Appendix A

Review of cumulative effects management concepts and international frameworks

Jackie Lerner

UBC Institute for Resources, Environment, and Sustainability
Aquatic Ecosystems Research Laboratory
429-2202 Main Mall
Vancouver, BC Canada V6T 1Z4

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Executive summary

Introduction

Transport Canada wishes to familiarize itself with current conceptions and implementations of regional cumulative effects management frameworks— systems of policies, procedures, and tools that enable management of cumulative effects at a broader regional scale— particularly as they relate to marine shipping activities, with the goal of ultimately developing a Canadian framework to be implemented at the regional level. This report has been prepared to address that objective. Transport Canada's specific issues of interest included (1) guidance on selecting temporal and spatial scales, (2) identifying valued components, and (3) applied examples from international practice.

The author conducted a literature review of international cumulative effects management frameworks with a focus on marine shipping and coastal contexts. Sources for the review were identified from a search of academic and grey literature and from the author's professional experience, as well as on the recommendation of Transport Canada, Fisheries and Oceans Canada, and knowledgeable colleagues.

Synthesis

Common themes drawn from the literature included (1) cumulative effects management terminology and concepts, (2) common tools and models, and (3) best practices and challenges—whenever possible, with a focus on marine and coastal contexts. Highlights of this synthesis are provided in the following paragraphs.

Much recent literature broadly conceptualizes approaches to assessing and managing cumulative effects as:

a) **project-level approaches**, where emphasis is placed on the cumulative impacts of individual and multiple development projects by essentially expanding environmental impact assessment methods over larger spatial and temporal scales; and
b) **strategic approaches**, where emphasis is placed on the cumulative effects of proposed or existing plans or development initiatives in a formal and systematic way that allows decision-makers to take cultural, economic, environmental, and social considerations into account early in the planning process.

While the precise terminology varies, cumulative effects management frameworks generally consider the relationships between six key elements. Depending on what a cumulative effects management framework is designed to achieve, one of these key elements becomes the framework's starting point or focus:

- **valued components:** specific parts of the human, biotic, or physical environment considered important because of their cultural, social, aesthetic, economic or scientific value, such as water quality or beluga whales;
- **activities:** things that humans do, such as building ports, fishing, or marine transportation;
- **sources:** specific aspects of or actions associated with activities—such as pile driving for port construction—with the potential to generate environmental pressure;
- **stressors:** environmental pressure, such as sedimentation and noise;
- **pathways:** mechanisms or causal links, such as exposure to water with high concentrations of sediment, by which stressors act on valued components; and
- **effects:** changes to valued components as the result of stressors, such as lowered water quality or decreased biodiversity.

For Transport Canada's purposes, a strategic, activity-based framework (i.e., one that focuses on the assessment of a single activity or sector) is most appropriate, since the goal is to manage the way that the effects of marine shipping, specifically, act cumulatively on the human and biophysical environment.

Many types of tools and models are used to help identify and organize cause-effect linkages between activities and cumulative effects on valued components. These tools enable managers to prioritize among issues, facilitate communication with decision-makers, and provide a consistent basis for reporting.

- **causal frameworks**, such as the Drivers–Pressures–State Change–Impact–Response (or DPSIR) framework, the enhanced DPSIR (or eDPSIR) framework, and Pathways of Effects (PoE) models map links from activities to effects on valued components, and can help identify appropriate control points and management responses.
- **ecological risk assessment frameworks (ERAFs)** are used to identify activities that pose the greatest risk to valued components, often scoring risk along two axes: (1) the exposure of a population to a human activity, and (2) the sensitivity of or consequences to the population for that activity, given a particular level of exposure.

- **ecosystem models** allow for computer-aided simulation and visualization of complex relationships within marine ecosystems. Two highly regarded marine ecosystem modeling frameworks that deal with cumulative impacts are Ecopath with Ecosim and Atlantis. Both frameworks attempt to model all elements of an ecosystem's food web, from primary producers to top predators.
- **cumulative impact mapping** overlays human activities and associated stressors with maps of habitats, assigning a vulnerability score to different habitat types, and modelling an impact score for each combination of activity-caused stressor and habitat. The resulting map provides an easily understood reference useful for evaluating where conservation and management efforts should be focussed, where development activities should be curtailed or relocated to less vulnerable areas, and where development can continue without serious consequences to the marine environment.

Best practices and challenges identified in the reviewed literature related to (1) selecting valued components, (2) selecting indicators, (3) setting temporal and spatial scales, (4) addressing uncertainty, and (5) public and Indigenous participation.

Selecting valued components focuses the process of assessment and management on 'what matters', allowing frameworks to place greater emphasis on components that may require enhanced management or be of particular importance to people or to the ecosystem. The literature offers a variety of methodologies for identifying valued components, typically basing their value to people and their ecological importance on input from Indigenous groups and the public, as well as scientific and professional judgement.

Selecting appropriate indicators involves consideration of important trade-offs. **Effects-based indicators** measure a characteristic of a valued component (e.g., marine mammal abundance), while **stressor-based indicators** measure the stress, disturbance, or risk to a valued component (e.g., percent of disturbed marine mammal habitat); essentially, the stressor *becomes* the indicator. Effects-based indicators are direct measurements of the valued component and inherently encompass cumulative effects of activities, but may not be as useful to decision-making because the cause-effect linkages are poorly understood, and are harder to monitor and generalize. Conversely, stressor-based indicators are usually well understood and can be more simply measured and proactively linked to management actions, but do not capture the effects of all human activities, or the non-additive ways effects from multiple activities can accumulate.

Similarly, the choice of temporal and spatial scales can have profound implications on any study's results. Narrower scales simplify assessment, but at the risk of neglecting wider-ranging or longer-term effects; on the other hand, larger scales are more appropriate to understanding the broader context of cumulative effects, but may lead to data availability challenges, in addition to effectively diluting the importance of local effects against a too-broad study area. Consideration should be given to a scale that represents both the processes and the actors that influence human activities or are affected by those activities. Whatever scale is ultimately selected, the rationale for the selection should be public and transparent.

Scientific findings are nearly always limited by uncertainty. It is important to explicitly acknowledge these uncertainties and any methodological steps taken to work around them. Application of the precautionary principle and adaptive management are common prescriptions for addressing uncertainty.

- The **precautionary principle** is the maxim that, where there is no full scientific certainty about the potential for serious or irreversible damage from a proposed activity, policy decisions should be made in a way that errs on the side of caution with respect to the environment and human well-being.
- **Adaptive management** is an iterative approach for improving management in the face of uncertainty by learning from management outcomes and feeding that learning back into the management process.

Participation in impact assessment and management processes has been the focus of much literature over the past two decades. Of particular importance is the participation of Indigenous peoples, especially those who elect to maintain a traditional relationship with their land, and for whom assessment and management decisions will have serious implications. In addition, in Canada, Indigenous peoples have constitutionally recognized rights and title and treaty rights with direct relevance to environmental decisions. As one writer argues, the goal of this participation should be to improve quality, legitimacy, and capacity, where:

- **quality** refers to identification of the values, interests, and concerns of all who are interested in or might be affected by the assessment or decision together with the range of actions that might be taken; consideration of the effects that might follow and uncertainties about them; application of the best available knowledge and methods relevant to the above tasks; and incorporation of new information, methods, and concerns that arise over time;

- **legitimacy** refers to a process that is seen as fair and competent by the interested parties and that follows the governing laws and regulations; and
- **capacity** refers to the benefits to all participants of gaining knowledge and skills, both by becoming more informed about the intricacies and variety of perspectives on the subject of the process, and by gaining experience in the participation process itself.

Realization of these three goals offers benefits for all, particularly decision-makers.

Case studies

Seven case studies of implemented cumulative effects management systems were reviewed: four from international regimes and three from regional initiatives from across Canada:

- The Barents Sea Integrated Management Plan (Norway);
- The Great Barrier Reef Strategic Environmental Assessment (Australia);
- The Xiamen Integrated Coastal Management Plan (China);
- The Mauri Model Decision-making Framework in post-Rena assessment (New Zealand);
- The Manitoba Hydro Regional Cumulative Effects Assessment (Canada);
- The Canada-Nova Scotia Offshore Petroleum Board Strategic Environmental Assessments (Canada); and
- The Metlakatla Cumulative Effects Management Program (Canada).

Table 1 compares the issues and practices discussed in the synthesis section (above) across all seven of these case studies.

Recommendations

Two broad but valuable principles for developing a cumulative effects management framework became apparent during the course of this review. The first is recognition of the necessity of an iterative and transparent approach to framework development: one that allows for improvements over time as knowledge grows and new opportunities arise. The second principle relates to the importance of navigating trade-offs. If we try to consider too many factors in any analysis, we may render our task impossible. However, by constricting a cumulative effects framework's scope, we may omit factors that have important bearings on the effects we wish to manage. The key in most cases is finding the right balance between different options.

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Table 1. Comparison of case studies reviewed.

Name	Approach	Project / Strategic	Tools used	Temporal scale	Spatial scale	Valued component selection	Indicators
Barents Sea Integrated Management Plan (Norway)	Place-based / Activity-based	Strategic	Risk assessment and professional judgement	Mostly forward-looking (to 2020); historical data on valued components to create pre-development baseline	1,400,000 km^2, based on ecological and administrative considerations	Method for selection not reported, but seems to have been done by expert group.	Effects-based
Great Barrier Reef Strategic Environmental Assessment (Australia)	Place-based	Strategic	DPSIR framework, structured lists, conceptual diagrams, and models	Focuses on present to – 2050, but considers older "legacy impacts"	346,000 km^2, based on ecological bounds	Selected based on scientific significance and value to Traditional Owners	Effects-based
Xiamen Integrated Coastal Management Plan (China)	Place-based	Strategic	DPSIR framework	Unknown	Unknown	Professional judgement, with some exceptions	Effects-based and stressor-based
Mauri Model Decision-making Framework in post-*Rena* assessment (New Zealand)	Place-based	Strategic	Decision support	100 years ago to present	Not measured in kilometres, but by affected community	Participatory	Effects-based
Manitoba Hydro Regional Cumulative Effects Assessment (Canada)	Activity-based (?)	Project	Pathways of Effects	1951 – 2013	210,000 km^2, follow "ecologically meaningful" boundaries	Professional expertise and desk-based (review of traditional knowledge	Effects-based
Canada-Nova Scotia Offshore Petroleum Board Strategic Environmental Assessments (Canada)	Activity-based	Project	Professional judgement (?)	Present + 10 years	37,280 km^2, area, but considers extent of valued components	Scientific judgement, board input, and consultation (via the board)	Unknown
Metlakatla Cumulative Effects Management Program (Canada)	Place-based	Strategic	Participatory processes	Unknown	Metlakatla traditional territory	Participatory	Effects-based

Appendix A

This report proposes a sequence of procedural steps for developing Transport Canada's cumulative effects management framework, listed below (and more fully defined in Chapter 5).

- Step 1: Define and document the draft terms of reference;
- Step 2: Define and document the framework scope;
- Step 3: Communicate with agencies, partners, and stakeholders;
- Step 4: Develop a priority set of valued components and indicators;
- Step 5: Develop an assessment toolkit;
- Step 6: Develop a management and response toolkit;
- Step 7: Implement the pilot phase; and
- Step 8: Evaluate, iterate, and improve.

Within these steps, framework tasks are allocated to three groups within a proposed governance structure: the *Steering Committee* (providing federal government oversight and overarching departmental control), the *Framework Design Group* (responsible for preliminary planning and reporting tasks), and the *Working Group* (with membership from a broad variety of agencies, interest groups, and other stakeholders.

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1. Introduction and background

The need to better predict, manage, and monitor cumulative environmental effects has been avidly discussed in environmental assessment circles for more than 35 years. Nevertheless, how to improve on current practice remains a perplexing issue.

Throughout Canada, the only well-established process for handling cumulative effects is still at the project level, when a proponent is seeking a permit to proceed. Many (e.g., Duinker and Greig 2006; Bonnell 2000; Connelly 2011; J. Gunn 2009; MacDonald 2000; Wärnbäck and Hilding-Rydevik 2009; Xue, Hong, and Charles 2004) have noted that these project by project-level processes are inappropriate for adequately addressing cumulative effects, which often occur over time frames and at geographical scales that far outstrip those used to assess and manage individual projects. Many of these writers have called for cumulative effects management frameworks: systems of policies, procedures, and tools that enable management of cumulative effects at a broader regional scale.

In November 2016, the Prime Minister of Canada formally announced the launch of the nation's *Oceans Protection Plan*, which includes the commitment to "develop a coastal environmental baseline and cumulative effects program," to be implemented in six regions on the country's three coasts (Office of the Prime Minister 2016). The Department of Fisheries and Oceans will develop a Coastal Environmental Baseline Program that will feed applicable data to Transport Canada who will be responsible for the Cumulative Effects of Marine Shipping Initiative. Transport Canada therefore wishes to familiarize itself with current conceptions and implementations of regional cumulative effects management frameworks, particularly as they relate to marine shipping activities, with the goal of ultimately developing a National Cumulative Effects of Marine Shipping framework that can be implemented at the regional level.

This report has been prepared to address that objective. The author conducted a literature review of international cumulative effects management frameworks with a focus on marine shipping and coastal communities. The methods used in this review are provided in Chapter 2, and the results are synthesized in Chapter 3. Chapter 4 introduces seven case studies of implemented frameworks from Norway, Australia, China, New Zealand, and Canada. Chapter 5 contains the author's recommendations for the development of a Canadian cumulative effects management framework, drawn from the research reviewed and from the author's professional experience. A bibliography of key sources appears as Appendix A.

2. Methodology

The author met with three representatives from Transport Canada on July 19, 2017, to understand more about the context and parameters for the literature review. At that meeting, Transport Canada indicated that development of the cumulative effects of shipping management framework was still in its nascent stages, and that therefore a broad exploration of best practices and applied examples would be of most use. Specific issues of interest included (1) guidance on selecting temporal and spatial scales, (2) identifying valued components, and (3) applied examples from international practice.

The author next performed a preliminary search of published academic literature from the 55 journals listed in Table 2 using two pairs of keywords: (1) "cumulative effects" and "management framework", and (2) "cumulative effects" and "marine shipping." These documents were retrieved electronically and stored in a database. An additional academic source, a book by Gillingham et al. (2016) was also retrieved as part of this search.

Table 2. Journals and catalogue extents searched in literature review.

Journal	Years searched
Aestimum	1993 – 2017
Agriculture, Ecosystems and Environment	1983 – 2017
Aquatic Conservation: Marine and Freshwater Ecosystems	1996 – 2017
Arctic	1987 – 2017
Arctic Review on Law and Politics	1992 – 2017
Biological Conservation	1994 – 2017
Biomass and Bioenergy	1991 – 2017
Canadian Journal of Fisheries and Aquatic Sciences	1980 – 2017
Computers, Environment and Urban Systems	1980 – 2017
Conservation Ecology	1980 – 2017
Conservation Letters	2008 – 2017
Ecological Applications	2002 – 2017
Ecological Economics	1993 – 2017
Ecological Indicators	2001 – 2017
Ecological Modelling	1975 – 2017
Ecology and Society	2004 – 2017
Ecology Letters	1980 – 2017
EcoSphere	1980 – 2017
Energy Policy	1973 – 2017
Energy Procedia	2009 – 2017
Environment, Development and Sustainability	1984 – 2017
Environment International	1978 – 2017
Environmental Impact Assessment Review	1980 – 2017
Environmental Management	1977 – 2017
Environmental Monitoring and Assessment	1990 – 2017
Environmental Reviews	1990 – 2017

Environmental Science & Policy	1998 – 2017
Estuarine, Coastal and Shelf Science	1981 – 2017
Extractive Industries and Society	2014 – 2017
Frontiers in Marine Science	2014 – 2017
Global Environmental Change	1990 – 2017
Impact Assessment and Project Appraisal	1998 – 2017
Integrated Environmental Assessment and Management	1990 – 2017
Journal for Nature Conservation	2002 – 2017
Journal of Environmental Management	1990 – 2017
Journal of Environmental Assessment Policy and Management	1999 – 2017
Journal of Environmental Planning and Management	1997 – 2017
Journal of Hydrology	1963 – 2017
Land Use Policy	1984 – 2017
Marine and Freshwater Research	1987 – 2017
Marine Ecology Progress Series	1979 – 2017
Marine Policy	1977 – 2017
Marine Pollution Bulletin	1970 – 2017
Minerals Engineering	1988 – 2017
Ocean & Coastal Management	1992 – 2017
PLoS Biology	1997 – 2017
Procedia Earth and Planetary Science	2009 – 2017
Procedia Environmental Sciences	2010 – 2017
Resources Policy	1974 – 2017
Resources, Conservation and Recycling	1988 – 2017
Stanford Environmental Law Journal	1984 – 2017
Science	1980 – 2017
Science of the Total Environment	1972 – 2017
Transport Policy	1993 – 2017
Transportation Research Procedia	2014 – 2017
Trends in Ecology and Evolution	1986 – 2017

Additional sources were added to the database on the recommendation of knowledgeable colleagues: the author gratefully acknowledges suggestions from James Mortimor, Dr. Bram F. Noble, Dr. Jordan Tam, and Dr. Gerald Singh. These sources are listed in Table 3.

Table 3. List of recommended sources.

Title	**Author**	**Type**	**Year**
Metlakatla Cumulative Effects Management Phase 1	Metlakatla First Nation	Report	2015
Grounded in values, informed by local knowledge and science: The selection of valued components for a First Nation's regional cumulative effects management system	Katerina Kwon	Thesis	2010
Cumulative Effects in Marine Ecosystems: Scientific Perspectives on its Challenges and Solutions	Cathryn Clarke Murray, Megan E. Mach, Rebecca Martone	Report	2014

Regional Action Framework	Marine Plan Partnership (MaPP) Initiative	Report	2016
A Framework for Understanding Cumulative Impacts, Supporting Environmental Decisions and Informing Resilience-Based Management of the Great Barrier Reef World Heritage Area	Kenneth R.N. Anthony, Jeffrey M. Dambacher, Terry Walshe, and Roger Beeden	Report	2013
Cumulative Effects Framework - Interim Policy for the Natural Resource Sector	BC MFLNRO and BC MOE	Report	2016
Integrated Management of the Marine Environment of the Barents Sea and the Sea Areas off the Lofoten Islands	Royal Norwegian Ministry of the Environment	Report	2006
An Ecological Risk Assessment Framework (ERAF) for Ecosystem-based Oceans Management in the Pacific Region	O. Miriam, Rebecca Martone, Lucie Hannah, Lorne Greig, Jim Boutillier, and Sarah Patton	Report	2015
Development of Indicators for Arctic Marine Biodiversity Monitoring in Canada	R. John Nelson	Report	2013
Pilot application of an ecological risk assessment framework to inform ecosystem-based management in the Pacific North Coast Integrated Management Area	DFO	Report	2014
Cumulative Impacts - A Good Practice Guide for the Australian Coal Mining Industry	Franks, D.M., D. Brereton, C.J. Moran, T. Sarker and T. Cohen	Report	2010
Regional Cumulative Effects Assessment	Manitoba Hydro and the Manitoba Government	Website	2017

A number of additional sources not included in the previous search were provided directly to the author by Transport Canada or by Fisheries and Oceans Canada. These sources are listed in Table 4.

Table 4. Sources supplied by Transport Canada or Fisheries and Oceans Canada.

Title	**Author**	**Type**	**Year**
Development of a reference document on key information sources related to cumulative effects of multiple activities on fish habitat and fish populations in Canada	Canter, Larry and Barry Sadler	Report / Review	n.d.
Cumulative Effects Research and Applications within Fisheries and Oceans Canada (DFO): Draft for Transport Canada	Clarke Murray, Cathryn, and Lucie Hannah	Report	2017
Atlantis – Ecosystem Model (http://atlantis.cmar.csiro.au)	CSIRO	Website / Software	2017
Ecopath with Ecosim (http://ecopath.org/)	Ecopath International Initiative	Website / Software	2017

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	Lawson, J.W. and V. Lesage	Report	2012
Scientific Considerations for Designing Cumulative Environmental Effects Monitoring Programs (Draft)	Science and Technology Branch, Environment and Climate Change Canada	Report	2016
Assessment of Proposals Related to Oil Spill Risk for the South Coast of Newfoundland	Transport Canada and Canadian Coast Guard	Report	2009

Some additional sources were identified based on professional knowledge, bringing the total raw results to 262 documents. The abstracts or introductory chapters of the sources assembled in the database were then read to determine which articles were largely irrelevant and could be excluded from the review. From this initial screening, the number of sources was reduced to 156 articles. These sources were read more closely; several additional sources were excluded and several more added based on closer review of articles deemed especially relevant. A total of 167 sources are contained in the final database. A word frequency analysis was conducted to create an initial map of the major themes discussed in the literature, and to roughly group sources by topic.

The author then developed an outline for the review and began writing a synthesis based on the identified themes (the final version of that synthesis is presented as Chapters 3 and 4). As sources were more closely scrutinized, it became apparent that several of them had relevance to more than one theme, and the sources were annotated accordingly within the database as writing progressed.

A surprising number of search results related to frameworks applied in the Canadian context; among them, the province of British Columbia's cumulative effects framework (BC MFLNRO and BC MOE 2016), the Beaufort Sea regional cumulative effects framework (AMEC 2015), the unimplemented framework developed for British Columbia's northeast (AXYS Environmental Consulting Ltd. 2003), Alberta's since-terminated terrestrial ecosystem management framework (CEMA 2008), and several others. In keeping with Transport Canada's desire to focus on framework implementations, and with the goal of providing a less homogenous set of case studies, the author decided to include examples from only three Canadian frameworks: two that focus on specific industry sectors and are therefore more relevant to Transport Canada's project, and one that deals in depth with the process of valued component selection (see Sections 4.5 to 4.7).

The resulting review, presented in the following chapters, is not comprehensive. The scope of research on the assessment and management of cumulative effects is massive and growing yearly. The discussion presented, and the recommendations that accompany it, reflect the author's attempt to provide a broad understanding of the work that has been done to date and some concrete examples of frameworks from a wide range of contexts.

3. Synthesis

Cumulative effects are "changes to the environment that are caused by an action in combination with other past, present and future human actions" (Hegmann et al. 1999).[1] In Canada and around the world, most study of cumulative effects is currently undertaken at the project level, as a component of environmental impact assessments (EIAs) conducted for individual project permitting. Much recent literature (e.g, Noble and Harriman 2008; Bragagnolo and Geneletti 2012; Bragagnolo, Geneletti, and Fischer 2012; Du et al. 2012) broadly conceptualizes approaches to assessing and managing cumulative effects as:

c) **project-level approaches**, where emphasis is placed on the cumulative impacts of individual and multiple development projects by essentially expanding EIA methods over larger spatial and temporal scales; and

d) **strategic approaches**, where emphasis is placed on the cumulative effects of proposed or existing plans or development initiatives in a formal and systematic way that allows decision-makers to take cultural, economic, environmental, and social considerations into account early in the planning process.

Strategic approaches do not replace the need for project-level approaches; rather, the two are complementary, incorporating environmental concerns at multiple levels of decision-making, with strategic approaches addressing the implications of decisions made above the individual project level (Partidário 2000). Strategic approaches are sometimes described as being proactive, while project-level approaches are thought of as reactive (Vicente and Partidário 2006).

The limitations of project-level approaches are broadly acknowledged, particularly their inability to sufficiently address cumulative effects (e.g., Dubé 2003; Duinker and Greig 2006; O'Faircheallaigh 2007; O'Faircheallaigh 2010; Parkins 2011), and there is wide consensus that a shift towards a strategic regional approach to cumulative effects management is needed (e.g., Partidário 1996; Noble and Harriman 2008; CCME 2009; J. H. Gunn and Noble 2009; Wärnbäck

[1] There is no commonly accepted definition for cumulative effects (MacDonald 2000; Cooper and Sheate 2002; Wärnbäck and Hilding-Rydevik 2009; Bragagnolo and Geneletti 2012)**.** The term has been in use since the early 1970s, and has been defined, re-defined, and categorized by academics and environmental practitioners ever since (see Duinker et al. 2012 for a review of over a dozen different definitions).

and Hilding-Rydevik 2009; Johnson et al. 2011; Fidler and Noble 2012; Gillingham et al. 2016; Noble and Nwanekezie 2017) but no universally recommended approach.

The World Bank (1999) further subdivides strategic approaches into two sub-types:

- **Sectoral:** which examines environmental issues and impacts associated with a particular strategy, policy, plan, or program, or with a series of projects for a specific sector; and
- **Regional:** which examines environmental issues and impacts associated with a particular strategy, policy, plan, or program, or with a series of projects for a particular region (e.g., an urban area, a watershed, or a coastal zone).

The reviewed literature all contributes in some way to the study of strategic approaches to cumulative effects management frameworks, both sectoral and regional. This chapter narratively discusses common themes drawn from this literature, including (1) cumulative effects management terminology and concepts, (2) common tools and models, and (3) best practices and challenges—whenever possible, with a focus on marine and coastal contexts.

3.1 Terminology and concepts

The term **cumulative effects management framework** is used broadly to refer to a variety of systems designed to measure and manage cumulative effects by considering the relationships between six key elements. While the precise terminology used to refer to these elements varies from framework to framework, and elements are sometimes reformulated or sub-divided in different ways, the basic concepts are virtually universal, and are as follows:

- **Valued components:** specific parts of the human, biotic, or physical environment considered important because of their cultural, social, aesthetic, economic or scientific value, such as water quality or beluga whales;
- **Activities:** things that humans do, such as building ports, fishing, or marine transportation;
- **Sources:** specific aspects of or actions associated with activities—such as pile driving for port construction—with the potential to generate environmental pressure;
- **Stressors:** environmental pressure, such as sedimentation and noise;
- **Pathways:** mechanisms or causal links, such as exposure to water with high concentrations of sediment, by which stressors act on valued components; and

- **Effects:** changes to valued components as the result of stressors, such as lowered water quality or decreased biodiversity.

How a cumulative effects management framework approaches these six elements depends on what the framework is intended to achieve. Murray and Hannah (2017; adapting a typology originally developed in Clarke Murray, Mach, and Martone 2014) distinguish between four types of frameworks, each with a different starting point or focus (presented conceptually in Figure 1): stressor-based, activity-based, species-based, and place-based. **Stressor-based frameworks** focus on a single stressor (usually one anticipated to have the potential for significant effects) resulting from human activities. **Activity-based frameworks** focus on the assessment of a single activity or category of activity (i.e., sector) and the stressors associated with that activity. **Species-based frameworks** focus on a single valued component (a species), looking at the various stressors on that valued component caused by all human activities. **Place-based frameworks** attempt to include all activities and stressors occurring in a specific area and their potential effects.

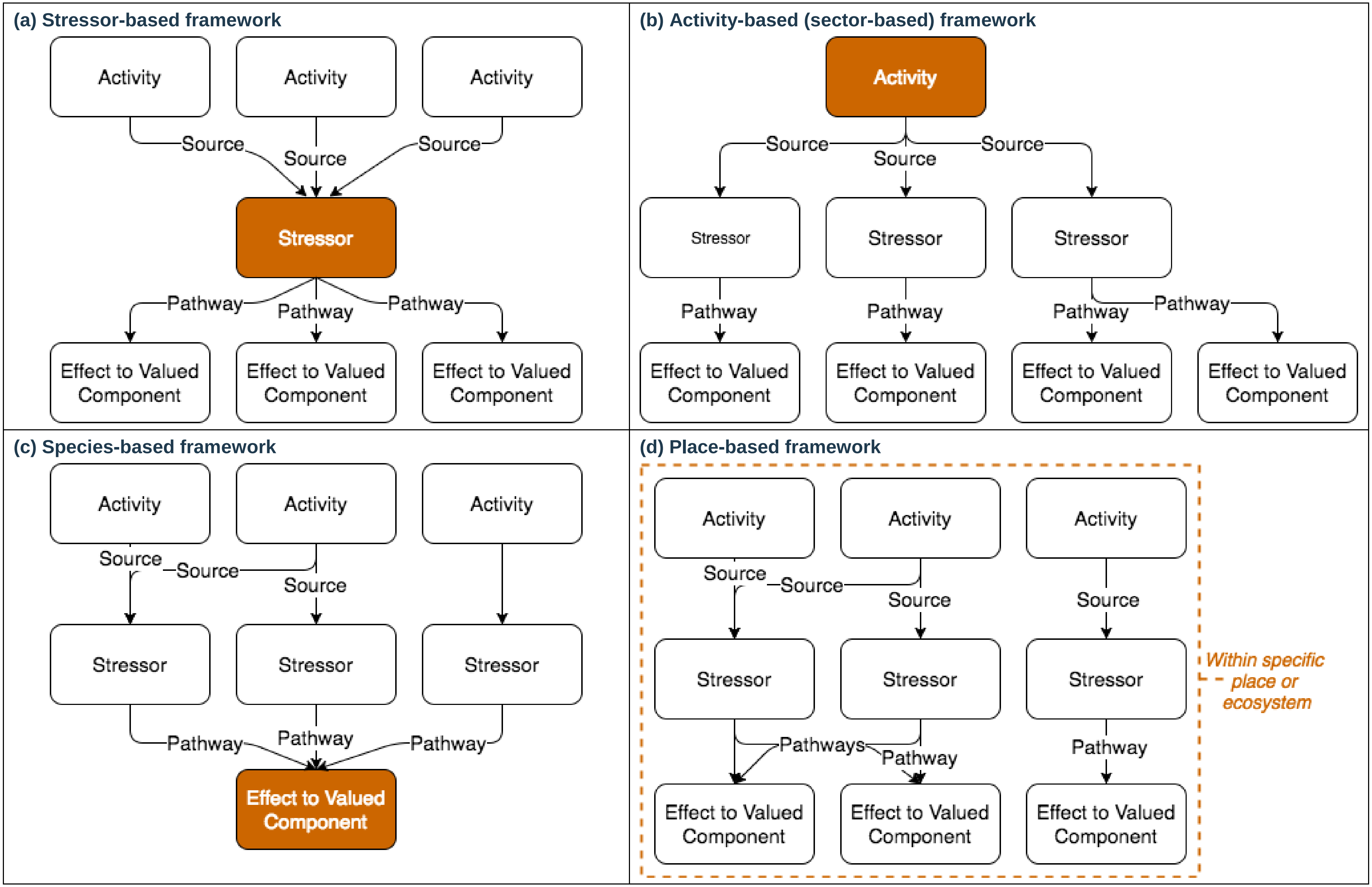
Transport Canada's mandate under the Oceans Protection Plan is to manage the way that the effects of marine shipping, specifically, act cumulatively on the human and biophysical environment. Thus, under two of the typologies discussed above, Transport Canada are seeking to develop a strategic, activity-based framework: i.e., one that can help Transport Canada better understand the linkages from marine shipping to the stressors it generates, and to the effects those stressors have on valued components.

Sectoral cumulative effects management frameworks are not unheard-of, but they are unusual, both in academic literature and in practice. Frameworks are generally designed to help identify and manage the effects of many kinds of activities on one or many valued components. In order to provide Transport Canada with a more comprehensive look at existing frameworks and knowledge on best practices, the author took an inclusive approach to this review. Literature dealing with frameworks (or components of frameworks) that do not correspond precisely to Transport Canada's current needs specific to marine shipping were reviewed with the goal of retrieving learning and recommendations applicable to Transport Canada's project.

Managing cumulative effects requires knowledge about all the elements depicted in Figure 1: the activities themselves, the stresses they put on the environment (Halpern et al. 2009), and the pathways by which stressors are likely to interact and affect valued components (Crain, Kroeker, and Halpern 2008). This understanding is necessary to identify specific cause-effect linkages and the best management actions to take. Several tools and models exist for investigating these linkages, some of them purpose-built for marine applications; these are discussed in the next section.

Appendix A

Figure 1. Typology of cumulative effects frameworks (adapted from Clarke Murray and Hannah 2017; and Clarke Murray, Mach, and Martone 2014).



3.2 Common tools and models

As noted above, a major task of cumulative effects management is understanding the relationships between human activities and effects on valued components. Many types of tools and models are used to help identify and organize these cause-effect linkages. These tools enable managers to prioritize among issues, facilitate communication with decision-makers, and provide a consistent basis for reporting (Niemeijer and de Groot 2008a).

Desirable traits in a model are (1) manageability, (2) generality, (3) realism, and (4) precision; however, models rarely if ever exhibit all four of these traits at once (Levins 1966). For example, simple models are easier to understand, manipulate, and customize for different contexts, but may not be as reflective of the real world. More complex models may give more accurate results, but may be more difficult to use and must be developed specifically for each application. Manageability is non-negotiable—a model that is too complex to use is of no utility to anyone—so choosing an appropriate model therefore inherently involves trade-offs between the remaining three traits. Model choice is also dictated by the resources available to the modeller in terms of available data, time, and cost. Table 5 presents the characteristics and trade-offs associated with different kinds of tools and modelling approaches.

Table 5. Continuum of methodological approaches and associated trade-offs (adapted from Noble and Harriman 2008; MacDonald 2000).

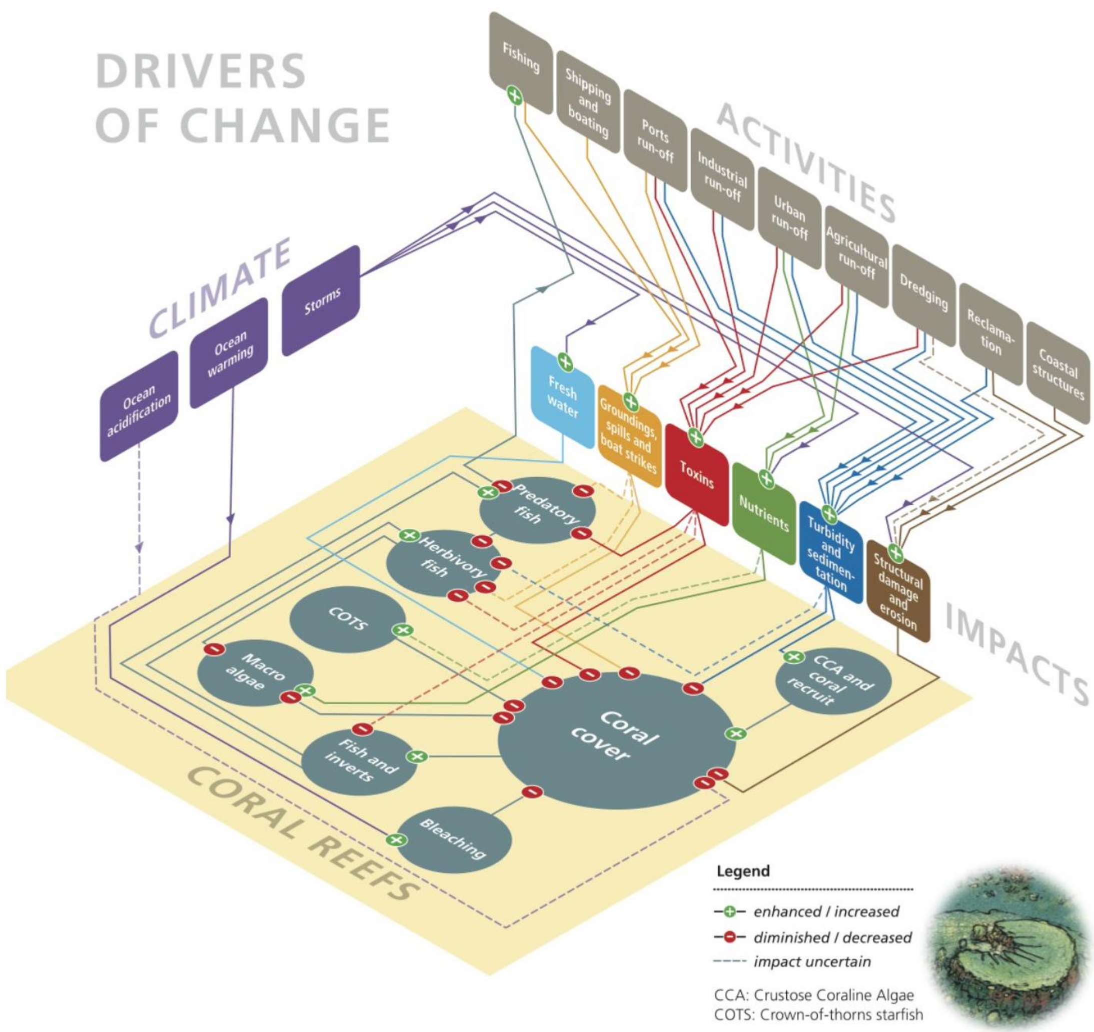
	Availability of data / assessment time and resources	
	← Decreasing	**Increasing →**
More reliance on…	Non-technical / judgment-driven methods	Technical / data-driven methods
Characteristics and trade-offs	a. Qualitative b. Lower cost c. More uncertainty d. Less ability to determine cause-effect links and statistical relationships	a. Quantitative b. Higher cost c. Less uncertainty d. More ability to determine cause-effect links and statistical relationships
Examples	a. Delphi processes b. Multi-criteria evaluation c. Participatory appraisal d. Lessons from similar cases	e. Geographic Information systems f. Detailed models g. Network analysis h. Input–output analysis

The following section provides an overview of some of the tools most commonly used for this purpose. Each of the tools described attempts to make sense of the complex and unintuitive tangle of avenues from human activity to environmental impact.

3.2.1 Causal frameworks

Perhaps the best known causal framework is the **Drivers–Pressures–State Change–Impact–Response (or DPSIR) framework** (Atkins et al. 2011; Anthony et al. 2013). This approach maps the links from activities to effects on valued components (as shown in Figure 2) and suggests management responses. DPSIR thus facilitates exploration of scenarios that may lead to cumulative impacts at various scales and guides users toward alternatives for management intervention. The DPSIR framework is useful for its communicative power, but has been criticized for over-simplifying the relationships it portrays, including the often non-additive ways that stressors and effects can combine (Gari, Newton, and Icely 2015).

Figure 2. Simplified sample output of DPSIR framework used to assess links between activities and effects on coral reef ecosystems in Australia's Great Barrier Reef (from Anthony et al. 2013). Note that the 'R' in DPSIR (i.e., management response) is not shown in this diagram.



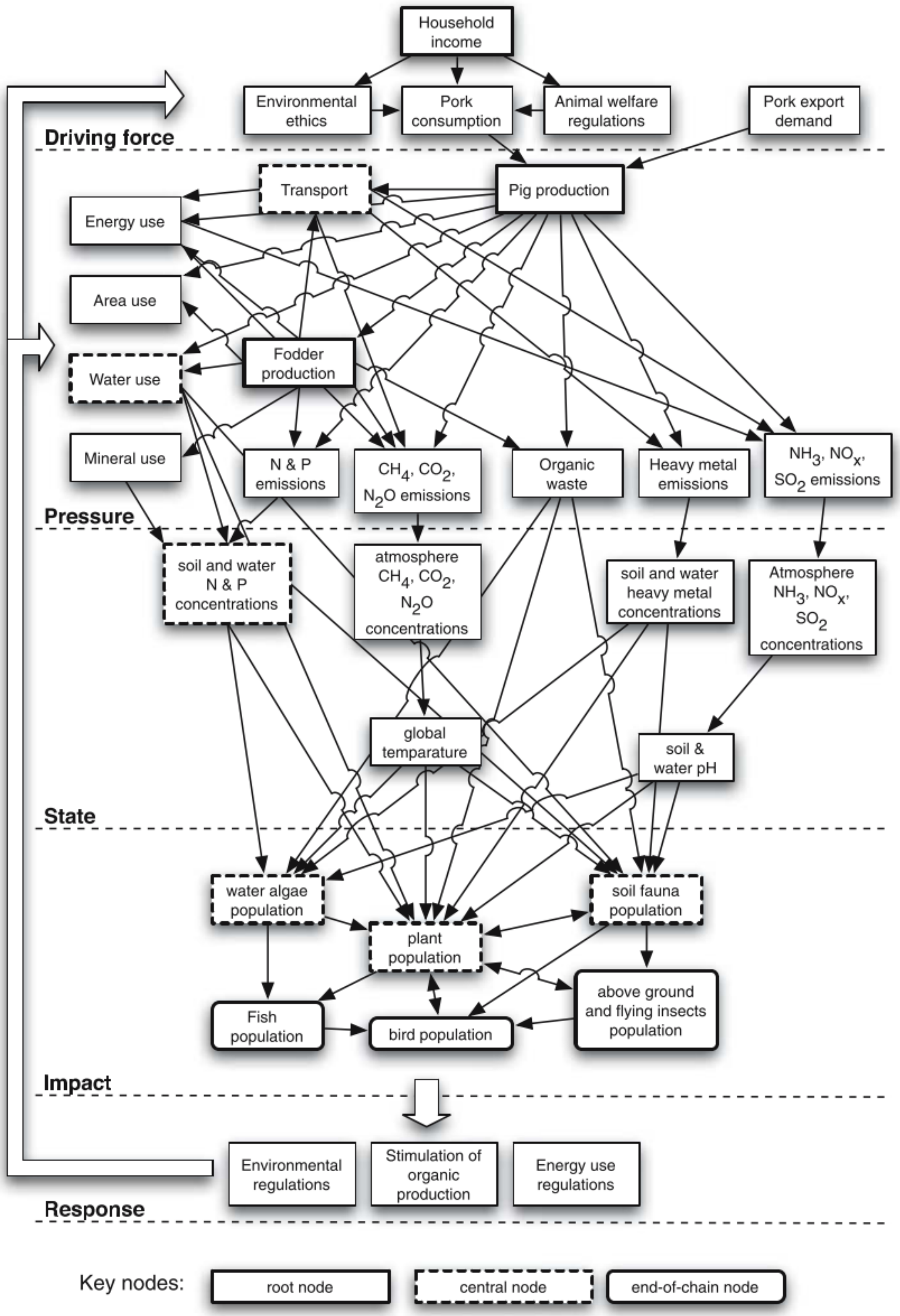
Using the same terminology of the DPSIR framework, Niemeijer and De Groot (2008a; 2008b) proposes the **enhanced DPSIR (or eDPSIR) framework** to map individual impact pathways into an impact network (as opposed to a simple impact chain) with the objective of identifying key nodes (Figure 3). Understanding these key nodes can help users to build more focused indicator sets and identify effective 'control points' for monitoring and management.

Again borrowing from DPSIR in much of its terminology and concepts, **Pathways of Effects (PoE) models** diagrammatically represent fact-based relationships between activities and associated stressors and the environmental effects or impacts they may have on a specific ecological or biological endpoints, with accompanying rationales and narrative descriptions (Stephenson and Hartwig 2009; DFO 2009; Knights, Koss, and Robinson 2013; DFO 2015). In particular, PoE models can trace the potential effects derived from a specific sector (Government of Canada 2012).

Clarke Murray and Hannah (2017) report that a PoE model has already been developed for marine shipping by Canada's Department of Fisheries and Oceans, and a Scientific Advice Report has been published by the Canadian Science Advisory Secretariat (DFO 2015): however, the related detailed research document has not been published. Two sample diagrams consistent with DFO (2015) are provided as Figures 4 and 5 for illustrative purposes.

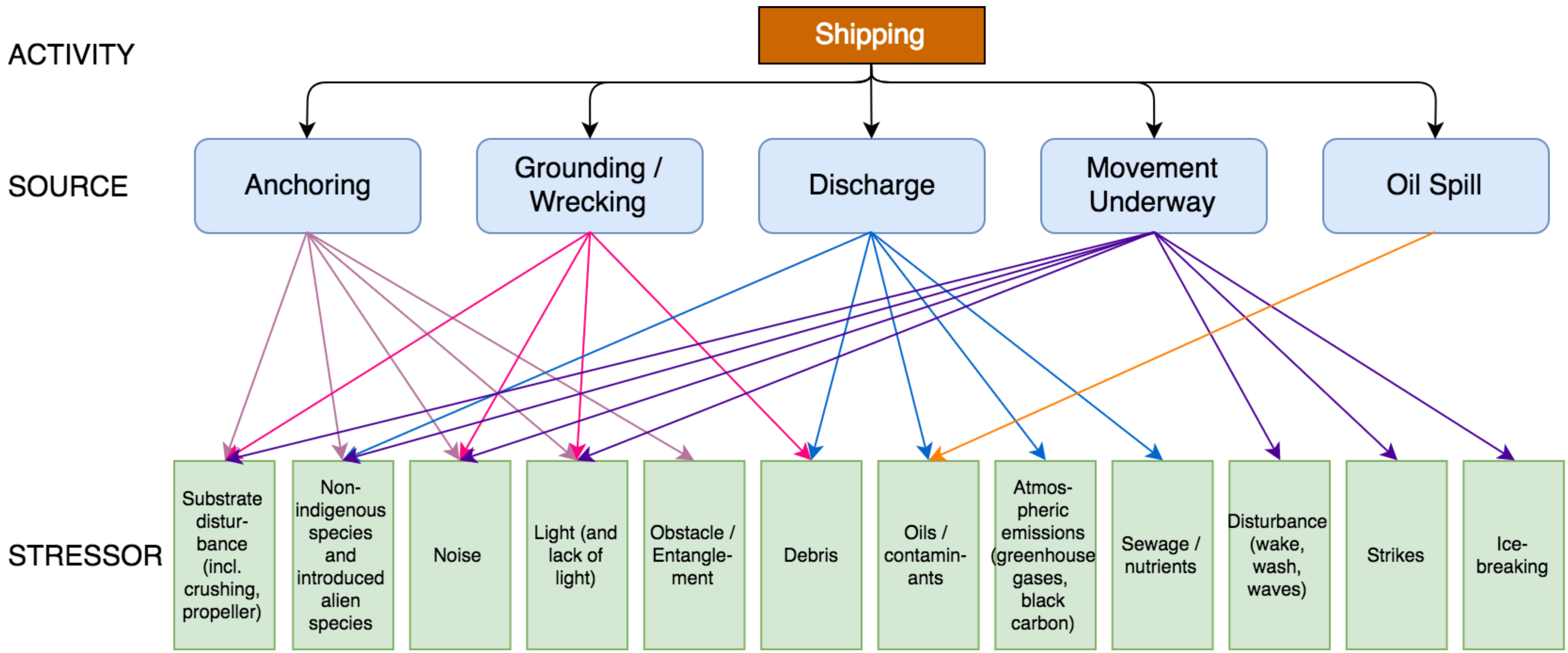
Some authors (e.g., Adams 2005) have proposed alternative guidelines for using a weight of evidence approach to establish causal relationships between environmental stressors and effects on marine biota or resources. Ban, Pressey, and Graham (2014) modelled expert judgement as Bayesian belief networks (an analytical technique of generating predictions based on known statistics about connected variables) to understand the interaction of multiple stressors and related management options where data about the effects of these interactions were incomplete.

Figure 3. Sample eDPSIR causal network for pork production, showing key nodes (from Niemeijer and de Groot 2008b).



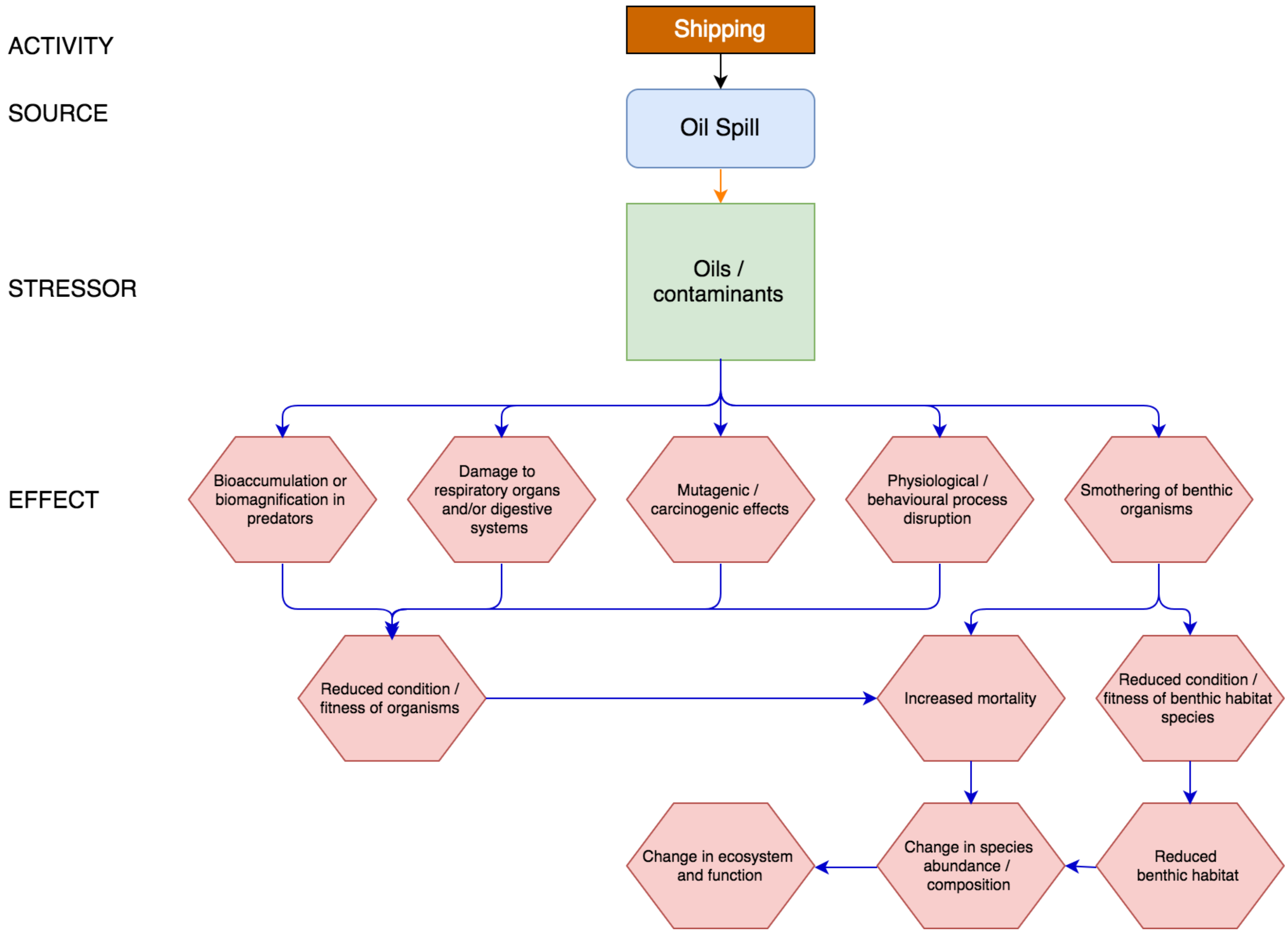
Appendix A

Figure 4. Sample PoE diagram showing linkages from shipping activities to stressors (modified from James Mortimor, pers. comm.).



Note: This draft diagram is generally consistent with DFO (2015) but as yet has not been formally approved or published.

Figure 5. Sample PoE diagram showing detail of linkages between single activity from Figure 4—oil spills—to impacts (modified from James Mortimor, pers. comm.).



Note: This draft diagram is generally consistent with DFO (2015) but as yet has not been formally approved or published.

3.2.2 Ecological risk assessment frameworks

Ecological risk assessment frameworks (ERAFs) are used to identify human activities that pose the greatest risk to valued components, often scoring risk along two axes: (1) the exposure of a population to a human activity, and (2) the sensitivity of or consequences to the population for that activity, given a particular level of exposure (Samhouri and Levin 2012; Piet et al. 2017). This type of framework is typically used in contexts where high quality data is unavailable.

(Stelzenmüller et al. 2018) suggest that such risk-based approaches decrease the overall complexity of cumulative effects assessment and allow for the transparent treatment of uncertainty. The Department of Fisheries and Oceans has applied ERAF to support ecosystem-based management in the Pacific Region (Clark-Murray et al. 2014; O et al. 2015), which builds on an area-specific PoE model Figure 6, as well as in several other locations (e.g., Thornborough, Dunham, and O 2015; Thornborough, Dunham, and O 2016). A risk assessment study was completed in Placentia Bay by Transport Canada and the Canadian Coast Guard in 2009, though the methods used were not reported in the document reviewed (Transport Canada and Canadian Coast Guard 2009)

Figure 6. Sample hypothetical ERAF matrix showing calculation of cumulative risk (CRisk) score (from O et al. 2015).

	Recovery											Consequence	Risk
Key Activity/ Stressor	Max age (ma)	Max size (ms)	Von Bert growth coeff (vb)	Natural mortality (m)	Fecundity (f)	Breeding strategy (bs)	Recruit-ment pattern (rec)	Age at maturity (am)	Population connectivity (conn)	COSEWIC status (stat)	average of (ma + ms + vb + m + f + bs + rec + am + tl + conn + stat)	(ac + cc) x Recovery	Exposure x Consequence
Activity 1/Stressor 1	-	-	-	3	2	3	3	3	2	-	2.67	13.33	2.82
Activity 1/Stressor 3	1	2	1	2	2	1	1	1	1	-	1.33	4.00	1.02
Activity 2/Stressor 1	3	3	3	3	3	3	3	3	3	3	3.00	9.00	13.50
Activity 2/Stressor 2	-	-	-	3	2	2	2	3	3	-	2.50	15.00	150.00
Activity 3/Stressor 1	-	-	-	2	1	1	1	2	3	3	1.86	5.57	36.55
Activity 3/Stressor 2	-	-	-	3	3	3	2	3	2	2	2.57	5.14	41.14
Activity 3/Stressor n	-	-	-	1	2	2	2	1	1	-	1.50	3.00	27.00
											CRisk =	Σ(Risk)	272.04

3.2.3 Ecosystem models

Ecosystem models allow for computer-aided simulation and visualization of complex relationships within marine ecosystems. These models do not fully represent the dynamic suite of causal processes by which human activities and stressors produce effects; no model could do this. However, ecosystem models can help users to understand the mechanisms within ecosystems that lead to observable changes in some species.

Appendix A

Two marine ecosystem modeling frameworks that deal with cumulative impacts are Ecopath with Ecosim and Atlantis. Both frameworks attempt to model key elements of an ecosystem's food web, from primary producers to top predators. As a trade-off for this breadth of scope, large simplifications and assumptions are an intrinsic part of model development (Plaganyi 2007). These types of frameworks are also often criticized as a "black boxes": systems that consume data and produce results, while their inner workings and core assumptions remain largely opaque to the average user. Ecopath with Ecosim has a longer history and a wider application, and is discussed in greater detail in the next paragraphs, followed by a brief sketch of Atlantis.

Ecopath with Ecosim (Christensen and Walters 2004) also simulates the past and future impacts of fishing and environmental disturbances (through modelling stressors to food webs), and allows users to explore and optimize management policies. Development of Ecopath with Ecosim is primarily done by the University of British Columbia's Institute for the Oceans and Fisheries, in conjunction with international institutional partners, including the United States' National Oceanographic and Atmospheric Organization. The framework has been in use since 1984, and has hundreds of applications worldwide, including many Canadian contexts. Most of these applications have focussed on food web functioning in marine systems, though the framework has more recently been applied in other research areas, including pollution and aquaculture, as well as other ecosystem types, including polar regions and terrestrial systems (Colleter et al. 2015).

The Ecopath with Ecosim framework is composed of three modules:

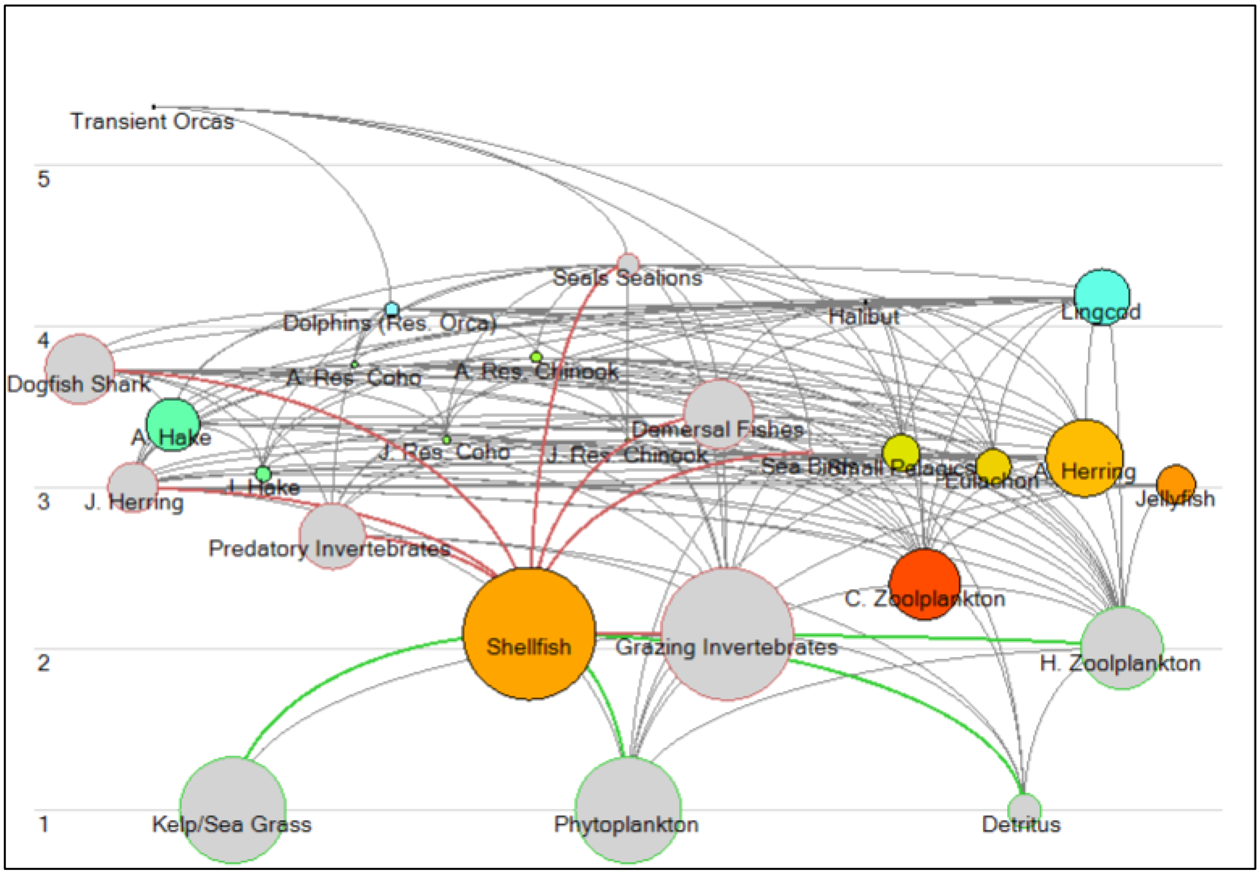
- Ecopath: a mass-balanced model of the ecosystem;
- Ecosim: a module for simulating changes (for example, as the result of new policy); and
- Ecospace: a spatial and temporal module used to evaluate effects on the ecosystem resulting from changes to environmental conditions.

Within an Ecopath with Ecosim model, species are categorized into functional groups. A functional group might consist of a single species, a different life history stage of a single species (juvenile or adult), or a group of species that depend on the same resources in similar ways or serve the same ecosystem function. The model links the functional groups together through a diet matrix. Ecopath with Ecosim requires data inputs on functional group biomass, total mortality, consumption, and fishery catches. If all but one of these parameters is available, the framework sets up a series of linear equations to solve for the missing values.

At the core of Ecopath with Ecosim models are two key equations. The first calculates each functional group's production rate (i.e., the total living matter, or biomass, produced by the group over a specific time period, typically a year), while the second ensures mass balance within each functional group.

Figure 7 presents a screenshot from Ecopath with Ecosim showing flow diagrams of food web linkages. The links between shellfish (represented by the largest orange circle) and organisms at higher and lower trophic levels are shown with red and green lines, respectively.

Figure 7. Flow diagram of web food linkages created in Ecopath with Ecosim model. The model used was developed for British Columbia's Strait of Georgia by Li, Ainsworth, and Pitcher (2010).



Plaganyi (2007) suggests that Ecopath with Ecosim's graphic user interface makes it a useful tool for managers and stakeholders to participate in gaming scenarios to explore potential ecosystem responses to change (e.g., new projects, new policies, climate change). The author of this review experimented with Ecopath with Ecosim, and found creation of a simple model and exploration of existing published models to be relatively straightforward. However, developing complex new models and preparing a system to allow users to play games with different development and policy scenarios would evidently require a substantial investment of time and technical expertise.

The **Atlantis** package (Fulton et al. 2011) models the biophysical system, human use of the system, socioeconomic drivers of human use, and three management components (monitoring, assessment, and management decisions). Compared to Ecopath with Ecosim, Atlantis is much more data-intensive, takes much more effort to set up and calibrate, and does not have a simple user interface.

3.2.4 Cumulative impact mapping

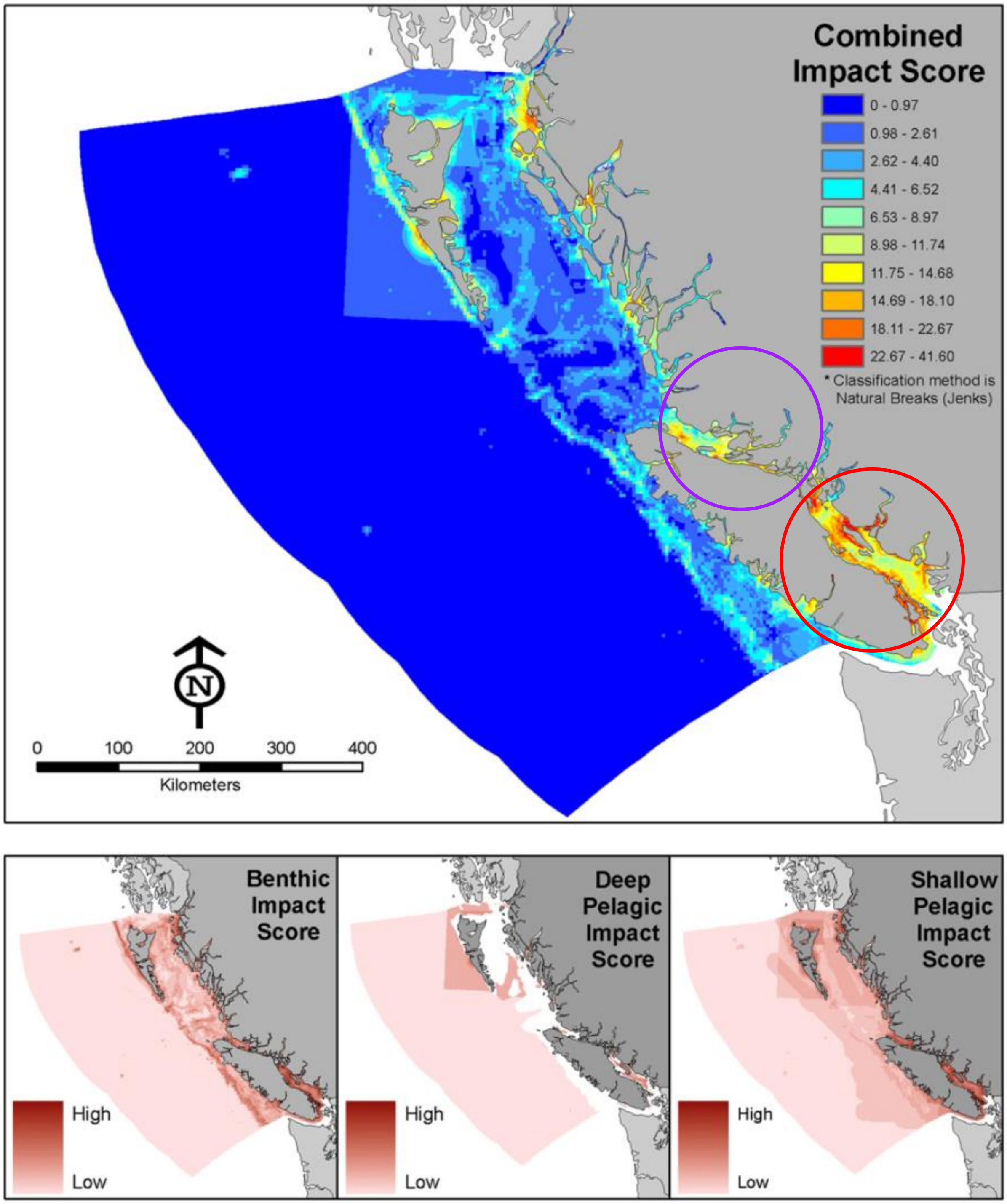
Applied first by Halpern et al. (2008) to the entire globe, **cumulative impact mapping** has subsequently been applied in many regional contexts around the world (e.g., Halpern et al. 2009; N. C. Ban, Alidina, and Ardron 2010; Halpern and Fujita 2013; Marcotte, Hung, and Caquard 2015). These are very data/expert dependent models and not always useful for cumulative effects (high chance of Type II Error).

Maps of human activities and associated stressors are overlaid with maps of habitats, and expert judgement is used to assign a vulnerability score to different habitat types. An impact score is then modelled for each combination of activity-caused stressor and habitat (Halpern, McLeod, et al. 2008; Halpern et al. 2009). The resulting map provides an easily understood reference useful for evaluating where conservation and management efforts should be focussed, where development activities should be curtailed or relocated to less vulnerable areas, and where development can continue without serious consequences to the marine environment. Ban et al. (2010) expand on this method by including a zone of likely influence for human activities to better estimate the footprint of stressors (Figure 8). This technique is useful in scenarios where managers are interested in identifying areas where the greatest potential for impact exists.

To create the map shown in Figure 8, Ban et al. (2010) combined (1) spatial data on the location and intensity of activities; (2) the types of stressors resulting from these activities; (3) the relative impact of these activities on habitats, and (4) the distance to which the effect of activities is likely distributed. The mapped results indicate that while habitats in all ecoregions were affected by multiple activities, the Strait of Georgia (circled in red for the purposes of this report) was the most highly stressed ecoregion within the study area, with a combined impact score over 2.5

times greater than the next most stressed ecoregion, the Queen Charlotte Strait (circled in purple).

Figure 8. Modeled impact scores for Canada's Pacific maritime area using cumulative impact mapping techniques (from N. C. Ban, Alidina, and Ardron 2010; purple and red circles were added and are discussed in the preceding text).



3.3 Best practices and challenges

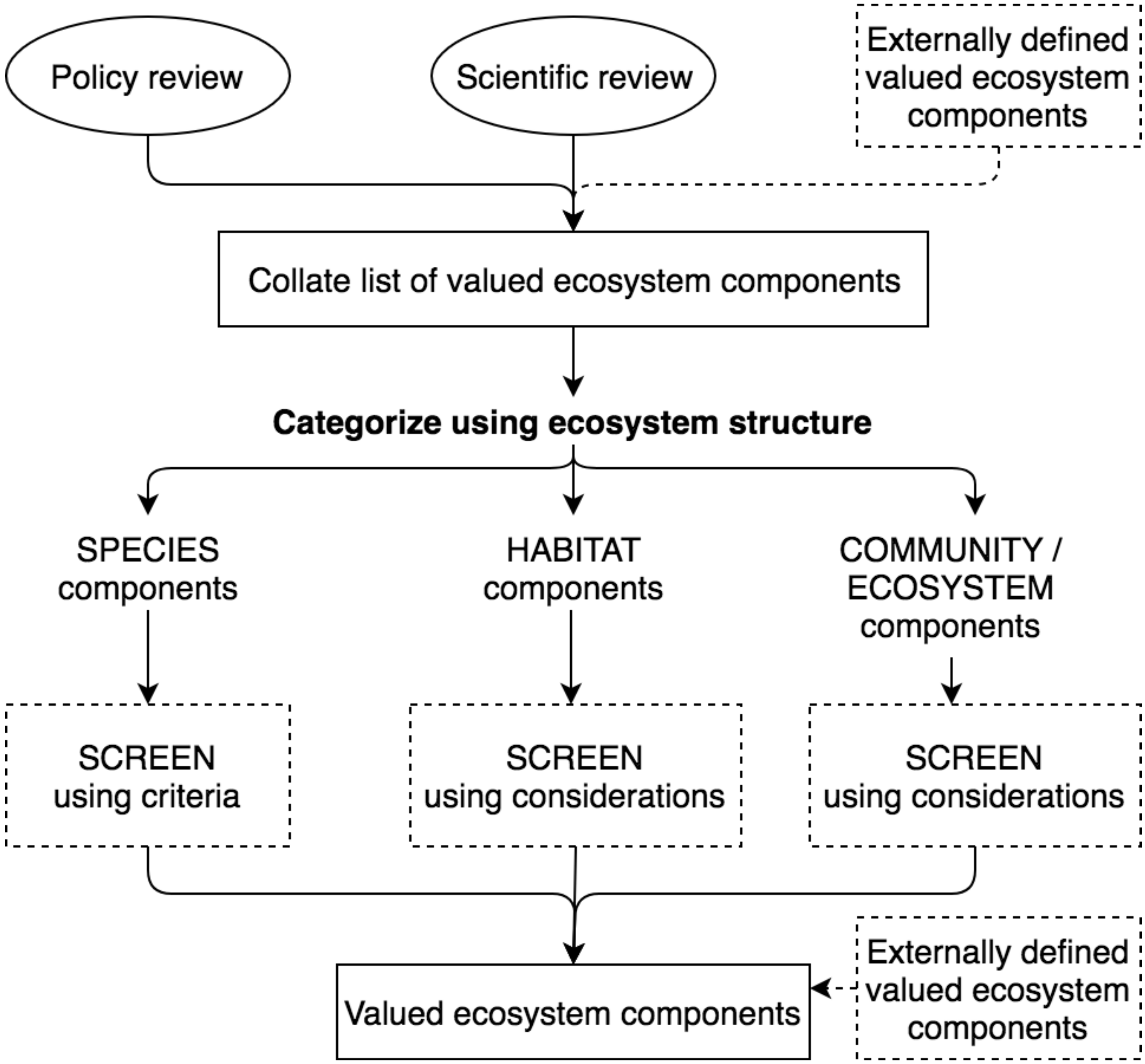
3.3.1 Selecting valued components

Selecting valued components focuses the process of assessment and management on ‘what matters’, allowing frameworks to place greater emphasis on components that may require enhanced management or be of particular importance to people or to the ecosystem. The literature offers a variety of rationales as to why a particular component should be included as a valued component, typically based on their value to people or their ecological importance. Hay et al. (1996) developed the following criteria:

- **Rarity**: features or species that occur over a restricted geographic range or sparsely over a larger area. Species may be rare in a local, regional or national context;
- **Fragility:** Features susceptible to change from human impact and generally sensitive to small amounts of human disturbance;
- **Ecological importance:** Features that influence the integrity of a variety of other resources (e.g., aquatic ecosystems or key wildlife habitats);
- **Scientific value:** Features providing important opportunities for scientific study or monitoring and hence, of high interpretive value;
- **Societal value:** Features that are of high concern to the quality of life or the functioning of society (e.g., air and water quality, noise); and
- **Aesthetic value:** viewscapes with high landscape complexity and limited intrusion for human disturbance, including noise and smells.

O et al. (2015) lay out a systematic procedure for selection of valued components using scientific criteria, with components defined by socio-economic criteria being added in as part of an external process Figure 9.

Figure 9. Outline of DFO process to identify valued components (from O et al. 2015).



Most project-level cumulative effects studies also incorporate consideration of feedback from the public and indigenous groups, including directly affected communities, into the selection of valued components (Ball, Noble, and Dubé 2013).

The final list of valued components, at the project level, usually comprises components mandated by some combination of legislation, input from indigenous groups and the public, and scientific and professional judgement. As the process of identifying valued components is lengthy, the list of valued components selected for analysis of an individual project's direct effects is often the same list used for the cumulative effects assessment. Olagunju and Gunn

(2015) argue that this practice is inadequate, as “by definition, cumulative effects necessitate that stakeholders consider a wider range of environmental components than those directly affected by the project.”

Therefore, regional valued component selection should begin by creating a new inventory of potential candidate components in the region of concern, not by combining the lists of valued components used in the permitting of individual projects. Kwon (2010) reports on how this was accomplished as part of the Metlakatla Cumulative Effects Management Framework (see Section 4.7 for more information about this process).

3.3.2 Selecting indicators

Once potential links between activities and effects on valued components are identified, they can be verified and monitored using **indicators**. Indicators are used to assess the state or condition of a valued component. As defined by Dubé (2003), **effects-based indicators** measure a characteristic of a valued component (e.g., marine mammal abundance), while **stressor-based indicators** measure the stress, disturbance, or risk to a valued component (e.g., percent of disturbed marine mammal habitat); essentially, the stressor *becomes* the indicator.[2]

Effects-based indicators are meaningful because they are direct measurements of the valued component, and inherently encompass the cumulative effects of many human activities. However, they may not be as useful to decision-making because the cause-effect linkages are poorly understood. Monitoring of effects-based indicators tends to be data intensive and highly context-specific. In addition, the indicator change reflects an impact that has already occurred, forcing management to occur reactively.

Conversely, stressor-based indicators are usually well understood and can be more simply measured and proactively linked to management actions. However, they do not capture the effects of all human activities, or the non-additive ways effects from multiple activities can accumulate.

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[2] Other literature, such as the cumulative effects guidance produced by British Columbia’s Ministry of Forests, Land and Natural Resource Operations and Ministry of Environment (BC MFLNRO and BC MOE 2016), makes a similar distinction but uses the terms **state indicators** and **pressure indicators**.

In a review of several applied regional cumulative effects efforts, Gunn (2009) reports that while one group (the Alberta Environment Regional Sustainable Development Strategy, or AB RSDS) initially tried to adopt effects-based indicators, they ultimately elected to take a stressor-based approach:

> A member of the AB RSDS team explains that “in modeling effects, many assumptions are required and modeling outputs often do not reflect eventual realities.” The AB RSDS team at first endeavoured to select environmental indicators that could act as a “canary in a mine,” able to detect effects long before a large scale environmental change could occur. It was found, however, that natural variability complicated these efforts and that it was very difficult to distinguish ‘safe’ effects levels from effects levels that required management intervention. […] An effects-based approach is regarded as being relatively reactive, compared with a stressor-based approach. The RSDS team found that managing environmental stressors was an important part of the strategy to proactively address cumulative effects issues. (J. Gunn 2009, 60)

Indicators can be selected using a variety of approaches, including some that are by-products of the tools and models described in the preceding sections:

1. Simple lists or matrices (Ward 2000);
2. Causal frameworks (as noted in discussion of eDPSIR above; Niemeijer and de Groot 2008a);
3. Risk-based indicators derived from ecological risk assessments (Thornborough, Dunham, and O 2016);
4. Ecosystem models (Fulton et al. 2011; Sutherland et al. 2016);
5. Participatory processes (Reed, Fraser, and Dougill 2006; Kwon 2010; Faaui, Morgan, and Hikuroa 2017; see discussion in case studies of Mauri Model Decison-making Framework and Metlakatla Cumulative Effects Management System)

There is general agreement in the literature (e.g., Ward 2000; L. W. Canter and Tomey 2008; Niemeijer and de Groot 2008a; Noble and Harriman 2008; L. W. Canter and Atkinson 2011) that the indictors selected should:

1. be measurable (quantitatively or qualitatively) and scientifically valid;
2. be relevant to the valued component and appropriate to its scale;

3. be readily interpretable by decision-makers and other stakeholders, including indigenous communities and the general public;
4. be diagnostic and useful in decision-making, including contributing to the evaluation of progress relative to policy goals;
5. be associated with quantitative or qualitative thresholds;
6. have ideally been used in other environmental impact studies, or in adaptive management programs; and
7. be cost-effective.

3.3.3 Setting temporal and spatial scales

Determining appropriate temporal and spatial scales is a recurring challenge in evaluating and managing cumulative effects. The choice of scale has profound implications on any study's results (João 2007). Narrower scales simplify assessment, but at the risk of neglecting wider-ranging or longer-term effects; on the other hand, larger scales are more appropriate to understanding the broader context of cumulative effects, but may lead to data availability challenges, in addition to effectively diluting the importance of local effects against a too-broad study area (Z. Ma, Becker, and Kilgore 2012).

Natural and anthropogenic processes have shaped the present landscape over time. Similarly, current and reasonably foreseeable future activities may directly or indirectly affect future conditions for decades (Lerner, n.d.). For project-level assessments—where most of the study of cumulative effects actually occurs in current practice—temporal boundaries are generally confined to the lifetime of the proposed project, beginning at construction and ending with the decommissioning and closure phases. The baseline conditions against which the project's potential impacts are assessed are thus roughly contemporary: a snapshot of an ecosystem in the present with limited consideration of its history. This has resulted in the phenomenon known as 'shifting baseline syndrome', wherein human ecological standards gradually lower and environmental degradation is increasingly accepted as normal by decision-makers because of a lack of a historical perspective: effectively, the impact of yesterday's activities becomes part of today's baseline (Pauly 1995; Knowlton and Jackson 2008; Turner et al. 2008; Papworth et al. 2009; Lotze and Worm 2009; D. M. Franks, Brereton, and Moran 2010). Turner et al. (2008) further argue that this practice—failing to acknowledge historical losses by using the present as baseline—constitutes a "profound injustice, another form of invisible loss" to Aboriginal people.

It is therefore critical to consider historical information about the pre-impacted state of ecosystems, and to set temporal boundaries accordingly. McCold and Saulsbury (1996) suggest selecting a time in the past when the valued component was most abundant or least affected by human activities. The effects of the proposed project on the existing environment should then be compared to this historic condition (D. M. Franks, Brereton, and Moran 2010; Masden et al. 2010). Pauly (1995) advocates incorporating anecdotes and other forms of evidence outside the realm of conventional scientific data collection into these historic baselines; Lotze and Worm (2009) suggest using approaches from several disciplines to reconstruct the past, including paleontological, archaeological, historical, and scientific records and oral histories (and see Salomon, Tanape, and Huntington 2007; and Renberg et al. 2009 for applied technical examples from Alaska and Sweden, respectively).

In project-level cumulative effects assessment, the spatial scale of analysis usually roughly corresponds to the extent of stressors from the proposed project. In many regional studies, as Foley et al. (2017) point out, “The footprint of an agency's jurisdiction is often the default scale for analysis because it is the scale at which decisions are made and for which data for ecosystem conditions and overlapping projects is available.” These approaches simplify analysis, but overlook the fact that cumulative effects—by their very nature—often extend over broad areas without regard for project footprints or administrative boundaries.

Both temporal and spatial boundaries should be based on intellectually sound criteria. The International Finance Corporation suggests taking an iterative approach to scale selection…

> …in which the first boundaries are often set by educated guess but incrementally improved as new information indicates that a different boundary is required for the analysis. Boundaries are expanded to the point at which the [valued component] is no longer affected significantly or the effects are no longer of scientific concern or of interest to the affected communities (International Finance Corporation 2013, 34).

Consideration should be given to a scale that represents both the processes and the actors that influence human activities or are affected by those activities (MacDonald 2000; Masden et al. 2010; Gillingham et al. 2016). Spatially, this may correspond to an ecologically determined area or natural boundary, such as a watershed, geological region, or ecosystem (Riki Therivel and Ross 2007; Eccleston 2001), but must also be sufficiently flexible to reflect the extent or distribution of valued components (Spaling and Smit 1993; Eccleston 2001; Noble and Harriman 2008).

No single scale will be universally appropriate for all valued components, or even for distinct types of impacts on the same valued component. João (2002) and Karstens et al. (2007) argue against searching for a definitive 'right' scale; rather, practitioners should consider the range of scales that may be suitable. Whatever scale is ultimately selected, the rationale for the selection should be public and transparent (João 2002). Karstens et al. (2007) suggest that the following steps be taken to understand the trade-offs between scale choices:

Determine the function of the study in the policy process.

1. Generate alternatives for scale choices.
2. Assess the impacts of these alternatives from different perspectives.
3. Elucidate the values that are important for making decisions.
4. Communicate the impacts and trade-offs with the study managers and with other stakeholders, and reflect on them in light of the function of the study.

3.3.4 Addressing uncertainty

Scientific findings are nearly always limited by uncertainty. Even the best-designed and executed study will leave gaps in knowledge somewhere. Experts make assumptions or rely on professional judgment to fill in those gaps. However, it is important to explicitly acknowledge uncertainties and any methodological steps taken to work around them. In practice, at least in project-level considerations of cumulative effects, uncertainty is often handled poorly in this respect (Tennøy, Kværner, and Gjerstad 2006; Masden et al. 2014; Leung et al. 2015; Lees et al. 2016). In their review of 22 Norwegian project-level assessments, Tennøy, Kværner, and Gjerstad (2006) found that decision-makers and other stakeholders were consistently not made aware of considerable uncertainties in the analyses. Geneletti et al. (2003) and Leung et al. (2015) reported similar findings in the United States and Canada, respectively. Risk-based approaches (such as the framework discussed in Section 3.2.2) can aid in making some kinds of uncertainties transparent (Stelzenmüller et al. 2018).

Strategic approaches themselves represent a step towards reducing uncertainty, as they provide knowledge about cumulative effects early in the planning process. However, knowledge is not a cure-all for uncertainty, as new information may actually increase uncertainty, perhaps by revealing other issues that had previously been overlooked or under-scrutinized (Larsen, Kørnøv, and Driscoll 2013). Uncertainty can appear in many other forms in cumulative effect assessment and management: in understanding the details of present and proposed activities, in knowledge of historical and current conditions of valued components, in identifying effect pathways, in assigning importance to anticipated effects, and in modeling and monitoring techniques (Sadler 1996; Leung et al. 2015; Leung et al. 2016). Indeed, initiating a framework in a new regulatory context is likely to introduce a host of uncertainties (Noble et al. 2013). Any of these uncertainties may frustrate management efforts and reduce internal and external stakeholder confidence.

Application of the precautionary principle and adaptive management are also common prescriptions for addressing uncertainty. The **precautionary principle** is the maxim that, where there is no full scientific certainty about the potential for serious or irreversible damage from a proposed activity, policy decisions should be made in a way that errs on the side of caution with respect to the environment and human well-being.

Adaptive management is an iterative approach for improving management in the face of uncertainty by learning from management outcomes and feeding that learning back into the management process. Effective adaptive management must thus (1) collect feedback from management actions, (2) translate that feedback into a new understanding, and (3) incorporate that new understanding into subsequent management actions. An obvious limitation of adaptive management is that if the feedback in question is a change in a valued component, for example, that change has to occur before the management action can be refined. If the adaptation happens slowly, therefore, the consequences may be severe (MacDonald 2000).

The trade-off between attempting to address uncertainty by acknowledging its existence and applying the precautionary principle, or through the use of adaptive management, should be evaluated on a case-by- case basis. Gustavson (2003) has proposed an explicit framework to guide environmental management strategies based on the precautionary principle, which includes avoidance of the proposed activity on one end of the spectrum and adaptive management at the other.

3.3.5 Public and Indigenous participation

Participation in impact assessment and management processes has been the focus of much literature over the past two decades. In this report, **participation** is defined broadly as the actions taken by government decision-makers to engage with interested and affected parties (individuals, groups, and communities) in impact assessment and management. Of particular importance is the participation of Indigenous peoples, especially those who elect to maintain a traditional relationship with their land, and for whom assessment and management decisions will have serious implications. In addition, in Canada, Indigenous peoples have constitutionally recognized rights and title and treaty rights with direct relevance to environmental decisions.

Strategic assessment requires a greater degree of participation and collaboration, and longer-term commitments than what typically takes place at the project level (Noble 2017). According to Dietz and Stern (2008), the goal of this participation should be to improve *quality*, *legitimacy*, and *capacity*, where:

- *quality* refers to identification of the values, interests, and concerns of all who are interested in or might be affected by the assessment or decision together with the range of actions that might be taken; consideration of the effects that might follow and uncertainties about them; application of the best available knowledge and methods relevant to the above tasks; and incorporation of new information, methods, and concerns that arise over time;
- *legitimacy* refers to a process that is seen as fair and competent by the interested parties and that follows the governing laws and regulations; and
- *capacit*y refers to the benefits to all participants (not just interested parties, but also government officials and experts) of gaining knowledge and skills, both by becoming more informed about the intricacies and variety of perspectives on the subject of the process, and by gaining experience in the participation process itself.

Realization of these three goals offers benefits for all, particularly decision-makers. Participation can take many forms, with participants having lesser or greater involvement with decision-making. However, as O'Faircheallaigh (2010) and Booth and Skelton (2011) point out, unless participation involves some real influence over decision-making, interested and affected parties (Indigenous and public) will be reluctant to participate.

O'Faircheallaigh (2010) identifies three broad types of participation: (1) obtaining input into decisions taken separately by decision-makers, (2) providing some level of sharing of decision-making, and (3) altering the structures and power relationships of decision-making. The first two types assume that the distribution of power and existing decision-making processes are static and equitable, while the third provides marginalized groups with a degree of influence over decision-making that they do not already possess. Sharing or re-locating decision-making power may thus be critical to ensuring that meaningful participation occurs.

Appendix A

Finally, Dietz and Stern (2008) offer the following five key recommendations for participation:

1. Participation should be a requisite of effective action, not merely a formal procedural requirement.
2. Governments engaging in participation should do so with clarity of purpose, commitment to use the process to inform actions, adequate funding and staff, appropriate timing in relation to decisions, a focus on implementation, and commitment to self-assessment and learning from experience.
3. Participation processes should be inclusive and transparent, with collaborative problem formulation and process design and good faith communication between parties.
4. In processes with substantial scientific content (such as impact assessment), it is vital to ensure the transparency of relevant information and analysis, to be explicit about any assumptions or uncertainties, to pay attention to both facts and values, and to engage in collaborative inquiry with interested and affected parties.
5. Participation practitioners, working with the responsible agency and the participants, should first consider the context to identify likely difficulties, then collaboratively select techniques to address those difficulties, monitor the process's performance, and iteratively revise the process to overcome ensuing difficulties.

4. Case studies

The following chapter reviews seven case studies of implemented cumulative effects management systems: four from international regimes and three from regional initiatives from across Canada. Table 6 compares the issues and practices discussed previously in this chapter across all seven case studies.

These case studies rely, for the most part, on the reporting of the same agencies that developed the frameworks, and thus have at least three notable limitations. First, information on what led to the development of the case study frameworks (their history and institutional organization) was not the main focus of the documents, and therefore was not consistently available. Where information was available, it is summarized here. Second, while the primary work was done by technical experts, the resulting reports were often prepared for less specialized audiences, meaning that some methodological details were sometimes glossed over or roughly sketched in. Third, the nature of these types of reports is to frame every result as a success, to a certain extent: there is little discussion of techniques that were tried and failed, for example, or critical reflections on the framework's outcomes in terms of realized goals.

4.1 Barents Sea Integrated Management Plan (Norway)

4.1.1 Background and organization

Development of Norway's Integrated Management Plans (IMPs) was prompted by emerging petroleum activity, together with a recognition of gaps in knowledge about a number of aspects of the marine environment, and a need for better coordination of environmental monitoring and management (Knol 2010). The oldest IMP, implemented in the Barents Sea / Lofoten Islands area roughly a decade ago and updated in 2011, was reviewed for this report; others have since been created, but the Barents Sea plan has the longest history (Royal Norwegian Ministry of the Environment 2006; 2011).

The Barents Sea IMP was developed over a roughly four-year period (2002 to 2006). The process toward the plan comprised three phases. In the first phase, encompassing the first two years of the project, the Steering Committee (an inter-ministerial committee headed by the Norwegian Ministry of Environment) set the overall objectives for the plan and the boundaries of the management area. The Steering Committee also commissioned research institutions and government agencies to write status reports, taking stock of existing knowledge on the environment, resources, valuable areas, socio-economic aspects and economic activities.

Appendix A

Table 6. Comparison of case studies reviewed.

Name	Approach	Project / Strategic	Tools used	Temporal scale	Spatial scale	Valued component selection	Indicators
Barents Sea Integrated Management Plan (Norway)	Place-based / Activity-based	Strategic	Risk assessment and professional judgement	Mostly forward-looking (to 2020); historical data on valued components to create pre-development baseline	1,400,000 km^2, based on ecological and administrative considerations	Method for selection not reported, but seems to have been done by expert group.	Effects-based
Great Barrier Reef Strategic Environmental Assessment (Australia)	Place-based	Strategic	DPSIR framework, structured lists, conceptual diagrams, and models	Focuses on present to – 2050, but considers older “legacy impacts”	346,000 km^2, based on ecological bounds	Selected based on scientific significance and value to Traditional Owners	Effects-based
Xiamen Integrated Coastal Management Plan (China)	Place-based	Strategic	DPSIR framework	Unknown	Unknown	Professional judgement, with some exceptions	Effects-based and stressor-based
Mauri Model Decision-making Framework in post-*Rena* assessment (New Zealand)	Place-based	Strategic	Decision support	100 years ago to present	Not measured in kilometres, but by affected community	Participatory	Effects-based
Manitoba Hydro Regional Cumulative Effects Assessment (Canada)	Activity-based (?)	Project	Pathways of Effects	1951 – 2013	210,000 km^2, follow “ecologically meaningful” boundaries	Professional expertise and desk-based (review of traditional knowledge	Effects-based
Canada-Nova Scotia Offshore Petroleum Board Strategic Environmental Assessments (Canada)	Activity-based	Project	Professional judgement (?)	Present + 10 years	37,280 km^2, area, but considers extent of valued components	Scientific judgement, board input, and consultation (via the board)	Unknown
Metlakatla Cumulative Effects Management Program (Canada)	Place-based	Strategic	Participatory processes	Unknown	Metlakatla traditional territory	Participatory	Effects-based

The knowledge compiled in Phase 1's status reports served as a basis for SEAs related to several industry sectors in Phase 2. The Steering Committee commissioned research institutions and government agencies to assess the impact of individual industries (e.g., fisheries, marine transportation). These SEAs went through public hearings and consultation rounds; the SEA reports were posted online for comments from the public, industry, NGOs, local and regional authorities and the academic community.

Phase 1 and 2 served as a basis for the aggregated assessments in Phase 3. The Steering Committee established an expert group, consisting of research institutions and governmental directorates that are closely linked to the public system. This expert group formulated more precise management goals based on discussion, representing compromises between various interests. The objectives were then incorporated into the management plan and refined during the implementation phase. The expert group also determined which indicators should be included in the management plan, and which could be excluded. Based on the SEAs prepared in Phase 2, the expert group reported on the full suite of human impacts in the management area. The Steering Committee established a new working group to identify vulnerable areas as well as conflicts of interests between sectors.

After completing the aggregated assessments, the Steering Committee developed the IMP using the assessment reports written in Phase 2 and 3 to craft policy measures.

The final IMP system is headed by the Steering Committee, which coordinates government control of the work and administrative follow-up of the reports that the system generates, while the appropriate ministries and their sub-agencies are responsible for appropriate management measures. The Steering Committee established three advisory groups as part of the IMP:

1. A *Monitoring Advisory Group* that assists in the coordination of the monitoring system. The group is made up of representatives from public institutions with responsibility for and experience in relevant sectors, as well as other institutions involved in research and monitoring in the region. This group is responsible for coordinating the implementation of monitoring programs under the framework, and for producing annual reports of monitoring results.
2. An *Environmental Risk Management Forum* that was established to provide better information on risk trends in the region, especially trends related to acute oil pollution. The forum has broad membership, with representatives from relevant public institutions and drawing expertise from other sources as necessary, and interest groups involved in the process as appropriate. This forum exchanges information, particularly about risk

factors, develops monitoring of risk trends, and coordinates monitoring activities applicable to risk management, especially in relation to marine transportation. The forum compiles a report of its activities at regular intervals (not annually), and this report is submitted to the Management Forum.

3. The *Management Forum* is responsible for the coordination and overall implementation of the scientific aspects of management of the region. Working with the heads of the Advisory Group and the Environmental Risk Management Forum, the Management Forum is responsible for ensuring that status reports are compiled on the results obtained through research, monitoring, surveys, and other scientific activities relevant to the goals of the management plan. The reports are submitted to the Steering Committee.

The IMP also has a *Working Group* representing the various interests involved, including business and industry, environmental organizations, and Sami interest groups. The Working Group has opportunities, through meetings with the bodies responsible for implementing the IMP and in other appropriate ways, to express its views on the implementation of the plan. The IMP is updated on a regular basis to include any new measures needed to achieve the goals of the plan, based on the submitted status reports.

4.1.2 System details

As far as possible, the IMP was built on existing and planned monitoring programs and in line with Norway's international obligations (Royal Norwegian Ministry of the Environment 2006). This was done deliberately to ensure that existing time series data would continue to be collected and that future research and monitoring needs were taken into account in the ongoing development of the IMP.

The IMP is a strategic, place-based framework, but largely focuses on three sectors: shipping, fisheries, and petroleum. Tools used include risk assessments carried out for issues related to oil pollution and spills, and expert judgement for other issues.

The IMP is a mostly forward-looking plan, exploring planning futures to the year 2020. However, trends in indicator values are compared against **reference values** (i.e., the ecological quality expected in a similar but more or less undisturbed ecosystem, or a pre-development state, adjusted for natural variation and development trends), though there is no explicit consideration of past activities. The spatial boundaries for the study were based on "ecological and administrative considerations."

Indicators of ecological quality are largely chosen on the basis of their relevance to ecosystem management, their relevance in relation to Norway's international obligations, and the feasibility of measuring them, in addition to their role in the ecosystem. Indicators are used to assess how far the management goals have been reached and whether trends in the ecosystem are favourable. As mentioned, these indicators are compared with reference values, and precautionary reference values are used for harvestable stocks. References values for the various indicators are as far as possible determined on the basis of scientific advice, and are refined as new knowledge is gained over time.

The method for valued component selection was not clear from the reviewed reports, but seems to have been done by an expert group. A list of potential indicators (largely effects-based) was drafted by expert scientists on the basis of their relevance to ecosystem management and feasibility of measurement, and refined by steering committee to select indicators where long time series were already available and that were already being systematically monitored.

The monitoring system implemented through the Barents Sea IMP considers the overall ecological quality of the ecosystem, taking into account physical, biological and chemical conditions, including the effects of anthropogenic pressures. Monitoring of a large number of factors fundamental to the state and functioning of valued components within the ecosystem—for example, temperature, salinity, water transport, extent of the sea ice, nutrient distribution, and the occurrence and production of phytoplankton and zooplankton—is conducted in order to distinguish between the effects of human activity and natural fluctuations in an ecosystem. As well as maintaining long time series, the monitoring system for marine ecosystems must also be dynamic and flexible enough to be changed and updated by the Monitoring Advisory Group in the light of new knowledge.

The IMP establishes **action thresholds**, which are the points at which a change in an indicator in relation to the reference value is so great that new measures must be considered. Action thresholds are not used as measures of performance, but as triggers to authorities that action must be taken. Action thresholds are only given for indicators that reflect anthropogenic pressures. In areas where it is possible to set action thresholds, the indicators must be able to show the impact of any mitigation measures.

Knol (2010) notes the IMP's emphasis on the role of scientific institutions to reduce uncertainties and "fill the knowledge gaps," concluding that, to a certain extent, the IMP's framework "has been an attempt to translate a political game into a matter of information and knowledge gathering. With that, the production of knowledge becomes more politicized." Dale (2016), who attended a public conference on the topic of the IMP in 2010, suggests that local knowledge was effectively excluded as a basis for the Plan's revision. A local businessman explained to her why he and others at the conference did not speak up about the lack of local knowledge in the Plan thusly: "There was nothing more to say. The ministers closed the doors on all the things I thought was important."

4.1.3 Key sources reviewed

Dale, Brigt. 2016. "Governing Resources, Governing Mentalities. Petroleum and the Norwegian Integrated Ecosystem-Based Management Plan for the Barents and Lofoten Seas in 2011." *Extractive Industries and Society* 3 (1). Elsevier Ltd.: 9–16.

Fidler, Courtney, and Bram Noble. 2012. "Advancing Strategic Environmental Assessment in the Offshore Oil and Gas Sector: Lessons from Norway, Canada, and the United Kingdom." *Environmental Impact Assessment Review* 34 (April). Elsevier Inc.: 12–21.

Fixdal, Jon. 2000. "Norwegian Experiences of Strategic Environmental Assessment in Regional Development Programmes." In *Regional Development Programmes and Integration of Environmental Issues: - the Role of Strategic Environmental Assessment*, edited by Tuija Hilding-Rydevik, 47–52. Oslo: Nordregio.

Knol, Maaike. 2010. "Scientific Advice in Integrated Ocean Management: The Process towards the Barents Sea Plan." *Marine Policy* 34 (2). Elsevier: 252–60.

Moe, Arild. 2010. "Russian and Norwegian Petroleum Strategies in the Barents Sea." *Arctic Review on Law and Politics* 1 (2): 225–48. http://www.fni.no/doc&pdf/AM-Arctic_Review2010.pdf.

Royal Norwegian Ministry of the Environment. 2006. Integrated Management of the Marine Environment of the Barents Sea and the Sea Areas off the Lofoten Islands. Report No. 8 to the Storting.

Royal Norwegian Ministry of the Environment. 2011. First Update of the Integrated Management Plan for the Marine Environment of the Barents Sea-Lofoten Area. Meld. St. 10 (2010–2011) Report to the Storting.

4.2 Great Barrier Reef Strategic Environmental Assessment (Australia)

4.2.1 Background and organization

The Great Barrier Reef SEA was implemented through the Great Barrier Reef Ministerial Forum, which is supported by three groups:

- A multi-sectoral *Reef advisory committee,* which facilitates engagement with industry and the broader community on implementation and review of the Plan. The committee includes members from the Reef 2050 Long-Term Sustainability Plan Partnership Group, Traditional Owners and community representatives.
- An *independent expert panel,* which provides expert advice on implementation and review of the Plan, including objectives and targets, knowledge gaps and science priorities for Plan delivery. The panel includes members with scientific (biophysical, heritage, social and economic) expertise.
- An *intergovernmental operational committee* of senior officials from the Australian and Queensland governments, who oversee implementation of the Plan, facilitate coordination of Reef-related activities and report annually to the Great Barrier Reef Ministerial Forum.

4.2.2 System details

The Great Barrier Reef strategic environmental assessment is a place-based study. The framework relies on a whole suite of models and tools, including the DPSIR framework, structured lists, conceptual diagrams, quantitative and qualitative models, and Bayesian networks, depending on the valued component.

The framework focuses on the period between the present and 2050, but considers the “legacy impacts” of human activities such as commercial harvesting on the Great Barrier Reef. The spatial boundaries were set based on the ecological boundaries of the valued components (called ‘key ecological features’).

The valued components used in the framework were selected based on their scientific significance and their value to the Traditional Owners (individuals recognised in the indigenous community as having spiritual or cultural affiliations with a site). A suite of effect-based indicators were selected using a procedure developed specifically for the framework, wherein qualitative modelling is used to identify potential ecological indicators for valued components and then refined using selection criteria.

The strategic environmental assessment was part of a larger Integrated Monitoring and Reporting Program, which measures and reports progress towards achieving objectives and targets, and guides adaptive management. The program includes:

- *compliance monitoring* focused on the impacts of individual development action (for example construction of a marina) and undertaken in accordance with conditions specified in a permit, license or approval;
- *short to medium-term, issue-specific monitoring* examining the condition of, extent of impact on and recovery rates of species, habitats or community benefits; and
- *long-term monitoring* to assess the condition and trend of the Reef's values and broad-scale impacts, such as land-based run-off, over many years.

Most monitoring in the program was based on pre-existing monitoring programs, but integration across programs has been developed through:

- standardizing protocols for information collection, collation, modeling, analysis and reporting;
- explicit links to management actions, targets, objectives and outcomes;
- unifying monitoring through a DPSIR framework to inform assessment of cumulative effects; and
- incorporating new information and knowledge into monitoring.

An annual report on Plan implementation progress is provided to the Great Barrier Reef Ministerial Forum and made publicly available.

4.2.3 Key sources reviewed

Anthony, Kenneth R.N., Jeffrey M. Dambacher, Terry Walshe, and Roger Beeden. 2013. A Framework for Understanding Cumulative Impacts, Supporting Environmental Decisions and Informing Resilience-Based Management of the Great Barrier Reef World Heritage Area. Townsville, Queensland: University of Melbourne and Greater Barrier Reef Marine Park Authority.

Australian Government. 2014. *Great Barrier Reef Region Strategic Assessment: Strategic Assessment Report*. Townsville, Queensland: Great Barrier Reef Marine Park Authority.

Commonwealth of Australia. 2015. Reef 2050 Long-Term Sustainability Plan.

Hayes, Keith R, Jeffrey M Dambacher, Vincent Lyne, Ruth Sharples, Wayne A Rochester, Leo X C Dutra, and Rick Smith. 2012. Ecological Indicators for Australia's Exclusive Economic Zone: Rationale and Approach with Application to the South West Marine Region. Hobart, Australia: prepared for the Australian Government Department of Sustainability, Environment, Water, Population and Communities, CSIRO Wealth from Oceans Flagship.

Ward, Trevor J. 2000. "Indicators for Assessing the Sustainability of Australia's Marine Ecosystems." *Marine and Freshwater Research*, no. 51: 435–46.

4.3 Xiamen Integrated Coastal Management Plan (China)

(The discussion of this case study is less detailed than the others included in this review. As the primary literature on this program was not available in English, the summary presented here is solely based on secondary sources.)

4.3.1 Background and organization

At the end of the 1980s, environmental issues relating to the development and utilization of marine resources came to the fore in China. A policy instrument known as **marine functional zoning** was first proposed in China in 1988. Marine functional zoning divides the sea (along with islands, shorelines, and adjacent land areas) into different types of zones, according to both natural characteristics (e.g., natural resources, geographical and ecological features) and social ones (e.g., socioeconomic development needs).

Beginning in the 1990s, under the overall supervision of the State Council, China's eleven coastal provinces, autonomous regions, and municipalities formulated a nation-wide marine functional zoning scheme. Over two-thirds of these zoning schemes have been approved and implemented.

In 1995, Xiamen's Municipal Government established an inter-agency, multi-sectoral coordinating mechanism for integrated coastal management: the **Xiamen Marine Management and Coordination Committee** (Xue, Hong, and Charles 2004) and (D. Ma et al. 2017). (The organizational structure of this committee is noteworthy for placing municipal government officials in positions of authority, with the municipal deputy mayors serving as committee directors and deputy directors.)

Xiamen has also established a **Marine Expert Group** to advise the Marine Management and Coordination Committee on matters relating to proposed development projects. This group comprises marine scientists, legal experts, and economists, who provide socio-economic, ecological and technical expertise.

4.3.2 System details

The Xiamen framework is strategic and place-based. Details about the temporal and spatial boundaries selected for the Xiamen framework were not provided in the sources reviewed.

The Xiamen framework identifies valued components from five major ecological categories: water circulation and siltation, water quality, sediment quality, the benthic community, and mangrove forests. A combination of applicable effect- and stressor-based indicators were initially selected using professional judgement, to which several indicators of special interest to stakeholders and to the government (relating to specific species) were added.

In 1996, the Marine Expert Group developed the Xiamen Marine Functional Zoning Scheme to mitigate cumulative impacts, which was accepted by the Marine Management and Coordination Committee. This zoning scheme is the key component of the cumulative effects management system.

Xiamen's zoning scheme defines use priorities in terms of dominant, compatible, or restricted functions. **Dominant functions** are uses considered high priority, while **compatible functions** are uses considered to have no major adverse effects on the dominant functions. **Restricted functions** are uses that should be reduced or eliminated due to their detrimental effects on the dominant and compatible functions.

Xue et al. (2004) provide the example of the Western Seas zone, where the dominant function has been identified as port development. Within this zone, land reclamation activities are restricted functions (i.e., forbidden), based on the potential for circulation and siltation impacts that may impinge on marine navigation.

4.3.3 Key sources reviewed

Ma, Deqiang, Liyu Zhang, Qinhua Fang, Yuwu Jiang, and Michael Elliott. 2017. "The Cumulative Effects Assessment of a Coastal Ecological Restoration Project in China: An Integrated Perspective." *Marine Pollution Bulletin* 118 (1–2). 254–60.

Xue, Xiongzhi, Huasheng Hong, and Anthony T Charles. 2004. "Cumulative Environmental Impacts and Integrated Coastal Management: The Case of Xiamen, China." *Journal of Environmental Management* 71 (3): 271–83.

4.3.4 Mauri Model Decision-making Framework in the post-*Rena* assessment (New Zealand)

4.3.5 Background and organization

The Mauri Model Decision-making Framework (MMDMF) is an assessment approach developed specifically for the New Zealand context in 2003. The MMDMF measures impacts on **mauri**: a central concept in the Māori worldview "analogous to the 'life force' within living things and the capacity to support life in air, water and soil" (Morgan, Sardelic, and Waretini 2012). Mauri is one of the key principles that the indigenous peoples of New Zealand apply to understand the actual, potential or cumulative effects of activities on the environment (Bennett 2015). The MMDMF has been used in a number of environmental and engineering case studies, including as part of the New Zealand government's response to the grounding of the motor vessel *Rena*.

In 2011, the *Rena* ran aground on Otāiti, also known as the Astrolabe reef, releasing hundreds of tonnes of heavy fuel oil into the Bay of Plenty, New Zealand. The country's Minister for the Environment called the *Rena* grounding New Zealand's worst maritime environmental disaster. Later that year, in response to the *Rena* event and its associated impacts, the New Zealand government released a recovery plan with the goal of restoring "the mauri of the affected environment to its pre-*Rena* state" (Ministry for the Environment 2011, 3), defining mauri as:

> lifeforce, the integrity, form, functioning and resilience of the coastal environment, including its ecosystems, all *kaimoana* [fish and shellfish], marine and inter-tidal areas, rocks, estuaries, rivers and streams, islands, dunes and land, and customary fishing areas (Ministry for the Environment 2011, 3).

As part of the plan, the Ministry of Environment established a Governance Group to oversee the long-term environmental recovery. This group comprised representatives of *iwi* (the Maōri word for *people* or *nation*) and local and central governments. The MMDMF was employed to assess the cumulative effects to the *Rena*-affected environment. The plan is thus notable for this explicit inclusion of an indigenous concept to represent the target state of the environment in the assessment and management of cumulative effects.

The specifics of the MMDMF were formulated for New Zealand, and this case study has largely been included as an example of how indigenous values can be used to inform decision-making in cumulative effects management. However, it should be noted that the MMDMF has been adapted for use in at least two contexts outside New Zealand: China (Morgan, Sardelic, and Waretini 2012) and Papua New Guinea (Wambrauw and Morgan 2016).

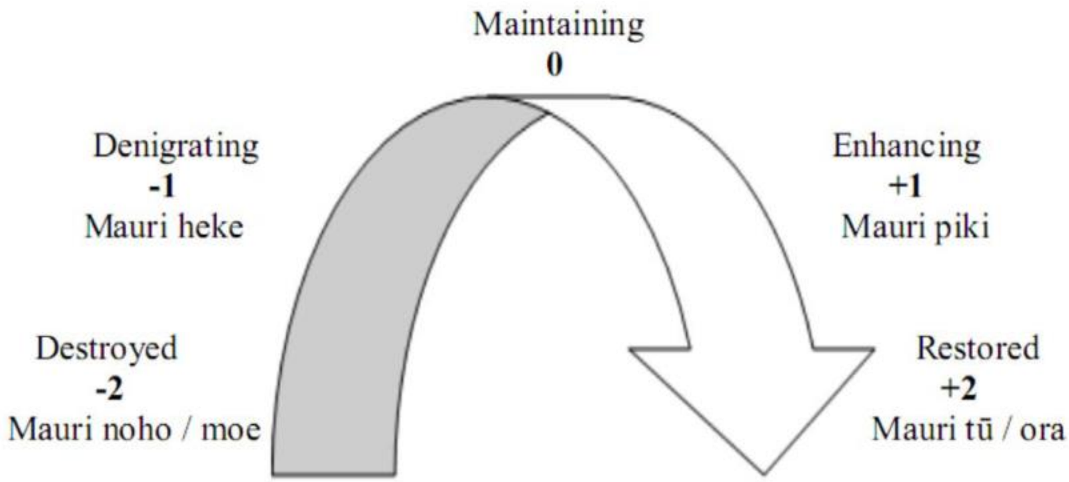
4.3.6 System details

The MMDMF is a strategic, place-based study. The framework employs multi-criteria decision-making methods as part of a community-centred participatory process.

An extended pre-disaster timeline was selected (from 100 years ago until the present) to allow for insights into factors that contributed to pre-*Rena* conditions, and how mauri was eroded during that time. The authors plot changes to the ecosystem's mauri over the entire period to show trends pre-disaster and during disaster recovery. The authors report that the process of assessing impact over this time period is useful "to quantify the cumulative effects of seemingly separate and unlinked impacts experienced within an environment" (Faaui, Morgan, and Hikuroa 2017). The spatial boundaries for the study are not delineated by square kilometres, but by the affected communities.

Valued components were not identified individually as part of this study, but are implicitly included within four mauri dimensions: environmental, cultural, social, and economic. Indicators for assessing impacts to each mauri dimension were selected using an iterative process of working with community groups to compile a set of working and living indicators for each dimension of mauri, and then refined and applied within the model by the researchers, with developments in the indicator sets and overall analysis being presented back to the communities for feedback. For each dimension, indicators were assessed using a simple scoring rubric, as shown in Figure 10. The scores for each dimension were then averaged, yielding a single impact score for each dimension of mauri.

Figure 10. Mauri meter for indicator assessment (from Faaui, Morgan, and Hikuroa 2017).



4.3.7 Key sources reviewed

Bennett, Piatarihi C. 2015. An Assessment of Mauri: The Grounding of MV Rena on Otaiiti and the Oil Spil and Debris Pollution Impacts upon Mauri (Ko Te Mauri Be Mea Buna Ki Te Moana). Maketu, New Zealand: Prepared for and on behalf of Te Arawa ki Tai, Ngati Makino Heritage Trust & nga Iwi whanui o Te Arawa waka. Mauri Tau Solutions Report 04-415.

Faaui, Tumanako Ngawhika, Te Kipa Kepa Brian Morgan, and Daniel Carl Henare Hikuroa. 2017. “Ensuring Objectivity by Applying the Mauri Model to Assess the Post-Disaster Affected Environments of the 2011 MV Rena Disaster in the Bay of Plenty, New Zealand.” *Ecological Indicators* 79 (March). 228–46.

Ministry for the Environment. 2011. *Rena Long-Term Environmental Recovery Plan*. Wellington, New Zealand: New Zealand Government.

Morgan, Te Kipa Kepa Brian, Daniel N. Sardelic, and Amaria F. Waretini. 2012. “The Three Gorges Project: How Sustainable?” *Journal of Hydrology* 460–461 (April). 1–12.

Morgan, Te Kipa Kepa Brian, Te Arawa, Ngati Pikiao, Ngati Kahungunu, and Kai Tahu. 2004. “A Tangata Whenua Perspective on Sustainability Using the Mauri Model Towards Decision Making Balance with Regard to Our Social, Economic, Environmental, and Cultural Well-

Being." In *Papers Presented at the International Conference on Sustainability Engineering and Science*, July 7-9, 2004, 14. Aukland, New Zealand.

Wambrauw, Elisabeth Veronika, and Te Kipa Kepa Brian Morgan. 2016. "Transferring The Mauri Model Of Decision Making Framework From New Zealand To Merauke Regency In Southern Papua." *KnE Social Sciences* 1 (1): 146–53.

4.4 Manitoba Hydro Regional Cumulative Effects Assessment (Canada)

4.4.1 Background and organization

In 2011, Manitoba Hydro filed an environmental impact statement with the Manitoba Clean Environment Commission (MCEC) for the construction and operation of the Bipole III high-voltage direct current transmission project. The study concluded that there would be no significant adverse cumulative effects caused by the project, and any residual cumulative effects following impact mitigation would be negligible.

The MCEC did not accept the conclusions of Manitoba Hydro's study, stating in its panel report: "it is simply inconceivable— given the 50-plus-year history of Manitoba Hydro development in northern Manitoba and given that at least 35 Manitoba Hydro projects have been constructed in the north in that time—that there are few, if any, cumulative effects identified in this EIS" (Noble 2017).

The MCEC recommended that Manitoba Hydro, in collaboration with the province of Manitoba, conduct a regional assessment of the history of hydroelectric development in the region, in order to better plan for future projects.

4.4.2 System details

The Manitoba Hydro regional cumulative effects assessment is ostensibly activity-based, but it is interesting to note that the authors do not isolate the impacts of other human activities from those caused by hydro developments; the resulting study is thus arguably place-based. The study most aligns with a project-level assessment due to its retrospective nature (as discussed later in this section), though the future goal seems to be for the MCEC to use the data from the study as part of some sort of ongoing strategic monitoring and management program.

Pathways of effects diagrams were primarily used to establish links between activities and effects to valued components. Manitoba Hydro reports that modeling software (the Nature

Conservancy's Indicators of Hydrologic Alterations package) was trialed to see if a no-development scenario could be created to compare with current baseline data; however, the model was found to be inappropriate for technical reasons, including deficits in its treatment of ice and wind effects.

As mentioned, the study is retrospective in nature; future development is not included in the analysis, which focuses on the impact of hydro projects up until present-day. The authors include qualitative discussions of historical records for some valued components (e.g., beluga whales in the Nelson River, Hudson's Bay Company records from 1725); however, in the absence of quantitative data during these periods, they conclude comparison is not possible. Other than noting the way the lack of "pre-development scientific data" for many valued components limited their analysis, the authors do not explain how the qualitative information about pre-development conditions were factored into their conclusions, but generally focus on the period from immediately before the first hydro project was built until the present. Spatial boundaries were defined by what the authors considered ecologically meaningful for individual valued components (e.g., population ranges for wildlife species).

Valued components were selected based on professional expertise and desk-based review of traditional knowledge reports in the public domain. The indicators selected were effects-based in nature.

A useful takeaway from the Manitoba Hydro regional cumulative effects assessment is that a regional program initiated in response to widespread community and public concerns should take care to involve those stakeholders early and transparently throughout the process. While the regional cumulative effects assessment was originally conceived as a two-phase endeavour, it is currently entering its third phase. The reasons for this are not spelled out plainly, but may be inferred from the sequence of events. The study was initiated as a government response to community outcry:

> …some communities expressed concerns regarding effects they have experienced, and continue to experience, as a result of existing [Manitoba Hydro] projects. The [MCEC] noted that "…it became apparent that past hydro-electric developments in northern Manitoba have had a profound impact on communities in the area of these projects, as well as on the environment upstream and downstream." (Manitoba Conservation and Water Stewardship and Manitoba Hydro 2014, 1)

Community concern was the catalyst for the regional cumulative effects assessment, but the first two phases of the study seem to have had little input from communities. The final report documented cumulative effects to land, water, and people explicitly “from a technical perspective” (Minister of Sustainable Development 2017). Incorporation of traditional knowledge into the regional cumulative effects assessment was limited to studies already in the public domain (Government of Manitoba and Manitoba Hydro 2015, 1.3-10). The Nisichawayasihk Cree Nation (2016, 7)—one of eight First Nations in the RCEA’s region of interest—wrote about the lack of inclusion of traditional knowledge in the study, and that First Nation involvement was “simply dismissed by Manitoba and Hydro.” The summaries of impacts to individual communities that were to be included in the Phase II report were ultimately withheld, as communities had not yet had an opportunity to review and comment on them (Government of Manitoba and Manitoba Hydro 2015, 3.5-9). In an amendment to the original Terms of Reference, the provincial Minister of Sustainable Development noted:

> There was considerable public interest in the regional cumulative effects assessment and limited opportunities for affected study area residents and communities to participate in the completion of either of the phases of the assessment. Therefore, a public outreach program should be implemented to supplement the findings of the second phase report. (Minister of Sustainable Development 2017, 1)

4.4.3 Key sources reviewed

Government of Manitoba, and Manitoba Hydro. 2015. Regional Cumulative Effects Assessment for Hydroelectric Developments on the Churchill, Burntwood, and Nelson River Systems: Phase II Report. Winnipeg, Manitoba.

Manitoba Conservation and Water Stewardship, and Manitoba Hydro. 2014. Terms of Reference: Joint Approach to Undertaking a Regional Cumulative Effects Assessment for Hydro Developments as per Recommendation 13.2 of the Clean Environment Commission (CEC) Bipole II Report. Winnipeg, Manitoba: Manitoba Hydro.

Minister of Sustainable Development. 2017. Terms of Reference: Clean Environment Commission Regional Cumulative Effects Assessment of the Nelson, Burtwood and Churchill Rivers System (the Project). Winnipeg, Manitoba: Province of Manitoba.

4.5 Canada-Nova Scotia Offshore Petroleum Board SEAs (Canada)

4.5.1 Background and organization

Offshore oil and natural gas exploration and development activities in Canada's Atlantic region are regulated by two federal-provincial bodies: the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) and the Canada-Newfoundland and Labrador Offshore Petroleum Board. These boards are responsible for managing significant environmental risks associated with offshore oil and gas activities.

Since 2003, these boards have conducted numerous strategic environmental assessments, which provide information on the regional environmental setting and associated environmental considerations. This information is then used to inform subsequent regulatory decisions regarding future offshore oil and gas activities in the area in question. In particular, the information and findings of these studies help inform the boards' associated planning and decision-making processes regarding the potential issuance of licenses in the areas they manage (Amec Foster Wheeler 2016).

The CNSOPB system was reviewed for the purposes of this report: in particular, the strategic environmental assessment conducted for Sydney Basin and Orpheus Graben.

4.5.2 System details

The CNSOPB conducts activity-based strategic environmental assessments, which, despite their name, for the most part appear to borrow methods from EIA (i.e., project-level assessments), extended over a larger area. While it is unclear which tools and models are used to map effect pathways, the report reviewed stated that this was done "based on existing knowledge and literature," suggesting that professional judgement was employed.

No evidence of consideration of the pre-development conditions of valued components was discovered in the report reviewed. The temporal boundaries extend 10 years into the future; the established process is for the CNSOPB to review the findings of the strategic environmental assessment after five years and judge whether an update is warranted at that time. Spatial boundaries include the specific areas of Sydney Basin and Orpheus Graben, but also the overall areas within which the valued components that could potentially be affected by activities (including accidental events) are located.

Valued components were selected based on scientific judgement and the specifications of the CNSOPB. Public consultation in the form of opportunities to submit comments via the CNOPB website was also factored into the valued component selection process. The methods used to select indicators were not specified in the report reviewed, and the concept appeared to be conflated with that of valued components.

4.5.3 Key sources reviewed

Amec Foster Wheeler. 2016. *Strategic Environmental Assessment: Sydney Basin and Orpheus Graben, Offshore Cape Breton, Nova Scotia*. Dartmouth, Nova Scotia: Submitted to the Canada-Nova Scotia Offshore Petroleum Board by Amec Foster Wheeler.

4.6 Metlakatla Cumulative Effects Management Program (British Columbia, Canada)

4.6.1 Background and organization

In 2014, in response to a boom in development proposals—in particular for liquefied natural gas projects—the Metlakatla First Nation initiated a cumulative effects management project for their traditional territory (Metlakatla First Nation 2015; Kwon 2010) designed to inform decision-making both at the project level and at a territory-wide scale.

The Metlakatla First Nation governance system includes the Metlakatla Stewardship Society and its sub-agency, the Metlakatla Stewardship Office; these two bodies are the primary authorities responsible for natural resource decision-making in Metlakatla's traditional territory.

The Metlakatla case study was primarily chosen for inclusion in the review for its extensive documentation on the processing of selecting of valued components, as discussed in the following section.

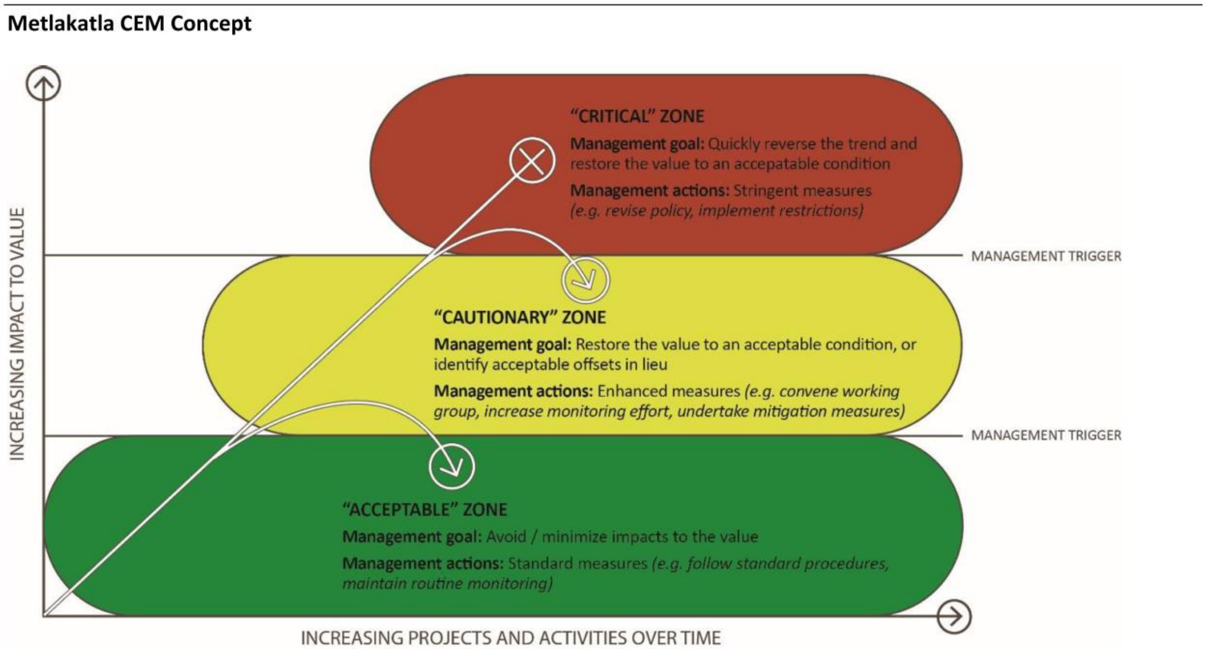
4.6.2 System details

The Metlakatla approach to cumulative effects management consists of ten steps (Metlakatla First Nation 2015):

1. Clarifying the decision context (how the results will be used);
2. Creating preliminary list of valued components;
3. Examining current and future activity scenarios;

4. Clarifying linkages between activities and effects to valued components using pathway diagrams;
5. Selecting indicators for priority valued components;
6. Identifying interim management triggers for each indicator;
7. Assessing the condition and trend of each indicator; re-assessing whether the valued component should still be priority;
8. Determining final management triggers as part of a tiered system, with associated management goals and actions Figure 11;
9. Implementing monitoring program; and
10. Re-assessing list of valued components (i.e., return to first step).

Figure 11. Tiered management trigger system (from Metlakatla First Nation 2015).



A major component of the Metlakatla cumulative effects management program's development thus far has been the selection of environmental, socio-economic, cultural and governance valued components and associated indicators. Kwon (2010), who assisted with the program's design, writes about the environmental valued component selection process in detail, which consisted of five development stages.

First, through a comprehensive issues scoping exercise, Kwon created an extensive inventory of environmental valued components, reviewing all relevant and available documents to identify issues, concerns, and values. Kwon used the Marine Plan Partner Initiative's categories for organizing valued components (North Coast-Skeena First Nations Stewardship Society and Province of British Columbia 2015), and a master list of valued components developed by the British Columbia Environmental Assessment office (this document was searched for but could not be located for the purposes of this review). To reduce the number of valued components, Metlakatla managers elected to focus on the key species in the marine environment, narrowing the list from 628 to 85.

Second, selection criteria for environmental valued components and indicators were developed and used to create an initial candidate valued component list. Kwon used the BC EAO's criteria as a starting point, and modified the criteria to address deficiencies identified in both academic literature and Metlakatla knowledge and local values, to produce a list of 14 environmental valued components. These were:

- Sockeye Salmon (*Oncorhynchus nerka*);
- Eelgrass (*Zostera spp*.) – as habitat for valued species like salmon and Dungeness Crab (*Metacarcinus magister*);
- Red Laver Seaweed (*Porphyra spp*.);
- Eulachon (*Thaleichthys pacificus*);
- Northern Abalone (*Haliotis kamtschatkana*);
- Pacific Harbour Porpoise (Phocoena phocoena);
- Chinook Salmon (*Oncorhynchus tshawytscha*);
- Pacific Halibut (*Hippoglossus stenolepis*);
- Butter Clam (*Saxidomus gigantea*);
- Red Sea Urchin (*Mesocentrotus franciscanus*);
- Rhinoceros Auklet (*Cerorhinca monocerata*);
- marine biodiversity;
- clean water; and
- primary production.

Third, Kwon interviewed content experts, held working sessions with research collaborators, and took part in a workshop with Metlakatla managers where the suitability of both the valued components and the proposed indicators were discussed and refined, producing a final candidate list of four environmental valued components: Chinook Salmon, Dungeness Crab, Eulachon, and Butter Clam.

Fourth, to address the Metlakatla managers' concern that resource constraints would prevent them from tracking and monitoring the full candidate list, the Metlakatla First Nation decided that a subset of priority valued components would be tracked and monitored first to allow them to gain confidence, knowledge and experience in the process. A prioritization exercise was conducted to identify two priority valued components (Chinook Salmon and Butter Clam), and a pilot project was undertaken for the first of these valued components (Butter Clam). These were added to eight other socio-economic, cultural and governance valued components (it is not clear from the sources reviewed if these were derived through a similar process to the one utilized to select environmental valued components and indicators). The final list of ten priority valued components are presented in Table 7:

Table 7. Ten priority valued components and indicators in Metlakatla Cumulative Effects Management Program (modified from Metlakatla First Nation 2015).

Valued component	Indicator
Adequate housing	Percent of tenants in core housing
Access to health services	Ambulatory care sensitive conditions per 10,000 in Prince Rupert
Individual health	Diabetes prevalence (percent of population with diabetes)
	Hypertension prevalence (percent of population with heart disease)
Wealth distribution	Income equality (ratio of low-income to middle-income households)
Economic self-sufficiency	High school completion rate (ratio of graduates to total Metlakatla cohort)
Personal safety	Crime severity index (crimes weighted by seriousness)
Ability to steward Metlakatla lands	Stewardship evaluated on constructed scale (not described in sources reviewed)
Food, social, and ceremonial activity	Food, social, and ceremonial participation (youth and household participation, effort in person-days/year)
Chinook Salmon	Spawner abundance (number of adults returning to spawn in each Metlakatla conservation unit)
	Critical juvenile habitat (areal extent of eelgrass beds in hectares)
Butter Clam	Population density (number of individuals per square metre on beaches)

Note: Shaded rows indicate valued components selected as part of the pilot project.

Lastly, a broader implementation plan was developed to incorporate other final candidate valued components in the future.

Most of the above work was completed as part of Phase 1 of the cumulative effects management program. In Phase 2 (implemented between May 2015 and February 2016), a working group was convened to develop a butter clam monitoring framework, a Metlakatla census was administered to collect socio-economic data, and work plans were developed for the pilot project. Phase 3 of the program, which is still ongoing, includes establishing management benchmarks for pilot values, pilot value monitoring, and continuing administration of the Metlakatla census. While the objective of the cumulative management program is to inform Metlakatla decision-making processes related to resource development proposals, it is unclear whether the program has yet reached the stage where it can be used for this purpose.

4.6.3 Key sources reviewed

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5. Recommendations

This chapter presents the author's recommendations for Transport Canada's development of a regional cumulative effects management framework for marine shipping. This recommended approach is based on the foregoing review of existing literature, conceptual frameworks, and applications in Canada and elsewhere. Section 5.1 provides some broad lessons derived from the review, while Section 5.2 presents a series of conceptual steps to guide framework development, beginning with a proposed governance structure.

5.1 Key principles

Two broad but valuable principles for developing a cumulative effects management framework became apparent during the course of this review. The first is recognition of the necessity of an iterative and transparent approach to framework development: one that allows for improvements over time as knowledge grows and new opportunities arise. Open acknowledgement of the framework's constraints and limitations, especially in its initial stages, will be essential to managing stakeholder expectations. While the steps described later in this chapter do include the participation of representatives of local communities and other parties as part of a working group, they notably do not detail opportunities for communities and the broader public to participate in framework development. This should not be taken to mean that these opportunities are not part of the framework; rather, it is suggested that the frequency and form of participation must be highly context-specific, and thus should be shaped by the parties involved.

The second principle relates to the importance of navigating trade-offs. One of the daunting characteristics of studying cumulative effects is the breadth of scope involved: if we try to consider too many factors in any analysis, we may render our task impossible. A narrower scope simplifies the exercise considerably, in addition to making the administration of such a framework more feasible from an institutional and organizational standpoint. However, it is important to remember the reason we study cumulative effects is precisely because effects to human and ecological systems do not stay neatly within the narrow bounds of a project footprint, for example, or of a scientific discipline. By constricting a cumulative effects framework's scope, we may omit factors that have important bearings on the effects we wish to manage. The key in most cases is finding the right balance between different options. All systems reviewed, particularly the Norwegian, Australian, and Metlakatla systems discussed in Sections 4.1, 4.2, and 4.7, respectively, showcase decision-makers attempting to make thoughtful and informed choices about where to invest significant resources (e.g., applying complex modeling techniques or wholly novel methods) and where to be more circumspect (e.g., leveraging existing monitoring programs, re-purposing indicator lists).

5.2 Suggested steps for framework development

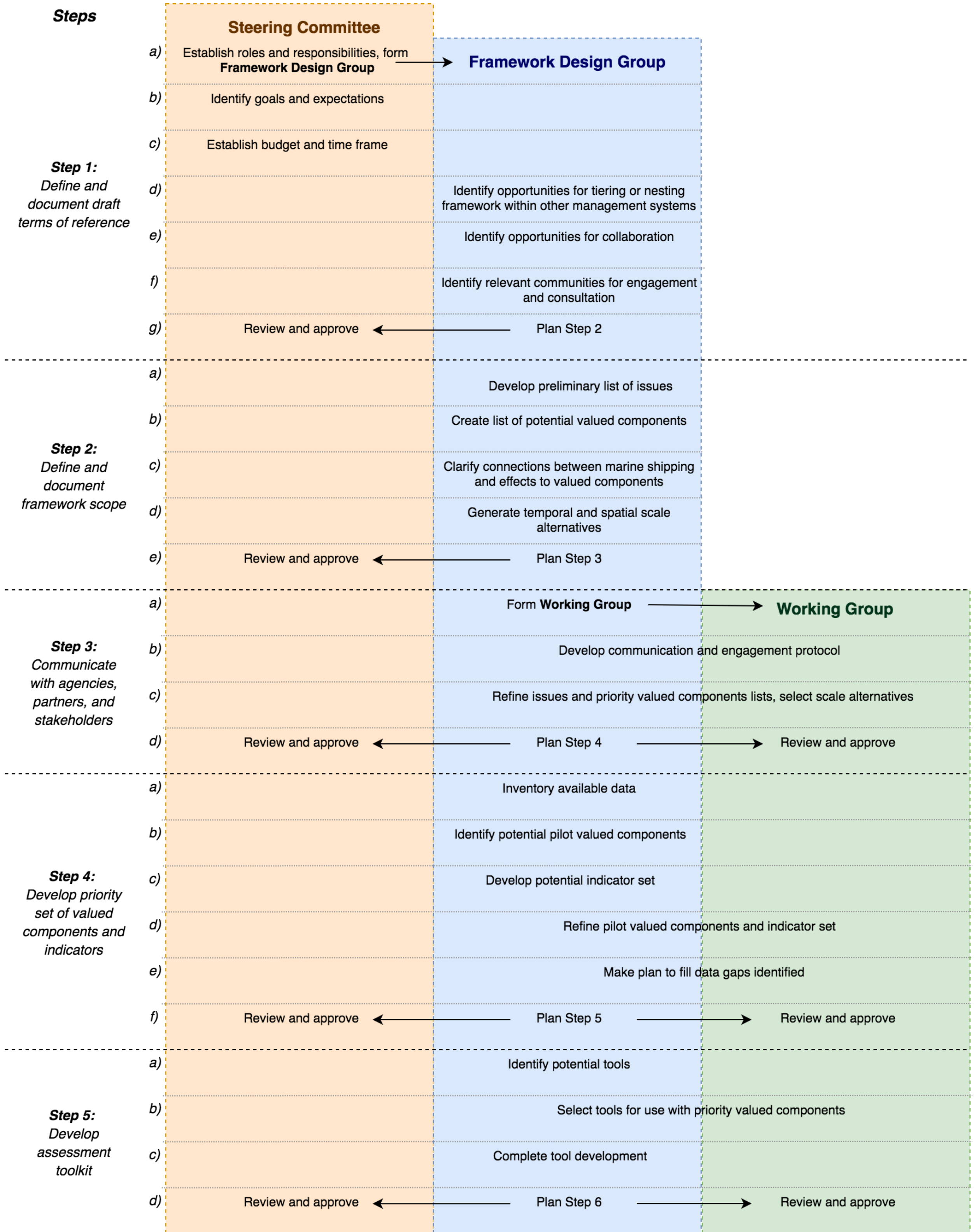
The remainder of this chapter presents a proposed sequence of procedural steps for developing Transport Canada's cumulative effects management framework. These steps are summarized in Figures 13 and 14 and enumerated in more detail in the body of the text.

Framework tasks are allocated to three groups within a proposed governance structure: the *Steering Committee* (providing federal government oversight and overarching departmental control), the *Framework Design Group* (responsible for preliminary planning and reporting tasks), and the *Working Group* (with membership from a broad variety of agencies, interest groups, and other stakeholders). The majority of tasks are performed by the Framework Design Group, working alone or in collaboration with the Working Group. Figure 12 and 13 delineate these group's separate and shared responsibilities at each step.

This proposed governance structure is partly inspired by the Norwegian and Australian case studies reviewed in this report (see Sections 4.1 and 4.2). Though not identical, both of these frameworks consist of four groups with the following general functions:

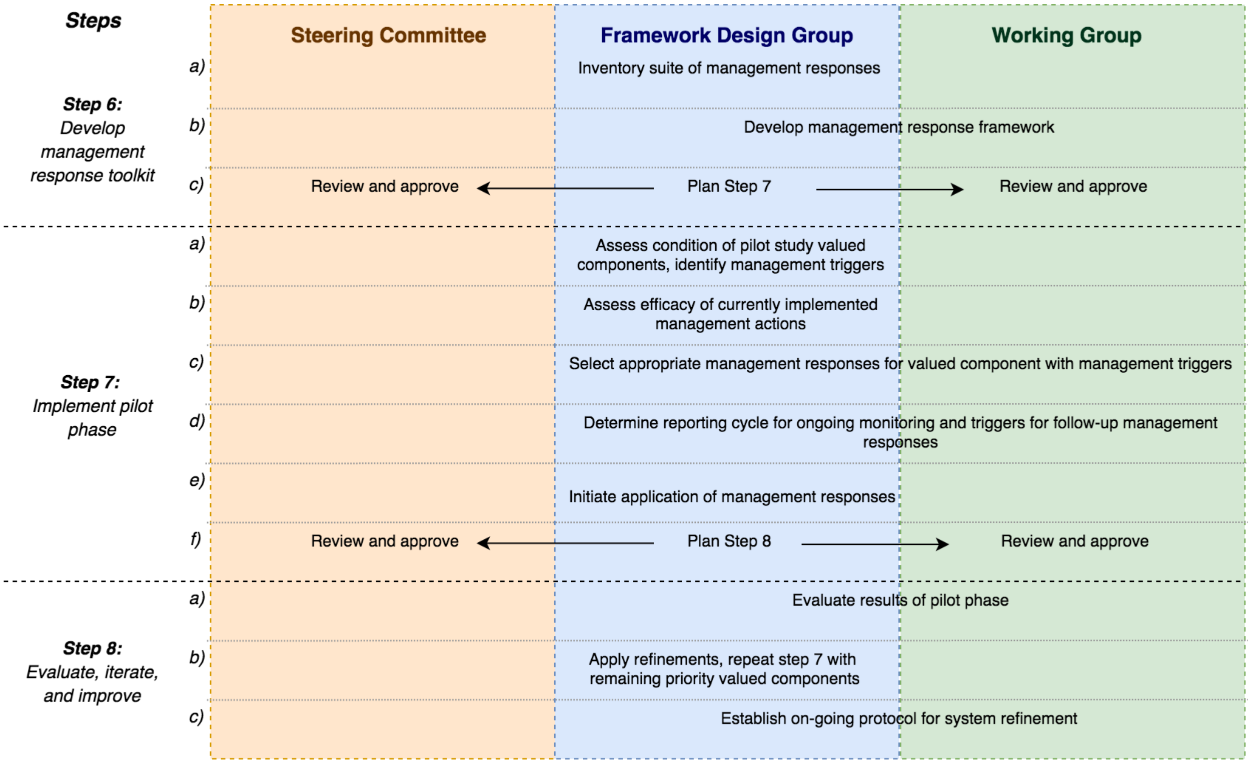
- **a high-level management and administrative oversight group**, corresponding to the Steering Committee in the proposed approach, the Steering Group in the Norwegian system, and the Great Barrier Reef Ministerial Forum in the Australian system;
- **a research and planning group**, corresponding to the Framework Design Group in the proposed approach, the Management Forum in Norway, and the Intergovernmental Operational Committee in Australia;
- **a group of technical experts**, corresponding to the Working Group in the proposed approach, the Monitoring Advisory Group in the Norwegian framework, and the Independent Expert Panel in the Australian framework; and
- **a collaborative group** including broad representation from agencies, communities, and special interest groups, also corresponding to the Working Group in the proposed approach (see the following paragraph), the Working Group and Environmental Risk Management Forum in Norway, and the Reef Advisory Committee in Australia.

Figure 12. Recommended steps for framework development.



(continued in Figure 13*)*

Figure 13. Recommended steps for framework development (completed).



In Norway, members of the third group—the technical experts—are also involved in one of the two collaborative groups: the Environmental Risk Management Forum. In order to maximize opportunities for collaboration and promote greater transparency, it is suggested that the work these last two groups be largely combined into one unit (the Working Group) within Transport Canada's framework, with technical work that cannot feasibly be performed as collaborative exercises being initiated by the Framework Design Group and then reviewed and refined in conjunction with the Working Group.

In the Norwegian and Australian case studies, the groups analogous to the Steering Committee and Framework Design Group (i.e., responsible for administrative oversight and initial research and planning) are intra-governmental units. In the approach recommended in this chapter, the Steering Committee is envisioned as having federal government membership, though it should be noted that from Step 3 onwards, completion of each task is also reviewed and approved by the Working Group. It is further suggested that—to increase the likelihood for meaningful participation—opportunities be provided for representatives of Indigenous groups to be part of the Framework Design Group.

Step 1. Define and formally document the draft terms of reference for the framework:

- Establish the roles and responsibilities for developing the framework: a Framework Design Group overseen by a Steering Committee.
- Identify goals and expectations for the framework, including specific problems to be addressed and questions to be answered. This is a key step before starting the process and must be clearly defined at the outset.
- Establish the budget and time frame to design and implement the framework.
- Identify opportunities for tiering or nesting the framework within or above other levels of management (such as project-level EIA).
- Identify opportunities for inter-agency or external collaboration, and the parties or partnerships that may be involved.
- Identify the relevant communities and other parties likely to be involved in engagement and consultation (these may be the same parties identified in 1(d).
- Identify the current suite of potential management instruments to be guided by the framework: those under the sole purview of Transport Canada and those that could be applied in conjunction with the parties identified in 1(d) and (e) or as part of processes identified in 1(c).
- Prepare and distribute a detailed outline of the next step of the framework development process.

Step 2. Define and formally document the scope of the framework:

- Develop a preliminary list of key regional issues and concerns.
- Create a list of potential valued components and their approximate locations, if applicable.
- Use a Pathway of Effects diagram or other tool/model to clarify links between marine shipping activities and effects to valued components;
- Generate alternatives for temporal and spatial scales and identify the implications of these different scale choices.
- Prepare and distribute a detailed outline of the next step of the framework development process.

Step 3. Communicate with agencies, partners, and stakeholders:

- Verify the interest of parties identified in 1(d) and (e), and form the Working Group. It will be helpful to transparently communicate the time and budget constraints determined in 1(c) at this early stage, so that Working Group participants can make informed decisions regarding trade-offs throughout subsequent steps of the framework development process.

- Collaboratively develop a communication and engagement protocol for next steps in the process.
- Workshop and refine the findings of Step 2: key issues, priority valued components list, and scale selection.
- Prepare and distribute a detailed outline of the next step of the framework development process.

Step 4. Develop priority set of valued components and indicators:

- Conduct a thorough inventory of the data available in governmental and external repositories (including reviewed literature) relating to key issues, activities (past, present, and future) and indicators for valued components, documenting the data's temporal scope (and whether monitoring is ongoing) and spatial resolution. Consider paleontological, archaeological, and historical records, and oral histories, as well as scientific sources.[3] Note any gaps that exist.
- Based on the data currently available at the temporal and spatial scales selected, identify a number of candidate valued components for pilot study.
- Develop a set of indicators for the pilot study valued components. Consider using a mix of effects-based and stressor-based indicators.
- In conjunction with the Working Group, further refine pilot valued components list and indicator set.
- Develop plan for filling in data gaps identified in 4(a) for remaining priority valued components and indicators (e.g., via additional monitoring or research programs).
- Prepare and distribute a detailed outline of the next step of the framework development process.

[3] On the topic of data scarcity: while cumulative effects studies are notoriously data-hungry, it is also key to mention that—unlike the case of project-level assessments—the iterative nature of regional strategic studies can allow for work to begin with incomplete data. As Therivel (2004) points out, a study's initial stages "can be seen as a way of identifying what needs to be monitored in the future." As objectives and indicators are identified as relevant, future monitoring can be undertaken to address data gaps.

Step 5. Develop assessment toolkit:

- Identify a suite of potential tools for use in the ongoing evaluation of cumulative effects to the priority valued components, based on budgetary and time restraints established in 1(c) the data inventoried in 4(a), and the future data available as the result of plans in 4(d).
- In collaboration with the Working Group, select appropriate tools for use with the priority valued components.
- Complete tool development (e.g., develop Ecopath with Ecosim model).
- Prepare and distribute detailed outline of the next step of the framework development process.

Step 6. Develop management response toolkit (can be done in parallel with Steps 4 and 5):

- Using the suite of internal and external management responses identified in 1(g), evaluate potential management responses to address cumulative effects, including a candid assessment of their potential efficacy and the degree of difficulty associated with each response.
- In collaboration with the Working Group, develop and document a tiered framework for management responses, including management goals, triggers, actions, and potential barriers; establish external agreements and protocols, if necessary. Consider strategies from Xiamen, Mauri, and Metlakatla frameworks for developing goals and trigger systems.
- Prepare and distribute a detailed outline of the next step of the framework development process.

Step 7. Implement pilot phase of cumulative effects management system:

- Assess the condition of pilot study valued components (both historical and forward-looking trends) and identify any with management triggers.
- Assess the efficacy of any currently implemented management actions to address cumulative effects to the pilot study valued components.
- Communicate the results of the assessments to Working Group and collaboratively select the appropriate management responses to valued components with management triggers.
- With the Working Group, determine the reporting cycle for ongoing monitoring of pilot valued components and the potential triggers for follow-up actions.
- Apply the selected management responses.

- Prepare and distribute a detailed outline of the next step of the framework development process.

Step 8. Evaluate, iterate, and improve:

- In conjunction with Working Group, evaluate initial results of pilot phase (evidence of longer term success will not be instantly apparent); identify elements that require refinement.
- Apply these refinements to the implementation of the full cumulative effects management system: repeat Step 7 with the remaining priority valued components.
- Establish an ongoing protocol for system refinements based on lessons learned from within the framework (e.g., monitoring results, Working Group findings) or from outside the framework (e.g., knowledge gained by frameworks implemented in other regions).

5.3 Limitations

The recommendations contained in this chapter are the author's, and neither necessarily reflect the views of Transport Canada, nor represent a commitment by Transport Canada to adopt the precise approach proposed herein. Transport Canada may elect to change or adapt these recommendations as appropriate in developing its cumulative effects management framework.

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Appendix A: Bibliography of key sources

The following section provides short capsule summaries of the key sources reviewed for this report, arranged by major theme (or at least, by the contribution the author of this report judged to be most valuable to Transport Canada's project). A complete alphabetical listing of all the reviewed literature can be found in the preceding References section. This section does not include sources related to the individual case studies discussed in Chapter 4; those sources can be found under the final subheading (i.e., *Key sources reviewed*) in each case study section.

A.1 General concepts

Atlin, Cole, and Robert Gibson. 2017. "Lasting Regional Gains from Non-Renewable Resource Extraction: The Role of Sustainability-Based Cumulative Effects Assessment and Regional Planning for Mining Development in Canada." *Extractive Industries and Society* 4 (1). Elsevier Ltd.: 36–52.

Atlin and Gibson (2017) review the current status of assessment regimes, identifying deficiencies and opportunities for best practice. The implications are summarized as recommendations for assessment regime design that addresses cumulative effects, largely through regional processes linked to project-level assessments, and that incorporate the following five characteristics: (1) Multi-dimensional: covers the full suite of cumulative effects of multiple undertakings, past, present and reasonably foreseeable in the relevant regional future (well beyond the individual project level), in light of contribution to sustainability objectives; (2) Long term: uses scenarios or some equivalent to explore and illuminate the nature and potential implications of plausible and desirable futures, to identify alternative pathways and plan options to examine; (3) Credible: establishes explicit open processes for elaborating and evaluating regional alternatives and justifying decisions in light of context-specified sustainability-based criteria and trade-off rules; (4) Authoritative: integrates regional assessment conclusions as decisions in legislatively authoritative regional plans or the equivalent with provisions for ensuring compliance in project level planning and assessment; and (5) Accountable: ensures clear and accountable assignment of cumulative effects management responsibilities and expectations, including provisions for engaged monitoring, effective responses and public reporting.

Atkinson, Samuel F., and Larry W. Canter. 2011. "Assessing the Cumulative Effects of Projects Using Geographic Information Systems." *Environmental Impact Assessment Review* 31 (5). Elsevier Inc.: 457–64.

Atkinson and Canter examine how geographic information systems have been used in typical environmental assessment and its use for cumulative impact assessment. The authors explore litigation that occurred in the United States Federal court system where geographic information systems were used in some aspect of cumulative effects. The paper also summarizes fifteen case studies that range from area wide transportation planning to wildlife and habitat impacts, and draws together a few lessons learned from this review of literature and litigation.

Bragagnolo, Chiara, and Davide Geneletti. 2012. "Addressing Cumulative Effects in Strategic Environmental Assessment of Spatial Planning." *AESTIMUM* 60: 39–52.

Bragagnolo and Geneletti (2012) discuss the analysis of cumulative effects in strategic environmental assessments, with reference to spatial planning by: providing a review of key concepts and methods related to cumulative effects literature; presenting a rationale for the inclusion of cumulative effects in strategic environmental assessment of spatial plans; advancing a proposal to address cumulative effects in different strategic environmental assessmentsstages. The paper concludes that strategic environmental assessment offers the opportunity to support a better management of cumulative effects arising from many local-level spatial planning decisions. Three aspects emerged as critical to ensure good practices: the selection of valued environmental components, the adoption of future-oriented approaches, and the use of spatially explicit information.

Bragagnolo, C., Geneletti, D. & Fischer, T.B., 2012. Cumulative effects in SEA of spatial plans – evidence from Italy and England. *Impact Assessment and Project Appraisal*, 30(2), pp.100–110.

This paper investigates whether and how cumulative effects are currently treated in strategic environmental assessments of Italian and English spatial plans. This is based on the results of (1) a questionnaire survey and (2) a systematic review of strategic environmental assessment reports of local and regional Italian and English spatial plans. It is found that, opposite to what even some experts think, while cumulative effects remain unsatisfactorily addressed, there is ample space for improving current practice. In this context, better scoping, future-oriented approaches to strategic environmental assessments and more effective tiering are identified as key elements that can enable more effective cumulative effects assessment.

Canter, Larry, and Barry Sadler. n.d. "Development of a Reference Document on Key Information Sources Related to Cumulative Effects of Multiple Activities on Fish Habitat and Fish Populations in Canada."

Canter and Sadler (n.d.) present an annotated list of key information sources related to cumulative effects assessment and management with particular reference to concepts, models, methodologies, and tools and their application to the science and management of aquatic ecosystems, fish habitat and fish populations.

Canter, L. W., B. Sadler, and R.G. Randall. 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, Ontario: Canadian Technical Report of Fisheries and Aquatic Sciences 2998.

Canter et al. **(2012)** provide an annotated list of key information sources related to cumulative effects assessment and management (CEAM) with particular reference to concepts, models, Methods and tools and their application to the science and management of aquatic ecosystems, fish habitat and fish populations. The rationale, background and main findings of the review are described.

Clarke Murray, Cathryn, Megan E. Mach, and Rebecca G. Martone. 2014. "Cumulative Effects in Marine Ecosystems: Scientific Perspectives on Its Challenges and Solutions." Vancouver, British Columbia.

Clarke Murray et al. (2014) discuss four components of cumulative effects science and application: (1) how cumulative effects manifest in ecosystems as a result of multiple human activities; (2) challenges in applying scientific knowledge in cumulative effects assessment, including defining spatial and temporal scales, baselines, reference points, indicators, and identifying significant changes in the face of uncertainty and natural environmental variability; (3) models and tools that have been developed to assess cumulative effects; and (4) priorities for science and management of cumulative effects.

Clarke Murray, C., Mach, M.E. & Martone, R.G., 2014. Cumulative Effects in Marine Ecosystems: Scientific Perspectives on its Challenges and Solutions, Vancouver, British Columbia.

In this review, the authors discuss four components of cumulative effects science and application: (1) how cumulative effects manifest in ecosystems as a result of multiple human activities; (2) challenges in applying scientific knowledge in cumulative effects assessment, including defining spatial and temporal scales, baselines, reference points, indicators, and identifying significant changes in the face of uncertainty and natural environmental variability; (3) models and tools that have been developed to assess cumulative effects; and (4) priorities for science and management of cumulative effects. Conservation of marine ecosystems and support for sustainable development requires using primary research, models, and tools in an integrated, adaptive ecosystem-based framework to address cumulative effects.

Clarke Murray, Cathryn, and Lucie Hannah. 2017. *Cumulative Effects Research and Applications within Fisheries and Oceans Canada (DFO): Draft for Transport Canada*. Victoria, British Columbia: Ecosystem Stressors Program, Oceans Sciences Division, Pacific Region, Fisheries and Oceans Canada.

In this draft DFO document, Clarke Murray and Hannah (Clarke Murray and Hannah 2017) summarise the work that has been done to date related to cumulative effect assessment within DFO.

Connelly, Robert (Bob). 2011. "Canadian and International EIA Frameworks as They Apply to Cumulative Effects." *Environmental Impact Assessment Review* 31 (5). Elsevier Inc.: 453–56.

Connelly (2011) presents a brief history of the development of cumulative effects, the current requirements in North America and elsewhere in the world, challenges at the project level, thoughts on how emerging concepts of strategic environmental assessment and regional assessment may offer means to improve the examination of cumulative effects.

Crain, Caitlin Mullan, Kristy Kroeker, and Benjamin S. Halpern. 2008. "Interactive and Cumulative Effects of Multiple Human Stressors in Marine Systems." *Ecology Letters* 11 (12): 1304–15.

Crain, Kroeker and Halpern synthesize 171 studies that manipulated two or more stressors in marine and coastal systems and find that cumulative effects in individual studies were additive (26%), synergistic (36%), and antagonistic (38%). The overall interaction effect across all studies was synergistic, but interaction type varied by response level (community: antagonistic, population: synergistic), trophic level (autotrophs: antagonistic, heterotrophs: synergistic), and specific stressor pair (seven pairs additive, three pairs each synergistic and antagonistic).

Addition of a third stressor changed interaction effects significantly in two-thirds of all cases and doubled the number of synergistic interactions.

Du, Jing, Yang Yang, Ling Xu, Shushen Zhang, and Fenglin Yang. 2012. "Research on the Alternatives in a Strategic Environmental Assessment Based on the Extension Theory." ***Environmental Monitoring and Assessment*** **184 (9): 5807–19.**

Du et al. present a new methodology based on the extension theory to identify a range of alternatives and screen the best one. Extension planning is applied to formulate a set of alternatives that satisfy the reasonable interests of the stakeholders. Extension priority evaluation is used to assess and optimize the alternatives and present a scientific methodology for the strategic environmental assessment alternative study. Thereafter, the urban traffic plan of Dalian City is used as an example to demonstrate the feasibility of the new method. The traffic planning scheme and the environmental protection scheme are organically combined based on the extension theory, and the reliability and practicality of this approach are examined.

Duinker, Peter N., Erin L. Burbidge, Samantha R. Boardley, and Lorne A. Greig. 2012. "Scientific Dimensions of Cumulative Effects Assessment: Toward Improvements in Guidance for Practice." ***Environmental Reviews*** **21 (October 2012). NRC Research Press: 40–52.**

This article provides an update on progress in scientific developments associated with cumulative effects assessment and also to guide practitioners to a broad selection of the recent relevant peer-reviewed formal literature on the topic. The authors point to ways in which guidance for cumulative effects assessment practice could be improved, and address such key topics as the definition of other activities to be assessed, establishment of time and space bounds, impact thresholds, methods for impact prediction, and stressor-based versus effect-based approaches. Several case examples of CEA in practice are summarized. Recommendations for improvements in guidance materials for practitioners address definitions, scenarios, analytical methods, collaborative methods, thresholds, knowledge accumulation, accidents and malfunctions, project scale, and knowledge integration.

Duinker, P.N. & Greig, L.A., 2006. The impotence of cumulative effects assessment in Canada: ailments and ideas for redeployment*. Environmental Management*, 37(2): 153–61.

This article examines six major problems with cumulative effects assessment, and proposes solutions. The six problem areas include (1) application of cumulative effects assessment in project-level environmental impact assessments, (2) an environmental impact assessment focus on project approval instead of environmental sustainability, (3) a general lack of understanding of ecologic impact thresholds, (4) separation of cumulative effects from project-specific impacts, (5) weak interpretations of cumulative effects by practitioners and analysts, and (6) inappropriate handling of potential future developments. The authors advocate improvements not only within the purview of project-specific environmental impact assessments, but also mainly in the domain of region-scale cumulative effects assessments and regional environmental effects frameworks (or perhaps land use planning).

Foley, Melissa M., Lindley A. Mease, Rebecca G. Martone, Erin E. Prahler, Tiffany H. Morrison, Cathryn Clarke Murray, and Deborah Wojcik. 2017. "The Challenges and Opportunities in Cumulative Effects Assessment." *Environmental Impact Assessment Review* 62. Elsevier B.V.: 122–34.

Foley et al. (2017) surveyed CEA practitioners in California, USA; British Columbia, Canada; Queensland, Australia; and New Zealand on how well their practices reflect current scientific recommendations. They found that practitioners used a broad and varied definition of impact for CEA, which led to differences in how baseline, scale, and significance were determined. They identified opportunities to improve environmental assessment: (1) developing guidance for standardizing the conditions and impacts used to determine baselines, (2) increased access to data and project details.

Gillingham, Michael P. Greg R. Halseth, Johnson, Chris J., and Margot W Parkes (eds). 2016. The Integration Imperative: Cumulative Environmental, Community and Health Effects of Multiple Natural Resource Developments. Switzerland: Springer.

Gillingham et al.'s (2016) book combines knowledge and career experience from its authors' varied backgrounds in community development, public health, and environmental processes and change to address a number of key challenges and potential solutions for addressing cumulative impacts. Early chapters explore the fundamental concepts underlying CEA and the range of approaches capable of addressing impacts. The book's eighth chapter may be of particular interest to Transport Canada, presenting a general framework for an integrative and regional approach to the assessment and management of cumulative impacts. In this chapter, the authors propose six principles and five elements that provide the structure for an integrative regional cumulative impacts framework that can be adapted to unique regional circumstances.

Gunn, Jill. 2009. "Integrating Strategic Environmental Assessment and Cumulative Effects Assessment In Canada." Ph.D. Thesis. Department of Geography and Planning, University of Saskatchewan.

and

Gunn, Jill Harriman, and Bram F. Noble. 2009. "Integrating Cumulative Effects in Regional Strategic Environmental Assessment Frameworks: Lessons From Practice." ***Journal of Environmental Assessment Policy and Management*** **11 (3): 267–90.**

and

Gunn, Jill, and Bram F. Noble. 2011. "Conceptual and Methodological Challenges to Integrating SEA and Cumulative Effects Assessment." ***Environmental Impact Assessment Review*** **31 (2): 154–60.**

Gunn's dissertation (2009) presents a typology of current approaches to regional cumulative effects assessment, reviewing lessons from recent attempts at regional-scale, strategically-focused environmental analysis in Canada that include an impact assessment component and explicit attention to cumulative environmental effects (this latter topic appears in a more polished form in J. H. Gunn and Noble 2009). The author presents a structured framework for regional strategic environmental assessment in Canada, and discusses conceptual and methodological challenges that accompany the integration of strategic environmental assessment and cumulative effects assessment (an abbreviated form of the latter was published as J. Gunn and Noble 2011). Section 4.5, which lays out steps to creating a regional framework, may be of particular interest to Transport Canada.

Harriman, Jill A.E., and Bram F. Noble. 2008. "Characterizing Project and Strategic Approaches To Regional Cumulative Effects Assessment in Canada." ***Journal of Environmental Assessment Policy and Management*** **10 (1): 25–50.**

In this paper, Harriman and Noble (2008) present a typology of regional approaches to CEA based on its multiple characteristics, functions, and expectations: two EIA-driven approaches (single- and multiple-project) and two SEA-driven approaches (single- and multiple-sector). The single-sector, SEA-driven example, which would be of most relevance to Transport Canada within the context of this review, is that of the Canada-Nova Scotia Offshore Petroleum Board. The authors argue that each approach to CEA has its own merits that make it suitable to address particular types of cumulative problems at different tiers of assessment, and each of which can be expected to deliver different types of assessment results. They conclude that failure to match expectations with appropriate frameworks/approaches has been responsible for many historical disappointments with CEA.

Hegmann, George, and G.A. Yarranton. 2011. "Alchemy to Reason: Effective Use of Cumulative Effects Assessment in Resource Management." ***Environmental Impact Assessment Review*** **31 (5). Elsevier B.V.: 484–90.**

Hegmann and Yarranton (2011) argue that the best and most appropriate use of CEA is not at the project level, but in defining and improving the planning and regulatory framework. They suggest that CEA should be used in a more general way to help define the long-term public interest, and to help construct a planning and regulatory framework that embodies that interest. CEA at the project level would then be unnecessary, so long as projects were consistent with the framework.

Noble, Bram F., and Kelechi Nwanekezie. 2017. "Conceptualizing Strategic Environmental Assessment: Principles, Approaches and Research Directions." ***Environmental Impact Assessment Review*** **62. Elsevier Inc.: 165–73.**

This paper revisits the principles of strategic environmental assessment: conceptualizing the process as multi-faceted and multi-dimensional. It is suggested that strategic environmental assessment can be conceptualized as series of approaches operating along a spectrum from less to more strategic – from impact assessment-based to strategy-based – with each approach differentiated by the specific objectives of application and the extent to which strategic principles are reflected in its design and implementation.

Sadler, Barry. 1996. *Environmental Assessment in a Changing World: Evaluating Practice to Improve*. Ottawa, Ontario: Minister of Supply and Services Canada.

Though 20 years old, Sadler's (1996) report—comprising the framework, findings, conclusions, and recommendations of the International Study of the Effectiveness of Environmental Assessment (led by the Canadian Environmental Assessment Agency and the International Association for Impact Assessment)—is still very instructive. Of particular interest is Chapter 6, reviewing the then-emerging use of SEA in several countries and international organizations, based on a review of ten major processes and 40 case studies. This chapter presents common institutional barriers encountered in these cases, as well as a set of guiding principles derived.

Sinclair, A. John, Meinhard Doelle, and Peter N. Duinker. 2017. "Looking Up, Down, and Sideways: Reconceiving Cumulative Effects Assessment as a Mindset." *Environmental Impact Assessment Review* 62. Elsevier B.V.: 183–94.

Sinclair, Doelle, and Duinker (2017) review CEA, SEA and REA literatures and argue that CEA should be reconceived as a mindset central to every tier of assessment, operating through a technical lens; a law and policy lens; and a participatory lens. The authors use an example from Canada's Bay of Fundy as a case study for how to establish the concept of the CEA mindset and move forward with implementation.

Spaling, Harry, and Barry Smit. 1993. "Cumulative Environmental Change: Conceptual Frameworks, Evaluation Approaches, and Institutional Perspectives." *Environmental Management* 17 (5): 587–600.

and

Smit, Barry, and Harry Spaling. 1994. "Methods for Cumulative Effects Assessment." *Environmental Impact Assessment Review*, no. 15: 81–106.

In the first of these two foundational articles, Spaling and Smit (1993) review conceptual frameworks of cumulative environmental change and describe analytical (i.e., scientific) and institutional (i.e., planning-oriented) approaches to CEA. The authors see these approaches not as competing paradigms but rather different interpretations of the scope of CEA. They compare institutional and legislative responses to CEA in Canada and the United States. In their second article, Smit and Spaling (1995) classify and evaluate methods for CEA using criteria derived from previously proposed conceptual frameworks of cumulative environmental change. Methods evaluated include analytical approaches (spatial analysis, network analysis, biogeographic analysis, interactive matrices, ecological modeling, and expert opinion) and planning approaches (multi-criteria evaluation, programming models, land suitability evaluation, and process guidelines). This article is a little antique—GIS approaches were still in their infancy when it was written—but is useful for providing an accessible nomenclature of CEA methods.

Vicente, G. & Partidário, M.R., 2006. SEA - Enhancing communication for better environmental decisions. Environmental Impact Assessment Review, 26(8), pp.696–706.

This paper explores the potential of strategic environmental assessment to enhance communication between different stakeholders, enabling discussion and agreement independently of different beliefs, convictions, social roles, values, accumulated experiences, individual needs, or any other factors, that express different world visions and determine the context within which decisions are taken. To face up to this challenge the authors suggest the establishment of communication strategies that enhance the role of SEA in the construction of social expectations and platforms of discussion, in the multiple negotiation processes that take place between stakeholders and decision-makers.

A.2 Temporal and spatial boundaries

Franks, Daniel, David Brereton, Chris Moran, Tapan Sarker, and Tamar Cohen. 2010. *Cumulative Impacts: A Good Practice Guide for the Australian Coal Mining Industry*. Brisbane, Australia: University of Queensland, Australian Coal Association Research Program.

In this guide, Franks et al. (2010) focus on the opportunities and challenges involved in proactively identifying and responding to cumulative impacts at the local and regional scale and provide examples of collaboration to assess manage, monitor and report cumulative impacts. This guidance is really aimed at good practices for proponents rather than sector-based approaches for environmental managers, but contains some useful practical strategies, drawn from working examples, to better manage cumulative impacts at project and regional scales.

Franks, Daniel M., David Brereton, and Chris J. Moran. 2013. "The Cumulative Dimensions of Impact in Resource Regions." *Resources Policy* 38 (4): 640–47.

Franks et al. (2013) discuss the cumulative impact issues that have manifested in resource regions (within the context of mining in Australia), critically appraise current conceptions of cumulative impacts, and detail management and policy responses to address the cumulative dimensions of impact. They conclude with some key insights drawn from the cumulative impact literature that have implications beyond the mining sector.

João, Elsa. 2002. "How Scale Affects Environmental Impact Assessment." ***Environmental Impact Assessment Review*** **22 (4): 289–310.**

and

João, Elsa. 2007. "A Research Agenda for Data and Scale Issues in Strategic Environmental Assessment (SEA)." ***Environmental Impact Assessment Review*** **27 (5): 479–91.**

In these two papers, João (2002; 2007) evaluates the influence of geographical scale on the outcomes of environmental impact assessment and strategic environmental assessments. The first paper presents results obtained by using spatial data with different scales for an environmental impact assessment for a proposed road bypass in Southeast England. Scale effects were measured separately for spatial extent and spatial detail, and were measured both quantitatively using GIS and qualitatively using the judgement of environmental impact assessment experts. The study found that changes in scale could affect the results of environmental impact assessments. The paper concludes with recommendations for future practice on how best to control the quality of environmental impact assessments in relation to scale choice. The second paper proposes a research agenda, and recommendations for future practice, on data and scale issues in strategic environmental assessment. João recommends more research on data issues, spatial and temporal scales (both in terms of detail and extent), tiering, data quality and links to decision-making, concluding that questions of data and scale are essential to identifying and understanding the issues that strategic environmental assessment addresses.

Karstens, S. A M, P. W G Bots, and Jill H. Slinger. 2007. "Spatial Boundary Choice and the Views of Different Actors." ***Environmental Impact Assessment Review*** **27 (5): 386–407.**

Karstens et al. (2007) present an assessment of the impacts of scale choice from varying points of view (i.e., those of political actors, commissioners, analysts and scientists) focusing on one type of scale choice: the spatial boundary of the study. An examination from a study of an estuary commissioned by the Flemish and Dutch governments is used to illustrate how actors vary both in the boundaries they choose and the assessment they make of the implications of that boundary choice. The authors argue that no perfect spatial scale choice appears to exist, and recommend ways to structure the problem of scale selection to facilitate rational deliberation.

Knowlton, N. & Jackson, J.B.C., 2008. Shifting baselines, local impacts, and global change on coral reefs. PLoS Biology, 6(2).

This paper traces both assumptions and prescriptions relating to shifting baseline syndrome through key works in the literature, and interrogates them via ecological and social science theory and research. The authors argue that an expanded discussion of shifting baseline syndrome is needed, one that engages a broader range of social scientists, ecologists, and resource users, and that explicitly recognizes the value judgments inherent in deciding both what past ecosystems looked like and whether or not and how we might reconstruct them.

Lerner, Jackie. n.d. "If You Build It, Will They Come? Using Historical Development Patterns to Improve Prediction and Mitigation of Cumulative Environmental Impacts." ***In preparation*****: University of British Columbia.**

This paper argues the need to better align our accounting of environmental consequences with our expectation of economic gains, particularly when it comes to consideration of "reasonably foreseeable" future projects in formal cumulative effects assessments. The argument presented is illustrated by a case study involving the recent successful permitting of a large Canadian infrastructure project: the Northwest Transmission Line.

Lotze, Heike K., and Boris Worm. 2009. "Historical Baselines for Large Marine Animals." ***Trends in Ecology and Evolution*** **24 (5): 254–62.**

Lotze and Worm (2009) review the diversity of approaches used and resulting patterns of historical changes in large marine mammals, birds, reptiles and fish. Across 256 reviewed records, they find that exploited populations declined 89% from historical abundance levels. In many cases, long-term fluctuations are related to climate variation, rapid declines to overexploitation and recent recoveries to conservation measures. These emerging historical patterns offer new insights into past ecosystems, and provide important context for contemporary ocean management.

McCold, Lance N., and James W. Saulsbury. 1996. "Including Past and Present Impacts in Cumulative Impact Assessments." ***Environmental Management*** **20 (5): 767–76.**

McCold and Saulsbury (1996) investigate how past and present impacts should be included in cumulative impact analyses. The definition of cumulative impacts implies that cumulative impact analyses should include the effects of all past and present actions on a particular resource. Including past and present impacts in cumulative impact assessments increases the likelihood of identifying significant impacts. NEPA requires agencies to give more consideration to alternatives and mitigation and to provide more opportunities for public involvement for actions that would have significant impacts than for actions that would not cause or contribute to significant impacts. For an action that would contribute to significant cumulative impacts, the additional cost and effort involved in increased consideration of alternatives and mitigation and in additional public involvement may be avoided if the action can be modified so that its contributions to significant cumulative impacts are eliminated.

Papworth, S.K., J. Rist, L. Coad, and E.J. Milner-Gulland. 2009. "Evidence for Shifting Baseline Syndrome in Conservation." ***Conservation Letters*** **2: 93–100.**

The authors outline two forms of shifting baseline syndrome: (1) generational amnesia, where knowledge extinction occurs because younger generations are not aware of past biological conditions and (2) personal amnesia, where knowledge extinction occurs as individuals forget their own experience. Two conditions are essential to the identification of shifting baseline syndrome: (1) biological change must be present in the system and (2) any perceived changes must be consistent with the biological data. If age or experience- related differences in perception are then found, generational amnesia may be occurring.

Renberg, Ingemar, Christian Bigler, Richard Bindler, Matilda Norberg, Johan Rydberg, and Ulf Segerström. 2009. "Environmental History: A Piece in the Puzzle for Establishing Plans for Environmental Management." ***Journal of Environmental Management*** **90 (8): 2794–2800.**

Renberg et al. present five case studies from Sweden concerning pollution, lake acidification, lake eutrophication, biodiversity, and landscape dynamics and conservation - topics of broad interests - and discuss benefits of including a longer time perspective in environmental management.

Salomon, Anne K., Nick M. Tanape, and Henry P. Huntington. 2007. "Serial Depletion of Marine Invertebrates Leads to the Decline of a Strongly Interacting Grazer." *Ecological Applications* 17 (6): 1752–70.

Salomon, Tanape, and Huntington investigated the relative roles of natural factors and shoreline harvest leading to recent declines of the black leather chiton (on the outer Kenai Peninsula, Alaska). This intertidal mollusk is a strongly interacting grazer and a culturally important subsistence fishery for Sugpiaq natives. The authors took multiple approaches to determine causes of decline. Field surveys examined the significant predictors of Katharina density and biomass across 11 sites varying in harvest pressure, and an integrated analysis of archaeological faunal remains, historical records, traditional ecological knowledge, and contemporary subsistence invertebrate landings examined changes in subsistence practices through time.

Therivel, Riki, and Bill Ross. 2007. "Cumulative Effects Assessment: Does Scale Matter?" *Environmental Impact Assessment Review* 27 (5): 365–85.

Therivel and Ross (2007) discuss how CEAs consider, and could consider, scale issues: spatial extent, level of detail, and temporal issues. Their paper is based analysis of Canadian project-level CEAs and UK strategic-level CEAs, and concludes that scale issues are poorly considered at both levels, with particular problems being unclear or non-existing cumulative effects scoping methodologies; poor consideration of past or likely future human activities beyond the plan or project in question; attempts to apportion 'blame' for cumulative effects; and, at the plan level, limited management of cumulative effects caused particularly by the absence of consent regimes. Scale issues are important in most of these problems.

A.3 Valued components

Ball, M.A., Noble, B.F. & Dubé, M.G., 2013. Valued ecosystem components for watershed cumulative effects: An analysis of environmental impact assessments in the South Saskatchewan River watershed, Canada. *Integrated Environmental Assessment and Management*, 9(3), pp.469–479. Available at: http://doi.wiley.com/10.1002/ieam.1333.

This study examines the use of aquatic ecosystem components and indicators in environmental impact assessment practice in the South Saskatchewan River watershed, Canada, to determine whether current practice at the project scale could be "scaled up" to support ecosystem component and indicator development. The hierarchy of assessment components and indicators used in a sample of 35 environmental impact assessments was examined and the factors affecting aquatic ecosystem component selection and indicator use were identified. Results showed that public environmental impact statements are not necessarily publically accessible, thus limiting opportunities for data and information sharing from the project to the watershed scale.

Hay, D.E., Waters, R.D. & Boxwell, T.A. eds., 1996. Proceedings, Marine Ecosystem Monitoring Network Workshop, Nanaimo, British Columbia: Department of Fisheries and Oceans, Science Branch, Pacific Region.

Developing indicators involves a number of systematic tasks, including scoping Issues, specifying ecosystem goals and objectives, selecting indicators, undertaking stakeholder consultations, conducting targeted research and monitoring, and ultimately making informed decisions. Only the challenge of selecting the indicators is addressed in this paper, which is an annotated version of an unpublished manuscript by D.J. Thomas, W. Duval and B. D. Smiley.

A.4 Selecting indicators

Atkins, J.P. et al., 2011. Management of the marine environment: Integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. *Marine Pollution Bulletin*, 62(2), pp.215–226. Available at: http://dx.doi.org/10.1016/j.marpolbul.2010.12.012.

The authors integrate the DPSIR framework with ecosystem services and societal benefits, and create a specific framework for supporting decision-making in the marine environment. Based on a linking of these three concepts, the paper presents a set of basic postulates for the management of the marine environment and emphasizes that these postulates should hold for marine management to be achieved. The authors illustrate these concepts using two case studies: the management of marine aggregates extraction in the United Kingdom and the management of marine biodiversity at Flamborough Head, United Kingdom.

Canter, L. W., and S. F. Atkinson. 2011. "Multiple Uses of Indicators and Indices in Cumulative Effects Assessment and Management." *Environmental Impact Assessment Review* 31 (5). Elsevier Inc.: 491–501.

Canter and Atkinson (2011) review several examples and case studies associated with indicators and/or indices, concluding that there are numerous examples of such tools which have been or could be used in both EIA and CEAM. Some key lessons are: (1) in conducting CEAM studies, it is useful to think from the mindset that "I am the VEC or indicator, and what is my historical and current condition and how have I, or will I, be affected by multiple past, present, and future actions?"; (2) due to the likely absence of detailed information on future actions, the described tools can still be used to "predict" future conditions by focusing on qualitative up-or-down changes in individual indicators or indices with their aggregated displays; and (3) numerous regional and site-specific tools are currently available, with one example being indices of biological integrity for specific watersheds and water bodies. Such tools, even though they may not have been developed for CEAM usage, can certainly benefit CEAM studies and practice. Finally, usage of selected and appropriate tools as described herein can aid in conducting science-based, systematic, and documentable CEAM studies.

Canter, L.W., and David Tomey. 2008. "A Matrix-Based CEA Process for Marine Fisheries Management." In *28th Annual Meeting of the International Association for Impact Assessment*, 1–35. Calgary, Alberta.

This paper details a matrix-based, two-component process for planning and conducting cumulative effects assessment studies to be incorporated into environmental impact statements and environmental assessments prepared for Marine Fishery Management Plans. The process incorporates the Council for Environmental Quality's 11-step cumulative effects assessment approach divided into two components – scoping and baseline, and impact analysis.

Niemeijer, David, and Rudolf S. de Groot. 2008. "A Conceptual Framework for Selecting Environmental Indicator Sets." *Ecological Indicators* 8 (1): 14–25.

Niemeijer and de Groot (2008a) propose a conceptual framework for environmental indicator selection that puts the indicator set at the heart of the selection process and not the individual indicators. To achieve this objective, the framework applies the concept of the causal network that focuses on the inter-relation of indicators. The concept of causal networks can facilitate the identification of the most relevant indicators for a specific domain, problem and location, leading to an indicator set that is at once transparent, efficient and powerful in its ability to assess the state of the environment.

Niemeijer, David, and Rudolf S. de Groot. 2008. "Framing Environmental Indicators: Moving from Causal Chains to Causal Networks." *Environment, Development and Sustainability* 10 (1): 89–106.

In this paper, the authors propose an enhanced DPSIR (eDPSIR) framework for environmental indicators that takes inter-relations of indicators into account by relying on the use of causal networks rather than causal chains. They show how the concept of causal networks can increase insight into the inter-relation of environmental issues and associated indicators, can facilitate the identification of key indicators for particular kinds of questions, and can provide a useful first step to the establishment of dose–response functions. The authors argue that working with causal networks can contribute to more appropriate environmental policies and better management decisions.

Reed, M.S., Fraser, E.D.G. & Dougill, A.J., 2006. An adaptive learning process for developing and applying sustainability indicators with local communities. Ecological Economics, 59(4), pp.406–418.

Abstract: Sustainability indicators based on local data provide a practical method to monitor progress towards sustainable development. However, since there are many conflicting frameworks proposed to develop indicators, it is unclear how best to collect these data. The purpose of this paper is to analyse the literature on developing and applying sustainability indicators at local scales to develop a methodological framework that summarises best practice. First, two ideological paradigms are outlined: one that is expert-led and top-down, and one that is community-based and bottom-up. Second, the paper assesses the methodological steps proposed in each paradigm to identify, select and measure indicators. Finally, the paper concludes by proposing a learning process that integrates best practice for stakeholder-led local sustainability assessments. By integrating approaches from different paradigms, the proposed process offers a holistic approach for measuring progress towards sustainable development. It emphasizes the importance of participatory approaches setting the context for sustainability assessment at local scales, but stresses the role of expert-led methods in indicator evaluation and dissemination. Research findings from around the world are used to show how the proposed process can be used to develop quantitative and qualitative indicators that are both scientifically rigorous and objective while remaining easy to collect and interpret for communities.

Sutherland, Glenn D., F. Louise Waterhouse, Jason Smith, Sari C. Saunders, Katherine Paige, and Joshua Malt. 2016. "Developing a Systematic Simulation-Based Approach for Selecting Indicators in Strategic Cumulative Effects Assessments with Multiple Environmental Valued Components." ***Ecological Indicators*** **61.**

For a 909,000 ha case study area involving 214 watersheds in coastal British Columbia, the authors defined a suite of twenty indicators linked to six valued components that could be forecasted for forest, riparian and species at risk as three key values consistent with present land-use planning policies in British Columbia, Canada. The authors used spatiotemporal process-based models to project and integrate the stressor-response relationships between forest harvesting and run-of-river power resource management activities and the suite of selected indicators. For a likely development scenario, the authors assessed the correlative structure among projected indicator responses and identified both patterns of potential redundancies and ecological processes linking indicators and dominant processes influencing valued components.

Thornborough, Kate, Jason Dunham, and Miriam O. 2016. *Development of Risk-Based Indicators for the SGaan Kinghlas-Bowie Seamount Marine Protected Area*. DFO Canadian Science Advisory Secretariat Research Document 2016/027. http://waves-vagues.dfo-mpo.gc.ca/Library/363985.pdf).

Thornborough et al. (2016) develops a framework to select and prioritize ecological risk-based indicators based on the outputs of an ecological risk assessment conducted. Risk-based indicators are a novel approach to selecting indicators to monitor the risk of harm to valued components from anthropogenic activities and associated stressors. Measures of abundance were commonly proposed across all indicator suites, highlighting the need to establish baselines of information as a priority. Both current snapshot and potential stressor indicator suites should be considered when developing monitoring strategies and plans, using a combination of valued components, stressor, and valued components -stressor interaction indicators.

Vandermeulen, Herb. 1998. "The Development of Marine Indicators for Coastal Zone Management." *Ocean & Coastal Management* 39 (1–2): 63–71.

Vandermuelen (1998) presents the methods, criteria and categories used by the Working Group as a part of Canada's national set of environmental indicators. A list of marine indicators is outlined along with an example (Pacific herring fishery).

Ward, T.J., 2000. Indicators for assessing the sustainability of Australia's marine ecosystems. Marine and Freshwater Research, (51), pp.435–446.

In this paper, the authors use principles of integrated ecosystem-based management to derive 61 potential environmental indicators for reporting on Australia's marine and estuarine ecosystems. These indicators are focused on tracking the condition of marine ecosystems in the face of a variety of uses and pressures, and are consistent with approaches used for assessment of public- and private-sector environmental activities, and with international standards.

A.5 Tools and methods

Adams, S. Marshall. 2005. "Assessing Cause and Effect of Multiple Stressors on Marine Systems." ***Marine Pollution Bulletin*** **51: 649–57.**

Adams (2005) develops an operational framework to serve as a guideline for investigating causal relationships between environmental stressors and effects on marine biota. Because of the complexity and variability of many marine systems, multiple lines of evidence are needed to understand relationships between stressors and effects on marine resources. Within this framework, a weight of evidence approach based on multiple lines of evidence are developed and applied in a sequential manner by (1) characterizing the study system which involves determining if target biota are impaired, assessment of food and habitat availability, and measuring contaminant levels in the environment, (2) assessing direct effects of contaminant exposure on target biota using biomarkers and assessing indirect effects of exposure using suites of bioindicators, and (3) applying standard causal criteria based on epidemiological principles and diagnostic health profiling techniques to assess potential causes.

Anthony, Kenneth R.N., Jeffrey M. Dambacher, Terry Walshe, and Roger Beeden. 2013. A Framework for Understanding Cumulative Impacts, Supporting Environmental Decisions and Informing Resilience-Based Management of the Great Barrier Reef World Heritage Area. Townsville, Queensland: University of Melbourne and Greater Barrier Reef Marine Park Authority.

Anthony et al. present a framework for Great Barrier Reef Marine Park managers and stakeholders, using qualitative and probabilistic modeling to provide a systems-level understanding of how cumulative stressors affect coral reefs and sea grass ecosystems in the Great Barrier Reef. The modeling approach enables managers to identify precautionary spatial and temporal boundaries for the assessment of development proposals. These "Zones of Influence" are integrated with a structured decision-making process that is designed to help managers and stakeholders use the results of the models to make informed choices between a range of possible intervention scenarios to achieve management objectives.

Ban, Natalie C, Hussein M Alidina, and Jeff A Ardron. 2010. "Cumulative Impact Mapping: Advances, Relevance and Limitations to Marine Management and Conservation, Using Canada's Pacific Waters as a Case Study." ***Marine Policy*** **34 (5). Elsevier: 876–86.**

Ban et al. (2010) expand upon existing approaches, aiming for a realistic consideration of cumulative impacts at a regional scale. They consider 38 human activities, with each broken down according to stressor types and a range of spatial influences. Their results indicate the entire continental shelf of Canada's Pacific marine waters is affected by multiple human activities at some level. Commercial fishing, land-based activities and marine transportation accounted for 57.0%, 19.1%, and 17.7% of total cumulative impacts, respectively.

Christensen, V. and Walters, C.J., 2004. Ecopath with Ecosim: Methods, capabilities and limitations. Ecological Modelling, 172(2–4): 109–139.

Christensen and Walters describe the Ecopath with Ecosim modeling approach, which combines software for ecosystem trophic mass balance analysis (Ecopath), with a dynamic modeling capability (Ecosim) for exploring past and future impacts of fishing and environmental disturbances as well as for exploring optimal fishing policies. Ecosim models can be replicated over a spatial map grid (Ecospace) to allow exploration of policies such as marine protected areas, while accounting for spatial dispersal/advection effects.

Clarke Murray, Cathryn, Selina Agbayani, Hussein M. Alidina, and Natalie C. Ban. 2015. "Advancing Marine Cumulative Effects Mapping: An Update in Canada's Pacific Waters." ***Marine Policy*** **58: 71–77.**

Clarke Murray et al. (2015) present an updated analysis of potential cumulative effects in Canada's Pacific marine waters. Their results show increased potential cumulative effects for the region. Fishing remains the biggest overall impact amongst marine activities, while land-based activities have the highest impact per unit area in affected ocean areas. Intertidal areas were the most affected habitat per unit area, while pelagic habitats had the highest total cumulative effect score. Regular updates of cumulative effects assessments will make them more useful for management, but these require regularly updated, high resolution datasets across all activity types, and automated, well-documented procedures to make them accessible to managers and decision--makers.

DFO. 2015. *Shipping Pathways of Effects: An Overview*. DFO Canadian Science Advisory Secretariat Research Document 2014/059. http://waves-vagues.dfo-mpo.gc.ca/Library/364433.pdf.

DFO (2015) presents an overview of shipping Pathways of Effects (i.e. anchoring, grounding, movement underway, oils spills, and discharge) and their potential impacts on aquatic ecosystems. The authors provide general guidance to inform more detailed risk assessments related to shipping in Canadian waters.

Halpern, Benjamin S, and Rod Fujita. 2013. "Assumptions, Challenges, and Future Directions in Cumulative Impact Analysis." *EcoSphere* 4 (10): 1–11.

Halpern and Fujita provide a review of the key assumptions that underlie most cumulative impact mapping efforts, describing the implications and rationales for the assumptions, and highlight the many challenges cumulative impact mapping efforts face. The authors end with a brief summary of several future research directions that will help greatly improve application of cumulative impact mapping to resource management and conservation planning efforts.

Halpern, Benjamin S, Shaun Walbridge, Kimberly A Selkoe, Carrie V Kappel, Fiorenza Micheli, Caterina D Agrosa, John F Bruno, et al. 2008. "A Global Map of Human Impact on Marine Ecosystems." *Science* 319 (5865): 948–52.

The authors develop an ecosystem-specific, multi-scale spatial model to synthesize 17 global data sets of anthropogenic drivers of ecological change for 20 marine ecosystems. Their analysis indicates that no area is unaffected by human influence and that a large fraction (41%) is strongly affected by multiple drivers. However, large areas of relatively little human impact remain, particularly near the poles. The analytical process and resulting maps provide flexible tools for regional and global efforts to allocate conservation resources; to implement ecosystem-based management; and to inform marine spatial planning, education, and basic research.

Halpern, Benjamin S., Carrie V. Kappel, Kimberly A. Selkoe, Fiorenza Micheli, Colin M. Ebert, Caitlin Kontgis, Caitlin M. Crain, Rebecca G. Martone, Christine Shearer, and Sarah J. Teck. 2009. "Mapping Cumulative Human Impacts to California Current Marine Ecosystems." *Conservation Letters* 2 (3): 138–48.

Halpern et al. apply methods developed to map cumulative impacts globally to the California Current using more comprehensive and higher-quality data for 25 human activities and 19 marine ecosystems. This analysis indicates where protection and threat mitigation are most needed in the California Current and reveals that coastal ecosystems near high human population density and the continental shelves off Oregon and Washington are the most heavily impacted, climate change is the top threat, and impacts from multiple threats are ubiquitous.

Halpern, Benjamin S., Karen L. McLeod, Andrew A. Rosenberg, and Larry B. Crowder. 2008. "Managing for Cumulative Impacts in Ecosystem-Based Management through Ocean Zoning." ***Ocean and Coastal Management*** **51 (3): 203–11. doi:10.1016/j.ocecoaman.2007.08.002.**

Halpern et al. develop a framework for evaluation, focusing on five core concepts: (1) activities have interactive and cumulative impacts, (2) management decisions require consideration of, and tradeoffs among, all ecosystem services, (3) not all stressors are equal or have impacts that increase linearly, (4) management must account for the different scales of activities and impacts, and (5) some externalities cannot be controlled locally but must be accounted for in marine spatial planning.

Knights, Antony M, Rebecca Sarah Koss, and Leonie A Robinson. 2013. "Identifying Common Pressure Pathways from a Complex Network of Human Activities to Support Ecosystem-Based Management . Identifying Common Pressure Pathways from a Complex Network of Human Activities to Support Ecosystem-Based Management." ***Ecological Applications*** **23 (4): 755–65.**

The authors demonstrate an approach for using linkages to build a simple network to capture the complex relationships arising from multiple sectors and their activities. Using data-analysis tools common to ecology, the authors show how linkages can be placed into mechanistically similar groups. Management measures can be combined into fewer and more simplified measures that target groups of pressures rather than individual pressures, which is likely to increase compliance and the success of the measure while reducing the cost of enforcement.

Marcotte, Danielle, Samuel K. Hung, and Sébastien Caquard. 2015. "Mapping Cumulative Impacts on Hong Kong's Pink Dolphin Population." ***Ocean and Coastal Management*** **109: 51–63. doi:10.1016/j.ocecoaman.2015.02.002.**

This paper outlines the authors' proposed cumulative effects assessment methodology, involving mapping and analysis of anthropogenic marine impacts in relation with historical dolphin distributions in the area. Local scale results show evidence of a relationship between the addition of new high-speed ferry routes into the cumulative environment and the decrease in dolphins in a specific region known as the Brothers Islands.

O, Miriam, Rebecca Martone, Lucie Hannah, Lorne Greig, Jim Boutillier, and Sarah Patton. 2015. *An Ecological Risk Assessment Framework (ERAF) for Ecosystem-Based Oceans Management in the Pacific Region*. Ottawa, Ontario: DFO Canadian Science Advisory Secretariat Research Document 2014/072.

O et al. present an ecological risk assessment framework to support ecosystem-based Management efforts in the Pacific Region in both the Pacific North Coast Integrated Management Area and Marine Protected Areas, building on methodologies from existing ecological risk assessment frameworks and processes, including the Australian Ecological Risk Assessment for the Effects of Fishing and risk frameworks developed for other DFO Large Ocean Management Areas. The authors describe the methodology and structure of the Ecological Risk Assessment Framework, which involves a scoping phase and three increasingly quantitative levels of risk assessment, and discuss how this framework could be used to inform management activities.

Samhouri, Jameal F., and Phillip S. Levin. 2012. "Linking Land- and Sea-Based Activities to Risk in Coastal Ecosystems." *Biological Conservation* 145 (1). Elsevier Ltd: 118–29.

In this article, the authors introduce a framework for identifying land- or sea-based activities that pose the greatest risk to valued members of marine ecosystems, including mammals, fishes, and invertebrates. Ecosystem-based risk is scored along two axes of information: the exposure of a population to an activity, and the sensitivity of the population to that activity, given a particular level of exposure. The authors apply this risk assessment framework to regional populations of indicator species in Puget Sound, Washington. This case study provides insight into how risk varies for particular activity-species combinations, and, because it is applied to indicator species, it also provides an estimate of how different activities influence risk to overall ecosystem structure and function. More generally, the risk assessment approach highlights the linkages between land-based activities and risk to marine species and can be used to evaluate the potential impacts of a diversity of human activities on coastal oceans.

Stephenson, S A, and L Hartwig. 2009. *The Yukon North Slope Pilot Project: An Environmental Risk Characterization Using a Pathways of Effects Model*. Canadian

Manuscript Report of Fisheries and Aquatic Sciences 2896. http://waves-vagues.dfo-mpo.gc.ca/Library/340530.pdf.

Stephenson and Hartwig (2009) developed a series of Pathways of Effects models as part of a pilot project for the Yukon North Slope in the Beaufort Sea to determine what activities might have a potentially negative effect on valued or vulnerable components of the ecosystem. Part of the purpose of this pilot was to see how these models worked in “real life” and to determine if Pathways of Effects might be a useful tool which could be used to help manage some activities in the Beaufort Sea. This pilot study showed the usefulness of the Pathways of Effects method to display the potential threats from proposed activities and therefore could be used as a valuable tool to assist marine planning by industry, stakeholders, managers and co-managers.

Stelzenmüller, V., J. Lee, A. South, and S. I. Rogers. 2009. “Quantifying Cumulative Impacts of Human Pressures on the Marine Environment: A Geospatial Modelling Framework.” *Marine Ecology Progress Series* 398: 19–32.

Stelzenmüller et al. (2009) mapped the impact of human activities by accounting for the sensitivity of marine landscapes to related pressures, and developed four scenarios to quantify the risk of cumulative impacts, assigning different importance to ranked pressures (equal, linear and logistic decrease), including a simulated expert consultation. The sensitivity of the scenario outcomes to changes to input parameters and compared model outcomes were then assessed. All scenarios revealed similar locations with an increased risk of cumulative impacts.

Turner, Nancy J, Robin Gregory, Cheryl Brooks, Lee Failing, and Terre Satterfield. 2008. “From Invisibility to Transparency : Identifying the Implications.” *Ecology and Society* 13 (2).

Turner et al. (2008) explore the need for a broader and more inclusive approach to decisions about land and resources, one that recognizes the legitimacy of cultural values and traditional knowledge in environmental decision making and policy. The authors recommend six processes: focusing on what matters to the people affected, describing what matters in meaningful ways, making a place for these concerns in decision-making, evaluating future losses and gains from a historical baseline, recognizing culturally derived values as relevant, and creating better alternatives for decision making so that invisible losses will be diminished or eliminated in the future.

A.6 Public and Indigenous participation

Dietz, Thomas, and Paul C. Stern, eds. 2008. *Public Participation in Environmental Assessment and Decision Making*. Washington, DC: Panel on Public Participation in Environmental Assessment and Decision-making, National Research Council.

Dietz and Stern argue that correctly conducted public participation improves the quality of decision-making about the environment, and increases the legitimacy of decisions in the eyes of those affected by them, which makes it more likely that the decisions will be implemented effectively. The authors recommend that agencies recognize public participation as valuable to their objectives, not just as a formality required by the law, and provide principles and approaches government decision-makers can employ in participation initiatives.

O'Faircheallaigh, Ciaran. 2007. Environmental agreements, EIA follow-up and aboriginal participation in environmental management: The Canadian experience. Environmental Impact Assessment Review, 27(4), pp.319–342.

O'Faircheallaigh draws on Canadian case studies to consider the potential of negotiated environmental agreements to address two issues widely recognized in academic and policy debates on environmental impact assessment and environmental management. The first relates to the need to secure indigenous participation in environmental management of major projects that affect indigenous peoples. The second and broader issue involves the necessity for specific initiatives to ensure effective follow-up on assessments. The Canadian experience indicates that negotiated environmental agreements have considerable potential to address both issues.

O'Faircheallaigh, Ciaran. 2010. Public participation and environmental impact assessment: Purposes, implications, and lessons for public policy making. Environmental Impact Assessment Review, 30(1), pp.19–27.

This paper distinguishes various purposes for public participation in environmental impact assessment, and discusses their implications for decision-making. O'Faircheallaigh then offers a broad typology of public participation in policy making to consider how approaches to participation in environmental impact assessment can be interpreted and valued, and asks what environmental impact assessment experience reveals about the utility of these models.

Udofia, Aniekan, Bram Noble, and Greg Poelzer. 2017. "Meaningful and Efficient? Enduring Challenges to Aboriginal Participation in Environmental Assessment." *Environmental Impact Assessment Review* 65: 164–74.

Udofia, Noble, and Poelzer (2017) explore challenges to "meaningful and efficient" Aboriginal participation in environmental assessment (i.e., participation that provides meaningful opportunities for Aboriginal communities to shape environmental assessment, yet assures a degree of efficiency for project proponents). The authors do so based on an analysis of the environmental assessment policy community's experience with uranium exploration and mining in Saskatchewan, Canada.

A.7 Institutional requirements

Noble, Bram, Skye Ketilson, Alec Aitken, and Greg Poelzer. 2013. "Strategic Environmental Assessment Opportunities and Risks for Arctic Offshore Energy Planning and Development." *Marine Policy* 39 (1). Elsevier: 296–302.

Noble et al. (2013) examine stakeholder perceptions of opportunities and risks of strategic environmental assessment for oil and gas development in Beaufort Sea, identifying opportunities and challenges. Their results indicate that strategic environmental assessment could result in increased regulatory efficiency, better regulatory baselines and planning practices, opportunities to assess for cumulative effects, more management for project-based assessment, and greater certainty for stakeholders. Risks include foregoing anticipated development opportunities, loss of flexibility in decision-making, adding more bureaucracy, and the uncertainties inherent in a novel approach.

Noble, Bram F. 2009. "Promise and Dismay: The State of Strategic Environmental Assessment Systems and Practices in Canada." *Environmental Impact Assessment Review* 29 (1). Elsevier Inc.: 66–75.

Noble reviews past and recent strategic environmental assessments and similar frameworks based on a set of input, process, and output evaluation criteria. His results suggest considerable variability in strategic environmental assessment experience and value added, "due in large part to the institutional and methodological pluralism of strategic environmental assessment, the boundaries of which are not well defined."

Ma, Zhao, Dennis R Becker, and Michael A Kilgore. 2012. "Barriers to and Opportunities for Effective Cumulative Impact Assessment within State-Level Environmental Review Frameworks in the United States." ***Journal of Environmental Planning and Management*** **55 (7): 961–78.**

Ma, Becker, and Kilgore (2012) argue that a major barrier to effective cumulative effects assessment is the inability of state programs to facilitate practices, particularly reflected by the perceived lack of explicit procedures and data for conducting assessments. The authors suggest strategies to improve practice, including adopting detailed guidelines specifying what to include in an assessment, and developing institutional mechanisms to encourage state agency co-ordination.

Partidário, Maria Rosário. 1996. "Strategic Environmental Assessment: Key Issues Emerging from Recent Practice." ***Environmental Impact Assessment Review*** **16 (95): 31–55.**

Partidário (1996) reviews existing strategic environmental assessment approaches with the purpose of understanding the existing status of strategic environmental assessment and identifying key practical issues raised by practitioners in the countries reviewed. Such practical issues reflect the strengths and weaknesses experienced with the adoption of particular approaches.

Partidário, Maria Rosário. 2000. "Elements of an SEA framework - Improving the added-value of SEA." ***Environmental Impact Assessment Review*****, 20(6), 647–663.**

Partidário argues that the value of strategic environmental assessment is a function of the extent it influences, and adds value, to decision-making. The paper suggests that strategic environmental assessment should be conceptualized as a framework, defined by core elements, that are incrementally integrated into policy and planning procedures and practices, whatever decision-making system in place.

A.8 Uncertainty

Gustavson, Kent R. 2003. Applying the Precautionary Principle in Environmental Assessment: The Case of Reviews in British Columbia. Journal of Environmental Planning and Management, 45(3): 37–41.

This paper examines the application of the precautionary principle in environmental assessment, specifically using the Salmon Aquaculture Review and the Burns Bog Ecosystem Review in British Columbia as case studies. The author presents a conceptual model for application of a sliding scale of strategies responding to the level of uncertainty regarding impacts and the likelihood of those impacts, as well as the irreversibility of impacts on the environmental system. The model presented in this paper is suggested as a tool from which a more specific methodological framework can be developed.

Larsen, S.V., Kørnøv, L. and Driscoll, P., 2013. Avoiding climate change uncertainties in Strategic Environmental Assessment. Environmental Impact Assessment Review, 43: 144–150.

Larsen, Kørnøv and Driscoll discuss the Danish Planning system's handling of climate change uncertainties in strategic environmental assessment, developing a model of five strategies: "reduction" and "resilience", "denying", "ignoring" and "postponing". They analyze 151 Danish assessments, focusing on discussion and acknowledgement of climate change uncertainties, and discuss these findings in relation to the model. Their study indicates that climate change uncertainties were systematically avoided or downplayed in all but 5 of the reviewed assessments.

Lees, Juliette, Jochen A.G. Jaeger, Jill A.E. Gunn, and Bram F. Noble. 2016. "Analysis of Uncertainty Consideration in Environmental Assessment: An Empirical Study of Canadian EA Practice." ***Journal of Environmental Planning and Management*** **568 (May). Taylor & Francis: 1–21.**

Lees et al. evaluate the extent to which uncertainties are considered and addressed in Canadian environmental assessment practice. The authors reviewed 12 environmental assessments between 1995 and 2012, and found that the types of uncertainties and levels of disclosure varied greatly. Uncertainties were never discussed in depth. Lees et al. identify five different approaches used to address uncertainties, where they were acknowledged: proposing additional research, sensitivity analysis or conservative estimates, precautionary approaches, justifying uncertainties, or estimating uncertainties and then ignoring them.

Leung, Wanda, Bram Noble, Jill Gunn, and Jochen A G Jaeger. 2015. "A Review of Uncertainty Research in Impact Assessment." ***Environmental Impact Assessment Review*** **50. Elsevier Inc.: 116–23.**

and

Leung, Wanda, Bram F. Noble, Jochen A G Jaeger, and Jill A E Gunn. 2016. "Disparate Perceptions about Uncertainty Consideration and Disclosure Practices in Environmental Assessment and Opportunities for Improvement." ***Environmental Impact Assessment Review*** **57. Elsevier Inc.: 89–100.**

These two papers examine uncertainty in the context of environmental assessment, both in scholarly literature and in practice. In the first paper, the authors analyze 134 journal papers published between 1970 and 2013 that address uncertainty in impact assessment, 75% of which were published since 2005, finding that 90% of impact assessment research addressing uncertainty focused on uncertainty in assessment practice, 9% focussed on uncertainty communication, and 1% focussed on theories for human behaviour relating to uncertainty avoidance. The second paper is based on a survey of 77 Canadian practitioners, regulators, and interest groups involved in environmental assessment, exploring uncertainties in regulatory process, uncertainty consideration and disclosure in practice and decision-making, and opportunities for improved disclosure. Most participants indicated that all assessments contain uncertainty; however, uncertainty disclosure was described as poor. Almost half of the participants believe that there is overconfidence in impact predictions and mitigation measures, and the majority indicated that if uncertainties were more openly reported then assessments would be a better tool for informing decisions. The authors identify several opportunities for improving the practice of uncertainty consideration and disclosure.

Tennøy, A., Kværner, J. & Gjerstad, K.I., 2006. Uncertainty in environmental impact assessment predictions: the need for better communication and more transparency. Impact Assessment and Project Appraisal, 24(1), pp.45–56.

In this paper, based on a study of 22 cases, evidence is presented that decision-makers and other stakeholders are often not made aware that uncertainty in environmental assessment exists, and are given only limited access to information about input data and the assumptions underlying predictions. It is argued that more emphasis should be given to improving the communication of uncertainty in impact assessment predictions and to making the prediction processes more transparent in order to improve impact assessment as a decision-aiding tool.

A.9 Conceptual frameworks

DFO. 2014. Pilot Application of an Ecological Risk Assessment Framework to Inform Ecosystem-Based Management in the Pacific North Coast Integrated Management Area. Nanaimo, BC: DFO Canadian Science Advisory Secretariat Research Document 2014/026.

The DFO (2014) conducted this pilot application of the ecological risk assessment framework methodology with a subset of valued components and activities/stressors in the Pacific North Coast Integrated Management Area. This report also evaluates operational modifications to the methodology and assesses the performance of the methodology in providing a relative ranking of valued components and activities/stressors.

Dubé, Monique G. 2003. "Cumulative Effect Assessment in Canada: A Regional Framework for Aquatic Ecosystems." ***Environmental Impact Assessment Review*** **23 (6): 723–45.**

In this paper, Dubé (2003) reviews the existing conceptual basis of cumulative effects assessment in Canada, including existing methodologies, limitations and strengths. A conceptual framework for integrating project-based and regional-based cumulative effects assessment is presented.

Lawson, J.W., and V. Lesage. 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. St. John's, Newfoundland: Canadian Science Advisory Secretariat, Fisheries and Oceans Canada, Newfoundland and Labrador Region (Research document 2012/154).

Lawson and Lesage (2012) outline a general framework to quantify and cumulate risks of impacts on marine mammal populations associated with marine development project, and which has been used to assess marine mammal risks from exposure to vessel noise or ship strikes associated with the Mary River Iron Mine project. The authors believe this framework could be extended to encompass other types of anthropogenic activities, and would benefit from further expert review to refine threshold values of impact and to determine if it is sufficiently precautionary.

MacDonald, Lee H. 2000. "Evaluating and Managing Cumulative Effects : Process and Constraints." *Environmental Management* 26 (3): 299–315.

MacDonald (2000) presents a conceptual process for assessing and managing cumulative effects, comprising a scoping phase, an analysis phase, and a planning and management phase, with each phase consisting of two to five discrete but interrelated tasks. He also reviews a continuum of existing approaches ranging from simple checklists to complex, physically based models, and argues for a tiered or nested approach to cumulative effects management at different spatial and temporal scales.

Masden, Elizabeth A., Anthony D. Fox, Robert W. Furness, Rhys Bullman, and Daniel T. Haydon. 2010. "Cumulative Impact Assessments and Bird/wind Farm Interactions: Developing a Conceptual Framework." *Environmental Impact Assessment Review* 30 (1). Elsevier Inc.: 1–7.

Masden et al. (2010) proposes a conceptual framework to promote transparency in cumulative effects assessment through the explicit definition of impacts, actions and scales within an assessment. This framework requires improved legislative guidance on the actions to include in assessments, and advice on the appropriate baselines against which to assess impacts.

Taylor, George. 2005. "Cumulative Effects of Forestry Practices - an Example Framework or Evaluation From Oregon, USA." *Biomass and Bioenergy* 13: 204.

Taylor (2005) reviews the literature and concepts associated with cumulative effects and proposes a framework for evaluating them. He argues that in order to evaluate potential adverse effects of forestry on vegetation, soils, streams, aquatic organisms, wildlife and air, baseline conditions and natural variations of resource characteristics must be known. In addition, systems for decision-making and systems of measurements and monitoring must be implemented along with databases and geographic information systems for displaying information at spatial scales from individual sites to landscapes and regions. The author provides an example of a framework for such a system in a mountainous, forested river basin in northwest Oregon.