)
- Introduction of invasive species resulting in shift in community composition (5, 4)

From this list, it is first safe to say that all the outcomes from approving activities that lead to these risk criteria will be problematic from a management perspective. Despite the fact that three of the six criteria are effectively nested within each other, assigning the cases to the categories will be very difficult because thresholds between Elimination, Extinction and Permanent Loss vs. Almost Eliminated, Endangered and Significantly Damaged with little chance of recovery are clearly very slight, and so empirical measures or expert judgment will likely be overwhelmed by uncertainty.

Overall, the review of ERCs from regulatory guidelines and primary literature on environmental management suggest that the existing five category risk assessment framework (DFO 2006) or a three category framework will be able to fit the wide range of other options available. As demonstrated in the previous section, the number of risk categories and types of thresholds between categories are quite variable among guidelines and studies. However, rather than focusing on aligning ERCs among guidelines, it is perhaps more valuable to determine how other regulatory frameworks inform the ERCs for the management of Canada’s oceans through the pathways of effects. Many of the guidelines reviewed in this report use a relative ranking system of risks and impacts such that the answers to Yes and No questions (e.g. FISK) or cumulative scores (e.g. the IBI developed by Karr (1981) or Park et al.’s (2011) work in Placentia-Bay/Grand Banks Large Ocean Management Area) sort a wide set of ecosystem services and activities into those that require the closest attention. This same type of ranking system was used by Halpern and colleagues (2007) to assess the risk to marine resources from human activities across the globe. From the wide range of thresholds available it seems clear that some are more useful for ranking pathways-of-effects (e.g. single thresholds for contaminants) in this manner while others might serve better as holistic risk categories (e.g. rates of population decline).

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APPENDIX 1

Table A1. List of acronyms.

Abbreviation	Definition
CSRA	Contaminated Sites Risk Assessment
SQG	Sediment Quality Guideline
EEM	Environmental Effects Monitoring
CWA	Clean Water Act
EPA	Environmental Protection Agency
FISK	Fish Invasiveness Scoring Kit
FI-ISK	Freshwater Invertebrate Invasiveness Scoring Kit
FPP	Fisheries Protection Program
MFISK	Marine Fish Invasiveness Scoring Kit
MI-ISK	Marine Invertebrate Invasiveness Scoring Kit
CITES	Convention on International Trade in Endangered Species
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CSAS-FPP	Canadian Science Advisory Secretariat-Fisheries Protection Provisions
CABIN	Canadian Aquatic Bio-monitoring Network
EU EPA	European Environmental Protection Agency
IBI	Index of Biotic Integrity
AFS	American Fisheries Society
IUCN	International Union for Conservation of Nature

APPENDIX 2

Table A2. Description of ecological risk criteria associated with DFO programs.

Risk Framework	**Lowest Impact**				**Highest Impact**
	1	**2**	**3**	**4**	**5**
DFO Departmental Risk Criteria - General Criteria (2006)	**Negligible**: An event, the consequences of which can be absorbed through normal activity.	**Low**: An event, the consequences of which can be absorbed but management effort is required to minimize the impact.	**Medium**: A significant event that can be managed but with consequences that could require significant review or changed ways of operation.	**Very High**: A critical event that with proper management can be endured by the organization.	**Extreme**: An event with the potential to lead to permanent or long-term change to the ability of DFO to achieve its objectives.
DFO Departmental Risk Criteria - Environmental / Biological Criteria (2006)	**Negligible**: Minimal change, falling within normal fluctuations or circumstances, with no impact on stock or habitat. Habitat change completed within acceptable guidelines.	**Low**: Minor, recoverable short term (i.e. 1 year); e.g. seasonal changes in fish stock or habitat	**Medium**: Species is under significant pressure or at historic lows. Moderate impacts to fish habitat, with longer term for recovery (i.e. 3-5 years).	**Very High**: Major shift in species composition. Minimum limit reference point is reached. A species is listed as endangered or extinct, recovery plan required. Reduction in genetic diversity of a species. Significant damage to critical fish habitat with limited ability to recover.	**Extreme**: Extinction of an entire species. Permanent large scale loss of habitat.

Risk Framework	**Lowest Impact**				**Highest Impact**
	1	**2**	**3**	**4**	**5**
Draft Risk Criteria for Impacts on Ecosystem Structure and Function (November 2013)	**Negligible**: The point where cumulative change to the affected oceanic ecosystem structure or function has no effect on its contribution to the ongoing productivity, biodiversity, and/or structure/physical function of the [geographic scope of assessment].	**Low**: The point where cumulative change to the affected oceanic ecosystem structure or function is affected to the extent that its contribution to the ongoing productivity, biodiversity, and/or structure/physical function of the [geographic scope of assessment] is materially reduced.	**Medium:** The point where cumulative change to the affected oceanic ecosystem structure or function is affected to the extent that its contribution to the ongoing productivity, biodiversity, and/or structure/physical function of the [geographic scope of assessment] is severely reduced.	**Very High:**The point where cumulative change to the affected oceanic ecosystem structure or function is great enough that its contribution to the ongoing productivity, biodiversity, and/or structure/physical function of the [geographical scope of assessment] is almost eliminated.	**Extreme**: The point where cumulative change to the affected oceanic ecosystem structure or function is great enough that its contribution to the ongoing productivity, biodiversity, and/or structure/physical function of the [geographic scope of assessment] is limited.
Harvest Strategy Compliant with the Precautionary Approach for Fisheries (2006)	**Healthy Zone**: Stock status is considered to be good. The Removal Rate should not exceed the Removal Reference.		**Cautious**: Fisheries management actions should promote stock rebuilding towards the Healthy Zone. The Removal Rate should not exceed the Removal Reference. The Removal Reference should progressively decrease as the stock level approaches the Critical Zone; any progressively decreasing removal rate in the Cautious Zone is permissible.	**Critical Zone**: The status of the stock has declined to such a low level that it is considered to be in a precarious state. In this zone, fisheries management actions must promote stock growth. Removals by all human sources must be kept to the lowest possible level.	

Risk Framework	Lowest Impact				Highest Impact
	1	2	3	4	5
Managing Risk and Uncertainty in Operational Decisions of the Fisheries Protection Program (2014)	**Healthy**: Potential stressors are having little to no impact on the productivity of a CRA fishery species.		**Cautious**: The productivity of a CRA fishery species is declining as the state of species or habitats is reduced.	**Critical**: The state of species or habitats has declined to a point where they are no longer contributing to the ongoing productivity of a CRA fishery species.	
Ecological Risk Assessment Framework (ERAF) for Coldwater Corals and Sponge Dominated Communities	**Low**: The fishing activity presents a negligible risk of serious or irreversible harm to the significant benthic areas. No additional management measures are required.		**Moderate**: The fishing activity presents a moderate risk of serious or irreversible harm to the significant benthic areas. Management measures may be required to mitigate or avoid serious or irreversible harm, depending on specific circumstances.	**High**: The fishing activity presents a high risk of serious or irreversible harm to the significant benthic areas. Management measures are required to mitigate or avoid the risk of serious or irreversible harm.	
Pacific Ecological Risk Assessment Framework (ERAF) for Pacific Region (in press) *Appendix B includes a suite of specific criteria for species, habitats, & community/ecosystem properties.	Negligible / minimal impact on population / habitat / community structure or dynamics.	Maximum impact that still meets an objective.	Wider and longer term impacts.	Very serious impacts occurring, with a relatively long time period likely to be needed to restore to an acceptable level.	Widespread and permanent/irreversible damage or loss will occur; unlikely to ever be fixed.

Risk Framework	Lowest Impact				Highest Impact
	1	**2**	**3**	**4**	**5**
National Risk Assessment Guidelines for Aquatic Invasive Species (2011)	**Negligible**: Undetectable change in the strcuture or function of the ecosystem. No management action required.	**Low:** Minimally detectable change in the strcuture of the ecosystem, but small enough that it would not change the functional relationships or survival of species. Unlikely to affect management of the ecosystem.	**Moderate:** Detectable change in the structure or function of the ecosystem that would require consideration in the management of the ecosystem.	**High**: Significant changes to the structure or function of the ecosystem leading to changes in the abundance of native species and a need for management to adapt to the new food web. May have implications beyond the extraction or use of ecosystem resources.	**Extreme**: Impacts that restructure the ecosystem resulting in, for exampl, the extirpation or extinction of at least one species and the need for significant modification of the management of the ecosystem. Will probably have implications beyond the extraction or use of ecosystem resources.
COSEWIC Assessment Process, Categories, & Guidelines (2012)	**Data Deficient**: A category that applies when the available information is insufficient i) to resolve a wildlife species' eligibility for assessment or ii) to permit an assessment of the wildlife species' risk of extinction.	**Not At Risk**: A wildlife species that has been evaluated and found to not be at risk of extinction given the current circumstances.	**Special Concern**: A wildlife species that may become threatened or endangered because of a combination of biological characteristics and identified threats.	**Threatened**: A wildlife species that is likely to become an endangered species if nothing is done to reverse the factors leading to its extirpation or extinction.	**Extinct / Extirpated**: A wildlife species that no longer exists. A wildlife species that no longer exists in the wild in Canada, but exists elsewhere.