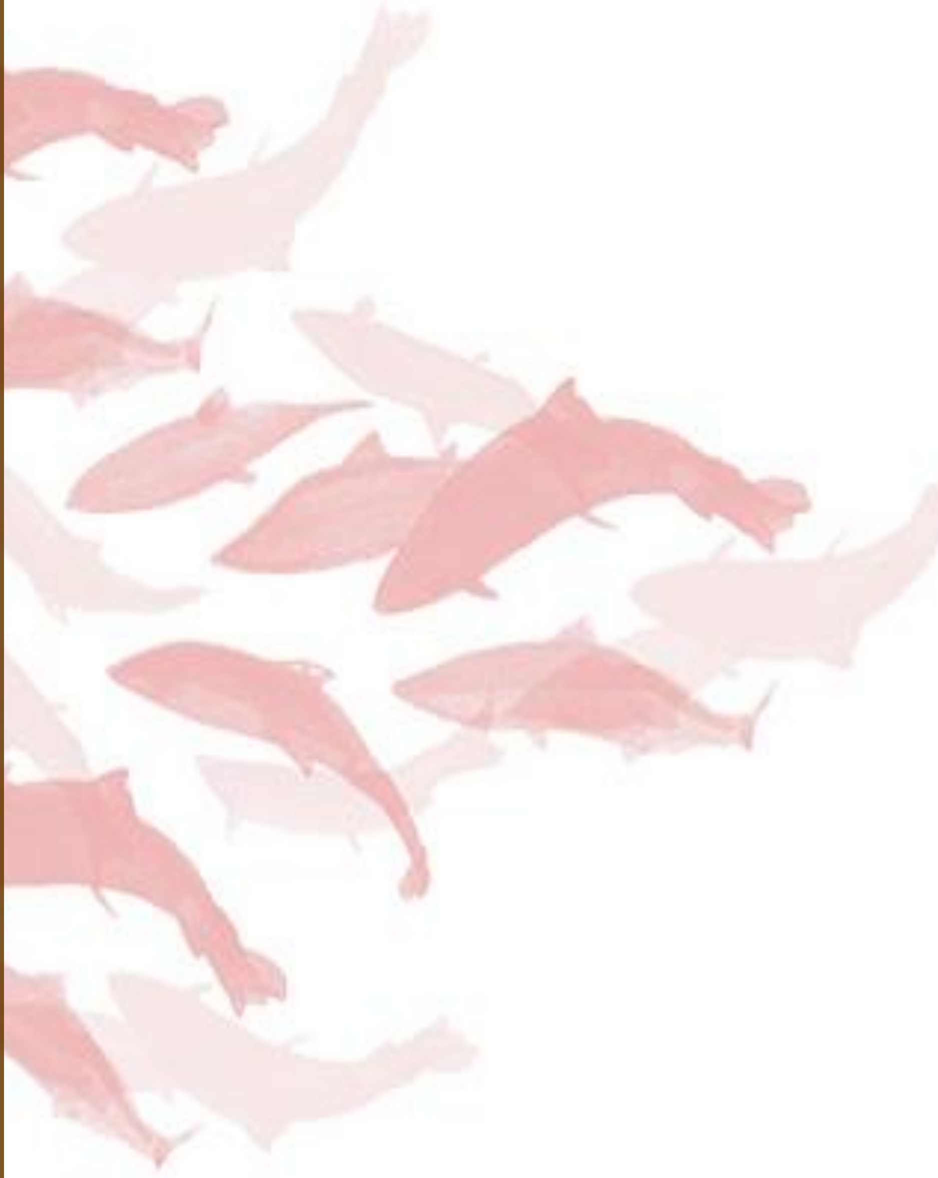
# Skeena River Estuary Assessment

## Technical Report



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More information about this project can be found in these publications:

Pacific Salmon Foundation. 2015. *The Skeena River Estuary – A Snapshot of Current Status and Condition*. Vancouver, BC.

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# EXECUTIVE SUMMARY

The Skeena is the second largest river in British Columbia, and one of the longest un-dammed rivers in the world. The Skeena River estuary possesses extensive mudflats and shallow, intertidal passages that have been identified as potentially critical habitats for juvenile salmon (Higgins and Schouwenburg 1973 as cited in Ocean Ecology 2014). Maintaining the integrity and function of these estuarine habitats is therefore predicted to be important to the conservation of Skeena River salmon populations. However, there are significant information gaps in the status of the Skeena estuary. These gaps hinder the ability to manage the status of estuarine salmon habitats and the human activities that have the potential to impact them.

The objective of this project was to assess the status and condition of the Skeena estuary from the perspective of salmon. Three questions framed this project:

1. What are the key pressures on salmon habitat?
2. What is the status of salmon habitat in the Skeena River estuary?
3. What are the critical gaps in our understanding of the Skeena River estuary?

This project was initiated in response to the need to quantify baseline conditions against which to evaluate future pressures in the estuary, monitor changes in condition over time, and to support local communities in identifying potential threats to salmon and their habitats.

With input from a regional Technical Advisory Committee (TAC), we generated a snapshot of the current status of the estuary, established a baseline for monitoring changes in the condition of the estuary over time, and developed a framework for evaluating key pressures on salmon habitat in the Skeena estuary.

A global review of estuary assessments informed the approach undertaken for this project.  The review, in conjunction with input from the TAC, informed the development of a salmon-focused conceptual model for the Skeena estuary. Elements within the conceptual model helped to identify 37 potential indicators for the assessment of pressures, habitat and salmon populations within the estuary. Existing and available datasets were identified and compiled to inform 23 of these key indicators. Indicators were then assessed against various benchmark values to determine the status of each estuary indicator.  The assessment made use of existing datasets, which were reviewed through a standardized Data Quality Assessment (DQA) to ensure scientific quality and relevance to the Skeena estuary assessment.

Substantial limitations in the availability, quality, and spatial coverage of the data across all indicators precluded an assessment of the status and condition of the estuary as a whole. The analysis was instead restricted to individual indicators, which provided an indication of the current status and condition of salmon habitat and habitat pressures in specific areas and helped establish baseline conditions against which future changes in the status of individual indicators can be evaluated.

This project revealed considerable gaps in information for the Skeena estuary, highlighting the need for increased monitoring and a long-term commitment to assess trends in estuary indicators.  We recommend that future monitoring efforts focus on four priority topics:

1. Distribution and abundance of juvenile salmon;
2. Growth and condition of juvenile salmon;
3. Extent of eelgrass; and
4. Density and diversity of key salmon food.

Addressing these knowledge gaps should be an immediate priority for government agencies, First Nations, and all stakeholders with an interest in the Skeena estuary.  By advancing our scientific understanding of the Skeena estuary in relation to juvenile salmon, we will be better able to identify strategies that conserve and protect high value salmon habitats and minimize risks to wild salmon.

# 1 INTRODUCTION

## 1.1 Objective

The objectives of the Skeena estuary assessment were to:

1. Utilize existing data to document salmon habitat characteristics in the Skeena estuary;
2. Select key estuary indicators and assess their status;
3. Identify data gaps and limitations; and
4. Develop a prioritized, salmon-focused, monitoring framework for the Skeena estuary.

These objectives are intended to support the long-term assessment of status and trends in pressures, key salmon habitats, and salmon condition in the estuary and aid our understanding of how realized and potential natural and human-induced changes in the Skeena estuary affect salmon populations.

## 1.2 Report Structure

This report details the methods used to assess the condition of the Skeena estuary from the perspective of salmon. Section 2 describes a review of regional and international estuary assessments and of the approach used to complete this assessment. Sections 3-8 provide a detailed description of the methods used for each element of the assessment, including the development of a conceptual model, the selection of indicators and benchmarks, a data quality assessment, and the results of the Skeena estuary assessment. Section 9 summarizes data gaps, prioritizes associated monitoring needs, and provides preliminary recommendations for future monitoring in the Skeena estuary.

More detailed information regarding the project methods can be found in Appendices 1-4. In addition, the methods and results of the data quality assessments are detailed in *Skeena River Estuary Assessment Supplemental: Data Quality Assessments* (Pickard et al. 2015).

A complementary document, *The Skeena River Estuary – A Snapshot of Current Status and Condition* (Pacific Salmon Foundation 2015), presents the main results of the estuary assessment, including maps which display the spatial data used in the assessment and the status of individual estuary indicators. *The Skeena River Estuary – A Snapshot of Current Status and Condition* is meant to be read in tandem with *Skeena River Estuary Assessment: Technical Report* (i.e. this document), which provides more technical and methodological detail.

# 2 APPROACH

## 2.1 Global Review of Estuary Assessment Approaches

A broad review of the literature on estuary assessments was undertaken, including an examination of implemented assessments and conceptual frameworks employed across multiple jurisdictions (e.g. British Columbia, US Pacific Northwest, other international jurisdictions). In the end, 17 relevant estuary projects were evaluated, with a focus on the identifying following key elements:

1. Estuary project location.
2. Estuary size (or range of sizes evaluated).
3. Objective of project.
4. Whether or not there were explicit conceptual models developed to support indicator selection and aggregation.
5. General approaches taken within the project.
6. Citable reference(s) or websites to support further review.
7. Total number of indicators used for the project and types of indicators developed.
8. Indicator categories developed (if any), capturing broad processes and functions.
9. Specific indicators used for the project.
10. Approaches used for setting indicator benchmarks (e.g. absolute vs. relative benchmarks).
11. Indicator aggregation and final roll-up (cumulative) approaches.
12. Spatial scale of indicator monitoring and roll-ups.
13. Temporal scale of indicator monitoring and roll-ups.
14. Approaches for explicitly recognizing data quality and uncertainty issues.
15. Clear examples of information reporting applications or estuary report card formats.
16. General comments on the projects.

These elements represent the core building blocks for structuring an estuary assessment and allowed us to examine similarities and differences across projects and develop a framework for assessing the Skeena estuary. See Appendix 1 for the list of projects reviewed.

Project objectives varied extensively across the 17 projects reviewed, ranging from the assessment of habitat conditions and pressures, reporting on ecological processes and functions, determining environmental risk, and tracking long-term trends in environmental conditions. Indicators represented habitat state, biotic state, pressures, and system vulnerability, and the total number of indicators in each project was highly variable. While a few projects used conceptual pathways of effects to justify indicator selection, most projects did not provide a clear rationale for the selection of indicators. Further information about indicator selection within the reviewed estuary assessments is provided in Section 4 and Appendix 4.

## 2.2 Skeena River Estuary Assessment Approach

The framework for the estuary assessment was informed by the global review of estuary assessments (see Section 2.1). The basic steps involved in completing the Skeena estuary assessment are outlined below.

1. *Conceptual Model:* A salmon-focused conceptual model was developed to provide a common understanding of the key factors that influence salmon populations in the Skeena estuary.
2. *Data Compilation:* Existing datasets for the Skeena estuary were identified and compiled from multiple data sources.
3. *Data Quality Assessment (DQA):* A DQA was undertaken to systematically and objectively review the scientific merit and the relevance of the data to our stated project objectives.
4. *Selection of Indicators:* The conceptual model informed the selection of indicators for assessing pressures on the Skeena estuary and the condition of habitat and salmon populations.
5. *Selection of Benchmark Values & Assessment of Indicators:* For each indicator, benchmark values were developed with guidance from the TAC, and used to assess the status of each estuary indicator.
6. *Gap Analysis and Proposed Monitoring Framework:* Gaps in monitoring efforts and data collection related to the elements of the Skeena Estuary Conceptual Model were identified. A two-tier prioritization process was developed and applied to the data gaps in order to identify priorities for future monitoring needs.

Two Technical Advisory Committee (TAC) workshops were held in Prince Rupert, British Columbia in December, 2014 and May, 2015. TAC contributions and feedback were incorporated into the assessment methods and the interpretation of project results.

# 3 CONCEPTUAL MODEL

## 3.1 Overview of Conceptual Modelling

Ecological systems are inherently complex. A large number of natural and human drivers can interact with a system's components to affect its form and function. By providing a common understanding of how a system works, conceptual models can be helpful for identifying the key elements needed for habitat assessments and long-term monitoring programs. For the Skeena estuary assessment, a qualitative "systems approach" for developing a conceptual model was employed. A systems approach characterizes the system of interest from a socio-ecological perspective according to its components (e.g. species or habitats) and processes (e.g. forest disturbance) and then uses a series of impact pathways to represent relationships among natural and human drivers, linkages, and outcomes of interest (e.g. species or habitat endpoints; Grant et al. 1997).

While a qualitative systems approach does provide an informative conceptual model for understanding the Skeena estuary, an important caveat is that it does not provide an explicit indication of the relative importance of various components and linkages and all pathways are considered to be of equal importance. Other approaches can be developed that are semi-quantitative and combine graphical illustrations with quantitative techniques to provide numerical predictions of how a system functions (see Nelitz et al. 2012 and references therein). Semi-quantitative approaches typically rely on expert judgement to quantify linkages based on their relative importance or influence in a system. A semi-quantitative approach could be considered for future development of the Skeena River Estuary Conceptual Model.

## 3.2 Conceptual Model of the Skeena River Estuary

The Skeena Estuary Conceptual Model was developed with the intent of informing indicator selection for assessment and monitoring (i.e. a top-down approach for indicator selection using pathways of effects to identify quantifiable indicators necessary for capturing key estuarine processes and functions). Consistent with the principles described in Appendix 2, the conceptual model consists of a fairly simple structure. First, three independent impact categories were used to capture major processes and drivers of change in the estuary: (1) water quality, (2) habitat and lower food web, and (3) salmon populations. The approach and general impact categorizations are consistent with those used by other jurisdictions for estuary assessments (Section 2.1). This helped structure a simple top-down conceptual model that could be easily understood, worked with, and communicated. Second, elements in the conceptual model were organized into distinct pressure and state indicator types. A pressure-state framework

(Ironside 2003, Newton 2007) has been recommended by Stalberg et al. (2009) to guide salmon habitat monitoring under Action Step 2.2 of Strategy 2 of Canada's Wild Salmon Policy (Fisheries and Oceans Canada 2005). Adopting this approach is consistent with general guidance under the Wild Salmon Policy and should allow for seamless integration with some key projects within the Skeena estuary that have been developing assessment elements using different indicator types (e.g. habitat and biotic stat indicators used in Ocean Ecology 2014).

Pressure indicators represent proactive measures of potential impacts on salmon habitats. They are often monitored over broad spatial extents. Pressure indicators provide information about the degree of stress on key salmon habitats. State indicators are detailed descriptors (generally based on field measurements) of the actual "on-the-ground" condition of ecosystem elements. They provide information on salmon and salmon habitats at a localized scale. Pressure and state indicators can be used together to provide a basis for understanding system status and the key drivers affecting salmon population responses.

The Skeena Estuary Conceptual Model in Figure 1 displays key estuary pathways of effect resulting from current or potential future pressures (red) in the estuary within and across three primary impact categories (water quality, salmon habitat & lower food web, and salmon populations). Key pathway linkages that ultimately affect wild salmon (yellow) either directly or indirectly through a given ecosystem component[1] (purple) are grouped by receptor (identified by numbered circles) and described in Table 1.

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[1] Ecosystem components in this conceptual model are analogous to habitat and biotic "state" indicators within the WSP Strategy 2 pressure-state framework.

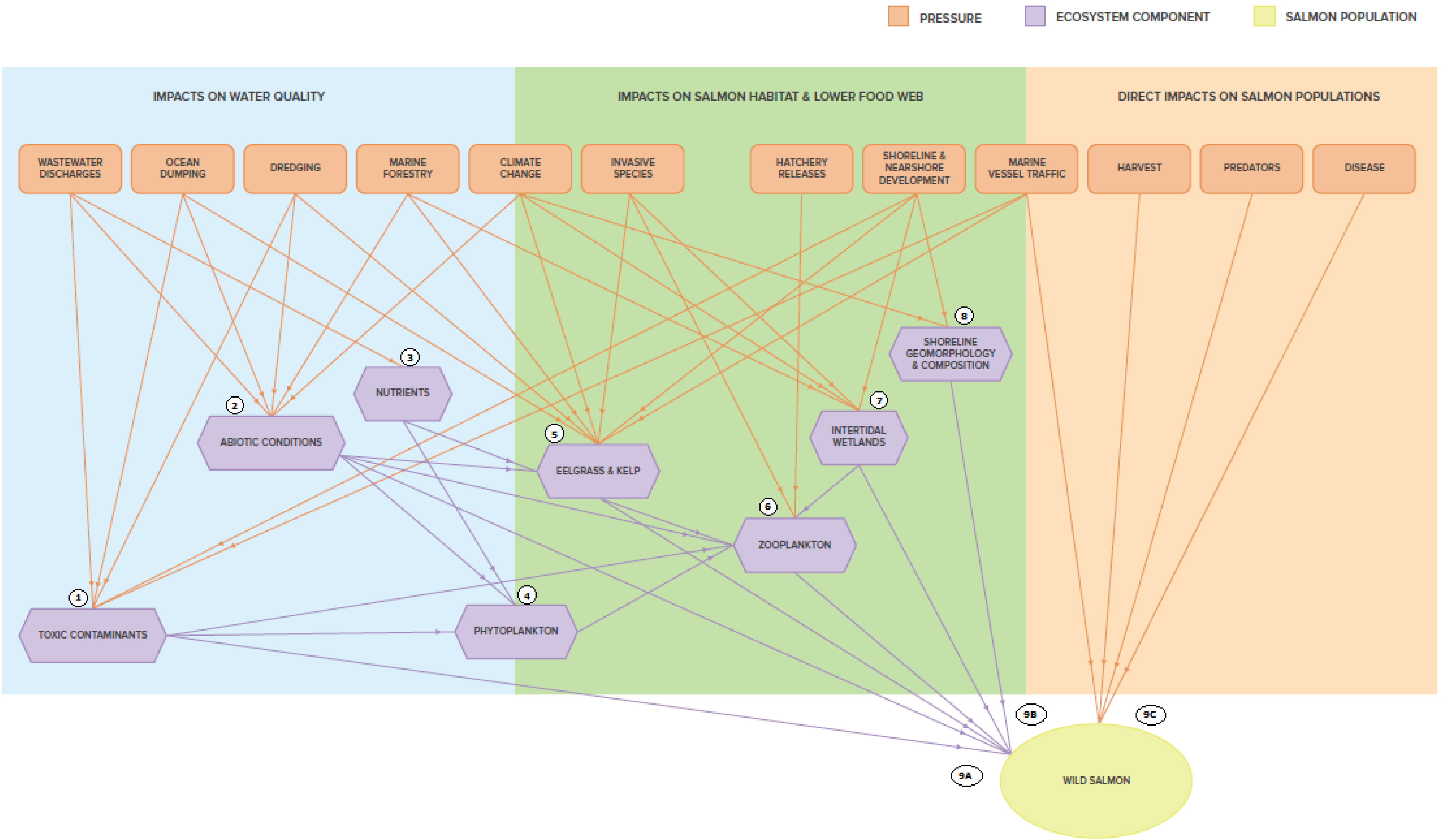


Figure 1. Conceptual model of the Skeena River estuary. The model is organized in three high-level impact categories that capture the major pressures and processes that relate to wild salmon. Linkages are denoted by numbered circles, which are described in Table 1.

**Table 1. Description of numbered linkages in the salmon-focused Skeena River Estuary Conceptual Model (see Figure 1).**

| Impact Category | Model Linkage # | Linkage Description |
|---|---|---|
| Water Quality | 1 | **Increase in Toxic Contaminants due to Increased Industrial Activity**<br>• Pollutants from municipal and industrial sources (e.g. wastewater, ocean dumping, marine vessels, train traffic, industrial plants, etc.) could impact water quality through chemical or bacterial contamination of the water column and sediments. The impacts to water quality will depend on the amount and toxicity of the polluting substance.<br>• Fuel and oil spills are a risk from regular marine vessel traffic (*note that in the event of a major oil/gas spill the extent of toxic pollutants from marine vessels could increase significantly; such spills may be infrequent, but have potentially high consequences).<br>• Some industrial disturbances (e.g. dredging) may cause the release of pollutants from benthic sediments previously contaminated by past industrial activities (e.g. pulp mill effluent). |
| | 2 | **Changes in Abiotic Conditions due to Increased Industrial Activity and/or Changes in Climate**<br>• Local municipal and industrial activities could impact water quality by increasing turbidity or depleting dissolved oxygen levels in areas affected.<br>• More broad-scale changes in key water quality parameters (e.g. sea surface temperature, pH, salinity) could potentially be caused by climate change. |
| | 3 | **Changes in Nutrients due to Increased Industrial Activity**<br>• High levels of pollutants from municipal and industrial sources could impact water quality through excessive nutrient enrichment (phosphorus and nitrogen). |
| Habitat & Lower Food Web | 4 | **Changes in Phytoplankton due to Changes in Water Quality**<br>• Some industrial waste products can directly injure or kill aquatic life even at low concentrations.<br>• Rates of primary production by phytoplankton are regulated by a range of abiotic conditions that could be disrupted by industrial activities or by broadscale changes resultant from climate change.<br>• Excessive nutrient levels can trigger large increases in phytoplankton production that impact water quality and contribute to development of noxious algae blooms that deplete dissolved oxygen, harming fish and other aquatic life. |
| | 5 | **Changes in Eelgrass & Kelp due to Increased Industrial Activity, Changes in Climate, and/or Introductions of Invasive Species**<br>• Physical disturbance of substrate resulting from industrial activities (e.g. dumping, dredging, log booming, marine vessel traffic, nearshore development) can remove or damage beds of eelgrass and kelp.<br>• Invasive eelgrass could potentially displace native eelgrass and kelp species and limit their spatial distribution.<br>• Excessive levels of nutrients can harm eelgrass due to algal light shading, stimulation of epiphyte (plants which live on eelgrass) growth, and, metabolic impacts.<br>• Toxic contaminants in sediment could be taken up by eelgrass and macroalgae and limit their growth and local distribution.<br>• More broadscale impacts on key abiotic parameters (e.g. sea surface temperature, pH, salinity, UV) from climate change could limit distribution and growth of both eelgrass and kelp. |
| | 6 | **Changes in Zooplankton due to Changes in Productivity, Invasive Species, Competition, and/or Climate**<br>• Changes in primary productivity from phytoplankton, and aquatic plants, and kelp could affect zooplankton productivity.<br>• Invasive zooplankton species or invasive shellfish that feed on zooplankton could alter native zooplankton population dynamics.<br>• Hatchery released salmon smolts could compete for zooplankton prey, reducing the food base for wild salmon.<br>• Loss of eelgrass, kelp beds and intertidal wetlands could reduce nutrient inputs |

| | | |
|---|---|---|
| | | into the estuary that help support zooplankton. |
| | 7 | **Changes in Intertidal Wetlands due to Increased Industrial Activity and/or Changes in Climate**<br>• Local shoreline development (e.g. industrial infrastructure, log booming, etc.) could lead to temporary or permanent loss or impairment of estuarine intertidal wetlands.<br>• Invasive wetland plants could affect wetland structure and associated nutrient inputs.<br>• Broad scale loss of intertidal wetlands could be a consequence of sea level rise under potential climate change scenarios. |
| | 8 | **Changes in Shoreline Geomorphology & Composition due to Increased Industrial Activity and/or Changes in Climate**<br>• Development of industrial infrastructure in the nearshore environment could simplify shoreline geomorphology) and damage the structure and composition of coastal and riparian vegetation, which are important sources of nutrients and shade in estuaries.<br>• Broad-scale simplification of shoreline geomorphology could also be a consequence of sea level rise under potential climate change scenarios. |
| **Water Quality** | 9A | **Changes in Salmon Populations due to Changes in Water Quality**<br>• Contaminants resulting from industrial activities and local development have the potential to cause direct mortality to juvenile salmon if sufficiently toxic. Other effects may be damaging but sublethal and may manifest themselves through bioaccumulation in the food chain.<br>• Changes in the abiotic environment brought about by industrial activities could create local conditions in the estuary outside the requirements for salmon growth and survival (e.g. changes in DO, salinity, pH)<br>• Climate trend-related changes in abiotic conditions in the estuary could have broad, long-term consequences for Skeena salmon growth and survival. |
| **Habitat & Lower Food Web** | 9B | **Changes in Salmon Populations due to Changes in Habitat and Lower Food Web Dynamics**<br>• Early marine survival of all species of wild salmon is dependent on abundant food resources and sheltered, intact estuarine habitats. Eelgrass beds can support high biodiversity of forage fish and plankton, while high turbidity and vegetation in estuaries can provide shelter to juvenile salmon. Damage to these habitats and to associated food production could result in reduced growth and survival for juvenile salmon with consequent effects on returning adult population abundance. |
| **Salmon Populations** | 9C | **Changes to Salmon Populations due to Increased Morbidity or Mortality from Marine Vessel Traffic, Harvest, Predators, or Disease**<br>• Heavy predation on juvenile salmon by marine mammals, birds and predatory fish in the estuary can directly reduce juvenile salmon population size or alter juvenile salmon behaviour.<br>• Heavy commercial/recreational harvest pressures on adult salmon can reduce salmon stock abundance and impede stock recovery.<br>• Noise and pressure waves from heavy marine vessel traffic could alter behavior, or cause direct physical damage to juvenile salmon.<br>• Periodic outbreaks of disease or parasites may cause increased mortality of juvenile salmon Changes in abiotic conditions (e.g. water temperature) of the estuary due to impacts from industrial infrastructure or climate change may increase susceptibility of juvenile salmon to disease. |

# 4 INDICATORS

## 4.1 Review of Indicators

The review of estuary assessments (Section 2) indicated that a variety of approaches have been used to aggregate and present information on estuary indicators, to document salmon habitat and population characteristics, and to allow for some assessment of indicator status in relation to different benchmarks values. Based on the projects reviewed, the number of estuary indicators used ranged from nine to over 40 indicators per project, with a total of 72 distinct indicators across all estuary projects (see Appendix 4 for details). Many projects organized pressure, state, and vulnerability indicators into three to six "impact categories." Most projects also used another level of indicator organization: most common was a simple two-tier structure (e.g. pressure/state indicator split), while a few projects used a more complex structure (e.g. pressure, vulnerability, state, conservation value, etc.).

## 4.2 Selection of Key Indicators for the Skeena River Estuary

Skeena estuary indicators were organized into a simple assessment framework based on separation into either pressure or state (i.e. ecosystem component) indicators. This method was consistent with the majority of the estuary assessment projects that were reviewed and also with monitoring recommendations from Strategy 2 of the Wild Salmon (Stalberg et al. 2009). Pressure and state indicators for the Skeena estuary were selected through an iterative process and were chosen to inform the linkages depicted in the Skeena River Estuary Conceptual Model. First, a range of estuary indicators that have been used successfully in other estuary assessments were identified and reviewed with the TAC. Next, indicators were grouped into common themes that could be matched to the linkages in the conceptual model. Finally, a smaller subset of key indicators were selected to most effectively represent the state of each of the elements within the conceptual model (see Table 2 below). Together, pressure and state indicators provide a basis for understanding the status of the estuary ecosystem and, ultimately, identify the key drivers that affect salmon populations.

Pressure indicators: Pressure indicators measure potential impacts on salmon. Some pressures impact salmon directly (e.g. predators), while others can impact salmon indirectly by affecting habitat and the lower food web (e.g. invasive species). Pressure indicators provide information about the degree of stress on key salmon habitats and are often measured at a broad spatial scale.

State indicators: The condition of salmon habitat and other important ecosystem components is measured using state indicators. State indicators are usually based on field measurements and provide detailed descriptions of the actual “on-the-ground” condition of ecosystem components. They provide information on salmon and salmon habitats at a localized scale. In this project, state indicators are referred to as “ecosystem component indicators.”

**Table 2. Selected indicators for evaluating identified linkages in the Skeena River Estuary Conceptual Model (see Figure 1) (P = pressure indicator, EC = ecosystem component indicator, SP = salmon population indicator).**

| Conceptual Model Element | Indicator | Indicator Type | Conceptual Model Linkage(s) |
|---|---|---|---|
| Wastewater Discharges | Wastewater Discharge Sites | P | 1, 2, 3 |
| Ocean Dumping | Disposal at Sea Sites | P | 1, 2, 5 |
| Dredging | Dredging Extent | P | 1, 2, 5 |
| Marine Forestry | Log Boom Sites | P | 2, 5, 7 |
| Invasive Species | Invasive Species Distribution or Abundance (Zooplankton, Macroalgae & Vascular Plants) | P | 5, 6, 7 |
| Shoreline & Nearshore Development | Shoreline & Nearshore Development Extent | P | 1, 5, 7, 8 |
| Hatchery Releases | Hatchery Salmon Abundance | P | 6 |
| Marine Vessel Traffic | Marine Vessel Traffic Density | P | 1, 5, 9C |
| Intertidal Wetlands | Intertidal Wetlands Extent | P | 7, 9B |
| Harvest | Commercial Harvest | P | 9C |
| Harvest | Recreational Harvest | P | 9C |
| Predators | Predatory Fish Distribution or Abundance | P | 9C |
| Predators | Marine Mammal Distribution or Abundance | P | 9C |
| Predators | Predatory Seabird Distribution or Abundance | P | 9C |
| Disease | Disease & Pathogen Prevalence | P | 9C |
| Toxic Contaminants | Water Column Chemical Contaminants | EC | 1, 9A |
| Toxic Contaminants | Water Column Bacterial Contaminants | EC | 1, 9A |
| Toxic Contaminants | Sediment Chemical Contaminants | EC | 1, 9A |
| Abiotic Conditions | Turbidity or Total Suspended Sediments (TSS) | EC | 2, 9A |
| Abiotic Conditions | Dissolved Oxygen (DO) | EC | 2, 9A |
| Abiotic Conditions | pH | EC | 2, 9A |
| Abiotic Conditions | Sea Surface Temperature (SST) | EC | 2, 9A |
| Abiotic Conditions | Salinity | EC | 2, 9A |
| Abiotic Conditions | UV | EC | 2, 9A |
| Nutrients | Phosphorus Concentration (P) | EC | 3, 4, 5, 9B |
| Nutrients | Nitrate Concentration (N) | EC | 3, 4, 5, 9B |
| Phytoplankton | Chlorophyll a Concentration | EC | 4, 6, 9A, 9B |
| Phytoplankton | Algae Bloom Number or Extent | EC | 4, 6 |
| Eelgrass & Kelp | Native Eelgrass Extent | EC | 5, 6, 9B |
| Eelgrass & Kelp | Native Macroalgae Extent | EC | 5, 6, 9B |
| Zooplankton | Zooplankton Density or Diversity | EC | 6, 9B |
| Shoreline Geomorphology & Composition | Intact Riparian Vegetation Extent | EC | 8, 9B |
| Wild Salmon | Adult Salmon Abundance | SP | 9A, 9B, 9C |
| Wild Salmon | Smolt Survival | SP | 9A, 9B, 9C |
| Wild Salmon | Smolt Growth | SP | 9A, 9B, 9C |
| Wild Salmon | Smolt Density | SP | 9A, 9B, 9C |
| Wild Salmon | Smolt Residence Time | SP | 9A, 9B, 9C |

# 5 BENCHMARKS

## 5.1 Review of Benchmarks

Benchmarks are a standard or point of reference against which the status of an indicator can be compared. Defining benchmarks can be a challenging task, often combining scientific knowledge of ecological thresholds with management objectives and risk tolerances. Scientific research into ecological thresholds, metadata review (e.g. weight of evidence from multiple correlative studies), statistical spread, and expert opinion are all potential approaches used to define benchmarks. The global review of estuary assessment approaches indicated that a variety of benchmarking approaches have been used to inform estuary status assessments both regionally and internationally including the following:

- *Absolute benchmarks (quantitative):* A fixed level of a measured indicator (e.g. dissolved oxygen), generally based on scientific research of ecological thresholds (e.g. water temperature threshold for mortality of a given species).
- *Absolute benchmarks (qualitative/categorical):* A fixed level for evaluating a categorical indicator (e.g. a categorical assessment of habitat quality: 1-5, with a benchmark set = 3), generally applied to indices that represent a composite of related indicators and are usually justified based on metadata review or expert opinion.
- *Relative benchmarks (spatial/temporal):* Relative benchmark values are dependent on the observed value of other units in space or periods in time. Spatial: Benchmarks values are based on the spatial units which have the best and worst indicator condition, and then require spatial replicates at the scale the data are collected to be meaningful. Temporal: Benchmark value is based on the comparison of indicator between two or more periods of time. For example, a benchmark might be set as the level the indicator would have been prior to disturbance.
- *Performance relative to target:* Where management targets exist, a benchmark might be set to indicate the degree to which the target has been achieved.

Appendix 4 outlines the types of benchmark categories and approaches used in the 17 estuary projects reviewed.

## 5.2 Setting Benchmark Values for the Skeena River Estuary

Ideally, absolute quantitative benchmarks would be defined for all indicators based on scientific research of ecological thresholds. However, for many of the indicators selected for the Skeena estuary, there was insufficient research to be able to develop science-based benchmarks (with some exceptions, e.g. chemical contaminant loads). Thus, for some indicators, relative benchmarks were developed based on data spread and the expert opinion of the TAC. For other indicators, a simple binary rating (presence/absence) was incorporated into the assessment. For indicators where reasonable benchmarks could not be developed at this time, absolute or average values were used. Table 3 details the benchmarks used for each of the Skeena estuary assessment indicators, with green, yellow, and red representing ratings of “good”, “fair”, “poor”, and grey representing “insufficient data.”

**Table 3.** **Summary of indicators used for the Skeena estuary assessment with associated source datasets and indicator benchmark values. Further information about each of the datasets is provided in the *Skeena River Estuary Assessment Supplemental: Data Quality Assessments* (Pickard et al. 2015).**

| Impact Category | Indicator | Indicator Type | Measurement Unit | Dataset | Benchmarks | | | Citation for Benchmark |
|---|---|---|---|---|---|---|---|---|
| | | | | | Good | Fair | Poor | |
| **Water Quality** | Wastewater Discharge Sites | P | # of discharge permits | BC MoE – Wastewater Discharges | **Absent** | | **Present** | *n/a – (TAC consulted* |
| | Disposal at Sea Sites | P | # of disposal at sea sites | EC – Disposal at Seat Sites | **Absent** | | **Present** | *n/a - (TAC consulted)* |
| | Dredging Extent | P | area dredged | *data unavailable for this project or does not exist* | *No specific benchmarks* | | | *n/a* |
| | Log Boom Sites | P | # of log storage/ handling permits | Tantalus Crown Tenures – Log Storage & Handling | **Absent** | | **Present** | *n/a - (TAC consulted)* |
| | Water Column Chemical Contaminants – Arsenic | EC | arsenic concentration (mg/L) | PR Harbour Water Quality Sampling | **<0.0125** | | **>0.0125** | CCME 1996 |
| | Water Column Chemical Contaminants – Mercury | EC | mercury concentration (mg/L) | PR Harbour Water Quality Sampling | **<0.000016** | | **>0.000016** | CCME 1996 |
| | Water Column Chemical Contaminants – Naphthalene | EC | naphthalene concentration (µg/L) | PR Harbour Water Quality Sampling | **<0.0014** | | **>0.0014** | CCME 1996 |
| | Water Column Bacterial Contaminants – Enterococci | EC | enterococci concentration (CFU/100mL) | PR Harbour Water Quality Sampling | **<4** | **4-11** | **>11** | BC MOE 2001 |
| | Water Column Bacterial Contaminants – Fecal Coliform | EC | fecal coliform concentration (CFU/100mL) | PR Harbour Water Quality Sampling | **<14** | **14-43** | **>43** | BC MOE 2001 |
| | Sediment Chemical Contaminants | EC | concentration of key sediment contaminants | *data unavailable for this project or does not exist* | *n/a* | | | *n/a* |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | Turbidity or Total Suspended Sediments (TSS) | EC | total suspended sediment concentration (mg/L) | PR Harbour Water Quality Sampling | **<25** | **25-80** | **>80** | DFO 2000 |
|  | Dissolved Oxygen (DO) | EC | dissolved oxygen concentration (mg/L) | PR Harbour Water Quality Sampling | **>5** | **2-5** | **<2** | US EPA 2012 |
|  | pH | EC | pH | PR Harbour Water Quality Sampling | **7.0-8.7** |  | **<7.0 or >8.7** | CCME 1996 |
|  | Sea Surface Temperature (SST) | EC | water temperature (ºC) | PR Harbour Water Quality Sampling | *No specific benchmarks* |  |  | *n/a* |
|  | UV | EC | UV level | *data unavailable for this project or does not exist* | *n/a* |  |  | *n/a* |
|  | Phosphorus Concentration (P) | EC | total dissolved phosphorus (P) (mg/L) | PR Harbour Water Quality Sampling | **<0.07** | **0.07-0.1** | **>0.1** | US EPA 2012 |
|  | Nitrate Concentration (N) | EC | nitrate (N) (mg/L) | PR Harbour Water Quality Sampling | **<200** |  | **>200** | CCME 1996 |
| **Habitat & Lower Food Web** | Invasive Species Distribution or Abundance (Zooplankton, Macroalgae & Vascular Plants) | P | distribution or abundance of invasive species | *data unavailable for this project or does not exist* | *n/a* |  |  | *n/a* |
|  | Shoreline & Nearshore Development Extent | P | shoreline development (% of assessment area) | Ocean Ecology – Shoreline Development | **<10** | **10-50** | **>50** | *n/a - (TAC consulted)* |
|  | Hatchery Salmon Abundance | P | # of hatchery salmon releases | *data unavailable for this project or does not exist* | *n/a* |  |  | *n/a* |
|  | Marine Vessel Traffic Density | P | # of vessel hours | BCMCA – Marine Vessel Traffic | *No specific benchmarks* |  |  | *n/a* |
|  | Chlorophyll a Concentration | EC | chlorophyll a concentration (µg/L) | PR Harbour Water Quality Sampling; BCMCA – Chlorophyll a | **<5** | **5-20** | **>20** | US EPA 2012 |
|  | Algae Bloom Number or Extent | EC | # or area of algae blooms | *data unavailable for this project or does not exist* | *n/a* |  |  | *n/a* |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Intertidal Wetlands Extent | EC | intertidal wetlands (% of assessment area) | Ocean Ecology – Intertidal Wetlands | **>50** | **10-50** | **<10** | *n/a – (TAC consulted)* |
| | Native Eelgrass Extent | EC | # of eelgrass beds and extent of shoreline eelgrass presence (% of assessment area) | BC Shorezone Bioband Mapping; Borstad CASI Survey – Eelgrass; BCMCA – Eelgrass; Ocean Ecology – Eelgrass; WWF – Eelgrass; PR Harbour Foreshore Habitat Classification | *No specific benchmarks* | | | *n/a* |
| | Native Macroalgae Extent | EC | # of kelp beds and extent of shoreline kelp presence (% of assessment area) | BC Shorezone Bioband Mapping; GeoBC - Kelp | *No specific benchmarks* | | | *n/a* |
| | Zooplankton Density and Diversity | EC | zooplankton density (#/$m^3$) | Ocean Ecology - Zooplankton | *No specific benchmarks* | | | *n/a* |
| | Intact Riparian Vegetation Extent | EC | riparian vegetation (%) | Ocean Ecology – Riparian Vegetation | **>50** | **10-50** | **<10** | *n/a - (TAC consulted)* |
| **Salmon Populations** | Harvest (Commercial) | P | # of adult salmon caught in commercial fishery | *assessed in other PSF projects* | *n/a* | | | *n/a* |
| | Harvest (Recreational) | P | # of adult salmon caught in recreational fishery | *data unavailable for this project or does not exist* | *n/a* | | | *n/a* |
| | Predatory Marine Mammal Distribution or Abundance | P | # and locations of harbour seal haulouts | BCMCA – Harbour Seal Haulouts | **Absent** | **Present** | | *n/a - (TAC consulted)* |
| | Predatory Fish Distribution or Abundance | P | # and locations of predatory fish | *data unavailable for this project or does not exist* | *n/a* | | | *n/a* |
| | Predatory Bird Distribution or Abundance | P | # and locations of predatory birds | *data unavailable for this project or does not exist* | *n/a* | | | *n/a* |
| | Disease & Pathogen Prevalence | P | disease & pathogen prevalence | *data unavailable for this project or does not exist* | *n/a* | | | *n/a* |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Wild Salmon** | Smolt Survival | SP | smolt survival rates | *assessed in other PSF projects* | *n/a* | *n/a* |
| | Smolt Growth | SP | smolt growth rates | *data unavailable for this project or does not exist* | *n/a* | *n/a* |
| | Smolt Density | SP | smolt abundance or density | *data unavailable for this project or does not exist* | *n/a* | *n/a* |
| | Smolt Residence Time | SP | smolt residence time | *data unavailable for this project or does not exist* | *n/a* | *n/a* |
| | Adult Salmon Abundance | SP | salmon escapement numbers | *assessed in other PSF projects* | *developed in other PSF projects* | *n/a* |

# 6 SPATIAL FRAMEWORK FOR THE SKEENA RIVER ESTUARY

## 6.1 Review of Estuary Assessments – Spatial Frameworks

The spatial scale of data collection, analysis, interpretation, and reporting has implications for the range of questions that can be answered. Ideally, data are collected at a spatial scale appropriate for informing management decisions or actions (e.g. critical habitat designation). The global review of estuary assessments revealed a range of spatial scales used (see Table 4 below). Most estuary assessments focused on a single estuary, and used a variety of methods to partition the estuary or estuaries into distinct units or zones for evaluation and reporting. These methods included catchment-based units, shoreline segments, habitat or physical characteristics, and jurisdictional units, and some projects utilized more than one method. The review of existing projects provided guidance for how to partition the Skeena estuary into functional evaluation and reporting units, as well as how to summarize the available data and structure recommendations for future monitoring.

**Table 4. Spatial scale of evaluation and reporting across the estuary projects reviewed (P1 - P17 refer to the 17 estuary projects reviewed).**

| **Spatial Scale of Evaluation & Reporting** | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | **P8** | **P9** | **P10** | **P11** | **P12** | **P13** | **P14** | **P15** | **P16** | **P17** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Whole estuary | X | | X | | X | | X | | | | X | X | X | | X | X | | 9 |
| Catchment basins | | | | | | | | | | X | X | | | | | | | 2 |
| Chemical or physical zones | | | | X | | | | | X | | | | | | | | X | 3 |
| Ecotypes | | | | | | X | | X | X | | | | | | | | X | 4 |
| Life history | X | X | | | | | | | | | | | | | | | | 2 |
| Shore zones | | X | | | | | | | X | | | | | | | | | 2 |
| Jurisdictional | | | | | | | | | | | | | | | | | X | 1 |
| Not identified | | | | | | | | | | | | | | X | | | | 1 |

## 6.2 Skeena River Estuary

For this project, defining the outer boundary of the Skeena estuary was a critical aspect of identifying our study area and defining the spatial scope of the assessment. An estuary is defined as a semi-enclosed and coastal body of water, with free communication to the ocean, and within which ocean water is diluted by freshwater derived from land (Cameron and Pritchard 1963). With the unique characteristic of constantly fluctuating salinity due to the mixing of fresh and salt water, estuaries are generally classified based on the character of their salinity structure (Kelson 2011).

Defining a precise outer boundary is particularly difficult for the Skeena estuary as it is one of the more physically complex estuaries on the west coast of North America due to its variation in salinity structure, the effect of multiple channels, distributaries and islands that dissect the delta, and the outer Islands that enclose both the Skeena and Nass Estuaries (Kelson 2011). The Skeena River enters the ocean near the village of Port Edward on the northwest coast of British Columbia, where it divides into three channels (Carr-Harris et al. 2015). During the period of highest flow, this zone of freshwater influence originating from the Skeena River extends from the mouth of the river south to Ogden and Grenville Channels, and northwest through Chatham Sound, which also receives freshwater from the Nass River (Carr-Harris et al. 2015; Figure 2). Salinity surveys suggest that there is no clear demarcation between the Skeena and Nass estuaries and that the whole of Chatham Sound is essentially a large compound estuary (Tera Planning 1993 as cited in Ocean Ecology 2014). Therefore, ecosystem function is linked and fisheries values are to some extent shared between the Skeena and Nass estuaries (Kelson 2011; B. Faggetter, pers. comm.).

Delineation of the Skeena estuary for this project involved review and interpretation of published salinity structure studies (i.e. Cameron 1948, Trites 1956, Rabnett 2006, Gottesfeld et al. 2006), with an outer bounding based on salinity measurements in comparison to full-strength seawater, which is approximately 33 ppt (Quinn 2005). The estuary delineation also integrated existing information from past bathymetric mapping and an expert-based assessment of the estuary's overall geomorphic and hydrologic context (B. Faggetter, pers. comm.). This interpretation of the extent of freshwater influences was used to define the maximum extent of the Skeena estuary during freshet flow conditions (see Skeena estuary boundary in Figure 3). Note that the channel bisecting Porcher Island was not identified as being within the estuary boundary as no salinity surveys have been undertaken within this channel and classification is therefore not possible. At the northern extent of the estuary, the boundary between the Skeena and Nass estuaries is indeterminate because there is simply no clear demarcation between the brackish water contributions from the two watersheds. An expert-based decision was therefore made as to the point in Chatham Sound where the influence of inflows from the Nass River predominated over those from the Skeena River (B. Faggetter pers. comm.).

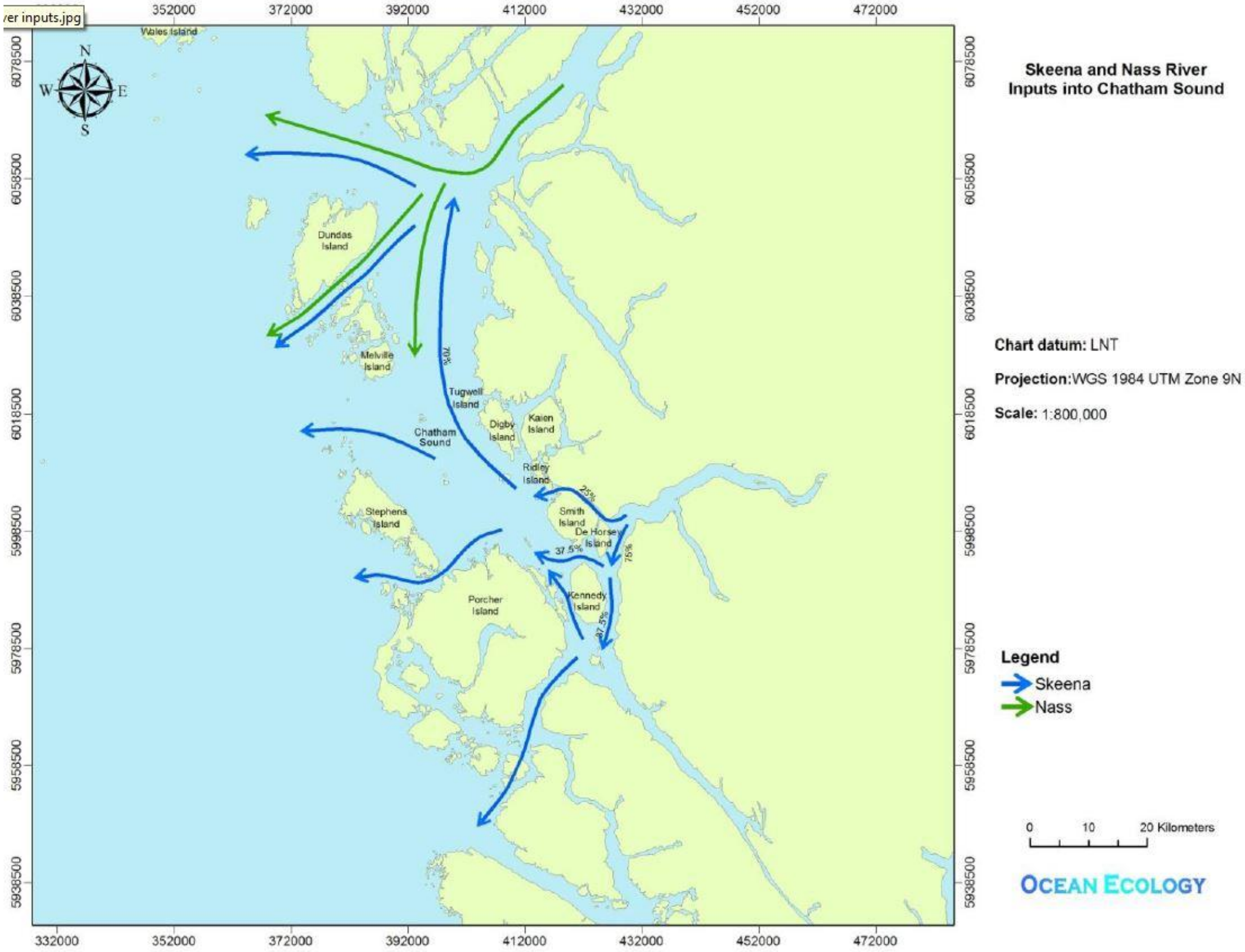


**Figure 2. Skeena and Nass River inputs into Chatham Sound (from Ocean Ecology 2014).**

## 6.3 Skeena River Estuary Project Reporting Units

During their downstream migration from natal streams to the sea, all Skeena salmon species will transit through the Skeena estuary where some may remain for weeks or months (Ocean Ecology 2014). As salmon smolts move through the estuary, they experience a range of complex temperature and salinity gradients associated with different energetic costs (Webster and Dill 2006).

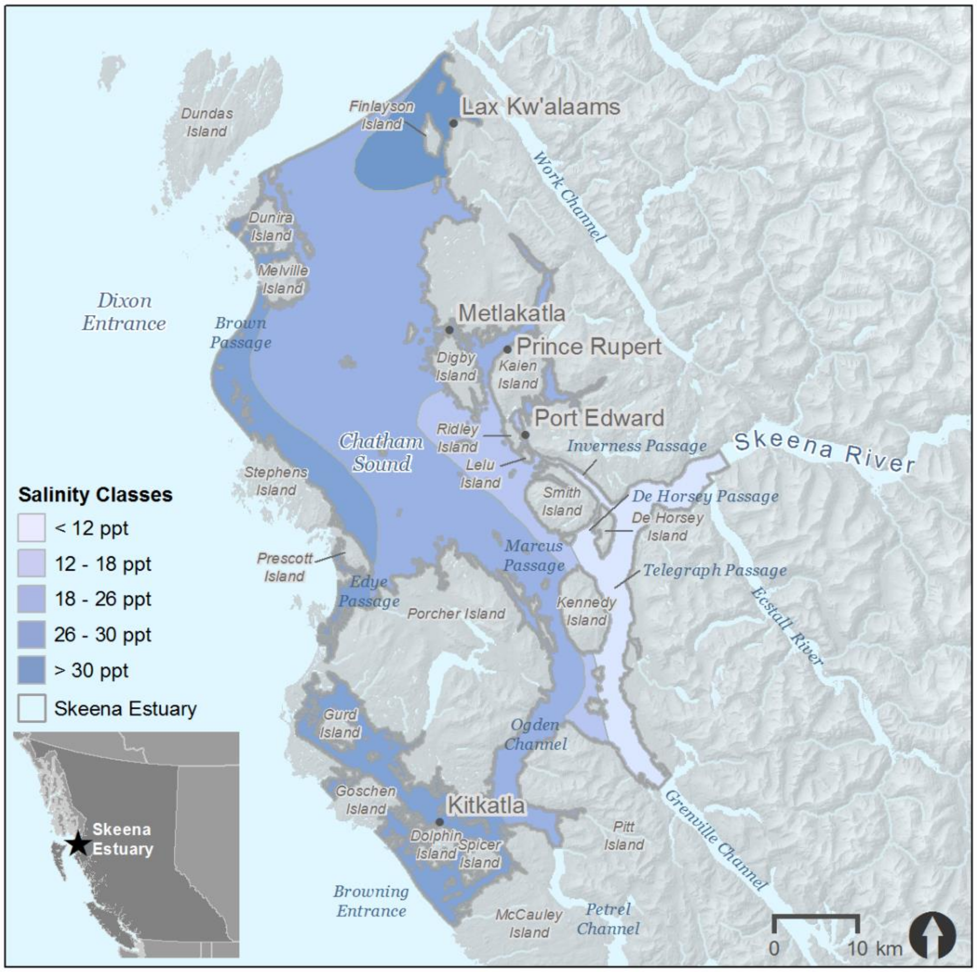


**Figure 3. Skeena estuary boundary and salinity classes.**

Foraging in areas that are more or less saline than the fish's internal osmotic state at any particular stage in their smoltification process will result in reduced growth rates because of the increased metabolic costs associated with maintaining homeostasis (Morgan and Iwama 1991). Past research has shown that salmon smolts generally prefer salinities of approximately 10-15 ppt as they reside in and move through estuaries (Quinn 2005). Such salinities correspond to the typical distribution of their zooplankton prey populations which are generally higher within the estuarine plume than in waters outside the plume (Quinn 2005). However, high densities of pink salmon juveniles in the Skeena estuary have been most commonly recorded in areas with higher salinities (26 ppt and above), feeding close to the turbulent zones near tide-generated currents (Gottesfeld et al. 2006). Regions within the Skeena estuary with salinities of <12–18 ppt overlap predominantly with areas of the estuary supporting the highest documented densities of juvenile sockeye, chinook, and coho salmon (Carr-Harris et al. 2015) suggesting that such zones may represent important rearing areas for most species of out-migrating salmon smolts. In addition, highest abundances of most species of juvenile salmon have been observed within

10 km of the northern entrance of the Skeena River (Carr-Harris et al. 2015).

Reflecting the importance of different salinity zones to juvenile salmon, the Skeena estuary was partitioned into five distinct salinity zones for assessment of indicators and associated project reporting purposes (Figure 3).

# 7 DATA QUALITY ASSESSMENT (DQA)

## 7.1 Selection of Datasets

A data quality assessment (DQA) was undertaken to systematically and objectively review the quality of the data obtained for this project. A novel set of criteria specifically designed for this project was developed. The criteria were applied to each of the datasets chosen for the assessment to generate overall DQA scores, which reflected the relevance and scientific quality of each individual dataset.

Before the DQA was conducted, datasets were filtered based on their ability to provide information about an indicator, the spatial coverage, whether the data were in a format that was interpretable and quantifiable, and whether there was another dataset that could better inform the same indicator (e.g. a more current dataset). In some cases a single dataset was selected, while in other cases multiple datasets could be combined to inform a single indicator (i.e. in order to achieve more complete spatial coverage, e.g. eelgrass). All of the datasets deemed most useful to inform the indicators were selected for the DQA.

## 7.2 DQA Criteria

The DQA criteria were organized as a series of questions (see Table 5 below) which were applied to each dataset evaluated in the Skeena estuary assessment. Each of the DQA criteria were assigned to one of two groups:

1. *Relevance*: relevance of the data to the Skeena estuary assessment. In many cases, data gathered for other purposes may have been collected using high standards of scientific rigour but may not be appropriate for this assessment and therefore received a lower score for the relevance criteria.
2. *Scientific Quality:* the scientific rigor of the data collection given the objectives of the original study.

Relevance and scientific quality of the dataset were evaluated based upon whether the data was collected at the right spatial and temporal scale, following an appropriate methodological approach, and in a clearly documented manner. Criteria for this assessment were organized into five categories: (1) Type of Data, (2) Documentation and Metadata, (3) Quality Assurance and Quality Control, (4) Coverage, and (5) Methodology. Scoring levels for each criterion were either binary (i.e. yes/no) or trinary (i.e. low/medium/high, which occasionally included a fourth "not within information provided" option).

Each indicator dataset received DQA score for both or both "relevance" and "scientific quality," which represents an average of the scores for the criteria within the group (details in Section 7.3, and scores in Table 6). A detailed discussion of the details and rationale for the criteria in each category and further information about scoring levels can be found in *Skeena River Estuary Assessment Supplemental: Data Quality Assessments* (Pickard et al. 2015)

**Table 5. Data Quality Assessment criteria and scoring. Questions with an asterisk (*) are answered first.**

| **R**elevance or **S**cientific quality | **Criteria & Question** | **Scoring Levels** |
|---|---|---|
| Criteria Category: Type of Data | | |
| **R** | *Type: Is the data an aggregate/composite dataset? | Yes/No |
| **R** | *Consistency: Were the methods the same for all observations? If no, was there methodology for combining? | Yes/No |
| Criteria Category: Documentation/Metadata | | |
| **S** | Metadata: Do metadata exist/available? | Yes/No |
| **R** | *Documentation: Is there sufficient documentation to evaluate our criteria? | Low – no information<br>Medium – some information but not complete or clear<br>High – metadata, reports or papers |
| Criteria Category: QAQC | | |
| **S** | Review: Was the data reviewed? (e.g. published paper, grey lit, QAQC process, advisory committee, 3rd party review, formal review process, informal review) | Low – no review<br>Medium – no scientific review<br>High – scientific review (eg. published, grey literature, review process) |
| Criteria Category: Coverage | | |
| **R** | *Spatial: Are the data spatial? | Yes/No |
| **R** | Spatial: What proportion of area of interest within the estuary does the data cover? | Low – <10%<br>Medium – 10-50%<br>High – >50% |
| **R** | Temporal: How recent are data? | Low – before 2001<br>Medium – 2001-2010 |

| | | |
|---|---|---|
| | | High – after 2010 or not pertinent<br>NI – not within information provided |
| **R** | Temporal: How many years of data were collected? | Input number of years |
| Criteria Category: Methodology | | |
| **S** | Best Practices: Were best practices used or was there a logical rationale for methods used (if no best practices)? | Low – did not follow best practices and no rationale<br>Medium – did not follow best practices but seems to have a rationale<br>High – followed best practices or logical rationale |
| **S** | Consistency: Were the methods the same for all observations within the project? | Low – methods were not the same<br>Medium – minor differences in methods<br>High – methods were the same |
| **S** | Precision: Did project have quantitative estimates of variability? | Yes/No – for projects with replicates<br>NA – for exploratory (one-offs) |
| **S** | Sample Size: Did samples per strata meet protocol requirements? (eg., power analyses, best practices) | Low – sample size not sufficient to meet objective or was not discussed<br>Medium – sample size discussed but not fully rationalized<br>High – census or sample size requirements discussed and rationalized |
| **S** | Site Selection: How were sites chosen? | Low – targeted, judgement or opportunistic<br>Medium – tried to place randomly but didn't have true random design<br>High – census or probabilistic |
| **S** | Time of Collection: Was data collected at the appropriate time? | Low – not appropriate time<br>Medium – close to appropriate time<br>High – appropriate time |
| **S** | Goals: Did the data meet the intended goals and criteria of the study in which it was collected? | Low – no<br>Medium – met some of the intended goals<br>High – yes<br>NI – not enough information provided |
| **R** | Resolution: Is the resolution at a scale appropriate for this assessment? | Low – no<br>Medium – resolution not ideal but usable<br>High – yes |

## 7.3 Dataset Scores

For each dataset, criteria scores are provided in the completed DQA tables, which are available in *Skeena River Estuary Assessment Supplemental: Data Quality Assessments* (Pickard et al. 2015). Using the criteria scores, an overall *relevance* score and *scientific quality* score was produced for each dataset (see Table 6. Criteria and Dataset Scores*). For each criterion, values were applied to each scoring level: High = 3, Medium = 2, Low = 1, Yes = 3, No = 1, No Information = 1. NAs were excluded from the calculation. Overall relevance and scientific quality scores were then calculated by taking the average of all criterion values within each group. Scores of one, two or three stars were determined using the following:

✶ - average 0 – 2
✶✶ - average 2.01 – 2.5
✶✶✶ - average 2.51 – 3

If datasets are combined, then a combined data quality score is calculated by taking the average of the dataset averages. For example, combining the BC Shorezone Bioband and Borstad CASI datasets, which have relevance averages of 2.25 and 2 respectively, resulted in a combined average of 2.125 and a combined relevance data quality score of two stars (see Table 6).

**Table 6. Criteria and Dataset Scores***

| **R**elevance or **S**cientific | **Criteria & Question** | Wastewater Discharges | Disposal at Sea Sites | Log Storage & Handling | PRH Water Quality Sampling | Shoreline Development | Marine Vessel Traffic | Intertidal Wetlands | BCMCA - Chlorophyll a | BC Shorezone Bioband | Borstad CASI - Eelgrass | Chatham Sound Study - Eelgrass | BCMCA - Eelgrass | WWF - Eelgrass | PRH Foreshore Habitat Classification | GeoBC - Kelp | Zooplankton | Riparian Vegetation | Harbour Seal Haulouts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type of Data | | | | | | | | | | | | | | | | | | | |
| **R** | Type | N | Y | N | N | N | N | Y | N | N | N | N | N | N | N | N | Y | N | Y |
| **R** | Consistency | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | N |
| Documentation/Metadata | | | | | | | | | | | | | | | | | | | |
| **S** | Metadata | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| **R** | Documentation | H | H | H | H | H | H | H | H | H | H | H | H | H | H | M | H | H | H |
| QAQC | | | | | | | | | | | | | | | | | | | |
| **S** | Review | H | H | H | L | H | H | H | H | H | H | H | H | H | H | H | H | H | H |
| Coverage | | | | | | | | | | | | | | | | | | | |
| **R** | Spatial: Y/N | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| **R** | Spatial: proportion | H | H | H | L | L | H | L | M | H | L | M | H | L | L | H | L | L | M |
| **R** | Temporal: how recent? | H | H | H | H | H | M | M | M | L | L | H | M | M | M | M | L | H | L |
| **R** | Temporal: # years collected | 84 | 70 | NA | 1 | NA | 1 | 2 | 4 | 1 | 1 | 1 | 1 | 5 | 2 | NI | 2 | 1 | 33 |
| Methodology | | | | | | | | | | | | | | | | | | | |
| **S** | Best Practices | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H |
| **S** | Consistency | H | H | H | M | H | H | H | H | H | H | H | H | H | H | H | H | H | H |
| **S** | Precision | NA | NA | NA | NA | NA | NA | NA | N | NA | NA | NA | NA | NA | NA | NA | N | NA | Y |
| **S** | Sample Size | H | H | H | M | H | H | H | H | H | H | H | H | H | H | H | H | H | H |
| **S** | Site Selection | H | H | H | L | H | H | H | H | H | H | M | H | M | H | H | L | H | H |
| **S** | Time of Collection | H | H | H | H | H | H | H | H | H | H | H | M | H | H | NI | H | H | H |
| **S** | Goals | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H |
| **R** | Resolution | H | H | H | H | H | M | H | H | M | H | H | H | H | H | H | H | H | H |
| Dataset Score | | | | | | | | | | | | | | | | | | | |
| | **Relevance:** | ✶✶✶ | ✶✶✶ | ✶✶✶ | ✶✶ | ✶✶ | ✶✶ | ✶✶ | ✶✶ | ✶✶ | ✶ | ✶✶✶ | ✶✶✶ | ✶✶ | ✶✶ | ✶✶ | ✶ | ✶✶ | ✶✶ |
| | **Scientific Quality:** | ✶✶✶ | ✶✶✶ | ✶✶✶ | ✶✶ | ✶✶✶ | ✶✶✶ | ✶✶✶ | ✶✶✶ | ✶✶✶ | ✶✶✶ | ✶✶✶ | ✶✶✶ | ✶✶✶ | ✶✶✶ | ✶✶✶ | ✶✶ | ✶✶✶ | ✶✶✶ |

*For criteria scores, N=no; Y=yes, H=high, M=medium, L=low, NI=no information. Dataset scores are determined using the criteria scores following the methods described in Pickard et al. 2015.

# 8 SKEENA RIVER ESTUARY ASSESSMENT RESULTS

## 8.1 Aggregation of Indicators

A wide range of approaches can be used for aggregating indicators in order to generate rolled-up assessments or a simple report card. Out of the 17 projects reviewed, pressure and state indicators were evaluated and aggregated separately in some cases, while in others they were merged together into composite indicator categories. A variety of approaches were then used to aggregate estuary state, pressure, and/or vulnerability indicators to generate cumulative risk or cumulative condition ratings. Of the projects reviewed, aggregations were most commonly conducted using algorithms for summing or averaging individual indicator (normalized) values within the various defined indicator categories and summing or averaging these scores (after normalization) across the indicator categories. In many cases the indicator categories were considered as being equally important (unweighted), and in some cases they were differentially weighted, with some rationalization provided as to which categories are more important and why. In these cases, the differential weighting was often highly subjective and weighting criteria were variable across projects.

For each of the selected indicators, we compared the data against the benchmark values identified in Table 3. In order to determine the status of each indicator, ratings were aggregated within each of the five salinity zones identified in Figure 3. The aggregation method required a minimum of three data points within the salinity zone; for salinity zones with fewer than three data points, the indicator was classified as "insufficient data." For indicators with data that were point estimates or shoreline segments, and for which there were benchmarks, (e.g. Water Column Chemical Contaminants), aggregated indicator ratings were generated based on the percent of points or shoreline segments within each salinity zone that fell into each benchmark category, following the rules proposed by EPA (2012) (see Table 8). For indicators with data that were point estimates or shoreline segments, but for which there were no benchmarks (e.g. Eelgrass Extent), the status of each indicator was summarized by either estimating the average value of the indicator within the salinity zone (e.g. Marine Vessel Density) or by reporting raw values of the indicator (e.g. the number of eelgrass beds within a salinity zone). For pressure indicators for which there were no benchmarks (e.g. Wastewater Discharge Sites), aggregated indicator ratings were generated based on the presence (red) or absence (green) of the pressure within the salinity zone.

Table 7. Summary of data for each indicator within each salinity zone. Cells shaded red are considered poor status, yellow is fair status, and green is good status, based on the benchmarks in Table 3.

| Impact Category | Indicator | Summary Method | Summary of Data by Salinity Zone | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | <12 ppt | 12-18 ppt | | | 18-26 ppt | | | 26-30 ppt | >30 ppt |
| **Water Quality** | Wastewater Discharge Sites | # of sites | 7 | 19 | | | 5 | | | 0 | 0 |
| | Disposal at Sea Sites | # of sites | 2 | 3 | | | 2 | | | 0 | 1 |
| | Dredging Extent | n/a | insufficient data | | | | | | | | |
| | Log Boom Sites | # of sites | 1 | 1 | | | 6 | | | 0 | 1 |
| | Water Column Chemical Contaminants – Arsenic | % of R/Y/G | insufficient data | 0 | 0 | 100 | 0 | 0 | 100 | insufficient data | insufficient data |
| | Water Column Chemical Contaminants – Mercury | % of R/Y/G | insufficient data | 0 | 0 | 100 | 0 | 0 | 100 | insufficient data | insufficient data |
| | Water Column Chemical Contaminants – Naphthalene | % of R/Y/G | insufficient data | 0 | 0 | 100 | 0 | 0 | 100 | insufficient data | insufficient data |
| | Water Column Bacterial Contaminants – Enterococci | % of R/Y/G | insufficient data | 0 | 0 | 100 | 1 | 38 | 61 | insufficient data | insufficient data |
| | Water Column Bacterial Contaminants – Fecal Coliform | % of R/Y/G | insufficient data | 0 | 0 | 100 | 0 | 10 | 90 | insufficient data | insufficient data |
| | Sediment Chemical Contaminants | n/a | insufficient data | | | | | | | | |
| | Turbidity or Total Suspended Sediments (TSS) | % of R/Y/G | insufficient data | 0 | 0 | 100 | 0 | 0 | 100 | insufficient data | insufficient data |
| | Dissolved Oxygen (DO) | % of R/Y/G | insufficient data | 0 | 0 | 100 | 0 | 0 | 100 | insufficient data | insufficient data |
| | pH | % of R/Y/G | insufficient data | 0 | 0 | 100 | 0 | 0 | 100 | insufficient data | insufficient data |
| | Sea Surface Temperature (SST) | average of all samples | insufficient data | 7.79°C | | | 8.05°C | | | insufficient data | insufficient data |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UV | n/a | insufficient data | | | | | | | | | | | | |
| | Phosphorus Concentration (P) | % of R/Y/G | insufficient data | 0 | 0 | 100 | 0 | 0 | 100 | insufficient data | | | insufficient data | | |
| | Nitrate Concentration (N) | % of R/Y/G | insufficient data | 0 | | 100 | 0 | | 100 | insufficient data | | | insufficient data | | |
| **Habitat & Lower Food Web** | Invasive Species Distribution or Abundance (Zooplankton, Macroalgae & Vascular Plants) | n/a | insufficient data | | | | | | | | | | | | |
| | Shoreline & Nearshore Development Extent | % developed in zone | insufficient data | 17 | 10 | 73 | 15 | 6 | 79 | insufficient data | | | insufficient data | | |
| | Hatchery Salmon Abundance | n/a | insufficient data | | | | | | | | | | | | |
| | Marine Vessel Traffic Density – all vessel sizes | average vessel hours -all grids in zone | 35.25 | 72.94 | | | 109.17 | | | 15.29 | | | 27.30 | | |
| | Marine Vessel Traffic Density – vessels >200m | average vessel hours from all grids in zone | 0.44 | 7.22 | | | 4.98 | | | 1.63 | | | 0 | | |
| | Intertidal Wetlands Extent | % of R/Y/G | insufficient data | 62 | 1 | 37 | 48 | 5 | 47 | insufficient data | | | insufficient data | | |
| | Chlorophyll a Concentration – direct sampling | % of R/Y/G | insufficient data | 0 | 0 | 100 | 0 | 0 | 100 | 0 | 0 | 100 | insufficient data | | |
| | Chlorophyll a Concentration – remote sensing | % of R/Y/G | insufficient data | 0 | 100 | 0 | 0 | 99 | 1 | 0 | 83 | 17 | 31 | 69 | 0 |
| | Algae Bloom Number or Extent | n/a | insufficient data | | | | | | | | | | | | |
| | Native Eelgrass Extent - beds | # of beds | 1 | 295 | | | 419 | | | 173 | | | 65 | | |
| | Native Eelgrass Extent - shoreline | % shoreline | 1 | 11 | | | 39 | | | 44 | | | 6 | | |
| | Native Macroalgae Extent - beds | # of beds | 17 | 62 | | | 229 | | | 478 | | | 15 | | |
| | Native Macroalgae Extent - shoreline | % shoreline | 2 | 6 | | | 30 | | | 60 | | | 2 | | |

|  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Zooplankton Density and Diversity | average zooplankton/ $m^3$ | 14.43 | 22.79 |  |  | 74.46 |  |  | insufficient data | insufficient data |
|  | Intact Riparian Vegetation Extent | % shoreline | insufficient data | 19 | 7 | 74 | 6 | 8 | 86 | insufficient data | insufficient data |
| **Salmon Populations** | Commercial Harvest | n/a | assessed in other PSF projects |  |  |  |  |  |  |  |  |
|  | Recreational Harvest | n/a | insufficient data |  |  |  |  |  |  |  |  |
|  | Predatory Fish Distribution or Abundance | n/a | insufficient data |  |  |  |  |  |  |  |  |
|  | Marine Mammal Distribution or Abundance |  | 5 | 8 |  |  | 11 |  |  | 0 | 0 |
|  | Predatory Bird Distribution or Abundance | n/a | insufficient data |  |  |  |  |  |  |  |  |
|  | Disease & Pathogen Prevalence | n/a | insufficient data |  |  |  |  |  |  |  |  |
| **Wild Salmon** | Adult Salmon Abundance | n/a | assessed in other PSF projects |  |  |  |  |  |  |  |  |
|  | Smolt Survival | n/a | assessed in other PSF projects |  |  |  |  |  |  |  |  |
|  | Smolt Growth | n/a | insufficient data |  |  |  |  |  |  |  |  |
|  | Smolt Density | n/a | insufficient data |  |  |  |  |  |  |  |  |
|  | Smolt Residence Time | n/a | insufficient data |  |  |  |  |  |  |  |  |

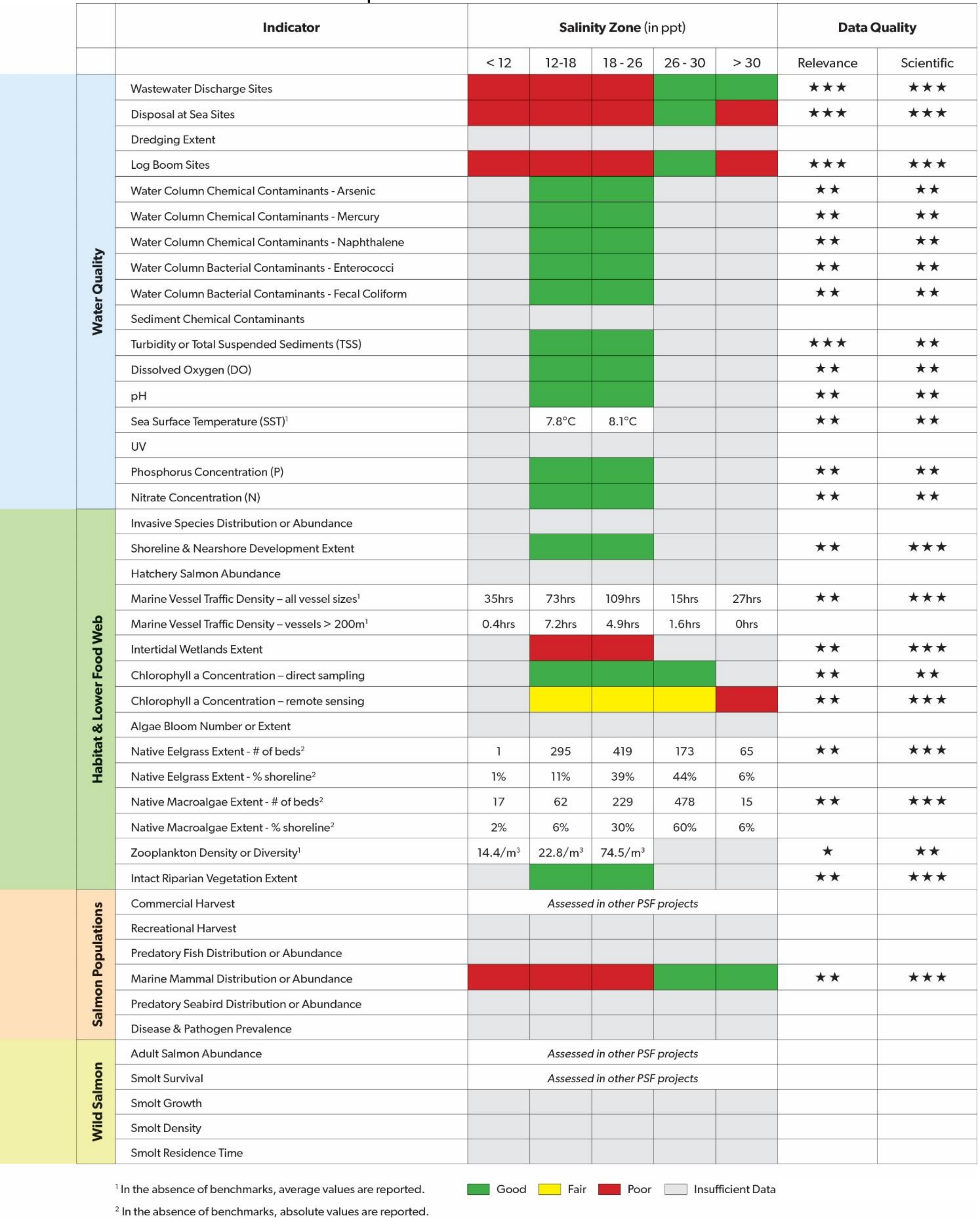
**Table 8. Rules for determining indicator ratings by salinity zones (adapted from EPA 2012).**

| Rating | Rule |
|---|---|
| Good (green) | Less than 10% of points/shoreline in poor condition and more than 50% of points/shoreline in good condition. |
| Fair (yellow) | 10-20% of points/shoreline in poor condition or 50% or less of points/shoreline in good condition. |
| Poor (red) | More than 20% of points/shoreline in poor condition. |

## 8.2 Indicator Summary

The results of the Skeena estuary assessment are summarized in Table 9 below, with a good (green), fair (yellow), poor (red), or insufficient data (grey) rating. In some cases, benchmarks were not available and average or absolute values were used (as described in 8.1). Maps displaying the status of each of the indicators can be found in *The Skeena River Estuary – A Snapshot of Current Status and Condition* (Pacific Salmon Foundation 2015).

**Table 9. Skeena Estuary Report Card. Each indicator was given a status designation within each of the five salinity zones: good (green), fair (yellow), poor (red), or insufficient data (grey). Status ratings are based on the benchmark values in Table 7 and roll-up rules in Table 8.**



| | **Indicator** | **Salinity Zone** (in ppt) | | | | | **Data Quality** | |
|---|---|---|---|---|---|---|---|---|
| | | < 12 | 12-18 | 18 - 26 | 26 - 30 | > 30 | Relevance | Scientific |
| **Water Quality** | Wastewater Discharge Sites | 🟥 | 🟥 | 🟥 | 🟩 | 🟩 | ★★★ | ★★★ |
| | Disposal at Sea Sites | 🟥 | 🟥 | 🟥 | 🟩 | 🟥 | ★★★ | ★★★ |
| | Dredging Extent | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |
| | Log Boom Sites | 🟥 | 🟥 | 🟥 | 🟩 | 🟥 | ★★★ | ★★★ |
| | Water Column Chemical Contaminants - Arsenic | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | ★★ | ★★ |
| | Water Column Chemical Contaminants - Mercury | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | ★★ | ★★ |
| | Water Column Chemical Contaminants - Naphthalene | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | ★★ | ★★ |
| | Water Column Bacterial Contaminants - Enterococci | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | ★★ | ★★ |
| | Water Column Bacterial Contaminants - Fecal Coliform | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | ★★ | ★★ |
| | Sediment Chemical Contaminants | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |
| | Turbidity or Total Suspended Sediments (TSS) | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | ★★★ | ★★ |
| | Dissolved Oxygen (DO) | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | ★★ | ★★ |
| | pH | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | ★★ | ★★ |
| | Sea Surface Temperature (SST)[1] | ⬜ | 7.8°C | 8.1°C | ⬜ | ⬜ | ★★ | ★★ |
| | UV | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |
| | Phosphorus Concentration (P) | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | ★★ | ★★ |
| | Nitrate Concentration (N) | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | ★★ | ★★ |
| **Habitat & Lower Food Web** | Invasive Species Distribution or Abundance | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |
| | Shoreline & Nearshore Development Extent | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | ★★ | ★★★ |
| | Hatchery Salmon Abundance | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |
| | Marine Vessel Traffic Density – all vessel sizes[1] | 35hrs | 73hrs | 109hrs | 15hrs | 27hrs | ★★ | ★★★ |
| | Marine Vessel Traffic Density – vessels > 200m[1] | 0.4hrs | 7.2hrs | 4.9hrs | 1.6hrs | 0hrs | | |
| | Intertidal Wetlands Extent | ⬜ | 🟥 | 🟥 | ⬜ | ⬜ | ★★ | ★★★ |
| | Chlorophyll a Concentration – direct sampling | ⬜ | 🟩 | 🟩 | 🟩 | ⬜ | ★★ | ★★ |
| | Chlorophyll a Concentration – remote sensing | ⬜ | 🟨 | 🟨 | 🟨 | 🟥 | ★★ | ★★★ |
| | Algae Bloom Number or Extent | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |
| | Native Eelgrass Extent - # of beds[2] | 1 | 295 | 419 | 173 | 65 | ★★ | ★★★ |
| | Native Eelgrass Extent - % shoreline[2] | 1% | 11% | 39% | 44% | 6% | | |
| | Native Macroalgae Extent - # of beds[2] | 17 | 62 | 229 | 478 | 15 | ★★ | ★★★ |
| | Native Macroalgae Extent - % shoreline[2] | 2% | 6% | 30% | 60% | 6% | | |
| | Zooplankton Density or Diversity[1] | 14.4/m$^3$ | 22.8/m$^3$ | 74.5/m$^3$ | ⬜ | ⬜ | ★ | ★★ |
| | Intact Riparian Vegetation Extent | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | ★★ | ★★★ |
| **Salmon Populations** | Commercial Harvest | *Assessed in other PSF projects* | | | | | | |
| | Recreational Harvest | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |
| | Predatory Fish Distribution or Abundance | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |
| | Marine Mammal Distribution or Abundance | 🟥 | 🟥 | 🟥 | 🟩 | 🟩 | ★★ | ★★★ |
| | Predatory Seabird Distribution or Abundance | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |
| | Disease & Pathogen Prevalence | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |
| **Wild Salmon** | Adult Salmon Abundance | *Assessed in other PSF projects* | | | | | | |
| | Smolt Survival | *Assessed in other PSF projects* | | | | | | |
| | Smolt Growth | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |
| | Smolt Density | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |
| | Smolt Residence Time | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | | |

[1] In the absence of benchmarks, average values are reported.

[2] In the absence of benchmarks, absolute values are reported.

🟩 Good 🟨 Fair 🟥 Poor ⬜ Insufficient Data

# 9 DATA GAPS AND MONITORING RECOMMENDATIONS

## 9.1 Overview

One of the primary goals of this project was to develop a framework for assessing status and trends in pressures, key salmon habitats, and salmon condition in the estuary and provide an understanding of how environmental and anthropogenic changes in the estuary potentially affect Skeena salmon populations. This objective reflects a growing need to quantify baseline conditions against which to evaluate future pressures in the estuary, monitor changes in condition over time, and support local efforts to identify potential threats to salmon and their habitat.

To develop a prioritized list of salmon-focused activities for the Skeena estuary, we first identified gaps in Skeena estuary data. Once the gap analysis was complete, a systematic two-tier prioritization approach was developed to prioritize monitoring activities. For the highest priority knowledge gaps, a preliminary monitoring framework was developed, which identifies monitoring objectives, spatial and temporal considerations, methodological alternatives, trade-offs and efficiencies in approaches, and recommended approaches.

## 9.2 Gap Analysis for Skeena River Estuary Data

The elements of the Skeena River Estuary Conceptual Model (see Section 3, Figure 1) display the information needed to represent the condition of the estuary over time (i.e. status and trends monitoring). The linkages represent hypothesized relationships among elements which could be explored via response monitoring; however, this assessment focused on status and trends monitoring for the elements (i.e. pressures and ecosystems components) in the conceptual model.

To identify data and information gaps, each element of the conceptual model was systematically evaluated. For each element and associated indicators, relevant datasets were identified and reviewed through the data quality assessment described in Section 7. Indicators were then classified into one of four possible categories:

- <u>No data</u>: indicators for which, to the best of our knowledge, no data has been collected.
- <u>Unavailable data</u>: indicators for which data are known to exist but were not acquired at the time of writing.

- Limitations: indicators with data that could be reviewed and which had spatial, temporal or methodological limitations as identified through the DQA.
- High quality: indicators with data that could be reviewed and which were not considered to have spatial, temporal or methodological limitations as identified through the DQA.

Most indicators were classified as having "Limitations", typically because of spatial or temporal gaps in the data (see Figure 4 below). For example, most water column indicators (Turbidity, P, N, SST, Salinity, DO, and contaminants) are currently being monitored by the Prince Rupert Port Authority, but have a limited spatial scale relative to our study area.

No previous monitoring activities were identified for five of the estuary indicators, which were classified as "No data." While some indicators have been the focus of previous monitoring activities, the corresponding datasets had not been acquired for the project, and were thus classified as "Unavailable data".

The remaining four indicators were classified as having corresponding data that was of "High quality" because they did not have considerable spatial, temporal or methodological limitations related to the methods of data collection.

Details of the rationale for the classification of each indicator can be found in *Skeena River Estuary Assessment Supplemental 1: Data Quality Assessments* (Pickard et al. 2015).

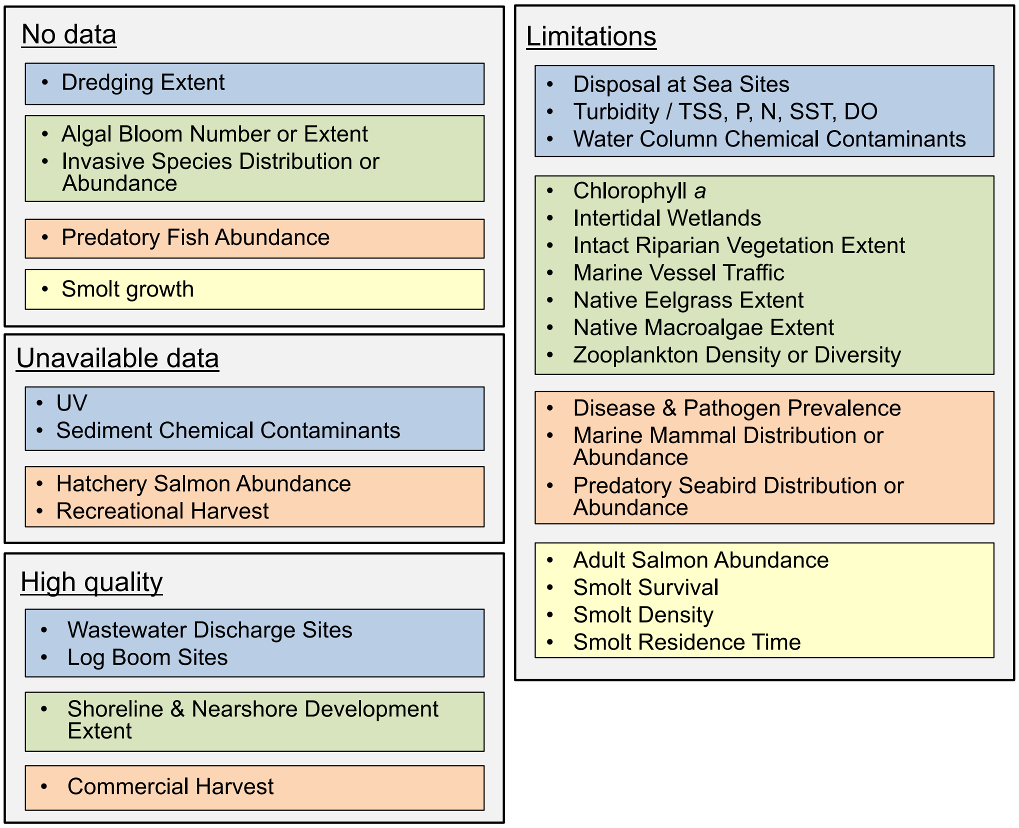


**Figure 4.** **Gap analysis classifications of indicators from the Skeena River Estuary Conceptual Model. Indicators highlighted in blue, green, orange and yellow correspond to the water quality, habitat and lower food web, salmon populations, and wild salmon impact categories, respectively.**

## 9.3 Monitoring Prioritization – Tier 1

The first tier of the prioritization process consisted of a series of questions that were asked for each indicator from the conceptual model (see Figure 5 below):

Q1. *Will the monitoring activity fill a gap identified by the gap analysis?*
If not, then monitoring was considered a low priority.

Q2. *Is the monitoring activity directly related to the overarching monitoring goal of assessing status and trends in pressures, key salmon habitats, and salmon condition in the estuary?*
If not, then while monitoring may help to fill an identified gap, it was considered a low priority because it did not directly inform the overall monitoring goal. Classifying a monitoring activity as a low priority at this point did not mean that monitoring the indicator was not important; it simply implied that it was not central to informing the overarching project objective.

Q3. *Is the monitoring activity part of ongoing or proposed monitoring?*
If not, then monitoring of the indicator was considered a high priority. If monitoring of the indicator was known to be ongoing or proposed, then whether or not it was a high priority depended on whether there were identified limitations to the monitoring approach (see Q4).

Q4. *Is the monitoring activity at an appropriate scale and following an appropriate methodology?*
If the monitoring activity is one that underwent the DQA process and the data were scored as high quality, then further monitoring was considered a low priority. However, if there were limitations to the ongoing or proposed monitoring, then monitoring of the indicator was considered a high priority. If there was insufficient information to evaluate the monitoring activity (e.g. no details of a monitoring program or resulting data), then the indicator was classified as "more information needed."

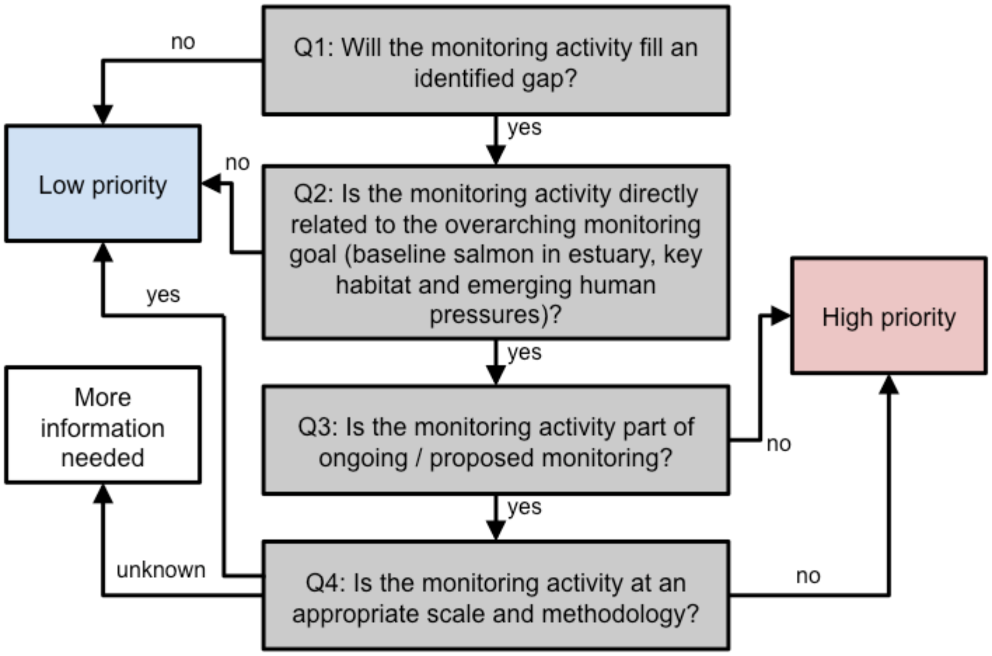


**Figure 5. Flow chart displaying the Tier 1 prioritization process.**

Based on the Tier 1 prioritization process, 17 indicators were classified as "Low priority" because they either did not fill a monitoring gap, were not directly related to stated project objectives, or because they are already being monitored (or will soon be monitored) using an appropriate methodology at an appropriate spatio-temporal scale (see Section 6). Two indicators could not be classified without further information on the methodologies being used or the location and frequency of ongoing or proposed monitoring. The remaining indictors were classified as "High priority" because monitoring activities focused on these indicators would fill identified monitoring gaps (including those in existing or proposed monitoring programs) and are directly related to the overarching monitoring goals (see Figure 6 below). Details of the rationale for the classification of each indicator can be found in Appendix 5.

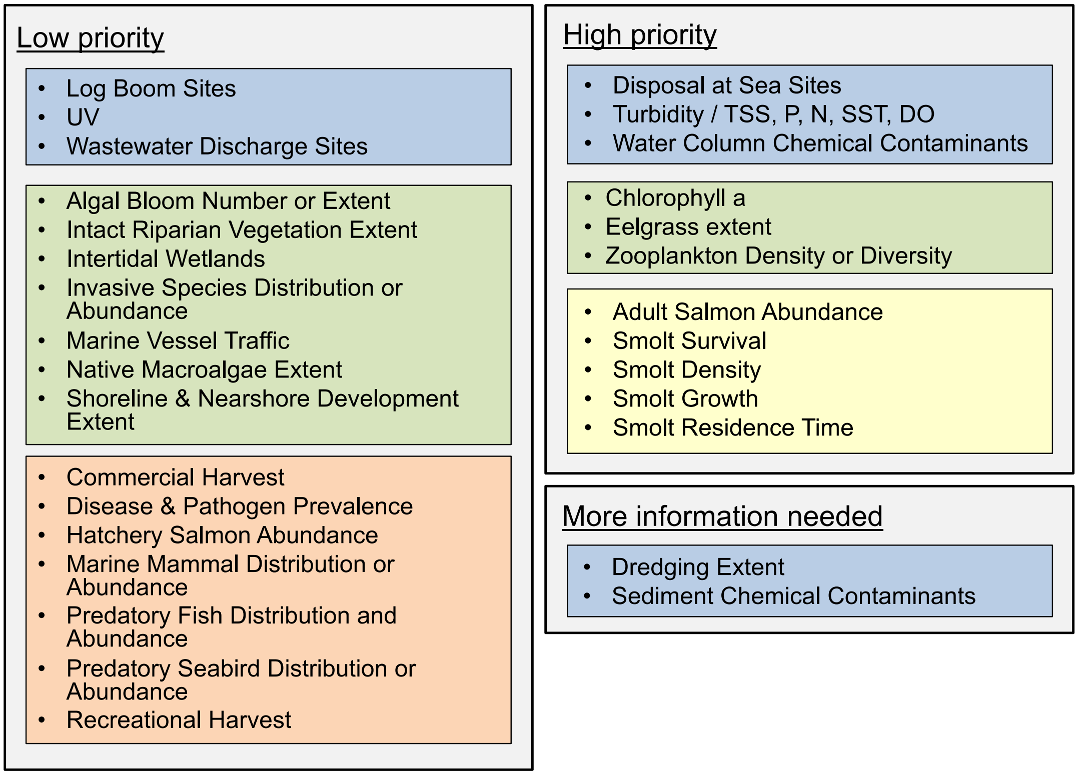


**Figure 6. Indicator classifications based on the Tier 1 prioritization. Indicators highlighted in blue, green, orange and yellow correspond to the water quality, habitat and lower food web, salmon population, and wild salmon impact categories in the Skeena River Estuary Conceptual Model.**

## 9.4 Monitoring Prioritization – Tier 2

The second tier further prioritized monitoring activities based on their sensitivity to change, and the extent to which they are already subject to monitoring activities, based on the following questions:

- Would the indicator respond quickly enough to changes to provide results in the time-frame desired (i.e. within a year or two of change occurring)? This is analogous to asking if the indicator is sufficiently sensitive to change.
- Is the monitoring of the indicator part of ongoing or proposed monitoring?

If the monitoring of the indicator was predicted to be sensitive to change then it was classified as a primary high priority Skeena estuary monitoring activity. If the variable was predicted to be insensitive to change then it was classified as a secondary high priority monitoring activity. Indicator monitoring activities that are already being (or are proposed to be) partially monitored were also classified as secondary high priority monitoring activities for the purposes of the current prioritization.

Based on the tier 2 prioritization process, five indicators were classified as primary indicator monitoring activities while the remaining indicators were classified as secondary indicator monitoring activities (see Figure 7 below). Water column indicators (Turbidity, P, N, SST, Salinity, DO, Chlorophyll *a*, and chemical contaminants) were classified as secondary priorities because they are currently being monitored within the Skeena, albeit at a limited spatial scale. Adult salmon abundance and smolt survival were also classified as secondary priorities because they are expected to respond more slowly to changes in conditions in the estuary than indicators like juvenile salmon growth, density and residence time, which were classified as primary priorities.

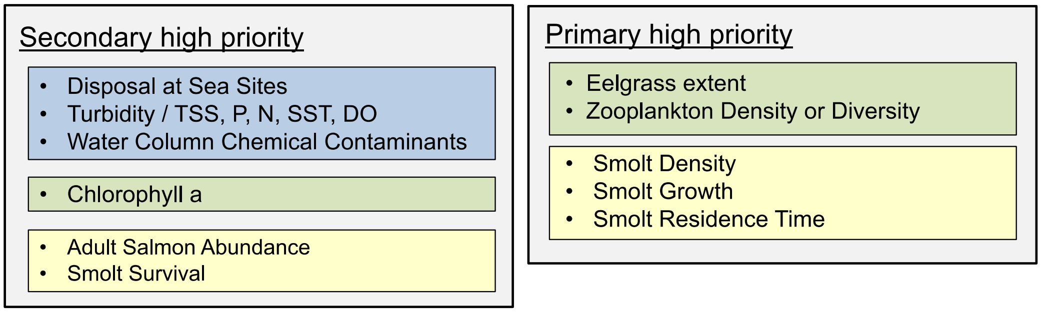


**Figure 7. Indicator classifications based on the Tier 2 prioritization. Indicators highlighted in blue, green, and yellow correspond to the water quality, habitat and lower food web, and wild salmon impact categories in the Skeena River Estuary Conceptual Model.**

## 9.5 Monitoring Recommendations

For each of the primary high priority indicators, the objective(s) of the monitoring activity and the specific question(s) that monitoring is intended to answer were identified. Then, important spatio-temporal sampling considerations were identified, including the information needed to determine the appropriate frequency and spatial extent of sampling necessary to answer the monitoring question(s). Next, specific metrics that can be monitored and quantified were identified for each indicator. Last, a brief review was conducted regarding the strengths and weaknesses of the individual metrics, as well as sampling contingencies (i.e. monitoring that is dependent upon other monitoring activities) and efficiencies to arrive at a recommended monitoring approach for the indicator.

The tables below provide detail on each primary high-priority Skeena estuary monitoring activity: (1) distribution and abundance of juvenile salmon, (2) growth and condition of juvenile salmon, (3) extent of eelgrass, and (4) density and diversity of key salmon food. Specifically, the tables address (1) key question(s) to be asked by monitoring, (2) spatial and temporal monitoring considerations, (3) methodological alternatives, (4) trade-offs and efficiencies between monitoring approaches, and (5) a brief description of the recommended approach.

In determining the proposed monitoring approaches for each of the primary high-priority indicators, there were two main considerations. The first consideration was whether monitoring the metric generates quantitative estimates that are meaningful to the specific question at hand, given predicted levels of natural variation and measurement error. The ideal metric will have low natural variability and be subject to little measurement error so that changes in the metric will be relatively easy to detect because estimates of the metric are relatively precise. The second consideration when evaluating alternative metrics was how cost-effective monitoring the metric is at the required level of precision and accuracy. Some metrics may require substantial effort and resources to generate estimates that are of sufficient precision and accuracy, while others may require less effort by building upon other existing or proposed monitoring activities.

### *9.5.1 Distribution and Abundance of Juvenile Salmon*

| Question(s) to be answered |
|---|
| What is the density of juvenile salmon, by species and population, in the estuary?<br>What is the residence time of juvenile salmon, by species and population, in the estuary? |
| **Spatial and temporal considerations** |
| The target population for sampling is the juvenile salmon within the whole estuary as defined in Figure 3.<br>There is substantial variability in the relative abundance of juvenile salmon among regions within the Skeena estuary (Carr-Harris et al 2015). To improve the efficiency of a sampling design beyond a simple random |

survey, stratified random sampling may be suitable based on regions with historic estimates of relative density or habitat characteristics (e.g. eelgrass beds or salinity zones).

Sampling to estimate density should occur every year with the temporal extent of sampling within year depending on variability in density over time. Variability in density over time within year could be assessed by a pilot study, an initial year of higher frequency sampling, and/or examination of historical sampling data. To begin, sampling could occur bi-weekly or monthly spanning the period of outmigration for each species (e.g. April – August).

Sampling a single region (e.g. of high usage by juveniles) more frequently to quantify residence time will generate more precise estimates of the timing and duration of migration through a region than sampling many regions less frequently. Therefore, estimating densities in multiple locations at multiple times of the year during the first year of a sampling program could help to identify sampling locations (or regions) that could be the focus of more intensive sampling to estimate residence time in subsequent years.

Methodologies

Net based sampling approaches such as surface (e.g. Carr-Harris et al. 2015) or midwater (e.g. Beamish et al. 2000) trawls, purse seines (e.g. Preikshot et al 2014), and beach seines (e.g. Carr-Harris et al. 2015) can be used to estimate the relative abundance (or density) and residence time of juvenile salmon. Relative abundance can be quantified as catch per unit effort (CPUE; e.g. distanced towed, number of purse or beach seines). Residence time can be quantified based on CPUE over time in a given location. Fish captured in trawls all die upon capture (unless there is a holding box designed for live capture) while those captured in purse or beach seines can be released alive after having been enumerated.

Acoustic arrays can be used to quantify residence time and migration speeds in areas between receivers for fish that are implanted with acoustic tags as they migrate out of their natal watersheds (e.g. when captured at smolt traps; Welch et al. 2008, McMichael et al. 2013).

Otolith microchemistry, which quantifies microelement concentrations, can be combined with daily growth ring counts from otoliths sampled from juvenile salmon to determine the date of first entry into the marine environment and therefore the residence time in the estuary up to the point of capture (Stocks et al. 2014).

Stock identification can be performed on individual salmon sampled using molecular analysis of fin clips to assign sampled fish to their population of origin (e.g. Beacham et al. 2014).

Summary

Because of the local characteristics of sampling sites, and ontogenetic and species-specific shifts in habitat use, a combination of net-based sampling approaches is typically required to estimate abundance in a given area. Juvenile salmon species with broad vertical distributions in the water column (i.e. Chinook) are most appropriately sampled by depth-stratified trawl surveys while those that feed near the surface (i.e. coho, sockeye, pink and chum) during daylight hours can be sampled using a surface trawl. However, those species that rear in the estuary at a small size close to the shoreline (i.e. chum and pinks) are most appropriately sampled by beach seine during early marine life. Purses seines enable sampling in areas where trawls are not logistically feasible (e.g. constrained channels) while trawls allow for broader coverage of areas to be sampled. Net-based approaches generate relatively coarse estimates of residence time within a region.

Collecting data on the characteristics of each sampling location (e.g. depth, salinity, temperature, eelgrass presence/extent) allows for subsequent analyses to determine relationships (if any) between habitat characteristics and juvenile salmon density.

Acoustic arrays and tags provide detailed data on migration speed and residence time (between arrays). They also provide fine scale information on survival by tracking the fate of individual fish, something that is otherwise extremely difficult to quantify.  However, there are limits to the size of fish that can be tagged so smaller species (e.g. pink and chums) or life history stages (e.g. 1 year old sockeye) are difficult or impossible to include in an acoustic approach to estimating residence time. In addition acoustic arrays do not provide data on density of fish within the estuary.

Though not the primary goal of a sampling program designed to estimate density, by estimating the density of juvenile salmon within the estuary one can also generate coarse estimate of the spatial distribution of juvenile salmon at the scale at which the sampling is done (e.g. among strata such as habitat types).

By capturing juvenile salmon across multiple regions over time, net-based approaches to estimate abundance and residence enable a suite of additional downstream monitoring activities to occur including quantifying the date of marine entry and residence time based on otolith microchemistry, examining growth and condition (see growth section) and providing a platform from which to base oceanographic sampling (see zooplankton section).

*We recommend a net-based approach to quantifying the density of juvenile salmon in the Skeena estuary, consisting of a combination of trawl and beach seines surveys based on a stratified random survey in combination with sampling at high frequency in a few locations to quantify residence time. In a subset of fish sampled, we also recommend otolith microchemistry be used to estimate the date of marine entry and residence time along with molecular analyses to assign fish sampled back to their population of origin.*

### 9.5.2 Growth and Condition of Juvenile Salmon

Question(s) to be answered

What is the status and trend in juvenile salmon growth (and condition) by population and species, within the estuary?

Spatial and temporal considerations

The target population for sampling is juvenile salmon within the whole estuary as defined in Figure 3. The primary period of interest is from entry until departure from the estuary.

The extent of variability in juvenile salmon growth within the estuary is unknown. Sampling juvenile salmon to estimate growth could, in its simplest form, consist of a retaining a random subset of the fish captured in a density sampling program from a random subset of the sampling locations. However, for condition or questions related to short-term growth, one may want to design the sampling program around specific features (e.g. random sample of eelgrass beds vs. other habitats).

Sampling should occur annually. The temporal extent of sampling within year to quantify growth could, as stated above, consist of retaining a random subset of the fish captured in a density sampling program from a random subset of the sampling locations.

Methodologies

Daily growth increments can be determined by reading scale (Duffy and Beauchamp 2011) or otolith (Volk et al. 2010) samples taken from juvenile salmon. These increments can be used to quantify average growth rates during the entire residence in the estuary (or finer scale periods) up to the point of capture.

Bio-chemical metrics of growth including insulin-like growth factor 1 (IGF-

1; Ferris et al. 2014), as quantified from blood sampled from juveniles, and RNA:DNA ratios (MacLean et al. 2008) from muscle tissue, can be used to generate a snapshot of growth just prior to the period of capture.

Condition of juvenile salmon can be quantified based on a number of metrics. These include body condition indices such as residuals from the relationship between natural log transformed length and body mass of individual fish (Jakob et al. 1996, Brodeur et al. 2004) and stomach content metrics such as quality of prey and stomach fullness (Schabetsberger et al. 2003). Combining tissue samples with molecular technologies such as high-throughput microfluidics platforms can be used to quantify juvenile salmon condition based on gene expression (Miller et al. 2011), as well as the intensity of infection with microbes (Miller et al. 2014). Intensity of infection with parasites (e.g. sea lice) can be quantified on juvenile salmon lethally sampled using dissecting microscopes (Gottesfeld et al. 2009).

### Summary

Daily growth increments provide a measure of growth through time in the habitats occupied prior to capture. Conversely, metrics such as IGF-1 and RNA:DNA ratios provide a snapshot of growth over a relatively short period of time (e.g. a few days to a week). As a result daily growth increments are most useful for understanding growth history (e.g. average daily growth rates), quantifying size selective mortality when fish are sampled repeatedly through time (Duffy and Beauchamp 2010) and, when compared to early marine growth estimates from fish sampled when they return as adults, quantifying evidence for early marine growth effects on overall marine survival (Cross et al. 2009). Sampling juvenile salmon at the margins of the estuary as they exit would provide samples that characterize growth, of surviving fish, during the period of residency in the estuary. IGF-1 and RNA:DNA ratios on the other hand are most useful for providing an indication of growth in relation to the habitat in which juvenile salmon were captured or recently occupied, and so can provide information on the quality of different habitat from a growth perspective.

Condition can be estimated a multitude of ways with the most appropriate metric to use depending on the question being asked. Body condition indices are easy to quantify but only provide a coarse measure of the “health” of individual fish. Stomach contents analyses provide useful information on the quality and quantity of important salmon food and can be related back to growth metrics as well as the habitat in which the fish was sampled but can be labor intensive to generate. Molecular technologies provide “state-of-the-art” opportunities to study juvenile salmon condition in response to their biotic (e.g. food, habitat, microparasites) and abiotic environment but processing and storing samples can be logistically challenging and expensive (i.e. storage in liquid nitrogen and then at -80$^0$C).

*We recommend that a random subset of the juvenile salmon collected via the net-based sampling in the previous section have scales and otoliths sampled to estimate daily growth increments and residence time in the estuary. These same collections should also have blood and tissue samples taken to facilitate biochemical estimates growth just prior to capture. We recommend that condition also be quantified in these same fish based on body condition indices and stomach contents and that a subset of fish be collected in a manner that samples could be used for molecular analyses such as gene expression at a later date (i.e. in liquid nitrogen and then at -80$^0$C).*

### 9.5.3 Extent of Eelgrass

Question(s) to be answered

What is the spatial extent of eelgrass habitat in the Skeena estuary and how is it changing over time?

Spatial and temporal considerations

The target population for sampling is the eelgrass beds within the whole estuary as defined in Figure 3.

There are certain areas in the estuary that cannot support eelgrass beds. These can be predicted by physical characteristics of the shoreline. Monitoring should be focused on the areas that have the potential to support eelgrass.

The temporal extent of sampling depends on the rate at which the distribution of eelgrass is predicted to change over time or after activities that are predicted to significantly perturb eelgrass habitat occur (e.g. the construction of a LNG terminal). The seasonal timing of the surveys should occur to the extent practical in late-summer and fall (e.g. July through September) to capture the maximum developed extent of eelgrass beds at depth.

Methodologies

The extent of eelgrass beds can be determined via direct and indirect methods.

Direct methods to quantify eelgrass extent include dive surveys, underwater video and transects of subtidal and intertidal beds (Mason 2002; Duarte and Kirkman 2003; Ocean Ecology 2013).

Indirect methods to quantify eelgrass extent aerial photography and optical remote sensing as well as single beam, multi beam and side scan sonar (Vis et al. 2003; Sánchez-Carnero et al. 2010).

Eelgrass quality can be quantified based on shoot density and leaf area index (e.g. from a random sample of 30 shoots), which is then used to estimate the productivity of eelgrass, the amount of habitat available for colonization by epifauna and can be tracked over time to detect changes (Mason 2002).

Summary

Direct eelgrass sampling techniques can provide highly accurate localized data on the density, quality and distribution of eelgrass, but are time and labor intensive and so impractical for mapping the spatial distribution of eelgrass over broad areas. Aerial photography and optical remote sensing allow for greater spatial coverage of surveys than direct sampling and so are often the preferred method for mapping of intertidal eelgrass. However mapping of subtidal eelgrass can be limited by water clarity, cloud coverage and sea surface roughness (Vis et al., 2003) and so can result in systematic underestimation of the extent of seagrass. Sonar approaches to characterizing eelgrass extent allow for the detection of both intertidal and subtidal beds with side scan sonar providing the broader spatial resolution than single and multi beam sonar (Sánchez-Carnero et al. 2010).

*We recommend that the distribution of eelgrass beds be quantified via a one-time census of eelgrass in the estuary to fill data gaps (i.e. areas not already recently surveyed), conducted using primarily sidescan sonar and supplemented with other compatible methods as may be most applicable to a specific area and bathymetry where practical (e.g. aerial photography or dive surveys). The resulting comprehensive regional map of the extent of eelgrass can then be followed up with a periodic (e.g. every 5 years; Berstein et al. 2011) census or random sample (depending out the outcome of an evaluation of the logistical and efficiency tradeoffs between the two approaches) to update maps of eelgrass extent and track trends.*

### 9.5.4 Density and Diversity of Key Salmon Food

Question(s) to be answered

What is the density and diversity of key zooplankton prey for juvenile salmon in the Skeena estuary during the spring and summer salmon growth period?

### Spatial and temporal considerations

The target population for sampling is zooplankton within the whole estuary as defined in Figure 3.

Zooplankton density can be highly variable in space and so to improve the efficiency of a sampling design beyond a simple random survey, stratified random sampling may be suitable based on a pilot study or historic estimates of zooplankton density or habitat characteristics (e.g. eelgrass beds or salinity zones). Because the sampling program is primarily interested in the role of zooplankton density and diversity of key zooplankton as prey for salmon, the spatial extent of sampling should include at least a subset of sampling sites where juvenile salmon are sampled.

The temporal extent of sampling (e.g. weekly or semi-weekly) will depend on temporal variability in zooplankton composition and abundance, which could be assessed by a pilot study and should coincide with the period of time that juvenile salmon utilize the estuary (e.g. April – August).

Ultimately there is a tradeoff between low temporal replication at many locations (which can capture spatial patchiness well but requires large blocks of time and can misidentify phenological changes as interannual variability) and frequent sampling at fewer locations (which can capture phenological changes within a season or year and can be compared to other time series on similar scales, but lacks within sampling period replication and information on spatial patchiness).

### Methodologies

Zooplankton diversity, density and biomass is typically monitored by deploying oblique tows at multiple depths or vertical plankton tows from depth using multiple mesh sizes (e.g. 60-240 microns) to generate quantitative estimates of the zooplankton occupying the water column from a desired depth at the time of the tow (Chittenden et al. 2013; Tommasi et al. 2013). By quantifying flow (using a flow meter) through the plankton net during the tow a precise estimate of density in the region sampled can be generated.

### Summary

Vertical plankton tows from depth sample the zooplankton community across the entire water column. In contrast, oblique plankton tows from the upper part of the water column (e.g. upper 10 - 30 meters) provide a finer spatial scale indication of the zooplankton community in the portion of the water column that juvenile salmon are typically feeding. Plankton nets that are typically 150- 250 microns are most often used when trying to sample zooplankton species that are of size classes that constitute typical prey for juvenile salmon (Tommasi et al. 2013). Zooplankton prey fields can be compared to stomach contents of juvenile salmon captured in the same location to quantify prey selectivity and to estimate the abundance of key prey in space and time (Schabetsberger et al. 2003; Price et al. 2013).

At locations where the zooplankton community is sampled, additional oceanographic parameters can also be easily measured. These include phytoplankton and chlorophyll a, which provide an indication of the timing of the spring plankton bloom as well as temperature and conductivity (salinity). These water quality samples add very little extra effort to the sampling program but can yield important abiotic information at the sample location.

*We recommend that at a random subset of locations where juvenile salmon are collected zooplankton should be sampled by oblique plankton tows from the upper part of the water column to quantify composition, density and biomass of key salmon prey. Sampling should span the duration of juvenile salmon residence in the estuary. In addition, at the same sampling locations phytoplankton and chlorophyll a should be sampled and temperature and salinity profiles recorded.*

# 10 SUMMARY AND RECOMMENDATIONS

A global review of estuary assessments from multiple jurisdictions was undertaken to inform the development of a salmon-focused conceptual model that could be used to assess the status of the Skeena estuary and identify monitoring needs. The resulting Skeena River Estuary Conceptual Model was structured around three independent impact categories that capture major processes or drivers in the estuary: (1) Water Quality, (2) Habitat & Lower Food Web, and (3) Salmon Populations, with elements within each impact category organized into distinct pressure and state indicator types. This pressure-state assessment framework has been recommended as an approach for habitat monitoring under Strategy 2 of Canada's Wild Salmon Policy (Fisheries and Oceans Canada 2005). Linkages within the Skeena River Estuary Conceptual Model helped to identify key indicators that could be used to assess the extent or intensity of Skeena estuary pressures and the associated condition of estuary habitats and juvenile salmon populations across Skeena estuary reporting units (i.e. salinity zones).

In order to systematically and objectively evaluate the scientific merit of available data and their relevance to an estuary-wide assessment, datasets related to the Skeena estuary indicators were subjected to a detailed Data Quality Assessment (DQA). While most datasets scored high on scientific quality, many scored low on relevance because of limitations in spatial and temporal coverage.

For the Skeena estuary assessment, we attempted to use absolute quantitative benchmarks for all indicators based on scientific research of ecological thresholds. However, for many of the indicators, there was insufficient research available to inform science-based benchmarks. For these indicators, status ratings were instead generated based on the average value of the indicator within the reporting unit, or simply on the presence or absence of the indicator in the reporting unit. For other indicators, defensible benchmarks could not be defined and so only the relative intensities or extents of indicator values (i.e. raw numbers) were presented across estuary reporting units. The approaches used for defining indicator benchmarks represent an initial, largely descriptive, exercise. Further development of consistent, agency and stakeholder-vetted benchmarks of concern, particularly for estuary pressures, should be a central component of future assessments.

Overall, many of the indicators were ranked as "good" (i.e. green). However, it is important to note that the available information was generally restricted to a small proportion of the estuary and therefore not indicative of the estuary as a whole. Assessing the overall status of the estuary requires data at the full spatial extent of the Skeena estuary, something that was not available at the time this project was conducted.  The significant gaps in data identified through this project severely limit our understanding of the status and condition of estuarine habitats and our understanding of how multiple natural and anthropogenic pressures may interact to impact wild salmon and their estuarine habitats.  Improving our collective understanding of the status of salmon and their Skeena estuary habitats requires a long-term commitment to monitor key indicators across the full extent of the estuary and the ongoing identification of data gaps related to the elements of the Skeena River Estuary Conceptual Model.  By advancing our scientific understanding of the Skeena estuary in relation to juvenile salmon, we will be able to identify strategies that conserve and protect high value salmon habitat and minimize risks to wild salmon.

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# APPENDIX 1. ESTUARY PROJECTS, ASSESSMENTS OR CONCEPTUAL FRAMEWORKS REVIEWED

| Project Identifier | Project Reference |
|---|---|
| P1 | DFO Wild Salmon Policy reports (Stalberg et al. 2009; Nelitz et al. 2007) |
| P2 | Skeena River Estuary Juvenile Salmon Habitat report (Ocean Ecology 2014 (original chum model: Lestelle et al. 2005)) |
| P3 | EPA's National Coastal Condition Reporting (EPA 2012 National Coastal Condition Report IV) |
| P4 | NOAA's Estuarine Eutrophication Surveys (Pacific Coast Region) (NOAA. 1998. Estuarine eutrophication survey (V5 Pacific Region)) |
| P5 | EPA's National Coastal Condition Reporting (Approach for assessment of the status of the nation's estuary and coastal ecosystems - unpublished) |
| P6 | Concept paper on ecological assessment criteria for PNW estuaries (Simenstad and Cordell. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries) |
| P7 | EQUATION (Estuarine QUAlity and condiTION index) paper (Ferreira. 2000. Development of an estuarine quality index based on key physical and geochemical features) |
| P8 | Marine ecosystem vulnerability articles (Teck et al. 2010. Using expert judgement to estimate marine ecosystem vulnerability in the California current & Halpern et al. 2009. Mapping cumulative human impacts to California Current marine ecosystems) |
| P9 | Fraser River Estuary Management Program (FREMP) (FREMP. 2003. A living working river: The Estuary Management Plan for the Fraser River) |
| P10 | Moreton Estuary Ecosystem Health Monitoring Program (EHMP) (2013 Healthy waterways annual report card methods) |
| P11 | Morro Bay National Estuary Program (State of the Bay. 2014. A report on the health of the Morro Bay Estuary. Morro Bay National Estuary Program) |
| P12 | Queensland Integrated Estuary Assessment Framework (Moss et al. 2006. Integrated estuary assessment framework. Cooperative Research Centre for Coastal Zone, Estuary & Waterway Management, Technical Report 69) |

| | |
|---|---|
| P13 | National Estuarine Environmental Condition Assessment Framework (Arundel and Mount. 2007. National estuarine environmental condition assessment framework round table. National land & water resources audit.) |
| P14 | Australian Catchment, River and Estuary Assessment Program (National Heritage Trust. 2002. Australian catchment, river and estuary assessment. 2002. Volume 1) |
| P15 | New South Wales Department of Infrastructure, Planning and Natural Resources (DIPNR) Report Cards on Estuaries (Office of Environment & Heritage. 2013. Assessing estuary ecosystem health: Sampling, data analysis and reporting protocols.) |
| P16 | Assessing anthropogenic pressures on estuarine fish nurseries paper (Vasconcelos et al. 2007. Assessing anthropogenic pressures on estuarine fish nurseries along the Portuguese coast: A multi-metric index and conceptual approach) |
| P17 | Chesapeake Bay Program (Weisberg et al. 1997, Dauer et al. 2000, Alden et al. 2002; http://www.chesapeakebay.net/) |

# APPENDIX 2. PRINCIPALS FOR DEVELOPING A CONCEPTUAL MODEL OF THE SKEENA RIVER ESTUARY

The following set of general principles were adopted to develop a simple but useful conceptual model for the Skeena River estuary.

1. Bound the system of interest according to the valued ecosystem component of interest (i.e. salmon) and related spatial and temporal boundaries.

2. Identify the critical model components within the system of interest, including human stressors, natural drivers, as well as the indirect and direct outcomes of interest for a salmon-focused estuary assessment.

3. Represent the complexity of relationships so as to provide a realistic representation of the ecosystem (i.e. pathways of effects from stressors and drivers to outcomes of interest). It is also important that the pathways illustrate sufficient complexity so that appropriate indicators can be identified and prioritized.

4. For the needs of communication and indicator prioritization, develop a parsimonious conceptual model (i.e. sufficiently simple and clear, yet sufficiently complex to be realistic).

5. To be useful for eliciting expert judgements, develop a manageable number of pathways and represent the pathways using meaningful language for the TAC.

6. Describe the conceptual model using a schematic and supporting narrative table to illustrate linkages among the identified components.

7. Constrain the model to fit on one page so as to provide a complete and an “at a glance” overview of the estuary system.

8. Review the conceptual model with the TAC and revise as needed to ensure there is broad support for the model and that it is sufficiently realistic for our assessment purposes.

# APPENDIX 3. INDICATORS FROM REVIEW OF ESTUARY ASSESSMENTS

| Indicators | Indicator Type* | Estuary Assessment "Projects" (Reports/Discussion Papers) | | | | | | | | | | | | | | | | | Sum of indicators |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P 9 | P 10 | P 11 | P 12 | P 13 | P 14 | P 15 | P 16 | P 17 | |
| Nutrients (N, P) | **S** | X | | X | X | X | X | X | | | X | | X | X | X | | X | X | 12 |
| Dissolved Oxygen | **S** | X | X | X | X | | | X | | | X | X | | X | X | X | | X | 11 |
| Chlorophyll a | **S** | | | | X | | | X | | | X | | X | X | X | X | | X | 8 |
| Sediment Contaminants | **S** | X | X | X | | | | X | | | | | | X | X | | X | X | 8 |
| Eelgrass/macrophytes extent/status | **S** | | X | | | X | | | | | X | X | X | | X | X | | X | 8 |
| Turbidity/water clarity | **S** | | X | X | X | | | | | | X | | | X | X | X | | X | 8 |
| Water temperature | **S** | | X | | | X | X | X | | | | X | | X | X | | | | 7 |
| Water column contaminants | **S** | X | X | | | X | | | | | | | | X | X | | X | X | 7 |
| Salinity | **S** | | | | | X | X | | | | | X | | X | X | | | | 5 |
| Kelp/macroalgae extent/status | **S** | | X | | X | | | | | | | | X | | | X | | | 4 |
| Habitat diversity/extent of key habitat types | **S** | | X | | | | X | | | X | | | | X | | | | | 4 |
| Harmful algae blooms | **S** | | | | X | X | | | | | | | X | X | | | | | 4 |
| Intertidal wetland extents/status | **S** | | | | X | X | | | | | | | | | X | | | X | 4 |
| Bottom habitat extents (hard, soft) | **S** | | | | | X | | | | | | | | | | | | X | 2 |
| Sediment TOC | **S** | | | X | | | | | | | | | | | | | | | 1 |
| Habitat connectivity | **S** | | | | | | X | | | | | | | | | | | | 1 |
| Extent of low energy environments | **S** | | | | | | X | | | | | | | | | | | | 1 |
| Extent of fish nursery areas | **S** | | | | | | | X | | | | | | | | | | | 1 |
| Habitat productivity | **S** | | | | | | | | | X | | | | | | | | | 1 |
| pH | **S** | | | | | | | | | | | | | X | | | | | 1 |
| Invertebrate | **S** | | | X | X | X | | X | | | | | | | X | | | X | 6 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| biomass/species richness | | | | | | | | | | | | | | | | | | | |
| Fish community species richness/abundance | **S** | | | | | | | X | | | | | | | X | X | | X | 4 |
| Zooplankton biomass/species richness | **S** | | X | | X | X | | | | | | | | | | | | | 3 |
| Disease/pathogens prevalence | **P** | | | | | | | | X | | | | | X | X | | | | 3 |
| Fish tissue contaminants | **S** | | | X | | | | | | | | | | X | | | | | 2 |
| Primary productivity | **S** | | | | X | | | | | | | | | | | | | | 1 |
| Invertebrate bioaccumulation loads | **S** | | | | | X | | X | | | | | | | | | | | 2 |
| Salmon carcasses | **SP** | | X | | | | | | | | | | | | | | | | 1 |
| Hatchery salmon releases (intra-specific competition) | **P** | | X | | | | | | | | | | | | | | | | 1 |
| Wild salmon status (interspecific competition) | **P** | | X | | | | | | | | | | | | | | | | 1 |
| Predatory marine fish abundance | **P** | | X | | | | | | | | | | | | | | | | 1 |
| Marine mamal abundance | **P** | | X | | | | | | | | | | | | | | | | 1 |
| Seabird abundance | **P** | | X | | | | | | | | | | | | | | | | 1 |
| Habitat specific fish residence time | **SP** | | | | | | X | | | | | | | | | | | | 1 |
| Fish growth | **SP** | | | | | | X | | | | | | | | | | | | 1 |
| Fish survival | **SP** | | | | | | X | | | | | | | | | | | | 1 |
| Phytoplankton density/richness | **S** | | | | | | | | | | | X | | | | | | | 1 |
| Permitted waste discharges/nutrient & contaminant inputs | **P** | X | | | | | | | X | | | | | | X | | X | | 4 |
| Invasive/pest species extent/status | **P** | | | | | X | | | X | | | | | X | X | | | | 4 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aquaculture activities (fish, shellfish, plants) | **P** | | | | | | | X | X | | | | | | X | | X | | 4 |
| Fishing intensity | **P** | | | | | | | X | X | | | | | | X | | X | | 4 |
| Marine vessel/shipping traffic | **P** | X | | | | | | | X | | | | | | X | | | | 3 |
| Dams | **P** | | | | | X | | | | | | | | | X | | X | | 3 |
| Dredging extents | **P** | | | | | | | | X | | | | | | X | | X | | 3 |
| Land use (land cover) | **P** | | | | | | | | | X | | | | | X | | | X | 3 |
| Human population density | **P** | | | | | | | X | | | | | | | | | X | X | 3 |
| Riparian disturbance/condition | **P** | X | | | | | | | | | X | | | | | | | | 2 |
| Coastal engineering projects | **P** | | | | | | | | X | | | | | | X | | | | 2 |
| Ocean dumping | **P** | | | | | | | | X | | | | | X | | | | | 2 |
| Sediment inputs/accretion rate | **P** | | | | | | | | | | | X | | X | | | | | 2 |
| Industrial infrastructure | **P** | | | | | | | | | | | | | | X | | X | | 2 |
| Intertidal/subtidal disturbance | **P** | X | | | | | | | | | | | | | | | | | 1 |
| Obstructions | **P** | | X | | | | | | | | | | | | | | | | 1 |
| Rate of habitat loss | **P** | | | X | | | | | | | | | | | | | | | 1 |
| Shoreline armouring | **P** | | | | | X | | | | | | | | | | | | | 1 |
| Benthic structures | **P** | | | | | | | | | | | | | | X | | | | 1 |
| Projected climate change risks (UV, SST, Acidification, sea level) | **P** | | | | | | | | X | | | | | | | | | | 1 |
| Extent of direct human impacts (trampling, etc.) | **P** | | | | | | | | X | | | | | | | | | | 1 |
| Marine forestry | **P** | | | | | | | | X | | | | | | | | | | 1 |
| Military activities | **P** | | | | | | | | X | | | | | | | | | | 1 |
| Pollution (multiple potential sources) | **P** | | | | | | | | X | | | | | | | | | | 1 |
| Ocean mining | **P** | | | | | | | | X | | | | | | | | | | 1 |
| Power/desalination | **P** | | | | | | | | X | | | | | | | | | | 1 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| plants | | | | | | | | | | | | | | | | | | | |
| Scientific research impacts | **P** | | | | | | | | X | | | | | | | | | | 1 |
| Tourism/recreational activity intensity (kayaking, boating, etc.) | **P** | | | | | | | | | | | | | | X | | | | 1 |
| Creek inflow WQ assessments | **P** | | | | | | | | | | | X | | | | | | | 1 |
| Freshwater flows | **V** | | X | | | X | | X | X | | | | | | X | | | X | 6 |
| Wave exposure | **V** | | X | | | | | | | | | | | | | | | | 1 |
| Tidal flow/flushing | **V** | | | | | | | | | | | | | | X | | | | 1 |
| Tidal elevation/range | **V** | | | | | | | X | | | | | | | | | | | 1 |
| Estuary Area/volume | **V** | X | | | | | | X | | | | | | | | | | | 2 |

***Indicator Types: S = State, P = pressure, SP = salmon population, V = vulnerability**

**Projects evaluated:**

P1 = DFO WSP reports (Stalberg et al. 2009. (also see Nelitz et al. 2007))

P2 = Skeena River Estuary Juvenile Salmon Habitat report (Ocean Ecology 2014 (original chum model: Lestelle et al. 2005))

P3 = EPA's National Coastal Condition Reporting (EPA 2012 National Coastal Condition Report IV)
P4 = NOAA's Estuarine Eutrophication Surveys (Pacific Coast Region) (NOAA. 1998. Estuarine eutrophication survey (V5 Pacific Region)
P5 = EPA's National Coastal Condition Reporting (Approach for assessment of the status of the nation's estuary and coastal ecosystems - unpublished)

P6 = Concept paper on ecological assessment criteria for PNW estuaries (Simenstad and Cordell. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries)
P7= EQUATION (Estuarine QUAlity and coniTION index) paper (Ferreira. 2000. Development of an estuarine quality index based on key physical and geochemical features)
P8 = Assessment of marine ecosystem vulnerability papers (Teck et al. 2010. Using expert judgement to estimate marine ecosystem vulnerability in the California current / Halper et al. 2009. Mapping cumulative human impacts to California Current marine ecosystems)
P9 = Fraser River Estuary Management Program (FREMP) (FREMP. 2003. A living working river: The Estuary Management Plan for the Fraser River)

P10 = Moreton Estuary Ecosystem Health Monitoring Program (EHMP) (2013 Healthy waterways annual report card methods)
P11 = Morro Bay National Estuary Program (State of the Bay. 2014. A report on the health of the Morro Bay Estuary. Morro Bay National Estuary Program)

P12 = Queensland Integrated Estuary Assessment Framework (Moss et al. 2006. Integrated estuary assesssment framework. Cooperative Research Centre for Coastal Zone, Estuary & Waterway Management, Technical Report 69)

P13 = National Estuarine Environmental Condition Assessment Framework (Arundel and Mount. 2007. National estuarine environmental condition assessment framework round table. National land & water resources audit.)

P14 = Australian Catchment, River and Estuary Assesssment Program (National Heritage Trust. 2002. Australian catchment, river and estuary assessment. 2002. Volume 1)

P15 = New South Wales Department of Infrastructure, Planning and Natural Resources (DIPNR) Report Cards on Estuaries (Office of Environment & Heritage. 2013. Assessing estuary ecosystem health: Sampling, data analysis and reporting protocols.)

P16 = Assessing anthropogenic pressures on estuarine fish nurseries paper (Vasconcelos et al. 2007. Assessing anthropogenic pressures on estuarine fish nurseries along the Portugese coast: A mult-metric index and conceptual approach)

p17 = Chesapeake Bay Program

# APPENDIX 4. INDICATOR BENCHMARK CATEGORIES FROM REVIEW OF ESTUARY ASSESSMENTS

| **Benchmark Categories** | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | **P8** | **P9** | **P10** | **P11** | **P12** | **P13** | **P14** | **P15** | **P16** | **P17** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Absolute benchmarks (quantitative) | X | X | X | X | | | X | | | | X | X | | X | X | | X | 10 |
| Absolute benchmarks (categorical) | | | X | X | | | X | | X | X | | X | | X | | | X | 8 |
| Relative benchmarks (spatial/temporal) | X | | | | | | | X | | | | | | | X | X | | 4 |
| Performance relative to target | | | | | | | | | | | | | | X | X | | X | 3 |
| No information* | | | | | X | X | | | | X | | | X | | | | X | 5 |
| **Benchmark Defining Approach** | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | **P8** | **P9** | **P10** | **P11** | **P12** | **P13** | **P14** | **P15** | **P16** | **P17** | **Total** |
| Scientific support | X | X | X | | | | X | | | | X | X | | X | X | | X | 9 |
| Statistical spread | X | | | | | | | X | | | | | | | X | X | | 4 |
| Expert opinion | X | X | X | | | | X | X | X | | | X | | X | | | X | 9 |
| No information* | | | | | X | X | | | | | | | X | X | | | | 5 |

*In some cases there is no information at all, in other cases there are benchmarks for some indicators and not for others and so the 'no information' row may be ticket as well.

**Projects evaluated:**

P1 = DFO WSP reports (Stalberg et al. 2009. (also see Nelitz et al. 2007))

P2 = Skeena River Estuary Juvenile Salmon Habitat report (Ocean Ecology 2014 (original chum model: Lestelle et al. 2005))

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P7= EQUATION (Estuarine QUAlity and coniTION index) paper (Ferreira. 2000. Development of an estuarine quality index based on key physical and geochemical features)
P8 = Assessment of marine ecosystem vulnerability papers (Teck et al. 2010. Using expert judgement to estimate marine ecosystem vulnerability in the California current / Halper et al. 2009. Mapping cumulative human impacts to California Current marine ecosystems)
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P11 = Morro Bay National Estuary Program (State of the Bay. 2014. A report on the health of the Morro Bay Estuary. Morro Bay National Estuary Program)

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p17 = Chesapeake Bay Program

# APPENDIX 5. MONITORING SUMMARY TABLE

| Impact category | Indicator | Monitoring effort to date | Questions that can be answered by monitoring | Gap classification | Tier 1 classification | Tier 2 classification | Comments on classifications |
|---|---|---|---|---|---|---|---|
| Habitat & Lower Food Web | Shoreline & Nearshore Development Extent | Extensive data on existing and proposed development compiled by multiple efforts (Faggetter photo comparison, Province, PNWLNG, Prince Rupert Port Authority). | What is the extent of shoreline development in the Skeena estuary? | High quality | Low priority | N/A | High quality because there are no significant spatio-temporal limitations to monitoring or methodology used. |
| Habitat & Lower Food Web | Native Eelgrass Extent | For eelgrass, numerous datasets exist that in combination provide an indication of the extent of eelgrass for intertidal and subtidal portion of much of the estuary. However, still limitations to individual methodologies and variability in space and time. Also derived data available from Ocean Ecology (2014). | What is the spatial and temporal distribution of native eelgrass in Skeena estuary? | Limitations | High priority | Primary | Limitations because of spatial scale of monitoring and methodological limitations. Tier 1 High priority because related to overarching monitoring goal. Primary Tier 2 classification because it is sensitive to change. |
| Habitat & Lower Food Web | Zooplankton Density or Diversity | Zooplankton data collected in 1970s and compiled by Ocean Ecology (2014). | What is the phenology of secondary production in the Skeena estuary? | Limitations | High priority | Primary | Limitations because of spatial and temporal scale of past monitoring. Tier 1 High priority because related to overarching monitoring goal. Primary Tier 2 classification because it is sensitive to change. |
| Habitat & Lower Food Web | Chlorophyll a Concentration | Routine monitoring of Chl *a* by Prince Rupert Port Authority has recently occurred at locations throughout harbor (5 times per year). Satellite derived Chl *a* is available for whole estuary at larger spatial scale with poor/no resolution near shore. | What is the [Chl a] and phenology of primary production in the Skeena estuary? | Limitations | High priority | Secondary | Limitations because of spatial scale of monitoring. Tier 1 High priority because related to overarching monitoring goal. Secondary Tier 2 classification because it is currently being partially monitored. |

| Impact category | Indicator | Monitoring effort to date | Questions that can be answered by monitoring | Gap classification | Tier 1 classification | Tier 2 classification | Comments on classifications |
|---|---|---|---|---|---|---|---|
| Habitat & Lower Food Web | Intact Riparian Vegetation Extent | Data on the extent of riparian vegetation within harbor as compiled by Ocean Ecology (2014). | What is the extent of riparian vegetation intactness/disturbance across estuary? | Limitations | Low priority | N/A | Limitations because of spatial scale of monitoring. Tier 1 Low priority because not directly related to overarching monitoring goal. |
| Habitat & Lower Food Web | Intertidal Wetlands Extent | There are multiple spatial layers on distribution of tidal channels and freshwater and tidal marshes for the harbor area only as derived by Ocean Ecology (2014). | What is the spatial extent of intertidal wetlands in the Skeena estuary? | Limitations | Low priority | N/A | Limitations because of spatial scale of monitoring. Tier 1 Low priority because not directly related to overarching monitoring goal. |
| Habitat & Lower Food Web | Marine Vessel Traffic | Marine vessel traffic is monitored for AIS system boats by Coastguard. In theory AIS data should be available continuously but data we looked at was only from 2010 in 5x5 km grids compiled by BCMA. Noise data has been generated for 2010 at 250x250m scale for whole estuary by WWF based on finer scale habitat characteristics. | Where, when and what type of vessels are travelling through the Skeena estuary? | Limitations | Low priority | N/A | Limitations because there is no small vessel data; otherwise high quality. Tier 1 Low priority because not directly related to overarching monitoring goal. |
| Habitat & Lower Food Web | Native Macroalgae Extent | Kelp distribution linked to shorezone units mapped for much of the estuary. However, still limitations to individual methodologies and variability in space and time. Also derived data available from Ocean Ecology (2014). | What is the spatial and temporal distribution of native macroalgae in Skeena estuary? | Limitations | Low priority | N/A | Limitations because of spatial scale of monitoring and methodological limitations. Tier 1 Low priority because not directly related to overarching monitoring goal. |
| Habitat & Lower Food Web | Algal Bloom Number or Extent | Not currently occurring, but could potentially be derived from air photo or satellite imagery interpretation. | What is the timing and spatial distribution of plankton blooms (including spring plankton bloom) in the Skeena estuary? | No data | Low priority | N/A | Tier 1 low priority because HABs are considered a lower probability threat at present (although occurrences have been documented). |

| Impact category | Indicator | Monitoring effort to date | Questions that can be answered by monitoring | Gap classification | Tier 1 classification | Tier 2 classification | Comments on classifications |
|---|---|---|---|---|---|---|---|
| Habitat & Lower Food Web | Invasive Species Distribution or Abundance (Zooplankton, Invertebrates, Macroalgae & Vascular Plants) | Not currently occurring. | What is the spatial and temporal distribution of invasive organisms in Skeena estuary? | No data | Low priority | N/A | Tier 1 Low priority because invasives are considered a low probability threat at present and because not directly related to overarching monitoring goal. |
| Salmon Populations | Commercial Harvest | Data on commercial harvest is collected annually by fishery opening and Fishery Management Area by DFO. | What is the spatial and temporal distribution of commercial harvest within the Skeena estuary? | High quality | Low priority | N/A | High quality because there are no significant spatio-temporal limitations to monitoring or methodology used. Tier 1 Low priority because does not fill identified gap in monitoring. |
| Salmon Populations | Disease & Pathogens Prevalence | There is limited data on sea lice on juvenile salmon from broad regions within estuary over a few years (2004-7). No data on other microbes. | What is the spatial and temporal distribution of disease causing microbes in juvenile and adult salmon in the Skeena estuary? | Limitations | Low priority | N/A | Limitations because of spatial and temporal scale of monitoring and methodological limitations. Tier 1 Low priority because not directly related to overarching monitoring goal. |
| Salmon Populations | Marine Mammal Distribution or Abundance | Data has been collected on harbor seal haul out locations and occurrence of cetaceans from the cetacean sighting network. | What is the spatial and temporal distribution of possible marine mammal predators in Skeena estuary? | Limitations | Low priority | N/A | Limitations because of spatial and temporal scale of monitoring and methodological limitations. Tier 1 Low priority because not directly related to overarching monitoring goal. |
| Salmon Populations | Predatory Seabird Distribution or Abundance | Data on a coarse scale has been collected on the abundance of salmon smolt predatory seas birds throughout estuary over numerous years. | What is the spatial and temporal distribution of possible sea bird predators in Skeena estuary? | Limitations | Low priority | N/A | Limitations because of spatial and temporal scale of monitoring and methodological limitations. Tier 1 Low priority because not directly related to overarching monitoring goal. |

| Impact category | Indicator | Monitoring effort to date | Questions that can be answered by monitoring | Gap classification | Tier 1 classification | Tier 2 classification | Comments on classifications |
|---|---|---|---|---|---|---|---|
| Salmon Populations | Predatory Fish Distribution or Abundance | Not currently occurring. | What is the spatial and temporal distribution of salmonid fish predators in the Skeena estuary? | No data | Low priority | N/A | Tier 1 Low priority because not directly related to overarching monitoring goal. |
| Salmon Populations | Hatchery Salmon Abundance | The number of hatchery produced fry and smolts per year, along with timing and location of release, is documented by SEP/DFO on an annual basis. | How many hatchery produced juvenile salmon might compete with wild salmon in the estuary in a given year? | Unavailable data | Low priority | N/A | Tier 1 Low priority because not directly relate to overarching monitoring goal. |
| Salmon Populations | Recreational harvest | Data on recreational harvest data is collected annually by DFO via creel surveys | What is the spatial and temporal distribution of recreational harvest within the Skeena estuary? | Unavailable data | Low priority | N/A | Tier 1 Low priority because not directly relate to overarching monitoring goal. |
| Water Quality | Log Boom Sites | Data on the location of active log booming tenures throughout the estuary is available from the Province of BC. | What is the spatial distribution of log booming activities in the Skeen estuary? | High quality | Low priority | N/A | High quality because there are no significant spatio-temporal limitations to monitoring or methodology used. Tier 1 Low priority because does not fill identified gap in monitoring. |
| Water Quality | Wastewater Discharge Sites | Volume of wastewater discharge is currently recorded for all known discharge sites on a daily basis by the Province of BC. Contaminants are not monitored, but allowable limits are known which provides a coarse estimate of maximum contaminant input at a given point in time. | How much wastewater is being discharged into the estuary and what is the concentration of contaminants of interest in the wastewater? | High quality | Low priority | N/A | High quality because there are no significant spatio-temporal limitations to monitoring or methodology used. Tier 1 Low priority because does not fill identified gap in monitoring. |

| Impact category | Indicator | Monitoring effort to date | Questions that can be answered by monitoring | Gap classification | Tier 1 classification | Tier 2 classification | Comments on classifications |
|---|---|---|---|---|---|---|---|
| Water Quality | Disposal at Sea Sites | The location and type of dumped material at active and historical (inactive) disposal at sea sites has been compiled by Environment Canada. | Where, when and what is being dumped? | Limitations | High priority | Secondary | Limitations because of unknown volume and characteristics of load (e.g. contaminants). Tier 1 High priority because related to overarching monitoring goal. Secondary Tier 2 classification because it is being monitored though more information on ability to track volume and characteristics of load are needed. |
| Water Quality | Dissolved oxygen (DO) | Routine monitoring by Prince Rupert Port Authority for DO in water column has occurred recently at locations throughout harbor (5 times per year). Some older data are also available for the estuary (based on shoreline segments) based on Ocean Ecology (2014). | What is the dissolved oxygen concentration in the Skeena estuary in space and time? | Limitations | High priority | Secondary | Limitations because of spatial scale of monitoring. Tier 1 High priority because related to overarching monitoring goal. Secondary Tier 2 assessment because it is being monitored by Prince Rupert Port Authority. |
| Water Quality | Nitrogen concentration (N) | Routine monitoring of N by Prince Rupert Port Authority has recently occurred at locations throughout harbor (5 times per year). | What is the [N] and associated nitrogen compounds in the Skeena estuary in space and time? | Limitations | High priority | Secondary | Limitations because of spatial scale of monitoring. Secondary Tier 2 assessment because it is being monitored by Prince Rupert Port Authority. |
| Water Quality | pH | Routine monitoring of PH by Prince Rupert Port Authority has recently occurred at locations throughout harbor (5 times per year). | What is the pH in the Skeena estuary in space and time? | Limitations | High priority | Secondary | Limitations because of spatial scale of monitoring. Tier 1 High priority because related to overarching monitoring goal. Secondary Tier 2 assessment because it is being monitored by Prince Rupert Port Authority. |

| Impact category | Indicator | Monitoring effort to date | Questions that can be answered by monitoring | Gap classification | Tier 1 classification | Tier 2 classification | Comments on classifications |
|---|---|---|---|---|---|---|---|
| Water Quality | Phosphorus concentration (P) | Routine monitoring of P by Prince Rupert Port Authority has recently occurred at locations throughout harbor (5 times per year). | What is the [P] in the Skeena estuary in space and time? | Limitations | High priority | Secondary | Limitations because of spatial scale of monitoring. Tier 1 High priority because related to overarching monitoring goal. Secondary Tier 2 assessment because it is being monitored by Prince Rupert Port Authority. |
| Water Quality | Sea surface temperature (SST) | Routine monitoring of SST by Prince Rupert Port Authority has occurred at locations throughout harbor (5 times per year). Derived data are available for estuary (based on shoreline segments) based on Ocean Ecology (2014). | What is the SST in the Skeena estuary in space and time? | Limitations | High priority | Secondary | Limitations because of spatial scale of monitoring. Tier 1 High priority because related to overarching monitoring goal. Secondary Tier 2 assessment because it is being monitored by Prince Rupert Port Authority. |
| Water Quality | Turbidity or Suspended Sediments | Routine monitoring by Prince Rupert Port Authority for turbidity in water column has occurred recently at locations throughout harbor (5 times per year). Derived data are available for estuary (based on shoreline segments) based on Ocean Ecology (2014). Additional data from the harbor (PNWLNG) and some older data is also available. Various protocols and reporting in different units. | What is turbidity or total suspended sediment concentration of the water column in the Skeena estuary in space and time? | Limitations | High priority | Secondary | Limitations because of spatial scale of monitoring. Tier 1 High priority because related to overarching monitoring goal. Secondary Tier 2 assessment because it is being monitored by Prince Rupert Port Authority. |
| Water Quality | Water Column Chemical Contaminants | Routine monitoring by Prince Rupert Port Authority for contaminants in water column has occurred at locations throughout harbor (5 times per year). Some older data is also available for harbor. | What are the concentrations of toxic contaminants in the water column in the Skeena estuary in space and time? | Limitations | High priority | Secondary | Limitations because of spatial scale of monitoring. Tier 1 High priority because related to overarching monitoring goal. Secondary Tier 2 assessment because it is being monitored by Prince Rupert Port Authority. |

| Impact category | Indicator | Monitoring effort to date | Questions that can be answered by monitoring | Gap classification | Tier 1 classification | Tier 2 classification | Comments on classifications |
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| Water Quality | Dredging Extent | The extent of proposed dredging has been recorded in some locations (e.g. PNWLNG terminal), although such information is in flux as plans change. No information available on any past dredging that may have occurred. | Where and when will dredging occur? | No data | More information needed | N/A | Classified as more information needed because it is not clear what information exists on proposed and potential future dredging within the estuary. |
| Water Quality | UV | Broad Pacific Northwest scale extractions of climate change data for UVB change (1996 - 2004 data as synthesized by Halpern et al. 2008) | Are UV levels increasing and if so, are they effecting aquatic habitats/biota | Unavailable data | Low priority | | Tier 1 Low priority because not directly relate to overarching monitoring goal. |
| Water Quality | Sediment Chemical Contaminants | Routine monitoring by PNWLNG for contaminants in sediments has occurred at locations within harbor. Some older data is also available at same scale. | What are the concentrations of toxic contaminants in sediment in the Skeena estuary in space and time? | Unavailable data | More information needed | N/A | More information needed because the data was unavailable to review and so it is not clear what information exists on concentrations of toxic contaminants in sediment in the Skeena estuary. |
| Wild Salmon | Smolt Density | Some data collected by trawl, dip net and beach seine from some regions of estuary in 2004-7 and 2013. Also estimates of species specific habitat suitability for the harbor. | What is the abundance and spatial & temporal distribution of juvenile salmon in the Skeena estuary? | Limitations | High priority | Primary | Limitations because of spatial and temporal scale of past monitoring. Tier 1 High priority because related to overarching monitoring goal. Primary Tier 2 classification because it is sensitive to change. |
| Wild Salmon | Smolt Residence Time | Some data collected by trawl, dip net and beach seine from some regions of estuary in 2004-7 and 2013 (Carr-Harris et al. 2015). | What is the timing and duration of migration and use of Skeena estuary by juvenile salmon? | Limitations | High priority | Primary | Limitations because of spatial and temporal scale of past monitoring. Tier 1 High priority because related to overarching monitoring goal. Primary Tier 2 classification because it is sensitive to change. |

| Impact category | Indicator | Monitoring effort to date | Questions that can be answered by monitoring | Gap classification | Tier 1 classification | Tier 2 classification | Comments on classifications |
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| Wild Salmon | Adult Salmon Abundance | The abundance of returning adult salmon is monitored in streams in many of the Conservation Units (but not all) within the Skeena watershed. | What is the abundance of spawning salmon that utilize and migrate through the Skeena estuary? | Limitations | High priority | Secondary | Limitations because of not all wild salmon populations in the Skeena are monitored. Tier 1 High priority because related to overarching monitoring goal. Secondary Tier 2 assessment because it is not sensitive to change. |
| Wild Salmon | Smolt Survival | Estimates of marine survival of variable duration are available for sockeye (wild Babine CUs, Kitwancool/Kitwanga, Slamgeesh), coho (Slamgeesh, middle-Skeena/toboggan creek), and Chinook (late-Kalum). | What is the marine survival of salmon that migrate through the Skeena estuary? | Limitations | High priority | Secondary | Limitations because only a small portion of wild salmon populations in the Skeena are monitored. Tier 1 High priority because related to overarching monitoring goal. Secondary Tier 2 assessment because it is not sensitive to change. |
| Wild Salmon | Smolt Growth | Not currently occurring. | How does growth vary from region to region, year to year, and by CU and species, within the Skeena estuary? | No data | High priority | Primary | Tier 1 High priority because related to overarching monitoring goal. Primary Tier 2 classification because it is sensitive to change. |