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REPORT

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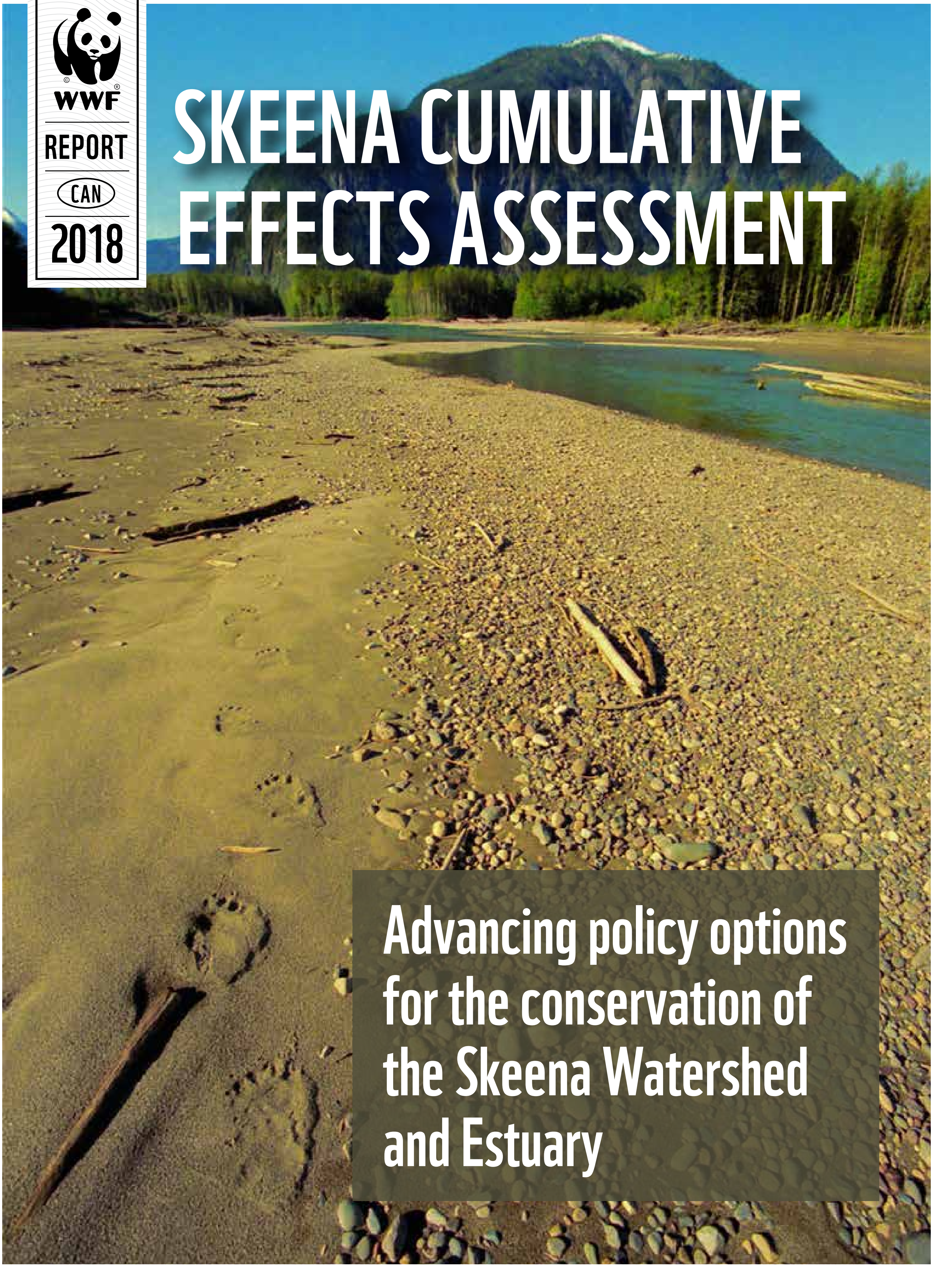
2018

SKEENA CUMULATIVE EFFECTS ASSESSMENT



Advancing policy options for the conservation of the Skeena Watershed and Estuary

Front cover: Bear Prints Lower Skeena.
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This work was funded by the Gordon and Betty Moore Foundation.

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EXECUTIVE SUMMARY

"If the province is to effectively manage the cumulative effects from natural resource development, clear ministry and agency direction, and a clear decision-making framework, need to be in place."

Managing the Cumulative Effects of Natural Resource Development in B.C., B.C. Auditor General, May 2015

The Skeena Cumulative Effects Assessment analyzes where and from what sources cumulative effects are likely to occur in the Skeena Watershed and Estuary. The report also makes recommendations around policy options to conserve the Skeena Estuary. As the largest estuary in Canada's Great Bear region, the health of the Skeena Estuary is central to the condition of the surrounding marine environment and the communities that rely on the ocean for their livelihood.

Situated adjacent to one of the most efficient trading corridors between Asia and North America, the estuary is increasingly subject to a large number of activities associated with international trade. When combined with shipping, pipelines and railroads, more established activities such as forestry, fishing and tourism are having an unprecedented cumulative impact on the species found in the region. If not understood and addressed, the region's natural resources will be put at risk.

Through an expert-based approach that included 30 interviews with traditional knowledge holders, academic researchers and experts from federal agencies, this Skeena Cumulative Effects Assessment (SCEA) documents the analysis of the cumulative effects of individual and multiple physical, biological and chemical stressors associated with human activities on three key species: eulachon, Chinook salmon and eelgrass. As well, this study assessed how these species will be impacted by climate change and future human activities such as mining, liquefied natural gas and port development. More than 1,000 species-stressor relations were assessed by specific life-history stages for all three species, using existing, planned and proposed development under consideration in 2016. That includes port terminals, roads and the liquefied natural gas terminals under consideration at the time of the study. *(Since the time of study, various LNG projects were cancelled by the primary stakeholders – not by government. Other development projects could be proposed resulting in similar cumulative effects; this SCEA allows communities and governments to see how the combined effects of stressors associated with human activity impact key species.)*


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WWF-Canada, with longstanding relationships with Skeena communities, developed the SCEA as a tool to help decision-makers plan for and manage development and other changes to ensure the future well-being of the ecosystem for the wildlife and people who use and benefit from the Skeena Watershed.

Key findings of this study are:

Overall:

Development of multiple terminals in the Skeena Estuary would be a serious new source of negative impacts on eelgrass, eulachon and Chinook salmon in the estuary. Multiple terminals will likely result in loss of habitat for both Chinook salmon and eelgrass, and harm the overall abundance of both species in the estuary.

Climate change will have the largest impact across both the estuary and watershed. However, extensive additional research is necessary to better model and measure the impacts.

For eelgrass:

Coastal industrial development and moorages are considered the largest source of negative impacts on eelgrass in the estuary. Negative impacts are expected to grow as new terminals are developed in the future.

For eulachon:

Considering that eulachon are a cornerstone of the ecosystem, are critical to First Nations culture, and the Skeena population is listed in the federal Species at Risk Registry as being of Special Concern (the Central Pacific Coast and Fraser River populations are Endangered), surprisingly little information is available for this species. This must be rectified as soon as possible, given the importance of eulachon to fish, marine mammals and seabirds. Overall, the largest impact on eulachon is considered to be climate change; however, given the lack of information, more research is required.

For eulachon and Chinook in the watershed:

Forestry and roads have the greatest impact out of all human activities assessed (this is consistent with WWF-Canada's national Watershed Report for the Skeena), and will remain the main source of impact over the next decade. Mining and pipelines are expected to become additional sources of impact.

For Chinook:

For Chinook in the estuary, fishing activities are currently the main sources of impact, following climate change. In future, these impacts are matched by industrial development impacts on estuary habitat.

Communities of the Skeena must act now if they are to succeed in mitigating the harmful impacts expected from port development in the estuary. However, the main impacts in the estuary are related to federally managed activities and require federal policy tools to address.

A review of the conservation options available for application in the Skeena found that:

- All levels of government should begin to implement regional cumulative effects assessments aligned with the draft B.C. Cumulative Effects Framework.
- The Port of Prince Rupert needs to develop policy tools to conserve estuary health.
- Flora Bank, at the mouth of the Skeena River, needs protection to maintain it as vital estuary habitat for Chinook salmon.
- The Marine Plan Partnership recommendations for the estuary should be taken up by the Marine Protected Areas Network Planning Initiative for the Northern Shelf Bioregion.
- The local municipalities of Port Edward and Prince Rupert can explore how their respective Official Community Plans could be updated to build on the opportunities provided in the Marine Plan Partnership and the Great Bear Agreement.
- The legislative guidance provided for the Port of Prince Rupert in the Letter Patent should be updated to include a commitment to the principles of ecosystem-based management.
- A fine-scale planning effort is needed to manage the intensive and complex uses of the Skeena Estuary. The Open Standards for the Practice of Conservation – an internationally recognized systematic approach to planning, implementing and monitoring conservation initiatives – provides a means to integrate the multiple human and ecological objectives for the region, and should be used to develop a fully defined estuary management plan.

The communities of the Skeena Watershed and Estuary and the Great Bear Region are currently experiencing a period of major transition that could greatly alter the ecosystem – with repercussions for the region's economy, communities and wildlife. The successful development of a world-class container terminal in Prince Rupert has demonstrated to the world that the Skeena region can be part of a global trading network. New developments will need to be handled in a way that maintains the health of the existing ecosystem – which will require greater attention to environmental stewardship from all those having an impact. The Skeena and Great Bear are unique places. There is an opportunity for Canada to demonstrate a more sustainable approach to community building, and for the global trade sector to make a positive, lasting contribution that will ensure wildlife and communities in the Skeena region are healthy and able to thrive for generations to come.

Conservation of the Skeena Estuary will require effective management of both emerging and existing stressors and their cumulative impacts in a manner that continues to maintain the ecological function of the estuary, broader connected components, and the ecosystem services they collectively provide (including filtration of land-based pollutants by the estuary, storage of carbon by eelgrass, a source of food for salmon and other fish, and as a migration stop for birds). WWF-Canada is working with communities in the Skeena to ensure healthy ecosystems go hand-in-hand with economic activities that support vibrant communities.

INTRODUCTION

"Cumulative effects have been identified as a priority issue by First Nations on the North Coast, who are seeking ways to improve upon the current methods of assessment..."

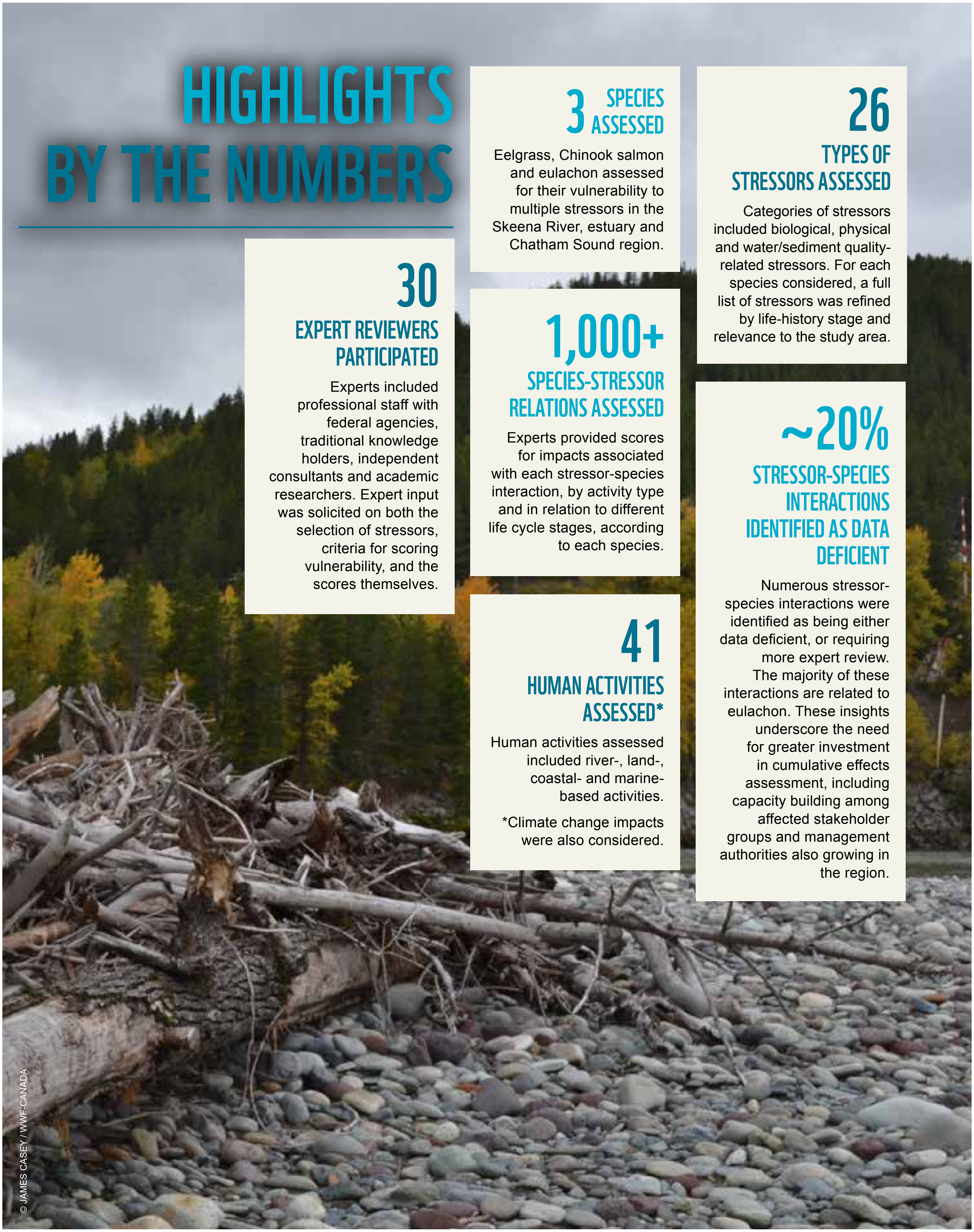
North Coast-Skeena First Nations Stewardship Society & Province of British Columbia North Coast Marine Plan, 2015.

The Skeena Estuary is a place of enormous richness that has provided goods and services to communities for time immemorial. The key to the long-term presence of people in the region has been the abundance of species that the Skeena and Chatham Sound provide. Today this abundance is at risk due to the scale of industrial development being considered for the region. While each individual project may be able to mitigate at least some of the impacts of that project, over time a general erosion of the health of the environment occurs. Communities across Canada are learning that the economy, the environment and community wellbeing need to be managed holistically if sustained benefit to communities is to be realized.

Although estuaries are at the centre of much of the country's ecological and economic productivity, the health of estuaries is much neglected in current policy across Canada. As such, the policies associated with estuary management must be modernized to reflect the emerging understanding of the connection between ecological health, economic development and vibrant communities.

The Skeena Estuary is a prime example of the need to modernize estuary management. Understanding how to go about it requires exploring elements of a conservation strategy that could apply to the estuary, the current and future impacts facing some of the key values in the estuary, and some existing policy tools that can be used to protect the estuary. The Skeena Cumulative Effects Assessment (SCEA) analyzed where and from what sources cumulative effects are likely to occur in the Skeena Watershed and Estuary and analyzed impact on three key species: eulachon, eelgrass and Chinook salmon. The SCEA provides information to decision-makers about the possible impacts of development scenarios, and serves as an applied example to consider when formulating cumulative effects policies. As a resource for the communities in the Skeena, the SCEA can assist in developing approaches to cumulative impacts assessment and management.

In an effort to enable more of an ecosystem-based approach to decision-making than is currently practiced, the SCEA encompasses the Skeena Watershed and Estuary and parts of Chatham Sound. This report summarizes findings of some of the key learnings regarding the attributes of a conservation strategy, the condition of key ecological values after accounting for impacts throughout the watershed, and concludes with a few recommended conservation options that could be applied in the estuary to maintain, conserve and protect this incredibly valuable ecosystem.



HIGHLIGHTS BY THE NUMBERS

30 EXPERT REVIEWERS PARTICIPATED

Experts included professional staff with federal agencies, traditional knowledge holders, independent consultants and academic researchers. Expert input was solicited on both the selection of stressors, criteria for scoring vulnerability, and the scores themselves.

3 SPECIES ASSESSED

Eelgrass, Chinook salmon and eulachon assessed for their vulnerability to multiple stressors in the Skeena River, estuary and Chatham Sound region.

1,000+ SPECIES-STRESSOR RELATIONS ASSESSED

Experts provided scores for impacts associated with each stressor-species interaction, by activity type and in relation to different life cycle stages, according to each species.

41 HUMAN ACTIVITIES ASSESSED*

Human activities assessed included river-, land-, coastal- and marine-based activities.

*Climate change impacts were also considered.

26 TYPES OF STRESSORS ASSESSED

Categories of stressors included biological, physical and water/sediment quality-related stressors. For each species considered, a full list of stressors was refined by life-history stage and relevance to the study area.

~20% STRESSOR-SPECIES INTERACTIONS IDENTIFIED AS DATA DEFICIENT

Numerous stressor-species interactions were identified as being either data deficient, or requiring more expert review. The majority of these interactions are related to eulachon. These insights underscore the need for greater investment in cumulative effects assessment, including capacity building among affected stakeholder groups and management authorities also growing in the region.

DEVELOPING A CONSERVATION STRATEGY

Estuaries are complex places in a state of constant change due to their location at the nexus of marine, terrestrial and freshwater systems. This complexity and dynamism needs to be maintained for estuaries to continue to be productive. Fortunately, the need to develop the means to manage such complexity is not novel to the Skeena; tools have been developed and applied in other circumstances to aid the conservation of estuaries.

One of the most useful tools for developing conservation strategies is the Open Standards for the Practice of Conservation, which combines principles and best practices in adaptive management and results-based management from conservation and other fields. Open Standards brings together common concepts, approaches and terminology in conservation project design, management and monitoring to help practitioners improve the practice of conservation. Open Standards has been applied to river conservation around the world, including the Coquitlam Roundtable in British Columbia. Just south of the Canada/U.S. border, Open Standards has provided the organizing framework for the multi-jurisdictional recovery efforts for Chinook salmon, and have been the foundation for the management plans for Puget Sound. If supported by multiple levels of government, Open Standards contains the structure needed to develop a results-based conservation strategy for the Skeena Estuary; the first step is to identify what is to be conserved. WWF-Canada has compiled a list of possible Valued Ecological Components that are seen as important in the Skeena Estuary based on their presence in community planning documents. This list has been supplemented with concepts found in the scientific literature about which elements of an estuary need to be maintained.

TABLE 1
Key ecological attributes in the Skeena Estuary

Eelgrass	Eelgrass is important habitat for a variety of species. DFO has identified eelgrass as an "Ecologically Significant Species." Eelgrass is a critical nursery and foraging habitat for species such as juvenile salmon.
Kelp	Kelp is a basic food source and habitat for many species, including sea urchins, herring (which deposit their eggs on kelp and other marine plants), other fish and invertebrates.
Forage fish (e.g. eulachon, capelin, Pacific herring, surf and longfin smelt)	Forage fish form an important part of marine ecosystems, feeding on plankton and, in turn, becoming food for many other species including predatory fish, seabirds and marine mammals.
Salmon	Salmon are a keystone species in the region supporting the entire ecosystem, including humans, with their river-to-sea-to-river cycle.
Marine mammals (e.g. orcas, harbour porpoises, humpback whales, Steller sea lions)	Marine mammals are consumers of much of the productivity of the Northeast Pacific. Some, such as the threatened orcas, have adapted to survive year-round on the north coast of B.C. Others, such as humpback whales, are international migrants that come to the region to feed and then head south to give birth.
Seabirds (e.g. common murre, rhinoceros auklet, murrelets)	The rich waters of the Northeast Pacific support globally significant numbers of seabirds. Islands on the north coast, which support nesting colonies, have been identified as Important Bird Areas.
Butter clams	Butter clams have been an important resource for the First Nations of the north coast from time immemorial.
Water quality	Water quality is a fundamental condition for the support of most of the Valued Ecosystem Components found in the estuary. From butter clams to orcas, every species is impacted by poor water quality.
Sediment quality	Condition of sediment is a good indicator of issues that may be developing over time. Pollutants often settle into the sediment and will start the chain of bio-accumulation through species that live in or on the sediment.
Habitat heterogeneity	The diversity of habitat is a source of resilience for coastal ecosystems. With multiple patches of various types of habitats, the temporary loss of a few habitat patches may not have a long-term effect on the health of the coast.
Habitat connectivity	Many species use different habitats at different stages of their life. Species need to be able to move from one habitat to another to successfully carry out activities such as feeding and spawning. As habitat connectivity is lost, the productivity of the estuary declines because species cannot move to different habitat types as needed.
Environmental flows	The discharge of freshwater into the marine environment is one of the main attributes defining estuaries. Any alteration of the five components of environmental flow (timing, magnitude, duration, frequency and rate of change) will have an impact on the habitat and species found in the estuary.

The second and third steps recommended in the Open Standards are to understand the condition of the values, and then identify and rank stressors from current and potentially emerging activities. WWF-Canada has conducted a vulnerability-based cumulative effects assessment on these three species to understand current levels of impact and future levels of risk.

CURRENT AND POTENTIAL ACTIVITIES

"Understanding the cumulative impacts of human activities on ecosystems are essential elements of operationalizing the practice of ecosystem-based management"

Halpern, et al, 2008

Since the time of contact between First Nations and settlers, the Skeena has had a resource extraction-based economy. For much of recent history, the primary economic activities in the region have been forestry in the watershed and fishing in the estuary. The shipment of these and other resources to remote markets has also been an important economic activity in the region. In the watershed, additional activities have included agriculture, some mining and a steady tourism industry. The primary stressor shared amongst all of these activities is the building of the roads and rail needed to move goods and people. Currently, commercial fishing and forestry have declined as a source of economic prosperity and new industries are emerging.

New developments, like liquefied natural gas (LNG) projects, will threaten the Skeena Estuary, and have a fundamental and irreparable impact on the structure and function of Northern B.C.'s coastal ecology. LNG export terminals directly next to the Flora Bank will put environmental wealth and biodiversity at risk, thereby undermining the long-term economic health of the region. Understanding cumulative effects will bring greater insight necessary for the management and conservation of this region.


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FIGURE 1
Future activities in the estuary (at the time of study)

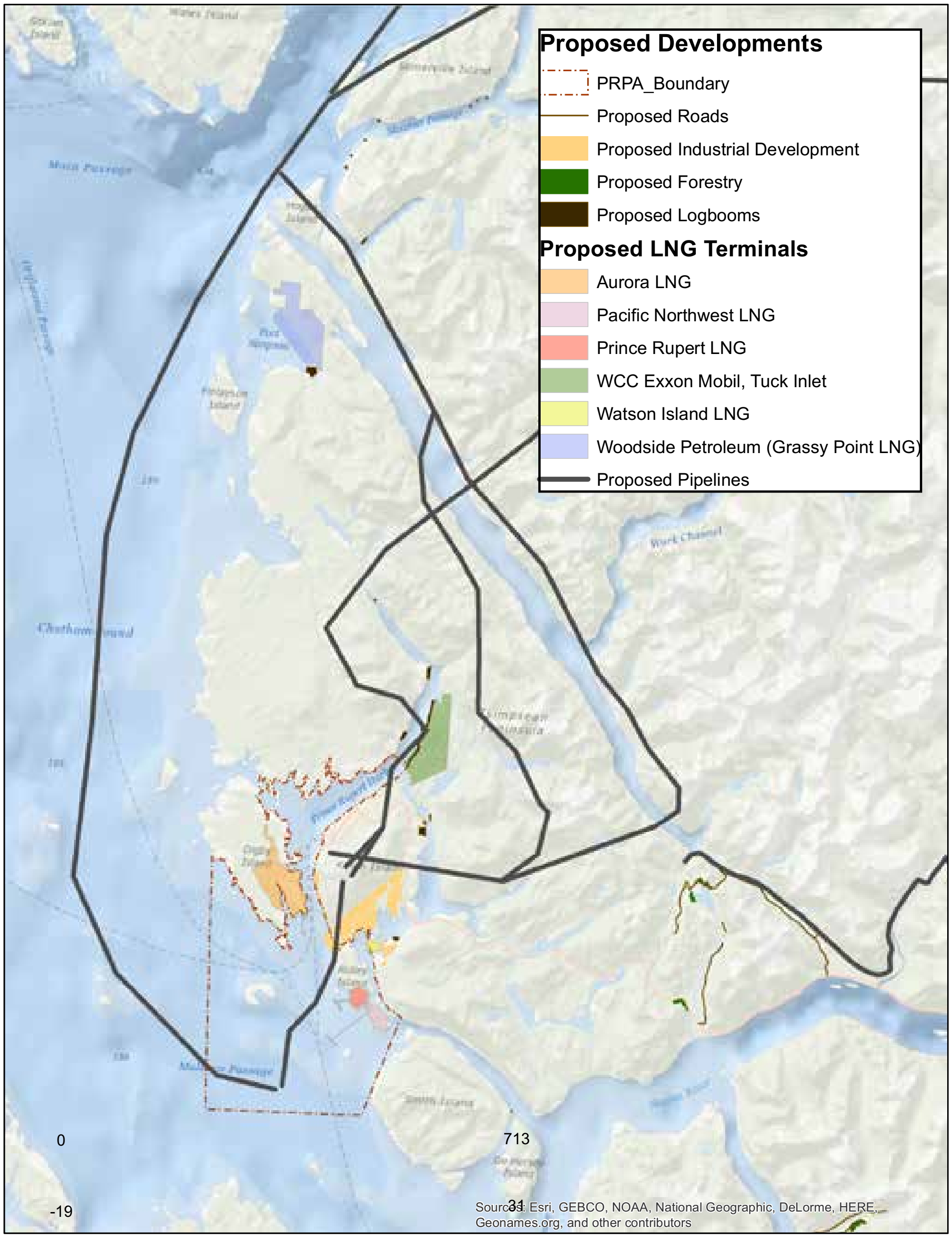

TABLE 2
LNG terminals proposed for the Skeena estuary (at the time of study)

LNG TERMINALS	ACTIVITIES	STRESSORS
Pacific Northwest LNG, Aurora LNG, WCC LNG, Watson Island LNG and Prince Rupert LNG	Port terminals	Bacteria, benthic disturbance, inorganic chemical contamination, light/shading, underwater noise, temperature change.
	Subsea pipelines	Benthic disturbance, heavy oils, light oils, sedimentation.
	Pipelines	Benthic disturbance, heavy oils, hydrologic flows, light oils, organic waste, riparian habitat alteration, temperature change and total suspended solids.

As the people of the Skeena attempt to maintain a commitment to the concept of ecosystem-based management while developing an international trading corridor, now is the time to implement measures that enhance the likelihood of achieving that goal for the region, as set out by Marine Plan Partnership (MaPP) and the Great Bear Rainforest land-use agreement. In this vision, "the ecological and cultural richness of the North Coast region is maintained and enhanced." (MaPP, 2015) To achieve this goal, a shift in emphasis away from intensive development toward ecosystem-based management is needed on the part of local decision-making bodies, including Prince Rupert Port Authority, the municipalities of Port Edward and Prince Rupert, and territories of local First Nations where this development is taking place. The establishment of a formalized joint Environmental Monitoring Committee between Lax Kw'alaams, Metlakatla, the federal and provincial governments to oversee environmental and compliance monitoring of the PNW LNG* facility is a step in the right direction. *(*since cancelled)*

British Columbia's international corridor is expanding immensely. In 2006, the Canadian government launched the Asia-Pacific Gateway and Corridor Initiative. In 2007, the Fairview Container Port opened, allowing Prince Rupert and the CN rail line to be part of this major new initiative. By 2008, $5 billion had been committed to this initiative, part of which was committed to a three-phase build-out of the Prince Rupert terminal. By 2015, 776,412 TEUs (twenty-foot equivalent units) were being transported through Prince Rupert and work had started on Phase II of the Fairview Container Terminal. Completion is expected to enable a total capacity of 1.3 million TEU's of container goods to move through Prince Rupert. The new owners of the Fairview Container Terminal have also begun to explore the southern expansion which would increase the total capacity to two million TEU. In 2012, the B.C. government released the Pacific Gateway Transportation Strategy that identified the need to invest $25 billion beyond $22 billion already committed to the respective Vancouver and Prince Rupert Gateways. As of early 2017, in addition to the container terminal, there are a number of bulk good projects being proposed for Prince Rupert as well, including several LNG terminals. A fifth project for a location known as Watson Island has also been proposed, but details are not listed for that project. An additional Propane Export Terminal was also being proposed for Prince Rupert, at the time of study.

Without doubt, the Asia-Pacific Gateway and Corridor Initiative, and its associated federal Asia-Pacific Gateway and Corridor Transportation Infrastructure Fund, will have major environmental implications for the region. Yet the strategy was developed with little connection to the regional planning effort and its accompanying vision of ecosystem-based management, the Great Bear Agreement and the four MaPP sub-regional plans. If the current resource boom is to provide sustainable development in the watershed and estuaries, then these communities need the tools to analyze and manage the impacts associated with these opportunities. This Skeena Cumulative Effects Assessment can serve as an important resource for local communities to ensure the Great Bear region becomes a global example of smart, modern conservation where strong communities, based on resilient ecosystems, can be built.

A CLOSER LOOK AT CONSERVATION AND CUMULATIVE EFFECTS

"Collectively, we can neither maintain the quality of what we have nor expand opportunities without considering the cumulative effects on the basic systems that provide the means for sustaining economic activities and human well-being."

Business Council of British Columbia (2012), Environment and Energy Bulletin, Volume 4, Issue 6, November 2012

Conservation of ecosystems plays out at much larger spatial and temporal scales than most decision-makers are tasked to consider. It is common knowledge that salmon use the whole watershed, and that impacts in the estuary will limit the ability of salmon to return every year to the headwaters of the Skeena. Despite this knowledge, few decisions are made with this ecosystem scale in mind. If we want to conserve the health of the Skeena, then we need to find ways to think about and act in the interest of the whole watershed.

"Cumulative effects" (CE) are defined by the Canadian government as "changes to the environment that are caused by an action in combination with other past, present and future human actions." (CEAA, 2016) Human actions or activities are associated with a number of environmental stressors: the physical, chemical and biological components of the activity that impact the surrounding environment. Stressors can have impacts of varying degrees on a suite of species and habitats in ecosystems, ranging from mortality to behavioral and physiological changes. WWF-Canada is concerned that the impacts of these stressors in the Skeena are increasing. Cumulative effects assessments offer an ecologically informed approach to decision-making that can allow people throughout the watershed to enjoy the multiple types of benefits provided by the river ecosystem.

Cumulative effects assessment and management is an important resource management challenge that has been revisited by numerous researchers and managers since at least the early 1980s. (Greig, 2005) Building on early assessments, CE was codified into Canadian law in 1995. (Gunn, 2011). In establishing the cumulative effects methodology used for the Skeena Cumulative Effects Assessment, WWF-Canada was aware of the need for "an approach that combines our current local, traditional and scientific knowledge with scenarios of future change." (Weber et al. 2012) This is a regional cumulative effects assessment at a scale that is limited enough to allow for a sense of community, but large enough to capture many of the ecological and human drivers of the Valued Ecosystem Components (VEC) being considered. The VEC concept is central to focusing the environmental assessment process and the cumulative effects assessments on the elements that will best inform decision-making. The original definition of VEC was "…the environmental attributes or components identified as a result of a social scoping exercise… (which) may be determined on the basis of perceived public concerns related to social, cultural, economic or aesthetic values. They may also reflect the scientific concerns of the professional community as expressed through the social scoping procedures."

This assessment is being released at an important juncture in B.C. with the province working to deliver cumulative effects assessment and management policy for inclusion in resource decision-making. (B.C. Government, 2014) The need to develop a CE policy has been identified by numerous parties. (Forest Practices Board, 2011, B.C. Auditor General's Office, 2015)

Another major influence is the process of reconciliation with First Nations. The province does not know the cumulative impacts of its decisions on other values, including on those guaranteed to First Nations under the Canadian constitution. If industrial development is to proceed in the North Coast Region, adjusting management practices to maintain First Nations rights will be a prerequisite as identified in the Marine Partnership Plan. (MaPP, 2015)

BUILDING ON PREVIOUS CUMULATIVE EFFECTS RESEARCH

Cumulative effects assessment is gaining momentum as an essential component of resource planning and decision-making. Scientific peer-reviewed marine cumulative effects studies have been completed at different scales, such as the B.C. coast (Ban et al. 2010; Clarke et al. 2015a, Clarke Murray et al. 2015b), the Pacific Northwest (Teck et al. 2010; Maxwell et al. 2013), and globally (Halpern et al. 2007). Unlike the previous studies that aim to understand cumulative effects across large study areas, the SCEA adapts these approaches and lessons at a regional scale.

The project includes two phases:

- **Phase I:** Development of SCEA methodologies and collection of relative vulnerability scores of species to a range of activity stressors.
- **Phase II:** Collection of spatial data of species, activities, and activity-stressor distribution and modelling of spatial cumulative effects (inputs to the modelling include results from Phase I).

WHAT IS VULNERABILITY?

Vulnerability is used in cumulative effects studies to understand and quantify how a species reacts to individual and multiple stressors. Vulnerability includes information about the exposure of species and habitats to each stressor, the sensitivity of species and habitats to the stressor, and the resilience of species and the potential of habitats to recover. This study incorporates local and expert input through surveys and local workshops as a forum to determine the vulnerability of each species in relation to a wide range of stressors.

CHALLENGES OF DEFINING ASSESSMENT BOUNDARIES

The Skeena Cumulative Effects Assessment covers a wide geographic area from the headwaters of the Skeena River to the outer edges of the Skeena Estuary. As with any regional cumulative effects assessment, defining boundaries was a challenge. On the terrestrial side, the heights of land that define the watershed boundary of the Skeena conformed with widely accepted practice of taking a watershed approach to understanding impacts on aquatic species. On the marine side, no clearly defined boundary exists. Three fundamental challenges had to be addressed to set the marine extent of CE assessment.

First, there is a high level of variability in the scientific literature about what counts as an estuary. Factors such as sediment deposition, constrained access to the open ocean and salinity all factor into how the boundaries of an estuary are defined on the seaward edge. There is also the upriver portion of an estuary that needs to be defined and this must consider the influence of the tides as well as the intrusion of the salt tongue into the river. For this study WWF defined the estuary on the seaward side by the level of salinity, and up the river by the upward edge of tidal influence.

The second fundamental challenge we had to address was the fact that all three species have ranges that extend far beyond the estuary. There are differing levels of scientific understanding of how the population dynamics of each of these species are affected by activities and behaviour beyond the estuary.

Chinook salmon

The best understood is Chinook. It is fairly well established that chinook from the Skeena migrate north up through the Gulf of Alaska in the Bering Sea where they feed for up to six years before returning to the Skeena to spawn. It is also known they are subject to both targeted and bycatch pressures in the American fishery which is managed through a transboundary fisheries agreement. It has also been proposed that Chinook, and indeed all salmon, are subject to competition of food supply amongst different populations, though details are yet to be well established.

Eulachon

Neither the behavior of eulachon or impacts on the species outside the estuary are well understood. Unlike salmon, eulachon are not believed to return to the same river generation after generation; so, defining a population of eulachon happens at a broader geographic scale.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) defined the Fraser and Central Coast population (listed in the federal Species at Risk Registry as Endangered), and the Skeena/Nass population (listed as being of Special Concern). Two concentrations of eulachon appear to occur on the B.C. coast: one in Hecate Strait and one off the west coast of Vancouver Island. It is thought that the Skeena/Nass population disperses to these two sites, with the majority moving to the Hecate Strait.

Eelgrass

We found no research on the population dynamics of eelgrass on the north coast. It has been suggested that the growth behaviour of eelgrass on the north coast differs from that at southern locations, but we know of no genetic studies that would indicate any genetic differentiation, or if this is driven purely by physical conditions. In light of the data gaps, limited resources and greatly enhanced geographic scope involved with expanding the study area to capture the full extent of the range for all three populations, the decision was made to limit the assessment to Skeena River and Estuary.

Physical geography

The third challenge was the physical geography of the north coast. The region is a fjord environment defined by a multitude of deep channels and islands that constrain access of freshwater to the open ocean and limit mixing. This results in large areas of lower salinity that run along the inside coast. This effect is enhanced in the Skeena Estuary by the close association of the Nass River immediately to the north. The discharge from the Skeena and the Nass combine in Chatham Sound resulting in lower salinity and higher sediment levels there. The research necessary to separate the influences of the Skeena and Nass in Chatham Sound has not taken place; as such, a rough estimation of the extent of the outer reaches of the Skeena estuary is all that can be provided at this point.

Keeping in mind that many of these factors are dynamic and change throughout the year and across years based on the discharge of the Skeena, a significant amount of data is required to identify boundaries within the estuary. Some information on salinity gradients does exist for the region and we used this to define an outer, middle and inner estuary. These boundaries are based on a limited set of measurements taken during the spring freshet. These boundaries will change throughout the year but we know of no studies that have mapped the shifting levels of salinity across the estuary throughout the year. For the very outer edge of the estuary we used the narrowest points of access to the higher salinity waters of Hecate Strait. This likely expands the estuary beyond the dominant impact of the Skeena to include regions of equal influence from the Nass River; however, it ensures that we included all activities that might be impacting the focal species within Chatham Sound.

STUDY METHODOLOGY

From a larger list of ecological values identified in step one of the Open Standards for the Practice of Conservation (see Table 2), WWF-Canada focused on three species that are important to both the health of the estuary and the people living in the region. Once the three core species were selected, the study team then identified a relevant range of human activities and associated stressors (including climate change). An expert elicitation method, combining surveys and interviews, was used to obtain relative vulnerability scores for each stressor-species interaction. The scores form the basis of subsequent spatial analysis combining the vulnerability scores with information about intensity of human activities to depict differences in the relative vulnerability of each species across the study area.

Attempting to assess all human-caused impacts on species is the foundation of this cumulative effects assessment. The approach taken considers physical, biological and chemical stressors associated with multiple current human activities in the marine, coastal, river and adjacent terrestrial environments. Additionally, stressors associated with planned future human activities, such as liquefied natural gas and port development, are considered, as is climate change. There are limitations in knowledge about species and gaps in data about activities that constrained the study, but it does demonstrate a far more comprehensive approach to cumulative effects assessment than is currently used in CE assessments conducted under the Canadian Environmental Assessment Act.

Because the assessment of cumulative effects is a requirement of the environmental assessment legislation, the process is defined by the Technical Guidance for Assessing Cumulative Environmental Effects under the Canadian Environmental Assessment Act, 2012. These have been described as project-based assessments that tend to consider cumulative effects from the perspective of multiple stressors from a single activity or a single stressor from multiple activities. Often the impacts from multiple activities beyond the boundaries of a specific project are not considered or discounted due to claims about mitigation efforts. The WWF-Canada assessment has accounted for multiple stressors from a multitude of activities on three values at a watershed scale. Though not a holistic ecosystem model, it has produced far more information on threats facing these values than anything produced to date for the Skeena.

Species interact with multiple stressors from multiple human activities – sedimentation occurring from forestry log sorts (sites where logs are sorted by different qualities in preparation for milling), for example, as well as ...” (sites where logs are sorted by different qualities in preparation for milling), for example, as well as sedimentation occurring from marina construction and operational phases. Marinas are a source of other stressors, such as invasive species and oil waste. By recognizing that human activities give rise to multiple stressors which interact cumulatively with the different life-cycle history stages of select species, the study seeks to support a multi-sector approach to managing impacts.

The activity-stressors assessed in the study were initially determined by reviewing human activity lists from other cumulative effects assessments, specifically Maxwell et al. (2013) and Ban et al. (2010), as well as undertaking extensive literature review of impacts from different human activities and tenure data sets relevant to the Skeena.

Building on the preliminary list of activities, the Chinook activity-stressor list was further informed through a preliminary literature review. An in-person survey of local watershed experts was undertaken to refine "key stressors" to Chinook. Those key activities and stressors identified were then included in the Chinook vulnerability scoring exercise.

For eulachon, the development of the list of relevant activities and stressors on eulachon life stages was conducted by leading eulachon experts in the province. This list then formed the basis for further discussion with local eulachon expertise in the watershed. With so little known about the life history of eulachon, these relationships need to be understood more as hypothesis of impact until further field research is conducted.

LIFE-HISTORY STAGES

The vulnerability of Chinook salmon and eulachon to various stressors and activities were assessed for five different life-history stages of each species, as defined below. We defined Chinook salmon and eulachon life-history stages based on consultation with species experts and review of literature. (Groot & Margolis 1991, Ocean Ecology 2014)

Chinook salmon life history stages:

- Eggs/alevins: Eggs and alevins in spawning beds in the Skeena River and its tributaries (freshwater life history stage)
- Freshwater juveniles: Rearing juveniles (eg: fry, parr and smolts) in stream and lake outlets and out-migrating smolts heading to the Skeena estuary (freshwater life history stage)
- Marine juveniles: Juveniles (parr, smolts) rearing in the Skeena estuary (marine life history stage)
- Sub-adults: Sub-adults foraging in Skeena estuarine/coastal waters (marine life history stage)
- Adult spawners: Returning spawners migrating along the main stem and tributaries of the Skeena River, and at spawning grounds (freshwater life history stage)

Eulachon life history stages:

- Eggs/larvae: Eggs and larvae in the Skeena River, on the bottom and in the water column (freshwater life history stage)
- Juveniles: Larvae and juveniles (young-of-year individuals) in pelagic habitats of the Skeena estuary and Chatham Sound (marine life history stage)
- Recruits and adults: Recruits and adults foraging in demersal habitats of the Skeena estuary and Chatham Sound (marine life history stage)
- Sexually maturing adults: Sexually maturing adults in estuary waters adjacent to Skeena River (marine life history stage)
- Adult spawners: Sexually mature adults, waiting and spawning in freshwater areas of the Skeena River (freshwater life history stage)

SELECTING EXPERTS

"Society often calls on experts for advice that requires judgments that go beyond well-established knowledge.... Done well, expert elicitation can make a valuable contribution to informed decision-making."

Morgan, 2014

A suite of human activities takes place in, on or near the Skeena Watershed and Estuary and exerts pressures on the ecosystem. Given the sheer number of impact pathways associated with multiple human activities, it is a massive task to complete field studies to adequately understand, prioritize and address the key stressors impacting keystone species and critical habitats.

Our assessment of species vulnerability is based on Halpern's (2007) vulnerability assessment framework and study approach to eliciting expert knowledge through survey. To better understand the impacts of multiple human activities, the framework relies on expert elicitation, a process through which experts quantify the vulnerability of habitats to human activities. We selected the Halpern Framework for expert elicitation as it uses a set of simplified vulnerability criteria and standardized scales, thereby providing an easy, transferable and repeatable method to describe and report on human threats on the environment. Halpern's approach is also easy to adapt to different needs. The framework was recently modified to quantify the relative impact of human activities to species. (Maxwell et al. 2013)

Our application of the Halpern Framework builds on past assessments in a few key ways. We completed a regional assessment, studying the impacts to both habitats and species, from individual stressors associated with multiple human activities2. Other applications, such as the California Current (Teck et al. 2010), the Pacific Northwest (Ban et al. 2010) and global applications (Halpern et al. 2008) tended to assess habitat vulnerability to a mix of activities and stressors at broad scales. The SCEA is one of the few studies that adopts the framework on a watershed scale and applies a species-specific focus. Finally, for the anadromous fish – those that hatch in freshwater, migrate to sea and then return to freshwater to spawn – we looked at the vulnerability of an individual life history stage to better understand when during their lifecycle salmon and eulachon are most impacted and by which threats.

The pool of potential experts to interview was initially developed with WWF-Canada staff and was distributed for review to a few regional individuals identified as knowledgeable on the species and/or the Skeena Region. Once launching the expert elicitation interviews, a snowball sampling methodology was used to build the expert pool.

We conducted interviews by phone or in-person. These interviews followed a semi-structured open-ended format where the experts were lead through fixed questions but they could add information and share narratives. We sent backgrounder material to experts in advance for review and the experts scored species vulnerability by following the activity-stressor list during the interview. Experts were asked to complete the scoring exercise considering the relative impact of a stressor from a single unit of an activity (eg: a single forestry cutblock, not a number of cutblocks).

Experts and community members were contacted by phone and email to inquire about their interest and suitability to participate based on their level of knowledge in relation to the type of data being sought. Some experts excused themselves from participating due to lack of regional experience and/or not having enough knowledge to contribute to scoring relative impacts. Further, some individuals were not able to participate owing to procedural or availability constraints within their organizations or government agencies. Experts who completed the vulnerability scoring interview were asked a set of biographical questions, such as professional affiliation, areas of expertise and years of knowledge or experience with the species they discussed.

The individuals conducting interviews were responsible for recording the scores provided or explained by the experts, sometimes in a narrative style. Experts began each interview by reviewing the scoring methodology with the interviewer, and then scoring species vulnerability would begin by following the activity-stressor list provided. The interviewer would often translate a discussion of species' vulnerability into a quantitative score. The interviewers consistently communicated with the expert to confirm the accuracy of the translated conversation into a score.

Experts were also asked to score their confidence in applying each vulnerability criteria score, with the following categories: low, moderate and high certainty. Each of these certainty categories referred to the amount of existing information (e.g.: expert knowledge, scientific literature) on how that activity-stressor combination affected each life-history stage in the Skeena Region. Low certainty indicated there were insufficient data to make an accurate assessment and experts scored with their "best guess." Moderate certainty represented moderate levels of information, inducing data specific to the entire B.C. coast. High certainty denoted extensive data were available, including data specific to the Skeena Region.

CALCULATING VULNERABILITY

To assess the vulnerability of eelgrass habitat in the Skeena, we asked experts to rank the vulnerability of the habitat to multiple human activities using five vulnerability criteria created by Halpern et al. (2007). For the fish species, we slightly modified Maxwell's species vulnerability criteria to express them more clearly for expert elicitation as species vulnerability was assessed in the original study through an extensive literature review. For each stressor-species interaction, experts were asked to assign rankings for each vulnerability criteria using a scale, ranging from zero to three or four (depending on the criteria) that represented simple discrete choices – for example, never (0) or persistent (4) for frequency, or fast (1) or slow (4) for recovery time. Experts could also rank threats as zero if there was no perceived threat and, in some cases, they could provide a range. For example, oil and chemical spills were commonly ranked with score ranges and not a single score. Experts also specified their overall level of confidence (or certainty) in the vulnerability criteria scores for each stressor-species combination on a three-tiered scale (low, medium, high).

Once all the expert data for each stressor-species (or species life stage) combination was collected and collated, the responses of the five vulnerability criteria were averaged and then summed up to yield a single vulnerability score. Individual vulnerability scores present the relative vulnerabilities of a species (or species life stage) to the different stressors associated with industrial and commercial activities.

TABLE 3
Vulnerability criteria and definitions for Skeena Cumulative Effects Assessment

VULNERABILITY CRITERIA & DEFINITIONS – EELGRASS	
Spatial scale	The spatial scale (sq. km) at which a single act of a stressor impacts the ecosystem, both directly and indirectly.
Frequency	Frequency of an activity-specific stressor occurring Example: count per life-history stage.
Trophic impact	Primary extent of marine life affected by a stressor.
Percentage change	Degree to which the species, trophic level(s), or entire ecosystem's "natural" state is impacted by a stressor.
Recovery time	Mean time (in years) required for the affected species, trophic level(s), or entire community to return to its former, "natural" state following disturbance by a particular activity.
VULNERABILITY CRITERIA & DEFINITIONS - CHINOOK SALMON, EULACHON	
Frequency	Frequency of an activity-specific stressor occurring Example: calculating a count per life-history stage.
Likelihood of mortality	Likelihood an individual will die from exposure to a stressor (within a life stage since the CE score was being developed for each life-history stage).
Recovery time	Amount of time it takes for an individual (in a given life stage) to fully recover to its pre-disturbance state.
Reproductive impacts	Considers how the impact of a stressor (on a life stage) affects the number of offspring produced by the population.
Population effects	The extent to which the population is affected by exposure to a stressor (within a given life-history stage).


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PATHWAYS OF EFFECTS

This complete list shows the human activities and climate change impacts, relevant stressors, and pathways of effects on species used in the Skeena Cumulative Effects Assessment study. The current model does not include projected marine changes due to climate change or projected impacts associated with shipping, and therefore underestimates total increases in impacts expected for the estuary. LNG is captured by three activities: port terminals, pipelines and sub-sea pipelines. The list provides the entire set of activities and stressors considered throughout the watershed and estuary. To see the full list activities and resulting stressors, please refer to the Appendix.

Activities

Marine activities

Groundfish hook and line
Herring fishery (gillnet, seine, spawn-on-kelp)
Salmon fishery (seine, gillnet)
Intertidal dive fishery (eg: Horseclam, geoduck)
Recreational/sport hook and line
Shrimp, prawn & crab trap
Shrimp bottom trawl
Eulachon gillnet, dip net or seine
Vessel<150m in length
Vessel 150-300m in length
Vessel>300m in length
Ocean disposal site
Sub-sea pipeline
Hydraulic dredging (one pass)
Landfill (leachate discharge to sea)

Coastal activities

Dock or wharf
Small craft harbour or marina
Port terminal
Seafood processing facility
Shellfish aquaculture (suspended)
Log dump and log boom
Pulp and paper mill (decommissioned)

River-based activities

Log dump and log boom
Salmon hatchery
Eulachon gillnet, dip net, or seine
Recreational/sport hook and line
Dam
Run-of-river hydropower
Small motorized boat traffic
Fish-stream crossing

Land-based activities

Linear development (road/rail)
Pipeline
Commercial or residential complex
Heavy industrial facility e.g. power plant, factory
Landfill
Sewage outfall site
Forestry cutblock (harvest)
Quarry or open-pit mine
Agriculture (farm)
Placer mining

Climate change

Stressors

Water & sediment quality

Inorganic chemical contamination
Coal ash pollution
Acidification
Anoxia/hypoxia
Ultraviolet radiation
Spills of heavier oils (minor, operational)
Spills of lighter oils or LNG (minor, operational)
Organic waste
Turbidity or total suspended solids (from sediment input)
Nutrient input or removal

Biological stressors

Direct capture/bycatch
Injury/incidental mortality
Bacteria/disease & parasites
Genetic contamination
Invasive species
Change in predator/prey dynamics

Physical stressors

Coastal engineering: Habitat alteration
Riparian zone engineering: Habitat alteration
Benthic disturbance (sedimentation or alteration of biota)
Change in temperature (oceans, rivers, lakes and streams)
Freshwater input or removal
Hydrology (coastal or river including stream flow dynamics)
Light or shade
Debris
Underwater noise
Direct loss of access to habitat or migration routes

Climate change stressors

Air temperature
Precipitation
Ultraviolet radiation
Sea surface temperature

Acidification

RESULTS

EULACHON

HUMAN ACTIVITIES (PARTIAL LIST)

- Linear development (pipelines and supporting infrastructure)
- Marine transport
- Small boat (including river boats)
- Forestry (log booming and sorting)
- Dredging
- Bycatch in commercial fisheries
- CLIMATE CHANGE

STRESSORS (PARTIAL LIST)

- Benthic disturbance
- Water quality
- Sedimentation
- Hydrology changes
- Direct mortality
- Contaminants

TOP SOURCES OF IMPACT ON EULACHON IN THE ESTUARY AND WATERSHED

	Current	Future
ESTUARY	1. Climate change 2. Vessels less than 150m 3. Vessels 150-300m 4. Vessels greater than 300m 5. Shrimp fishery 6. Anchorages 7. Moorages 8. Port terminals 9. Coastal forestry 10. Marinas	1. Climate change 2. Vessels less than 150m 3. Vessels 150-300m 4. Vessels greater than 300m 5. Shrimp fishery 6. Port terminal 7. Anchorages 8. Subsea pipelines 9. Moorages 10. Coastal forestry
WATERSHED	1. Climate change 2. Forestry 3. Railroads 4. Roads 5. Hydropower 6. Sewage 7. Dams 8. Oil and gas pipelines	1. Climate change 2. Forestry 3. Railroads 4. Roads 5. Hydropower 6. Sewage 7. Oil and gas pipelines

DATA GAPS AND RESEARCH PRIORITIES

Experts concurred that for eulachon there are many data gaps. In all, 117 stressor interactions across five life stages were identified as having limited or no data. In particular, the stage in which adults transition from the marine environment to the river prior to spawning was identified as an area of both limited knowledge/data and potentially higher vulnerability. The timing of this staging phase, as well as the species' behaviour and susceptibility to various stressors, were all felt to be critical data gaps.

Considering that eulachon are a cornerstone of the ecosystem, are critical to First Nations culture, and the Skeena population was classified as special concern by COSEWIC in 2014 (the Central Pacific Coast and Fraser River populations are endangered), surprisingly little information is available for this species. This must be rectified as soon as possible, given the importance of eulachon to fish, marine mammals and seabirds.

RECOMMENDATIONS

Experts identified the following areas as priorities for research:

- Migration/movement patterns, including offshore sampling, to determine presence.
- Information on early life history and dispersal in the estuary.
- Information on when eulachon are in a given area during their life cycle (eg: river, sub-watershed) and for how long.

CHINOOK SALMON

HUMAN ACTIVITIES

- Forestry
- Port development and operations
- Commercial fisheries
- Recreational fishing
- Stream crossings
- Operational discharges
- CLIMATE CHANGE

STRESSORS

- Hydrological changes
- Water quality and chemistry
- Water temperature
- Direct mortality/by-catch
- Noise
- Contaminants and spills

TOP SOURCES OF IMPACT ON CHINOOK IN THE ESTUARY AND WATERSHED

	Current	Future
ESTUARY	1. Climate change 2. Vessels less than 150m 3. Vessels greater than 300 m 4. Salmon seine 5. Salmon gillnet 6. Bycatch or incidental harm in other Commercial fisheries 7. Sport fisheries 8. Coastal mines 9. Coastal roads 10. Anchorages	1. Climate Change 2. Vessels less than 150m 3. Vessels 150-300m 4. Vessels Greater than 300 m 5. Shrimp Fishery 6. Port Terminal 7. Anchorages 8. Subsea pipelines 9. Moorages 10. Coastal Forestry
WATERSHED	1. Climate Change 2. Forestry 3. Railroads 4. Roads 5. Hydropower 6. Sewage 7. Oil and Gas Pipelines	1. Climate Change 2. Forestry 3. Railroads 4. Roads 5. Hydropower 6. Sewage 7. Oil and Gas Pipelines

DATA GAPS AND RESEARCH PRIORITIES

Notably, this study did not consider the life-cycle stage of adult ocean growth, which was beyond the scope of the research embodied here. Clearly, a variety of stressors and relevant human activity-related or climate change-related drivers could be considered at this life-history stage. Research on the adult ocean-growth life-cycle stage is strongly recommended.

The existing public data on Chinook use of the marine environment is very limited and likely led to an overestimation of impacts. Species data for information on how the Chinook use the estuary must be improved so that decision-makers have the data needed to understand the impacts of specific projects.

Though it is known that sport fishing has a negative impact on Chinook salmon, it is not included in the analysis. There is limited spatial data on sport fishing in both the estuary and watershed. Work needs to be done better quantifying the impact and location of sport fishing activities throughout the Skeena and Chatham Sound region.

RECOMMENDATIONS

Without a strategy to manage this impact, it will likely lead to fewer fish. To prevent this, actions need to put in place now to prevent impacts and enhance fish production throughout the watershed. Given past failures related to these goals, development projects should be required to demonstrate successful increases in productivity prior to proceeding.

EELGRASS

HUMAN ACTIVITIES (PARTIAL LIST)

- Dredging
- Shipping
- Oil spills (including exposure to chronic spills)
- Fishing (fixed gear, trawl, anchoring)
- Fixed intertidal structures
- Coastal development, including residential, industrial, reclamation
- Coastal forestry
- CLIMATE CHANGE

STRESSORS

- Eutrophication
- Anoxia
- Organic pollutants
- Contaminants
- Sediment disruption, erosion
- Suspension affecting light levels
- Pathogens
- Contaminants
- Salinity, pH, temperature
- Sediment chemistry

TOP SOURCES OF IMPACT ON EULACHON IN THE ESTUARY AND WATERSHED

	Current	Future
ESTUARY	1. Climate change 2. Coastal industrial development 3. Vessels less than 150m 4. Moorages 5. Commercial crab fishery 6. Anchorages 7. Port terminals 8. Coastal mines 9. Marinas 10. Urban development	1. Climate change 2. Port terminals 3. Coastal industrial development 4. Vessels less than 150m 5. Moorages 6. Commercial crab fishery 7. Anchorages 8. Coastal mines 9. Marinas 10. Urban development

DATA GAPS AND RESEARCH PRIORITIES

The value of eelgrass, including ecosystem-service values such as providing habitat for salmon smolts, is well documented. However, more research is needed to characterize eelgrass abundance and use by species across its range in the study area, and across different gradients of impacts (for example, reflecting the range of substrate composition, current and turbidity, levels, degree of habitat disruption, etc.). This level of detail would provide more insight into the spatial distribution of the habitat and ecosystem services for which this species is considered critical. Such work would include, at a minimum: expanded effort to map eelgrass in Chatham Sound, more study to determine optimum growth requirements of eelgrass, collection of new quantitative data on turbidity, salinity and nitrate levels in the Skeena Estuary, and field studies on the effect of herbivory, bioturbation, pathogens, oxygen depletion and temperature.

Being located close to shore and unable to avoid impacts, of the three species analyzed eelgrass is the most sensitive to coastal development. As habitat for other species, impact on eelgrass will likely have a multiplying impact on other marine species, but what that will be is not well understood. Understanding the impacts on ecosystem productivity arising from the loss of a given area of eelgrass is complex, and requires even more investigation beyond this cumulative effects model.

RECOMMENDATIONS

Given the level of development and the importance of the estuary, it is recommended that a full ecosystem model be developed for the estuary to inform development decisions. The Ecopath with Ecosim model applied to Roberts Bank would be well suited to the Skeena Estuary.

UNDERSTANDING CUMULATIVE EFFECTS IN THE WATERSHED

For Chinook salmon:

Of all the stressors combined, cumulatively the most impact on Chinook salmon will be in the Lower Skeena around the community of Terrace and in the Upper Bulkley. The impacts appear to be aggregated along the main transportation corridor with the highway providing an access point for the multitude of other resource roads that have a significant contribution to the impacts on Chinook.

In fact, when considering a single life-history stage, the largest impact in the watershed is the impact of stream crossings off the main stem of the Skeena River for Chinook returning to spawn. Rail is not only a source of stream crossings, but also a source of habitat loss for juvenile salmon.

The ability to look at life-history stages was especially useful when it came to assessing the impact of different activities, as different stressors had more or less impact at different stages of life. In the Bulkley Valley, for example, agriculture was found to have more of an impact on the egg and alevin (yolk-sac fry) stage than the returning spawners. Benthic disturbance and riparian habitat alteration are harmful at the egg stage. Anoxia (absence of oxygen), benthic disturbance and environmental flow changes are most harmful to spawning adults.

Because climate change will have an impact all throughout the watershed, and therefore affect all life-history stages for Chinook, it is and will continue to be the largest source of impact on Chinook in the watershed. To what extent the impact will help or harm Chinook salmon, and in which part of the watershed, is still unknown.

For eulachon:

The distribution of habitat is far more limited for eulachon than Chinook salmon. As a result, very few activities taking place in watersheds directly connect to eulachon habitat. The two activities that do intersect with eulachon habitat and have impact are forestry and rail. Rail may limit access to historical spawning habitat along the north side of the main stem of the Lower Skeena River. And forestry, which causes benthic disturbance, alteration of environmental flows, the creation of organic waste and changes to water temperature will likely have an impact on the egg stage of eulachon in the lower Skeena.

As with Chinook salmon, climate change is having a negative impact on eulachon in the egg-larvae stage, as there is a temperature discharge relationship that impacts larvae hatching. As a result, of all the human-caused effects, climate change is seen as having the most impact on eulachon, with temperature playing more of a role than precipitation at this point in time. As already stated, there is a high level of uncertainty associated with impacts of activities on eulachon and much more research is needed to confirm the level of actual impact.

In general terms, for these two species (Chinook and eulachon) the majority of the watershed appears to be in fairly good condition. The impacts are concentrated around major population centres and points of access along the main transportation routes. The river is protected from main stem dams, and those dams in the tributaries are not thought to have large impacts on these species. The main impacts come from stream crossings and fragmentation by roads, which is fortunate since these are impacts that can be restored. As one moves away from the main transportation corridor, the system is far less impacted with a few isolated exceptions related to historical mining and forestry.

One important caveat is that this assessment looked only at habitat for Chinook and there may be more remote headwater streams that are being impacted. Additional assessments on species such as Coho or lesser known amphibians would help flesh out the overall condition of the watershed.

UNDERSTANDING CUMULATIVE EFFECTS IN THE ESTUARY

Understanding the impact of activities on fish species in the marine environment is complicated by three factors. First, we have a limited understanding of where Chinook move and concentrate in the estuary. The Skeena Fisheries Commission, Lax Kw'alaams and Simon Fraser University have made great progress on how salmon are using the middle estuary, however much remains to be learned further out into the estuary. Second, some of the activities, such as fishing, are reported as occurring at broad geographical scales although they actually occur in concentrated locations resulting in what may be an overcalculation of impact of fishing. Third, we don't have an extensive understanding of how stressors like sound and light move through the marine environment and affect fish species; this should be explored in further detail.

For Chinook salmon:

Considering accessible data, the activities deemed to have the highest impacts on returning adult Chinook salmon are vessel traffic and fishing. As with the watershed, climate change is a major source of negative impact, and in the Skeena River, in particular, is considered to have more impact overall than any single stressor currently impacting Chinook in the Skeena. For out-migrating smolts, various types of fishing are not considered a threat. However large vessels are having an impact along shipping routes. The fact large vessels have an impact on Chinook salmon during both life-history stages (out-migrating smolts and returning adults) means it is considered a major source of impact. Other types of impacts, such as current port terminals, moorages and coastal mines, are sources of concern for juvenile chinook salmon.

For eulachon:

None of the marine life-history stages of eulachon are directly targeted by fisheries. However, where eulachon overlap with the shrimp fishery, there are impacts either through bycatch or harm caused through interaction with the fishing gear.

As with all of the other species, climate change is a major concern.

Port and vessels are another source of impact high on the list of activities impacting eulachon in the estuary.

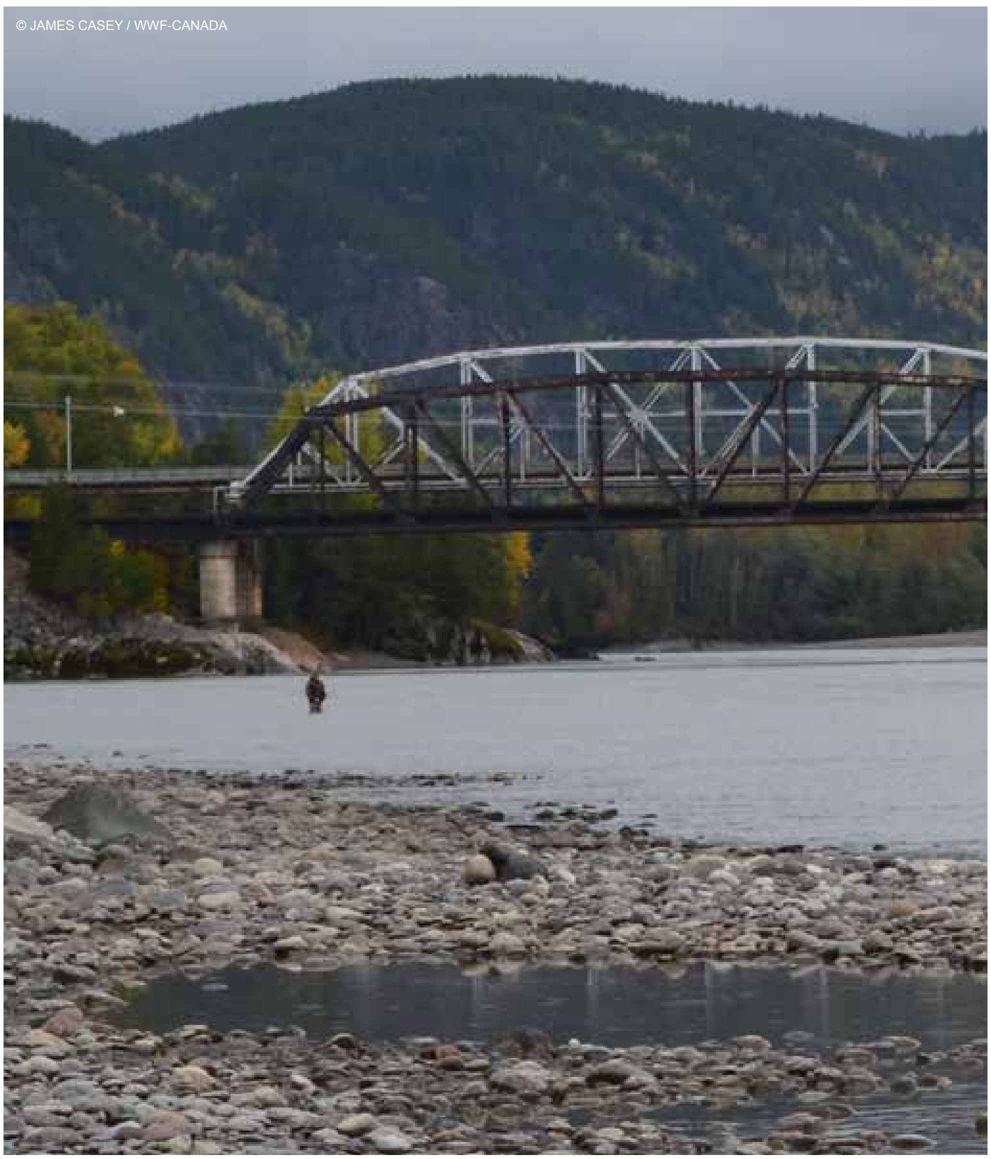
Unlike young salmon, eulachon aren't thought to venture as close to the shoreline, so impacts from shoreline activities like coastal roads and rail are thought to be fairly low.

For eelgrass:

Eelgrass, which is found close to the shoreline, is harmed by coastal activities: coastal industrial tenures, port terminals, moorages and anchorages are amongst the top sources of negative impact. These activities are concentrated around the Prince Rupert Harbour, with some impacts on Porcher Island to the south and around Big Bay to the north.

Climate change is also impacting eelgrass throughout its range in the estuary.

Finally, eelgrass beds are impacted by other coastal activities for which runoff reaches the estuary; coastal mines and coastal roads in communities are of particular concern.



CONSERVATION OPTIONS TO MAINTAIN THE HEALTH OF THE SKEENA ESTUARY

Securing the health of the Skeena Estuary will require effective management of emergent and existing stressors and their cumulative effects in a manner that maintains the ecological function of the estuary and its broader ecologically connected components, as well as the ecosystem services that they collectively provide. In addition to effective management of impacts, securing the long-term ecological functioning of the estuary will require spatial protection of key habitats and species that are ecologically, culturally and socially important and/or vulnerable.

WWF-Canada's research into mechanisms for protecting and conserving the Skeena Estuary revealed that no single level of government has the comprehensive regulatory tools, authority and capacity needed to protect the suite of values from the broad range of activities threatening the health of the estuary. If conservation of the estuary is to be achieved under the current level of jurisdictional fragmentation, it is clear that effective collaboration and partnerships between local government, provincial, federal and First Nations governments and agencies is required, along with meaningful engagement and participation of those who live and operate in, adjacent and upstream of the estuary. Such collaboration and engagement has to be sustained in the long-term, with a shared set of ecosystem-based goals and objectives that lay the framework to develop and implement specific measures to reduce impacts from stressors and maintain the values of the estuary and its ecological health and function. As noted, securing long-term functioning of the estuary at a local scale requires both the management of impacts and the protection of key areas within the estuary.

While such structured and co-ordinated management at the scale of the estuary is desirable, there are challenges to immediately moving along the path of integrated management. Conflict among competing uses and users, rapid industrial development pressure, overlapping jurisdiction and claims, together with limited co-ordination and resources to sustain long-term conservation and other competing priorities for respective governments, are just a few these challenges. Without longer-term planning, and a functional institutional structure that integrates management of impacts on important values, short-term decisions will continue to be made that enhance conflict between uses and users, and compromise the ecological values in the estuary. Conflict around Lelu Island and Flora Bank illustrates this point.

Despite the challenges, there are opportunities. The Marine Plan Partnership (MaPP) – a co-led process between 17 First Nations and the B.C. government to develop current and future plans for marine uses on B.C.'s North Pacific Coast – provides a governance structure and mechanism to begin addressing aspects of managing cumulative impacts and formalizing protection at a sub-regional scale, broader than the estuary, and with the participation of relevant interests and stakeholders in nearshore and foreshore areas. With the announcement of formalized marine plans for the Pacific North Coast Integrated Management Area, there is now tripartite governance structure based on the concept of ecosystem-based management that should guide decision-making across the coast of B.C. However, neither set of plans addresses challenges at the scale of the estuary and neither provides concrete performance measures that would influence the activities of key sectors. To translate the plans to action, industry stakeholders, such as the Port or development proponents, could play a more active role in recognizing and directing activities in the estuary as part of development plans actively mitigating local conflicts, for instance, in the case of Flora Bank.

Flora Bank is considered to have one of the largest eelgrass beds in B.C. and some of the most important intertidal habitat in the Skeena Estuary. Ample opportunity exists to mitigate the risk of harm to this habitat by relocating development to lands adjacent to the estuary that are already considered brown space. The Marine Protected Area (MPA) Network Planning Initiative for the Northern Shelf Bioregion offers another opportunity for stakeholders to convene and work to define the nature of spatial protection necessary to conserve the estuary.

Given this context and the current vacuum of effective interventions, WWF-Canada recommends both actions to reduce immediate threats in the short term (one to two years) while moving toward the development of a suite of management measures and functional institutional structure to conserve and manage impacts on the estuary in the middle term (two to five years). These recommendations are not iterative and there is overlap between them.

RECOMMENDATIONS

Governments implement policy mechanisms that result in regional cumulative effects assessments being applied at the appropriate ecological scale for the value being considered.

The current approach to making decisions about the environmental impacts of resource development is very project- and site-specific. As a result, opportunities for collaborative solutions are lost as the process encourages competition amongst similar development proponents. This compounds impacts as opposed to managing them strategically. For instance, the opportunity to place pipelines along a single corridor, or to examine the tradeoffs between the alternative export terminal locations, has been missed in the Skeena. The solution lies in implementing regional cumulative effects assessment and management to create a linkage between project decisions and strategic planning processes, such as marine planning or Land and Resource Management plans.

All levels of government should begin to implement regional cumulative effects assessments, similar to those proposed in the draft B.C. Cumulative Effects Policy, for the values they are mandated to maintain. Implementation of cumulative effects management will provide a means for government to offer co-ordinated recommendations to project developers about alternative locations and operational conditions that will maximize the development opportunities, while still maintaining the health of values, such as estuaries and rivers. The Skeena Cumulative Effects Assessment illustrates that watershed-scale assessments are possible, even with limited resources and data availability.

Enact interim measures for threat reduction to key estuary habitats.

Nearshore and juvenile fish habitat, such as eelgrass, are vital to the long-term function of the Skeena Estuary. With most of the new impacts on Chinook, eelgrass and eulachon projected to come from foreshore development, immediate action is needed on a strategy to maintain the eelgrass and intertidal habitat of the Skeena Estuary. With foreshore industrial development (terminals and port development) being the main emergent threat to these areas, it is recommended that a freeze on the footprint of industrial development and expansion in the inner estuary be established by the federal and provincial governments. Such a freeze should remain until measures that spatially protect sufficient and key portions of such habitat – so as to maintain the productivity and function of the estuary and its associated species assemblages – are put in place. Such measures may emerge from current planning processes, MaPP implementation, or the Northern Shelf Bioregion MPA Network Planning process. They can also emerge from other local initiatives that lead to management arrangements being negotiated among and between stakeholders and local First Nations.

As the largest contiguous eelgrass bed in the Skeena, Flora Bank should be protected from large-scale industrial development. Flora Bank and Lelu Island should remain undeveloped to allow for the creation of a wild salmon reserve as called for in the Lelu Island Declaration.

As most of the future impact on intertidal habitat would come from terminal development, the Port of Prince Rupert must be able to undertake meaningful actions within its jurisdiction to conserve the estuary. It is recommended that the Port of Prince Rupert's letter Patent and Port Authorities Operations Regulations (PAOR) be adjusted by the federal government to ensure the principles of ecosystem-based management are integrated into the Port of Prince Rupert's operational mandate, and thereby enable meaningful protection within the Port jurisdiction. The Letter's Patent should require the protection of sensitive habitats within the Port of Prince Rupert's boundary.

It is suggested that the PAOR be amended to turn it into a tool that enables the management of sensitive habitats that have already been identified by the Port of Prince Rupert, Fisheries and Oceans Canada and the District of Port Edward. This classification was last updated in 2010 and it is recommended that the Government of Canada develop regulations for inclusion in the PAOR that indicate how the Prince Rupert Port Authority is to maintain the condition of identified sensitive habitat.

Develop and implement estuary protection and conservation strategies through MaPP and other collaborative endeavours.

Collaboration and integrated planning already exist in the form of the Marine Plan Partnership, an effort between the Province and 17 Coastal First Nations. The MaPP North Coast Marine Plan Area encompasses an area from the Alaska border to Aristazabal Island (Figure 9). The North Coast Plan provides recommendations for achieving ecosystem health, social and cultural wellbeing, and economic development through an ecosystem-based approach to planning and management. Specifically, the plan focuses on direction for managing marine areas, uses and activities that are informed by First Nations strategic marine use plans and provincial strategic priorities, and where the province of B.C. has jurisdiction (MaPP 2015).

The Skeena Estuary is identified as a proposed Protection Management Zone (PMZ 14) within the MaPP Plan, along with several other areas in the North Coast. With the implementation of the plan still at an initial stage, there is an opportunity for stakeholders that have had limited engagement in the MaPP planning process stage to be more engaged during implementation. This includes the Prince Rupert Port Authority, marine transportation interests, and the commercial and recreational fisheries sectors. WWF-Canada recognizes that there are commercial and livelihood interests in the estuary that are important for the local economy. MaPP offers an existing venue where those with interests in the estuary can convene to develop meaningful measures for the management and protection of the estuary using a framework of ecosystem objectives. The estuary PMZ may be formally designated as some form of MPA in the future.

For the communities of Prince Rupert and Port Edward, the development permitting powers provided to them under the Local Government Act are useful tools for maintaining sensitive ecological habitat. These communities are encouraged to develop an ecologically sensitive lands strategy that integrates with the wider Great Bear Region and MaPP plans that surround the two cities. Efforts on the part of the two municipal governments to map and protect important habitats would help align the Official Community Plans of these communities with the large landscape plans developed for the Great Bear Region.

The SCEA found some of the main activities impacting the Skeena Estuary (marine fisheries, industrial development related to port development, shipping) are those managed by the federal government; federal tools and authority can further the management of impacts from such sectors on the Skeena Estuary.

It is recommended that through MaPP and with the collaboration of federal, provincial and local governments, a co-ordinated effort to implement a finer scale estuary management plan based on the Open Standards for Conservation be undertaken. The management plan should celebrate the fact that the communities of the region are located in one of Canada's most noteworthy estuaries.

The recently announced Environmental Monitoring Agreement between the Lax Kw'alaams and Metlakatla First Nations and the federal and provincial governments, to establish an environmental monitoring committee to oversee environmental monitoring and other compliance verification activities for the PNW LNG facility*, is a good example of enhanced First Nations, federal and provincial collaboration. The Environmental Monitoring Agreement should be expanded to address impacts that will arise if other LNG terminals are sited in the region. *(*since cancelled)*

Formally designate important valued areas in the estuary system for enhanced protection.

A significant government initiative also currently underway is the Northern Shelf Bioregion Marine Protected Area (MPA) Network planning process, which seeks to identify areas for designation as MPAs. It is recommended that the North Coast Marine Partnership Plan's identified Protection Management Zones (PMZs) be the foundation upon which the Northern Shelf Bioregion Marine Protected Area (MPA) Network base its proposal for an MPA network for B.C.'s North Coast. In addition to the PMZ for the Skeena Estuary, the Northern Shelf Bioregion MPA Network could include PMZs already identified in Chatham Sound, including around Lucy Island and Metlakatla Pass. In the process of conducting this study, it also came to light that the Skeena Estuary and Chatham Sound also contain very rare glass sponge reefs. These PMZs and other areas could be placed under some form of federal designation as a Marine Protected Area, National Marine Conservation Area, National Wildlife Area or, if effectively managed, some other effective area-based conservation measure.

As a second step, it is recommended that the Northern Shelf Bioregion MPA Network identify the suite of federal, First Nations and provincial spatial tools that can be applied in combination to maintain conservation objectives. The management plan should also incorporate the various Conservancies designated in the Great Bear Rainforest Land Use Order and parks in the vicinity. The marine area around Lucy Island (PMZ-25) has been identified as an Important Bird Area supporting a globally significant population of Rhinoceros Auklets and, as such, would be an appropriate location for the establishment of a National Wildlife Area to ensure it receives necessary protections. Similarly, the waters around Dundas are appropriate for the establishment of a National Wildlife Area that complements the intent of the provincial conservancies. While any protection measures in the Skeena Estuary should be developed in partnership with First Nations, First Nations could explore applied examples of Indigenous and Community Conserved Areas (ICCA) or

Tribal Parks in and adjacent to the Skeena Estuary. Both Big Bay (PMZ-15) and Metlakatla Pass (PMZ-26) are strong candidates for designation as Indigenous and Community Conserved Areas.

Develop upriver management actions.

Moving up the river into the upper estuary, the issue of jurisdiction is somewhat clearer, though the unaddressed issue of unceded territory remains. However, until such time as title is clarified, the province of B.C. does have the tools and responsibility to protect the aquatic health of the Skeena Region. Here eulachon spawning habitat needs to be protected. Perhaps the best spatial tool to achieve this is the provincial Wildlife Management Area (WMA) designation. The braided reach of the lower Skeena has such high wildlife values that it is clearly deserving of enhanced management. The WMA designation has the level of flexibility needed to allow non-harmful human uses in the area. Though rarely applied, the ability to create a critical wildlife area within a WMA could be drawn upon to help add additional protection for spawning eulachon within the river. A WMA designation could also include the flood plain islands in the lower Skeena that are such important sources of habitat complexity, benefitting both salmon and eulachon. Fully protecting a portion of the river requires addressing upstream impacts. The most important of those impacts is the flow of a river. Under the Water Sustainability Act, consideration of environmental flow is required by law. Any determinations of environmental flow in the Skeena should be set to maintain the condition of habitat in the upper and middle estuary.

As the largest estuary in the Great Bear, the Skeena Estuary is an integral part of one of Canada's unique contributions to global conservation. The conservation network created with the terrestrial Great Bear Agreement and recommended under the Marine Plan Partnership have created a highly valuable integrated system of protected areas for the area around the estuary. Unfortunately, within the estuary itself, the major activities that threaten Chinook salmon, eulachon and eelgrass are not addressed in the current plans. The recently launched Northern Shelf Bioregion Marine Protected Areas Network planning process may address this if shipping, ports and commercial fishing are included in the activities to be managed. Such wide-scale initiatives are needed but must be informed by, and enable, the necessary protections at finer scales. Actions need to be taken within the Port of Prince Rupert and the communities of Port Edward and Prince Rupert to maintain habitats and habitat connectivity. The municipalities have the policy tools they need to act, but have not applied those tools in a manner that would maintain the key ecological attributes of the estuary. The Prince Rupert Port Authority, on the other hand, currently does not have the policy tools needed and changes to key pieces of Canada's legislative framework are needed to enable the Port of Prince Rupert to adequately steward the estuary ecosystem of which it is part. The Skeena Cumulative Effects Assessment clearly highlights risks to the estuary. Enhanced protection is essential if the health of the Skeena Estuary is to be secured.

HOW THESE RESULTS CAN BE USED

BY ALL

- Informing conservation plans, such as identifying high- and low-cumulative effects locations that are important to species and could be prioritized for conservation.
- Supporting decision-making of referral applications or future marine or upland development applications by providing a tool to inform siting appropriateness for future developments.
- Supporting local and regional planning through zoning for future activities in areas with lower vulnerability or limited cumulative effects, while meeting the suitability needs of development activity.
- Co-ordinating mitigation and restoration priorities.

BY STAKEHOLDERS AND COMMUNITIES IN THE SKEENA

- The results provide strong rationale to leverage engagement of relevant management authorities whose decisions affect stakeholder values related to assessed species.
- Communities could use these results to inform future cumulative effects analyses on proposed projects in different locales.
- These results give communities the ability to see the impacts of cumulative effects from a number of projects in their vicinity as opposed to the cumulative effects of just one project, making them better able to safeguard against inadequacies in the existing decision-making process.

BY INDUSTRY

- This approach allows industry to characterize impacts in terms of likely changes to vulnerability on valued components, in a context of multiple human activities.
- These findings can help industry identify areas that may be high-risk regions for development given the current levels of impact.
- These findings do identify the key impact pathways that local experts have concerns about that may require collaborative research.

BY GOVERNMENT AUTHORITIES

- This approach identifies key areas where cross-sectoral management can be improved; for example, in data- and expertise-sharing on impacts for stressor-species interactions.
- This study provides an information base that can aid in objective setting in resource management; for example, it can be used to spatially consider trade-offs among values (eg: “How much increased vulnerability to species X are we willing to accept?”).
- This study can provide direction for monitoring plans for estuary and selected species.
- The study can help prioritize scientific research needs to support resource management decision-making.

CONCLUSION

The future of the Skeena River, its people and ecosystems will be closely influenced by the development of industries related to the movement of goods through the estuary to international markets. At the same time, the Skeena is located in the Great Bear Region, for which the local people have a longstanding commitment to the principles of ecosystem-based management. The Skeena has a history of extensive First Nations use and a renewed move toward local governance and management. Reconciling these two realities is a monumental challenge but one that holds the promise of substantive innovation around the relationship between trade and sustainability. As an ecologically rich region subject to increasing pressures from both climate change and industrial development, failing at this challenge will have real impacts on the natural wealth of the region.

The opportunity to realize a truly green economy is unprecedented in the Skeena but risks slipping away without serious efforts to conserve the estuary. Poor decisions of the past need to be revisited and adjusted to protect Flora Bank. The application of existing tools, such as the Port Land Use Planning and the Canadian Environmental Assessment Act 2012, has proven to be inadequate in securing the ecological health of the Skeena Region. New tools such as regional and strategic cumulative effects assessments can drive toward sustainability when matched with an ongoing integrated management process such as the Marine Plan Partnership (MaPP).

Despite the challenges, there are opportunities. The MaPP plans, and their forthcoming implementation, provide a governance structure and mechanism to begin addressing aspects of managing cumulative impacts and formalizing protection at a sub-regional scale with the participation of relevant interests and stakeholders. Industry stakeholders, such as port or development proponents, should play a more active role in recognizing and directing their activities toward the conservation of the estuary as part of development plans. Such collaboration and engagement has to be sustained and long term, with a shared set of goals and objectives that lay the framework to develop and implement specific measures to reduce impacts from stressors and maintain the values of the estuary and its ecological health and function.

The assessment of cumulative effects at the regional scale is an emerging practice and any assessment will have a number of weaknesses associated with data gaps and methodological challenges. However, to ensure that the important decisions that are informed by regional assessments are not left strictly to the technical experts, it is important that stakeholders are provided with the tools and capacity to engage and challenge the assessment methods being used.

WWF-Canada, as part of the Skeena community, developed the SCEA as one tool to help decision-makers plan for and manage the coming changes. ArcGIS toolboxes and user guides developed for this study can be used by others interested in replicating the assessment.

WWF-Canada will continue working with local communities to combat threats and strengthen biodiversity to improve the wellbeing of the people and wildlife for whom the Skeena Watershed is home.

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APPENDIX

Full list of activities and resulting stressors

Activity	Stressor
Agriculture	Stressor
	anoxia/hypoxia
	benthic disturbance
	hydrologic flows
	light/shading
	riparian habitat alteration
Anchorage	anoxia/hypoxia
	bacteria
	benthic disturbance
	Inorganic Chemical contamination (IOC)
	light/shading
	organic waste
	temperature change
	Total Suspended Solids (TSS)
Commercial residential tenures	anoxia/hypoxia
	benthic disturbance
	Inorganic Chemical contamination (IOC)
	organic waste
	temperature change
	Total Suspended Solids (TSS)
Docks and wharves	anoxia/hypoxia
	bacteria
	benthic disturbance
	Inorganic Chemical contamination (IOC)
	organic waste
	temperature change
Forestry	benthic disturbance
	hydrologic flows
	Loss of access to habitat/migration
	riparian habitat alteration
	temperature change
	Total Suspended Solids (TSS)
Hatchery	capture/bycatch
	disease/parasites
	genetic_contam
	incidental mortality
Hydraulic dredging	benthic disturbance
	incidental mortality
	Total Suspended Solids (TSS)

Activity	Stressor
Hydraulic dredging adjacent to inactive pulp mill (not used model)	Inorganic Chemical contamination (IOC)
Industrial tenures	anoxia/hypoxia
	benthic disturbance
	freshwater input/removal
	hydrologic flows
	Inorganic Chemical contamination (IOC)
	organic waste
	temperature change
	Total Suspended Solids (TSS)
Log booms	bacteria
	benthic disturbance
	detritus
	Inorganic Chemical contamination (IOC)
	light/shading
	Loss of access to habitat/migration
Marinas	anoxia/hypoxia
	bacteria
	benthic disturbance
	Inorganic Chemical contamination (IOC)
	light/shading
	organic waste
	temperature change
	Total Suspended Solids (TSS)
Mines	acidification
	benthic disturbance
	hydrologic flows
	Inorganic Chemical contamination (IOC)
	Total Suspended Solids (TSS)
Moorages	anoxia/hypoxia
	bacteria
	benthic disturbance
	Inorganic Chemical contamination (IOC)
	light/shading
	organic waste
	temperature change
	Total Suspended Solids (TSS)
Ocean disposal sites	sedimentation
	Total Suspended Solids (TSS)

APPENDIX (CONTINUED)

Activity	Stressor
Pipelines	benthic disturbance
	heavy oils
	hydrologic flows
	light oils
	organic waste
	riparian habitat alteration
	temperature change
	Total Suspended Solids (TSS)
Subsea pipelines	benthic disturbance
	heavy oils
	light oils
	sedimentation
Port terminals	bacteria
	benthic disturbance
	Inorganic Chemical contamination (IOC)
	light/shading
	underwater noise
	temperature change
	coal ash pollution
	organic grain waste
	organic potash waste
Quarries	benthic disturbance
	hydrologic flows
	Total Suspended Solids (TSS)
Railroads	benthic disturbance
	hydrologic flows
	Inorganic Chemical contamination (IOC)
	light oils
	Loss of access to habitat/migration
	riparian habitat alteration
	sedimentation
	Total Suspended Solids (TSS)
Roads	benthic disturbance
	hydrologic flows
	Inorganic Chemical contamination (IOC)
	light oils
	Loss of access to habitat/migration
	riparian habitat alteration
	sedimentation
	Total Suspended Solids (TSS)

Activity	Stressor
Seafood processing plants	bacteria
	disease/parasites
	organic waste
Coastal sewage outfalls	bacteria
	Inorganic Chemical contamination (IOC)
	organic waste
	predator-prey dynamics
Shellfish aquaculture	benthic disturbance
	light/shading
	nutri_inp_rem
	organic waste
	Total Suspended Solids (TSS)
Stream crossings (culverts)	benthic disturbance
	Loss of access to habitat/migration
	Total Suspended Solids (TSS)
Waste disposal sites (landfills and dumps)	benthic disturbance
	Inorganic Chemical contamination (IOC)
	organic waste
Freshwater climate change – precipitation	benthic disturbance
	hydrologic flows
Freshwater climate change – temperature change	anoxia/hypoxia
	temperature change
Dams	benthic disturbance
	hydrologic flows
	incidental mortality
	nutri_inp_rem
	temperature change
	Total Suspended Solids (TSS)
Recreational fishing – hook and line	capture/bycatch
	hook and line
	incidental mortality
Run of the River hydroelectric facilities	hydrologic flows
	incidental mortality
	temperature change
	Total Suspended Solids (TSS)
Sewage outfalls	bacteria
	Inorganic Chemical contamination (IOC)
	organic waste

APPENDIX (CONTINUED)

Activity	Stressor
Small boats on the river	debris
	incidental mortality
	Inorganic Chemical contamination (IOC)
	underwater noise
	organic waste
Commercial fishing - Crab trap	benthic disturbance
	capture/bycatch
Commercial fishing - Geoduck dive	benthic disturbance
	capture/bycatch
	light/shading
	underwater noise
Commercial fishing - Halibut longline	capture/bycatch
Commercial fishing - Herring gillnet (not applied in model)	benthic disturbance
Commercial fishing - Herring gillnet	capture/bycatch
Commercial fishing -Herring roe gillnet	benthic disturbance
	capture/bycatch
Commercial fishing - Herring roe seine	capture/bycatch
Commercial fishing - Herring seine	capture/bycatch
Commercial fishing - Herring Spawn on Kelp (not applied in model)	benthic disturbance
Commercial fishing - Herring Spawn on Kelp	capture/bycatch
Commercial fishing - Herring Spawn on Kelp	incidental mortality
Commercial fishing - Prawn trap	benthic disturbance
Commercial fishing - Prawn trap	capture/bycatch
Commercial fishing - Red urchin dive	benthic disturbance
Commercial fishing - Red urchin dive	capture/bycatch
Commercial fishing - Red urchin dive	light/shading
Commercial fishing - Red urchin dive	underwater noise

Activity	Stressor
Commercial fishing - Salmon gillnet	capture/bycatch
Commercial fishing - Salmon seine	capture/bycatch
Commercial fishing - Salmon seine	incidental mortality
Commercial fishing - Salmon troll	capture/bycatch
Commercial fishing - Salmon troll	incidental mortality
Commercial fishing - Schedule II license longline	capture/bycatch
Commercial fishing - Sea cucumber dive	benthic disturbance
Commercial fishing - Sea cucumber dive	capture/bycatch
Commercial fishing - Sea cucumber dive	light/shading
Commercial fishing - Sea cucumber dive	underwater noise
Commercial fishing - Shrimp beam trawl	benthic disturbance
Commercial fishing - Shrimp beam trawl	capture/bycatch
Commercial fishing - Shrimp beam trawl	incidental mortality
Commercial fishing - ZN License	capture/bycatch
Climate Change in the marine - Acidification	acidification
Climate Change in the marine - Sea surface temperature change	anoxia/hypoxia
Climate Change in the marine - Sea surface temperature change	disease/parasites
Climate Change in the marine - Sea surface temperature change	freshwater input/removal
Climate Change in the marine - Sea surface temperature change	hydrologic flows
Climate Change in the marine - Sea surface temperature change	temperature change
Climate Change in the marine - Sea surface temperature change	temperature change

APPENDIX (CONTINUED)

Activity	Stressor
Climate Change in the marine - Sea surface temperature change	temperature change
Climate Change in the marine - Sea surface temperature change	UV Radiation
Sport or recreational fishery – Anadromous fish	capture/bycatch

Activity	Stressor
Sport or recreational fishery – Anadromous fish	incidental mortality
Sport or recreational fishery – Groundfish	capture/bycatch
Sport or recreational fishery – Groundfish	incidental mortality