A Review of Cumulative Effects Research and Assessment in Fisheries and Oceans Canada

Cathryn Murray, Lucie Hannah, and Andrea Locke

Fisheries and Oceans Canada
Science Branch, Pacific Region
Institute of Ocean Sciences
9860 W Saanich Road
Sidney, BC, V8L 5T5

2020

Canadian Technical Report of Fisheries and Aquatic Sciences 3357

Fisheries and Oceans Canada | Pêches et Océans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. II n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques.*

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Canadian Technical Report of Fisheries and Aquatic Sciences 3357

2020

A REVIEW OF CUMULATIVE EFFECTS RESEARCH AND ASSESSMENT IN FISHERIES AND OCEANS CANADA

by

Cathryn Murray, Lucie Hannah, and Andrea Locke

Fisheries and Oceans Canada
Science Branch, Pacific Region
Institute of Ocean Sciences
9860 W Saanich Road
Sidney, BC, V8L 5T5
E-mail: Cathryn.Murray@dfo-mpo.gc.ca

Cat. No. Fs 97-6/3357E-PDF; ISBN 978-0-660-33831-6; ISSN 1488-5379

Correct citation for this publication:

Murray, C., Hannah, L., and Locke, A. 2020. A Review of Cumulative Effects Research and Assessment in Fisheries and Oceans Canada. Can. Tech. Rep. Fish. Aquat. Sci. 3357: vii + 51 p.

Table of Contents

List of Tables

List of Figures

ABSTRACT

Murray, C., Hannah, L., and Locke, A. 2020. A Review of Cumulative Effects Research and Assessment in Fisheries and Oceans Canada. Can. Tech. Rep. Fish. Aquat. Sci. 3357: vii + 51 p.

The study and management of cumulative effects is an emerging field and an area of critical importance to Fisheries and Oceans Canada (DFO). Cumulative effects are defined as "…*changes to the environment that are caused by an action in combination with other past, present and future human actions*" (Hegmann et al. 1999) and, crucially, can result from individually minor but collectively significant actions taking place over a period of time or across an area. The need for assessment of cumulative effects is evident throughout the programs and objectives of DFO, and is required to support management decisions by multiple DFO sectors. An overarching cumulative effects strategy for DFO, would provide a consistent approach and guidance for the assessment of cumulative effects through development of standard methods that build on existing general theoretical frameworks and applications. This report collates and reviews previous and ongoing existing cumulative effects research and assessments conducted by DFO, focusing on marine ecosystems. Based on the range of existing work and needs within DFO programs, we outline a strategy for assessing cumulative effects that uses a typology of cumulative effect assessment frameworks consisting of four types: activity-based, stressor-based, species- or habitat-based, and area-based.

RÉSUMÉ

Murray, C., Hannah, L., and Locke, A. 2020. A Review of Cumulative Effects Research and Assessment in Fisheries and Oceans Canada. Can. Tech. Rep. Fish. Aquat. Sci. 3357: vii + 51 p.

L'étude et la gestion des effets cumulatifs sont un domaine émergent et d'une importance capitale pour Pêches et Océans Canada (MPO). Les effets cumulatifs sont définis comme les « ... *changements qu'une action, conjuguée à d'autres actions humaines passées, présentes et futures, entraîne sur l'environnement* » (Hegmann et coll. 1999). Surtout, ils peuvent découler d'actions individuellement mineures, mais collectivement importantes qui se produisent sur une période de temps ou dans une zone. Pour tous les programmes et objectifs du MPO, ainsi que pour appuyer les décisions de gestion de plusieurs secteurs du MPO, la nécessité d'évaluer les effets cumulatifs est évidente. L'adoption d'une stratégie globale sur les effets cumulatifs pour le MPO fournirait une approche et une orientation cohérentes pour évaluer ceux-ci, en élaborant des méthodes normalisées fondées sur des cadres et des applications théoriques généraux et existants. Le présent rapport rassemble et examine les recherches et les évaluations antérieures et actuelles sur les effets cumulatifs menées par le MPO, en mettant l'accent sur les écosystèmes marins. En fonction de l'éventail des travaux et des besoins existants dans le cadre des programmes du MPO, nous présentons une stratégie d'évaluation des effets cumulatifs qui utilise une typologie de cadres d'évaluation des effets cumulatifs comprenant quatre types : selon les activités, selon les facteurs de stress, selon les espèces ou l'habitat et selon les zones.

INTRODUCTION

CUMULATIVE EFFECTS ASSESSMENT

Cumulative effects are defined by the Canadian Environmental Assessment Agency as: "…*changes to the environment that are caused by an action in combination with other past, present and future human actions*" (Hegmann et al. 1999). Operationally, cumulative effects represent the impact on the environment which results from the incremental impact of an action when added to other past, present and reasonably foreseeable future actions and, critically, can result from individually minor but collectively significant actions taking place over a period of time (Council on Environmental Quality, 1978).

Assessing cumulative effects goes beyond characterising a simple cause and effect relationship. In the simplest form, an impact chain (Figure 1) links a human activity (e.g., fishing) to the stressor it produces (e.g., biomass removal) which in turn is linked to the impact on an ecological component of interest (e.g., fish population). A fully comprehensive cumulative effects assessment would consider the effect of all activities (and all associated stressors) occurring in the area of interest as well as possible interactions among them on the ecological component. Because the undertaking of a fully comprehensive assessment is complex, time consuming and data intensive, the majority of cumulative effects assessments (CEAs) focus on a specific activity, or a specific stressor, rather than on the broader context (i.e., impacts of multiple stressors and multiple activities at the species, community and ecosystem levels) (Clarke Murray et al., 2014). As such, the term 'cumulative effects' can mean different things in different assessments such as the assessment of multiple exposures to a single stressor, or the cumulative effect of the same stressor at different life stages of a species.

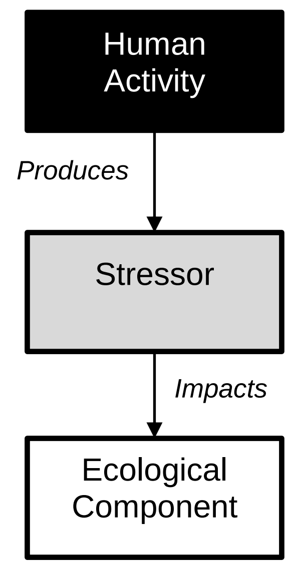


Figure 1 - A simplified impact chain relationship

A significant challenge in cumulative effects assessment is the incorporation of stressor interactions. Not all stressors are equal in impact or have impacts that increase linearly, and the outcomes of interactions between stressors, or between stressors and fluctuating conditions, can be difficult to predict. Interactions may be additive, synergistic, or antagonistic, potentially resulting in different impacts than might be anticipated based on a simple summation of two or more stressor impacts (Cote et al., 2016). Natural variability in ecosystem processes may also influence the way that impacts are manifested (Clarke Murray et al., 2014). An assessment method that can account for the inherent variability and potential stressor interactions is needed to assess the magnitude of cumulative effects.

To fully account for the cumulative effects on coastal and marine ecosystems from multiple human activities, scientists and managers must be able to understand: (1) which activities cause which stressors; (2) the magnitude, frequency, duration and spatial scale and extent at which the activities occur; (3) what the resulting direct and indirect cumulative effects will be on the ecosystem; and (4) how multiple ecological components at different levels of organization (e.g., individuals, populations, species, communities, and ecosystems) will respond (Clarke Murray et al., 2014).

THE ROLE OF CUMULATIVE EFFECTS ASSESSMENT IN DFO

The study and management of cumulative effects is an emerging field and area of critical importance to the Fisheries and Oceans Canada (DFO) as part of its responsibility for management of a healthy environment and sustainable aquatic ecosystems. Increasingly, there is a demand within DFO for management advice based on scientific evaluation of cumulative effects; indeed, this requirement has been expressed at the highest levels within DFO and the Government of Canada.

Legislative context

Under Canada's amended *Fisheries Act* (enacted June 21 2019 with royal assent to Bill C-68), cumulative effects requirements of the new Fish and Fish Habitat Protection Provisions came into force on August 28 2019[1]. Under the amended *Act*, "*the Minister…shall consider…the cumulative effects of the carrying on of the work, undertaking or activity referred to in a recommendation or an exercise of power, in combination with other works, undertakings or activities that have been or are being carried on, on fish and fish habitat*" [Section 34.1(1)[2]]. This amendment specifically speaks to the requirement to assess cumulative effects for the purposes of fish and fish habitat protection. Bill C-69, repealing the *Canadian Environmental Assessment Act* (2012) and enacting the *Impact Assessment Act*, also received royal assent and the new *Act* came into force on June 21 2019[3]. Among other things, it names the Impact Assessment Agency of Canada as the authority responsible for impact assessments. Federal authorities "*in possession of specialist or expert information or knowledge*" (this could, for example, include DFO) have an obligation to provide this information or knowledge to the Impact Assessment Agency at its request. The *Act* prohibits proponents of projects from causing impacts to environmental components and in geographic areas that are also of concern to DFO. Specifically, prohibitions include *"(a) a change to the following components of the environment …(i) fish and fish habitat, as defined in subsection 2(1) of the Fisheries Act, (ii) aquatic species, as defined in subsection 2(1) of the Species at Risk Act….* The areas where such changes are prohibited includes *"(b) (i) the internal waters of Canada, in any area of the sea not within a province, (ii) the territorial sea of Canada, in any area of the sea not within a*

[1] https://www.dfo-mpo.gc.ca/pnw-ppe/guidance-eng.html#_Annex_1:_Transitional
[2] https://www.parl.ca/DocumentViewer/en/42-1/bill/C-68/royal-assent

[3] https://www.parl.ca/DocumentViewer/en/42-1/bill/C-69/royal-assent#ID0EHEDI

province, (iii) the exclusive economic zone of Canada, and (iv) the continental shelf of Canada…" Specific to consideration of cumulative effects, the *Act* "*provides for the assessment of cumulative effects of existing or future activities in a specific region through regional assessments and of federal policies, plans and programs, and of issues, that are relevant to the impact assessment of designated projects through strategic assessments*". The scope of such impact assessments is potentially quite broad. The impact assessment of a designated project "*must take into account the following factors: (a) the changes to the environment or to health, social or economic conditions and the positive and negative consequences of these changes that are likely to be caused by the carrying out of the designated project, including (i) the effects of malfunctions or accidents that may occur in connection with the designated project, (ii) any cumulative effects that are likely to result from the designated project in combination with other physical activities that have been or will be carried out, and (iii) the result of any interaction between those effects*".

The *Canadian Energy Regulator Act* was also enacted on June 21 2019 with royal assent to Bill C-69[4]. This act established an independent energy regulatory body responsible for ensuring safe and secure construction, operation and abandonment of pipeline, power line and offshore renewable energy projects within Parliament's jurisdiction. The offshore area means *"(a) any part of the internal waters of Canada or of the territorial sea of Canada that is not situated in Ii) a province other than the Northwest Territories, or (i) the onshore, as defined in section 2 of the Northwest Territories Act; and (b) the continental shelf of Canada and the waters superjacent to the seabed of that shelf".* The term "offshore renewable energy project" is defined as "*any of the following carried on in the offshore area: (a) any research or assessment conducted in relation to the exploitation or potential exploitation of a renewable resource to product energy; (b) any exploitation of a renewable resource to produce energy; (c) any storage of energy produced from a renewable resource; or (d) any transmission of such energy, other than the transmission of electricity to a province or a place outside Canada*". Specifically in relation to the requirement for cumulative effects assessment in the offshore environment, "*The Commission must make its recommendation taking into account – in light of, among other things, any Indigenous knowledge that has been provided to the Commission and scientific information and data – all considerations that appear to it to be relevant and directly related to the offshore renewable energy project or offshore power line, including (a) …any cumulative environmental effects".*

The *Oceans Act* does not explicitly mention cumulative effects but cumulative effects methodologies are clearly required to support Integrated Oceans Management which is mandated by the *Oceans Act*. During a review of DFO's Integrated Oceans Management program, most DFO managers, stakeholders, and external experts identified a continued need in Canadian oceans management to understand oceans from an ecosystem perspective, taking into account the cumulative impact of human and environmental interactions (DFO 2012a).

---

[4] https://www.parl.ca/DocumentViewer/en/42-1/bill/C-69/royal-assent#ID0E2FEM

The *Species at Risk Act* (2002), under which the Minister of Fisheries and Oceans is the competent minister for aquatic species also requires the consideration of cumulative effects. Assessments of risk to marine and diadromous species conducted for the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) often recognize and refer to the potential or existence of cumulative effects although in most cases the assessments have not attempted to quantify them (e.g., COSEWIC (2010, 2012, 2015; DFO 2018a). In some cases, the recovery or action plan for a SARA species under DFO's management requires consideration of cumulative effects in recovery management and/or mandates that cumulative effects of threats be assessed as part of the recovery effort (e.g., DFO 2017a).

Cumulative effects research and assessments in DFO

A range of past, current and emerging anthropogenic activities and stressors are putting aquatic ecosystems under increasing pressure, leading to changes in ecosystems and shifts in the function and structure of aquatic environments, factors which contribute to losses in aquatic productivity and biodiversity (Sala et al. 2000; Worm et al. 2006). To develop and carry out oceans management policies and practices that support sustainable aquatic ecosystems, DFO needs to understand the nature, extent, impacts and interactions of stressors, and in particular their combined or cumulative effects, which can be achieved through cumulative effects research and assessment.

The definition for cumulative effects provided by the Canadian Environmental Assessment Agency (Hegmann, 1999) is intended specifically for single-project assessments and as such does not address the full scope of potential cumulative effects assessment types. Within DFO, the way that cumulative effects are understood can vary depending on the focus of the assessment, and the data and methods used to conduct the assessments. For example, in DFO stock assessment, cumulative effects can refer to the accumulation of factors or events, such as mortality, that occur in different life stages and that ultimately determine the size of a recruiting population (Jamieson et al. 2000). In DFO's new fish and fish habitat protection program policy (effective Aug 29, 2019), cumulative effects are defined as "*any cumulative harmful impacts on fish and fish habitat that are likely to result from the work, undertaking or activity in combination with other works, undertakings, or activities that have been or are being carried out*" (DFO FFHPP 2019). In the Federal Science Library, the first mention of DFO involvement in cumulative effects work was in Rosenberg et al (1981) "Recent Trends in Environmental Impact Assessment". Since then, results on "cumulative effects" or "cumulative impacts" in the title of publications in the Federal Science Library have become more frequent over time (Karanka and Karanka 1993; Jamieson and Chew 2000; DFO 2009a; Burt et al., 2010; Chaput and Cairns 2011; Canter et al., 2012; Lawson and Lesage 2012; etc.).

The consideration of cumulative effects in DFO programs was identified as lacking in a 2000 review (Jamieson and Chew, 2000), which concluded that a comprehensive cumulative effects research effort by DFO would only be achieved by a long term stand-alone initiative. Another DFO study identified a need in DFO for "*new tools to assess cumulative effects of multiple stressors*"; and for "*improvement of comprehensive* *ecosystem-level monitoring, assessment, and predictive capabilities*" as part of a national review of seven pilot Ecosystem Research Initiatives (ERIs) across Canada, established in 2007 by DFO Science to enhance the capacity to provide scientific advice in support of ecosystem-based management (DFO 2013a).

Increasing both the understanding of cumulative effects and the use of Cumulative Effects Assessment (CEA) within DFO will help respond to recommendations to consider cumulative effects by the Council of Canadian Academies (CCA, 2013), and in environmental impact assessments and species-at-risk recovery plans. This will also support Integrated Oceans Management under the *Oceans Act* and provide advice for the Fisheries Protection Program (FPP), which is increasingly seeking expert scientific review of environmental assessments related to project proposals in aquatic environments, including science advice on questions related to impacts of multiple stressors on fisheries productivity.

Areas across DFO that can benefit from cumulative effects research and assessment

The following list, which is not exhaustive, identifies areas where cumulative effects research and assessment have broad application to resource management decisions and policy development across DFO.

Fisheries and Aquaculture Management (FAM)

- Development of a strategy to assess cumulative effects of stressors on fish stocks and to consider these assessments in management (e.g., Cohen Commission recommendations #71 and #72)
- Characterizing the cumulative effects of aquaculture on the environment (e.g., DFO 2016a)

Fish and Fish Habitat Protection Program (FFHPP)

- Under DFO's fish and fish habitat protection program policy (effective Aug 29, 2019) the contribution of cumulative effects shall be considered in making regulations or exercising powers under the new FFHPP policy (DFO FFHPP 2019).
- Ensure compliance for development projects taking place in and around fish habitat under the fish and fish habitat protection provisions of the Fisheries Act and relevant provisions of the Species at Risk Act
- As part of compliance, evaluate and respond to assessments of cumulative effects on fish and fish habitat from development projects (DFO 2016b).

Integrated Oceans Management (IOM)

- Recognition and management of the long-term cumulative impacts of human actions on the marine environment in ocean management (DFO 2002).
- Cumulative effects is an important consideration in the ecosystem approach to fisheries, as identified in DFO's 2018-2019 departmental plan (DFO 2017b)

Marine Conservation Targets (MCT)

- The assessment of cumulative effects is part of the ecosystem approach to manage and monitor areas designated for marine conservation, such as integrated management areas and marine protected areas (MPAs).

Oceans Protection Plan (OPP)

- In collaboration with Transport Canada, there is a need to assess the cumulative effects of marine shipping across Canada (Transport Canada, 2016)

Species at Risk Act (SARA)

- Cumulative effects assessments are needed to inform and address specific legally mandated recovery measures outlined in SARA Action Plans relating to threats and impacts to species recovery (e.g., the action plan for resident killer whales in the Pacific (DFO 2017a))

DFO investments in cumulative effects

As part of DFO's Science Renewal 2016, the national Ecosystem Stressors Program (ESP) was created, a DFO program that was intended to address the lack of cumulative effects assessment (CEA) methods available within DFO (Jamieson and Chew 2000). The Program is to guide marine resource managers in the evaluation of potential future impacts or past actions. One of the goals of this national, permanent program is to develop and test a suite of methods that DFO can use to assess cumulative effects.

Before ESP but since 2000, a number of projects and programs within DFO have developed and carried out CEA research but they were generally project-specific and tailored to specific deliverables or clients. This document reviews and summarises existing research and assessments in DFO to ultimately build on our current understanding of best practices in CEA. We categorize past and ongoing research into four assessment types to structure future work in a coordinated CEA strategy, to identify gaps, and to enhance our understanding of future needs.

COMPONENTS OF A CUMULATIVE EFFECTS ASSESSMENT FRAMEWORK

A cumulative effects assessment (CEA) 'framework' outlines the components to be used in a specific type of assessment and the order in which they will be applied. A framework is a high-level order of operations, usually in the form of a flow diagram, showing the order of method components with supporting guidance (e.g. Figure 2). The components used in an assessment can vary, but generally use some or all of the following components: assessment structure, scoping methods, stressor models and assessment tools; all are described in more detail below. The assessment components may be explicitly or implicitly included in the framework.

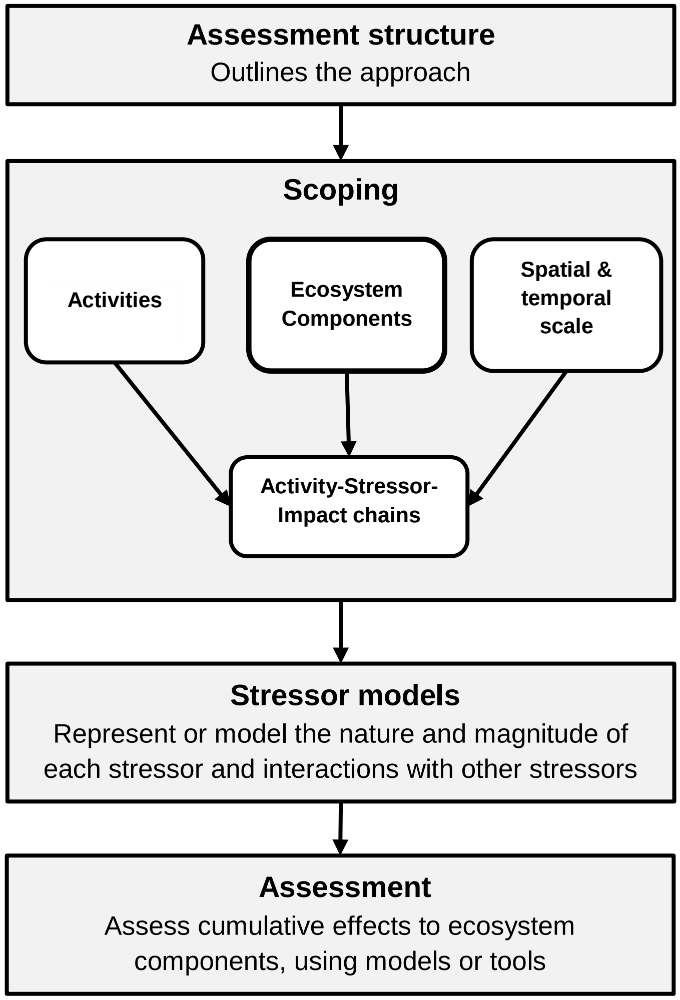


Figure 2 - The generic structure of a cumulative effects assessment framework

The **assessment structure** is commonly described at the beginning of a cumulative effects assessment. It can also be provided as a diagram to provide a high-level overview of the structure and focus of the assessment for guidance (Figure 2). **Scoping** brings together, or guides, the selection of relevant assessment components (activities, stressors, ecosystem components, spatial and temporal scales) based on the goal of the assessment. The selection of Ecosystem Components identifies the endpoints of the assessment that will be evaluated (e.g. sea otter population size, areal extent of eelgrass beds) and can be done using a screening process based on applying a range of environmental, social, and/or economic criteria.

The next step in scoping is to examine the linkages, or **Impact chains**, from activities to stressors to effects. Pathways of Effects (PoE) models are an example of an established scoping method that can be used to examine the linkages from activities to stressors and effects (see Box 1).

Stressor models are developed to quantify the way that stressors interact with ecosystem components or with each other. They can be informed using available data and expert input. Stressor interactions describe the documented or hypothesized interaction between stressors. Most assessments use the simplest default interaction between stressors - additive, but synergistic, antagonistic and non-linear interactions have been documented (Darling and Cote 2008; Crain et al 2008). The **Assessment** itself is a model of the ecosystem components that accumulates the stressors and their impacts. Assessment models can range from qualitative models that rank the relative impact to fully quantitative models that predict the net impact (e.g. number of mortalities, net gain or loss, etc.) on a species, population, habitat or ecosystem of interest. **Tools** are interfaces between the user and the models that facilitate the analysis and make the assessment user-friendly. An example of a tool for cumulative effects assessment (CEA) is *Vortex*, population viability analysis software developed by the Species Conservation Toolkit Initiative (SCTI).

The most appropriate type of CEA framework to apply for a specific purpose depends on the focus of the assessment and how assessment results are to be used. CEAs can use a top-down approach (starting from the human activity or stressor and identifying all the potential impacts on ecosystem components), a bottom-up approach (starting from the ecosystem component(s) and identifying all potential impacts and stressors) or a combination of the two. The next part of this document will describe the role of cumulative effects assessments in DFO in order to determine the potential uses for cumulative effects assessments in the department.

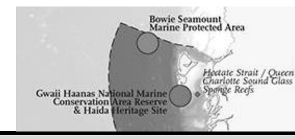
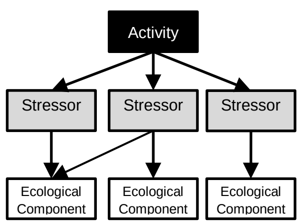
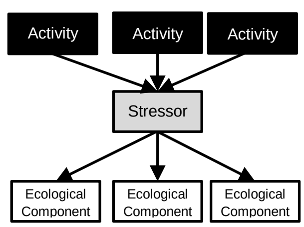
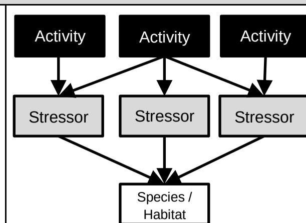
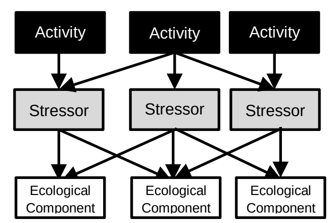
PROPOSED STRATEGY FOR CUMULATIVE EFFECTS ASSESSMENT IN DFO

Based on the range of existing work and needs within DFO programs for CEA as outlined above, we propose a strategy for assessing cumulative effects that uses a typology of cumulative effect assessment frameworks consisting of four types:

(1) Activity-based;
(2) Stressor-based;
(3) Species- or habitat-based; and
(4) Area-based.

This typology is consistent with the structure described in Clarke Murray et al. (2014) and similar to that used to describe pathways of effects models (Government of Canada, 2012). Each assessment type (summarised in Table 1) has a distinct primary focus based on the type of cumulative effects it would be used to assess. Activity-based and species- or habitat-based cumulative effects assessments exemplify top-down and bottom-up approaches, respectively. Stressor-based cumulative effects may be exclusively a top-down approach or may include elements of bottom-up methodology. Area-based cumulative effects may incorporate elements of any of the other three categories, but usually are wider in coverage of species and activities than any of the other categories would be individually. The following sections review the body of knowledge for each assessment type.

Table 1 – Overview of the proposed Cumulative Effects Assessment (CEA) strategy for Fisheries and Oceans Canada, comprising four types of method frameworks.

<table>
<tr><th colspan="4">FOCUS OF SPECIFIC METHOD FRAMEWORK</th></tr>
<tr><th>ACTIVITY</th><th>STRESSOR</th><th>SPECIES or HABITAT</th><th>AREA</th></tr>
<tr><td></td><td></td><td></td><td>
</td></tr>
<tr><th colspan="4">ASSESSES CUMULATIVE IMPACTS</th></tr>
<tr><th colspan="4">FROM:</th></tr>
<tr><td>All stressors resulting from a focal activity</td><td>One specific stressor from all potential source activities</td><td>Stressors from all activities affecting a species or a habitat</td><td>Stressors from activities occurring in a specific area</td></tr>
<tr><th colspan="4">TO:</th></tr>
<tr><td>One or more ecological components</td><td>One or more ecological components</td><td>A single focal species or habitat</td><td>One or more ecological components in area</td></tr>
<tr><th colspan="4">Structure</th></tr>
<tr><td>
</td><td>
</td><td>
</td><td>
</td></tr>
</table>

ACTIVITY-BASED CUMULATIVE EFFECTS ASSESSMENT

Overview of structure of assessment

The first type of method framework focuses on the assessment of activity-based cumulative effects. The structure of this assessment type is outlined in Figure 3. This assessment type aims to assess the cumulative effects of multiple stressors resulting from a single specific activity of interest (such as shipping or fishing). In DFO, activity-based cumulative effects assessments would be appropriate for use in fish and fish habitat protection, fisheries and aquaculture management, environmental assessment, and strategic cumulative environmental assessment.

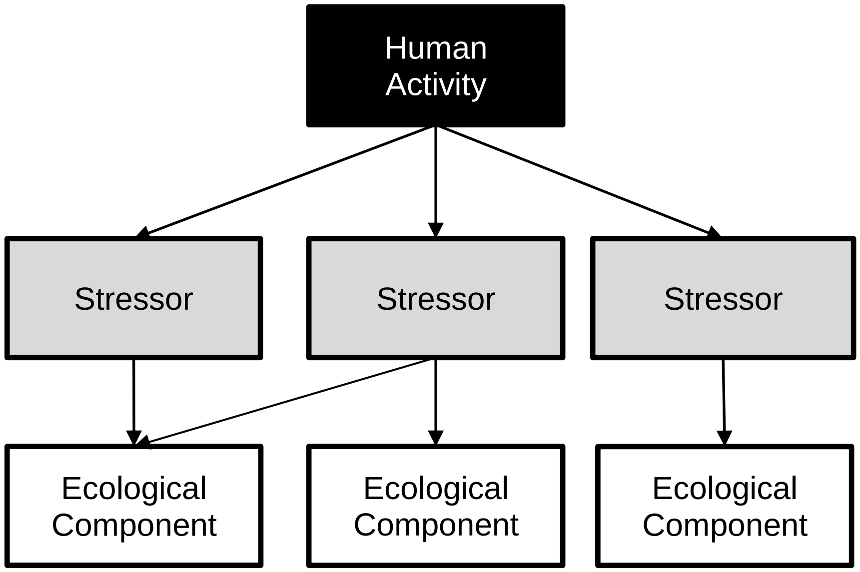


Figure 3 - Structure of an activity-based cumulative effects assessment, where a single activity produces multiple stressors and impacts on ecological components

Box 1: Pathways of Effects Models

Pathways of Effects (PoE) models are widely used conceptual modelling tools that can guide assessments by providing a science-based foundation for decision-making (Government of Canada, 2012). They can be used in all four types of cumulative effects assessments (i.e., activity, stressor, species and area) to help identify the stressors and clarify links between human activities and potential impacts on aquatic ecosystem components. These conceptual models of activities, stressors and effects are comprised of two components: a diagram showing the connections, and an accompanying evidence table providing supporting rationale to justify each connection. The Government of Canada has provided national guidelines for the format of these models (Figure 4, Government of Canada, 2012) and through consultation created a suite of PoE diagrams as a way to communicate potential effects of development proposals to fish populations and fisheries.

Table 2 - List of national Pathways of Effects Models for common in-water activities associated with a broad range of development proposals (DFO 2014a)

In-Water Activities
Addition or removal of aquatic vegetation
Change in timing, duration and frequency of flow
Dredging
Fish passage issues
Marine seismic surveys
Organic debris management
Placement of material or structures in water
Structure removal
Use of explosives
Use of industrial equipment
Wastewater management
Water extraction

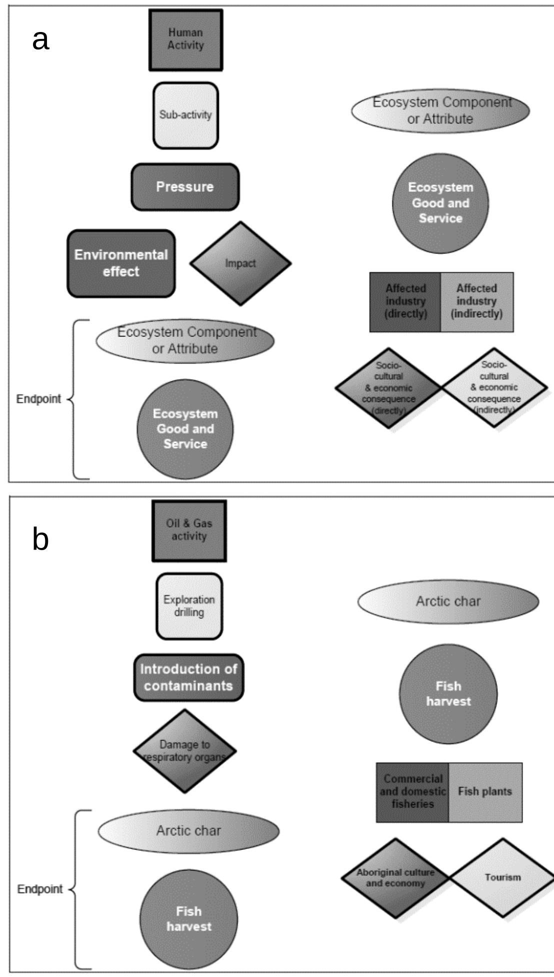


Figure 4 – Guidelines for the format of basic components of a Pathways of Effects (PoE) model (a); and an example PoE diagram without linkages (b)

PoEs can range from small scale, simple impact links, suitable for a specific habitat, to more complex, large scale networks, suitable for a bioregion (Government of Canada, 2012). Different types of PoE models address different goals and objectives:

1. *Activity- and sector-based models* show all stressors resulting from the activity/action (e.g. marine seismic surveys, see Table 2). Sector-based models are broader and look at impacts from a specific sector (e.g., marine shipping). These types of models can be used alone or can contribute to holistic models in combination with other models.

2. *'Endpoint' models* – show potential impacts on specific endpoints (such as ecosystem components), most relevant here are species-based and stressor-based types.

Box 2 Cont'd

A species-based model describes the pathways from human activities, their sub-activities, the stressors, and impacts to a specific species or ecosystem component. A stressor-based model examines linkages from a stressor to measureable endpoints (e.g., fish health).

3. Area based, or 'holistic' models – incorporate all human activities occurring in a spatial unit that can contribute to cumulative effects.

Pathways of effects models to inform this type of assessment

Activity (or 'Pressure'-based) PoE models (see Box 1) can be used to inform activity-based cumulative effects assessment and have been adopted by DFO as a tool to identify the impact chains for specific activities of interest (e.g. anchoring) within a sector (e.g. shipping).

National PoE models have been developed for some activities, including aquaculture (DFO 2009b), shipping (DFO 2015), and commercial fisheries (e.g. Baer et al 2010) and a number of activities associated with development (Table 2). Pathways of Effects models were also developed for a number of activities in the Yukon North Slope pilot project (Stephenson and Hartwig 2009). An example of an activity PoE model is provided in Figure 5.

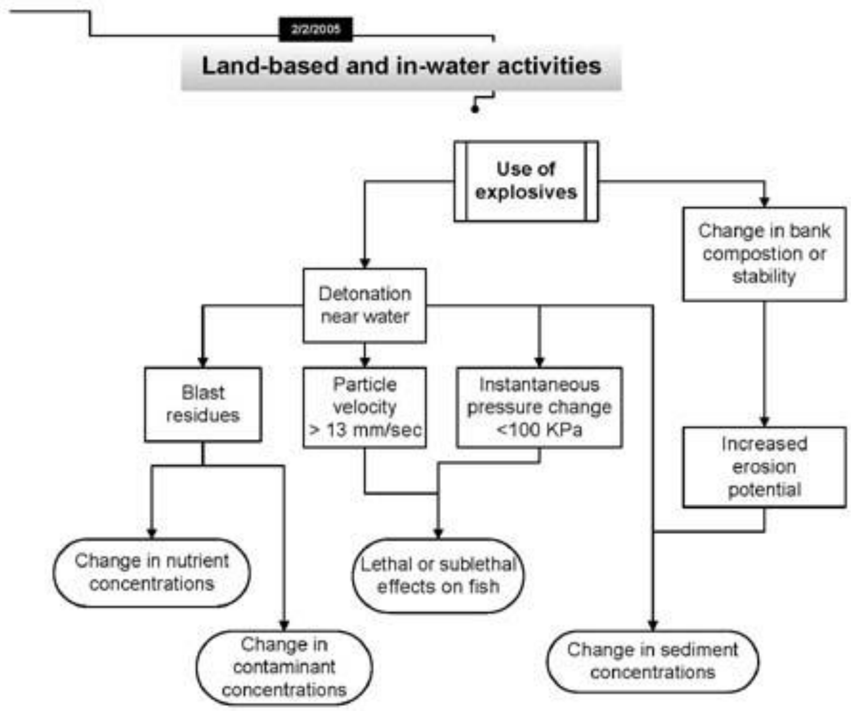


Figure 5 - Example of an Activity-based Pathways of Effects diagram for the use of explosives in the marine environment (after GOC, 2012)

Examples of activity-based assessments within DFO

Outlined here are examples of areas in DFO where activity-based CE assessment have been carried out, or where cumulative effects have been identified to be an area of interest for shipping, fishing, aquaculture and land-use activities.

Fishing

One of the five guiding principles of the DFO's Fisheries Protection Policy (FPP) is to use an ecosystem approach and include "*consideration of cumulative effects on the state, resiliency, and natural biodiversity of the ecosystem*" (DFO 2013b). DFO's Sustainable Fisheries Framework (SFF) establishes the policy basis for using an ecosystem approach to fisheries management. Though the SFF identifies the consideration of cumulative effects as a fundamental component for using an ecosystem approach to fisheries management, to date, there are only a few examples of explicit consideration of the cumulative effects of fishing impacts in DFO research publications. There are, however, many examples of DFO moving towards using the ecosystem approach which could be used as components of, or to inform a fishing-related cumulative effects assessment. For example:

- Elucidating the ways that fishing activities impact the marine environment
    - Description of the impacts of mobile gear (trawl gears and scallop dredges) and non-mobile bottom-contacting gears in marine habitats and communities (DFO National Capital Region DFO 2006a; DFO 2010)

    - Examination of the indirect effects of bottom-contact fishing (by trap) on sponge reefs in the Pacific region by estimating remobilized sediment footprints in the Hecate Strait/Queen Charlotte Sound (Boutillier et al. 2013) and Strait of Georgia and Howe Sound (DFO 2018b).
    - Creation of a holistic Pathways of Effects model for Capelin to highlight potential cumulative effects which could guide future efforts for CEA (Quebec Region, Giguère et al., 2011)
- Risk-based approaches
    - Using a risk-based approach to assess the risk of shrimp fishing to Narwhal overwintering habitat and food source (DFO 2017c)
    - A pilot application (Pacific Region, Holt et al. 2012) of an 'Ecosystem Risk Assessment Framework for the Effects of Fishing' (ERAEF) that assesses ecological risk from fishery or non-fishery impacts on species, habitats, and ecological communities to inform an ecosystem-based risk assessment approach to fisheries management (based on a method developed by Hobday et al. (2007; 2011)). Though the ERAEF was thorough in assessing risks from multiple stressors, the method (at Level 1 and 2) did not include an assessment of cumulative effects by combining the risks calculated, either across multiple stressors within a single fishery, or across all fisheries/activities (Holt et al. 2012). The authors of the ERAEF and other researchers have since tested ways to integrate cumulative effects into risk assessments of fishing but these have yet to be applied by DFO (Zhou et al. 2013; Micheli et al. 2014; Zhou et al. 2016).
- Fishing-Related Incidental Mortality (FRIM)
    - The FRIM work provides a synthesis, using a systematic review (quasi-meta-analysis), of the multiple factors (fishing, environmental, and intrinsic) affecting salmon survival in relation to a fisheries encounter (Patterson et al. 2017a), and provides a risk assessment approach (Patterson et al. 2017b) by modelling the cumulative impact of the key multiple stressors on fish survival. The risk approach calculates the impact of the different factors by assuming the interactions among stressors are antagonistic, additive or synergistic. The process used a weight of evidence approach, trying to avoid expert opinion where possible (DFO 2016c). This information is being used by DFO to assess the risk of FRIM for post-season mortality estimates of sockeye, as well as to develop quantitative estimates of FRIM for other salmon species (D. Patterson, DFO, pers. comm.).

Additional CEA work on salmon species in relation to fishing is described under species-based methods.

Shipping

Impacts on marine mammals from development projects

A cumulative effects framework, the Cumulative Ecological Risk Assessment Framework (CERAF), was developed (Newfoundland & Labrador and Quebec Regions; Lawson and Lesage, 2012; DFO 2017d) to quantify and accumulate the risks to marine mammals from major development projects. Application of the approach was first illustrated in the context of an impact assessment of shipping activities associated with the proposed marine development by the Mary River Project, Nunavut (Lawson and Lesage 2012). Cumulative effects, in this case, assessed repeated exposures from shipping noise and ship strikes on marine mammals over time. Outputs from Lawson and Lesage's (2012) case study included modelled estimates of the expected number of whales (by species) at risk of ship strike annually, and number of individual-exposures of whales to shipping noise levels ≥ a threshold of 120 dB re 1 µPa annually. A qualitative severity rating matrix was developed to combine magnitude, extent, and temporal duration/frequency into a severity rating. This severity rating combined with likelihood of occurrence yielded relative impact rating. In 2017, the framework was adapted to be more comprehensive in its incorporation and treatment of data inputs, and its acknowledgement and estimation of uncertainty and risk (DFO 2017d). The next steps in developing this CERAF will be to operationalise the framework to a greater extent, for example, by providing for both data-rich and data-poor contexts (J. Lawson pers. comm.).

National Cumulative Effects Framework for Marine Shipping (Oceans Protection Plan)
DFO is collaborating on the Government of Canada's Ocean Protection Plan (OPP) with Transport Canada (TC) and Environment and Climate Change Canada (ECCC). Transport Canada leads the development of a national cumulative effects framework for marine shipping with the goal of increasing understanding of impacts of marine vessel activity on the environment (under Pillar II of OPP - the preservation and restoration of marine ecosystems) (DFO 2017b). As well as framework development, the initiative is collecting data and developing tools to apply to existing vessel movements and future project developments. This project will assess six pilot coastal areas of Canada, where the scoping phase of the project will determine: the scope of marine shipping activities to be assessed; spatial and temporal boundaries; valued ecosystem components (VECs); and the stressors with the potential to impact them. The effects of proposed activities on VECs can then be assessed and mitigation tools and strategies developed. This initiative will involve a significant collection of coastal environmental data and regional marine shipping data for these focal areas. Engagement for this initiative began in autumn 2017.

Aquaculture
Fisheries and Oceans Canada (DFO) recognizes the importance of studying cumulative effects and ecosystem interactions with respect to aquaculture. Overall sustainability of the aquaculture industry can be enhanced by identifying possible cumulative effects of aquaculture activities, characterizing the capacity for an area to support aquaculture activities, validating indicators of aquaculture effects that can be used to predict, measure, and quantify ecosystem effects, and developing tools to support ecosystem-based environmental management, regulation, and decision-making.

In 2005-06, DFO held national workshops to inform the understanding of aquaculture impacts and provide science advice on the effects of aquaculture-environment interactions both in the near- and far-field. The first workshop on marine finfish aquaculture (DFO 2005a) discussed five papers on issues such as benthic impacts from increased sedimentation and nutrient-loading (Chamberlain *et al.* 2005; Page 2005; Strain 2005; Wildish *et al.* 2005; Vandermeulen *et al.* 2005). Some of these papers described the potential far-field impacts of finfish aquaculture, for example on sensitive marine habitat-forming species such as eelgrass and kelp (DFO 2005a; Vandermeulen *et al.* 2005), and the potential for widespread secondary effects on marine ecosystems due to the important role of these species as habitats and food sources.

The second workshop on shellfish aquaculture (DFO 2006b) discussed five papers (Anderson *et al.* 2006; Chamberlain *et al.* 2006; Cranford *et al.* 2006; McKindsey *et al.* 2006; Vandermeulen *et al.* 2006). One of these papers (Anderson *et al.* 2006) specifically examined how the cumulative effects of shellfish aquaculture on fish habitat (e.g. biodeposition, nutrient alteration, phytoplankton depletion, etc.) could be quantified and whether those effects can be predicted or measured in the far-field. It was recognized in the paper that *"cumulative effects of shellfish aquaculture and other human activities will depend on both the effects of each activity under consideration and the potential for synergistic or antagonistic effects*", however a clear process or framework for how to consider these interacting cumulative effects was not developed. Overall, the workshops identified a large number of knowledge gaps requiring further research and recognized that a 'bay-wide' management approach should be adopted so that aquaculture can be placed within the context of other cumulative stressors and their interactions.

In 2009, a Pathways of Effects (PoE) for Finfish and Shellfish Aquaculture model was reviewed through DFO's CSAS peer-review process. This model described the relationships between aquaculture activities and seven stressor categories relevant to both finfish and shellfish aquaculture: physical alteration of habitat structure; alteration in light; noise; release of chemicals and litter; release or removal of nutrients, non-cultured organisms, and other organic material; release or removal of fish; and release of pathogens (DFO 2009b). Seven research papers that described the nature, scale and variability of the activities-stressors-effects relationships were peer-reviewed as part of this process and provided the foundation and detail underpinning the overall Aquaculture PoE model (Burridge et al., 2010; Grant and Jones, 2010; Leggatt et al., 2010; McKindsey, 2010; Olesiuk *et al.* 2010; Trippel 2010; Chamberlain and Page, 2013).

To support development of the aquaculture industry in a sustainable manner that protects ecosystems and conserves wild fish populations, DFO established the Sustainable Aquaculture Program (SAP) in 2008. Science activities under SAP are advanced through the Program for Aquaculture Regulatory Research (PARR), which funds targeted research to advance our understanding of the interactions between aquaculture and the aquatic environment, to increase scientific knowledge, and ultimately to inform regulatory decision-making and policy development. One of the five themes for this research program is "cumulative effects and ecosystem management". There have been 18 research projects funded by the PARR under the cumulative effects management theme over the time period 2008-2017. For shellfish aquaculture, research has been focused on understanding how much aquaculture production a bay can support while maintaining wild species, communities, and the ecosystem. Some examples include examining relationships between benthic loading by farmed mussels and aquatic invasive species (McKindsey *et al.* 2009), evaluating interactions between bivalve aquaculture, land use, physical characteristics of bays, and eelgrass coverage at bay-wide scales (Niles *et al.* 2014), and projects developing and validating indicators and models for assessing carrying capacity (Comeau 2013; Guyondet *et al.* 2015). For finfish aquaculture, research has been focused on characterizing the likely interactions between farms in an area, understanding connectivity between these farms, and supporting the development of bay or area-based management zones. Some examples of this include evaluation of oceanographic conditions that may influence sea lice in salmon farming areas (DFO 2012) and development of circulation models to assess connectivity of zones for managing risks related to pathogens and and/or wastes (Foreman *et al.* 2012).

In 2015, the Aquaculture Science Environmental Risk Assessment Initiative was implemented under the SAP to assess the risks associated with each of the environmental stressors validated in the PoE for finfish and shellfish aquaculture. The four-step Aquaculture Science Environmental Risk Assessment Framework has been developed for this purpose (see Figure 6).

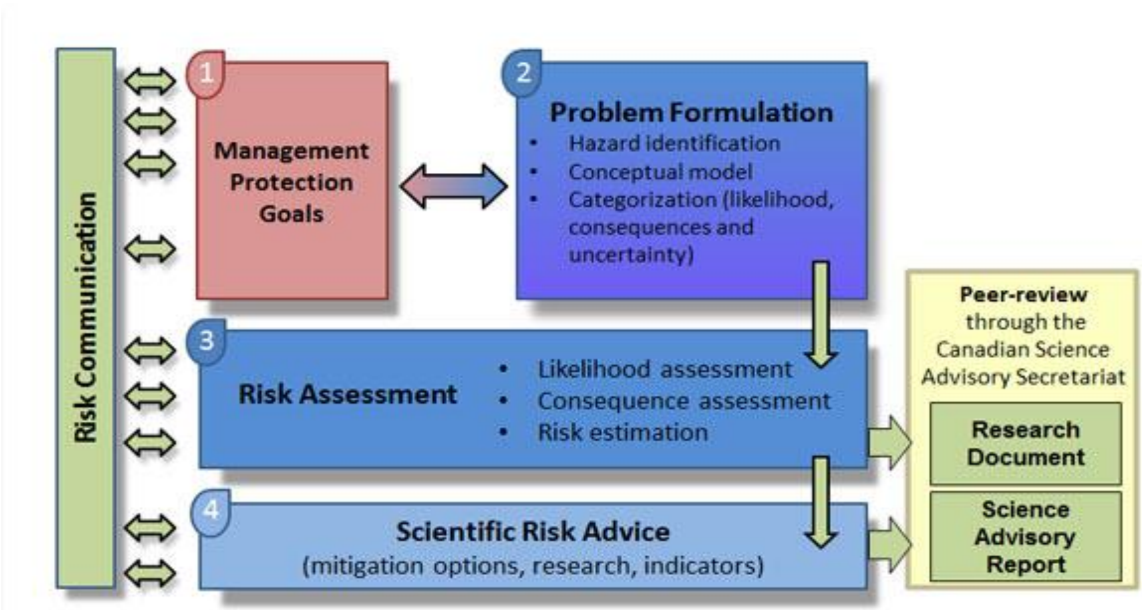


Figure 6 – DFO's Aquaculture Science Environmental Risk Assessment Framework

The first series of risk assessments to be conducted under the initiative was focused on the pathway related to the release of pathogens, and is specific to Atlantic salmon aquaculture activities in the Discovery Islands area of British Columbia. This is in direct support of DFO's role in the management of aquaculture in British Columbia and aligns with recommendations in the final report of the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (Cohen, 2012a). The first risk assessment has been completed and evaluated the risk of Infectious Hematopoietic Necrosis Virus (IHNV) transfer to Fraser River Sockeye Salmon from Atlantic Salmon farms in the Discovery Islands area of British Columbia (Mimeault *et al.* 2017). Cumulative effects were mentioned as a source of uncertainty in the consequence analysis (*"…the lack of knowledge of potential sublethal and cumulative effects of exposure to IHNV")*; however, this approach could include cumulative effects assessments as a component of the risk estimation phase in the future.

In 2016, two new DFO aquaculture science programs were announced, the Aquaculture Monitoring Program (AMP) and the Aquaculture Ecosystem Interactions Program (AEIP). The objective of the AMP is to conduct long-term far-field monitoring of the fate of aquaculture inputs (i.e. organic matter, trace metals, drugs, pesticides, and antibiotics). The program also aims at characterizing potential cumulative effects of multiple farms located in an area. This information can help make appropriate, science-based management decisions around issues such as farm siting, site management, and the use of fish health treatments that consider the fate and behaviour of these inputs in the environment, and their spatial and temporal distribution away from the farm sites. The AEIP supports research on the impacts of aquaculture activities and their interactions with the supporting ecosystem, including the cumulative effect of other stressors present in the environment in order to differentiate positive and negative associations induced by aquaculture. This type of work better positions DFO to address challenging and confounding ecological knowledge gaps that cannot be addressed through the current short-term, targeted research programs, and will help to inform managers and policy makers in making complex ecosystem-based management decisions.

In the regulatory context, DFO collects information that can be used to understand the potential interactions and cumulative effects of marine finfish aquaculture sites both prior to and during operation. Applications for new sites and boundary amendments require submission of baseline information under DFO's *Aquaculture Activities Regulations (AAR)* for marine finfish cage sites. While Provincial governments are the primary regulators and leasing authorities for aquaculture (except in British Columbia and Prince Edward Island), DFO continues to provide input to support provincial siting decisions, including through the provision of science advice.

Baseline survey submissions for aquaculture sites include information such as the predicted footprint of biochemical oxygen demand (BOD) matter deposition, surveys of fish and fish habitat, bathymetry data, and visual, geochemical, and sedimentological assessments of the benthic substrate. Location requirements of the survey are aimed at evaluating potential cumulative effects in the localised (below cages) and near-field (within metres) areas prior to licensing approval to develop aquaculture in a sustainable manner that protects marine ecosystems and mitigates risk to wild populations of fish and fish habitat. With this information, DFO provides science input for siting decisions to provincial regulators, when requested, and cumulative effects between sites in a given area is often evaluated in that context.

Even prior to the implementation of the AAR in 2015, DFO Science provided advice on the potential for and risks associated with cumulative interactions between a proposed and existing site in Port Mouton, Nova Scotia (DFO 2007; DFO 2009a). The *AAR* also outlined requirements for ongoing operational monitoring of the benthic substrate, and includes the establishment of reference stations to further assess the potential effects that can vary in scale from near- (within metres) and far-field (kilometres).

STRESSOR-BASED CUMULATIVE EFFECTS ASSESSMENT

Overview and structure of assessment

The second method framework focuses on the assessment of cumulative effects from a stressor. The structure of this assessment type is outlined in Figure 7. The method framework aims to assess the effects of a single stressor linked to single or multiple anthropogenic activities. The need for a focus on a single stressor may be because the stressor has the potential to have significant or complex impacts. These assessments are particularly useful in situations where mitigation is under consideration because the stressor levels can be directly measured and managed (e.g., ban of PCBs, closure of shellfish harvesting due to levels of bacteria or algal biotoxins), or where chemical and structural pollutants from multiple sources or source types may accumulate in the environment and in ecosystem components of concern (e.g. PDBEs – Ross, 2006).

Research within DFO has examined the cumulative effects of numerous stressors, including multiple chemical pollutants (e.g., Ross, 2006), sediment resuspension (e.g., Boutillier et al., 2013), and noise (e.g., O’Neill and Vagle 2015; Allen et al., 2018; Gervaise et al., 2015).

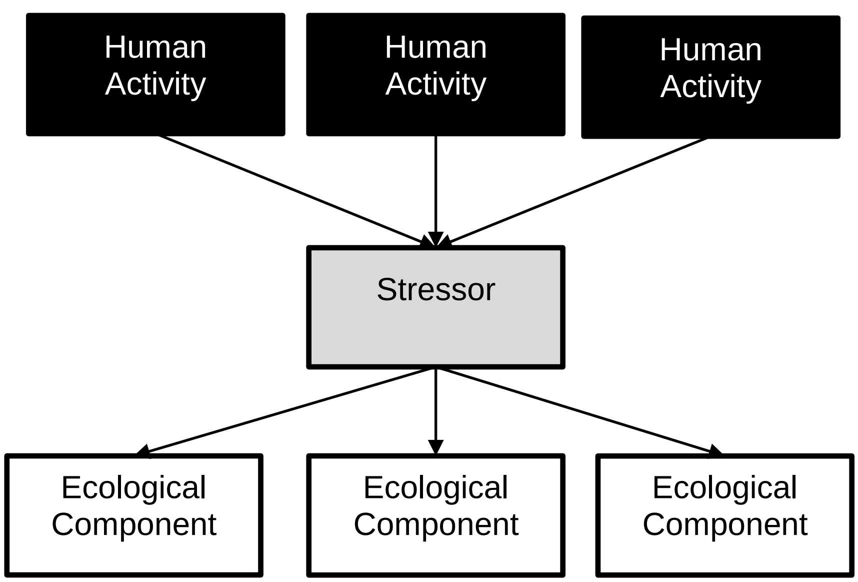


Figure 7 – Structure of a stressor-based cumulative effects assessment focusing on the activities that contribute to a single stressor and the impact of that stressor on the ecological component(s)

Pathways of Effects Models to inform this framework type

Stressor-based Pathways of Effects models can be used to determine the impact chains from the stressor to different endpoints, such as fish health, or from different contributing activities (see example in Figure 8).

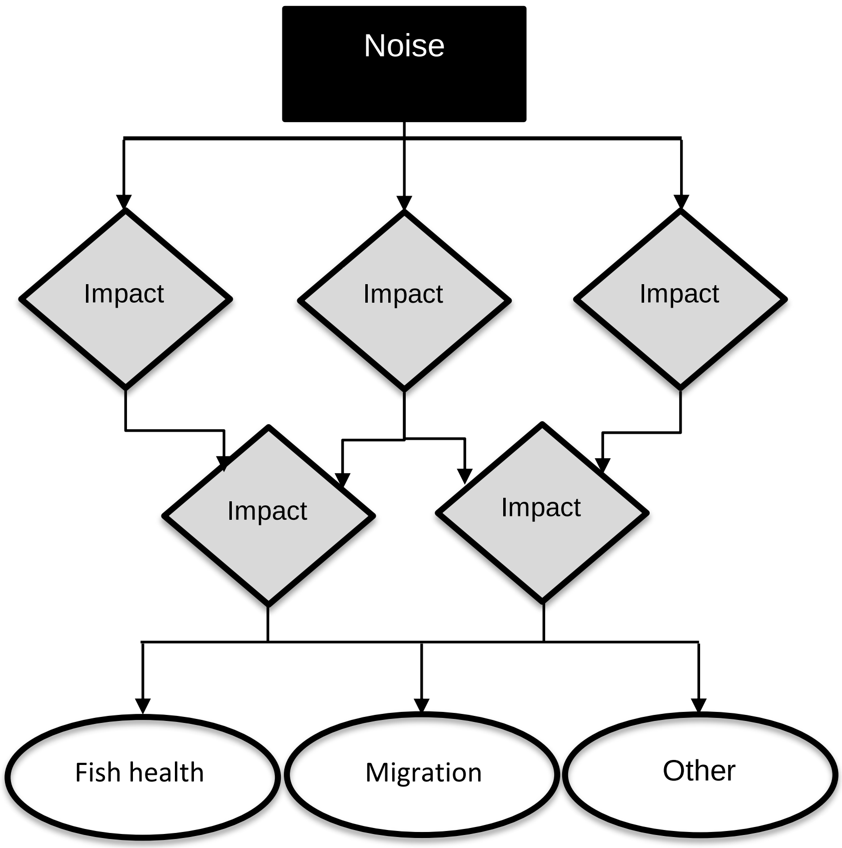


Figure 8 - Example of a generalised Stressor-based Pathways of Effects Model for Noise (adapted from GOC, 2012)

Examples of stressor-based assessments in DFO

Noise

Noise is a complex stressor of increasing research interest within DFO, in particular with regard to its potential impacts on marine mammals. DFO researchers are collaborating with external agencies to map cumulative shipping sound exposure levels (Quebec Region; Gervaise et al., 2015). These data are being used to support the development of a probabilistic shipping Sound Exposure Levels (SEL) model which will allow identification of areas where SEL exceed threshold values and the percentage of time that the threshold is exceeded, in order to guide management decisions regarding impacts to aquatic biota (Gervaise et al. 2015).

DFO has worked with the consultant JASCO to develop a regional cumulative noise model. JASCO noise models have been used to examine cumulative noise levels of marine vessels (commercial, recreational, and whale watching vessels) and how that might change with increased vessel traffic projected with the proposed Trans Mountain Expansion (TMX) project. The habitat of the endangered Southern Resident Killer Whale (SRKW) overlaps with major shipping lanes, making noise an acknowledged stressor of concern for this population (DFO 2017a, 2017e, 2017f). The anticipated increase in vessel traffic may increase the cumulative effects experienced by the SRKW and may have adverse impacts to SRKW populations (DFO 2017g). DFO Science provided advice on this question through CSAS in 2017 and proposed a number of potential mitigation measures to reduce noise impacts (DFO 2017g). Noise and cumulative effects on large whales is a major theme in the new Ocean Protection Plan (OPP) initiative, a partnership between DFO, Transport Canada, and Environment and Climate Change Canada (DFO 2016d).

DFO is a collaborator and participates on the advisory and acoustic technical committees of the Port of Vancouver's Enhancing Cetacean Habitat and Observation (ECHO) program, launched in 2014, an "*initiative aimed at better understanding and managing the cumulative impacts of shipping activities on at-risk whales throughout the southern coast of British Columbia*". The ECHO program identifies noise as one of the key threats to whales in this region (in addition to ship collisions, contaminants and prey availability (VFPA 2017).

Contaminants

Research within DFO has examined the cumulative effects of chemical pollutants (e.g. Ross et al. 2000; Ross, 2006; Burridge et al. 2008), in the context of a population's repeated exposure to pollutants through time. The interactions between chemical pollutants and other factors such as ultraviolet radiation and climate change have also been examined (e.g., Reist et al. 2006, Wrona et al. 2006). Currently, contaminants research is supported by DFO through the National Contaminants Advisory Group (NCAG) (http://www.dfo-mpo.gc.ca/science/environmental-environnement/ncag-gncc/index-eng.html). Research priorities identified for funding under this process include cumulative effects studies of aquaculture therapeutants and their effects on non-target organisms (http://www.dfo-mpo.gc.ca/science/environmental-environnement/ncag-gncc/2017/priorities-eng.html).

Sediment re-suspension

DFO Science assessed the risks associated with sediment remobilisation from fishing and provided mitigation options (Boutillier et al., 2013). To estimate the remobilised sediment footprint, a framework was developed and applied that described (i) the intensity of fishing activities (in relation to sediment remobilisation); (ii) the sediment types; (iii) the factors affecting resettlement rates of remobilised sediment; and (iv) dispersion of remobilised sediment as a result of ocean currents under different fishing scenarios. The framework incorporated components of the Ecological Risk Assessment Framework (ERAF) to estimate risk (O et al. 2015). Under this framework, the estimation of overall risk for fishing intensity incorporated the cumulative impacts of each day fished for each reef complex from all fisheries, as the fisheries do not always take place at the same time (Boutillier et al., 2013). A sediment resettlement model and dispersion model were used to calculate the impacted area. The sediment dispersion models were then used to inform the risk to sponge reefs of exposure to remobilised sediment from fishing activities under a range of mitigation strategies. More recently, this method has been applied and further developed to assess risks from bottom-contact trap fishing to sponge reefs in other areas of BC (Strait of Georgia sponge reefs) (DFO, 2018b)

Causeways and tidal barriers

The construction of causeways and tidal barriers can have a range of impacts on fish and fish habitat. An intensive effort by DFO and other agencies assessed the effects of the Petitcodiac River causeway which blocked tidal flow and fish passage in a macrotidal estuary of the Bay of Fundy. The objective of the study was to assess the effect of the causeway on a wide range of receptors, including water quality and flow, estuarine and freshwater habitat, diadromous fish composition, population structure and abundance, zooplankton composition and abundance, benthic invertebrates, and marine and freshwater macrophytes (e.g., Aubé et al. 2005, Locke 2001, Richardson et al. 2002).

As the watershed and its fisheries had been well studied by DFO researchers between the 1940s and 1960s, a form of cumulative effects assessment was conducted by qualitatively assessing the ecological value of the watershed before and after the causeway construction in 1967. This assessment considered criteria of temporal stability, uniqueness, conservation of native species, and level of disturbance (Locke et al. 2003). Subsequently, a full Environmental Impact Assessment was conducted for modification to the causeway (New Brunswick Department of Environment and Local Government 2005) and a critique of this EIA stated that based in part on the level of cumulative effects assessment conducted*, "the Environmental Impact Assessment Report for Modifications to the Petitcodiac River Causeway performs very strongly in light of academic criticisms of typical Canadian EIA practices*" (St. Pierre, 2014).

Aquatic Invasive Species

Risk assessments for aquatic invasive species in Canadian waters examine the effect of the stressor (the invasive species) on multiple receptors, including biodiversity, fisheries and aquaculture industries, wildlife and human health, habitat, and genetic consequences (e.g., Therriault et al. 2008). While there is no specific method of combining effects on multiple receptors, Mandrak et al. (2012) considered these assessments to be cumulative in the sense that they consider effects expressed incrementally through the stages of an invasion (i.e., arrival, survival, establishment and spread).

Climate Change

DFO has conducted risk assessments of each major ocean basin in relation to climate change, considering a wide range of receptors (DFO 2013c). Although the assessment could be considered cumulative in the sense that multiple impacts were identified, one conclusion of the report was that "*There is a gap in our understanding of how to incorporate cumulative effects into assessment (risk, vulnerability, etc.) processes*". The projected impacts of climate change are meant to be taken into consideration when making resource decisions (Prime Minister's Mandate Letter 2016[5]).

SPECIES-BASED CUMULATIVE EFFECTS ASSESSMENT

Overview and structure of assessment

The third method framework focuses on the assessment of cumulative effects to a species or habitat. Habitat may refer to habitat-forming species such as kelp and eelgrass, or to water quality, quantity and physical features. The structure of this assessment type is outlined in Figure 9. The method framework aims to assess the cumulative effects of multiple human activities and stressors on a single taxonomic or functional group (e.g., species, population) or habitat.

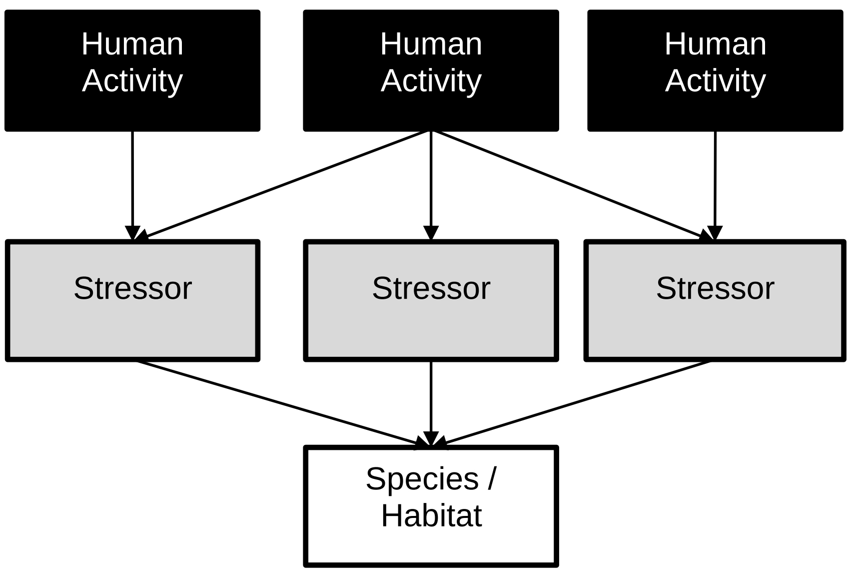


Figure 9 - Species-based cumulative effects framework showing relationship between multiple human activities, stressors and a single ecological component (species or habitat)

Within DFO, this type of assessment would be appropriate for SARA-listed species, fisheries species or habitat-forming species, or any other species of interest. The client sectors who would benefit from the outputs of this type of CEA would include species at

[5] https://pm.gc.ca/en/mandate-letters/minister-fisheries-oceans-and-canadian-coast-guard-mandate-letter

risk (SARA), fisheries and aquaculture management (FAM), and ecosystem-based management. Within DFO, there are a number of areas where cumulative effects to single species have been considered, even if not explicitly mentioned.

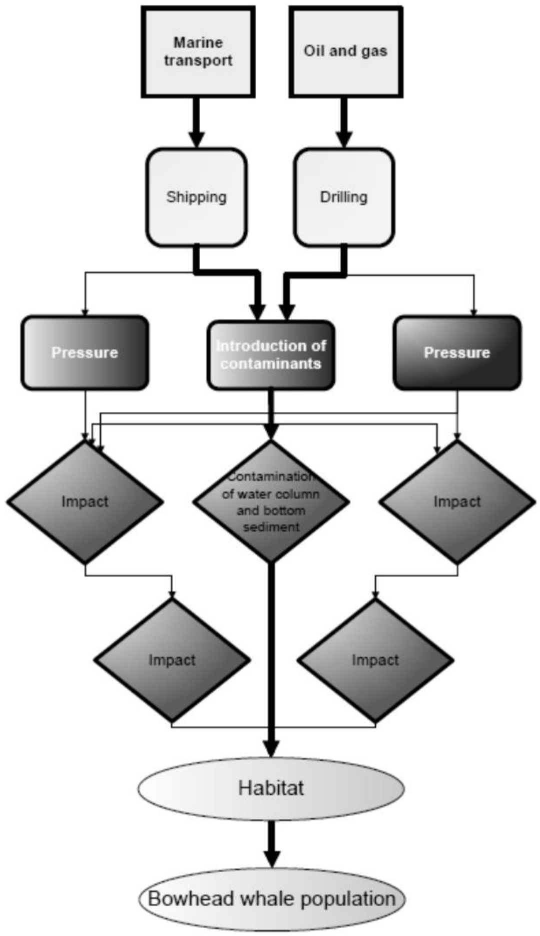


Figure 10 - Example of a species-based Pathways of Effects Model (PoE) for bowhead whales (after GOC, 2012)

Pathways of Effects Models to inform this framework type

Species-based Pathways of Effects models (Figure 10) can be used to elucidate the impact chains from the various activities that can affect a particular species and then structure a cumulative effects assessment. For example, species-specific CEA is of increasing interest to the fishing industry as the environmental impact assessment of fisheries entering into Marine Stewardship Council (MSC) certification requires the consideration of cumulative effects (Marine Stewardship Council 2013).

Examples of species-based assessments in DFO

Pacific Salmon

Stressors can act on different stages in the salmon life cycle so that the cumulative effects of these stressors can reduce overall salmon population levels (Healey 2011). This is consistent with DFO salmon stock assessment, where cumulative effects usually refer to the accumulation of factors, such as mortality, that occur in the different life stages and that ultimately determine the size of a recruiting population (Jamieson and Chew 2000). Impacts on salmon population size can be assessed using a population model which captures stressor input at various points in the life cycle. A framework developed by Bradford et al. 2014 assesses changes in fisheries productivity (vital rates and life processes needed for fish to complete their life cycle) caused by the effects of development projects. The framework, in a hybrid activity-species approach, uses Pathways of Effects Models (PoEs) to identify project impacts on fisheries productivity components such as survival.

The Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (Cohen, 2012a; 2012b) noted that the accumulation of small impacts from small-scale developments can result in a gradual loss of fish habitat but that DFO lacks methodologies for assessing such cumulative effects, possibly due to a project- by-project focus. Recommendation 71 was that DFO needed to consider the "*cumulative effects of stressors of Fraser River sockeye health and habitat in its management of fisheries and fish habitat*". Progress on the implementation of this recommendation (as well as the related recommendation 72) has been reported in the 2017 Cohen Response 2017 Status Update (DFO 2017h).

DFO is developing an implementation plan for its 2005 Wild Salmon Policy (WSP) (DFO 2005b). DFO's draft WSP implementation plan for 2018-2022 (DFO 2017i) states that salmon Conservation Units are exposed to cumulative impacts across the range of habitats throughout their life history, and outlines objectives including supporting "*ongoing national and provincial initiatives and increase interagency communication on cumulative effects assessment and management issues pertaining to shared aquatic ecosystem values*". To fulfil some of these objectives, DFO partnered with the Pacific Salmon Foundation to create an online tool in 2016 (the 'Pacific Salmon Explorer') that allows users to explore and visualise cumulative pressures (stressors) on freshwater salmon habitats in the Skeena watershed, and is an example of what could be used in other areas (http://salmonexplorer.ca).

DFO has examined the impact of multiple stressors on Pacific salmon in a number of initiatives. DFO Scientists at the DFO Pacific Cooperative Resource Management Institute (Simon Fraser University) have compiled and evaluated quantitative methods for analysing cumulative effects on fish migration success which can be used as a primer for researchers to model cumulative effects of a range of variables to fish migration success (Johnson et al., 2012). DFO has studied the impact of multiple stressors (mostly concurrent exposure) on salmon survival and/or surrogates of survival (i.e., physiology, behaviour: Teffer et al. 2018; McLean et al. 2016; Miller et al. 2014; Raby et al. 2015). The quantitative techniques used for assessing interactions among stressors is outlined in Johnson et al. (2012) and includes experimental (e.g. Robinson et al. 2013) and observational studies (Drenner et al. 2015). Though most of the information from this work is related to fisheries management, it contributes to work related to fish passage relevant to the Fisheries Protection Program (Middleton et al. 2018).

The multiple stressors affecting *en route* mortality of Fraser River Sockeye salmon have been examined using environmental information to proactively adjust harvest levels, as per Pacific Salmon Treaty obligation, and for determining post-season impact of multiple stressors on in-river mortality estimates. The quantitative modelling using environmental information for in-season adjustments (e.g. Macdonald et al. 2010; Cummings et al. 2011) is supported by migratory physiological stress work (see Patterson et al. 2016). The post-season assessment of mortality uses a qualitative risk assessment approach for dealing with multiple risk factors (e.g., water temperature, discharge, fishing, behaviour, fish condition), including a separate risk-based CEA on release mortality (Patterson et al. 2017b). The risk posed by water temperature on in-river survival is considered a dominant factor and is based on cumulative exposure across the in-river migration (e.g. Hague et al. 2011). Current work in this area is focused on using Bayesian Belief Network methods to assimilate the disparate factors that can influence in-river mortality (D. Patterson, pers. comm.). DFO partners on this work with the Pacific Salmon Commission and academia (UNBC, SFU, UBC, Carleton).

DFO is collaborating with academia (UNBC, SFU, UBC) to develop an approach to model the cumulative effects of different stressors on salmon survival to assess the utility of different management actions. Ongoing work by DFO scientists uses a generalized quantitative framework to assess the cumulative effects of stressors on Fraser River sockeye salmon developed by Dr. Eduardo Martins (SFU, now at UNBC). This work will conduct a detailed analysis of the cumulative effects of stressors on survival and fecundity of Fraser River sockeye salmon using Integrated Population Models (IPM; Schaub & Abadi 2011). IPMs will be used to assess the dynamics and viability of populations experiencing multiple stressors (Koons et al. 2017). The impact of a single stressor on one life-stage may not be as important to population dynamics as an equivalent stressor applied to a different life-stage, due to density dependent and independent responses. The model framework will be used to quantify the impact of specific stressors and assess the efficacy of potential management actions in reducing impacts (D. Patterson, DFO, pers comm.).

Marine Mammals

The Species at Risk Act (SARA) action plan for Northern and Southern Resident Killer Whales in the Pacific (DFO 2017a; DFO 2017f), outlines 98 Recovery Measures (RMs), three of which relate (directly or indirectly) to cumulative effects (Table 2). The Ecosystem Stressors Program (ESP) in DFO Science has collaborated with SARA to conduct a cumulative effects assessment for both killer whale populations (Clarke Murray et al. 2019), adapted from population models developed by Velez-Espino et al. (2014) and Lacy et al. (2017)).

Table 3 - SARA Recovery Measures for Resident Killer Whales related to cumulative effects from the primary threats (reduced prey availability, environmental contamination and disturbance)

#	Recovery Measure
6	Take into account both the seasonal (acute) as well as the cumulative (chronic) effects of poor returns for Chinook and other important prey species on Resident Killer Whales when managing fisheries.
11	Assess cumulative effects of potential anthropogenic impacts on Resident Killer Whales using an appropriate impact assessment framework for aquatic species.
17	Review and assess project impacts on Resident Killer Whales and their habitat, and provide advice on avoidance and mitigation measures as required.

The beluga whale SARA recovery strategy (St. Lawrence estuary population) states that "…*it is also important to take into account the cumulative and synergistic effects of these threats on the St. Lawrence beluga population*" (DFO 2012). DFO scientists in Quebec region have collaborated with other scientists to build a model to predict how the St. Lawrence beluga population may respond to changes in environmental conditions and to the cumulative effects of three threats (prey abundance, underwater noise and disturbance, and chemical pollution). In this work, a Population Viability Analysis (PVA) model was developed and threats were assessed using an additive approach (Williams et al. 2017). The CEA was used to examine the relative importance of these threats and the effect of single and multiple-threat management scenarios (Williams et al. 2017).

A national cumulative effects framework has been developed by DFO scientists to examine the impacts of major development projects on marine mammals and turtles, and has been applied to bowhead, narwhal and beluga whales (Lawson & Lesage 2012). This example was described under the previous 'Activity-based' section as it focuses on shipping, but it could also be considered a hybrid activity-species approach. Subsequent modifications of the framework have expanded the scope to include additional stressors and activities (DFO 2017d).

AREA-BASED CUMULATIVE EFFECTS ASSESSMENT

Overview and structure of assessment

The fourth method framework focuses on assessing the cumulative effects to ecological components in a specific area. The structure of this assessment type is outlined in Figure 11. This method framework aims to assess the cumulative effects of all human activities and stressors occurring in a specific area. Within DFO this type of assessment is appropriate for marine spatial planning and management, aquaculture siting, and in environmental assessment of development projects. O et al. (2014) developed an area-based cumulative effects assessment framework for guiding Ecosystem-Based Management and monitoring of Marine Protected Areas (MPAs) and Large Ocean Management Areas (LOMAs). This framework is called the ‘Ecological Risk Assessment

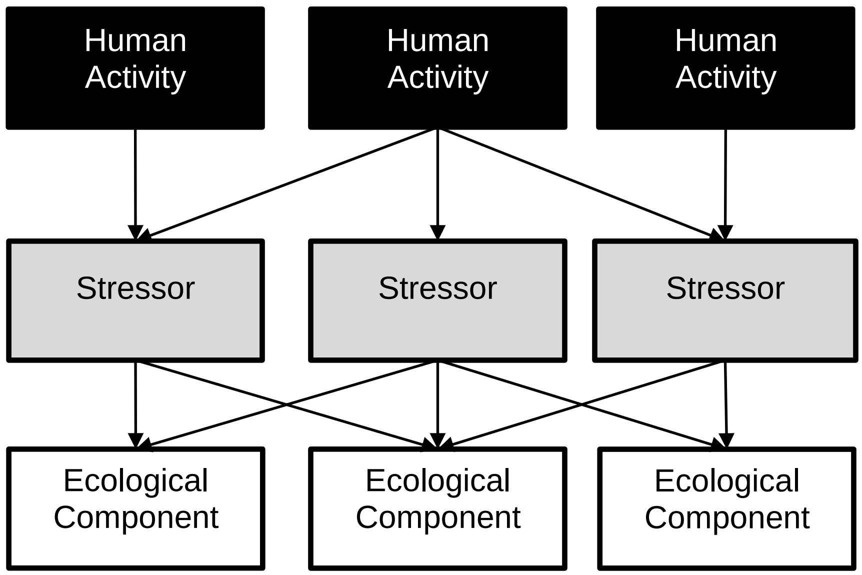


Figure 11 - Area-based (or ecosystem) cumulative effects framework capturing multiple human activities, stressors and ecological components.

Framework (ERAF) and uses a risk-based tiered approach progressing from qualitative to semi-quantitative to quantitative risk assessment depending on the objective and data availability. The ERAF accumulates risk scores from individual stressor-ecological component interactions additively.

Pathways of Effects Models to inform this framework type

Large scale, holistic PoE models can be integrated within ecosystem or area-based assessments. Holistic PoE models include all valued ecosystem components, stressors, and activities in the system of interest (e.g. Figure 12). Models of this type were developed for the Yukon Slope Shelf area (Stephenson and Hartwig 2009; Figure 12).

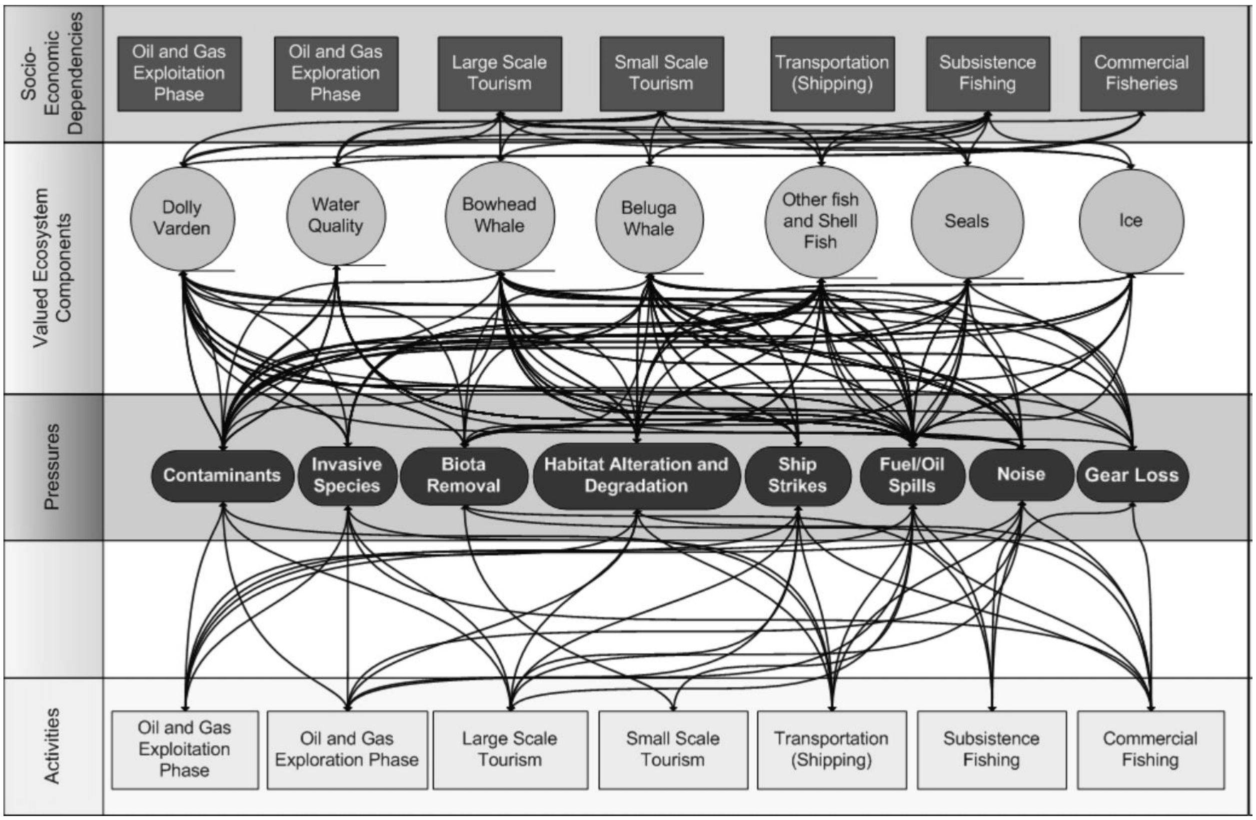


Figure 12 - Holistic Pathways of Effects (PoE) model for Yukon North Slope study area (Stephenson and Hartwig 2009)

Examples of area-based assessments in DFO

Ecological Risk Assessment Framework

The Ecological Risk Assessment Framework (ERAF) developed within DFO Science (O et al. 2014), considers multiple activities producing multiple stressors, and their impacts on multiple ecosystem components of interest. The ERAF is a transparent method to provide science-based advice on anthropogenic impacts for ecosystem-based management, and to guide the identification of indicators for Marine Protected Areas (MPAs) and Large Ocean Management Areas (LOMAS) in Canada. The ERAF has a scoping phase followed by three increasingly quantitative levels of risk assessment, and provides methods for calculating risk of harm to an ecosystem from both single and multiple stressors by considering elements of exposure, sensitivity and recovery. In the scoping phase, human activities and associated stressors in the area are identified, and species, habitats and communities in the area are assessed to produce a handful of ecosystem components. The potential impact of stressors to selected components is then assessed in the risk assessment phase (Level 1, 2 or 3). The framework is a top-down approach, where risk to each ecological component from each stressor is assessed by evaluating exposure, sensitivity and recovery to produce a risk score. The cumulative risk to a component is calculated by adding up the risk to that component from each stressor. When applied to Marine Protected Areas, the outputs of the ERAF have been used to select ecological risk-based indicators that will be used to develop research and monitoring strategies, refine conservation objectives further into operational objectives, and develop monitoring plans. The framework predominantly considers impacts as a snapshot of the present time, but can include ‘potential’ stressors which may occur in the future (such as an oil spill, or invasive species). It is area-based, but only considers impacts of stressors to the specific ecosystem components within that area.

As an initial pilot project, the ERAF was applied to a Large Ocean Management Area (LOMA), the Pacific North Coast Integrated Management Area (PNCIMA) (Clarke Murray et al., 2016a). The ERAF has since been applied to three MPAs: Bowie Seamount MPA (Rubidge et al 2018), Endeavour Hydrothermal Vents MPA (Thornborough et al., 2016); and the Hecate/Queen Charlotte Sound Glass sponge reefs MPA (DFO, 2018c). A similar risk-based cumulative effects assessment was applied in Newfoundland to the Placentia Bay/Grand Banks LOMA (Park et al., 2010; 2011). Though the ERAF framework includes guidance for estimating cumulative risk from synergistic, compensatory, and masking interactions, only additive risk has been tested in applications to date. The inclusion of indirect effects was considered in an extension of the PNCIMA pilot project (Clarke Murray et al., 2016b).

A national Climate Change Vulnerability Assessment (CCVA) framework has been proposed to assess commercially-important fisheries vulnerability (or risk) to climate change across DFO’s regions and was applied by Hunter et al. (2015). The CCVA Framework extends from DFO’s Pacific ERAF Framework and incorporates elements of other CCVA methods (e.g. Stortini et al. 2015) in an effort to develop a tool that expresses vulnerability spatially (both exposure and sensitivity), and incorporates fisheries governance adaptive capacity. The tool has been applied to 20 selected fisheries. In addition, the Marine Species Vulnerability Database (developed by Nadja Steiner, Karen Hunter, and Helen Drost) contains information on thermal limits and thresholds to multiple stressors for key Arctic and Pacific marine species that can be used in cumulative effects assessments.

Canadian Healthy Oceans Network

Two DFO-partnered research projects within the CHONE-2 cumulative effects research theme address cumulative effects within specific geographic areas at two different spatial scales in the Gulf and estuary of St. Lawrence. The project “Indicators of benthic condition at the Gulf-scale: Megabenthic community structure” will, among other objectives, develop a spatially explicit map of cumulative stressors for the Gulf of St. Lawrence (https://chone2.ca/find-research/megabenthos-indicators/). On a bay-wide spatial scale, the second project is “To evaluate and model how natural and anthropogenic stressors interact to impact pelagic and benthic communities along a sub-Arctic coastline and develop bay-scale condition indicators" (https://chone2.ca/find-research/coastal-stressors/).

Environmental Assessments
DFO Science is often asked to review and comment on CEAs from project environmental impact assessments (e.g. Roberts Bank T3 EIA). The Federal Canadian Environmental Assessment Agency (CEAA) manages environmental assessments (EAs) used to determine the potential environmental impacts of proposed developments to inform decision making. The Canadian Environmental Assessment Act (CEAA 2012) and its regulations are the legislative basis for these EAs. The requirement to consider cumulative effects in EAs began in the 1990's with the publication of a cumulative effects assessment reference guide and practitioner's guidelines (CEAA 1994; Hegmann et al., 1999). One of the specific purposes of CEAA 2012 was to "*encourage further studies of the cumulative effects of physical activities in a region and the consideration of the study results in environmental assessments*".

There is widespread criticism of the assessment of cumulative effects in the Canadian EA process (e.g. Burris and Canter 1997; Noble et al 2017). Cumulative effects assessment in environmental assessment is area-based in that assessments are focused on the site of a proposed development project. However, the cumulative effects analyses themselves employ a mix of Activity-based, Stressor-based and Species-based assessment types (top-down and bottom-up) and do not attempt to assess the entire suite of cumulative effects to the place of interest.

Ecosystem models
Ecosystem models can be a useful way to illustrate and evaluate the consequences of cumulative effects. A Strait of Georgia model was developed with Ecopath with Ecosim software to explore environmental and anthropogenic factors associated with changes in Coho and Chinook salmon populations in the Strait of Georgia. The model demonstrated that trophic dynamics and environmental forcing could emulate observed changes over a period of four decades (Preikshot et al. 2012). However, a synthesis of outcomes from the Strait of Georgia Ecosystem Research Initiative indicated that most analyses addressed individual stressors; and that cumulative effects were identified as a source of uncertainty, particularly in nearshore habitats (DFO, 2012).

In addition, a number of other DFO research initiatives have focused on understanding multiple activities and their impacts in specific places or ecosystems, although they have generally not assessed the cumulative effects of these activities (e.g. Johannessen and MacDonald, 2009). The Strait of Georgia Ecosystem Research Initiative conducted research on multiple stressors and ecosystem components. Perry and Masson (2013) examined the drivers of change for the Strait of Georgia marine ecosystem using Bayesian belief network analysis. The interactions between human and natural drivers were responsible for significant changes to the ecosystem over time, with three main anthropogenic drivers: human population growth, recreational fishing, and hatcheries releases.

SUMMARY AND CONCLUSIONS

The study and management of cumulative effects is an emerging field and an area of critical importance to DFO, and the need for cumulative effects assessment (CEA) is evident throughout the DFO programs, objectives, and diverse clients outlined in this report. This report has identified a wide range of areas in DFO where work linked to or relevant for CEA has begun, or where completed work would be crucial in informing CEA in the future. There have been significant advances in general theoretical frameworks and visualizations, such as PoE models, that can be used to inform CEA. However, the field of cumulative effects assessment is still emerging and fully developed CEA methods assessed thoroughly with real case studies are not common. There are methods for area-based cumulative effects assessments that have been developed and applied with case studies (e.g. ERAF), but clear and consistent species-, stressor- and activity-based CEA methods are lacking, and the continued development and implementation of method frameworks is needed to address this gap (Table 4).

This review has shown that the diverse types of cumulative effects assessments in DFO distribute logically into the four categories of assessment frameworks, as originally outlined in Clarke-Murray et al (2014). Consequently we propose a CEA strategy for Fisheries and Oceans Canada based on this structure (Table 1). An effective and comprehensive cumulative effects method framework should choose from the various approaches (activity, stressor, species or habitat, and area-based), depending on the research question and management objective, and combine approaches as needed. The available frameworks of the relevant type can then be examined for relevance and applicability to the stated purpose. Further work is needed to develop, test and refine the methods behind each framework type in order to provide a set of methodological guidelines to enable prospective users to apply the appropriate framework for their purposes. Ongoing development of assessment methods will build upon the existing work reviewed in this report as well as the body of work external to DFO, in other government agencies, academia and industry in Canada and around the world. It is anticipated that using this proposed strategy will support a more streamlined and effective approach to assessing cumulative effects within DFO.

Table 4 - Summary table for the four types of cumulative effects assessment and examples of the application of each type of assessment framework

Type	Subject	Region	Stressors	Taxa	Method/ Tool	Purpose	Reference
Activity	Fishing	Pacific region	Fishery and non-fishery related stressors	Commercial fisheries species	Risk Assessment	To assess ecological risk from fishery or non-fishery impacts on species, habitats, and ecological communities to inform an Ecosystem-based Risk Approach to Fisheries Management	Holt et al 2012
	Aquaculture	National	Chemicals, escapes, light, noise, nutrients, pathogens, structure	Various	Pathways of Effects (PoE)	To detail the cumulative impacts of individual aquaculture-related stressors on marine ecosystems	DFO 2009b
Stressor	Noise	Quebec region	Sound exposure	Aquatic biota	Sound exposure levels model	Map cumulative shipping sound exposure to identify areas with high sound exposure	Gervaise et al 2015
Species	Salmon	Pacific region	Stressors associated with development projects	Salmon	Pathways of Effects (PoEs)	Assess the cumulative impact of development projects on salmon population levels	Bradford et al 2014
	Beluga Whales	St. Lawrence Estuary	Loss of prey, underwater noise and disturbance, chemical pollution	St. Lawrence beluga whale	Population viability analysis model	Predict how the population may respond to changes in environmental conditions and cumulative effects of threats	Williams et al 2017
Area	Ecosystem	Strait of Georgia, BC	Multiple	Multiple	Bayesian belief network analysis	Characterize and assess the impacts of multiple stressors on multiple ecosystem components through time	Perry and Masson 2013
	Marine Protected Areas	Pacific Region	Multiple	Multiple Significant Ecosystem Components	Risk assessment	To provide advice on anthropogenic impacts for ecosystem-based management and identify indicators for management objectives	O et al 2014; Thornborough et al 2016
	Large Ocean Manageme nt Area	Pacific North Coast Integrated Management Area	Multiple	Multiple Significant Ecosystem Components	Risk assessment	To provide advice on relative impact of anthropogenic activities and stressors for ecosystem-based management	O et al 2014; Clarke Murray et al 2016a, b

REFERENCES

Anderson, M. R., Cranford, P. J., McKindsey, C. W., Strain, P., Hargrave, B. T., Li, W. K. W., and Harrison, W.G. 2006. Cumulative and far-field fish habitat effects. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/037. http://waves-vagues.dfo-mpo.gc.ca/Library/323203.pdf

Allen, A.S., Yurk, H., Vagle, S., Pilkington, J. and Canessa, R. 2018. The underwater acoustic environment at SGaan Kinghlas-Bowie Seamount Marine Protected Area: Characterizing vessel traffic and associated noise using satellite AIS and acoustic datasets. Marine Pollution Bulletin. 128:82-88.

Aubé, C.I., Locke, A., and Klassen, G. 2005. Zooplankton communities of a dammed estuary in the Bay of Fundy, Canada. Hydrobiologia. 548:127–139.

Baer, A., Donaldson, A., and Carolsfeld, J. 2010. Impacts of Longline and Gillnet Fisheries on Aquatic Biodiversity and Vulnerable Marine Ecosystems. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/012 vii + 78

Bradford, M.J., R.G. Randall, K.S. Smokorowski, B.E. Keatley and Clarke, K.D. 2014. A framework for assessing fisheries productivity for the Fisheries Protection Program. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/067. v + 25 p. http://waves-vagues.dfo-mpo.gc.ca/Library/359758.pdf

Brewer-Dalton, K. (ed), Page, F.H., Chandler, P., and Ratsimandresy, A. 2015. Oceanographic conditions of salmon farming areas with attention to those factors that may influence the biology and ecology of sea lice, *Lepeophtherius salmonis* and *Caligus* spp., and their control. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/048. vi + 47 p

Boutillier, J., Masson, D., Fain, I., Conway, K., Lintern, G., O, M., Davies, S., Mahaux, P., Nguyen, H., and Rutherford, K. 2013. The extent and nature of exposure to fishery induced remobilized sediment on the Hecate Strait and Queen Charlotte Sound Glass Sponge Reef. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/075. http://waves-vagues.dfo-mpo.gc.ca/Library/350277.pdf

Burridge, L.E., Haya, K., and Waddy, S.L. 2008. The effect of repeated exposure to the organophosphate pesticide, azamethiphos, on survival and spawning in female American lobsters (*Homarus americanus*). Ecotox. Environ. Saf. 69: 411–415.

Burridge, L.E., Doe, K.G. and Ernst, W. 2011. Pathway of effects of chemical inputs from the aquaculture activities in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/017. vi + 57 p.

Burris, R. K., and Canter, L. W. 1997. Cumulative effects are not properly addressed in environmental assessments. Environmental Impact Assessment Review. **17:**5-18.

Burt, M. D. B., and Wells, P. G. 2010. Threats to the health of the Bay of Fundy: Potential problems posed by pollutants : Proceedings of a workshop organized under the auspices of BoFEP's working group on stress and cumulative effects, Fairmount

Algonquin Hotel, St. Andrews, New Brunswick, 30th April 2010. Wolfville, N.S: Bay of Fundy Ecosystem Partnership, Acadia Centre for Estuarine Research.

Canter, L. W., Sadler, B., and Randall, R. G. 2012. Development of a reference document on key information sources related to cumulative effects of multiple activities on fish habitat and fish populations in Canada. Burlington, On. Canadian Technical Report of Fisheries and Aquatic Sciences. No. 2998 http://waves-vagues.dfo-mpo.gc.ca/Library/346756.pdf

CEAA. 1994. A Reference Guide for the Canadian Environmental Assessment Act: Addressing Cumulative Environmental Effects. https://ceaa-acee.gc.ca/default.asp?lang=En&n=9742C481-1

Canadian Environmental Assessment Act, 2012 (S.C. 2012, c. 19, s. 52). Act current to 2018-09-26 and last amended on 2017-06-22. Text available at https://laws-lois.justice.gc.ca/eng/acts/C-15.21/ (Accessed Oct 2018).

CEAA. 2015. Canadian Environmental Assessment Act Canadian Operational Policy Statement. Assessing Cumulative Environmental Effects under the Canadian Environmental Assessment Act, 2012 (https://www.canada.ca/content/dam/canada/environmental-assessment-agency/migration/content/1/d/a/1da9e048-4b72-49fa-b585-b340e81dd6ae/cumulative-20effects-20ops-20-20en-20-20march-202015.pdf) Accessed May 2018.

Chamberlain, J., Stucchi, D., Lu, L,. and Levings, C. 2005. The suitability of DEPOMOD for use in the management of finfish aquaculture sites, with particular reference to Pacific Region.

Chamberlain, J., Weise, A. M., Dowd, M., and Grant, J. 2006. Modeling approaches to assess the potential effects of shellfish aquaculture on the marine environment. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/032. http://waves-vagues.dfo-mpo.gc.ca/Library/323205.pdf

Chaput, G., and Cairns, D. 2011. Mortality reference points for the American Eel (*Anguilla rostrata*) and an application for evaluating cumulative impacts of anthropogenic activities. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/053. iv + 28 p.

Murray, C.C., Hannah, L.C., Doniol-Valcroze, T., Wright, B., Stredulinsky, E., Locke, A., and R. Lacy. 2019. Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/056. x. + 88 p.

Clarke Murray, C., Mach, M.E., and Martone, R.G. 2014. Cumulative Effects in Marine Ecosystems: Scientific perspectives on its challenges and solutions. WWF Canada / Center for Ocean Solutions, 62 pp. http://awsassets.wwf.ca/downloads/cumulativeeffects__updated_forwebupload_singlepages.pdf

Clarke Murray, C., Mach, M. E., and O, M. 2016a. Pilot Ecosystem Risk Assessment to Assess Cumulative Risk to Species in the Pacific North Coast Integrated Management Area

(PNCIMA). DFO Can. Sci. Advis. Sec. Res. Doc. 2016/049. http://waves-vagues.dfo-mpo.gc.ca/Library/365826.pdf

Clarke Murray, C., Mach, M., Martone, R., Singh, G., O, M., and Chan, K. 2016b. Supporting risk assessment: Accounting for indirect risk to ecosystem components. Plos One, 11(9), e0162932. doi:10.1371/journal.pone.0162932

Cohen, B.I. 2012a. Commission of Inquiry Into the Decline of Sockeye Salmon in the Fraser River. Recommendations, Summary, Process. The Uncertain Future of Fraser River Sockeye. Vol. 3. Minister of Public Works and Government Services Canada, Publishing and Depository Services, Public Works and Government Services Canada, Ottawa, ON K1A 0S5. 211 p.Final Report – October 2012.

Cohen, B.I. 2012b. Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River. The uncertain future of Fraser River Sockeye Volume 1 – The Sockeye Fishery. http://publications.gc.ca/site/eng/9.652532/publication.html

Comeau, Luc A. 2013. Suspended versus bottom oyster culture in eastern Canada: Comparing stocking densities and clearance rates. Aquaculture 410-411:57-65.

COSEWIC. 2010. COSEWIC assessment and status report on the Atlantic Salmon *Salmo salar* (Nunavik population, Labrador population, Northeast Newfoundland population, South Newfoundland population, Southwest Newfoundland population, Northwest Newfoundland population, Quebec Eastern North Shore population, Quebec Western North Shore population, Anticosti Island population, Inner St. Lawrence population, Lake Ontario population, Gaspé-Southern Gulf of St. Lawrence population, Eastern Cape Breton population, Nova Scotia Southern Upland population, Inner Bay of Fundy population, Outer Bay of Fundy population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xlvii + 136 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

COSEWIC. 2012. COSEWIC assessment and status report on the American Eel *Anguilla rostrata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 109 pp. (www.registrelep-sararegistry.gc.ca/default_e.cfm).

COSEWIC. 2015. COSEWIC assessment and status report on the Black Redhorse *Moxostoma duquesnei* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 50 pp. (www.registrelep-sararegistry.gc.ca/default_e.cfm).

Côté, I.M., Darling, E. S., and Brown, C.J. 2016. Interactions among ecosystem stressors and their importance in conservation. Proc Biol Sci. 2016 Feb 10; 283(1824): 20152592. doi: 10.1098/rspb.2015.2592

Council of Canadian Academies. 2013. Ocean science in Canada: Meeting the challenge, seizing the opportunity. The Expert Panel in Ocean Science. Ottawa. http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/oceans_2/oceans_fullreporten.pdf

Council on Environmental Quality. 1978. National Environmental Policy Act — Regulations. Federal Register, 43(230), 55978–56007.

Crain, C.M., Kroeker, K. and Halpern, B.S., 2008. Interactive and cumulative effects of multiple human stressors in marine systems. Ecology letters, 11(12), pp.1304-1315.

Cranford, P.J., Anderson, R., Archambault, P., Balch, T., Bates, S.S., Bugden, G., Callier, M.D., Carver, C., Comeau, L.A., Hargrave, B., Harrison, W.G., Horne, E., Kepkay, P.E., Li, W.K.W., Mallet, A., Oulette, M., and Strain. P. 2006. . Indicators and thresholds for ue in assessing shellfish aquaculture impacts on fish habitat. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/034.

Cummings, J.W., M.J. Hague, D.A. Patterson, and Peterman, R.M. 2011. The impact of different performance measures on model selection for Fraser River sockeye salmon North American Journal of Fisheries Management 31(2): 323-334

Darling, E.S. and Côté, I.M. 2008. Quantifying the evidence for ecological synergies. Ecology letters, 11(12), pp.1278-1286.

DFO. 2002. Canada's Ocean Strategy. DFO Oceans Directorate, Ottawa. Cat. No. Fs23-116/2002E. http://waves-vagues.dfo-mpo.gc.ca/Library/264675.pdf

DFO. 2005a. Assessment of finfish cage aquaculture in the marine environment. National Capital Region Canadian Science Advisory Secretariat Science Advisory Report 2005/034

DFO. 2005b. Canada's policy for conservation of wild Pacific salmon. 57pp. (Available at http://waves-vagues.dfo-mpo.gc.ca/Library/315577.pdf)

DFO. 2006. Assessing habitat risks associated with bivalve aquaculture in the marine environment. National Capital Region. Canadian Science Advisory Secretariat Science Advisory Report 2006/005

DFO, 2007. Port Mouton Aquaculture Site Review. DFO Can. Sci. Advis. Sec. Sci. Resp. 2007/009.

DFO. 2009a. Review of cumulative effects report for Port Mouton, Nova Scotia. Dartmouth, N.S: Centre for Science Advice, Maritimes Region, Dept. of Fisheries and Oceans. Science Response 2008/015.

DFO. 2009b. Pathways of Effects for Finfish and Shellfish Aquaculture. Canadian Science Advisory Secretariat Science Advisory Report 2009/071. http://waves-vagues.dfo-mpo.gc.ca/Library/339745.pdf

DFO. 2010. Potential impacts of fishing gears (excluding mobile bottom-contacting gears) on marine habitats and communities. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/003

DFO. 2012a. Evaluation of the Integrated Oceans Management Program. Evaluation Directorate Project No. 6B135. Final Report, February 2012. http://www.dfo-mpo.gc.ca/ae-ve/evaluations/11-12/IOM-eng.htm

DFO. 2012b. Recovery Strategy for the beluga whale (*Delphinapterus leucas*) St. Lawrence Estuary population in Canada. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. 88 pp + X pp.

DFO. 2013a. National synthesis of the “Ecosystem Research Initiatives”. Canadian Science Advisory Secretariat Science Advisory Report 2013/026. http://waves-vagues.dfo-mpo.gc.ca/Library/349843.pdf

DFO. 2013b. Fisheries Protection Policy Statement, October 2013. (Available at http://www.dfo-mpo.gc.ca/pnw-ppe/pol/PolicyStatement-EnoncePolitique-eng.pdf)

DFO. 2013c. Risk-based assessment of climate change impacts and risks on the biological systems and infrastructure within Fisheries and Oceans Canada's mandate - Pacific Large Aquatic Basin. Canadian Science Advisory Secretariat Science Response 2013/016

DFO. 2014a. Pathways of Effects. http://www.dfo-mpo.gc.ca/pnw-ppe/pathways-sequences/index-eng.html. Last updated Dec. 2014

DFO. 2014b. Sustainable Aquaculture Program, 2008-2013. http://www.dfo-mpo.gc.ca/aquaculture/programs-programmes/sustainable-durable/2008-2013-eng.htm

DFO. 2015. Pathways of effects for shipping: An overview. Science Advisory Report. Ottawa: Canadian Science Advisory Secretariat, National Capital Region, Fisheries and Oceans Canada. http://waves-vagues.dfo-mpo.gc.ca/Library/364433.pdf

DFO. 2016a. A Scientific Review of the Potential Environmental Effects of Aquaculture in Aquatic Ecosystems. Volume V. Behavioural Interactions Between Farm and Wild Salmon: Potential for Effects on Wild Populations (Laura K. Weir and Ian A. Fleming); Overview of the Environmental Impacts of Canadian Freshwater Aquaculture (C.L. Podemski and P.J. Blanchfield); A Scientific Review of Bivalve Aquaculture: Interaction Between Wild and Cultured Species (T. Landry, M. Skinner, A. LeBlanc, D. Bourque, C. McKindsey, R. Tremblay, P. Archambault, L. Comeau, S. Courtenay, F. Hartog, M. Ouellette and J.M Sevigny)

DFO. 2016b. Technical review of Roberts Bank Terminal 2 environmental assessment: section 10.3 – assessing ecosystem productivity. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/050.

DFO. 2016c. Review and evaluation of fishing-related incidental mortality for Pacific salmon. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2016/049.

DFO. 2016d. The DFO 2017-18 Departmental Plan. Cat. No. Fs1-82E-PDF. http://www.dfo-mpo.gc.ca/rpp/2017-18/2017-18_DP-EN.pdf

DFO. 2016e. Action Plan for the North Atlantic Right Whale (*Eubalaena glacialis*) in Canada: Fishery Interactions [Proposed]. Species at Risk Act Action Plan Series. Fisheries and Oceans Canada, Ottawa. v + 35 pp.

DFO. 2017a. Action Plan for the Northern and Southern Resident Killer Whale (*Orcinus orca*) in Canada. Species at Risk Act Action Plan Series. Fisheries and Oceans Canada, Ottawa. v+33 pp.

DFO. 2017b. Fisheries and Oceans Canada and the Canadian Coast Guard, 2017-2022 Departmental Development Strategy. (Available at http://www.dfo-mpo.gc.ca/sds-sdd/2017-2020/pdf/sds-sdd-2017-2020-eng.pdf)

DFO. 2017c. Assessment of risk of shrimp fishing to conservation objectives of the Narwhal Overwintering and Coldwater Coral Zone. DFO Can. Sci. Advis. Sec. Sci. Resp. 2017/018.

DFO. 2017d. Proceedings of the National Peer Review of a Risk-Based Framework for assessing Cumulative Impacts of Marine Development Projects (MDPs) on Marine Mammals and Turtles; March 3-5, 2015. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2017/026.

DFO. 2017e. Evaluation of the Scientific Evidence to Inform the Probability of Effectiveness of Mitigation Measures in Reducing Shipping-Related Noise Levels Received by Southern Resident Killer Whales. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/041.

DFO. 2017f. Southern Resident Killer Whale: A science based review of recovery actions for three at-risk whale populations. Fisheries and Oceans Canada, Ottawa. 71 pp.

DFO, 2017g. Evaluation of the Scientific Evidence to Inform the Probability of Effectiveness of Mitigation Measures in Reducing Shipping-Related Noise Levels Received by Southern Resident Killer Whales. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/041.

DFO. 2017h. Annex to the Cohen Response 2017 Status Update: Recommendation Response Detail. (Available at http://www.dfo-mpo.gc.ca/cohen/report-rapport-2017-eng.htm).

DFO. 2017i. Draft 2018-2022 Wild Salmon Policy Implementation Plan – Initial Draft for Consultations. 59pp.

DFO. 2017j. Action Plan for the Northern Bottlenose Whale (*Hyperoodon ampullatus*), Scotian Shelf population, in Atlantic Canadian waters. *Species at Risk Act* Action Plan Series. Fisheries and Oceans Canada, Ottawa. iv + 37 pp.

DFO. 2017k. Action Plan for Blue, Fin, Sei and North Pacific Right Whales (*Balaenoptera musculus*, *B. physalus*, *B. borealis*, and *Eubalaena japonica*) in Canadian Pacific Waters. Species at Risk Act Action Plan Series. Fisheries and Oceans Canada, Ottawa. iv + 28 pp.

DFO. 2018a. Amended recovery strategy for the Atlantic Whitefish (*Coregonus huntsmani*) in Canada. Species at Risk Act recovery strategy Series. Fisheries and Oceans Canada, Ottawa. xiii + 62 pp. https://www.canada.ca/content/canadasite/en/environment-climate-change/services/species-risk-public-registry/recovery-strategies/atlantic-whitefish-amended-final.html

DFO. 2018b. Indirect effects of bottom-contact fishing activities (by trap gear) on sponge reefs in the Strait of Georgia and Howe Sound. DFO Can. Sci. Advis. Sec. Sci. Resp. 2018/042.

DFO. 2018c. Ecological risk assessment and selection of risk-based indicators for the Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area. DFO Can. Sci. Advis. Sec. Sci. Resp. 2018/040.

DFO-FFHPP. 2019. DFO Fish and fish habitat protection policy statement, August 2019. Available at http://www.dfo-mpo.gc.ca/pnw-ppe/policy-politique-eng.html

Drenner, S.M., S.G. Hinch, E.G., Martins, N.B. Furey, T.D. Clark, S.J. Cooke, D.A. Patterson, D. Robichaud, D.W. Welch, A.P. Farrell, and Thomson, R.E. 2015. Environmental conditions and physiological state influence estuarine movements of homing sockeye salmon. Fisheries Oceanography. 24(4): 307-324.

Foreman, M.G.G., D.J. Stucchi, K.A. Garver, D. Tuele, J. Isaac, T. Grime, M. Guo, and J. Morrison. 2012. A circulation model for the Discovery Islands, British Columbia, Atmosphere-Ocean, doi:10.1080/07055900.2012.686900.

Gervaise, C., Aulanier, F., Simard, Y. and Roy, N., 2015. Mapping probability of shipping sound exposure level. The Journal of the Acoustical Society of America, 137(6): 429-435.

Giguère, N., Perreault, L., Nellis, P., Savenkoff, C., Bilodeau, F, Giangioppi, M., Tremblay, G.H., Dufour, R., Comtois, S. and Grégoire, F. 2011. Pathways of Effects (PoE) model development for capelin conservation as part of a risk analysis process. Can. Tech. Rep. Fish. Aquat. Sci. 2934: vii+71 pp.

Government of Canada. 2012. Pathways of Effects National Guidelines. Fisheries and Oceans Canada. 32 pp.

Grant, A. A. M. and Jones, S. R. M. 2010. Pathway of effects between wild and farmed finfish and shellfish in Canada: Potential factors and interactions impacting the bi-directional transmission of pathogens. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/018 vi + 58 p.

Guyondet, T., Comeau, L.A., Bacher, C., Grant, J., Rosland, R., Sonier, R., and Filguera, R. 2015. Climate change influences carrying capacity in a coastal embayment dedicated to shellfish aquaculture. Estuaries and Coasts 38: 1593-1618. http://archimer.ifremer.fr/doc/00275/38624/37191.pdf

Healey, M. 2011. The cumulative impacts of climate change on Fraser River sockeye salmon (*Oncorhynchus nerka*) and implications for management. Canadian Journal of Fisheries and Aquatic Sciences, 68(4), 718-737. doi:10.1139/f2011-010

Hague, M. J., M. R. Ferrari, J. R. Miller, D. A. Patterson, G. L. Russell, A. P. Farrell, and Hinch, S.G. 2011. Modelling the future hydroclimatology of the lower Fraser River and its impacts on the spawning migration survival of sockeye salmon. Global Change Biology 17(1):87-98.

Hegmann, G., Cocklin, C., Creasey, R., Dupuis, S., Kennedy, A., Kingsley, L., Ross, W., Spaling, H., and Stalker, D. 1999. Cumulative Effects Assessment Practitioners Guide. Prepared by AXYS Environmental Consulting Ltd. and the CEA Working Group for the Canadian Environmental Assessment Agency, Hull, Quebec.

Hobday, A.J., Smith, A.D., Stobtzki, I.C., Bulman, C., Daley, R., Dambacher, J.M., Deng, R.A., Dowdney, J., Fuller, M., Furlani, D., Griffiths, S.P., Johnson, D., Kenyon, R., Knuckey, I.A., Ling, S.D., Pitcher, R., Sainsbury, K.J., Sporcic, M., Smith, T., Turnbull, C., Walker, T.I., Wayte, S.E., Webb, H., Williams, A., Wise, B.S., and Zhou, S. 2011. Ecological risk Assessment for the Effects of Fishing. Fisheries Research 108:372-384.

Hobday, A.J., Smith, A., Webb, H., Daley, R., Wayte, S., Bulman, C., Dowdney, J., Williams, A., Sporcic, M., Dambacher, J., Fuller, M., and Walker, T. 2007. Ecological risk assessment for the effects of fishing: Methodology. Australian Fisheries Management Authority, Canberra. No. R04/1072.

Holt, K.R., Ackerman, B., Flemming, R., Forrest, R., Kronlund, A., Lacko, L., Rutherford, K., Workman, G.D., and Taylor, N. 2012. Ecological Risk Assessment for the Effects of Fishing: A Pilot Study for British Columbia Groundfish Fisheries. Canadian Technical Report of Fisheries and Aquatic Sciences. Vol 2990. http://waves-vagues.dfo-mpo.gc.ca/Library/347602.pdf

House of Commons Canada. 2018. Bill C-68 : An Act to amend the Fisheries Act and other Acts in consequence. First reading, February 6, 2018. http://www.parl.ca/Content/Bills/421/Government/C-68/C-68_1/C-68_1.PDF

Hunter, K. L., Wade, J., Stortini, C. H., Hyatt, K. D., Christian, J. R., Pepin, P., Pearsall, I.A., Nelson, M.W., Perry, R.I., and Shackell, N.L. 2015. Climate change vulnerability assessment methodology workshop proceedings. Canadian Manuscript Report of Fisheries and Aquatic Sciences 3086. http://publications.gc.ca/collections/collection_2016/mpo-dfo/Fs97-4-3086-eng.pdf

Jamieson G.S., and Chew L. 2000. Cumulative Effects Assessments: An Evaluation of DFO Science Research Options. Canadian Stock Assessment Secretariat Research Document 2000/105. http://waves-vagues.dfo-mpo.gc.ca/Library/256037.pdf

Johannessen, S. C., and Macdonald, R. W. 2009. Effects of local and global change on an inland sea: the Strait of Georgia, British Columbia, Canada. Climate Research. 40(1):1-21.

Johnson, J.E., Patterson, D.A., Martins, E.G., Cooke, S.J. and Hinch, S.G. 2012. Quantitative methods for analysing cumulative effects on fish migration success a review. Journal of Fish Biology. 81:600-631.

Karanka, E,. and Karanka, E. J. 1993. Cumulative effects of forest harvesting on the Kitimat river, British Columbia. Canadian manuscript report of fisheries and aquatic sciences 2218. http://waves-vagues.dfo-mpo.gc.ca/Library/149980.pdf

Koons, D. N., Arnold, T.W., and Schaub, M. 2017. Understanding the demographic drivers of realized population growth rates. Ecological Applications 27:2102–2115.

Lacy, R.C., Williams, R., Ashe, E., Balcomb III, K.C., Brent, L.J., Clark, C.W., Croft, D.P., Giles, D.A., MacDuffee, M. and Paquet, P.C. 2017. Evaluating anthropogenic threats to endangered killer whales to inform effective recovery plans. Scientific Reports, 7(1):14119.

Lawson, J. W., and Lesage, V. 2012. A draft framework to quantify and cumulate risks of impacts from large development projects for marine mammal populations: A case study using shipping associated with the Mary River Iron mine project. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/154. http://waves-vagues.dfo-mpo.gc.ca/Library/348009.pdf

Leggatt, R.A., O'Reilly, P.T., Blanchfield, P.J., McKindsey, C.W. and Devlin, R.H. 2010. Pathway of effects of escaped aquaculture organisms or their reproductive material on natural ecosystems in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/019. vi + 70 p.

Locke, A. 2001. Conditions for diadromous fish passage at the Petitcodiac River causeway. Pages 205-211 in Chopin T, Wells PG (eds.) Opportunities and challenges for protecting, restoring and enhancing coastal habitats in the Bay of Fundy. Proceedings of the 4th Bay of Fundy Science Workshop, Environment Canada – Atlantic Region Occasional Report 17.

Locke, A., Hanson, J.M., Klassen, G.J., Richardson, S.M. and Aubé, C.I., 2003. The damming of the Petitcodiac River: species, populations, and habitats lost. Northeastern Naturalist, 10(1), pp.39-54.

Macdonald, J. S., D. A. Patterson, M. J. Hague, and Guthrie, I.C. 2010. Modeling the influence of environmental factors on spawning migration mortality for sockeye salmon fisheries management in the Fraser River, British Columbia. Transactions of the American Fisheries Society 139(3):768-782.

Mandrak, N.E., Cudmore, B and Chapman, P.M. 2012. National detailed-level risk assessment guidelines: Assessing the biological risk of Aquatic Invasive Species in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/092. vi + 17 p.http://waves-vagues.dfo-mpo.gc.ca/Library/345462.pdf

Marine Stewardship Council. 2013. Cumulative Impacts on Retained Species. Program Improvements. https://improvements.msc.org/database/cumulative-impacts.

McLean, M. F., K.C. Hanson, S.J. Cooke, S.G. Hinch, D.A. Patterson, T.L. Nettles, M.K Litvak, and Crossin, G.T. 2016. Physiological stress response, reflex impairment, and delayed mortality of white sturgeon *Acipenser transmontanus* exposed to simulated fisheries stressors. Conservation Physiology 4(1): cow031

McKindsey, C.W., Anderson, M.R., Barnes, P., Courtenay, S., Landry, T., and Skinner, M. 2006. Effects of Shellfish Aquaculture on Fish Habitat. . DFO Can. Sci. Advis. Sec. Res. Doc. 2006/011. http://waves-vagues.dfo-mpo.gc.ca/Library/323203.pdf

McKindsey, C.W., Lecuona, M., Huot, M., Weise, A.M. 2009. Biodeposit production and benthic loading by farmed mussels and associated tunicate epifauna in Prince Edward Island. Aquaculture 295:44-51

Micheli, F., De Leo, G., Butner, C., Martone, R.G., and Shester, G. 2014. A risk-based framework for assessing the cumulative impact of multiple fisheries. Biological Conservation 176: 224-235.

Middleton, C.M., Hinch, S.G., Martins, E.G., Braun, D.C., Patterson, D.A., Burnett, N.J., Minke-Martin, V., and Casselman, M.T. 2018. Effects of natal water concentration and temperatures on the behaviour of up-river migrating sockeye salmon. Can. J. Fish. Aquat. Sci. (Online)

Miller, K.M., Teffer, A., Tucker, S., Li, S., Schulze, A.D. Trudel, M., Juanes, F., Tabata, A., Kaukinen, K.H., Ginther, N.G., Ming, T.J., Cooke, S.J., Hipfner, J.M., Patterson, D.A., and Hinch, S.G. 2014. Infectious disease, shifting climates, and opportunistic predators: cumulative factors potentially impacting wild salmon declines. Evolutionary Applications. 7: 812-855.

Mimeault, C., Wade, J., Foreman, M.G.G., Chandler, P.C., Aubry, P., Garver, K.A., Grant, S.C.H., Holt, C., Jones, S.R.M., Johnson, S.C., Trudel, M., Burgetz, I.J. and Parsons, G.J. 2017. Assessment of the risks to Fraser River Sockeye Salmon due to Infectious Hematopoietic Necrosis Virus (IHNV) transfer from Atlantic Salmon farms in the Discovery Islands of British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/075. vii + 75 p.

Moore, J.W., Beakes, M.P., Nesbitt, H.K., Yeakel, J.D., Patterson, D.A., Thompson, L.A., Phillis, C.C., Braun, D.C., Favaro, C., Scott, D., Carr-Harris, C., and Atlas, W.I. 2015. Emergent stability in a large, free-flowing watershed. Ecology. 96(2): 340-347.

New Brunswick Department of Environment and Local Government. 2005. Summary of the Environmental Impact Assessment Report for Modifications to the Petitcodiac River Causeway. https://www2.gnb.ca/content/dam/gnb/Departments/env/pdf/EIA-EIE/PetitcodiacRiver/PetitcodiacRiverSummaryEIAReport.pdf

Niles, M., Locke, A., Landry, T., Webster, T., Collins, K., Robichaud, G., Hanson, A., Mahoney, M., Vandermeulen, H., Doiron, and S., Maillet, M-J. 2014. Bivalve aquaculture and eelgrass (*Zostera marina*) coverage on a bay-wide scale utilizing bathymetric LiDAR and aerial photography. Canadian Technical Report of Fisheries and Aquatic Sciences 3103.

Noble, B., Liu, J., and Hackett, P. 2017. The contribution of project environmental assessment to assessing and managing cumulative effects: individually and collectively insignificant? Environmental Management. 59:541-545.

O, M., Martone, R., Hannah, L., Greig, L., Boutillier, J., and Patton, S. 2014. An Ecological Risk Assessment Framework (ERAF) for Ecosystem-based Oceans Management in the Pacific Region. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/072.vii + 59 p. http://waves-vagues.dfo-mpo.gc.ca/Library/360156.pdf

Olesiuk, P.F., Lawson, J.W., and Trippel, E.A. 2010. Pathways of effects of noise associated with aquaculture on natural marine ecosystems in Canada. DFO Can. Sci. Advis. Sec.Res. Doc. 2010/025. vi + 64 p.

O'Neill, C. and Vagle, S., 2015. Passive acoustic monitoring and ambient noise in the high Arctic: Resolute Bay, Nunavut. The Journal of the Acoustical Society of America, 138(3):1743-1743.

Page, F. 2005. A preliminary perspective on dissolved oxygen standards and models in the marine coastal zone with particular consideration of finfish aquaculture in the southwest New Brunswick portion of the Bay of Fundy. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/038.

Park, L. E., Beresford, L. A., and M. R. Anderson. 2010. Characterization and Analysis of Risks to Key Ecosystem Components and Properties. Oceans, Habitat and Species at Risk Publication Series, Newfoundland and Labrador Region. 0003: vi + 19 p. http://waves-vagues.dfo-mpo.gc.ca/Library/340905.pdf

Park, L. E., Beresford, L. A., and E. Kissler. 2011. Prioritization of Key Ecosystem Components Based on Risk of Harm from Human Activities within the Placentia Bay/Grand Banks Large Ocean Management Area. Oceans, Habitat and Species at Risk Publication Series, Newfoundland and Labrador Region. 0004: vi + 9 p. + working notes (2422p.) http://waves-vagues.dfo-mpo.gc.ca/Library/342998.pdf

Patterson, D.A., Cooke, S.J., Hinch, S.G., Robinson, K.A., Young, N., Farrell, A.P., and Miller, K.M. 2016. A perspective on physiological studies supporting the provision of scientific advice for the management of Fraser River sockeye salmon (*Oncorhynchus nerka*). Conservation Physiology doi:10.1093/conphys/cow026.

Patterson, D.A., Robinson, K.A., Lennox, R.J., Nettles, T.L., Donaldson, L.A., Eliason, E.J., Raby, G.D., Chapman, J.M., Cook, K.V., Donaldson, M.R., Bass, A.L., Drenner, S.M., Reid, A.J., Cooke, S.J., and Hinch, S.G. 2017a. Review and evaluation of fishing-related incidental mortality for Pacific salmon. Can. Sci. Advis. Sec. Res. Doc. 2017/010. ix + 155 p.

Patterson, D.A., Robinson, K.A., Raby, G.D., Bass, A.L., Houtman, R., Hinch, S.G., and Cooke, S.J. 2017b. Guidance to derive and update fishing-related incidental mortality rates for Pacific salmon. Can. Sci. Advis. Sec. Res. Doc. 2017/011. vii + 56 p.

Perry, I.R., and Masson, D. 2013. An integrated analysis of the marine social–ecological system of the Strait of Georgia, Canada, over the past four decades, and development of a regime shift index. Progress in Oceanography 115 (2013):14-27. DOI 10.1016/j.pocean.2013.05.021

Preikshot, D., Neville, C.M., and Beamish, R.J. 2012. Data and parameters used in a Strait of Georgia ecosystem model. Can. Tech. Rep. Fish. Aquat. Sci. 3005: viii + 58p.

Raby, G.D., Donaldson, M.R., Hinch, S.G., Clark, T.D., Eliason, E.J., Jeffries, K.M., Cook, K.V., Teffer, A., Bass, A.L., Miller, K.M., Patterson, D.A., Farrell, A.P., and Cooke, S.J.

2015. Fishing for effective conservation: context and biotic variation are keys to understanding the survival of Pacific salmon after catch-and-release. Integrative and comparative biology. icv088.

Reist, J.D., Wrona, F.J., Prowse, T.D., Dempson, J.B., Power, M., Köck, G., Carmichael, T.J., Sawatzky, C.D., Lehtonen, H., and Tallman, R.F., 2006. Effects of climate change and UV radiation on fisheries for arctic freshwater and anadromous species. AMBIO: A Journal of the Human Environment, 35(7), pp.402-410.

Richardson, S.M., Hanson, J.M., and Locke, A. 2002. Effects of impoundment and water-level fluctuations on macrophyte and macroinvertebrate communities of a dammed tidal river. Aquatic Ecology, 36(4), pp.493-510.

Robinson, K.A., Hinch, S.G., Gale, M.K., Clark, T.D., Wilson, S.M., Donaldson, M.R., Farrell, A.P., Cooke, S.J., and Patterson D.A. 2013. Effects of post-capture ventilation assistance and elevated water temperature on sockeye salmon in a simulated capture-and-release experiment. Conservation Physiology 1(1):1-23.

Rosenberg, D.M., Resh, V.H., Balling, S.S., Barnby, M.A., Collins, J.N., Durbin, D.V., Flynn, T.S., Hart, D.D., Lamberti, G.A., McElravy, E.P., and Wood, J.R., 1981. Recent trends in environmental impact assessment. Canadian Journal of Fisheries and Aquatic Sciences, 38(5):591-624.

Ross, P.S., Ellis, G.M., Ikonomou, M.G., Barrett-Lennard, L.G. and Addison, R.F., 2000. High PCB concentrations in free-ranging Pacific killer whales, *Orcinus orca*: effects of age, sex and dietary preference. Marine Pollution Bulletin, 40(6), pp.504-515.

Ross, P.S. 2006. Fireproof killer whales (*Orcinus orca*): flame-retardant chemicals and the conservation imperative in the charismatic icon of British Columbia, Canada. Canadian Journal of Fisheries and Aquatic Sciences 63(1): 224-234.

Rubidge, E., Thornborough, K., O, M. 2018. Ecological Risk Assessment for the Effects of Human Activities on the SGaan Kinghlas-Bowie Seamount Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/012. viii + 98 p.

Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A. and Leemans, R., 2000. Global biodiversity scenarios for the year 2100. Science, 287(5459):1770-1774.

Schaub, M., and Abadi, F. 2011. Integrated population models: a novel analysis framework for deeper insights into population dynamics. Journal of Ornithology 152:227–237.

Species at Risk Act. 2002. Available at https://laws-lois.justice.gc.ca/eng/acts/s-15.3/ (Act current to 2018-09-26 and last amended on 2018-05-30)

Stephenson, S.A., and Hartwig, L. 2009. The Yukon North Slope Pilot Project: An Environmental Risk Characterisation using a Pathways of Effects Model. Can. Manuscr. Rep. Fish. Aquat. Sci. 2896: vi+57p.

St Pierre, D.K.S., 2014. Evaluation of an Environmental Impact Statement for the Environmental Impact Assessment Report for Modifications to the Petitcodiac River Causeway. Dalhousie Journal of Interdisciplinary Management, 10(1).Stephenson, S.A., and L. Hartwig. 2009. The Yukon North Slope Pilot Project: An Environmental Risk Characterization using a Pathways of Effects Model. Can. Manuscr. Rep. Fish. Aquat. Sci. 2896: vi+57p.. http://waves-vagues.dfo-mpo.gc.ca/Library/340530.pdf

Stortini, C.H., Shackell, N.L., Tyedmers, P., and Beazley, K. 2015. Assessing marine species vulnerability to projected warming on the Scotian Shelf, Canada. ICES Journal of Marine Science 72:1731-1743.

Strain, P. 2005. Eutrophication Impacts of Marine Finfish Aquaculture. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/034.

Teffer, A.K., Bass, A.L., Miller, K.M., Patterson, D.A., Juanes, F., and Hinch, S.G. 2018. Infections, fisheries capture, temperature and host responses: multi-stressor influences on survival and behaviour of adult Chinook salmon. Can. J. Fish. Aquat. Sci. (Online)

Therriault, T.W., Herborg, L.M., Locke, A., McKindsey, C.W. 2008. Risk assessment for Chinese mitten crab (*Eriocheir sinensis*) in Canadian waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/041. http://waves-vagues.dfo-mpo.gc.ca/Library/335232.pdf

Thornborough, K., Dunham, J., and O, M. 2016. Development of risk-based indicators for the SGaan Kinghlas-Bowie Seamount Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/027. http://waves-vagues.dfo-mpo.gc.ca/Library/363985.pdf

Transport Canada. 2016. Canada's Oceans Protection Plan. https://pm.gc.ca/eng/news/2016/11/07/canadas-oceans-protection-plan-preserving-and-restoring-canadas-marine-ecosystems.

Trippel, E.A. 2010. Pathway of effects of artificial light on non-target organisms at aquaculture sites in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/023. vi + 14 p.

US EPA. 1998. Guidelines for Ecological Risk Assessment. EPA/630/R-95/002F, 1-114. Washington, D.C.

Vandermeulen, H. 2005. Assessing Marine Habitat Sensitivity: A case study with eelgrass (*Zostera marina* L.) and kelps (*Laminaria, Macrocystis*). DFO Can. Sci. Advis. Sec. Res. Doc. 2005/032.

Vandermeulen, H., Jamieson, G., and Ouelette, M. 2006. Shellfish aquaculture and marine habitat sensitivity case studies. 2006. DFO Can. Sci. Advis. Sec. Res. Doc.2006/036. vii + 62p.

Vélez-Espino, L.A., Ford, J.K., Araujo, H.A., Ellis, G., Parken, C.K., and Sharma, R., 2014. Relative importance of chinook salmon abundance on resident killer whale population growth and viability. Aquatic Conservation: Marine and Freshwater Ecosystems, 25(6):756-780.

VFPA, 2017. Vancouver Fraser Port Authority (VFPA) Enhancing Cetacean Habitat and Observation (ECHO) Program 2016 Annual Report. 16 pp.

Wildish, D.W., Pohle, G.W., Hargrave, B.T., Sutherland, T.F., and Anderson, M.R. 2005. Benthic monitoring methods for habitat management of finfish mariculture in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/039.

Williams, R., Lacy, R.C., Ashe, E., Hall, A., Lehoux, C., Lesage, V., McQuinn, I., and Plourde, S. 2017. Predicting responses of St. Lawrence beluga to environmental change and anthropogenic threats to orient effective management actions. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/027. v + 44 p.

Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B., Lotze, H.K., Micheli, F., Palumbi, S.R. and Sala, E., 2006. Impacts of biodiversity loss on ocean ecosystem services. Science. 314(5800):787-790.

Wrona, F.J., Prowse, T.D., Reist, J.D., Hobbie, J.E., Lévesque, L.M., Macdonald, R.W. and Vincent, W.F., 2006. Effects of ultraviolet radiation and contaminant-related stressors on Arctic freshwater ecosystems. AMBIO: A Journal of the Human Environment, 35(7), pp.388-401.

Zhou, S., Daley, R., Fuller, M., Bulman, B., Hobday, A., Courtney, T., Ryan, P., and Ferrel, D. 2013. ERA extension to assess cumulative effects of fishing on species. Final Report on FRDC Project 2011/029. Canberra, Australia.

Zhou, S., Hobday, A.J., Dichmont, C.M., and Smith, D.M. 2016. Ecological risk assessments for the effects of fishing: A comparison and validation of PSA and SAFE. Fisheries Research 183:518-529.

GLOSSARY

Term	Definition	Source
Action	Any project or activity of human origin.	CEAA Cumulative Effects Assessment Practicitioners guide (Hegmann et al. 1999)
Assessment Framework .	A description of a process that organizes actions and ideas, usually in a step-by step fashion. Frameworks help to guide practitioners in carrying out an assessment.	CEAA Cumulative Effects Assessment Practicitioners guide (Hegmann et al. 1999)
Effect	Any response by an environmental or social component to an action's impact8	CEAA Cumulative Effects Assessment Practicitioners guide (Hegmann et al. 1999)
Environmental Components	Fundamental elements of the natural environment. Components usually include air, water (surface and groundwater), soils, terrain, vegetation, wildlife, aquatics and resource use.	CEAA Cumulative Effects Assessment Practicitioners guide (Hegmann et al. 1999)
Environmental Assessment (EA)	As defined in the Act, "environmental assessment" means, in respect of a project, an assessment of the environmental effects of the project that is conducted in accordance with this Act and regulations. Environmental assessment is a process for identifying project and environment interactions, predicting environmental effects, identifying mitigation measures, evaluating significance, reporting and following-up to verify accuracy and effectiveness. Environmental assessment is used as a planning tool to help guide decision making, as well as project design and implementation	CEAA website glossary
Environmental Impact Assessment (EIA)	See Environmental Assessment	CEAA website glossary
Region	Any area in which it is suspected or known that effects due to the action under review may interact with effects from other actions. This area typically extends beyond the local study area; however, as to how far will vary greatly depending on the nature of the cause-effect relationships involved.	CEAA Cumulative Effects Assessment Practicitioners guide (Hegmann et al. 1999)
Scoping	A consultative process for identifying and possibly reducing the number of items (e.g., issues, VECs) to be examined until only the most important items remain for detailed assessment. Focussing ensures that assessment effort will not be expended in the examination of trivial effects	CEAA Cumulative Effects Assessment Practicitioners guide (Hegmann et al. 1999)
Threshold	A limit of tolerance of a VEC to an effect, that if exceeded, results in an adverse response by that VEC.	CEAA Cumulative Effects Assessment Practicitioners guide (Hegmann et al. 1999)
Valued ecosystem component (VEC)	The environmental element of an ecosystem that is identified as having scientific, social, cultural, economic, historical, archaeological or aesthetic importance.	CEAA website glossary

	The value of an ecosystem component may be determined on the basis of cultural ideals or scientific concern. Valued ecosystem components that have the potential to interact with project components should be included in the assessment of environmental effects.	
Valued Ecosystem Component (VEC) .	Any part of the environment that is considered important by the proponent, public, scientists and government involved in the assessment process. Importance may be determined on the basis of cultural values or scientific concern	CEAA Cumulative Effects Assessment Practicitioners guide (Hegmann et al. 1999)

Table 5 – Glossary of terms adapted from Stelzenmüller et al. 2018 (supplementary material)

Term	Definition	References
Additive effect	A combined effect produced by the action of two or more agents, being equal to the sum of their separate effects, i.e. the total impact is the sum of its parts.	Halpern, 2008; Crain, 2008
Antagonistic effect	A combined effect produced by the action of two or more agents, being less than the sum of their separate effects.	Halpern, 2008; Crain, 2008
Assessment	A process to determine the condition of values in relation to objectives.	
Baseline	A reference condition or value against which changes of the state of ecosystems or ecosystem components are assessed.	Pitcher, 1998
Drivers	Superior complex phenomena which could be both of human and natural origin, and directly or indirectly cause ecosystem change.	Nelson, 2006; Oesterwind, 2016
Ecosystem-based management (EBM)	An adaptive approach to managing human activities that seeks to ensure the coexistence of healthy, fully functioning ecosystems and human communities. The intent is to maintain those spatial and temporal characteristics of ecosystems such that component species and ecological processes can be sustained, and human well-being can be supported and improved.	Marine Plan Partnership Initiative 2015
Effect	An effect is a deviation from the expected— positive and/or negative. Here it refers to changes of the structure or function of the ecosystem (i.e. a change to the habit, biota, and (or) their interactions). An effect may lead to an impact on receptors or ecosystem state. Pressure and effect are always linked, but not every pressure necessarily leads to an impact.	Judd, 2015; Jones, 2016; ISO Guide 73:2009
Frequency	The frequency of a process over explicit temporal scales is a measure of variability (the number of events per unit of time or space). Frequency can be applied to past events or to potential future events, where it can be used as a measure of likelihood/probability.	Benedetti-Cecchi, 2003; ISO 31000: 2009
Impact	Measurable and detrimental change to an ecosystem or ecosystem component as a result of existing human	Judd, 2015; Maxim, 2009; Underwood,

	pressures and activities and the performance of their respective management measures.	1997; ISO Guide73:2009; ISO 31000:2009
Indicator	Measurable surrogates of assessment end points. Those should be widely applicable, easy and cost effective to measure, collect, and calculate. Indicators should enable continued assessments, allowing differentiation between natural disturbance and human-induced pressures.	Noss, 1990; Selkoe, 2015; Halpern, 2008
Pressure	Is an event or agent (biological, chemical or physical) exerted by one or more human activities to elicit an effect (that may lead to harm or cause adverse impacts).	Judd, 2015
Stressor	A type of direct or indirect, human related driver that causes undesired change in an ecosystem to any physical, chemical, or biological entity that can induce adverse effects on ecosystems or human health.	Selkoe, 2015; US EPA 1998
Synergistic effect	The interaction of two or more agents or actions so that their combined impact is greater than the sum of their individual impacts. Also, other impacts are included if their manners produce new impacts.	Garrido, 2011
Threshold	The boundary of a system, which by small changes in environmental conditions generates rapid responses in ecosystem state or functionality, shifting from one ecological condition to another.	Groffman, 2006; Selkoe, 2015
Vulnerability	A function of exposure, effect (also termed potential impact, sensitivity), and recovery (also termed resilience or adaptive capacity).	De Lange, 2010

Glossary References

Benedetti-Cecchi, L. 2003. The importance of the variance around the mean effect size of ecological processes. Ecology. 84, 2335-2346.

Crain, C. M., Kroeker, K., Halpern, B. S., 2008. Interactive and cumulative effects of multiple human stressors in marine systems. Ecol. Lett. 11, 1304-1315.

De Lange, H. J., Sala, S., Vighi, M., Faber, J. H., 2010. Ecological vulnerability in risk assessment - A review and perspectives. Sci. Total Environ. 408, 3871-3879.

Garrido, J., Requena, I., 2011. Proposal of ontology for environmental impact assessment: An application with knowledge mobilization. Expert. Syst. Appl. 38, 2462-2472.

Groffman, P. M., Baron, J. S., Blett, T., Gold, A. J., Goodman, I., Gunderson, L. H., Levinson, B. M., Palmer, M. A., Paerl, H. W., Peterson, G. D., Poff, L. N., Rejeski, D. W., Reynolds, J. F., Turner, M. G., Weathers, C, K., and Wiens, J., 2006. Ecological thresholds: the key to successful environmental management or an important concept with no practical application? Ecosystems. 9, 1-13.

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, C., Bruno, J. F., Casey, K. S., Ebert, C., Fox, H. E., Fujita, R., Heinemann, D., Lenihan, H. S., Madin, E. M. P., Perry, M. T., Selig, E. R., Spalding, M., Steneck, R., Watson, R., 2008. A global map of human impact on marine ecosystems. Science. 319, 948-952.

ISO Guide 73:2009. International Organization for Standardization (ISO), www.iso.org.

ISO 31000. ISO 31000 standard; International Organization for Standardization (ISO), www.iso.org.Jones, F. C., 2016. Cumulative effects assessment: theoretical underpinnings and big problems. Environ. Rev. 24, 187-204.

Judd, A. D., Backhaus, T., Goodsir, F., 2015. An effective set of principles for practical implementation of marine cumulative effects assessment. Environ. Sci. Policy. 54, 254-262.

Marine Plan Partnership Initiative, 2015. http://mappocean.org/science-and-planning-tools/ecosystem-based-management/

Maxim, L., Spangenberg, J. H., O'Connor, M., 2009. An analysis of risks for biodiversity under the DPSIR framework. Ecol. Econ. 69, 12-23.

Nelson, G. C., Bennett, E., Berhe, A. A., Cassman, K., DeFries, R., Dietz, T., Dobermann, A., Dobson, A., Janetos, A., Levy, M., Marco, D., Nakicenovic, N., O'Neill, B., Norgaard, R., Petschel-Held, G., Ojima, D., Pingali, P., Watson, R., Zurek, M., 2006. Anthropogenic drivers of ecosystem change: an overview. Ecol. Soc. 11, 29.

Noss, R. F., 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conserv. Biol. 4, 355-364.

Oesterwind, D., Rau, A., Zaiko, A., 2016. Drivers and pressures–Untangling the terms commonly used in marine science and policy. J. Environ. Manage. 181, 8-15.

Pitcher, T. J., Pauly, D. Rebuilding ecosystems, not sustainability, as the proper goal of fishery management. In: Pitcher TJ, Pauly D, P H, editors. Reinventing fisheries management. Springer, 1998, pp. 311-329.

Selkoe, K. A., Blenckner, T., Caldwell, M. R., Crowder, L. B., Erickson, A. L., Essington, T. E., Estes, J. A., Fujita, R. M., Halpern, B. S., Hunsicker, M. E., Kappel, C. V., Kelly, R. P., Kittinger, J. N., Levin, P. S., Lynham, J. M., Mach, M. E., Martone, R. G., Mease, L. A., Salomon, A. K., Samhouri, J. F., Scarborough, C., Stier, A. C., White, C., and Zedler, J., 2015. Principles for managing marine ecosystems prone to tipping points. Ecosystem Health and Sustainability. 1, art17.

Stelzenmüller, V., Coll, M., Mazaris, A.D., Giakoumi, S., Katsanevakis, S., Portman, M.E., Degen, R., Mackelworth, P., Gimpel, A., Albano, P.G., Almpanidou, V., Claudet, J., Essl, F., Evagelopoulos, T., Heymans, J.J., Genov, T., Kark, S., Micheli, F., Pennino, M.G., Rilov, G., Rumes, B., Steenbeek, J., and Ojaveer, H. 2018. A risk-based approach to cumulative effect assessments for marine management. Science of The Total Environment 612: 1132-1140. https://doi.org/10.1016/j.scitotenv.2017.08.289.

Underwood, A. J. 1997. Experiments in ecology: their logical design and interpretation using analysis of variance: Cambridge University Press, pp. 504.

US Environmental Protection Agency (USEPA). https://www.Epa.Gov/risk/about-risk-assessment.