Skeena River Estuary Juvenile Salmon Habitat

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Executive Summary

The Skeena is the second largest river in the province, and one of the longest un-dammed rivers in the world. The Skeena River estuary is a unique system in that it does not have a single distinct intertidal delta typical of most estuary systems. Instead, suspended sediments are deposited in shoals along the lower river and the channels which connect the estuary to the open ocean, creating a region of extensive mudflats and shallow, intertidal passages. The estuary mudflats and other intertidal areas have been identified as critical habitats for Skeena River juvenile salmon, as well as important habitat for eulachon and migratory/wintering waterfowl.

Although estuaries provide essential nursery and juvenile rearing habitats, with up to 80% of coastal wildlife species relying on estuaries during at least one stage of their life history, they frequently occur in areas highly valued for industrial development. In the Skeena River estuary, the Port of Prince Rupert is expanding its already extensive commercial activities. Increased vessel traffic associated with newly proposed terminals, as well as potential oil tanker activity from proposed projects such as the Enbridge Northern Gateway, will also increase the possibility of spills and other marine accidents. Estuaries worldwide are often areas of conflict between human resource need and environmental sustainability. A more holistic approach to habitat protection is required, underpinned by a thorough scientific understanding of the roles and vulnerabilities of the different species and habitats in the estuarine environment. In order to implement this approach, there is a need to better understand the cumulative, and often complex, anthropogenic impacts on estuarine environments.

A number of local environmental organizations and community groups are working together to try to protect the Skeena River estuary from poorly planned over-development, and to establish the framework for a Skeena estuary management plan. As a part of these efforts, the focus of this study was to analyze the habitat in and around the Skeena River estuary in terms of suitability as valuable or critical habitat to juvenile salmonids.

Juvenile salmonid habitat in the Skeena River estuary was modeled based on concepts similar to those from the Ecosystem Diagnosis and Treatment (EDT) methodology used for summer and fall chum salmon in the Hood Canal and the Strait of Juan de Fuca. This model can provide a "snapshot", both spatially and temporally, of qualitative changes in habitat attributes as they relate to juvenile salmonid survival. From the model, the following conclusions were made:

- The northwest and southwest shores of Kaien Island and the southwest shore of Ridley Island are poor habitat for all salmonid species as a result of industrialization and the attendant shoreline straightening and hardening, industrial pollutants, and poor water quality resulting from sewage and industrial effluents.
- Flora Bank is excellent habitat for epibenthic feeding salmonid species (e.g., pink, chum, and Chinook). It is in the direct path of approximately 331 million juvenile salmon outmigrating from the Skeena River, of which about 279 million are epibenthic feeders. Therefore, both location and habitat quality make Flora Bank an extremely important juvenile salmon rearing area.
- Stapledon Island is a high value habitat for all six salmonid species, and is also in the direct path of outmigrating Skeena River juvenile salmonids.
- The southwest shore of Lelu Island and Delusion Bay are highly valuable habitats for neritic feeding species (e.g., Coho, sockeye, and steelhead).
- The shoreline segments in the basins on the east side of Kaien Island and on southeast shore of Prince Rupert Harbour provide important nursery and rearing habitats for salmon outmigrating from the local natal streams. While these populations are small, they are important to the overall health and diversity of salmon in the region.

This study has also helped to highlight the need for more detailed and up-to-date information on factors affecting juvenile salmonids in the Skeena River estuary.

1 Introduction

1.1 Chatham Sound

Figure 1. Aerial view north over Chatham Sound. Photo: Brian Huntington.

Chatham Sound (see Figure 1) is situated in the northern part of British Columbia, located between Dundas and Stephens Islands and the Tsimpsean Peninsula near Prince Rupert and bordering on Alaska. It is a semi-enclosed basin with an area of approximately 1500 km^2, and is influenced by fresh water from two large rivers, the Skeena and the Nass (Trites 1956). The Nass River discharges into Portland Inlet, and fresh water flows from there into the northern end of Chatham Sound and eventually out through Dixon Entrance (Tera Planning Ltd. 1993). Water from the Skeena River enters Chatham Sound through a series of channels. Approximately 75% of the Skeena River flows equally through Marcus Passage (separating Smith and DeHorsey Islands from Kennedy Island) and Telegraph Passage, while the remaining 25% of the Skeena River flows through Inverness Passage (Trites 1956). As a result of the fresh water discharges of the Nass and Skeena Rivers, the whole of Chatham Sound is essentially a large compound estuary (Tera Planning Ltd. 1993). Figure 2 shows the regions in Chatham Sound affected by freshwater outflows from the Skeena and Nass Rivers. Generally, estuarine circulation occurs when a large volume of fresh water from a river flows out along the surface at the head of an inlet. As it moves seaward, this layer entrains saline water from the layer beneath it, and carries this entrained water seaward. The loss of water from the lower layer is replenished by a deep water flow which has a net landward movement. However, as a result of the fresh water influx from two rivers, a highly irregular coastline, and a large horizontal extent, the circulation patterns in Chatham Sound are considerably more complex than in most coastal BC inlets (Tera Planning Ltd. 1993).

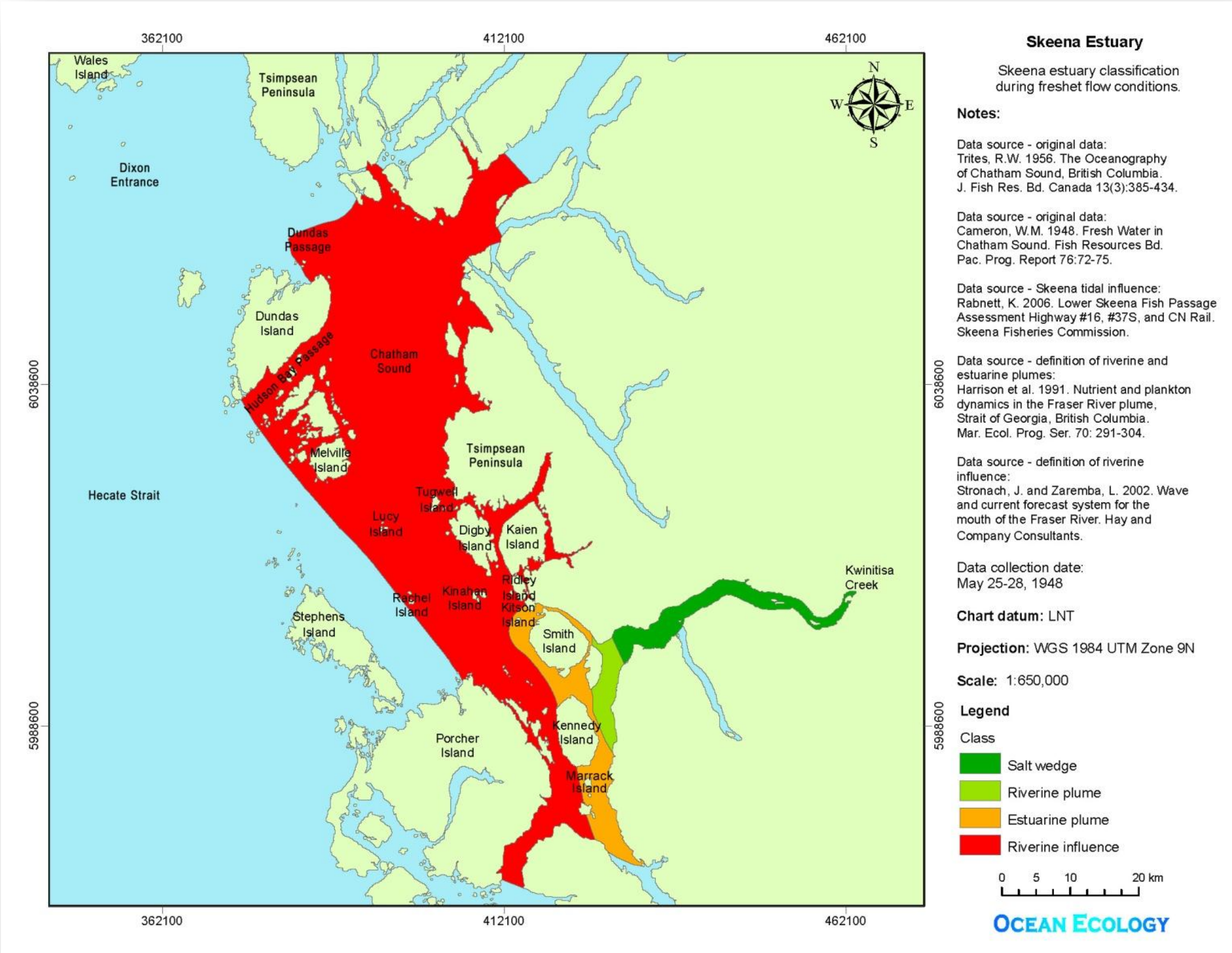


Figure 2. Skeena estuary classification during freshet flow conditions.

Snowmelt dominates the hydrology of the Nass and Skeena watersheds. Highest freshwater discharge ([freshet]) for the Skeena and Nass Rivers normally occurs from May through to June (EC 2014a; EC 2014b; Tera Planning Ltd. 1993) as a result of the melting snowpack, with a secondary peak from October through to December caused by rain on snow events (EC 2014a; EC 2014b). Although present throughout the year, estuarine circulation and the currents produced by this circulation are most pronounced during spring freshet. At this time of year, the amount of freshwater present in Chatham Sound can be 3 to 4 times the mean value (Cameron 1948). During normal (non-freshet) river discharge conditions, approximately 70% of the Skeena River water moves northward past Tugwell Island, along the Tsimpsean Peninsula to merge with Nass River water (Trites 1956). This water then exits Chatham Sound through Dundas Passage, with a smaller amount exiting through Hudson Bay Passage. Only a small proportion (30%) of the Skeena River discharge reaches Dixon Entrance and Hecate Strait through central and southern passages. This northward diversion of the Skeena River is due, in part, to the [Coriolis effect](), which diverts water to the right of the direction of flow in the northern hemisphere. Nass River water tends to be concentrated along the north shore of Chatham Sound, moving past Wales Island north of Dundas Island into Dixon Entrance. During freshet, fresh water flows are increased through all the passages and channels exiting Chatham Sound. Nass River water during freshet is thought to extend as far south as Melville Island, where it may interfere with the northern movement of Skeena River water past Dundas Island (Tera Planning Ltd. 1993; see Figure 3). The Nass and Skeena Rivers – two major Pacific salmon producing rivers – are unique in having a common estuary.

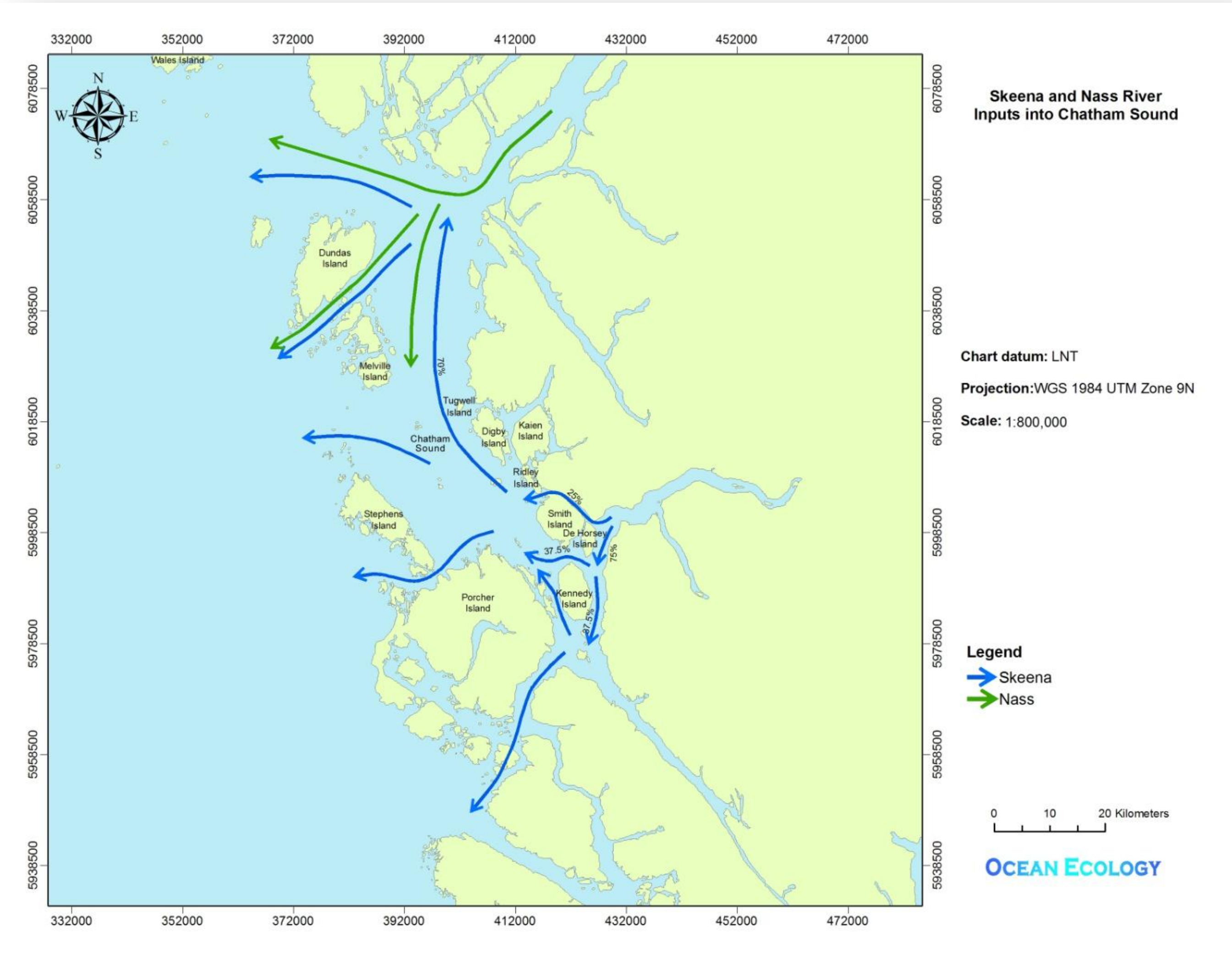


Figure 3. Skeena and Nass River inputs into Chatham Sound.

1.2 Skeena River Estuary

Figure 4. Aerial view of the Skeena River estuary looking northeast over Kitson Island, Flora Bank, and Lelu Island. Ridley Island is on the left hand side of the photo. Porpoise Channel is shown as a gap between Lelu and Ridley Islands. The proposed terminal for the Prince Rupert LNG would be located on southern Ridley Island along the north side of Porpoise Channel. The proposed terminal for the Pacific Northwest LNG would be located on Lelu Island along the south side of Porpoise Channel. Photo: Brian Huntington.

The Skeena River originates high in the Skeena Mountains of northwestern British Columbia, at the edge of the Spatsizi Plateau, and flows 610 km to reach the Pacific Ocean (see Figure 5). Draining a total area of 54,400 km^2, the Skeena is the second largest river in the province, and one of the longest un-dammed rivers in the world. The Skeena River estuary is a unique system in that it does not have a single distinct intertidal delta typical of most estuary systems (Hoos 1975). Suspended sediments from the Skeena River are deposited in shoals along the lower river and the channels which connect the estuary to the open ocean. This creates a region of extensive mudflats and shallow, intertidal passages around DeHorsey Island, through Inverness Passage, and between Kitson Island and Lelu Island (Flora Bank; see Figure 4 and Figure 6). Along the delta front, there is a sharp transition from sandy, channel sediment to muddy, deeper ocean basin sediment. At the mouth of the river, between Kennedy and Marrack Islands, sandy sediment extends into deeper water, suggesting that sediment deposition there is relatively great (Hoos 1975). These deposits in deeper water, which can be up to 40 m thick, result from debris flows down the steep delta front in areas of the delta where rapid sedimentation has occurred (Conway *et al*. 1996).

Figure 5. Skeena watershed, showing the location of major tributaries and communities (Walters *et al*. 2008).

The Skeena River estuary has a rich and complex ecosystem. Terrestrial nutrients carried from inland areas by the turbid Skeena River water mix with clear ocean water at the edge of the Skeena plume. This region of mixing, where the water is both rich in nutrients and clear enough to allow sunlight to penetrate, supports prolific populations of phytoplankton (microscopic plant-like organisms). These phytoplankton are, in turn, fed on by zooplankton (small animal-like organisms). The zooplankton become food for fish. Large eelgrass beds, such Flora Bank, are supported by both the sediments and the nutrients from the Skeena River. Both eelgrass beds and the abundant kelp forests found along the rocky shorelines of the coast provide important nursery, foraging, and spawning areas for fish. Epiphytic zooplankton, which spend their lives associated with the blades of eelgrass or fronds of kelps, also provide an important food source for fish. Many species of fish are supported by this ecosystem, including salmon, eulachon, herring, capelin, smelt, sandlance, flounder, halibut, rockfish, and lingcod. A Department of Fisheries and Oceans fisheries habitat study identified Inverness Passage, Flora Bank, and DeHorsey Passage, in that order, as critical habitats for Skeena River juvenile salmon, as well as important eulachon habitat (Higgins and Schouwenburg 1973). Abundant fish species, such as herring, eulachon, and salmon, support a wide variety of predators:

- ***Eulachon***. The timing of the eulachon run (March) provides a large influx of energy-rich food into the Skeena River ecosystem at a time when food supplies tend to be low. Eulachon are important to breeding sea lions, seals, eagles and gulls. In the spring months when the eulachon are near shore prior to entering spawning rivers, they also comprise a large portion of the dietary intake of salmon, halibut, and sturgeon, as well as hake, dogfish and Pacific cod (Hay & McCarter 2000; Lewis 2001; Stoffels 2001).
- ***Herring***. At all stages of their lives, herring are an important link in marine food webs. Annual herring spawn events contribute greatly to the overall productivity of the local area. Invertebrates, fish and seabirds, and particularly ducks and gulls, are all predators of herring eggs. Adult herring are fed upon by fish, sharks, whales, seals, sea lions, and marine birds. Herring are a considerable proportion of the diet of many commercially important fish species, such as lingcod, salmon, halibut, Pacific cod, hake, sablefish, and dogfish (Hart 1973; Hay & McCarter 2000; Ardron 2003; DFO 2013d).
- ***Salmon***. Salmon are consumed by many different organisms throughout the various stages of their life cycle. As juveniles, they are fed on by herons, osprey, terns and gulls, alcids (murres, murrelets, guillemots, puffins, auklets), mergansers, and river otters. As adults in the open ocean, they are prey for orcas, salmon sharks, harbour seals, sea lions, and various fisheries. When the spawn, they become food for bears, wolves, bald eagles, and ravens. Even in death, they enrich the ecosystem, as their carcasses feed juvenile salmon, or in decay, return nutrients back to both the freshwater and terrestrial components of the Skeena River ecosystem (Cederholm *et al.* 2000; Harvey & MacDuffee 2002).

The estuary mudflats and other intertidal areas have also been identified by the North Coast Wetlands Program as important migratory/wintering waterfowl habitat. Several rare species, including the yellow-listed trumpeter swan, which has suffered a significant reduction in range, the blue-listed brant, old squaw and great blue heron, and the red-listed western grebe, have all been recorded in the wetlands.

Figure 6. Mouth of the Skeena River estuary.

1.3 Environmental Concerns

The Port of Prince Rupert has a history of industrial development that started upon the completion of the Grand Trunk Pacific Railway in 1914. Skeena Cellulose, a bleached kraft pulp mill located on Watson Island, was opened 1951, and was once the major employer for Prince Rupert. In 1972, the Port of Prince Rupert was declared a National Harbour, and by 1975, construction of its first facility, Fairview Terminal, was completed. Ridley Terminals was constructed in 1984 as a joint venture between the Federal Government and Federal Commerce and Navigation in support of coal developments in northeast British Columbia. The Prince Rupert Grain terminal was also constructed in 1984. In 2001, Skeena Cellulose closed down, marking a period of slower growth for the region. However, the Port of Prince Rupert is expanding its already extensive commercial activities (see Figure 7), starting in 2004 when the Northland Cruise Terminal was constructed, and followed in 2007 by the construction of the Prince Rupert Container Terminal (Maher Terminals) at Fairview. Many more projects are on the horizon, such as the Pinnacle Renewable Energy pellet export terminal (construction underway), the Ridley Terminal Inc. coal port expansion (construction underway), the Pacific Northwest LNG terminal on Lelu Island (construction planned for 2015 to 2018), the Prince Rupert LNG terminal on Ridley Island (construction planned for 2015 to 2020), the Canpotex Potash export terminal (construction planned for 2014 to 2017), and the Maher Terminal's Fairview terminal phase 2 expansion project (construction start unknown). Many of these projects, and their associated dredge sites, are

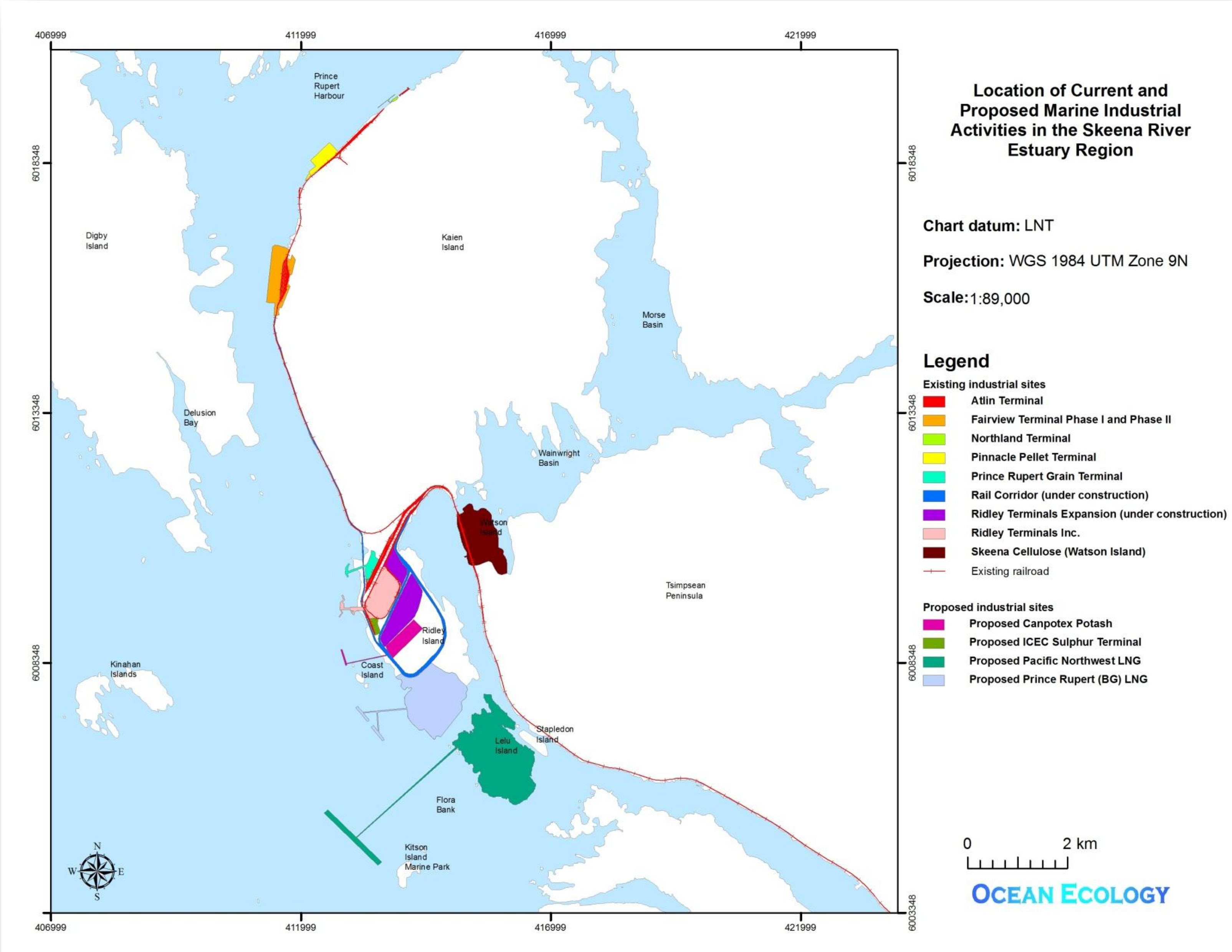


Figure 7. Location of current and proposed marine industrial activities in the Skeena River estuary region.

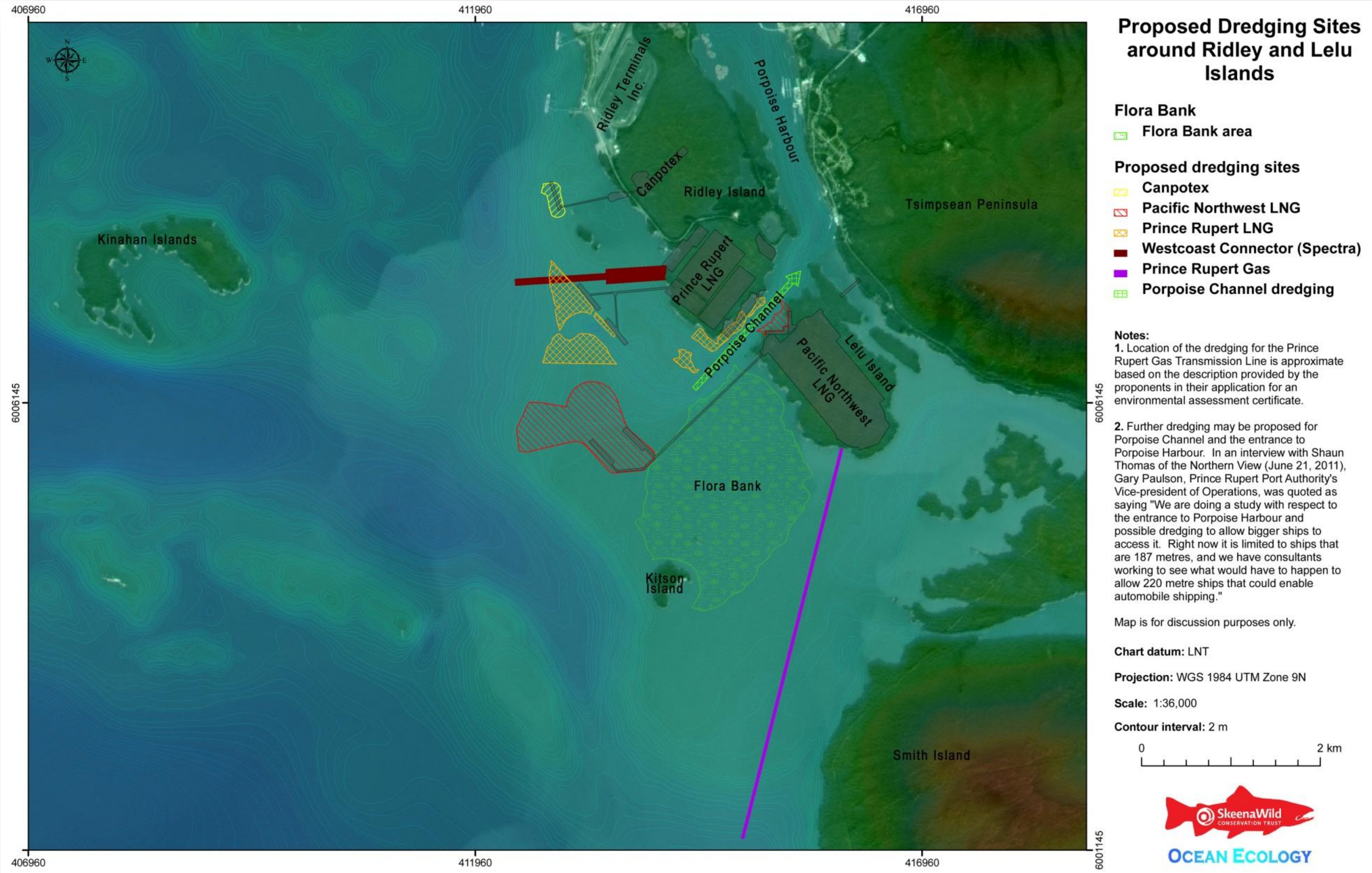


Figure 8. Location of proposed marine industrial activities, and their associated dredge sites, in the areas around southern Ridley Island, Lelu Island, and Flora Bank.

concentrated in the areas around southern Ridley Island, Lelu Island, and Flora Bank (see Figure 8). With all of these potential projects on the horizon, flat land for development, especially land owned by the Port of Prince Rupert, is in short supply, thus forcing some of the projects into serious trade-offs between deep-water access and sufficient land for site development. Increased vessel traffic associated with these planned terminals, as well as potential oil tanker activity from proposed projects such as the Enbridge Northern Gateway, will also increase the possibility of spills and other marine accidents.

Although estuaries provide essential nursery and juvenile rearing habitats, with up to 80% of coastal wildlife species relying on estuaries during at least one stage of their life history (BCMOE 2006), they frequently occur in areas highly valued for industrial development. In 1973, Higgins and Schouwenburg made the following comment with reference to port development in Prince Rupert:

> *It can be concluded that, when the factors of fish distribution, food availability, presence of aquatic vegetation and highly variable salinities are considered in combination, the shallow estuarine areas between Porpoise Channel and the mouth of the Skeena River are of high biological significance as a fish (especially juvenile salmon) rearing habitat. Inverness Passage, Flora Bank and De Horsey Bank, in that order, are habitats of critical importance for the rearing of juvenile salmon. The construction of a superport at the Kitson Island - Flora Bank site would destroy much of this critical salmon habitat.*

What has changed in our environment that has now allowed this region to be considered a prime site for industrial development?

Estuaries worldwide are often areas of conflict between human resource need and environmental sustainability. This is further exacerbated by a site-by-site approach to habitat protection, which often saves sensitive habitat from destruction by one project only to have the same piece of habitat threatened by a neighboring project. A more holistic approach to habitat protection is required, underpinned by a thorough scientific understanding of the roles and vulnerabilities of the different species and habitats in the estuarine environment. In order to implement this approach, there is a need to better understand the cumulative, and often complex, anthropogenic impacts on estuarine environments.

1.4 Study Purpose

A number of local environmental organizations and community groups are working together to try to protect the Skeena River estuary from poorly planned over-development, and to establish the framework for a Skeena estuary management plan. In order to do this, these various organizations are attempting to address, through research, data analysis, and modeling, issues such as:

- Insufficient knowledge of the locations of many ecologically important, sensitive, and/or vulnerable habitats.
- Lack of necessary baseline data on concerns such as ecologically important (e.g., keystone species), sensitive, and/or vulnerable species, sediment transport, sediment chemistry, and cumulative impacts, required for sound marine planning.
- Lack of understanding of the processes, such as ocean circulation and primary and secondary production, which control the distribution of species and habitats within Chatham sound.
- Lack of understanding of how global climate change will impact Chatham Sound and the Skeena River estuary.

As a part of these efforts, the focus of this study will be to analyze the habitat in and around the Skeena River estuary in terms of suitability as valuable or critical habitat to juvenile salmonids.

2 Methodology

2.1 Model Approach

The approach to the Skeena River estuary salmon habitat analysis is loosely based on the concepts from the Ecosystem Diagnosis and Treatment (EDT) methodology used for summer and fall chum salmon in the Hood Canal and the Strait of Juan de Fuca (Lestelle *et al*. 2005). The model is based on an analysis of pre-existing data (i.e., no new data have been collected for the model), and as such, has the following limitations:

- Some of the data used are quite old, and may no longer be valid.
- Many data sets are limited in their spatial and temporal distribution, thus some locations in the model domain will have good data coverage, while others will have poorer data coverage.
- No model ground-truthing can be done.
- Some important baseline data are completely lacking.

This model will be largely qualitative in nature, but is very valuable in that it formulates working hypotheses for future quantitative studies. It will also provide a "snapshot", both spatially and temporally, of changes in habitat attributes as they relate to juvenile salmonid survival. However, the model does not address cumulative impacts of the proposed development projects in the estuary, as there is a lack of cumulative environmental assessment for these projects, nor does it enable a full understanding of the estuary function due to the limitations resulting from incomplete and/or inadequate data. Nevertheless, given the lack of estuary planning and the relatively massive amount of proposed development predicted to adversely impact juvenile salmon, modify their nearshore habitats, and disrupt ecosystem-level functioning, this model is considered an appropriate initial analysis.

The method used in this study applies species-specific habitat rules that relate environmental conditions to life stage survival responses of salmonid fishes. When empirical data are not available, expert opinion and extrapolation of information from adjacent or similar reaches is relied on for inputs to habitat quality. This allows the method to be used when information on habitat attributes and conditions are limited. However, the weakness of this approach is that there may be disagreement amongst biologists regarding the relative importance of different habitat attributes to factors affecting juvenile salmonid survival, and the quality and/or availability of expert scientific opinion may vary from attribute to attribute. Thus, it is important to empirically test the result of qualitative models through future field work and ground-truthing in the region.

2.2 Estuarine Habitats of Importance to Juvenile Salmon

Figure 9. Juvenile salmon. Photo: Ken Rabnett.

In marine environments, juvenile salmon are typically found in estuarine or shallow nearshore habitats. Within the Chatham Sound estuarine system, there are many creek mouth estuaries ("subestuaries"), abundant tidal marshes along the shoreline, and eelgrass and kelp beds in the shallow nearshore regions.

A subestuary consists of the lower portion of a river or stream from the upper extent of tidal influence to the outer edge of its delta. It may be either a "pocket" estuary (Beamer *et al.* 2003) or a tidal creek (Hirshi *et al*. 2003). Pocket estuaries form behind spits or barrier beaches at submerged, tectonically- or glacially-derived valleys or at small creek deltas. They are typically tidal lagoons with local freshwater inputs and low wave or long-shore current energy. Subestuaries provide juvenile salmonids with their first exposure to the estuarine environment. Subestuaries may be large or small, and consist of marshes, lagoons, tidal sloughs, spits, and other landforms located in the transition between fresh and salt water. Tidal marshes are subject to tidal inundation, although this may be infrequent. Juvenile salmon can access these habitats during high tides. Subestuaries and tidal marshes serve directly as feeding and migratory habitats, in addition to being major sources of the detritus important in estuarine food webs.

The shallow nearshore habitats consist of beaches and flats with substrates ranging from cobble, gravel, sand, or mud. Eelgrass may be present in these habitats, and varies from patchy to contiguous and extensive (Faggetter 2013). Eelgrass habitats are important feeding areas for juvenile salmonids, and are a major source of detritus for estuarine food webs. Kelp is also common in the nearshore habitats, and may form dense forests where rocky substrates are available. Kelp provides feeding and migratory habitat for juvenile salmonids (Schaffer 2003).

A review of previous research indicates the importance of estuaries to the juveniles of various species of salmonids (Scott and Crossman 1973; Aitken 1998; Gottesfeld and Rabnett 2008):

- Juvenile Chinook and chum salmon are the most estuarine-dependent species, with Coho, sockeye, and pink salmon following in order of decreasing dependency.
- Estuaries are important to juvenile salmon for rearing, physiological transition, and refugia from high water flows and predators.
- Estuaries provide juvenile salmonids with neustonic, pelagic, and benthic prey, some of which are dependent on a detritus-based food web.
- Juvenile salmonids can be found in estuaries throughout the year; however, overall peak abundance occurs from March to July.
- Juvenile Chinook salmon are present in estuaries from January to November. In the Skeena River watershed, peak abundance occurs in May and June. Individuals may reside in the estuary from 6 to 189 days.
- Juvenile chum salmon are present in estuaries from March to June, with peak abundance in May and June. Individuals may reside in the estuary from 4 to 32 days.
- Juvenile Coho salmon are present in estuaries from March to October, with peak abundance around May. Individuals may reside in the estuary from 6 to 40 days.
- Juvenile sockeye and pink salmon are present in estuaries from March to June. In the Skeena River, peak abundance for juvenile pink salmon is from April to May, and peak abundance for juvenile sockeye salmon is from April to June. Individuals are not considered long-term residents.
- Residence time of juvenile salmonids in estuaries may be limited by (1) an increase in summer water temperature, (2) lack of preferred prey, (3) extremely high or low river discharge and surface outflow, and (4) density-dependent antagonistic interactions among juvenile fish.
- Juvenile salmonids prefer estuarine habitats that are vegetated (e.g., salt marsh), are heavily channelized with a moderate slope, and that offer a wide range of salinities. These habitats provide the juveniles with low water velocity refugia at low tide, cover in the form of vegetation and large woody debris, and a good prey base.
- Human activity (e.g., structural development, jetties, diking, dredging and filling, logging, pollution) in an estuary can negatively affect juvenile salmonids utilizing the estuarine environment.
- Competition occurs between wild and hatchery juvenile salmonids in estuaries, and must be accounted for to offset possible losses.

2.3 Model Assumptions from Best Available Science

Based on the best available science, and our current understanding of juvenile salmonid survival in estuarine environments (Aitken 1998; Lestelle *et al*. 2005), the following set of hypotheses/assumptions should be applicable to the Skeena River estuary.

(1) ***Arrival time***. Arrival time into the estuary may be the most important determinant of juvenile salmonid estuarine survival due to the strong seasonality and interannual variation in zooplankton abundance patterns (Johnson *et al*. 1997). The correspondence between smolt immigration and abundance of zooplankton prey in any given year can have significant impacts on marine survival of salmonids. Factors which affect the coupling of smolt estuarine arrival time with the presence of zooplankton prey are (Faggetter 2012):

   - Temporal (e.g., spring and fall blooms) and spatial (e.g., associated with fronts, upwellings) distribution of phytoplankton in the estuary. Phytoplankton form the base of the food chain, and are fed upon by zooplankton. Zooplankton populations are reduced if appropriate phytoplankton food species are absent.

- Phytoplankton species composition (e.g., preferred food species for zooplankton versus harmful algal blooms).
- Intra- and inter-annual variations in solar insolation (sunshine). Phytoplankton require sunlight for growth and reproduction, so variations in the amount of light they receive can change their abundance.
- Nutrient enrichment (e.g., Skeena River plume) which stimulates phytoplankton blooms.
- Temporal distribution of zooplankton, which is determined by the presence of appropriate phytoplankton prey.
- Spatial distribution of zooplankton, which is determined by a combination of localized concentrating effects (e.g., along bathymetric edges), and the retention of critical life stages (e.g., in eddies).
- Smolt arrival time, which is determined by the water temperature of the river (incubation period is inversely related to water temperature) and water velocity of the river (faster flows carry juveniles downstream in less time).

(2) ***Residence time***. The length of time that salmon species are exposed to estuarine conditions appears to be a major factor in determining survival between emigration from freshwater and return. In general, estuaries provide prey resources that are more optimal with respect to prey size, distribution, and density than those provided in oceanic habitats (Simenstad *et al*. 1982). The length of time that juvenile salmon are exposed to an estuary depends upon both estuary size and the speed at which they travel through it (Lestelle *et al*. 2005). Three main factors appear to control the overall migration rate of smolts out of the estuary (Simenstad 2000):

- *Foraging success* - the presence of abundant forage holds fish in the estuary longer because they are finding their preferred prey without needing to search for it (see Table 11).
- *Surface water circulation* - circulation in the Skeena River estuary, generally south to north, is likely to help transport neritic juveniles that are away from the shoreline, thus affecting the migration rate of large smolt (>50 mm) (see Table 11).
- *Shallow water habitat with eelgrass* - abundant shallow nearshore habitat (<2 m), particularly with eelgrass present, will hold small juveniles (< 50 mm) longer than habitats without such areas, promoting feeding and growth (see Table 12).

(3) ***Estuarine condition***. Certain characteristics of the estuary can affect residence time, fish utilization patterns, and presumably survival. In addition to those characteristics directly associated with residence time - prey availability, amount of shallow shoreline, and surface outflow velocity - there are other characteristics of estuarine condition that affect juvenile salmon survival. Some are these characteristics are entirely natural to estuarine and marine ecosystems, while others can be strongly affected by human activities. Estuarine characteristics and conditions which are likely to have an impact on salmonid survival are (Lestelle *et al*. 2005) (see Table 12):

- subestuaries
- estuarine characteristics
  - eelgrass distribution and abundance
  - extent of shallow shoreline
  - extent of shoreline development
  - riparian condition
  - sources of detritus
  - exposure
  - kelp distribution
  - chemical contamination
- ecological interactions (competition and predation)

Although there may be alternative hypotheses about the factors that affect survival from which alternative rule sets could be developed, the species-habitat rules described in this report - and the hypotheses upon which they are based - provide a reasonable and useful starting rule set for juvenile salmon in the Skeena River estuary system.

2.4 Key Habitat Factors

The model assumptions derived from the best available science allow us to define a set of key "habitat factors". These habitat factors act as "umbrella attributes", grouping the effects of various environmental attributes into broader synthetic concepts of habitat conditions for the species. The purpose of grouping effects of classes of attributes in this manner is to allocate mortality by the types of factors that biologists typically refer to in environmental analysis (e.g., limiting factors analysis).

The rules used for juvenile salmonids in this model were developed so that survival in the estuarine and marine environments is driven more by those factors that operate in a density-independent manner than those that operate through density-dependence. Reference to population density here refers to the density of juveniles of a specific salmonid species (i.e., the specific population being analyzed). Survival will therefore be determined more by the factors associated with habitat quality (i.e., productivity), than with those that define habitat quantity, such as the amount of key habitat. Seen from the perspective of the focal population, this is an appropriate assumption. It is recognized that juvenile salmonids produced from a single population compete with other juvenile salmonid populations within the nearshore environment; however, this constitutes a density independent effect as seen from the perspective of the focal population.

Table 1 lists the eleven key habitat factors used in this model, and provides a definition for each one.

Table 1. Definitions of the key habitat factors for the model.

Factor	Definition
Food	The effect of the amount, diversity, and availability of food that can support the juveniles of a specific salmonid species on that species relative survival or performance.
Flow	The effect of surface outflows, estuarine currents, or the pattern and extent of riverine flow fluctuations within an estuarine segment on the relative survival or performance of the juveniles of a specific salmonid species.
Obstructions	The effect of physical structures which impede the access of the juveniles of a specific salmonid species to subestuaries on that species relative survival or performance within an estuarine segment.
Habitat diversity	The effect of the extent of habitat complexity within an estuarine reach on the relative survival or performance of the juveniles of a specific salmonid species.
Chemicals	The effect of toxic substances or toxic conditions on the relative survival or performance of the juveniles of a specific salmonid species. Substances include chemicals and heavy metals. Toxic conditions include low pH.
Oxygen	The effect of the concentration of dissolved oxygen within the estuarine segment on the relative survival or performance of the juveniles of a specific salmonid species.
Temperature	The effect of water temperature with the estuarine segment on the relative survival or performance of the juveniles of a specific salmonid species.
Sediment load	The effect of the amount of the amount of fine sediment present in, or passing through, the estuarine segment on the relative survival or performance of the juveniles of a specific salmonid species.
Intraspecific competition (with hatchery fish)	The effect of competition with hatchery produced salmonids on the relative survival or performance of the juveniles of a specific salmonid species; competition might be for food or space within the estuarine segment.
Interspecific competition (with other species)	The effect of competition with other species on the relative survival or performance of the juveniles of a specific salmonid species; competition might be for food or space.
Predation	The effect of the relative abundance of predator species on the relative survival or performance of the juveniles of a specific salmonid species.

Each habitat factor F_i can be estimated as a function of the condition of the various environmental attributes within each segment, based on the relative importance of each attribute to survival associated with the factor. The various environmental attributes, and their relationship to the eleven habitat factors are given in Table 14 through to Table 38 in the Appendix.

For each habitat factor, it was assumed that the environmental attributes operated synergistically to affect survival. The relative importance of each environmental attribute to the effect of the habitat factor is defined by a weighting factor w_j used to compute an average weighted rating for all of the relevant environmental attributes. Weights represent conclusions about the relative effect of each contributing attribute. Computation of the habitat factor, F_i,is as follows:

$$F_i = \frac{\sum_j R_{i,j} w_{i,j}}{\sum_j w_{i,j}}$$

where $R_{i,j}$ is the rating for environmental attribute j. In some cases, a grouped rating $GR_{i,j,k}$ is first obtained for a subset of k environmental attributes as:

$$GR_{i,j,k} = \frac{\sum_k R_{i,j,k} w_{i,j,k}}{\sum_k w_{i,j,k}}$$

This grouped rating is then applied in place of the attributes being grouped in the equation for F_i above. Certain attributes are grouped in this manner because of their close similarity in ecological function.

The overall habitat factor for each estuarine or marine segment can then be estimated from the set of independent habitat factors, F_i ,as follows:

$$F = \sum_i a_i F_i$$

where a_i is a species-specific habitat utilization adjustment factor based on the hypotheses/assumptions regarding estuarine residence time and its impacts on specific salmonid species given in Table 11and Table 12. Values for a_i are given in Table 39.

A simple relative habitat suitability index (*HSI*) was then calculated for each salmonid species as follows:

$$HSI = 10 - \left(Round\left[\left(\frac{F_{shoreline\ segment} - F_{min}}{F_{min} - F_{max}}\right) \times 10\right]\right)$$

The HSI value ranged from 0 (very poor habitat suitability for the salmonid species) to 10 (very good habitat suitability for the salmonid species). While this value does not provide absolute numbers with respect to salmonid production, it will allow comparisons to be made within the Skeena River estuary, both spatially and temporally, of changes in habitat attributes and how they relate to juvenile salmonid survival.

Calculations were performed using overlays of maps for each environmental attribute in a geographical information system (GIS, specifically ArcGIS).

3 Salmon Life Histories in the Skeena River Watershed

Seven species of *Oncorhynchus* inhabit the Skeena River watershed, including five Pacific salmon species (sockeye salmon, *Oncorhynchus nerka*; pink salmon, *O. gorbuscha*; chum salmon, *O. keta*; Coho salmon, *O. kisutch*; and Chinook salmon, *O. tshawytscha*) and two anadromous trout (rainbow trout or steelhead, *O. mykiss*; and coastal cutthroat trout, *O. clarkii*). Management of Pacific salmon remains a federal responsibility (Fisheries and Oceans Canada [DFO]), whereas management of the trout species has been delegated to the Province of British Columbia. Pink and sockeye salmon are the most abundant salmon species, followed in order by coho, chinook and chum salmon (Riddell 2004; Wood 2008).

In some Skeena River salmon stocks, natural reproduction is supplemented (enhanced) by artificial propagation in hatcheries or spawning channels. Salmon enhancement has important implications for fisheries management. By increasing the abundance and productivity of target stocks, enhancement attracts or provides an opportunity for increased fishing effort while exacerbating natural variations in productivity. Mixed-stock harvest of wild and enhanced salmon stocks greatly complicates the conservation of salmon diversity (Wood 2008). Enhancement activities may impact wild salmon through several possible types of interactions (listed here in order of the severity of the risk they pose to wild salmon) (Gardner, *et al*. 2004):

- Over-harvesting of wild salmon in mixed stock fisheries that include enhanced runs.
- Genetic impacts.
- Ecological impacts in the form of competition and predation.
- Disease.
- Negative impacts on habitat from enhancement facilities.

In the Skeena watershed, there are three major types of enhancement facilities:

(1) OPS - Major Operations DFO Salmon Enhancement Program (SEP) facilities, such as the Fulton and Pinkut spawning channels, operated by DFO staff.
(2) CDP - Community Economic Development SEP facilities that are operated under contract to DFO SEP, by First Nations or community groups, and are supported by Community Advisors.
(3) DPI - Designated Public Involvement SEP facilities, such as the Oldfield Creek Hatchery and the Toboggan Creek Hatchery, that are operated by volunteers belonging to community organizations, and are supported by Community Advisors.

3.1 Chinook Salmon

Chinook salmon (*Oncorhynchus tshawytscha*) are the largest salmon species in the Skeena watershed, and have the most complex life history (Gottesfeld and Rabnett 2008). Table 2 describes the Chinook life history in the Skeena River watershed and Figure 11 shows the estuarine habitat utilization and coastal distribution of Chinook salmon. Skeena River Chinook enhancement began in 1906 at Lakelse Lake, and then developed rapidly in the 1980s and 1990s with the construction of many small hatcheries such as the ones at Kispiox, Toboggan Creek, Emerson Creek, Fort Babine, and Deep Creek (Gottesfeld and Rabnett 2008). Additionally, Oldfield Creek hatchery supplies Chinook to the Skeena River estuary via Kloiya Bay. Currently, there are three hatcheries in operation within the Skeena watershed and estuary producing Chinook: Toboggan Creek, Oldfield Creek, and Deep Creek. The combined release target for these hatcheries is approximately 420,000 Chinook (DFO 2010a, 2011, 2012, 2013a).

Figure 10. Juvenile Chinook salmon. Photo: Ken Rabnett.

Table 2. Life history of Chinook salmon in the Skeena River watershed (Williams 1989; Gottesfeld and Rabnett 2008).

Life stage	Description
Spawning	Mature adults return to medium and larger streams to spawn. Most spawning occurs in August to September in larger tributaries, on tributary alluvial fans in the mainstem, or in association with large lake outlets. Adults die soon after spawning. Eggs are laid in redds constructed in gravel reaches of the river.
Rearing (freshwater)	Alevins remain in the gravel until their yolk sac is absorbed. Fry emerge from the gravel in early March to late May. Fry follow one of three life history patterns: (1) "immediate" fry migrate immediately to the estuary or ocean, (2) "ocean-type" fry rear for 60-150 days in freshwater before migrating seaward as smolts, and (3) "stream-type" fry rear for 1-2 years in freshwater before migrating seaward as smolts the following spring. The majority of Skeena watershed Chinook are stream-type, with less than 10% of Skeena Chinook, mostly from coastal tributaries such as the Kitsumkalum River, being ocean-type. The stream-type Chinook migrate to the sea in May and June.
Smolts (estuary)	Smolt rear in shallow water in estuaries, tideflats or eelgrass beds from April to August. As they grow they move to more pelagic habitats. Ocean-type Chinook salmon tend to use estuaries and coastal areas more extensively than other Pacific salmonids for juvenile rearing.
Adult (ocean)	In fall the juveniles leave the inshore and undergo a 2-5 year ocean feeding migration. Some stocks, particularly ocean-type, remain inshore. Small numbers of males or "jacks" mature early and return to spawn at 2-3 years of age. Mature Chinook return to natal streams and may hold off the mouth for several days or weeks before migrating upstream to spawn. Maximum size is about 147 cm.

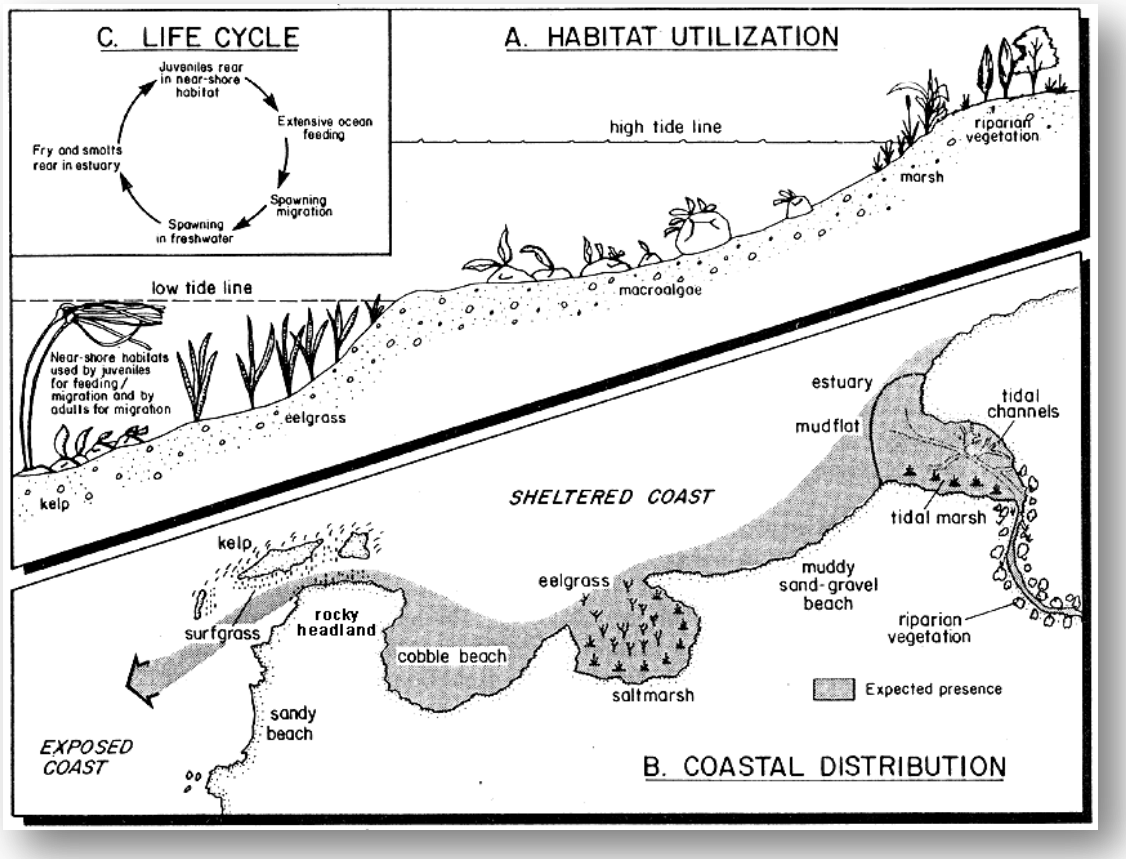


Figure 11. Estuarine habitat utilization and coastal distribution of Chinook salmon (Williams 1989).

3.2 Pink Salmon

Pink salmon (*Oncorhynchus gorbuscha*) are the most abundant salmon in the Skeena watershed (Gottesfeld and Rabnett 2008). Table 3 describes the pink life history in the Skeena River watershed and Figure 13 shows the estuarine habitat utilization and coastal distribution of pink salmon. Skeena River pink enhancement began in 1957 at the Kleanza Creek Hatchery, which operated from 1957 to 1961, incubating and rearing pink salmon fry for release into Kleanza Creek (Gottesfeld and Rabnett 2008). At present, there are no hatcheries for pink salmon in the Skeena watershed; however, the Oona River hatchery has a target release of approximately 50,000 pinks into the Skeena estuary via Oona River on Porcher Island (DFO 2010a).

Figure 12. Juvenile pink salmon. Photo: Ken Rabnett.

Table 3. Life history of pink salmon in the Skeena River watershed (Williams 1989; Gottesfeld and Rabnett 2008).

Life stage	Description
Spawning	Mature pink salmon return to their natal rivers to spawn in late summer. They may hold off of mouth for several days or weeks before migrating upstream to spawn. Pink salmon spawn in late August to September in gravel reaches of rivers or streams. Adults die soon after spawning.
Rearing (freshwater)	Eggs hatch from late-December to late February, and the alevins remain in gravel until emergence from April to May. Fry migrate immediately downstream to estuary.
Smolts (estuary)	The juvenile pink salmon school once they reach estuary. The smolts only remain in tidal channels for several days, but rear in shallow (less than 1 m) nearshore waters for 1-2 weeks. The smolts move to deeper water as they grow.
Adult (ocean)	The young salmon leave inshore waters in late summer and migrate to the open ocean. An extensive feeding migration occurs in northeast Pacific over the next 18 months. Pink salmon return as 2 year olds to spawn and die. The 2-year cycle is so invariable that adult runs in odd-calendar years are separate from even-year runs, and stocks are referred to as odd or even year. Adults may reach about 76 cm.

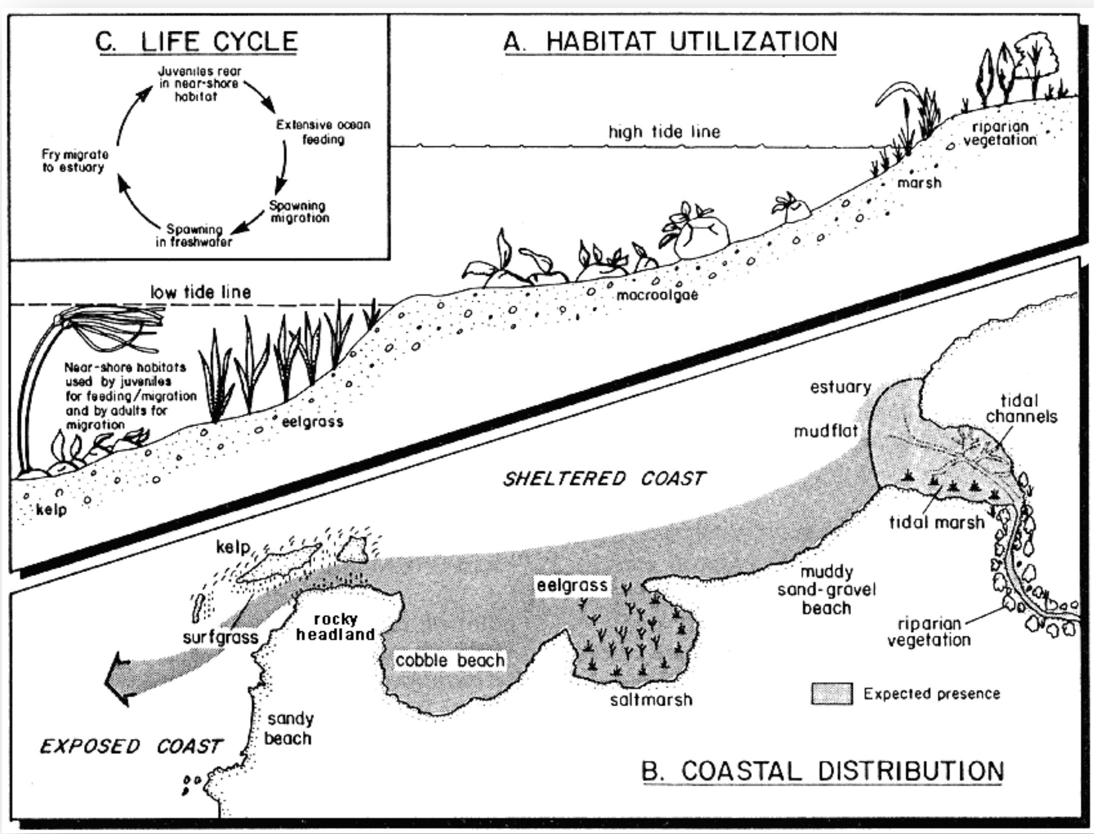


Figure 13. Habitat utilization and coastal distribution of pink salmon (Williams 1989).

3.3 Chum Salmon

Chum salmon (*Oncorhynchus nerka*) are the least abundant salmon in Skeena watershed (Gottesfeld and Rabnett 2008). Table 4 describes the chum life history in the Skeena River watershed and Figure 15 shows the estuarine habitat utilization and coastal distribution of chum salmon. In the past, chum salmon enhancement has been conducted at Kitsumkalum Hatchery for the Andesite groundwater channel and Zymacord River; there is currently no chum enhancement in the Skeena River watershed. However, two hatcheries release chum salmon into the Skeena River estuary: Oona River Hatchery releasing into Kumealon Bay and Oldfield Creek Hatchery releasing into Silver Creek. The combined release target for these hatcheries is approximately 35,000 chum (DFO 2010a).

Figure 14. Juvenile chum salmon. Photo: Ken Rabnett.

Table 4. Life history of chum salmon in the Skeena River watershed (Williams 1989; Gottesfeld and Rabnett 2008).

Life stage	Description
Spawning	Mature chum salmon migrate to spawning streams from late July to early September in the Skeena watershed. Chum spawn in gravel reaches of coastal streams, or as far as 100 km inland from the mouth of larger rivers. Unlike Coho and sockeye salmon, which may hold up for a month or two before spawning, many chum spawn soon after traveling up the Skeena River. Thus, in the Skeena River, chum spawn from late July to early September. Adults die soon after spawning.
Rearing (freshwater)	Alevins remain in gravel after hatching until yolk has been absorbed. Fry emerge in April and May and migrate directly to estuary. Fry school prior to reaching salt water.
Smolts (estuary)	Smolts rear in nursery areas along shoreline. Typically, they rear in eelgrass beds, tidal marsh channels, and protected bays. As they grow, they move to deeper water or into the outer estuary.
Adult (ocean)	During July and August, the young chum salmon move offshore to begin their ocean feeding migration. They spend 2 to 4 years in ocean, then return to their natal stream to spawn, where they may pause for several days or weeks at mouth, depending on discharge, prior to migrating upstream. Adults usually mature at 3-4 years and may reach 102 cm in length.

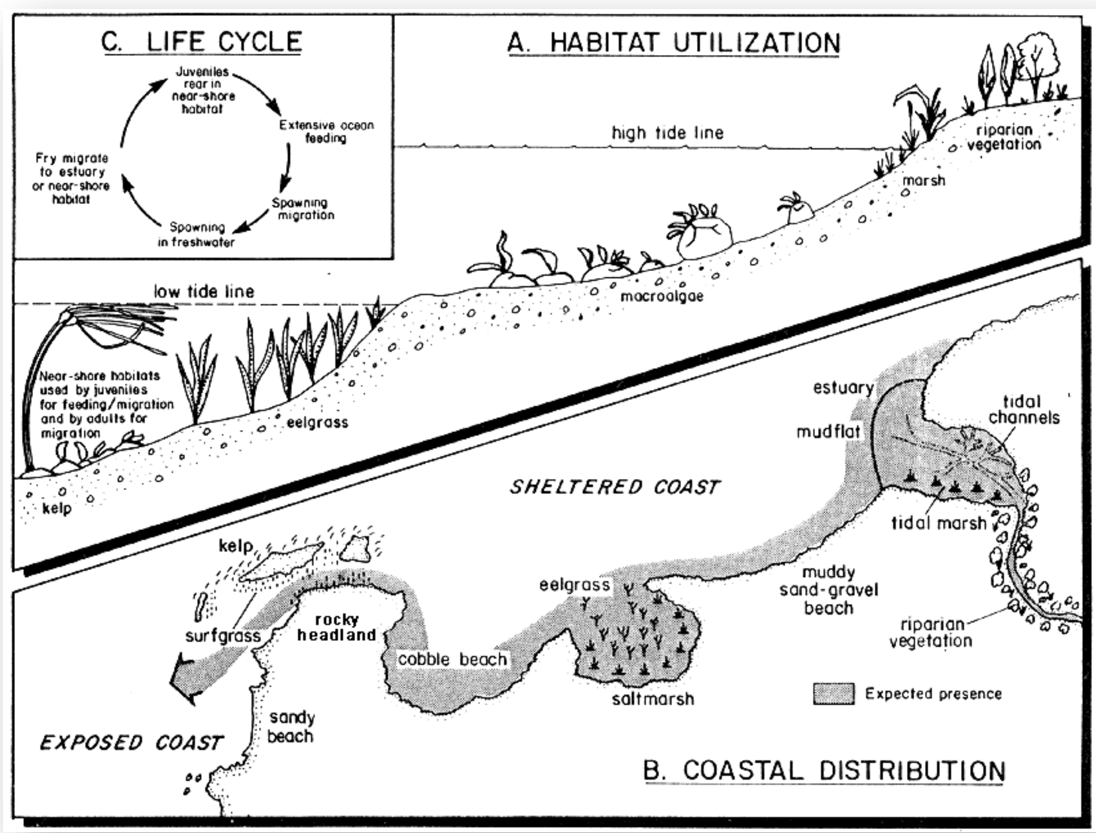


Figure 15. Habitat utilization and coastal distribution of chum salmon (Williams 1989).

3.4 Sockeye Salmon

Sockeye salmon (*Oncorhynchus keta*) are the most valuable and commercial salmon in Skeena watershed, and are second only to the Fraser River in terms of overall abundance (Gottesfeld and Rabnett 2008). Table 5 describes the sockeye life history in the Skeena River watershed and Figure 17 shows the estuarine habitat utilization and coastal distribution of sockeye salmon. Sockeye enhancement has taken place sporadically since the establishment of the first sockeye hatchery at Lakelse Lake in 1901, which was operational until 1937. The Babine (Morrison River) hatchery operated from 1907 to 1936. After 1937, most BC hatchery operations were shut down. The early 1960s saw a resurgence of sockeye enhancement within the watershed. The Nanika River hatchery operated, although not successfully, from 1960 to 1965, and Williams and Schulbuckhand (Scully) Creeks, tributaries to Lakelse Lake, were the sites of sockeye hatcheries from 1962 to 1967.

Sockeye salmon studies in the late 1950s and early 1960s concluded that sockeye salmon production from Babine Lake was limited by the availability of suitable spawning habitat, and that the main basin of the lake was underutilized by sockeye fry. As a result, artificial spawning channels were constructed on the Fulton River in 1965 and 1971, and on Pinkut Creek in 1968 (Gottesfeld and Rabnett 2007). The combined release target for these programs is approximately 186,000,000 sockeye (DFO 2010a, 2013a). Pinkut and Fulton sockeye typically represent 80% of the total Skeena sockeye return. At present, there are no hatcheries for sockeye salmon in the Skeena watershed; however, the Fulton and Pinkut spawning channels still produce enhanced natural channel fry, and the Lakelse Sockeye Enhancement program incubates and rears Lakelse sockeye at Snootli Creek Hatchery.

Figure 16. Juvenile sockeye salmon. Photo: Ken Rabnett.

Table 5. Life history of sockeye salmon in the Skeena River watershed (Williams 1989; Gottesfeld and Rabnett 2008).

Life stage	Description
Spawning	Adult sockeye salmon enter the mouths of natal rivers from June to September. They spawn during August through October in gravel redds located in lake tributaries, lake outlets or groundwater-fed areas along a lake shore. Adults die soon after spawning.
Rearing (freshwater)	Sockeye eggs hatch in the winter and spring, and the fry emerge from the gravel in April and May after yolk sac is absorbed. Most juveniles rear in lakes for 1-3 years, then migrate to sea as smolts. In some stocks, especially the river spawners , the fry migrate directly downstream and rear in the river or upper estuary for up to 5 months. [Yearlings]() may also rear in the upper estuary for up to 6 weeks. In the Skeena River, the smolts migrate seaward from April through June, and most have spent at least one full summer in their rearing lakes.
Smolts (estuary)	Smolts may remain in estuarine waters for 2 weeks or more, but generally migrate quickly through the shallow nearshore to deeper water.
Adult (ocean)	Skeena River sockeye typically travel northward along the coast and offshore, where they spend 1-3 years feeding in the North Pacific before returning to spawn in their natal tributary stream or lake. The vast majority of Skeena sockeye return as 4 and 5 year old fish, although 3 year old males (jacks) are common in some years. The maximum size of adult sockeye salmon is about 84 cm, and they may live for up to 8 years.

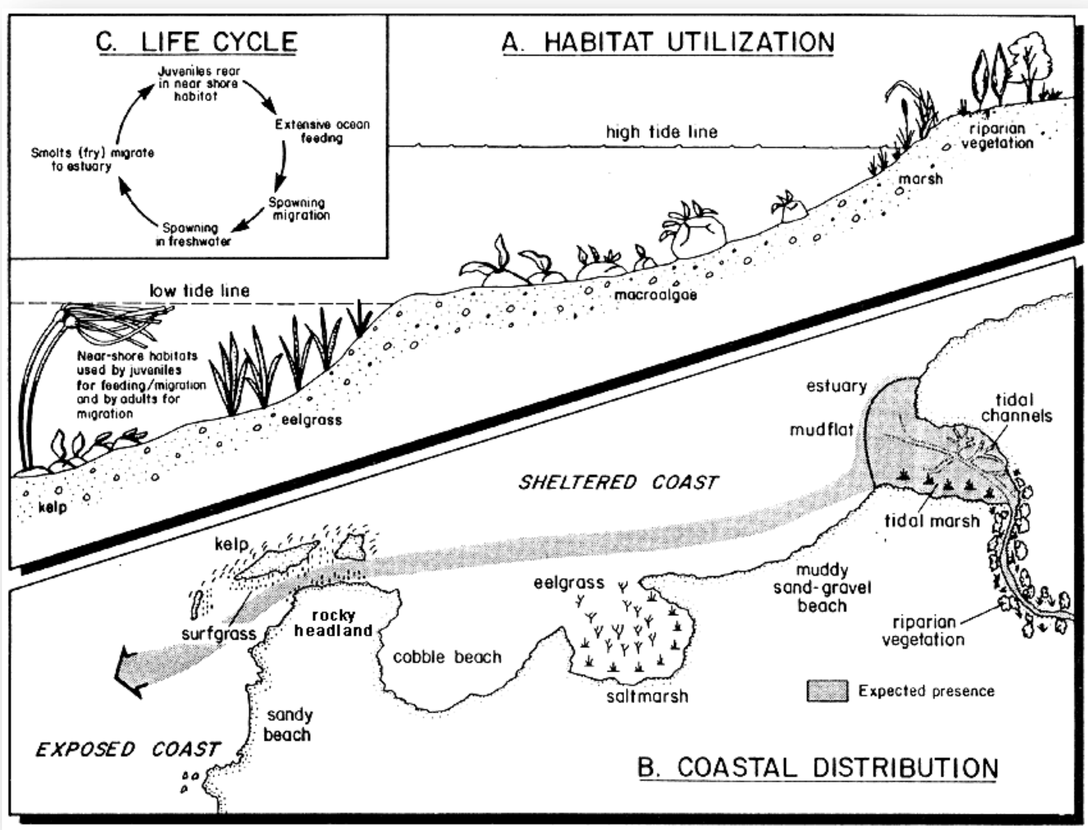


Figure 17. Habitat utilization and coastal distribution of sockeye salmon (Williams 1989).

3.5 Coho Salmon

Coho salmon (*Oncorhynchus kisutch*) are the most widely dispersed salmon throughout the Skeena watershed system, with the least amount of concentration (Gottesfeld and Rabnett 2008). Table 6 describes the Coho life history in the Skeena River watershed and Figure 19 shows the estuarine habitat utilization and coastal distribution of Coho salmon. Coho enhancement in the Skeena began with a small-scale hatchery at Fulton River which has been in operation on a discontinuous basis since the late 1970s. In 1977, the DFO announced the Salmonid Enhancement Program (SEP), with the primary goal of doubling salmon production. Within the Skeena watershed, three CDP hatcheries producing Coho were established: Fort Babine, Kispiox, and Toboggan Creek. In addition, two minor DPI hatcheries which produced Coho were also established: Chicago Creek and Eby Street (Gottesfeld and Rabnett 2007). Two DPI hatcheries also released Coho salmon into the Skeena River estuary: Oona River Hatchery releasing into Spiller River and Oona River, and Oldfield Creek Hatchery releasing into Diana, Hays, and Oldfield Creeks. At present, the active hatcheries releasing Coho in the Skeena watershed and estuary region are Toboggan Creek, Eby Street, Oldfield Creek, and Oona River. The combined release target for these hatcheries is approximately 216,000 Coho (DFO 2010a, 2013a).

Figure 18. Juvenile Coho salmon. Photo: Ken Rabnett.

Table 6. Life history of Coho salmon in the Skeena River watershed (Williams 1989; Gottesfeld and Rabnett 2008).

Life stage	Description
Spawning	Mature Skeena Coho salmon migrate to spawning streams between late July and the end of September, with the peak migration in late August. They spawn in gravel reaches of small streams from the end of September through December, with late spawning being especially common in coastal areas. Adults die soon after spawning.
Rearing (freshwater)	Alevins remain in gravel after hatching until their yolk sac has been absorbed. The fry emerge in April and May, and rear in freshwater. In May and June, after spending 1-2 years in stream or off-channel habitat, smolts migrate to estuary. In smaller systems, Coho fry may rear in the inner estuary until late September or November.
Smolts (estuary)	In smaller systems, smolts may overwinter in nearshore areas. Generally, however, smolts do not utilize the inner estuaries for extended periods of time, but may rear in the outer estuary until June or off tidal flats until fall.
Adult (ocean)	In late summer or fall, most juveniles migrate to the open ocean to feed. Ocean migration lasts about 18 months. Some Coho reside solely inshore. Approximately half of the Skeena Coho remain in coastal waters off B.C., while the other half migrate north off southeast Alaska. A small percentage of males or "jacks" only spend one summer in ocean before returning to freshwater to spawn. Returning mature adults may hold off the mouths of spawning rivers for several days or weeks prior to migrating upstream to spawn. Adults may reach 98 cm.

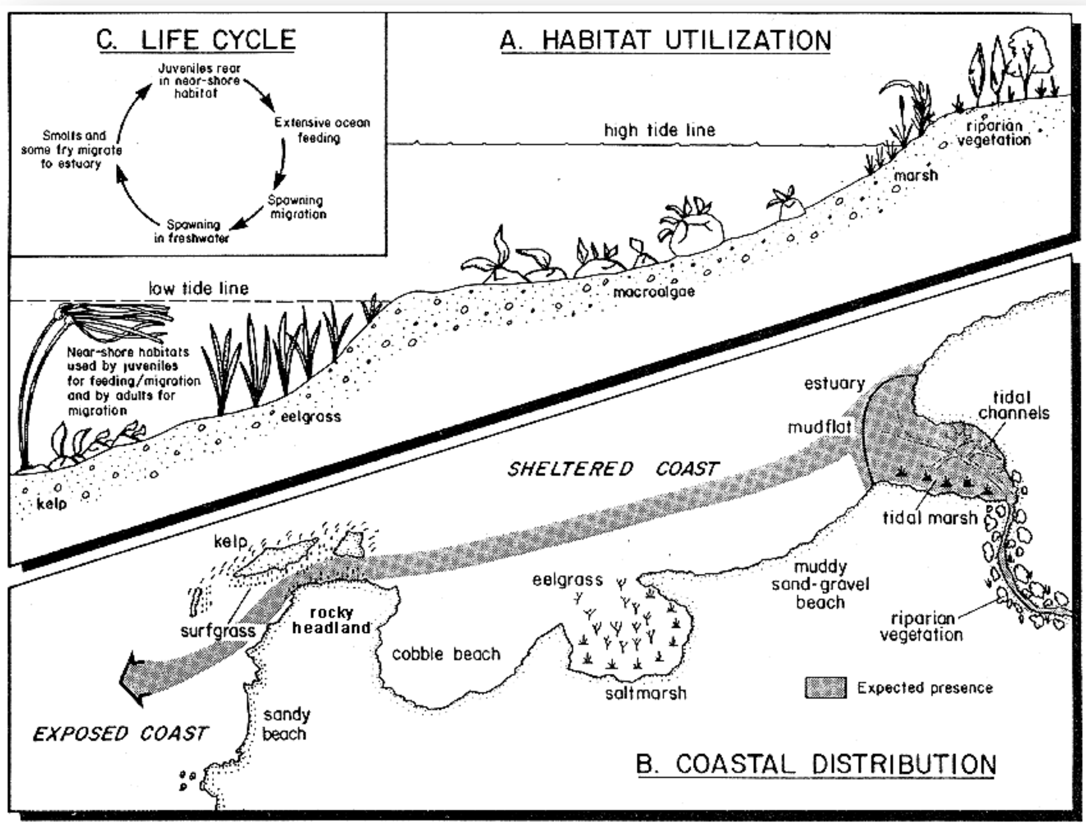


Figure 19. Habitat utilization and coastal distribution of Coho salmon (Williams 1989).

3.6 Steelhead

Both sea-going (steelhead) and resident (rainbow trout) populations of *Oncorhynchus mykiss* exist in the Skeena watershed. Unlike Pacific salmon, steelhead are iteroparous, and can spawn more than once (Gottesfeld and Rabnett 2008). Table 7 describes the steelhead life history in the Skeena River watershed and Figure 21 shows the estuarine habitat utilization and coastal distribution of steelhead. Enhancement of steelhead in the Skeena watershed was moderate in the late 1970s and early 1980s, but currently has been quite limited. The Fulton River Hatchery released steelhead from 1979 to 1980, and the Deep Creek hatchery released steelhead from 1985 to 1988. Currently, there are no hatcheries in the Skeena River watershed or estuary region releasing steelhead.

Figure 20. Juvenile steelhead salmon. Photo: Ken Rabnett.

Table 7. Life history of steelhead in the Skeena River watershed (Williams 1989; Gottesfeld and Rabnett 2008).

Life stage	Description
Spawning	Mature adults enter rivers and larger streams year round, but are generally concentrated as winter and summer runs. In the Skeena, summer-run steelhead comprise approximately 80% of the total run, and return from July through September. Winter-run steelhead return from October through May. Summer-run steelhead spend the fall and winter in rivers or lakes, usually not far from their spawning areas. Winter-run steelhead move onto the spawning beds soon after migration. Winter-run steelhead are limited to the coastal portions of the Skeena that are downstream of Terrace. Spawning in both groups takes place in the spring, generally in April and May, but may extend until late June in the Zymoetz and Kitsumkalum systems. The eggs are laid in gravel redds prepared by the female in a tributary stream or an inlet/outlet of the nursery lake from January to June. Steelhead may spawn more than once (< 10%of the population).
Rearing (freshwater)	The eggs hatch in 4-7 weeks, and the fry emerge from the gravel in July and August. The juveniles rear in freshwater for 1-4 winters. Most Skeena watershed steelhead spend three years in freshwater. Most steelhead smolts migrate to sea during the annual snowmelt flood from April to June.
Smolts (estuary)	Smolts only remain in estuary for a short period of time before moving offshore.
Adult (ocean)	Adults usually complete extensive feeding migrations in the Pacific Ocean before returning to spawn after 2-3 summers (range 1-4 summers) in the ocean. Adults live to 6-8years, and may reach 114 cm or 19 kg.

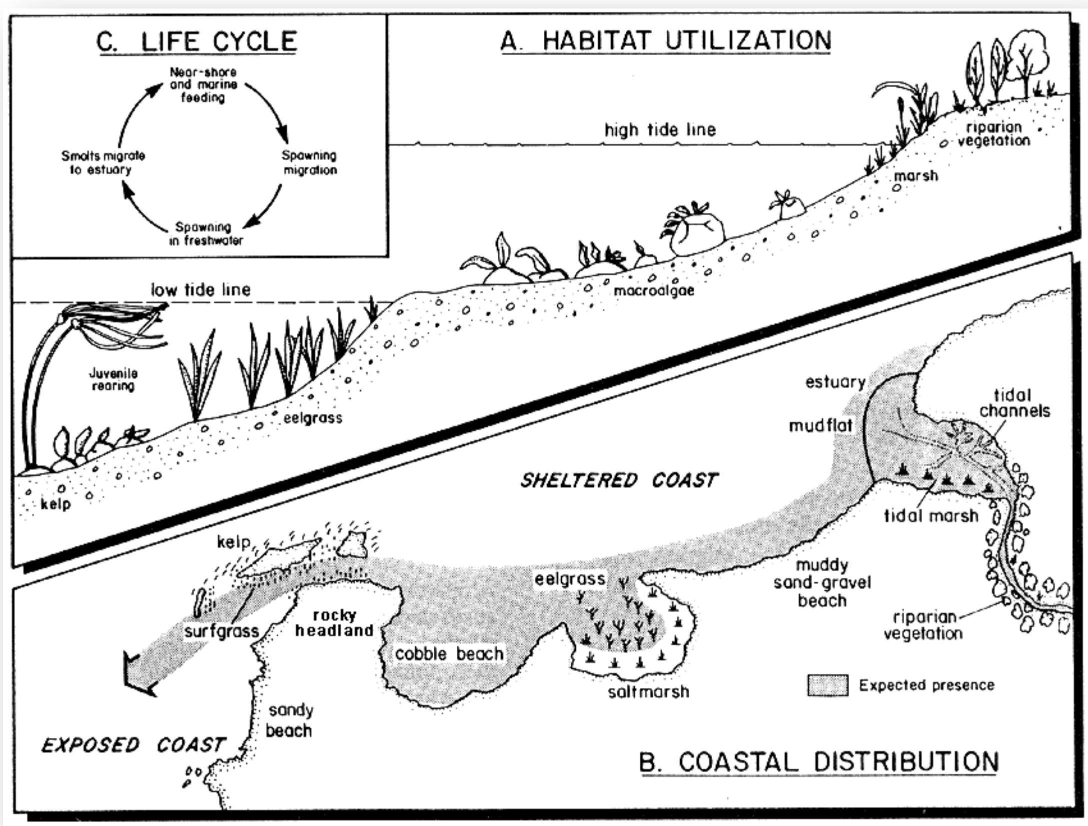


Figure 21. Habitat utilization and coastal distribution of steelhead (Williams 1989).

3.7 Sea-run Coastal Cutthroat Trout

Like steelhead, coastal cutthroat trout (*Oncorhynchus clarkii*) are also iteroparous, and may spawn each year for over 6 years. Unlike the other anadromous species of *Oncorhynchus*, coastal cutthroat trout remain in and around the estuaries of their natal streams and seldom venture further than a few kilometres into the ocean. Table 8 describes the cutthroat trout life history in the Skeena River watershed and Figure 22 shows the estuarine habitat utilization and coastal distribution of cutthroat trout.

Table 8. Life history of cutthroat trout in the Skeena River watershed (Williams 1989; Gottesfeld and Rabnett 2008).

Life stage	Description
Spawning	Coastal cutthroat trout spawn from December to May. Early-entry spawning migrations in larger rivers begin in July, but are concentrated in September and October. Often fish hold in pools in the lower reaches before migrating to the spawning areas. Late entry runs occur in small streams during December and January, taking advantage of the winter freshet. Eggs are laid in gravel redds in the tributary streams.
Rearing (freshwater)	The alevins emerge from gravel in June and July and rear in freshwater for 2-3 years.
Smolts and adults (estuary)	The smolts migrate to estuarine areas where they establish schools and move to nearshore marine water. Adult coastal cutthroat trout reside in salt water for 2-3 summers, usually over cobble/sand beaches influenced by a freshwater source (e.g., stream or creek). They overwinter in freshwater, and migrate to marine water each spring. Cutthroat have a limited salt water range, usually remaining within 15 km of their natal estuary, and forage in shallow water close to shore. Their maximum age is 10 years, but they normally live to 4-7 years and average about 45 cm.

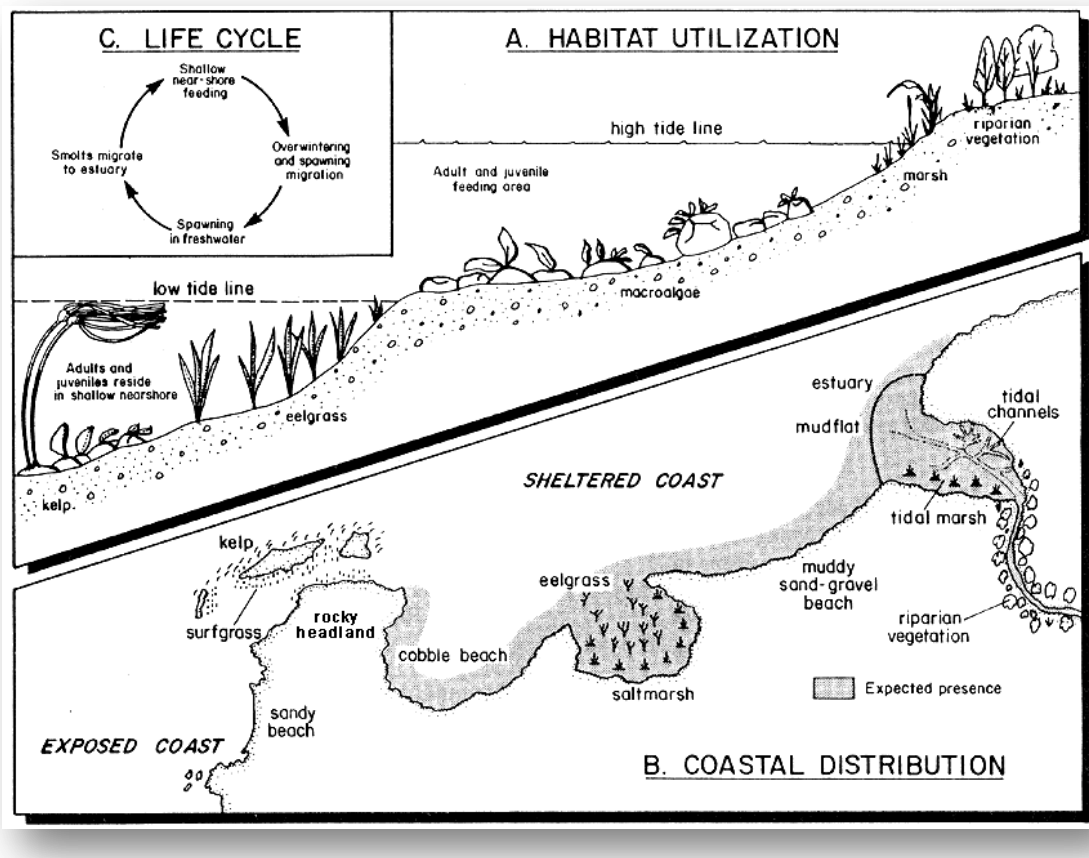


Figure 22. Estuarine habitat utilization and coastal distribution of cutthroat trout (Williams 1989).

3.8 Average Stage-Specific Survival Rates for Different Salmon Species

Table 9 gives a quick comparison of the fecundity and survival rates for the different life history stages of the various salmonid species.

Table 9. Average stage-specific survival rates for different salmon species, calculated from 215 published and unpublished estimates for wild or naturally rearing populations (Quinn 2005).

Life History Stage	Pink	Chum	Sockeye	Coho	Chinook	Steelhead	Cutthroat
Female length (mm)	522	683	553	643	871	721	413
Fecundity	1648	2876	3654	2878	5401	4923	1197
Egg size (mg)	190	290	130	220	300	150	110
Egg to fry survival	0.12	0.13	0.13	0.25	0.38	0.29	
Fry size (mm)	32	34	28	33	35	28	25
Fry to smolt survival			0.26	0.17	0.10	0.14	
Smolt size (mm)	32	40	80	105	60-120	200	190
Smolt to adult survival	0.03	0.01	0.1	0.1	0.03	0.1	0.2
Adults per female	5.2	5.1	15.7	12.5	6.4	25.5	
Egg to smolt survival			0.02	0.02	0.10	0.01	
Adults per female			10.2	5.4	17.5	9.2	

3.9 Outmigration of Juvenile Salmonids from the Skeena River

Although there are a number of natal streams within the study area which produce juvenile salmonids, by far the majority (99%) of young salmon utilizing and migrating through the study area come from the Skeena River watershed (see Table 10). These juveniles are carried by the riverine currents out through Marcus Passage (separating Smith and DeHorsey Islands from Kennedy Island), Telegraph Passage (separating Kennedy Island from the mainland), Inverness Passage, and Porpoise Channel. Those individuals which pass out through either Inverness Passage or Porpoise Channel will spend a portion of their outmigration in the shallow regions along the shores of Ridley or Lelu Island, or over Flora Bank.

Table 10. Estimate of juveniles from both natal streams within the study area and from the Skeena River.

	Pink	Chum	Sockeye	Coho	Chinook	Steelhead
Natal stream escapement [a]	4,378	108	2,052	967	188	124
Skeena River escapement [b,c,d]	2,749,207	13,848	1,282,141	177,149	71,935	45,302
Estimated juveniles from natal stream	432,897	20,190	126,716	59,139	19,292	12,392
Estimated juveniles from the Skeena River	271,841,588	2,588,745	79,175,540	10,833,990	7,381,898	4,527,341
Total juveniles	272,274,485	2,608,935	79,302,257	10,893,129	7,401,190	4,539,734
Percentage juveniles from the Skeena River	99.8	99.2	99.8	99.5	99.7	99.7

[a] Study area natal stream escapements values were taken from the most recent escapement values in the Pacific DFO escapement database (NuSEDS) for 1950 to 2013. For those water bodies with only an AP (adults present) code, the escapement value was set as 2. Steelhead escapement values were obtained from Tredger (1981).
[b] Escapement values for pink, sockeye, Coho, and Chinook were taken from the average values in Walters *et al*. (2008).
[c] Escapement values for chum were taken from the 1990-97 average values in Morrell (2000).
[d] Escapement values for steelhead were computed from the most recent decadal average for the Tyee test fishery total cumulative index using a test gill-net catchability (q) for steelhead of $\approx$ 0.41%.
[e] Juvenile salmonid abundance was calculated by (fry abundance = ½ * maximum escapement * species specific fecundity * species specific egg-to-fry survival * species specific fry-to-smolt survival). Average values for fecundity and survival values were obtained from Quinn (2005).

To date, there have been relatively few studies investigating the timing, presence, distribution, and residence duration of juvenile salmon in the Skeena estuary. However recently, several studies have shown that juvenile salmonids are present in the regions around Ridley and Lelu Island (Gottesfeld *et al.* 2008; Carr-Harris & Moore 2013). Based on the data from these studies, Figure 23, Figure 24, Figure 25, Figure 26, and Figure 27 hypothesize possible outmigration routes for each of the salmonid species observed in the area.

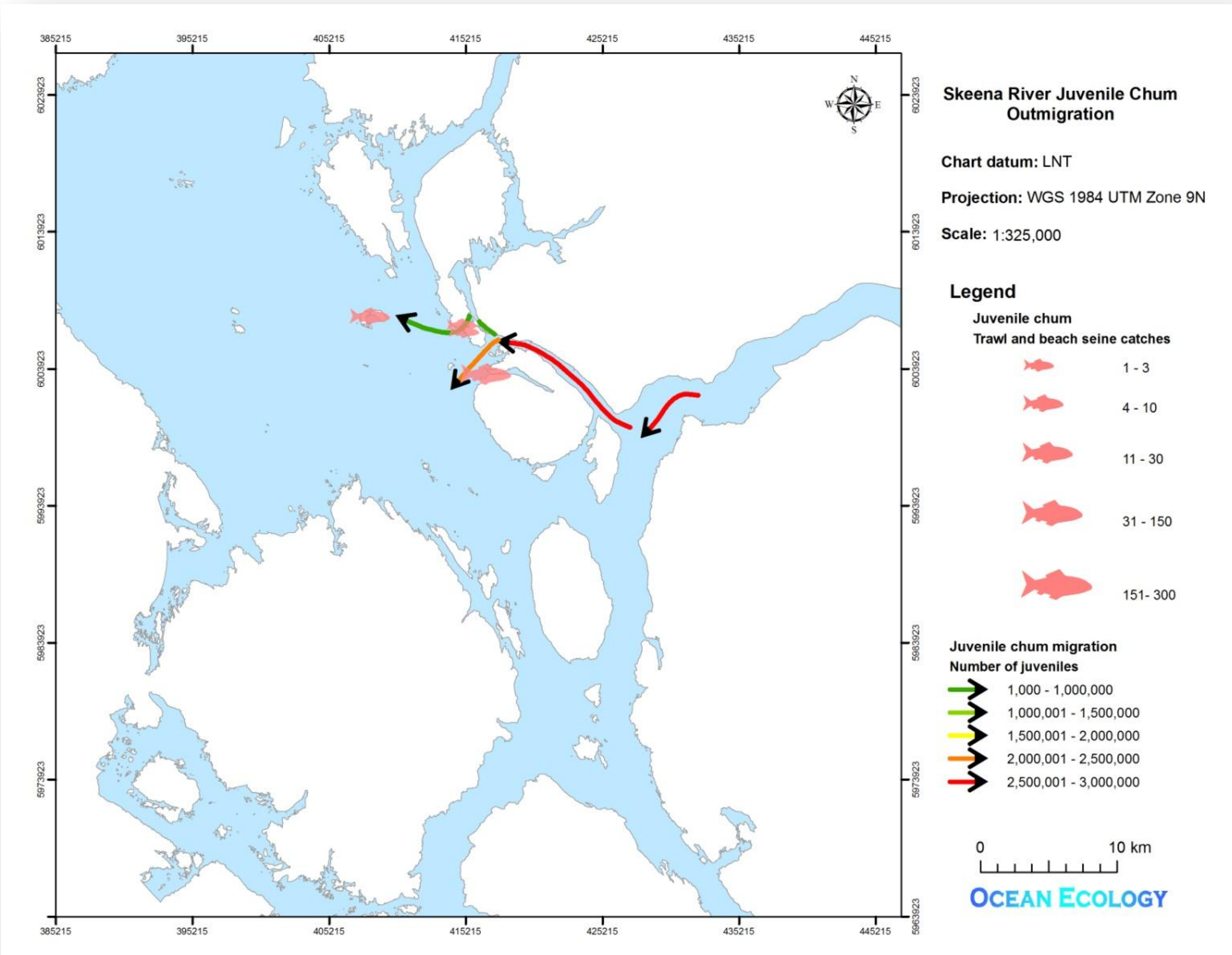


Figure 23. Skeena River juvenile chum outmigration (data from Gottesfeld *et al.* (2008) and Carr-Harris & Moore (2013).

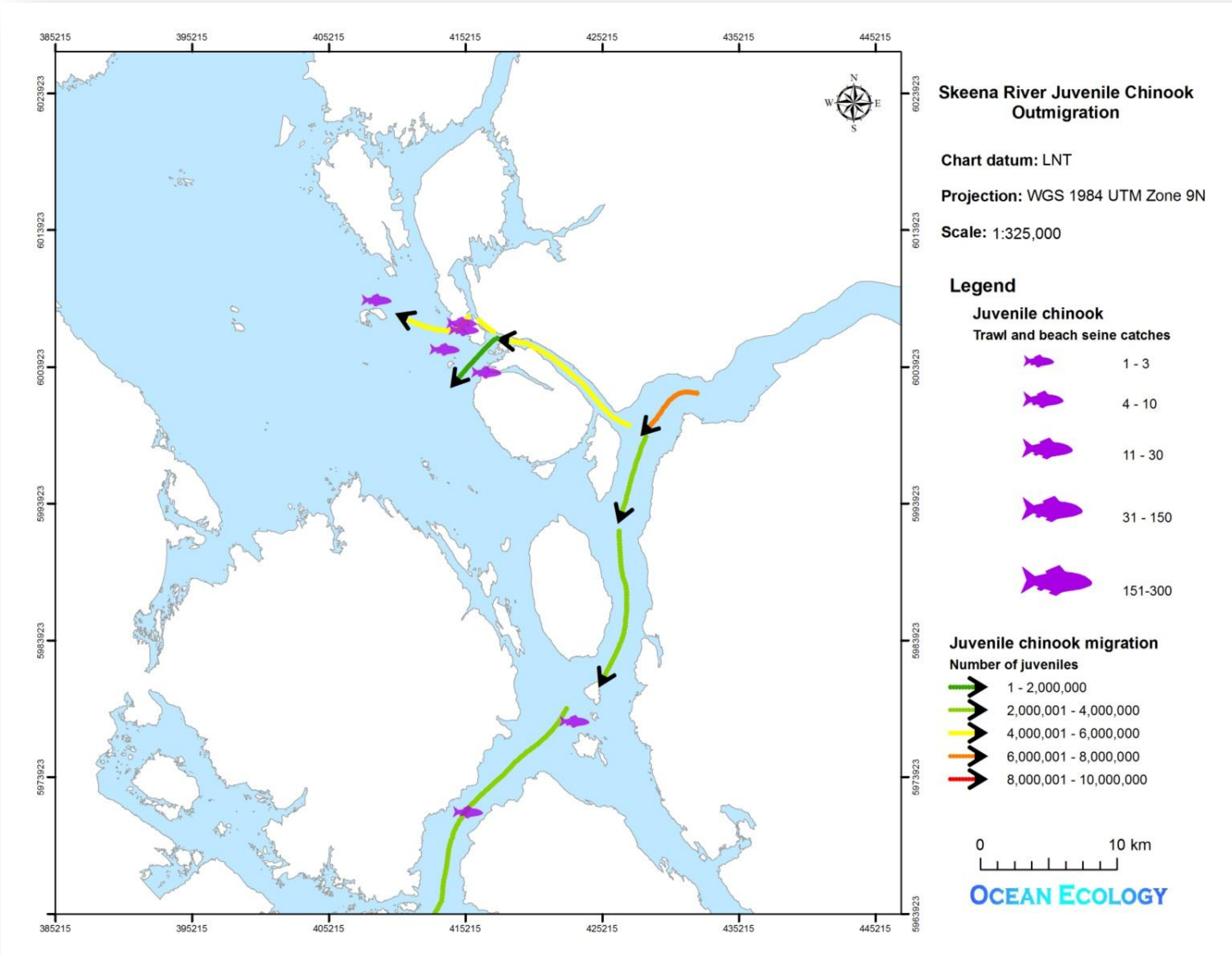


Figure 24. Skeena River juvenile Chinook outmigration (data from Gottesfeld *et al.* (2008) and Carr-Harris & Moore (2013).

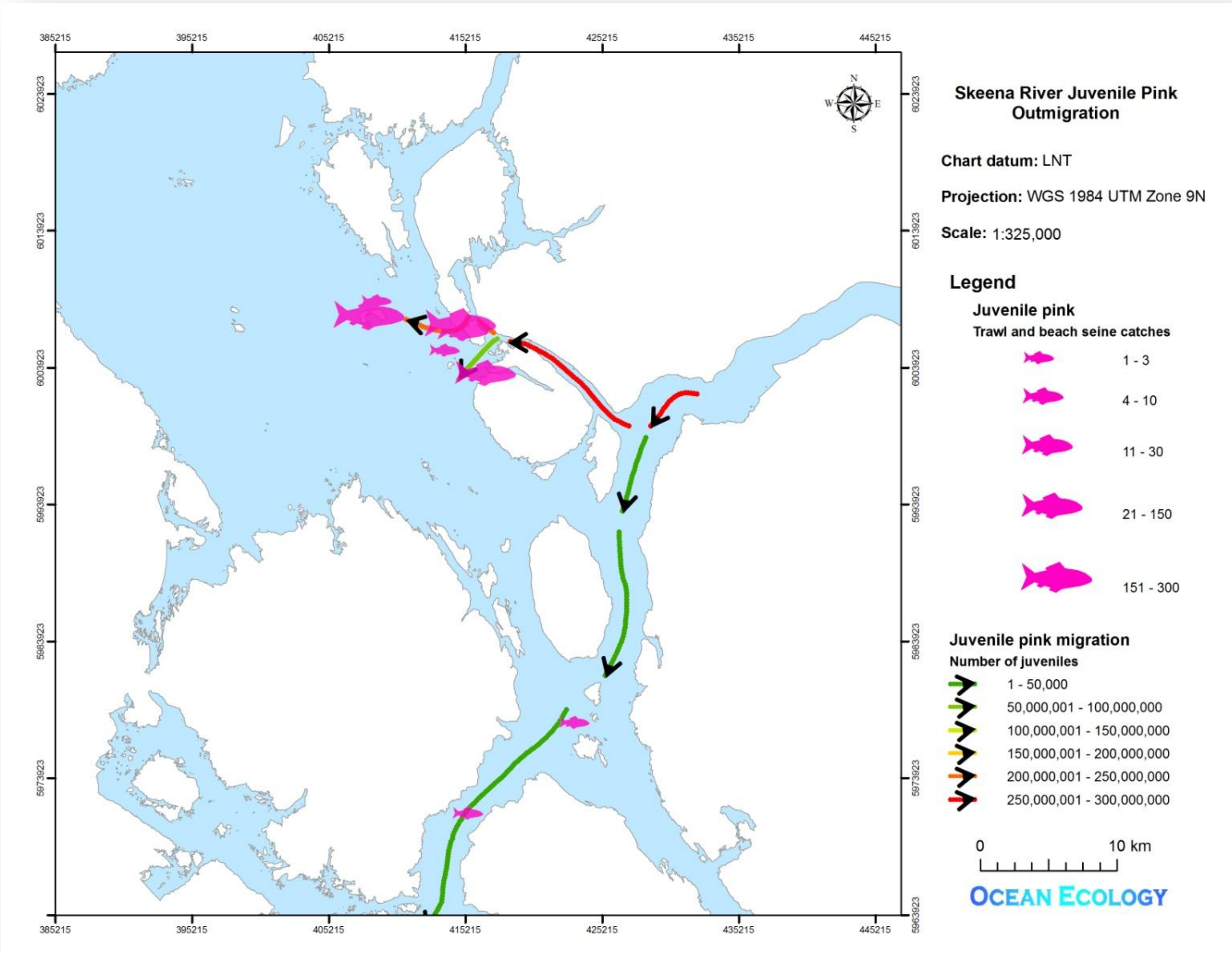


Figure 25. Skeena River juvenile pink outmigration (data from Gottesfeld *et al.* (2008) and Carr-Harris & Moore (2013).

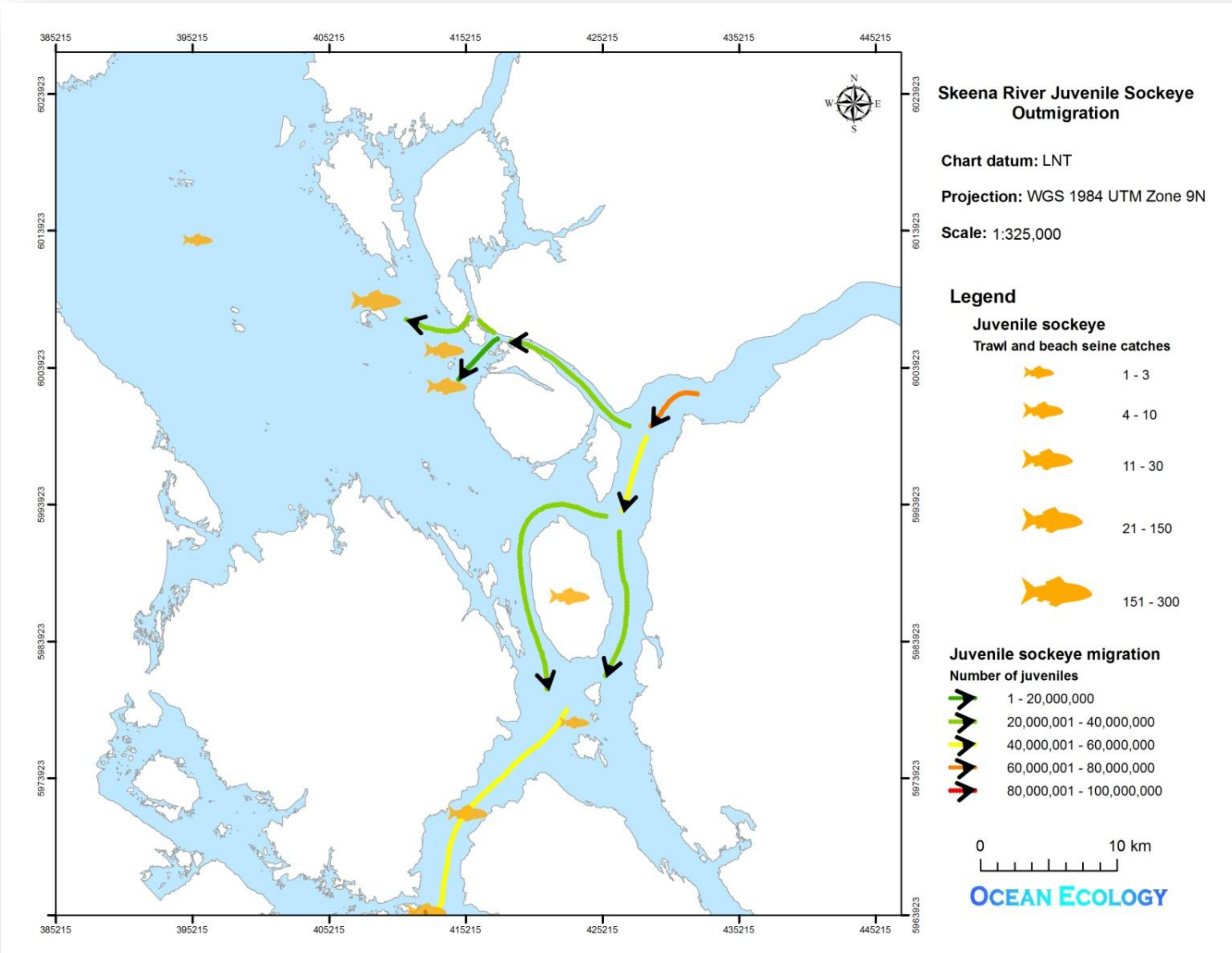


Figure 26. Skeena River juvenile sockeye outmigration (data from Gottesfeld *et al.* (2008) and Carr-Harris & Moore (2013).

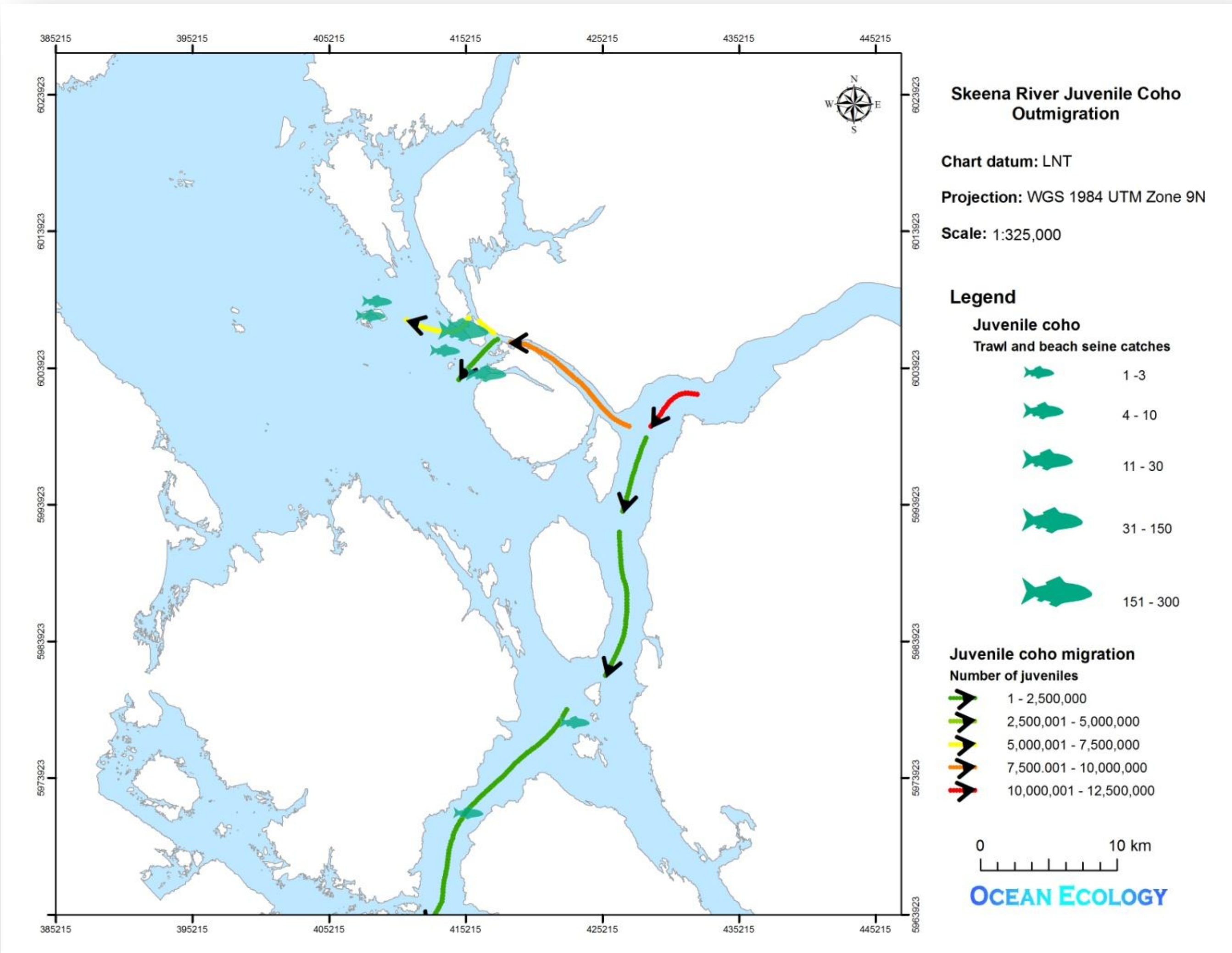


Figure 27. Skeena River juvenile coho outmigration (data from Gottesfeld *et al.* (2008) and Carr-Harris & Moore (2013).

4 Results and Discussion

The eleven key habitat factors, which describe classed habitat attributes, were used as the basis of juvenile salmon survival in the estuary; these habitat factors are shown in Table 1. It is important to note that juvenile survival is determined more by factors associated with habitat quality (i.e., productivity) than habitat quantity. Comprehensive environmental attribute indexes and environmental attribute data are found in Table 40 and Table 41 respectively within the Appendices.

Maps showing the habitat suitability index (HSI) for the juveniles of each of the six salmonid species were created using the model described in this paper (see Figure 28, Figure 29, Figure 30, Figure 31, Figure 32, and Figure 33). Based on these maps, juvenile salmonids can be loosely grouped into two feeding categories: (1) species (e.g., Chinook, pink, and chum) which spend their early life stages in the shallow water environments (e.g., eelgrass beds and sheltered subestuaries) of the estuary, feeding primarily on epibenthic zooplankton, such as harpacticoid copepods and epiphytic crustaceans; and (2) species (e.g., sockeye, Coho, and steelhead) which spend their early life stages in the deep water environments (e.g., the estuarine plume) of the estuary, feeding primarily on neritic zooplankton and small fish.

The most suitable habitats (HSI value ≥ 8) in the study area for epibenthic feeding species are (see Figure 34 for local place names):

- Flora Bank
- Stapledon Island
- The southeast shore of Ridley Island
- The northwest shore of Wainwright Basin (on the Tsimpsean Peninsula)
- The southeast shore of Morse Basin (on Kaien Island)
- The southeast shore of Prince Rupert Harbour (on the Tsimpsean Peninsula)

The most suitable habitats (HSI value ≥ 8) in the study area for neritic feeding species are (see Figure 34 for local place names):

- The southwest shore of Lelu Island
- Stapledon Island
- The southeast shore of Ridley Island
- The northwest shore of Wainwright Basin (on the Tsimpsean Peninsula)
- The southeast shore of Wainwright Basin and Morse Basin (on Kaien Island)
- The southeast shore of Prince Rupert Harbour (on the Tsimpsean Peninsula)
- Delusion Bay (on Digby Island)

Stapledon Island, the southeast shore of Ridley Island, the northwest shore of Wainwright Basin, the southeast shore of Morse Basin, and the southeast shore of Prince Rupert Harbour are high value habitats for all six salmonid species. Other areas are preferred more by either epibenthic feeders or neritic feeders - for example, Flora Bank is excellent habitat for epibenthic feeding species, whereas the southwest shore of Lelu Island and Delusion Bay are highly valuable habitats for neritic feeding species.

Some regions of the study area are uniformly poor habitat (HSI value ≤ 3) for all salmonid species. These include:

- The northwest and southwest shores of Kaien Island
- The southwest shore of Ridley Island

The west shore of Watson Island extending down towards Lelu Island is poor habitat (HSI value of 2-3) for epibenthic feeding species, and slightly better habitat (HSI value of 4-5) for neritic feeding species.

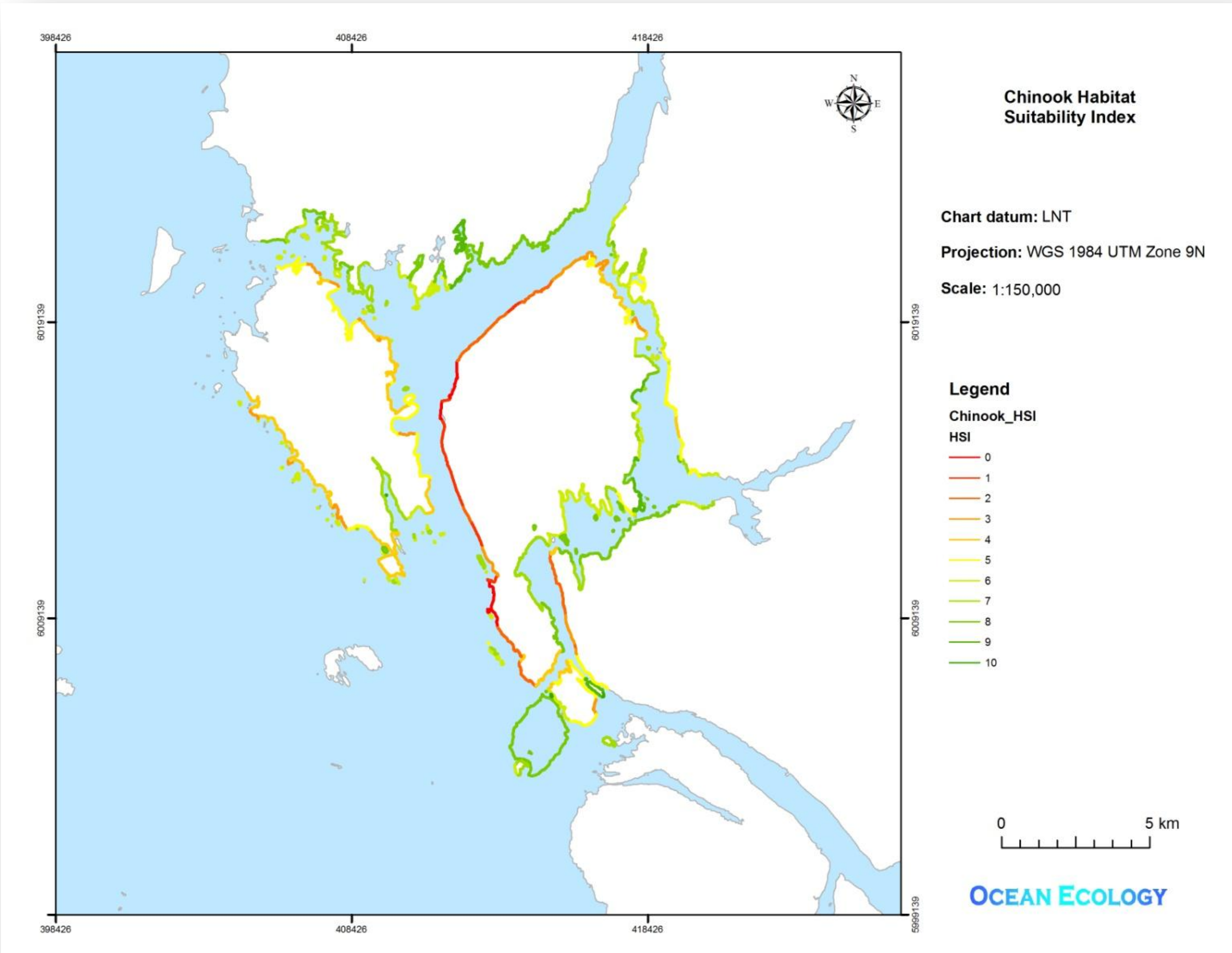


Figure 28. Chinook habitat suitability index.

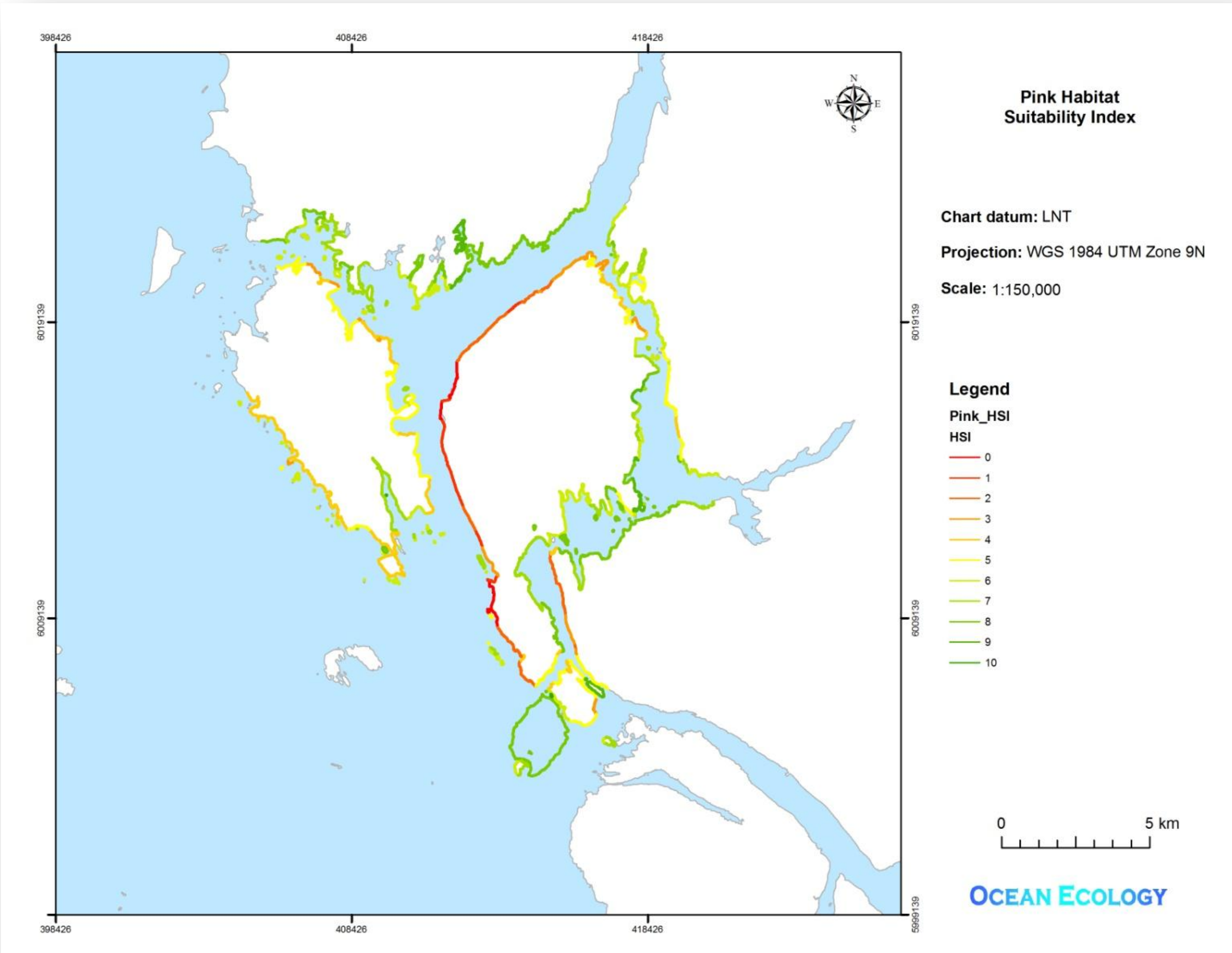


Figure 29. Pink habitat suitability index.

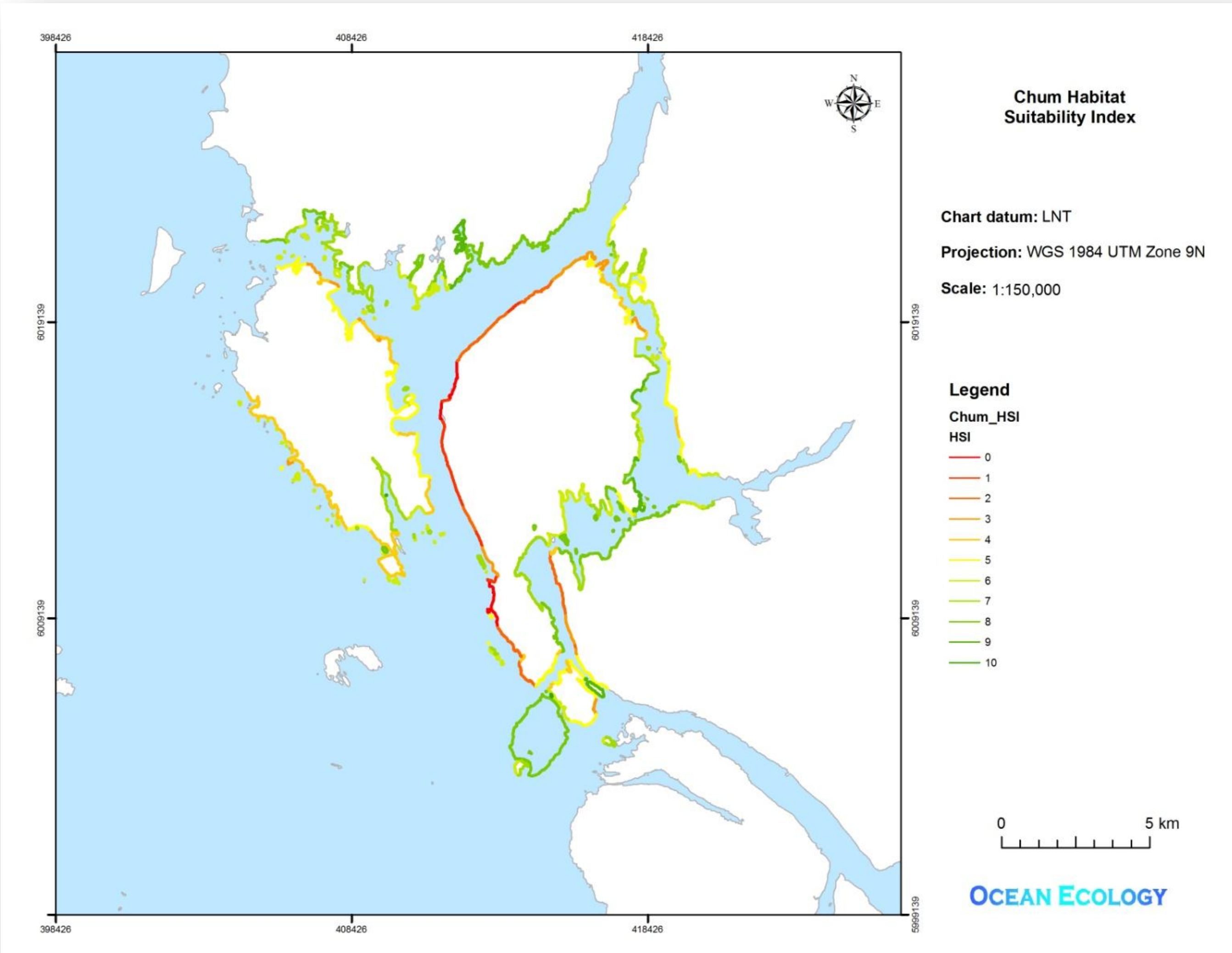


Figure 30. Chum habitat suitability index.

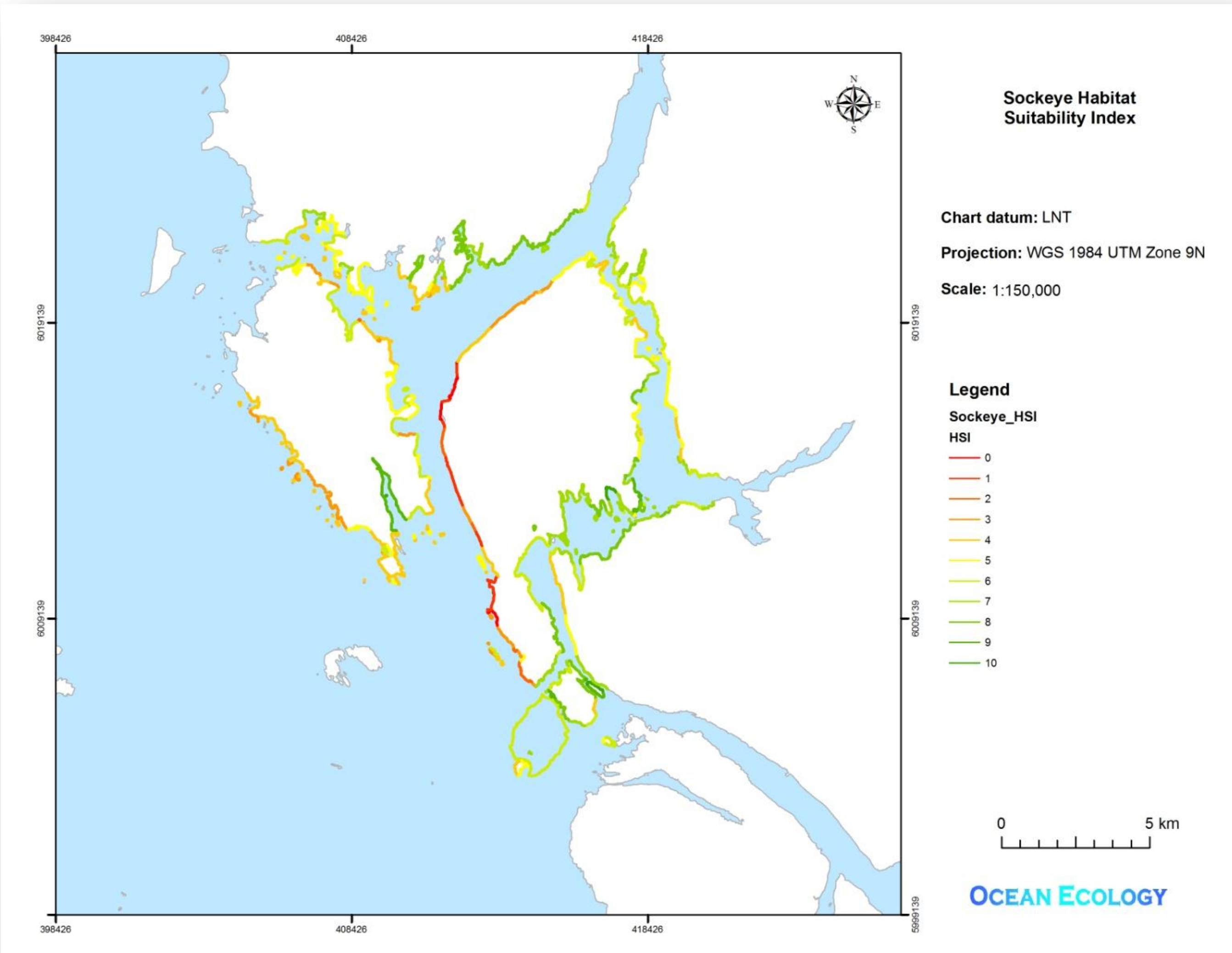


Figure 31. Sockeye habitat suitability index.

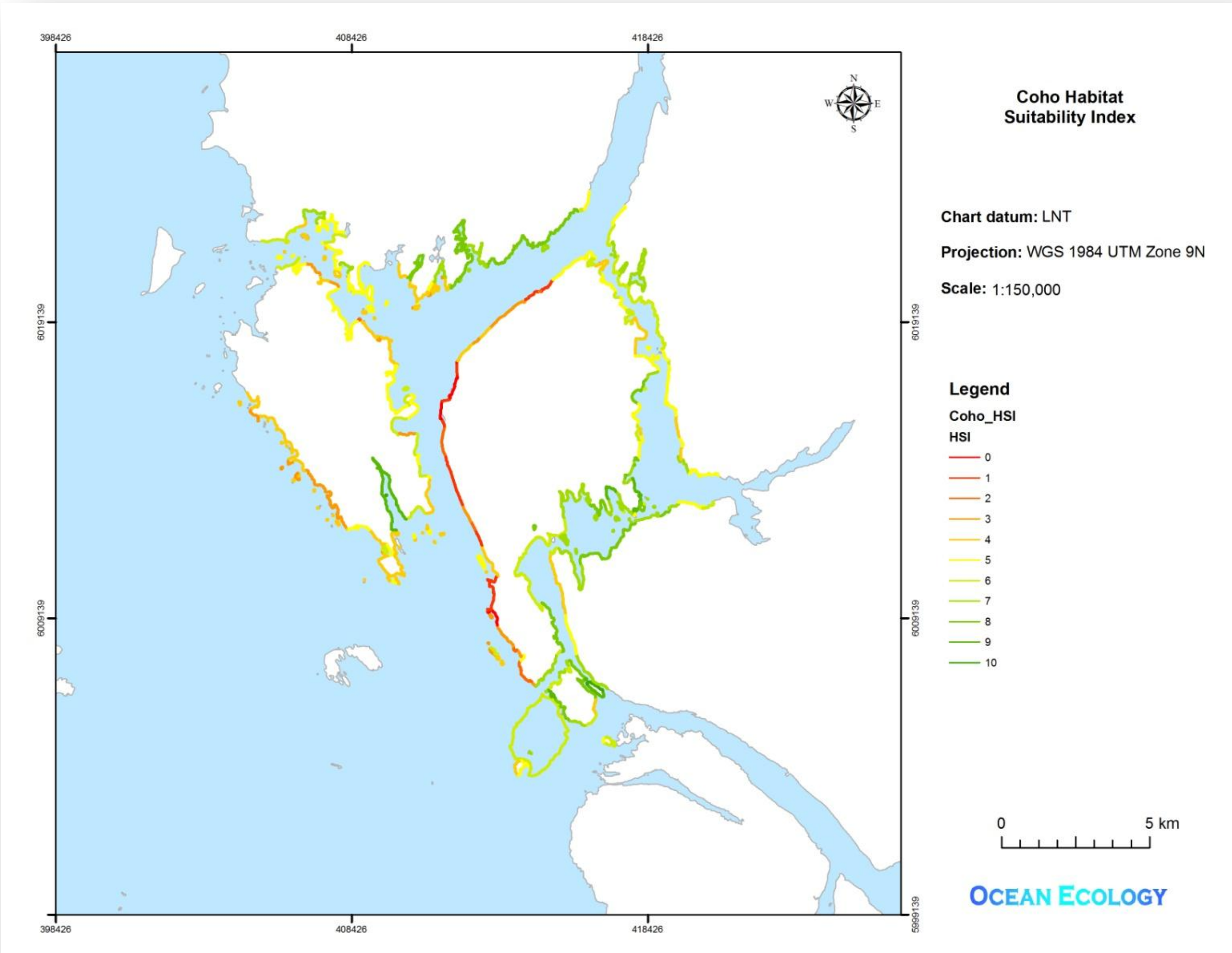


Figure 32. Coho habitat suitability index.

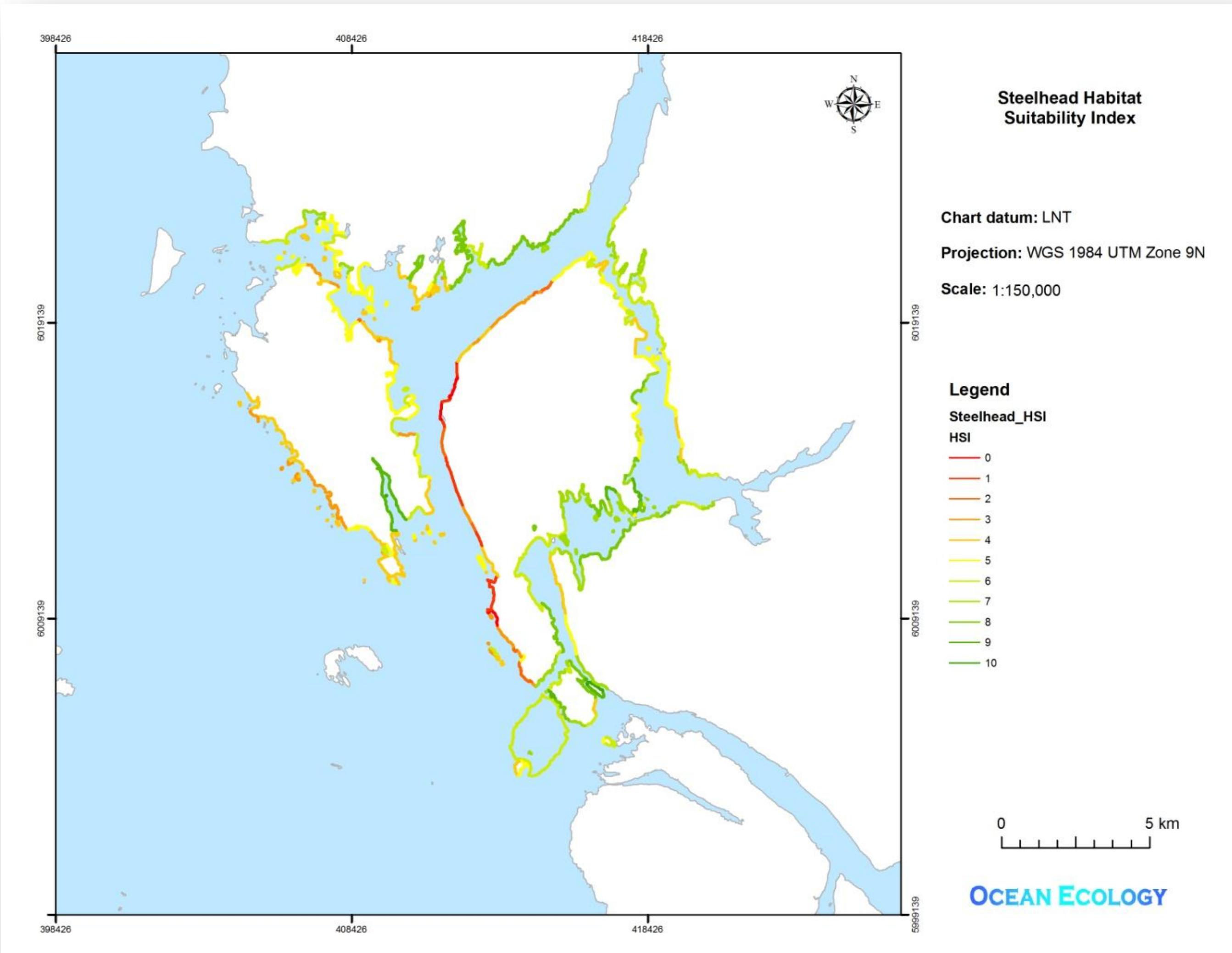


Figure 33. Steelhead habitat suitability index.

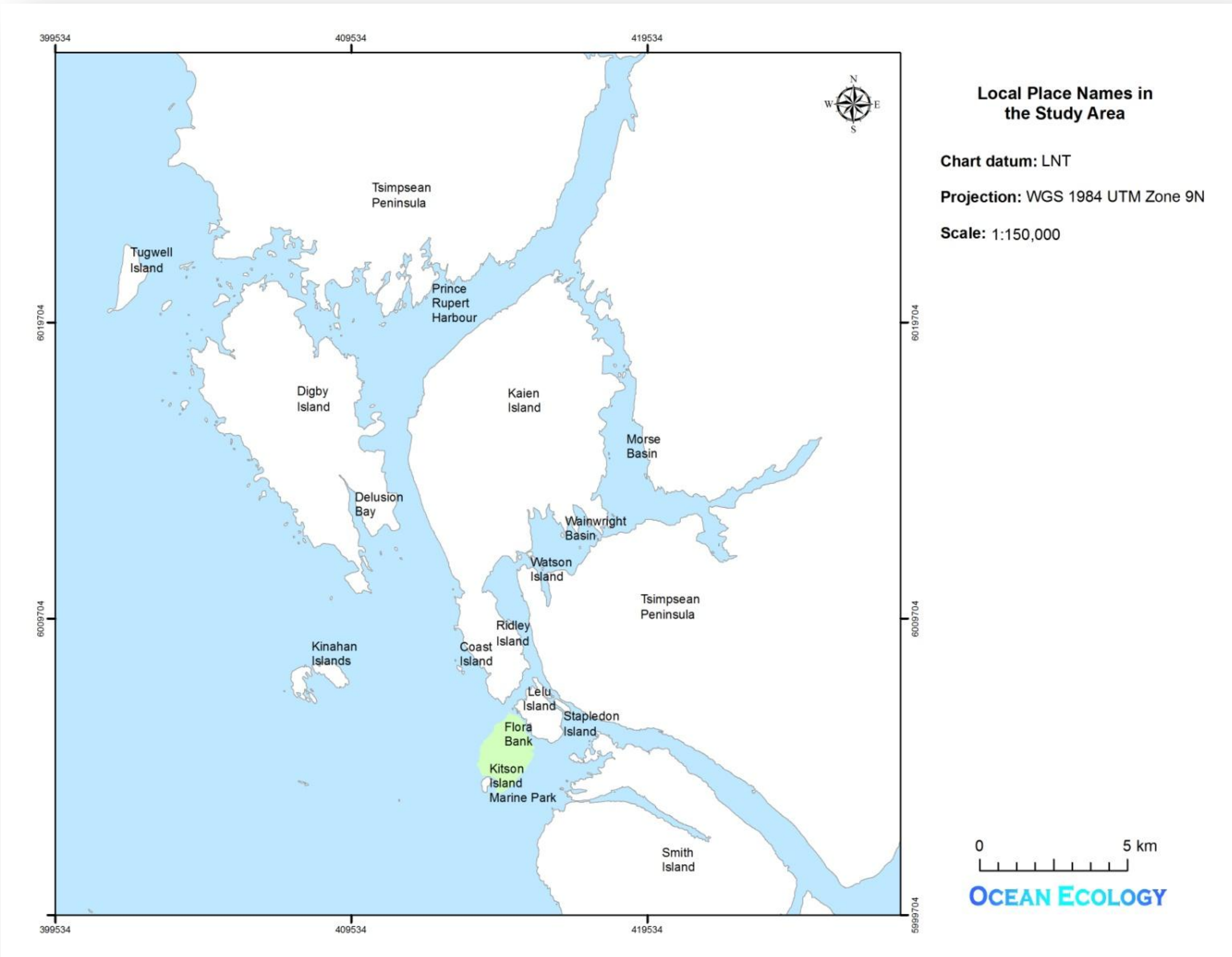


Figure 34. Local place names in the study area.

These areas of poor quality habitat are typically associated with past and current industrialization (including a railroad, a pulp mill, and several terminals) accompanied by shoreline straightening and hardening, industrial pollutants, and poor water quality resulting from sewage and industrial effluents. Once these shorelines were good quality habitat, with many small creek mouth and pocket subestuaries, which have since been lost due to industrialization.

Several large industrial developments are being proposed on and around Ridley (which already has some shipping terminals) and Lelu Islands (see Figure 35). These proposed developments are particularly concerning due to their proximity to both the mouth of the Skeena River and Flora Bank. Flora Bank is one of the most important habitats for epibenthic juvenile salmonids (HSI value of 8; broad shore segment line in Figure 35). It is somewhat less important for neritic juvenile salmonids (HSI value of 6; narrow, central shore segment line in Figure 35), but is still considered important for these juveniles since they spend a short period of time feeding in this habitat as they pass through it on their way to deeper water. Comparatively, epibenthic juveniles spend weeks to months feeding in the shallow water areas until they are large enough to forage successfully in the neritic environment. Degraded epibenthic habitats force juveniles of these species into the neritic environment while they are still very small, leading to starvation and increased predation.

To fully understand the importance of an HSI value of 8 for the epibenthic juvenile salmonids, it is necessary to consider the HSI values assigned to other nearby locations. Porpoise Channel (located between Ridley and Lelu Islands) has an HSI value of 4-5, the nearby Ridley Island shoreline has an HSI value of 2, and the Lelu Island shoreline has HSI values ranging from 3 to 6. Therefore, locally, in the area around Inverness Passage (southeast of Lelu Island), Lelu Island, Porpoise Channel, and southern Ridley Island, Flora Bank has the highest HSI value, and is the best epibenthic juvenile salmonid habitat in this region. In the entire study area for this research, there were very few other shoreline segments which had HSI values equal to or exceeding that of Flora Bank, and these few segments were on the southeast shore of Prince Rupert Harbour (on the Tsimpsean Peninsula) and in the basins on the east side of Kaien Island.

In addition to habitat quality, habitat location is vitally important to outmigrating juvenile salmonids, particularly those species which are epibenthic feeders. Species which require epibenthic food cannot travel far before they must find the right type of habitat for foraging. If they must travel any significant distance in open water, they will either starve or become food for predators. Thus, for example, epibenthic juveniles outmigrating from the Skeena River would be unable to cross Chatham Sound to reach other suitable habitats on Porcher Island. Therefore, not all suitable salmonid habitat in the Chatham Sound area will provide the same ecosystem functions with respect to Skeena River juvenile salmon survival that Flora Bank does.

Each year, approximately 377 million juvenile salmonids (see Table 10) enter the study area from their various natal streams. Of these, about 376 million (see Table 10), or 99.8%, are outmigrants from the Skeena River. The remaining juvenile salmonids (less than 1%) come from small natal creeks and rivers in the region (e.g., Hays, Oldfield, Silver, McNichol, and Diana Creeks, and Kloiya River). The composition of the Skeena River outmigration is roughly 72% pink, 21% sockeye, 3% Coho, 2% Chinook, 1% chum, and 1% steelhead.

Juvenile Pacific salmon migrating along the British Columbian coast instinctively turn northward as they exit their natal rivers and begin their migration along the coast to the Gulf of Alaska. Some individuals make this northward turn a little earlier than others during their outmigration. Based on beach seine and trawl catches of juvenile salmon in Chatham Sound (Gottesfeld *et al*. 2008; Carr-Harris & Moore 2013), it is estimated that approximately 88% of the juvenile salmon outmigrating from the Skeena River turn north into Inverness Passage. The remaining 12% travel through Telegraph Passage before turning north. Those juveniles traveling through Inverness Passage will pass over Flora Bank or around the shores of Lelu and Ridley Islands. Juveniles of species which forage in epibenthic habitats will remain in these areas until they are large enough to feed in the neritic environment. Thus, not only is Flora Bank a high quality habitat for juvenile salmon, it is in the direct path of approximately 331 million juvenile salmon, of which about 279 million are epibenthic feeders. Therefore, both location and habitat quality make Flora Bank an extremely important juvenile salmon rearing area. As a result, industrial developments around Flora Bank, Lelu Island, Inverness Passage, and Porpoise Channel have a significant likelihood of causing serious impacts to juvenile salmon outmigrating from the Skeena River.

Other regions of high quality salmonid habitat in the study area, such as those shoreline segments in the basins on the east side of Kaien Island and on southeast shore of Prince Rupert Harbour, do provide habitat for salmon, but not those outmigrating from the Skeena River. Rather, these areas provide important nursery and rearing habitats for salmon outmigrating from the local natal streams. While these populations are small, they are important to the overall health and diversity of salmon in the region. Many of these runs are enhanced by the Oldfield Creek Hatchery on Kaien Island, including Coho in Hays, Oldfield, Silver, McNichol, and Diana Creeks, Chinook in Kloiya River, and chum in Silver Creek.

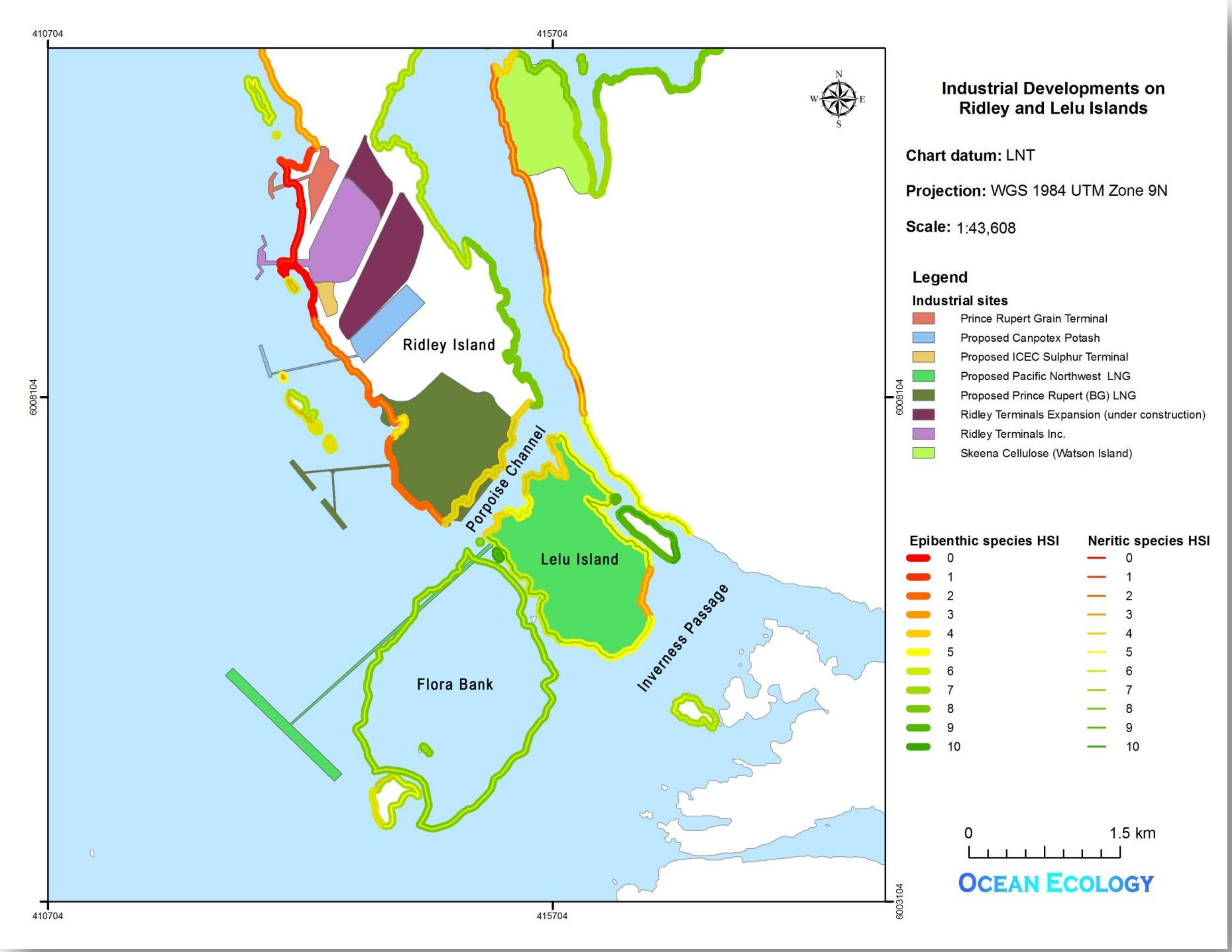


Figure 35. Location of industrial developments on Ridley and Lelu Islands. Broad shore segment lines indicates HSI values for epibenthic species. Narrow, central shore segment lines indicates HSI values for neritic species.

5 Conclusions and Recommendations

Juvenile salmonid habitat in the Skeena River estuary was modeled based on concepts similar to those from the Ecosystem Diagnosis and Treatment (EDT) methodology used for summer and fall chum salmon in the Hood Canal and the Strait of Juan de Fuca. Although qualitative in nature, this model provided a "snapshot", both spatially and temporally, of changes in habitat attributes as they related to juvenile salmonid survival. From the model, the following conclusions were made:

- The northwest and southwest shores of Kaien Island and the southwest shore of Ridley Island are poor habitat for all salmonid species as a result of industrialization and the attendant shoreline straightening and hardening, industrial pollutants, and poor water quality resulting from sewage and industrial effluents.
- Flora Bank is excellent habitat for epibenthic feeding salmonid species (e.g., pink, chum, and Chinook). It is in the direct path of approximately 331 million juvenile salmon outmigrating from the Skeena River, of which about 279 million are epibenthic feeders. Therefore, both location and habitat quality make Flora Bank an extremely important juvenile salmon rearing area.
- Stapledon Island is a high value habitat for all six salmonid species, and is also in the direct path of outmigrating Skeena River juvenile salmonids.
- The southwest shore of Lelu Island and Delusion Bay are highly valuable habitats for neritic feeding species (e.g., Coho, sockeye, and steelhead).
- The shoreline segments in the basins on the east side of Kaien Island and on southeast shore of Prince Rupert Harbour provide important nursery and rearing habitats for salmon outmigrating from the local natal streams. While these populations are small, they are important to the overall health and diversity of salmon in the region.
- There are siting issues with proposed developments adjacent to or subsuming high quality juvenile salmon habitat in the estuary. Given the risk to these high value habitats, proposed developments in these areas should be relocated.

The model used in this study was based on an analysis of pre-existing data, and as such, had the following limitations:

- Some of the data used were quite old, and may no longer be valid.
- Many data sets were limited in their spatial and temporal distribution, thus some locations in the model domain had good data coverage, while others had poorer data coverage.
- No model ground-truthing was done.
- Some important baseline data was completely lacking.

This study has helped to highlight the need for more detailed and up-to-date information on a number of factors affecting juvenile salmonids in the Skeena River estuary, including:

- ***Water quality data***. Much of the water quality data used in this study were quite old, generally from the 1960's through to the 1980's, and limited in spatial coverage primarily to the area around the old Skeena Cellulose pulp mill. New water quality baseline data are needed, especially with the proposed development activity.
- ***Sediment chemistry data***. The sediment chemistry data used in this study were very limited in spatial coverage. Data on sediment chemistry throughout the study area are required to provide a greater understanding of the distribution and degradation of toxic pollutants, such as heavy metals and dioxins, in the region.
- ***Juvenile salmonid residence times in eelgrass beds and subestuaries***. Understanding the length of time that each species of juvenile salmonid spends in these habitats will assist in determining the importance of these habitats to salmonid life histories, and ultimately, to the protection of specific habitats.

- ***Epibenthic fauna in eelgrass beds and subestuaries***. Knowledge of the composition and abundance of epibenthic fauna in these habitats, and the changes in this composition and abundance over time, will be important in predicting habitat value and variations in salmonid survival.
- ***Neritic juvenile salmonid distribution and feeding relative to the Skeena River plume***. Studies on the abundance, distribution, feeding, and migration of neritic salmonid species relative to the position of the Skeena River plume will provide information that can aid in predicting juvenile salmonid survival and the impacts of industrial development on these species.
- ***Detailed information on juvenile salmonid distribution throughout the Skeena River estuary***. Preliminary data have been collected on juvenile salmonid distribution at some locations in the Skeena River estuary; however, more information with wider temporal and spatial coverage is needed. Purse seining studies for neritic juveniles (e.g., sockeye) would be valuable.
- ***Temporal (both intra-annual and interannual) studies***. Very little data are available regarding temporal changes in habitats (e.g., eelgrass beds) or the seasonal succession of organisms using these habitats. Additionally, more long term monitoring to measure interannual changes is required.
- ***Oceanographic studies.*** Very little is known at present regarding the current patterns in the Skeena River estuary and Chatham Sound. More current measurements, and ultimately, an oceanographic model of the region, is required. Such a model would provide a basis for studies on sediment movement, nutrient distribution, and regional productivity.
- ***Salmonid population studies***. Although Carr-Harris & Moore (2013) showed that 9 different Chinook stocks and 26 different sockeye stocks were represented in their samples taken from the Skeena River estuary, there is scant data showing where particular juvenile salmon populations rear in the estuary. For instance, do Fulton and Pinkut enhanced sockeye juveniles spread throughout the estuarine nearshore habitats, or are they in clusters in particular areas, such as the high value habitats near the proposed LNG project sites? Some high interior Skeena salmon stocks are currently at risk due to adverse impacts on their inland habitats as a result of changing climate or proposed developments. Will the juveniles of these salmon stocks be at increased risk if they use habitat proposed to be modified or disturbed by the LNG projects in the Skeena River estuary?

6 Acknowledgments

Ocean Ecology would like to thank Skeena Watershed Conservation Coalition and Skeena Wild Conservation Trust who provided financial support for this project. We would also like to thank Ken Rabnett for support during the write-up phase of this work and for providing photos of juvenile salmonids, and Brian Huntington for the aerial photos used in this report.

7 Glossary

Adult salmon - a salmon that is at least two years old, generally three years or older, that has reached sexual maturity.

Alevin - a newly hatched salmon still attached to the yolk.

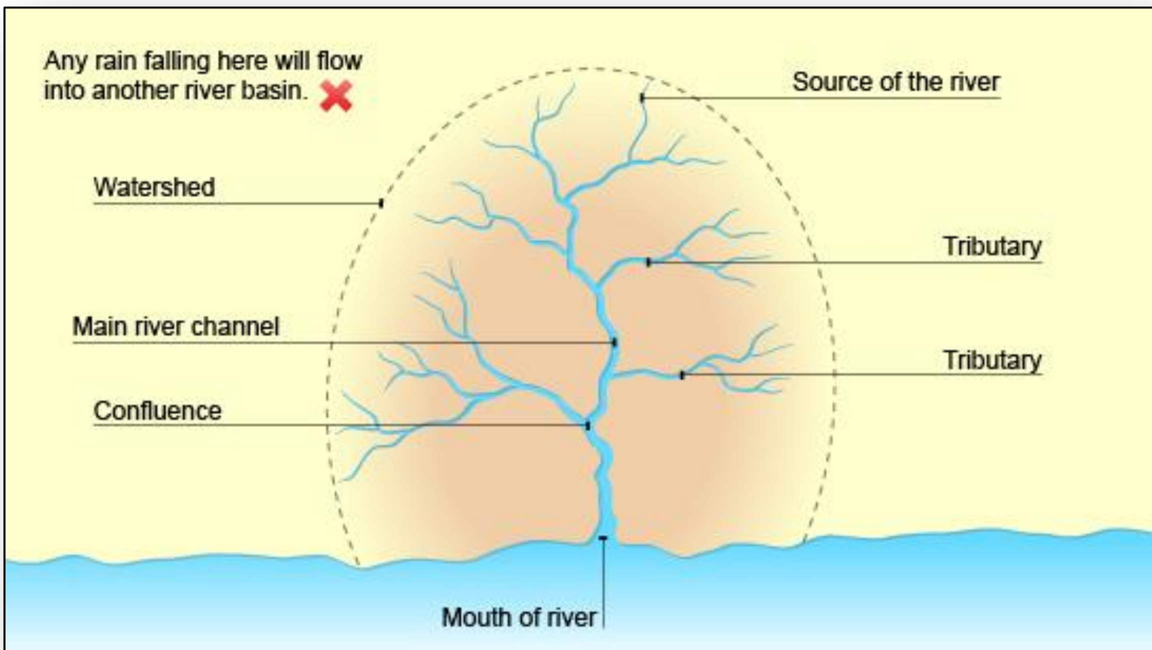
Anadromous - fish that hatch in freshwater, migrate to seawater as juveniles and return to freshwater as adults to spawn.

Anthropogenic - human made or human-caused.

Artificial propagation - with respect to salmon, fish reared in hatcheries.

Baseline data - data representing normal background levels or initial levels of a measurable quantity and used for comparison with values representing a response to an environmental stimulus or intervention.

Basin - the geographic area from which all water flows to a specific water body. Often referred to as a drainage basin. A watershed is the border between two drainage basins (see figure below from Hinchingbrooke [2013]).



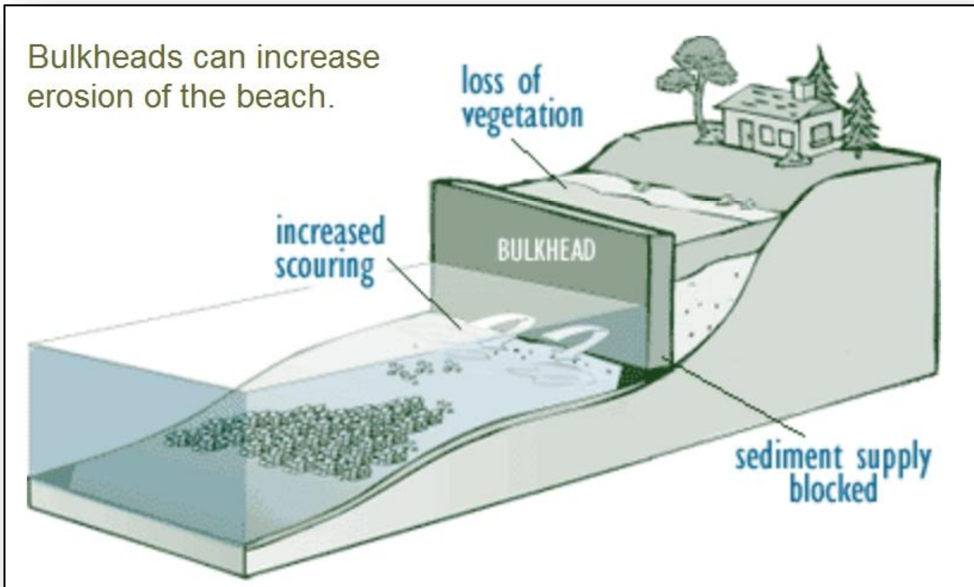
Benthic - an environment or habitat related to the bottom of a stream or body of fresh or salt water.

Biochemical oxygen demand (**BOD**) - the amount of oxygen required by aerobic microorganisms to decompose the organic matter in a sample of water, such as that polluted by sewage. It is used as a measure of the degree of water pollution. Also called biological oxygen demand.

Bioturbation - the stirring or mixing of sediment or soil by organisms, especially by burrowing or boring.

Blue-listed species - species in BC that are not immediately threatened, but of concern because of characteristics that make them particularly sensitive to human activities or natural events.

Bulkhead - a retaining wall along a waterfront (see figure below from Puget Sound Shorelines [2013]).

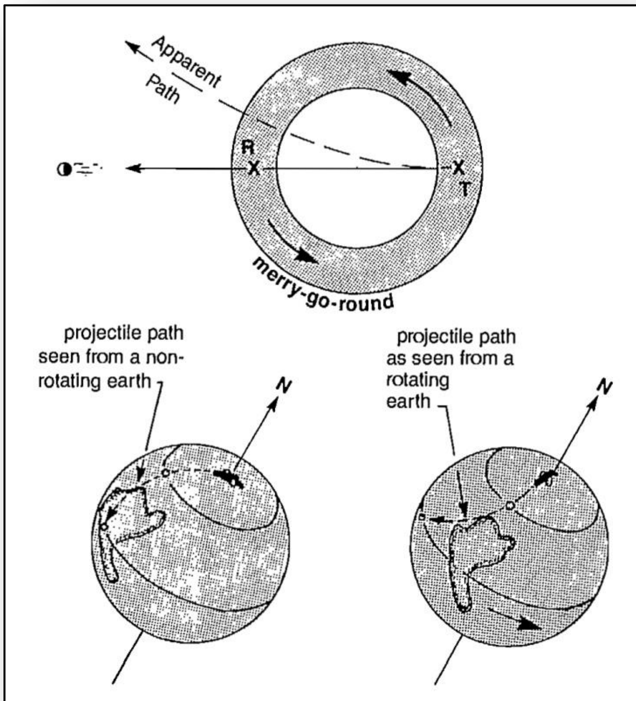


Climate change - changes in long-term weather patterns caused by natural phenomena and human activities that alter the chemical composition of the atmosphere through the build-up of greenhouse gases which trap heat and reflect it back to the earth's surface.

Cobble - stones of about 6 to 26 cm in diameter.

Competition - an interaction between organisms or species, in which the fitness of one is lowered by the presence of another. Limited supply of at least one resource (such as food, water, and territory) used by both can be a factor. Competition can be both within and between species. Competition among members of the same species is known as *intraspecific competition*, while competition between individuals of different species is known as *interspecific competition*.

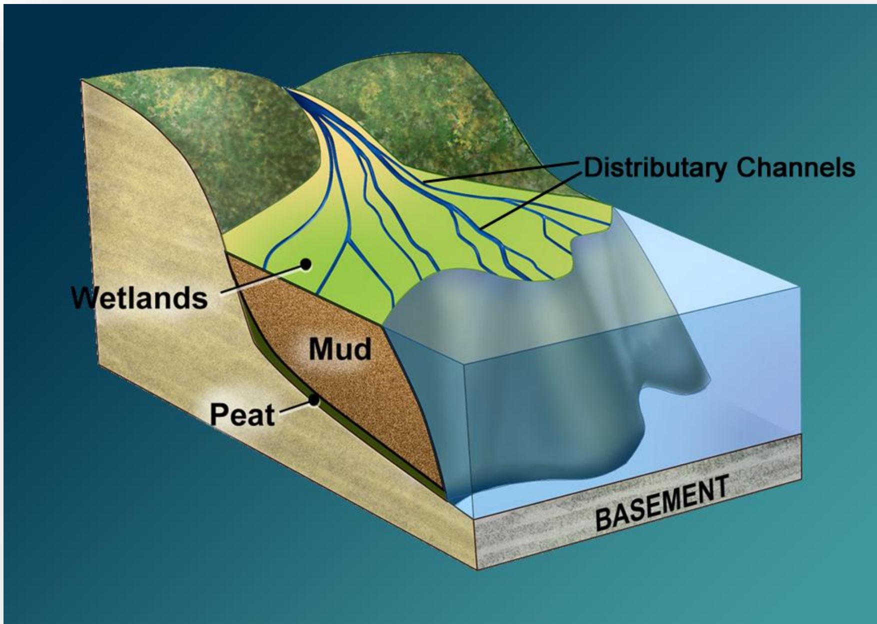
Coriolis effect - the apparent deflection (called *Coriolis acceleration*) of a body in motion (such as a projectile, airplane, or ocean and air currents) with respect to the earth, as seen by an observer on the earth, attributed to a fictitious force (called the *Coriolis force*), but actually caused by the rotation of the earth and appearing as a deflection to the right in the Northern Hemisphere and a deflection to the left in the Southern Hemisphere (see figure below from Thomson [1981]).



Critical habitat - areas of habitat that are crucial to the survival of a species and essential for its conservation.

Cumulative impacts - changes to the environment that are caused by an action in combination with other past, present and future human actions.

Delta - a landform that is formed at the mouth of a river, where the river flows into the ocean. Deltas are formed from the deposition of the sediment carried by the river as the flow leaves the mouth of the river. Over long periods of time, this deposition builds the characteristic geographic pattern of a river delta (see figure below showing a typical delta).



Deposition - the settlement or accumulation of suspended or bed load material out of the water column onto the stream bed or floodplain. It occurs when the energy of flowing water and channel gradient are unable to transport the sediment further.

Detritus - dead or decaying organic matter; technically called organic detritus to distinguish it from the mineral detritus classified by geologists.

Dissolved oxygen - oxygen held within the water so that it is accessible to aquatic life.

Diversity (**biodiversity**) - the degree of variation of life. This can refer to genetic variation, species variation, or ecosystem variation within an area, biome, or planet.

Dredging - clearing the bed of a harbour, river, or other area of water by scooping out mud, weeds, and rubbish with a dredge (an apparatus for bringing up objects or mud from a river or seabed by scooping or dragging).

Ecosystem - a community of organisms and their physical and biological environment functioning as a unit.

EDT - (Ecosystem Diagnosis and Treatment) - a science-based approach to formalizing and analyzing actions to improve the sustainability and production of migratory salmon. The approach integrates the quality and quantity of habitat across the salmon life cycle. It estimates the ability of the environment to support a population in terms of abundance, productivity, and life history diversity (developed by Lars Mobrand).

Empirical data - a source of knowledge acquired by means of observation or experimentation.

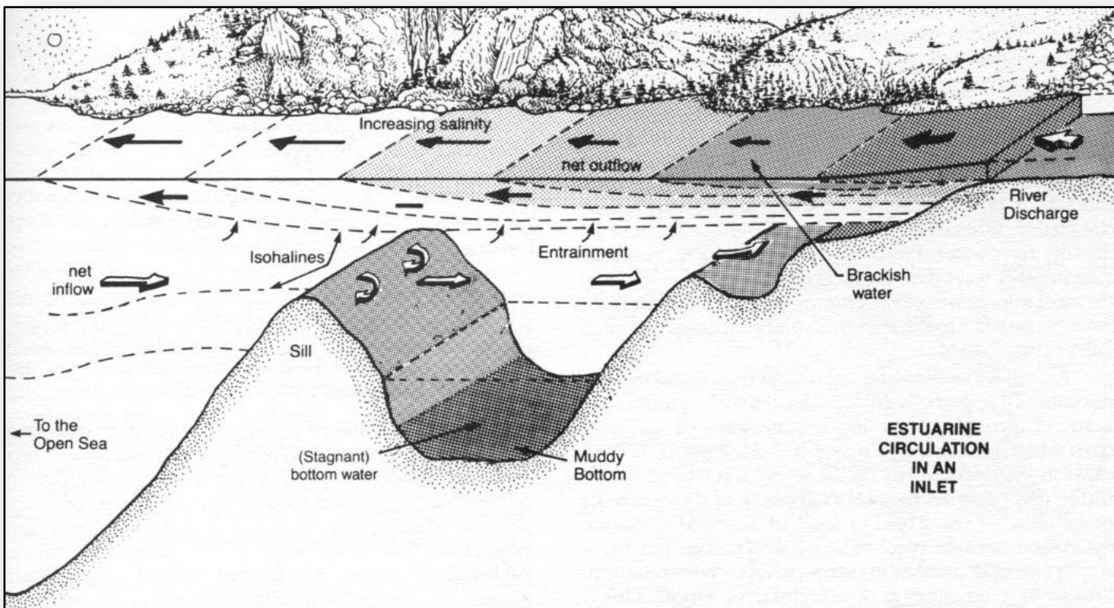
Entrainment — the process by which relatively high-density fluid is incorporated into an overlying layer of less dense fluid as a result of breaking wavelike disturbances or turbulent motions at the interface between the fluids. In an estuary, entrainment produces at net transport of salt from the saline ocean water to the overlying brackish layer.

Enbridge Northern Gateway Pipelines Project - a proposal to construct twin pipeline 1,170 km in length, running from Bruderheim, Alberta, to Kitimat, British Columbia. The eastbound pipeline would import hydrocarbon natural gas condensate and the westbound pipeline would export bitumen from the Athabasca oil sands diluted with the condensate to the new marine terminal in Kitimat where it would be transported to Asian markets by oil tankers. The project would also include terminal facilities with marine infrastructure at tidewater to accommodate loading and unloading of oil and condensate tankers, and marine transportation of oil and condensate.

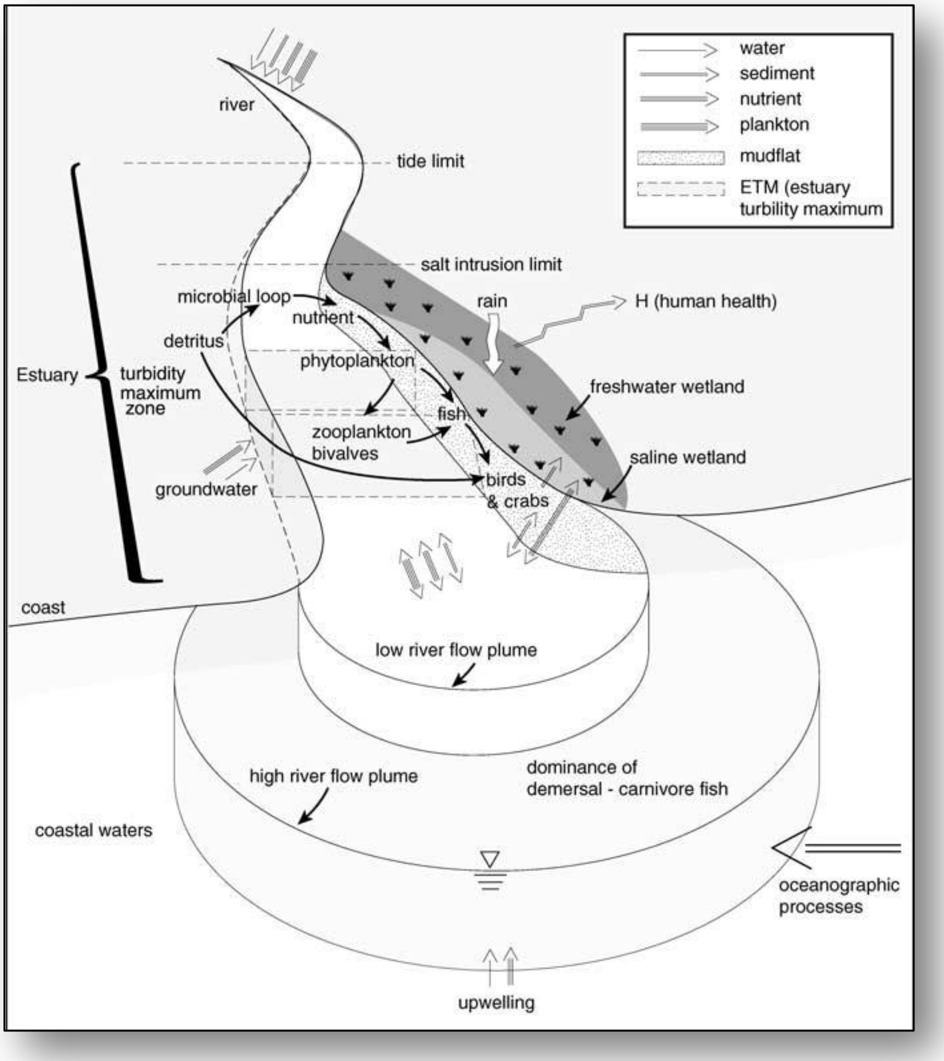
Environmental sustainability - a state in which the demands placed on the environment can be met without reducing its capacity to allow all people to live well, now and in the future. It is a process that creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations. Sustainability is important to making sure that we have and will continue to have, the water, materials, and resources to protect human health and our environment.

Epibenthic - on or just above the bottom of a stream or body of fresh or salt water.

Estuarine circulation - in an estuary, the outflow (seaward) of low-salinity surface water over a deeper inflowing layer of dense, high-salinity water (see figure below from Thomson [1981]).

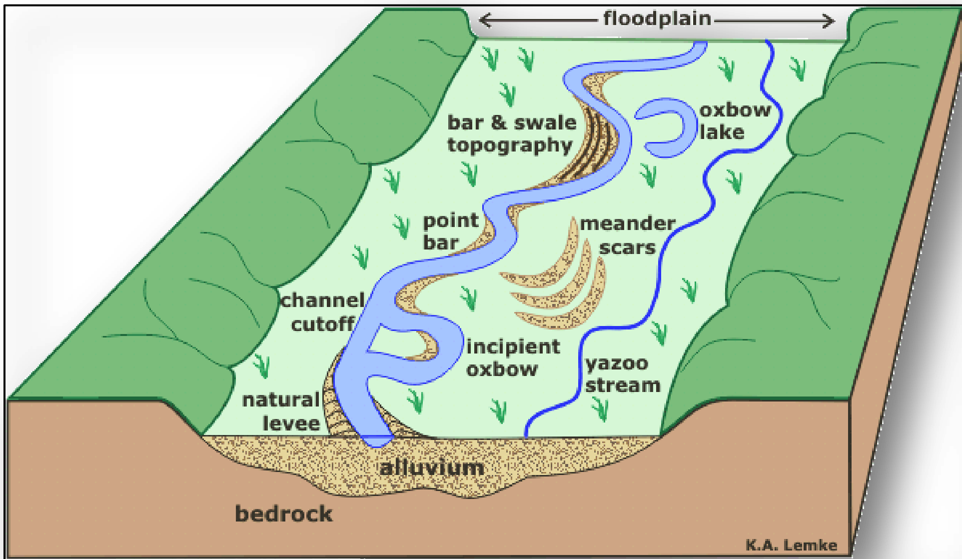


Estuary - a partially enclosed body of water where seawater is measurably diluted by mixing with river runoff (see figure below from Wolanski *et al*. [2004]).



Extrapolation - an inference about the future or about some hypothetical situation based on known facts and observations.

Floodplain - a low level area that may be submerged by floodwaters or an area built up by stream deposition (see figure below from The British Geographer [2013]).



Focal species - the species of interest or study.

Foraging - searching for and exploiting food resources. It affects an animal's fitness because it plays an important role in an animal's ability to survive and reproduce.

Freshet - a sudden rise in the level of a stream or a flooding caused by heavy rains or the rapid melting of snow and ice.

Fry - an early life stage of salmon that has emerged from gravel but still within its first few months of life. Generally about 30-50 mm in length.

Gravel - unconsolidated rock fragments that have a size range which includes size classes from granule- to boulder-sized fragments. Gravel is sub-categorized by the Udden-Wentworth scale into granules (>2 to 4 mm) and pebbles (>4 to 64 mm).

Ground-truthing - the process of gathering data to test the accuracy, or otherwise, of a scientific model.

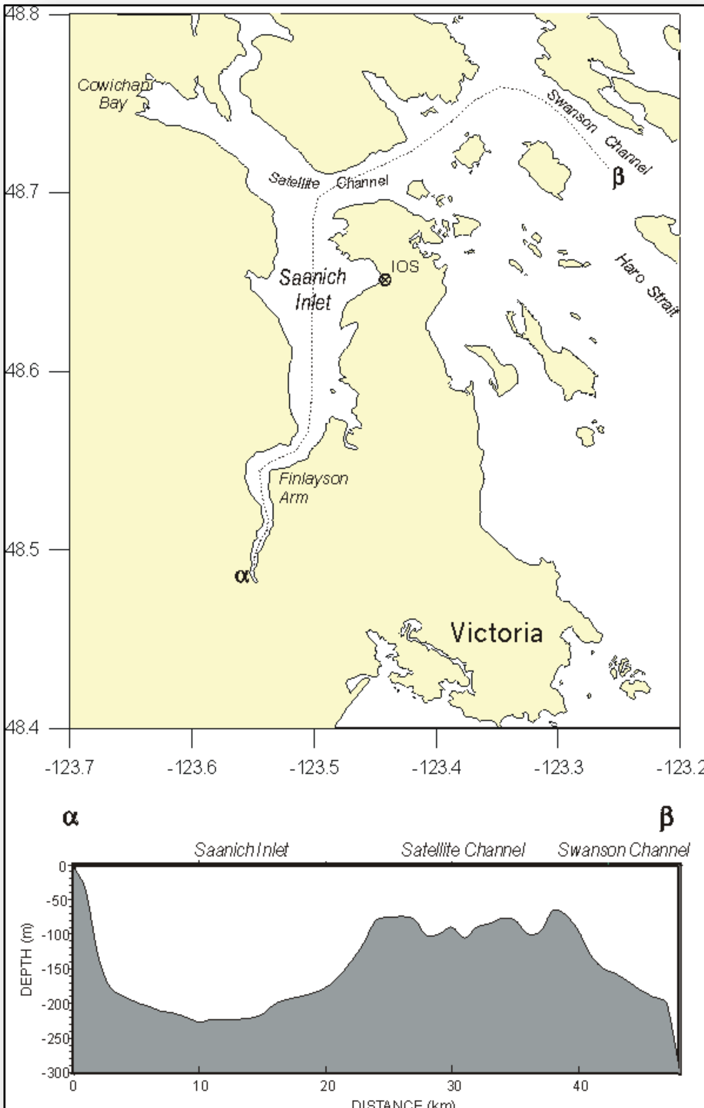
Habitat - the area or natural environment in which an organism or population normally lives. Habitats encompass physical factors such as light, temperature, substrate, wave action and oxygen availability, as well as biotic factors such as the availability of food and the presence of predators.

Hatchery stock - salmon that have been artificially bred and reared under controlled conditions, generally for more than one generation.

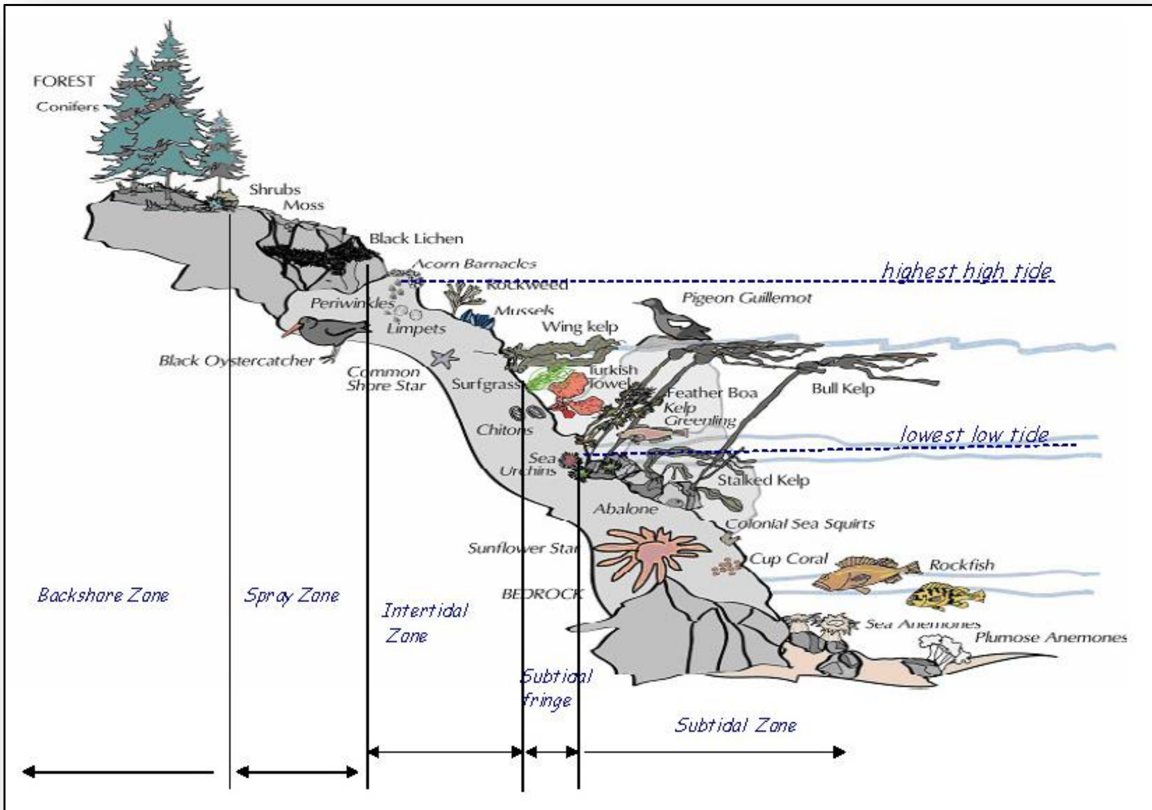
Heterotrophic - referring to organisms, such as animals, obtaining carbon for growth and energy from complex organic compounds.

Holistic - all encompassing view based on the knowledge of the nature, functions, and properties of the components, their interactions, and their relationship to the whole.

Inlet - the connection between a sound, bay, lagoon, or marsh and the ocean. A *fjord* is a type of inlet created by glaciation, typically but not always found in mountainous coastlines. The entrance of a fjord inlet is referred to as the *mouth*, and the end farthest from the sea, often at the outlet of a stream or river, is called the *head* (see figure below from DFO [2013b] showing an example of a fjord inlet).

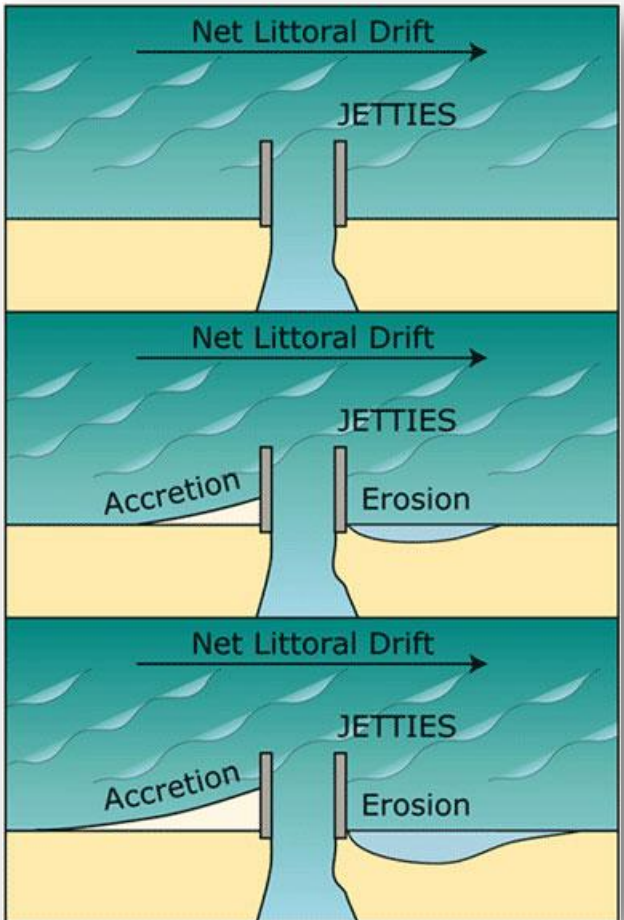


Intertidal zone (**littoral zone**) - the area of the seashore that is above water at low tide and under water at high tide (in other words, the area between tide marks) (see figure below from CRD [2013]).



Jack - a precocious or early maturing salmonid fish; most are males.

Jetty - a structure, such as a pier, dock, or wharf, that projects into a body of water to influence the current or tide or to protect a harbor or shoreline from storms or erosion (see figure below from ESSEA [2013]).



Juvenile salmon - young salmon (fry, smolt) that have not reached sexual maturity. Generally referring to young salmon that have not yet migrated to the sea, or have just entered the sea.

Keystone species - a species that has a disproportionately large effect on its environment relative to its abundance. Such species are described as playing a critical role in maintaining the structure of an ecological community, affecting many other organisms in an ecosystem and helping to determine the types and numbers of various other species in the community.

Large woody debris - large logs (generally 30 cm in diameter, or larger) and root wads that fall or are placed in or near a stream and become part of the riparian or aquatic habitat.

Life history - a history of the changes through which an organism passes in its development from the primary stage to its natural death.

Macrophytes - multicellular aquatic plants that attach to the bottom by roots or holdfasts, as opposed to planktonic plants which are free floating.

Mainstem - the principal stream or channel for any drainage basin.

Morphology - the external structure of rocks in relation to the development of erosional forms or topographic features.

Migratory - traveling from one place to another at regular times, often over long distances.

Mixed stock - a stock whose individuals originated from commingled native and nonnative parents, or a previously native stock that has undergone substantial genetic alteration.

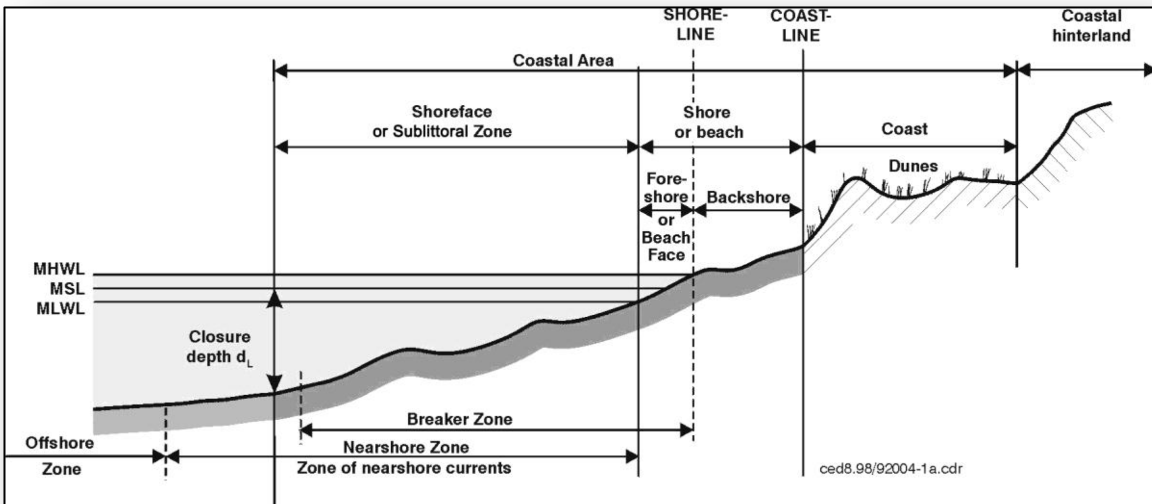
Model domain - the spatial location, orientation and grid size of a climate, ocean circulation, or biological model.

Mud - wet clay and silt-rich sediment with particles having a diameter of <0.62 mm. Mud may also be referred to as silt or silt-mud.

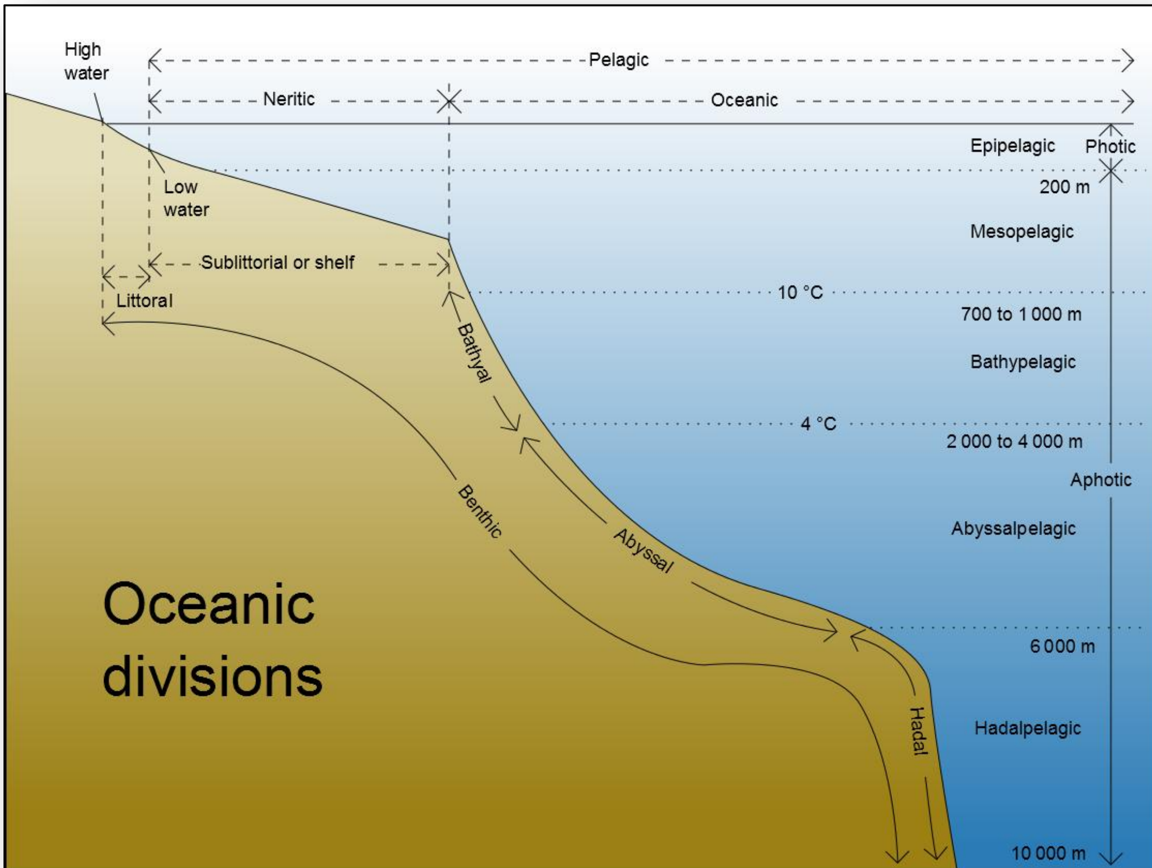
Mudflat - a muddy or sandy coastal strip often submerged at high tide (see tidal channel).

Natal stream - the stream in which an adult salmon returns to spawn where it originally incubated and reared.

Nearshore - the zone extending seaward from the low water line well beyond the breaker zone; it defines the area influenced by the nearshore currents. The nearshore zone extends somewhat further seawards than the sublittoral zone (see figure below from Coastal Wiki [2013]).



Neritic - relating to the ocean waters over the sublittoral zone of the ocean floor, ranging in depth between the low tide mark to about 200 m (see figure below from Wikipedia [2013a]).



Neustonic - relating to the community of organisms associated with the surface of a body of water; community includes organisms that float on the top of water (*epineuston*) or live right under the surface (*hyponeuston*).

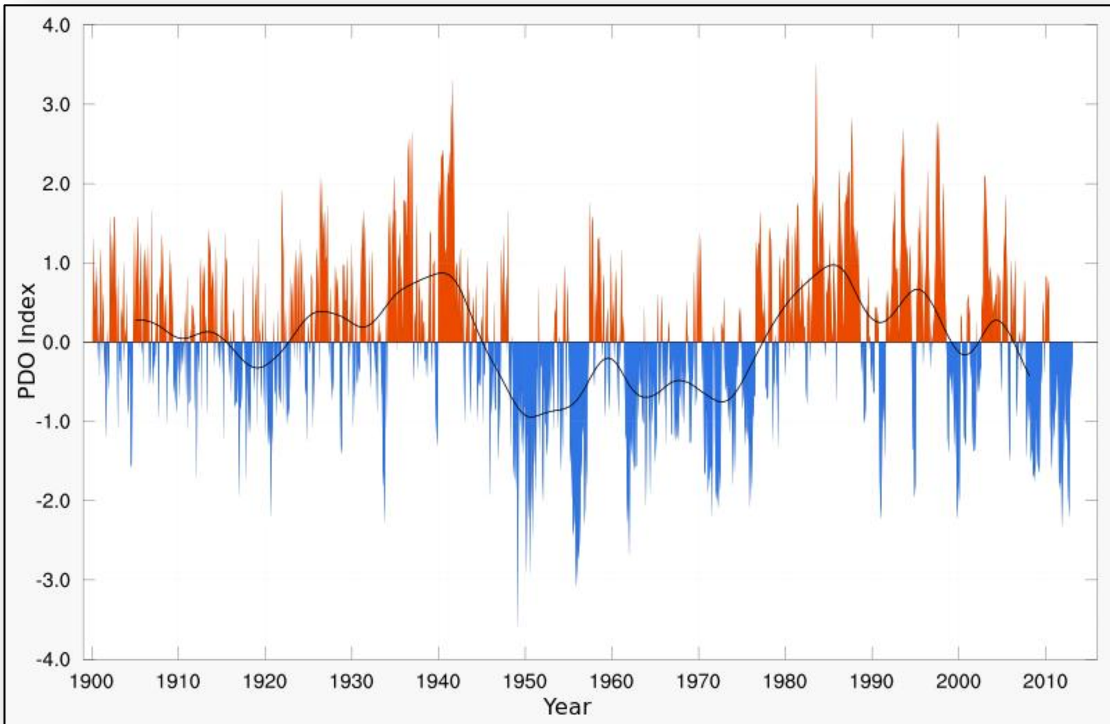
Nursery habitat - a subset of all habitats where juveniles of a species occur, having a greater level of productivity per unit area than other juvenile habitats.

Ocean-type - salmon that spend only a brief period (weeks to several months) rearing in freshwater before they migrate to seawater, as contrasted to “stream-type” salmon that spend at least one winter in freshwater.

Off-channel habitat - a relatively calm portion of a stream outside of the main flow such as a side channel, slough, dead-end channel, or wetland.

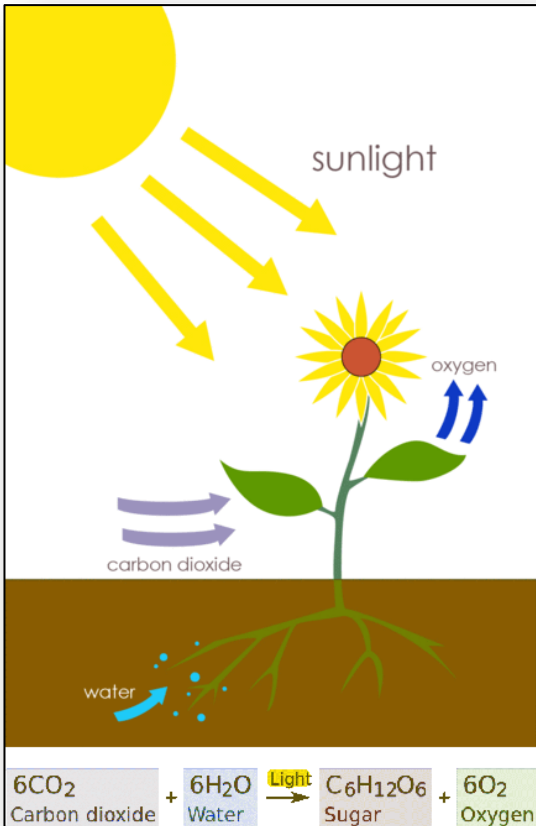
Outmigration - the downstream migration of fish toward the ocean.

Pacific decadal oscillation (**PDO**) - a pattern of change in the Pacific Ocean's climate. The PDO is detected as warm or cool surface waters in the Pacific Ocean, north of 20°N. During a "warm", or "positive", phase, the west Pacific becomes cool and part of the eastern ocean warms; during a "cool" or "negative" phase, the opposite pattern occurs. It shifts phases on at a least inter-decadal time scale, usually about 20 to 30 years (see figure below from Wikipedia [2013b]).

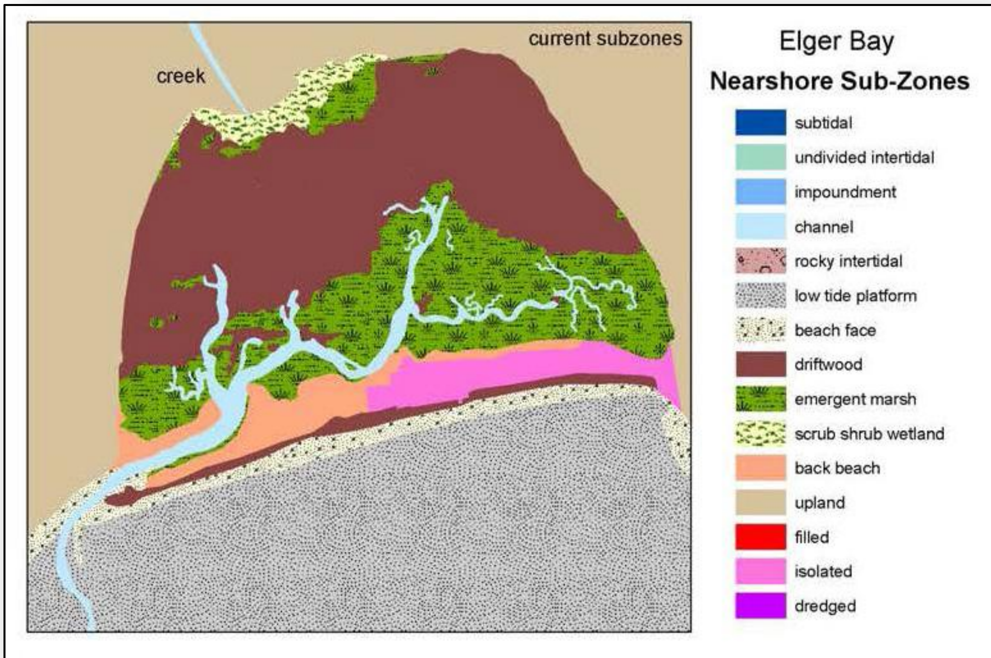


Pelagic - residing in the water column rather than near the bottom or shoreline in the sea (see neritic).

Photosynthesis - the process in green plants and certain other organisms by which carbohydrates are synthesized from carbon dioxide and water using light as an energy source. Most forms of photosynthesis release oxygen as a byproduct (see figure below from Wikipedia [2013c]).



Pocket estuary - a shoreline feature created by small to mid-scale (as compared to large river deltas) interactions between marine and fresh water at low elevations along the shoreline. These features appear similar to large river deltas in that pocket estuaries usually contain emergent marsh, sand or mudflats, a channel structure, uplands and open water in close proximity. However, pocket estuaries may or may not contain freshwater input (see figure below from Beamer *et al*. [2006]).



Population - a group of fish that is genetically self-sustaining and isolated geographically or temporally during reproduction.

Predation - consumption of a fish by another larger fish or other animal. Also consumption of smaller organisms by fish.

Primary production - production of organic compounds from carbon through photosynthesis.

Range - the geographical area within which that species can be found.

Red-listed species - species in BC that have been legally designated as Endangered or Threatened under the BC provincial *Wildlife Act*, are extirpated , or are candidates for such designation.

Redd - the nest formed by a spawning female salmon as it digs in a small area of the stream bottom with its tail to form several depressions (egg pockets) in which eggs are deposited.

Reach - any specific section of a stream's or shoreline's length that is usually identified by geographic barriers or unique characteristics.

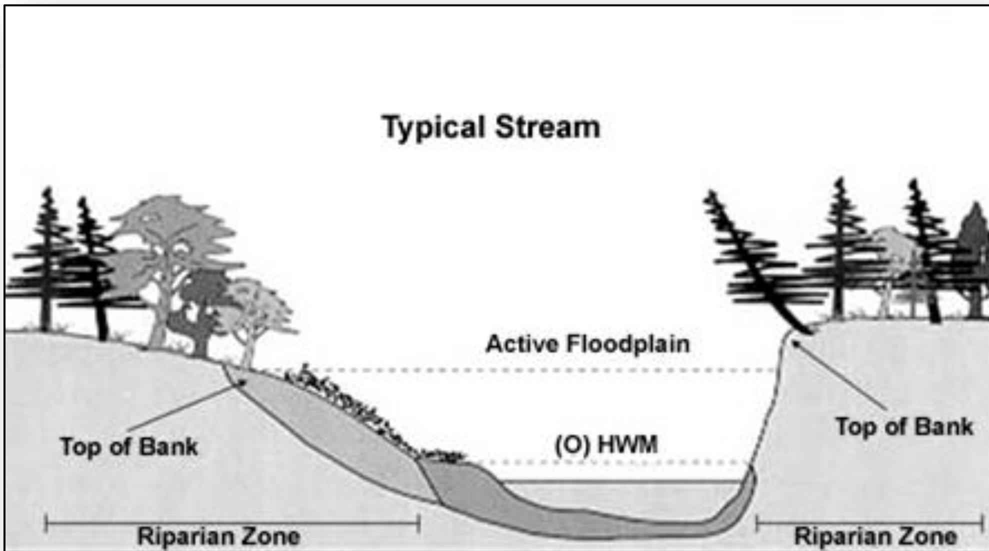
Rearing habitat - habitat favored by juvenile salmonids for growth and development before migrating to sea. Generally characterized by shady pools and quiet water, ponds, and sloughs.

Refugia - areas that have escaped ecological changes occurring elsewhere and so provide suitable habitat for relict species. They may also be areas in which a population of organisms can survive through a period of unfavourable conditions.

Relict species - an organism or species of an earlier time surviving in an environment that has undergone considerable change.

Resident salmonid species - salmonid species that spend their entire lives in freshwater with no migration to marine waters.

Riparian zone - that portion of the land adjacent to a stream or body of fresh or salt water; provides a transition zone between the water and upland habitat (see figure below from DFO [2013c]).



Riprap - large rocks, broken concrete, or other structure used to stabilize stream banks, shorelines, and other slopes.

Riverine - pertaining to river or stream systems.

Run - the sum of stocks of a single salmonid species that migrate to a particular region, river, or stream of origin at a particular season.

Salmonid - any fish of the taxonomic family Salmonidae, including salmon, trout, char, whitefish, and grayling.

Sand - a naturally occurring granular material composed of finely divided rock and mineral particles ranging in diameter from 0.0625 mm to 2 mm.

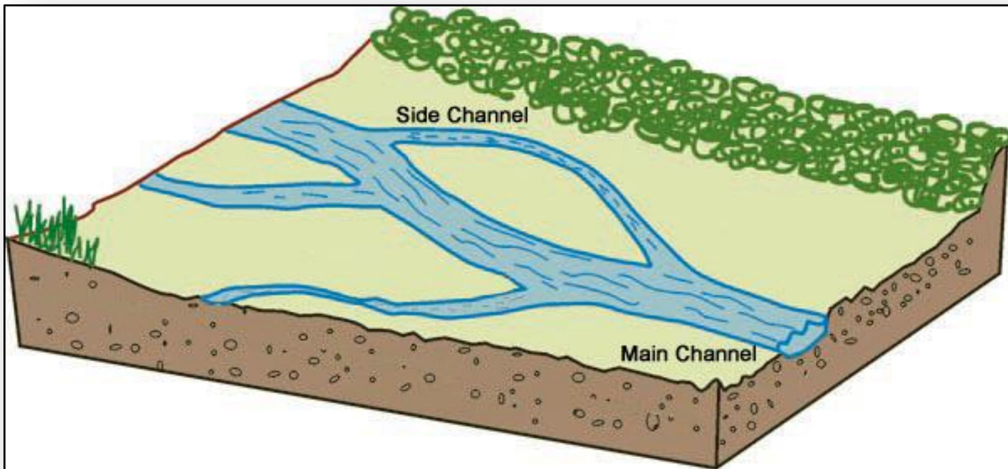
Secondary production - the generation of biomass of heterotrophic (consumer) organisms in a system.

Sediment - solid fragmented material, such as silt, sand, gravel, chemical precipitates, and fossil fragments, that is transported and deposited by water, ice, or wind or that accumulates through chemical precipitation or secretion by organisms, and that forms layers on the Earth's surface.

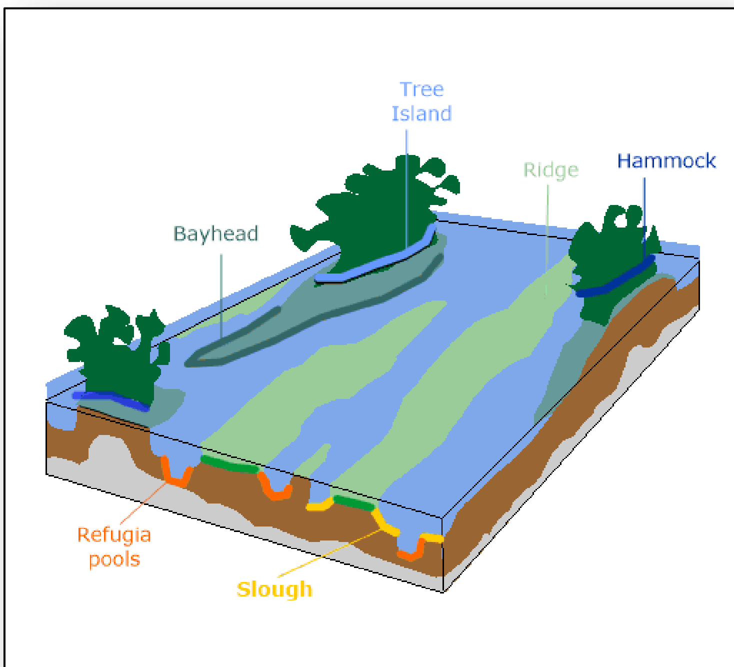
Sensitive habitat - a habitat that is at-risk or ecologically fragile. Sensitive habitats may provide critical habitat for species at risk, may contain rare species of plants and animals, are often biologically diverse, and may provide wildlife corridors and linkages.

Shoal - a sandbank or sand bar in the bed of a body of water, especially one that is exposed above the surface of the water at low tide (see tidal channel).

Side channel - a channel that typically runs parallel to the main channel, but is still connected. Characterized by lower flows than the main channel.



Slough - a place of deep mud, usually an inlet from a river; a section of abandoned stream channel containing water during all or part of the year. Often a creek in a marsh or tide flat (see figure below from Go Hydrology! a watershed journal [2013]).



Smolt - a life stage of salmon that is undergoing or has completed the physiological transition that allows it to live in seawater. Commonly involves changes in body form to a slightly more streamlined form and silvery body coloration.

Spawning - the production and deposition of eggs by aquatic animals. May also include the act of nest (redd) construction and egg fertilization.

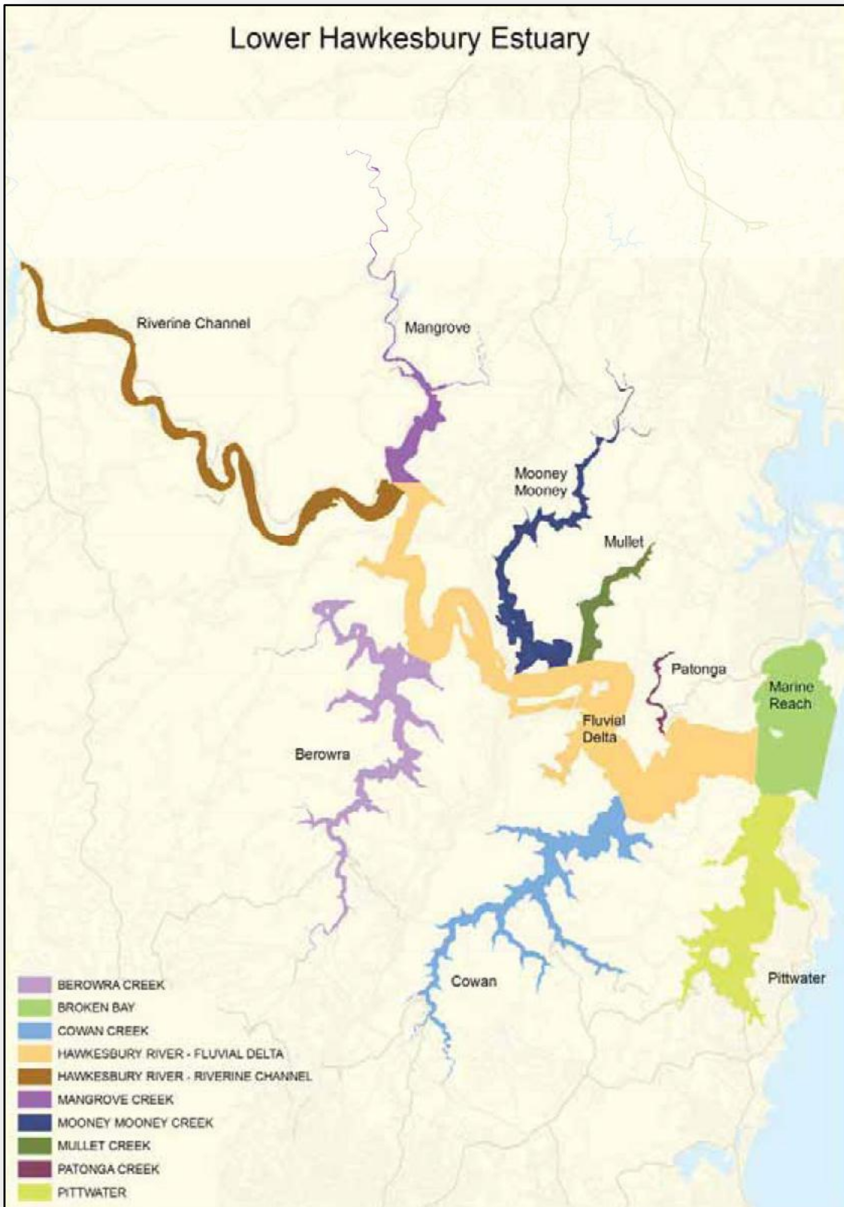
Spawning areas - those areas in the freshwater system which are used for egg laying by salmonids.

Spawning channel - an artificial gravel-bed area in which flow, depth and velocity are controlled at ideal levels for spawning by a particular species of salmon or steelhead.

Stream-type - salmon that rear for approximately a year or more in freshwater prior to migrating to seawater, as contrasted to "ocean-type" salmon.

Stock - subpopulations of a particular species of fish for which intrinsic parameters (growth, recruitment, mortality and fishing mortality) are the only significant factors in determining population dynamics, while extrinsic factors (immigration and emigration) are considered to be insignificant.

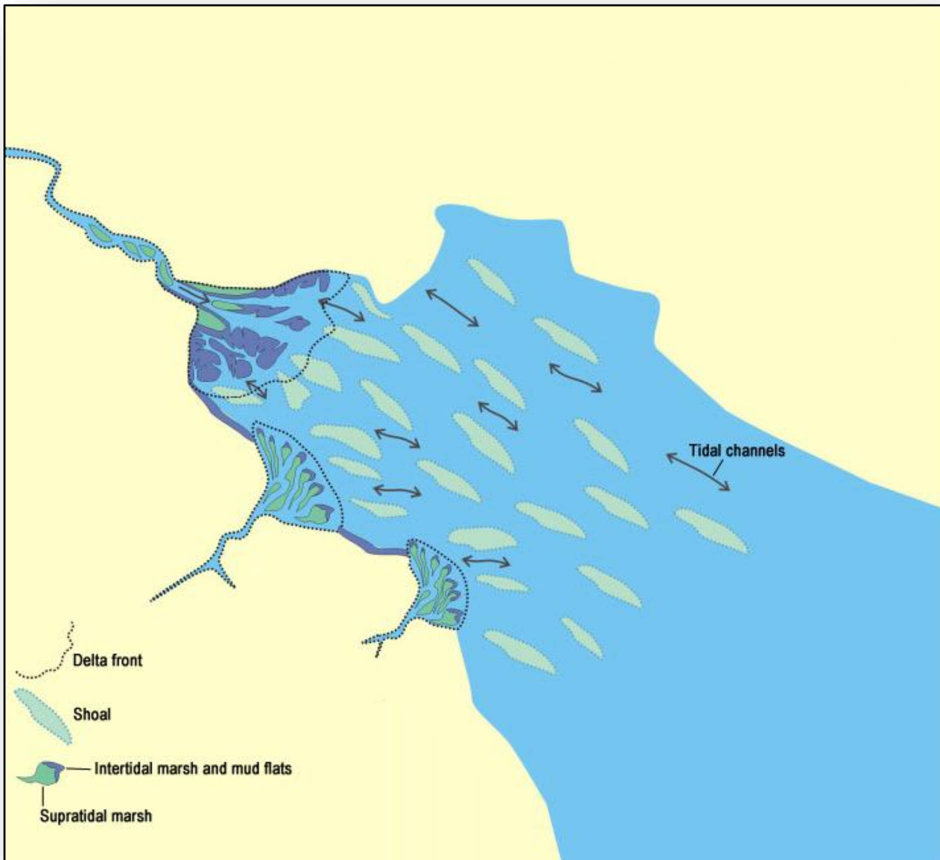
Subestuary - a tidal creek or smaller estuary that branches off the stem of the main estuary, and which consists of the lower portion of a river or stream from the upper extent of tidal influence to the outer edge of its delta (see figure below from Astles *et al*. [2010] which shows a major estuary subdivided into its subestuaries).



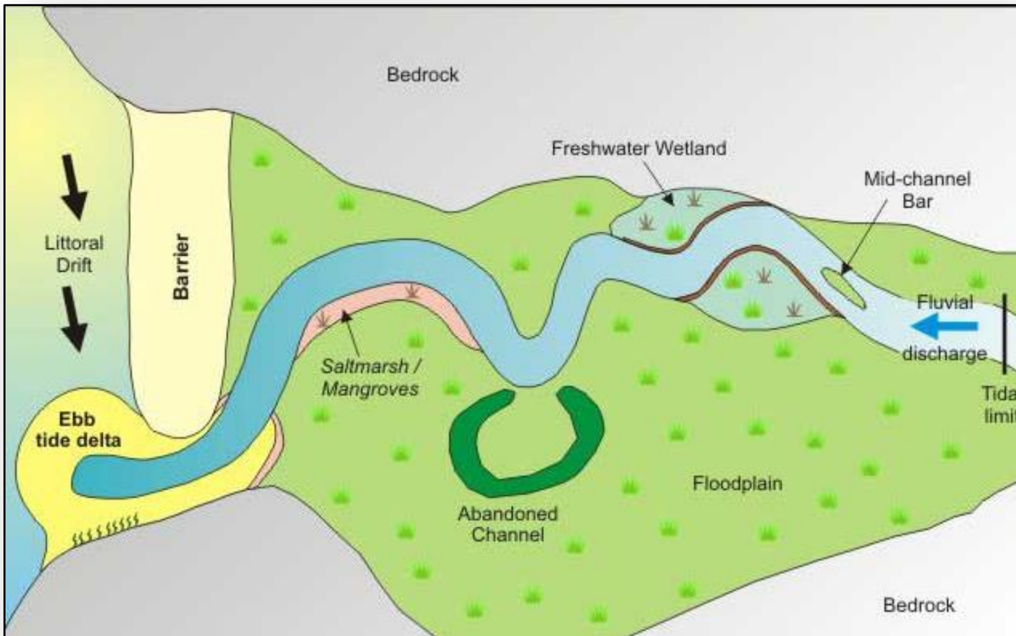
Substrate - mineral and organic material that forms a streambed or a sea bed. Surface upon which an organism lives.

Subyearling - a developmental life stage of fish that are less than one year old.

Tidal channel - a major channel followed by tidal currents, extending from the ocean into a tidal marsh or tidal flat (see figure below).

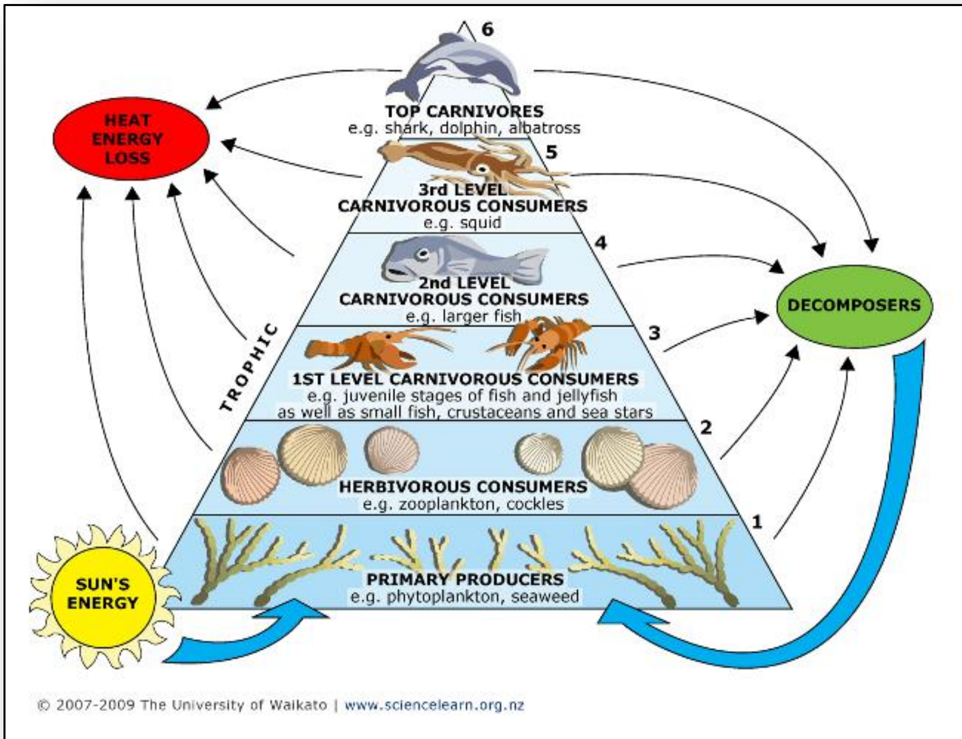


Tidal creek - a creek that is affected by ebb and flow of ocean tides. Thus it has variable salinity over the tidal cycle. There are unique, often specialized, biota associated with tidal creeks. Tidal creeks may often dry to a muddy channel with little or no flow at low tide, but often with significant depth of water at high tide (see figure below from OzCoast [2013]).



Tributary - a stream feeding a larger stream or lake (see basin).

Trophic pathway - the pathway along which energy flows in a food chain from the bottom trophic, or feeding level, to the top trophic, or feeding, level (see figure below from Science Learning [2013]).



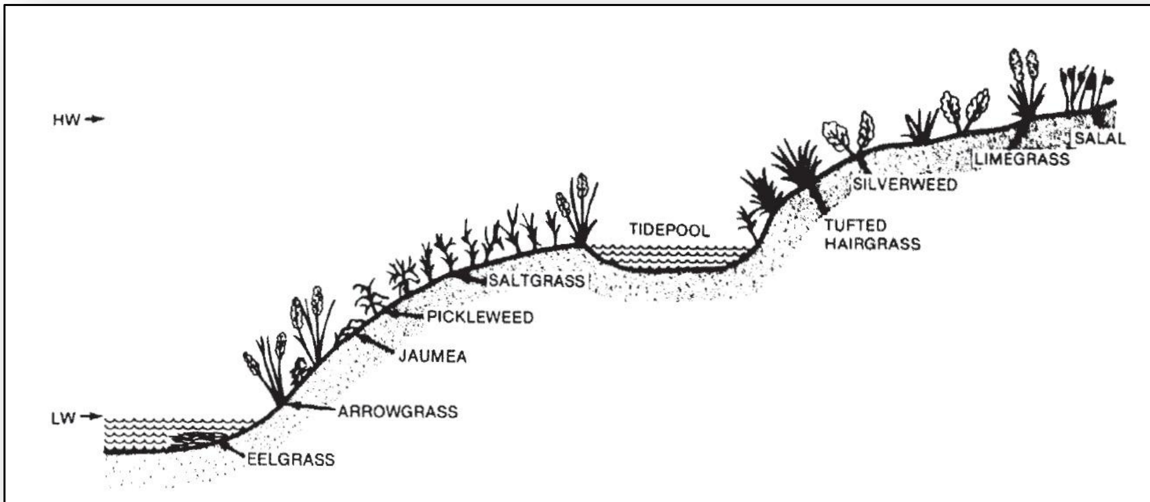
Turbidity - relative water clarity measured by the extent which light passing through water is reduced by suspended and dissolved materials.

Vulnerability - the degree to which a species or habitat is susceptible to, or unable to cope with, the adverse effects of climate change, hazards, or other disturbances.

Yellow-listed species - species in BC which are uncommon, common, declining or increasing - all species not included on the BC Red or Blue lists.

Watershed - the total land area that drains to any single river or stream. Also known as a basin or catchment. The term watershed may also apply to the border between two drainage basins (see basin).

Wetland - a low-lying area of land that is saturated with moisture, either permanently or seasonally, such that it takes on the characteristics of a distinct ecosystem. The main factor that distinguishes wetlands from other land forms or water bodies is the characteristic vegetation that is adapted to its unique soil conditions. Marshes, swamps, bogs, and fens are examples of wetlands. Wetlands may support both aquatic and terrestrial species (see figure below from Seliskar and Gallagher [1983] which shows the profile of a tidal marsh).



Wild stock - a group of fish from a watershed that have continuously spawned naturally, and have not been intermixed with a hatchery population.

Wintering - spending the winter in a particular place.

Yearling - a fish that has lived more than one year and is in its second year of life.

8 References Cited

Ahrens, R. N. M. 2005. The status of steelhead trout (*Oncorhynchus mykiss*) in British Columbia. Prepared for Pacific Fisheries Resource Conservation Council. Vancouver, B.C. p 384. ftp://ftpfsh.env.gov.bc.ca/pub/outgoing/wsLite/ahrens/Ahrens%2004/MWALP%20Steelhead/Documents/Status%20of%20Steelhead%20Trout.doc.

Aitken, J. K. 1998. The importance of estuarine habitats to anadromous salmonids of the Pacific Northwest: a literature review. U.S. Fish and Wildlife Service, Lacey, Washington. 25 pp. http://www.fws.gov/wafwo/fisheries/Publications/FP005.pdf.

Archipelago Marine Research Ltd. 1999. Prince Rupert Harbour Foreshore Habitat Classification and Proposed Development Study.

Ardron, J. 2003. BC Coast Information Team Marine Ecosystem Spatial Analysis, v. 1.2. Excerpted and revised from: Rumsey, C., Ardron, J., Ciruna, K., Curtis, T., Doyle, F., Ferdana, Z., Hamilton, T., Heinemyer, K., Iachetti, P., Jeo, R., Kaiser, G., Narver, D., Noss, R., Sizemore, D., Tautz, A., Tingey, R., Vance-Borland, K. An ecosystem analysis for Haida Gwaii, Central Coast, and North Coast British Columbia. DRAFT, Sept. 22, 2003. 184 pages.

Astles, K., West, G., Creese, R.G. 2010. Estuarine habitat mapping and geomorphic characterisation of the Lower Hawkesbury river and Pittwater estuaries. Industry & Investment NSW - Fisheries Final Report Series No. 117. Cronulla, NSW, Australia. 229pp. http://www.hornsby.nsw.gov.au/media/documents/environment-and-waste/water-catchments/estuary-management/reports/estuarine-health-surveys/Estuarine-habitat-mapping.pdf.

Bakun, A. 1996. Patterns in the Ocean. Ocean Processes and Marine Population Dynamics. California Sea Grant College System. University of California. La Jolla, CA. 323p.

Bard, S. 1998. A biological index to predict pulp mill pollution levels. Water Environmental Research Journal, 70(1): 108-122. http://www.ecotoxicology.ca/Publications/Pulp%20Mill%20Index.pdf.

Bax, N.J. 1982. Seasonal and annual variations in the movement of juvenile chum salmon through Hood Canal, Washington. Pages 208-218 in Brannon, E. L. and E. O. Salo (eds.) Proceedings of the Salmon and Trout Migratory Behavior Symposium. School of Fisheries, University of Washington, Seattle WA.

BC Eelgrass Inventory Application. 2014. Community Mapping Network. http://cmnmaps.ca/EELGRASS/.

BC Ministry of the Environment (BCMOE). 2006. Estuaries in British Columbia. http://www.env.gov.bc.ca/wld/documents/Estuaries06_20.pdf.

BCMCA. 2014a. Harbour Seal – Haulouts. http://bcmca.ca/datafeatures/eco_mammals_harboursealhaulouts/.

BCMCA. 2014b. Marine Atlas of Pacific Canada. Community Mapping Network (CMN). http://www.cmnmaps.ca/BCMCA/index.html?agree=0.

BCMCA. 2014c. Priority Eelgrass Habitat. http://bcmca.ca/datafeatures/eco_vascplants_priorityeelgrasshabitat/.

BCMCA. 2014d. Eelgrass Bioband. http://bcmca.ca/datafeatures/eco_vascplants_eelgrass_bioband/.

BCMOE (Ministry of Environment) 2006. Alive and Inseparable. British Columbia's Coastal Environment: 2006. http://www.env.gov.bc.ca/soe/archive/reports/bcce06/bcce_report.pdf.

BCMWLAP (British Columbia Ministry of Water, Land and Air Protection). 2004. Criteria for Managing Contaminated Sediment in British Columbia, Technical Appendix. http://www.env.gov.bc.ca/epd/remediation/standards_criteria/pdf/sed_criteria_tech_app.pdf.

Beamer, E., McBride, A., Henderson, R. Wolf, K. 2003. T he importance of non-natal pocket estuaries in Skagit Bay to wild Chinook salmon: an emerging priority for restoration. Skagit River System Cooperative Research Report. PO Box 368. LaConner WA 98257. 9 pages. http://www.cob.org/documents/pw/environment/restoration/pocket-estuary-report-beamer.pdf.

Beamer, E., McBride, A., Henderson, R., Wolf, K. 2003. The importance of non-natal pocket estuaries in Skagit Bay to wild Chinook salmon: an emerging priority for restoration. Unpublished report, Skagit System Cooperative Research Department. LaConner, WA. http://www.cob.org/documents/pw/environment/restoration/pocket-estuary-report-beamer.pdf.

Beamer, E.M., McBride, A., Henderson, R., Griffith, J., Fresh, K., Zackey, T., Wyllie-Echeverria, T., Wolf, K. 2006. Habitat and fish use of pocket estuaries in the Whidbey Basin and north Skagit County bays, 2004 and 2005. Skagit River System Cooperative. http://www.skagitcoop.org/documents/EB2207_Beamer_et_al_2006.pdf.

Beamish, R.J., Neville, C.M. 2001. Predation-based mortality on juvenile salmon in the Strait of Georgia. In: R. Beamish, Y. Ishida, V. Karpenko, P. Livingston, and K. Myers (eds.) Workshop on factors affecting production of juvenile salmon: comparative studies on juvenile salmon ecology between the east and west North Pacific Ocean, NPAFC Tech. Rept.2, pg.11-13. http://www.pac.dfo-mpo.gc.ca/science/people-gens/beamish/PDF_files/npafctechnicalreport2%28Beamish%29.PDF.

Beamish, R.J., Sweeting, R.M., Neville, C.M., Lange, K.L. 2010. Competitive interactions between pink salmon and other juvenile Pacific salmon in the Strait of Georgia. NPAFC Doc. 1284. 26 pp. http://www.npafc.org/new/publications/Documents/PDF%202010/1284%28Canada%29.pdf.

Birtwell, I.K., Nassichuk, M.D., Beune, H. 1987. Underyearling sockeye salmon (*Oncorhynchus nerka*) in the estuary of the Fraser River, p. 25-35. In H.D. Smith, L. Margolis, and C.C. Wood. [ed.] Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96. http://www.sfu.ca/grow/science/resources/1273772321.pdf.

Bollens, S.M., vanden Hooff, R., Butler, M., Cordell, J.R., Frost, B.W. 2010. Feeding ecology of juvenile Pacific salmon (*Oncorhynchus* spp.) in a northeast Pacific fjord: diet, availability of zooplankton, selectivity for prey, and potential competition for prey resources. Fishery Bulletin, 108(4), pp. 393-407. http://fishbull.noaa.gov/1084/bollens.pdf.

Borstad Associates Ltd. 1996. Mapping Intertidal Habitat in Prince Rupert Harbour.

Cameron, W.M. 1948. Fresh Water in Chatham Sound. Fish Resources Bd. Pac. Prog. Report 76:72-75.

Canadian Council of Ministers of the Environment (CCME). 2001. Canadian sediment quality guidelines for the protection of aquatic life: Polychlorinated dioxins and furans (PCDD/Fs). In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg. http://ceqg-rcqe.ccme.ca/download/en/245/.

Capital Regional District (CRD). 2013. Intertidal Zonation. http://www.crd.bc.ca/watersheds/ecosystems/intertidalzonation.htm.

Carr-Harris, C., Moore, J.W. 2013. Juvenile Salmonid Habitat Utilization in the Skeena River Estuary. Earth to Ocean Research Group, Department of Biological Sciences, Simon Fraser University. Prepared for: Skeena Wild Conservation Trust. http://bclnginfo.com/images/uploads/documents/Carr-Harris_JuvenileSalmonidHabitatUtilizationSkeenaEstuary-Nov2013.pdf.

Cederholm, C.J., Johnson, D.H., Bilby, R.E., Dominguez, L.G., Garrett, A.M., Graeber, W.H., Greda, E.L., Kunze, M.D., Marcot, B.G., Palmisano, J.F., Plotnikoff, R.W., Pearcy, W.G., Simenstad, C.A., Trotter, P.C. 2000. Pacific Salmon and Wildlife - Ecological Contexts, Relationships, and Implications for Management. Special Edition Technical Report, Prepared for D.H Johnson an T.A. O'Neil (Managing Directors), Wildlife-Habitat Relationships in Oregon and Washington. Washington Department of Fish and Wildlife, Olympia, Washington. http://wdfw.wa.gov/publications/00063/wdfw00063.pdf.

Christensen, V., Trites, A.W. 2011. Predation on Fraser River sockeye salmon. Cohen Commission Tech. Rept. 8:129p. Vancouver, B.C. http://www.cohencommission.ca/en/pdf/TR/Project8-Report.pdf.

City of Prince Rupert. 1995. Environment: A Background Report for the Prince Rupert Official Community Plan. http://www.princerupert.ca/images/editor/File/Cityplans/2007/OCP/background/Environment%20Report.pdf.

Coastal & Ocean Resources Inc. (CORI). 2000. North Coast 2000 Aerial Video Imaging Survey.

Coastal Wiki. 2013. Definitions of coastal terms. http://www.coastalwiki.org/wiki/definitions_of_coastal_terms.

Conway, K W, Bornhold, B D, Barrie, J V. 1996. Surficial geology and sedimentary processes, Skeena River delta, British Columbia. In Current Research / Recherches en cours; Geological Survey of Canada. Geological Survey of Canada, Current Research no. 1996-E, p. 23-32. http://ftp2.cits.rncan.gc.ca/pub/geott/ess_pubs/207/207866/cr_1996_e.pdf.

Cummins, P., Haigh, R. 2010. Ecosystem Status and Trends Report for North Coast and Hecate Strait ecozone. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/045. vi + 61 p. http://publications.gc.ca/collections/collection_2011/mpo-dfo/Fs70-5-2010-045.pdf.

DataBC Geo. 2006. BC Historical Fish Distribution - Zones (50,000). https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=47234&recordSet=ISO19115.

DataBC Geo. 2008a. Freshwater Atlas Obstructions. https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50645&recordSet=ISO19115.

DataBC Geo. 2008b. Freshwater Atlas Stream Network. https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50648&recordSet=ISO19115.

DataBC Geo. 2008c. Freshwater Atlas Watersheds. https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50652&recordSet=ISO19115.

De Groot, Adrian. 2005. Review of the Hydrology, Geomorphology, Ecology and Management of the Skeena River Floodplain. Drosera Ecological Consulting. Prepared for the Bulkley Valley Centre for Natural Resources. http://www.bvcentre.ca/files/research_reports/04-03SkeenaIslandsReview.pdf.

De Raedemaecker, F. 2004. A GIS-approach to compare intertidal diversity and contaminant loading in the marine receiving environment of two pulp mills in British Columbia, Canada Thesis Universiteit Gent/MareLac: Gent. 23 pp. http://www.ecotoxicology.ca/csi/FienThesis.pdf.

DFO. 2000. Guidelines for the in-stream placement of hatchery carcasses. http://www.pac.dfo-mpo.gc.ca/publications/pdfs/carcass-carcasse-guide-eng.pdf.

DFO. 2005. Canada's policy for conservation of wild pacific salmon. ISBN 0-662-40538-2. http://www.pac.dfo-mpo.gc.ca/publications/pdfs/wsp-eng.pdf.

DFO. 2010a. 2009 post season review salmon North Coast areas 1-6 & Central Coast areas 7-10. Fisheries and Oceans Canada, Vancouver, BC. 106. http://www.cec.org/Storage/91/8880_09-5-ARSP-Annex_11_2009_Post_Season_Review_Salmon.pdf.

DFO. 2010b. Population Assessment Pacific Harbour Seal (Phoca vitulina richardsi). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/011. http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/SAR-AS/2009/2009_011_e.pdf.

DFO. 2011. North Coast Salmon IFMP Post Season Production Tables - 2011 Brood. http://www.pac.dfo-mpo.gc.ca/sep-pmvs/data-donnees/IFMPPostSeasonNorth.xls.

DFO. 2012. North Coast Salmon IFMP Target Tables - 2013. http://www.pac.dfo-mpo.gc.ca/sep-pmvs/data-donnees/IFMPTargetNorth.xls.

DFO. 2013a. 2012 post season review salmon North Coast areas 1-6 & Central Coast areas 7-10. Fisheries and Oceans Canada, Vancouver, BC. 180. http://steelheadalliance.com/wp-content/uploads/2012/12/2012-Salmon-Post-Season-Review-Booklet-Areas-1-6-final.pdf.

DFO. 2013b. Saanich Inlet. http://www.pac.dfo-mpo.gc.ca/science/oceans/BCinlets/saanich-eng.htm.

DFO. 2013c. Pacific Region's Habitat Definitions. http://www.pac.dfo-mpo.gc.ca/habitat/Glossary-glossaire-eng.htm.

DFO. 2013d. Background: Pacific Herring. http://www.pac.dfo-mpo.gc.ca/science/species-especes/pelagic-pelagique/herring-hareng/hertags/pages/indicator-eng.htm.

DFO. 2014. Mapster v3.1. http://pacgis01.dfo-mpo.gc.ca/Mapster30/#/SilverMapster.

DMMP, 2010. Dredged Material Management Program New Interim Guidelines for Dioxins. December 6, 2010.
http://www.nws.usace.army.mil/Portals/27/docs/civilworks/dredging/Updates/2010-New_Interim_Guidelines_for_dioxin.pdf.

Duffy, E.J., Beauchamp, D.A.. 2008. Seasonal patterns of predation on juvenile Pacific salmon by anadromous cutthroat trout in Puget Sound. Trans. Am. Fish. Soc. 137(1): 165-181. http://weber.s.uw.edu/research/publications/ms_phd/Duffy_E_PhD_W09.pdf.

Earth System Science Education Alliance (ESSEA). 2013. Where Did My Beach Go? http://essea.strategies.org/module.php?module_id=117.

E-Fauna BC. 2014. http://www.geog.ubc.ca/biodiversity/efauna/.

Environment Canada (EC). 2005. Site-specific Water Quality Guidelines for the Skeena River at Usk for the purpose of national reporting. Tri-Star Environmental Consulting. http://waterquality.ec.gc.ca/WaterQualityWeb/PDFDocs/BC08EF0001%20-%20skeena%20at%20usk.pdf.

Environment Canada (EC). 2014a. Hydrometric Data. Daily Discharge for Skeena River at Usk. http://www.wsc.ec.gc.ca/applications/H2O/graph-eng.cfm?station=08EF001&report=daily&year=2012.

Environment Canada (EC). 2014b. Hydrometric Data. Daily Discharge for Nass River above Shumal Creek. http://www.wsc.ec.gc.ca/applications/H2O/graph-eng.cfm?station=08DB001&report=daily&year=2012.

Faggetter, B.A. 2008. Review of the Environmental and Socio-economic Impacts of Marine Pollution in the North and Central Coast Regions of British Columbia. Funded by and produced for the North Coast-Skeena First Nations Stewardship Society. http://www.oceanecology.ca/publications/Marine_pollution_report.htm.

Faggetter, B.A. 2012. Potential Impacts of Oil on Plankton and the Planktonic Larvae of Commercial Fisheries Species. Prepared for the United Fishermen and Allied Workers' Union - CAW. https://docs.neb-one.gc.ca/ll-eng/llisapi.dll/fetch/2000/90464/90552/384192/620327/624910/697824/781942/United_Fishermen_and_Allied_Workers%27_Union_-CAW_-_UFAWU-CAW_2.3_Faggetter_Oil_on_Plankton_-_A2K9X2?nodeid=781863&vernum=0.

Faggetter, B.A. 2013. Chatham Sound Eelgrass Study Final Report. Prepared for WWF. http://www.oceanecology.ca/publications/Chatham Sound Eelgrass Study Final Report.htm.

Forsyth, F., Borstad, G., Horniak, W., & Brown, L. 1998. Prince Rupert intertidal habitat inventory project. Unpublished report to the Prince Rupert Port Corporation, the Canadian Department of Fisheries and Oceans, and the City of Prince Rupert. 33 pp.

Fresh, K.L. 2006. Juvenile Pacific Salmon in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington. http://www.pugetsoundnearshore.org/technical_papers/pacjuv_salmon.pdf.

Gardner J, Peterson DL, Wood A, Maloney V. 2004. Making Sense of the Debate about Hatchery Impacts: Interactions Between Enhanced and Wild Salmon on Canada's Pacific Coast. Vancouver, BC: Prepared for the Pacific Fisheries Resource Conservation Council. http://www.fish.bc.ca/files/HatcheryDebate_2004_0_Complete.pdf.

Go Hydrology! a watershed journal. 2013. Glades. http://www.gohydrology.org/p/glades.html.

Gottesfeld, A.S., Carr-Harris, C., Proctor, B., Rolston, D. 2008. Sockeye Salmon Juveniles in Chatham Sound 2007. Pacific Salmon Forum, July. http://skeenafisheries.ca/pdfs/pub_sx_juv_chtm_snd.pdf.

Gottesfeld, A.S, Rabnett, K.A. 2007. Skeena Fish Populations and Their Habitat. Skeena Fisheries Commission. http://www.dfo-mpo.gc.ca/Library/327687.pdf.

Gottesfeld, A.S, Rabnett, K.A. 2008. Skeena River Fish And Their Habitat. Ecotrust, Portland, OR. Oregon. State. University Press.

Gregory, R.S., Levings, C. 1998. Turbidity reduces predation on migrating juvenile Pacific salmon. Transactions of the American Fisheries Society 127:275-285. http://www.swrcb.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/exhibits/dwr/dwr_exh9.pdf.

Hagen, M.E. and A.G. Colodey. 1995. Environmental response to decreased dioxin and furan loadings from British Columbia coastal pulp mills. Dioxins '95 International Conference, Edmonton, Alberta, August 21-25, 1995. Vol. 24, pp. 251-256. http://www.cohencommission.ca/DownloadExhibit.php?ExhibitID=1099.

Harding, L. and Goyette, D. 1989. Metals in northeast Pacific coastal sediments and fish, shrimp, and prawn tissues. Marine Pollution Bulletin 20: 187-189.

Haring, D. 1999. Salmon and Steelhead Habitat Limiting Factors – Water Resource Inventory Area 18 – Final Report. Washington State Conservation Commission, Lacey, WA. http://www.pugetsoundnearshore.org/supporting_documents/wria_18_salmonid_habitat_lfa_report.pdf.

Harrison, P.J., Clifford, P.J., Cochlan, W.P., Yin, K., St. John, M.A., Thompson, P.A., Sibbald, M.J., Albright, L.J. 1991. Nutrient and plankton dynamics in the Fraser River plume, Strait of Georgia, British Columbia. Mar. Ecol. Prog. Ser. 70: 291-304. http://www.int-res.com/articles/meps/70/m070p291.pdf.

Hart, J.L. 1973. Pacific Fishes of Canada. Fisheries Research Board of Canada Bulletin 180.

Harvey, B., MacDuffee, M. 2002. Ghost Runs: The future of wild salmon on the north and central coasts of British Columbia. Raincoast Conservation Society. Victoria, BC. http://www.raincoast.org/files/publications/reports/ghost-runs/ghostruns-1.pdf.

Hatfield Consultants Limited. 1994. Skeena Cellulose Environmental Effects Monitoring (EEM): Pre-design Reference Document. Skeena Cellulose Inc.

Hay, D., McCarter, P.B. 2000. Status of Eulachon *Thaleichthys pacificus* in Canada. Fisheries and Oceans Canada, Ottawa Ont. http://www.arlis.org/docs/vol1/76837410.pdf.

Hay, D., McCarter, P.B. 2013. Herring Spawn Areas of British Columbia: A review, geographic analysis and classification. Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, British Columbia. Revised edition: 2013. http://www.pac.dfo-mpo.gc.ca/science/species-especes/pelagic-pelagique/herring-hareng/hertags/pdf/project-eng.pdf.

Healey, M.C. 1979. Detritus and juvenile salmon production in the Nanaimo Estuary: I. Production and feeding rates of juvenile chum salmon (*Oncorhynchus keta*). Journal of the Fisheries Research Board of Canada 36:488-496.

Healey, M.C. 1982. Juvenile Pacific salmon in estuaries: the life support system. In Estuarine Comparisons. Edited by V.S. Kennedy. Academic Press. pp. 343-364.

Higgins, R.J. & Schouwenburg, W.J. 1973. A biological assessment of fish utilization of the Skeena River estuary, with special reference to port development in Prince Rupert. Dept. of Envir., Fish. & Mar. Ser. Tech. Rep. 1973-1.

Hinchingbrooke. 2013. Rivers. http://www.hinchingbrookeschool.co.uk/geography/OCRBRiversandCoasts.htm.

Hirschi, R., Labbe, T., Carter-Mortimer, A. 2003. Shoreline alterations in Hood Canal and the eastern Strait of Juan de Fuca. Unpublished report. Point No Point Treaty Council. Kingston, WA. http://www.pnptc.org/PNPTC_Web_data/Publications/habitat/PNPTC_Shoreline_Alterations_Report.pdf.

Hiss, J.M., Boomer, R.S. 1986. Feeding ecology of juvenile Pacific salmonids in estuaries: a review of the recent literature. Fisheries Assistance Office, U.S. Fish and Wildlife Service, Olympia, Washington. http://www.fws.gov/wafwo/fisheries/Publications/FP059.pdf.

Hoos, L.M. 1975. The Skeena River estuary status of environmental knowledge to 1975. Special Estuary Series No. 3. Environment Canada, Vancouver, BC, 418 pp. http://ecoreserves.bc.ca/wp-content/uploads/2012/06/skeena_river_estuary_status_of_environmental_knowledge.pdf.

Independent Multidisciplinary Science Team. 1998. Pinniped and Seabird Predation: Implications for Recovery of Threatened Stocks of Salmonids in Oregon Under the Oregon Plan for Salmon and Watersheds. Technical Report 1998-2 to the Oregon Plan for Salmon and Watersheds. Governor's Natural Resources Office. Salem, Oregon. http://www.fsl.orst.edu/imst/reports/1998-2.pdf.

Johnson, O.W., Grant, W.S., Kope, R.G., Neely, K., Waknitz, F.W., Waples, R.S. 1997. Status review of chum salmon from Washington, Oregon, and California. U.S. Dept. Commerce, NOAA Technical Memorandum. NMFS-NWFSC-32. 280 p. http://www.nwfsc.noaa.gov/assets/25/4235_06172004_120642_chum.pdf.

Korman, J., English, K. 2013. Benchmark Analysis for Pacific Salmon Conservation Units in the Skeena Watershed. Prepared for the Pacific Salmon Foundation. http://skeenasalmonprogram.ca/library/lib_318/.

Lestelle, L.C,. Blair, G.R., Mobrand, L.E., Todd, S.W. 2005. Rules and Concepts for Modeling Estuarine and Marine Habitat Effects: Summer and Fall Chum Salmon in Hood Canal and the Strait of Juan de Fuca. Mobrand Biometrics, Inc. http://www.nwr.noaa.gov/publications/recovery_planning/salmon_steelhead/domains/puget_sound/chum/hcc_app_b.pdf.

Levings, C.D. 1992. Estuarine science and management needed to maintain Pacific salmon production. Changes in Fluxes in Estuaries: Implications From Science to Management. Dyner, K.R., R.J. Orth, (eds.) Fredensborg, Denmark Olsen and Olsen 1994. pp. 417-421. http://www.robertsbankterminal2.com/wp-content/uploads/Estuarine-science-and-management-needed-to-maintain-Pacific-Salmon-production-1994.pdf.

Levings, C.D., Jamieson, G. 2001. Marine and estuarine riparian habitats and their role in coastal ecosystems, Pacific Region. Canadian Science Advisory Secretariat, Research document 2001/109. http://www.co.san-juan.wa.us/cdp/docs/CAO/MarineRiparianHabitats%28LevingsJamieson2001%29.pdf.

Lewis, A. 2001. Eulachon Conservation Society. Eulachon: Status, threats and research needs. Bulletin No. 1. February 2001.

Library and Archives Canada. 2014a. British Columbia. Prince Rupert Harbour and southern approaches [cartographic material]: from a chart published by the Department of Marine and Fisheries of Canada, Ottawa, October 1909/surveyed by Messrs. G.B. Dodge and P.C. Musgrave, assisted by Messrs. H.D. Parizeau and L.R. Davies, under the orders of the government of the Dominion of Canada, 1906-7. www.collectionscanada.gc.ca.

Library and Archives Canada. 2014b. British Columbia. Browning Entrance to Prince Rupert Harbour [cartographic material]/surveyed by Captain J.F.Parry R.N., assisted by Lieuts. J.D. Nares, O.T. Hodgson, J.H. Nankivell, E.A. Gore-Langton, A.E.S. Grant, A.C. Bell & C.P. Chearnley, H.M. Surveying Ship 'Egeria', 1907-9. www.collectionscanada.gc.ca.

MacDonald, D.D., Smorong, D.E., Lindskoog, R.A., Ingersoll, C.G. 2003. Development and evaluation of sediment quality criteria for managing contaminated sediments in British Columbia. Environmental Protection Division. British Columbia Ministry of Water, Land, and Air Protection. Victoria, British Columbia. http://www.env.gov.bc.ca/epd/remediation/standards_criteria/pdf/develop_applicat_sqc_rep_nov19_wma.pdf.

Mackas, D., Galbraith, M., Faust, D. 2010. Zooplankton along the BC continental margin: a spring cool-water crustacean community shifts to a summer and autumn warm-water gelatinous community. Fisheries Oceanography Working Group.

Mackas, D., Peña, A., Johannessen, D., Birch, R., Borg, K., Fissel, D. 2007. Appendix D: Plankton. In Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Edited by Lucas, B.G. Verrin, S., and Brown, R. Can. Tech. Rep. Fish. Aquat. Sci. 2667: iv + 33p. http://www.pncima.org/media/documents/pncima-publications/pncima_eoar_328842_d_plankton.pdf.

Magnhagen, C., Northcote, T.G., Gregory, R.S. 2007. Diet differentiation in three species of juvenile Pacific salmon (*Oncorhynchus* spp.) in estuarine tidal channels and laboratory experiments. Can. Tech. Rep. Fish. Aquat. Sci. 2758: vi + 20 p. http://www.dfo-mpo.gc.ca/Library/331362.pdf.

McGreer, E.R., Delaney, P.W., Vigers, G.A., McDonald, J.W., Owens, E.H. 1980. Review of oceanographic data relating to ocean dumping in the Prince Rupert area with comments on present and alternate dumpsites. Prepared for Dept. of Fisheries and Oceans, Institute of Ocean Sciences, Sidney, B.C. 81 p. http://www.dfo-mpo.gc.ca/Library/316051.pdf.

Morrell, M. 2000. Status of Salmon Spawning Stocks of the Skeena River System. Prepared for the Northwest Institute for Bioregional Research. http://northwestinstitute.ca/images/uploads/salmon_report_00.pdf.

Murphy, M. L., J. F. Thedinga, and K. V. Koski. 1988. Size and diet of juvenile Pacific salmon during seaward migration through a small estuary in southeastern Alaska. Fishery Bulletin 86:213–222. http://fishbull.noaa.gov/862/murphy.pdf.

Naish, K.A., Taylor, J.E. III, Levin, P.S., Quinn, T.P., Winton, J.R., Huppert, D., Hilborn, R. 2008. An Evaluation of the Effects of Conservation and Fishery Enhancement Hatcheries on Wild Populations of Salmon. Advances in Marine Biology, Volume 53. http://fish.washington.edu/research/alaska/publications/ASP_Papers/Naish et al 2007 Advances in Mar Bio salmon hatcheries.pdf.

Northcoast Environmental Analysis Team (NEAT). 1975. Federal-Provincial Joint Committee on Tsimpsean Peninsula Port Development. Northcoast Environmental Analysis Team, B.R. Hinton & Associates. Volumes 1 through 6.

North Coast Watershed Atlas. 2014. Community Mapping Network. http://cmnmaps.ca/NORTHCOAST/.

Northcote, T.G., Gregory, R.S., Magnhagen, C. 2007. Contrasting space and food use among three species of juvenile Pacific salmon (*Oncorhynchus*) cohabiting tidal marsh channels of a large estuary. Can. Tech. Rep. Fish. Aquat. Sci. 2759: vi + 24 p. http://www.dfo-mpo.gc.ca/Library/331363.pdf.

Oldfield Creek Fish Hatchery. 2014. https://www.facebook.com/OldfieldCreekFishHatchery.

OzCoast. 2013. Australian Online Coastal Information. Conceptual models of Australian estuaries and coastal waterways. http://www.ozcoasts.gov.au/conceptual_mods/introduction.jsp.

Peard, D.A. 2011. Results of the Kloiya River Resistivity Counter 2011. BC Min. of Environment, Skeena Region, Environmental Sustainability Division, Smithers, BC. http://www.env.gov.bc.ca/skeena/fish/sk_series_reports/sk159.pdf.

Peña, A., Crawford, W. 2004. Phytoplankton Distribution in the Queen Charlotte Basin: Regions of High Productivity. PICES 13th Annual Meeting, October 14-24, 2004. North Pacific Marine Science Organization (PICES). Honolulu, Hawaii. 87p.

Pomeroy, W.M. 1983. B.C. Timber pulp mill, Porpoise Harbour - an assessment of mill impact on the receiving environment. Environmental Protection Service, Regional Program Report 83-09.

Price, M.H.H. 2013. Sub-lethal metal toxicity effects on salmonids: a review. Report prepared for SkeenaWild Conservation Trust. Smithers, BC. 64p. http://skeenawild.org/images/uploads/docs/Price_2013_Sub-lethal_metal_toxicity_Final.pdf.

Puget Sound Shorelines. 2013. Bulkheads Can Change the Beach. http://www.ecy.wa.gov/programs/sea/pugetsound/building/bulkhead_eff.html.

Quinn, TP. 2005. The behavior and ecology of Pacific salmon and trout. Univ. Press, Seattle. 320p.

Ricker, K.E. 1989. Biophysical suitability of the northern British Columbia coastal waterways for net pen rearing of salmonids. Vol. II, Appendix. Oceanographic data. Prepared for the B.C. Ministry of Agriculture, Fisheries and Food, Aquaculture and Commercial Fisheries Branch. http://www.for.gov.bc.ca/hfd/library/documents/Bib61750.pdf.

Riddell, B. 2004. Pacific salmon resources in central and north coast British Columbia. Pacific Fisheries Resource Conservation Council, Vancouver. http://www.fish.bc.ca/files/SalmonResources-North_2004_0_Complete.pdf.

Riley, S.C., Scheurer, J.A., Mahnken, C.V.W., Blankenship, H.L. 2004. Assessing the potential for predation on wild salmonid fry by hatchery-reared salmonids in Washington. Report to the Hatchery Scientific Review Group, Olympia, WA. http://www.lltk.org/hrp-archive/pdf/hsrg/HSRG_Emerging_Issues_Marine_Predation.pdf.

Ruggerone, G.T., Nielsen, J.L. 2004. Evidence for competitive dominance of pink salmon (*Oncorhynchus gorbuscha*) over other salmonids in the North Pacific Ocean. Reviews in Fish Biology and Fisheries. 14:371-390. http://home.comcast.net/~ruggerone/DominantPinks.pdf.

Salo, E.O. 1991. Life history of chum salmon, *Oncorhynchus keta*. Pages 231-309 in Groot, C., and L. Margolis (eds.), Pacific Salmon Life Histories. UBC Press, Vancouver, B.C., Canada.

Science Learning. 2013. Life in the Sea: Marine trophic pyramid. http://www.sciencelearn.org.nz/Contexts/Life-in-the-Sea/Sci-Media/Images/Marine-trophic-pyramid.

Scott, W.B., Crossman, E.J. 1973. Freshwater Fishes of Canada. Bulletin 184. Fisheries Research Board of Canada. 966 pp.

Seliskar, D.M., Gallagher, J.L. 1983. The ecology of tidal marshes of the Pacific Northwest coast: a community profile. Federal Government Series: FWS/OBS - 82/32. http://www.nwrc.usgs.gov/techrpt/82-32.pdf.

Shaffer, A. 2003. Preferential use of nearshore kelp habitats by juvenile salmon and forage fish. In Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Puget Sound Action Team, Olympia, WA. http://www.caseinlet.org/uploads/SalmonKelp_Shaffer__1_.pdf.

Shaffer, A. 2003. Preferential use of nearshore kelp habitats by juvenile salmon and forage fish. In Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Puget Sound Action Team, Olympia, WA. http://www.caseinlet.org/uploads/SalmonKelp_Shaffer__1_.pdf.

Shaffer, J. A. 1998. Kelp bed habitats of the inland waters of Western Washington. Pages 353-362 In Proceedings of Puget Sound Research '98 Conference, March 12-13. Puget Sound Water Quality Action Team, Olympia, WA. http://blog.pugetsoundinstitute.org/wp-content/uploads/2011/12/PugetSoundResearch1998Vol1.pdf.

Simenstad, C.A. 2000. Estuarine landscape impacts on Hood Canal and Strait of Juan de Fuca summer chum salmon and recommended actions. Appendix Report 3.5, pp. A3.111-A3.132 in J. Ames, G. Graves, and C. Weller (eds.), Summer Chum Salmon Conservation Initiative: An Implementation Plan to Recover Summer Chum in the Hood Canal and Strait of Juan de Fuca Region. Washington Department of Fish and Wildlife and Point-No-Point Treaty Tribes, Olympia, WA. http://wdfw.wa.gov/publications/00155/wdfw00155.pdf.

Simenstad, C.A., Fresh, K.L., Salo, E.O. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: An unappreciated function. Pages 343-364 in Kennedy, V.S (ed.) Estuarine Comparisons. Academic Press, New York, NY.

Simenstad, C.A., Kinney, W.J., Parker, S.S., Salo, E.O., Cordell, J.R., Buechner, H. 1980. Prey community structure and trophic ecology of out-migrating juvenile chum and pink salmon in Hood Canal, Washington: A synthesis of three years' studies, 1977-1979. UW Fish. Res. Inst. no. FRIUW- 8026. University of Washington, Seattle, WA. https://digital.lib.washington.edu/researchworks/bitstream/handle/1773/3961/8026.pdf?sequence=1.

Simenstad, C.A., Wissmar, R.C. 1985. $\delta^{13}C$ evidence of the origins and fates of organic carbon in estuaries and nearshore food webs. Marine Ecology Progress Series 22:141-152. http://www.int-res.com/articles/meps/22/m022p141.pdf.

Singleton, H.J. 1987. Water Quality Criteria for Copper – Technical Appendix. Ministry of Environment and Parks, Water Management Branch, Province of British Columbia. http://www.env.gov.bc.ca/wat/wq/BCguidelines/copper/coppertech.pdf.

Spear, P.A., Pierce, R.C. 1979. Copper in the Aquatic Environment: Chemistry, Distribution and Toxicology. National Research Council Canada No. 16454. Associate Committee on Scientific Criteria for Environmental Quality. Ottawa, Canada. 227p.

Stantec. 2011. Comprehensive Study Report - Canpotex Potash Export Terminal and Ridley Island Road, Rail, and Utility Corridor. Sediment Technical Data Report. http://www.acee-ceaa.gc.ca/050/documents/53479/53479E.pdf.

Stantec. 2012. Comprehensive Study Report: Canpotex Potash Export Terminal and Ridley Island Road, Rail, and Utility Corridor. http://www.ceaa-acee.gc.ca/050/documents/p47632/81285E.pdf.

St. John, M.A., Macdonald, J.S., Harrison, P.J., Beamish, R.J., Choromanski, E. 1992. The Fraser River plume: some preliminary observations on the distribution of juvenile salmon, herring, and their prey. Fisheries Oceanography, Vol.1, pg.153-162. http://www.pac.dfo-mpo.gc.ca/science/people-gens/beamish/PDF_files/st john fraser river fo 1992.pdf.

Stoffels, D. 2001. Eulachon in the North Coast - Background Report. BC Ministry of Sustainable Resource Management - Skeena Region. http://142.36.5.21/northwest/eulachon/resources/NCeulachon.pdf.

Stronach, J. and Zaremba, L. 2002. Wave and current forecast system for the mouth of the Fraser River. Hay and Company Consultants. ftp://ftp.wmo.int/Documents/PublicWeb/amp/mmop/documents/JCOMM-TR/J-TR-34-9th-waves-workshop/Papers/Stronach.pdf.

Stucchi, D.J., Orr, U. 1993. Circulation and Water Property Study of Prince Rupert Harbour, Summer 1992. Can. Tech. Rep. Hydroqr. Ocean ScI. 154: 46p. http://www.dfo-mpo.gc.ca/Library/166692.pdf.

Tera Planning Ltd. 1993. Bulk Liquids Terminal South Kaien Island Prince Rupert, BC: Volume III - Environmental Report. Consultant report for Prince Rupert Port Corporation.

The British Geographer. 2013. River Landforms. http://thebritishgeographer.weebly.com/river-landforms.html.

Thomson, R.E. 1981. Oceanography of the British Columbia coast. Can. Spec. Publ. Fish. Aquat. Sci. 56: 291 pp. http://www.dfo-mpo.gc.ca/Library/487.pdf.

Trites, R.W. 1956. The Oceanography of Chatham Sound, British Columbia. J. Fish Res. Bd. Canada 13(3):385-434.

Tredger, C.D. 1981. Natural Rearing Capacity of the Kloiya River System, Near Prince Rupert, B.C. With Reference to the Kloiya River Community Development Program under S.E.P. Ministry of Environment. Victoria, B.C. http://www.env.gov.bc.ca/wld/documents/fisheriesrpts/RN169.pdf.

Walters, C.J., Lichatowich, J.A., Peterman, R.M. and Reynolds, J.D. 2008. Report of the Skeena Independent Science Review Panel. A report to the Canadian Department of Fisheries and Oceans and the British Columbia Ministry of the Environment. May 15, 2008, 144 p. http://www.psf.ca/sisrp.pdf.

Webb, D.G. 1991. Effect of predation by juvenile Pacific salmon on marine harpacticoid copepods. I. Comparisons of patterns of copepod mortality with patterns of salmon consumption. Mar . Ecol. Prog. Ser. 72: 25-36. http://www.int-res.com/articles/meps/72/m072p025.pdf.

Wikipedia. 2013a. Oceanic zone. http://en.wikipedia.org/wiki/Oceanic_zone.

Wikipedia. 2013b. Pacific decadal oscillation. http://en.wikipedia.org/wiki/Pacific_decadal_oscillation.

Wikipedia. 2013c. Photosynthesis. http://en.wikipedia.org/wiki/Photosynthesis.

Williams G.D., Thom, R.M., Starkes, J.E., Brennan, J.S., Houghton, J.P., Woodruff, D., Striplin, P.L., Miller, M., Pedersen, M., Skillman, A., Kropp, R., Borde, A., Freeland, C., McArthur, K., Fagerness, V., Blanton, S., Blackmore, L. 2001. Reconnaissance assessment of the state of the nearshore ecosystem: eastern shore of central Puget Sound, including Vashon and Maury Islands WRIAs 8 and 9, ed. JS Brennan. Report prepared for King County Department of Natural Resources, Seattle, Washington. http://www.kingcounty.gov/environment/watersheds/central-puget-sound/nearshore-environments/reconnaissance-assessment.aspx.

Williams, G.L. 1989. Coastal/estuarine fish habitat description and assessment manual. Part I: Species-Habitat Outlines. Prepared for Department of Fisheries and Oceans by G.L. Williams and Associates Ltd. http://www.dfo-mpo.gc.ca/Library/141642.pdf.

Williams, GD., Thom, RM. 2001. Development of guidelines for aquatic habitat protection and restoration: marine and estuarine shoreline modification issues, PNWD-3087. Prepared for the Washington State Department of Transportation, Washington Department of Fish and Wildlife, and the Washington Department of Ecology. Battelle Marine Sciences Laboratory, Sequim, Washington. http://wdfw.wa.gov/publications/00054/wdfw00054.pdf.

Wissmar, R.C., Simenstad, C.A. 1998. Variability of estuarine and riverine ecosystem productivity for supporting Pacific salmon, Pages 253-301 in McMurray, G.R., and R.J. Bailey (eds.) Change in Pacific Northwest Coastal Ecosystems. NOAA Coastal Ocean Program. Decision Analysis Series No. 11. http://www.cop.noaa.gov/pubs/das/das11.pdf.

Wolanski, E.; Boorman, L.A.; Chicharo, L.; Langlois-Saliou, E.; Lara, R.J.; Plater, A.J.; Uncles, R.J.; Zalewski, M. 2004. Ecohydrology as a new tool for sustainable management of estuaries and coastal waters. Wetl. Ecol. Manag. 12(4): 235-276. http://portal.nceas.ucsb.edu/working_group/valuation-of-coastal-habitats/wg-member-models/Wolanski%20et%20al%202004%20Wetlands%20Ecology_EW%20Model.pdf/attachment_download/file.

Wood, C. C. 1987. Predation of Juvenile Pacific Salmon by the Common Merganser (*Mergus merganser*) on Eastern Vancouver Island. I: Predation during the Seaward Migration Canadian Journal of Fisheries and Aquatic Sciences, , 44:941-949. http://www.nrcresearchpress.com/doi/pdf/10.1139/f87-112.

Wood, C.C. 2008. Managing biodiversity of Pacific salmon: lessons from the Skeena River sockeye salmon fishery in British Columbia. American Fisheries Society Symposium 49:349-364. http://www.researchgate.net/publication/235702477_Managing_Biodiversity_of_Pacific_Salmon_Lessons_from_the_Skeena_River_Sockeye_Salmon_Fishery_in_British_Columbia.

9 Appendix

9.1 Model Hypotheses/Assumptions

Table 11. Hypotheses/assumptions regarding estuarine residence time and its impacts on juvenile salmonid survival

Habitat attribute	Hypotheses/assumptions	Life stages affected	References
Foraging Success- Prey within subestuaries	• Both terrestrial and aquatic based prey are important within subestuaries • Subestuaries are important "stop-over" feeding areas for salmon fry migrating along the nearshore shoreline • Prey availability within subestuaries is related to riparian conditions within the subestuary and the lower portion of the adjoining freshwater system and to adjacent wetlands, marshes, and mudflats • Relative amounts of detrital input to subestuary systems are important to overall system productivity • Land uses within and adjoining subestuaries that result in diking or disconnecting wetlands, sloughs, and secondary channels from main channels will reduce amounts of prey • Subestuaries that have high forage availability will hold fry longer and promote rapid growth and facilitate transition to salt water	Small smolt <55-60 mm	Simenstad *et al*. 1980; Aitken 1998; Simenstad 2000
Foraging Success - Terrestrial based prey within shallow nearshore environments	• The riparian zone of the shoreline can be an important source of prey • Land uses that remove riparian vegetation will reduce inputs of prey to the nearshore environment • Chinook and sockeye juveniles feed more on adult insects than other juvenile salmonids.	Small smolt <55-60 mm	Simenstad *et al*. 1980; Aitken 1998; Magnhagen *et al.* 2007; Northcote *et al*. 2007

Habitat attribute	Hypotheses/assumptions	Life stages affected	References
Foraging Success - Epibenthic prey within shallow nearshore environments	• Epibenthic zooplankton, particularly some species of harpacticoids, are an especially important source of food to small smolts, particularly pink, chum and Chinook • Within year pattern of abundance can vary but generally follows a predictable pattern, peaking prior to the neritic zooplankton peak • Abundance of preferred species varies by month and tends to peak prior to peak abundance of neritic zooplankton • Abundance of preferred species is subject to being heavily cropped by juvenile salmonids • Eelgrass meadows are major production areas of epibenthic prey for juvenile salmonids and provide important feeding areas • Epibenthic organisms are more abundant along beaches less exposed to wave action • Forage availability is related to detrital inputs from eelgrass, marsh, and adjoining watersheds • Migration rate of juvenile salmonids is strongly influenced by forage availability; abundant prey slows migration rate for feeding, promoting rapid growth; scarce prey accelerates migration in search of preferred prey • Shift to neritic life style (associated with deep water) is accelerated by abundant epibenthic prey; shift is slowed by scarce epibenthic prey; however, an absence of suitable epibenthic prey may also force small smolts into the neritic environment earlier while they are still small in size • Shoreline development that results in deepening of existing shallow water areas, coarsening of substrates from sand or mixed-sand to cobble, and docks and piers will reduce eelgrass abundance and associated epibenthic prey production	Small smolt <55-60 mm	Simenstad *et al*. 1980; Webb 1991; Aitken 1998; Simenstad 2000; Northcote *et al*. 2007
Foraging Success - Neritic prey within shallow nearshore environments	• Pink salmon juveniles feed mainly on neritic prey, initially larval molluscs and larval fish, then calanoid copepods later in the season as they start to move into deeper water • Sockeye salmon juveniles also feed mainly on neritic prey, with copepods often forming the most common prey item	Small smolt <55-60 mm	Birtwell *et* al. 1987; Murphy *et al*. 1988 Aitken 1998

Habitat attribute	Hypotheses/assumptions	Life stages affected	References
Foraging Success - Neritic prey within deepwater areas of Chatham Sound	• Food availability for herbivorous zooplankton is adequate for much of the year in the Queen Charlotte Basin, with several areas around the perimeter sustaining high phytoplankton biomass throughout much of the spring, summer and fall (particularly Dogfish Banks, Chatham Sound, and off of Fitz Hugh and Smith Sounds), • The spatial distribution of zooplankton is determined by a combination of nutrient enrichment, which stimulates phytoplankton blooms, localized concentrating effects (e.g., along bathymetric edges), and the retention of critical life stages • Patchiness of zooplankton off the northern BC coast is very intense, and is not closely tied to the location of phytoplankton blooms, with factors such as current patterns, bathymetry, and zooplankton diel (daily) vertical migration controlling zooplankton patch location and intensity • Zooplankton populations are higher in the estuarine plume (10 - 15 ppt surface salinity) than in waters outside the plume, and juvenile salmonid populations are highest at the boundary between the estuarine plume and oceanic waters • Neritic zooplankton are more abundant in Chatham Sound than in the open ocean • Minimum annual zooplankton densities occur in winter, with densities increasing in the spring, lagging slightly behind the increase in the phytoplankton population • Peak abundance tends to follow peak abundance of inshore epibenthic prey	Large smolt (subyearlings) >55-60 mm	St. John *et al*. 1992; Bakun 1996; Peña and Crawford 2004; Mackas *et al*. 2007
Foraging Success - Neritic prey within the coastal waters of the North Pacific (outside Chatham Sound)	• The PDO (Pacific Decadal Oscillation) can have a strong influence on the zooplankton populations with cool years favoring endemic boreal taxa, whereas warm years favor colonization by southern taxa • Increases in the abundance of boreal copepods is associated with good regional survival and growth of juvenile salmon, sablefish, and planktivorous seabirds • Recently, the southern species have shown a long-term upward trend, suggesting that climate change may be producing a shift in dominant species	Large smolt (subyearlings) >55-60 mm	Mackas *et al*. 2007; Cummins and Haigh 2010; Mackas *et al*. 2010
Surface water circulation - Flow velocities within subestuaries	• High flows during smolt outmigration from natal streams will tend to push smolt through the subestuary unless suitable refuge or slow water areas exist • For the most estuarine-dependent salmonid species (Chinook and chum), accelerated emigration out of natal subestuary by high flows is disadvantageous to smolt survival because it results in sudden, abrupt changes in habitat types experienced by newly emerged juvenile salmon and exposes them to greater predation risk in deep water when pushed out beyond the delta face • Land uses that accelerate spring runoff or reduce refuge sites in subestuaries from high flows will result in faster emigration rates from natal subestuaries and reduced survival	Small smolt <55-60 mm	Bax 1982; Salo 1991; Lestelle *et al*. 2005

Habitat attribute	Hypotheses/assumptions	Life stages affected	References
Surface water circulation - Surface outflow velocities within the nearshore zone	• Small juvenile salmonids will be moved out of an area faster when relatively high surface outflow velocities occur as compared to when low velocities predominate • For the most estuarine-dependent salmonid species (Chinook and chum), relatively rapid, passive movement from nearshore areas will generally be unfavorable to survival because it diminishes feeding opportunities on epibenthic prey, exposing smolts to a greater array of predators per unit of time • Shoreline development that results in reduced epibenthic prey abundance will exacerbate the effects of high surface outflows on smolt survival because it would diminish opportunities for forage and growth upon arrival to the nearshore environment • Surface outflow velocities in the Skeena River estuary vary both intra- and interannually due to variability in runoff and wind; velocities tend to be greatest in spring and early summer (due to the melting of the winter snow pack), and on rare occasions peak velocities occur in the fall or winter (due to intense rainfall events) • Climate models, supported by trends over the past century, predict that salmon and steelhead in the Skeena watershed will encounter higher stream flows during warmer winters, and potentially lower flows and higher water temperatures in summer	Small smolt <55-60 mm	Bax 1982; Salo 1991; De Groot 2005; Lestelle *et al*. 2005; Walters *et al*. 2008

Table 12. Hypotheses/assumptions regarding estuarine condition and its impacts on juvenile salmonid survival.

Habitat attribute	Hypotheses/assumptions	Life stages affected	References
Subestuaries - Natal and non-natal	• Complexity of channels and structure within natal subestuaries provides refuge from high flows and predators; structure in non-natal estuaries provides refuge from predators • Interspersed subestuaries and tidal marshes along the nearshore shoreline provide "stop-over" feeding sites, predator refuge, and more effective transitioning from freshwater to saltwater conditions • Tidal gates and other impediments to free movement by juvenile chum can block access to blind channels and off-channel sites within subestuaries	Small smolt <55-60 mm	Simenstad 2000; Beamer *et al*. 2003
Estuarine characteristics - Eelgrass distribution and abundance	• Eelgrass provides habitat structure for predator refuge for small and larger smolts	Small smolt <55-60 mm	Simenstad and Wissmar 1985; Wissmar and Simenstad 1998; Haring 1999; Simenstad 2000; Williams and Thom 2001; Williams *et al*. 2001
Estuarine characteristics - Extent of shallow shoreline	• The preferred prey of small smolts which have not achieved the neritic phase occurs in these areas • Shallow beaches provide predator refuge for small fry migrating along shoreline	Small smolt <55-60 mm	Simenstad *et al*. 1980; Salo 1991; Simenstad 2000
Estuarine characteristics - Extent of shoreline development	• Land uses and shoreline development that steepen beaches, coarsen substrates, eliminate or reduce eelgrass or kelp will reduce the quality of the nearshore environment for small smolts	Small smolt <55-60 mm	Simenstad 2000; Williams and Thom 2001; Hirschi *et al*. 2003
Estuarine characteristics - Riparian condition	• The riparian zone along subestuaries and the nearshore shoreline can be an important source of forage for salmon fry feeding in these areas, particularly those species which prey on terrestrial insects	Small smolt <55-60 mm	Simenstad 2000; Levings and Jamieson 2001
Estuarine characteristics - Sources of detritus	• In subestuaries and the intertidal zones of larger estuarine complexes, juvenile salmon, in large part, are supported by detritus-based trophic pathways • Estuarine productivity is related to the efficiency of trapping and processing of detritus, which is related to the estuary configuration with respect to tidal channels, intertidal marshes, creek and river delta configuration, lower intertidal and subtidal weed beds, and basin morphology • Major sources of detritus in estuaries are, in order of significance: (1) eelgrass; (2) benthic algae and phytoplankton; and (3) terrestrial (river-derived) and marsh • Human activities that alter detritus inputs or the trapping efficiency of estuarine subsystems impact estuarine productivity for juvenile salmon food	Small smolt <55-60 mm	Healey 1982; Simenstad and Wissmar 1985; Wissmar and Simenstad 1998; Simenstad 2000
Estuarine characteristics - Exposure	• Small smolts appear to prefer bays and sheltered areas, whereas exposed areas of relatively high energy within subestuaries are avoided even when preferred prey are present • Areas of low wave exposure and calm water provide bioenergetically preferred feeding sites	Small smolt <55-60 mm	Healey 1979;Healey 1982; Simenstad *et al*. 1982; Salo 1991

Habitat attribute	Hypotheses/assumptions	Life stages affected	References
Estuarine characteristics - Kelp distribution	• Kelp forests provide habitat structure for predator refuge for small and larger smolts • Kelp also provides substrate for production of prey used by juvenile salmonids	Small smolt <55-60 mm	Shaffer 1998; Shaffer 2003
Estuarine characteristics - Chemical contamination	• Prince Rupert has ten sewage outfalls which release untreated sewage in anto the Skeena River estuary region; in addition to high BOD, these sewage outfalls may also be sources of heavy metal contamination and other chemical contaminants • Historically, Prince Rupert Harbour has been the site of a number of industrial activities, including shipbuilding and the Skeena Cellulose pulp mill; impacts from the chemical contaminants produced by these activities were severe • Dioxins and furans are of particular concern from the Skeena Cellulose pulp mill; significant decreases in dioxins and furans in sediment and tissues samples have been observed since changes in the mill process in 1989, and later closure of the mill in 2001; however bioturbation and dredging may bring buried contaminated sediments back to the surface and further expose biota to these compounds	All size classes of subyearlings	Hoos 1975; Stucchi and Orr 1993; Hagen *et al*. 1995; Bard 1998; BCMOE 2006; De Raedemaecker 2004; Faggetter 2008
Estuarine characteristics - Oxygen	• The maintenance of adequate dissolved oxygen levels is critical for juvenile salmonids migrating through or rearing in estuaries • Low dissolved oxygen resulting from high BOD (e.g., from pulp mills) have resulted in kills of large numbers of juvenile sockeye • While tidal mixing in the Prince Rupert Harbour is generally good, there is the possibility for oxygen depletion to occur in regions with restricted circulation if BOD levels are high	All size classes of subyearlings	Levings 1992; Stucchi and Orr 1993
Estuarine characteristics - Temperature	• Small increases in temperature may affect the timing of salmon smolt migration through the estuary, and thus their residence time in the estuary • Large increases in temperature may be lethal to juvenile salmon • Climate change may result in increased temperatures in both the Skeena River and its estuary	All size classes of subyearlings	Fresh 2006; Walters *et al*. 2008; Levings 1992
Estuarine characteristics - Sediment load	• High levels of turbidity may help reduce predation on juvenile salmon • Turbidity can reduce visibility of salmon juveniles to predators	All size classes of subyearlings	Simenstad *et al*. 1982; Gregory and Levings 1998 ; Fresh 2006
Ecological interactions - Interspecific competition with wild and hatchery fish	• Potential for competition for food between chum and Chinook, coho, steelhead, and cutthroat populations is small due to timing differences in outmigrations and differences in habitat utilization and diet (potential is greatest between chinook and chum) • Potential for competition for food between pink salmon and other juvenile salmonids is high during strong pink abundance years; chum fry behavior is changed when pink are abundant	All size classes of subyearlings	Ruggerone and Nielsen 2004; Magnhagen *et al.* 2007; Northcote *et al*. 2007; Beamish *et al*. 2010; Bollens *et al*. 2010
Ecological interactions - Intraspecific competition with hatchery fish	• Potential for competition for food between wild juvenile salmon and hatchery juvenile salmon of the same species can be substantial due to the possibility for very large numbers of hatchery fish	All size classes of subyearlings	Gardner *et al*. 2004; Naish *et al*. 2008

Habitat attribute	Hypotheses/assumptions	Life stages affected	References
Ecological interactions - Predation on juvenile salmonids	• Potential for predation effects on juvenile salmonids by wild cutthroat, steelhead, Coho, and Chinook can be high when these populations of other species are abundant • Potential for predation by seabirds, marine fish (e.g., spiny dogfish and river lamprey), and marine mammals is generally relatively low, though unusual concentrations of seabirds and certain species of marine fish can cause high predation	All size classes of subyearlings	Wood 1987; Independent Multidisciplinary Science Team 1998; Beamish and Neville 2001; Riley *et al*. 2004; Lestelle *et al*. 2005; Duffy and Beauchamp 2008; Christensen and Trites 2011

9.2 Morphological Classifications

Table 13. Subestuary and tidal marsh classifications.

Type	Description
River mouth subestuary	Tidally influenced portion of stream mouths designated as rivers (with some exceptions).
Creek mouth subestuary	Tidally influenced portion of stream mouths with named creeks and that have (or had) anadromous fish spawning (with some exceptions).
Tidal channel with salt marsh and freshwater input	Tidally influenced portion of stream mouths with unnamed creeks without current or historic anadromous fish spawning and that have some associated tidally influenced marsh.
Tidal channel without salt marsh with freshwater input	Tidally influenced portion of stream mouths with unnamed creeks without current or historic anadromous fish spawning and that have no associated tidally influenced marsh.
Salt marsh without tidal channel with freshwater input	Tidally influenced marsh without a channel connection to marine water body with some freshwater input.
Tidal channel with salt marsh and no freshwater input	Tidally influenced marsh with a channel connection to marine water body and without freshwater input.
Salt marsh without tidal channel with no freshwater input	Tidally influenced marsh without a channel connection to marine water body and without freshwater input.

9.3 Food Habitat Factor

Table 14. Environmental attribute weights for the food habitat factor for smolts during the epibenthic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Macrophytes	1			Macrophytes are high production areas for epibenthic prey.
2	Eelgrass – all %		0.5		Patchy eelgrass beds assumed to be less productive than continuous.
2	Eelgrass – continuous %		1		Continuous eelgrass assumed to be most productive.
1	Neritic zooplankton	0.5			Small smolts in shallow nearshore make forays into deeper water at night.
1	Salmon carcasses	0.25			Salmon carcasses provide a direct source of food; also provide nutrients.
1	Riparian vegetation	0.6			Riparian vegetation is a source of terrestrial insect drop.
1	Wave exposure	0.5			Prey production is highest in low wave energy areas.
1	Subestuary density/function	0.6			Subestuaries and some tidal marshes are stop-over feeding sites.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
2	Subestuary density		1		Density of subestuaries (no./km) determines frequency of encounter.
3	River mouth subestuary			1	River mouth estuaries provide most productive feeding areas.
3	Creek mouth subestuary			0.75	Creek mouth estuaries somewhat less productive as feeding areas.
3	Tidal chan with sm & fw			0.2	Limited feeding opportunity exists.
3	Tidal chan no sm with fw			0.15	Limited feeding opportunity exists.
3	Salt marsh no tide chan with fw			0	No access for feeding.
3	Tidal chan with sm no fw			0.2	Limited feeding opportunity exists.
3	Salt marsh no tide chan no fw			0	No access for feeding.
2	Subestuary functional loss		2		Degraded subestuaries and tidal marshes are less productive for feeding.
3	River mouth subestuary			1	Degraded river mouth estuaries would contribute most to loss of feeding area.
3	Creek mouth subestuary			0.75	Degraded creek mouth estuaries would contribute less to loss of feeding area.
3	Tidal chan with sm & fw			0.25	Limited feeding opportunity exists.
3	Tidal chan no sm with fw			0.15	Limited feeding opportunity exists.
3	Salt marsh no tide chan with fw			0	No access for feeding.
3	Tidal chan with sm no fw			0.25	Limited feeding opportunity exists.
3	Salt marsh no tide chan no fw			0	No access for feeding.
1	Detrital input	0.6			Detritus provides energy source for estuarine food web (others listed above).
2	Ratio emerg veg to ITZ area		1		Emergent vegetation is source of detritus.
2	Ratio watersheds to ITZ area		1		Watersheds are sources of detritus.

Table 15. Environmental attribute weights for the food habitat factor for smolts during the neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Macrophytes	0.25			Epibenthic feeding by neritic smolts greatly diminished than during the epibenthic phase, hence role of macrophytes is reduced.
2	Eelgrass		1		Eelgrass is particularly productive for epibenthic prey.
3	Eelgrass – all %			0.5	Patchy eelgrass beds assumed to be less productive than continuous.
3	Eelgrass – continuous %			1	Continuous eelgrass assumed to be most productive.
2	Kelp		0.3		Kelp is identified as a production area for juvenile salmon prey.
3	Kelp – all %			0.5	Patchy kelp beds assumed to be less productive than continuous.
3	Kelp – continuous %			1	Continuous kelp beds assumed to be most productive.
1	Neritic zooplankton	1			Neritic zooplankton is the primary source of food during the neritic phase of fry outmigration.
1	Salmon carcasses	0			Salmon carcasses likely have no influence on forage availability for neritic phase of outmigration.
1	Riparian vegetation	0.2			Role of riparian vegetation as a source of food to neritic phase is diminished from epibenthic phase.
1	Wave exposure	0.25			Effect of exposure on prey production reduced than for epibenthic phase but still operative.
1	Subestuary density/function	0.15			Role of subestuaries/tidal marshes as stop-over feeding sites reduced for neritic phase.
2	Subestuary density		1		Density of subestuaries (no./km) determines frequency of encounter.
3	River mouth subestuary			1	River mouth estuaries provide most productive feeding areas.
3	Creek mouth subestuary			0.75	Creek mouth estuaries somewhat less productive as feeding areas.
3	Tidal chan with sm & fw			0.2	Limited feeding opportunity exists.
3	Tidal chan no sm with fw			0.15	Limited feeding opportunity exists.
3	Salt marsh no tide chan with fw			0	No access for feeding.
3	Tidal chan with sm no fw			0.2	Limited feeding opportunity exists.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
3	Salt marsh no tide chan no fw			0	No access for feeding.
2	Subestuary functional loss		1		Degraded subestuaries and tidal marshes are less productive for feeding.
3	River mouth subestuary			1	Degraded river mouth estuaries would contribute most to loss of feeding area.
3	Creek mouth subestuary			0.75	Degraded creek mouth estuaries would contribute less to loss of feeding area.
3	Tidal chan with sm & fw			0.25	Limited feeding opportunity exists.
3	Tidal chan no sm with fw			0.15	Limited feeding opportunity exists.
3	Salt marsh no tide chan with fw			0	No access for feeding.
3	Tidal chan with sm no fw			0.25	Limited feeding opportunity exists.
3	Salt marsh no tide chan no fw			0	No access for feeding.
1	Detrital input	0.2			Role of detrital input from emergent vegetation and watersheds to zooplankton production assumed to be negligible at a segment scale.
2	Ratio emerg veg to ITZ area		1		Emergent vegetation is source of detritus.
2	Ratio watersheds to ITZ area		1		Watersheds are sources of detritus.

9.4 Flow Habitat Factor

Table 16. Environmental attribute weights for the flow habitat factor for smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Surface outflow average velocity	1			Surface outflow velocity directly affects smolt outmigration rate.

9.5 Obstructions Habitat Factor

Table 17. Environmental attribute weights for the obstructions habitat factor for smolts during the epibenthic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Accessibility to subestuary habitats	1			Complexity of channels and structure within natal subestuaries provides refuge from high flows and predators; structure in non-natal estuaries provides refuge from predators.

9.6 Habitat Diversity Habitat Factor

Table 18. Environmental attribute weights for the habitat diversity habitat factor for smolts during the epibenthic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Macrophytes	1.5			Macrophytes provide areas of refuge from predators.
2	Eelgrass		1		Eelgrass is particularly attractive for epibenthic smolts.
3	Eelgrass – all %			0.5	Patchy eelgrass assumed to be less attractive than continuous.
3	Eelgrass – continuous %			1	Continuous eelgrass assumed to be most attractive.
2	Kelp		0.3		Kelp provides some extent of refuge from predators.
3	Kelp – all %			0.5	Patchy kelp assumed to be less attractive than continuous.
3	Kelp – continuous %			1	Continuous kelp assumed to be most attractive.
1	Intertidal zone slope	1			Low gradient beaches (very shallow) provide refuge from predators during day time for small smolts.
1	Percent of shoreline modified	2			Modified beaches are less likely to have features preferred by small smolts.
1	Wave exposure	0.5			Low energy beaches are more easily utilized than high energy beaches from a bioenergetic aspect.
1	Subestuary density/function	1			Subestuaries and some tidal marshes are stop-over feeding sites, provide predator refuge, and improved acclimation to saline environment.
2	Subestuary density		1		Density of subestuaries (no./km) determines frequency of encounter.
3	River mouth subestuary			1	River mouth estuaries are the largest of subestuary types and provide greatest opportunities.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
3	Creek mouth subestuary			0.75	Creek mouth estuaries somewhat less attractive as stop-over sites during fry migration.
3	Tidal chan with sm & fw			0.2	Limited opportunity for access.
3	Tidal chan no sm with fw			0.15	Limited opportunity for access.
3	Salt marsh no tide chan with fw			0	No access for stop-over.
3	Tidal chan with sm no fw			0.2	Limited opportunity for access.
3	Salt marsh no tide chan no fw			0	No access for stop-over.
2	Subestuary functional loss		2		Degraded subestuaries and tidal marshes provide less benefit to migrating smolts.
3	River mouth subestuary			1	Degraded river mouth estuaries would contribute most to loss of opportunities for migrant smolts.
3	Creek mouth subestuary			0.75	Degraded creek mouth estuaries would contribute less to loss of opportunities for migrant smolts.
3	Tidal chan with sm & fw			0.25	Limited opportunity for access.
3	Tidal chan no sm with fw			0.15	Limited opportunity for access.
3	Salt marsh no tide chan with fw			0	No access for stop-over.
3	Tidal chan with sm no fw			0.25	Limited opportunity for access.
3	Salt marsh no tide chan no fw			0	No access for stop-over..

Table 19. Environmental attribute weights for the habitat diversity habitat factor for smolts during the neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Macrophytes	1			Macrophytes provide areas of refuge from predators.
2	Eelgrass		1		Eelgrass is particularly attractive for epibenthic smolts.
3	Eelgrass – all %			0.5	Patchy eelgrass assumed to be less attractive than continuous.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
3	Eelgrass – continuous %			1	Continuous eelgrass assumed to be most attractive.
2	Kelp		0.5		Kelp provides some extent of refuge from predators.
3	Kelp – all %			0.5	Patchy kelp assumed to be less attractive than continuous.
3	Kelp – continuous %			1	Continuous kelp assumed to be most attractive.
1	Intertidal zone slope	1			Low gradient beaches (very shallow) provide refuge from predators during day time for small smolts.
1	Percent of shoreline modified	1			Modified beaches are less likely to have features preferred by small smolts.
1	Wave exposure	0.5			Low energy beaches are more easily utilized than high energy beaches from a bioenergetic aspect.
1	Subestuary density/function	0.5			Subestuaries and some tidal marshes are stop-over feeding sites, provide predator refuge, and improved acclimation to saline environment.
2	Subestuary density		1		Density of subestuaries (no./km) determines frequency of encounter.
3	River mouth subestuary			1	River mouth estuaries are the largest of subestuary types and provide greatest opportunities.
3	Creek mouth subestuary			0.75	Creek mouth estuaries somewhat less attractive as stop-over sites during fry migration.
3	Tidal chan with sm & fw			0.2	Limited opportunity for access.
3	Tidal chan no sm with fw			0.15	Limited opportunity for access.
3	Salt marsh no tide chan with fw			0	No access for stop-over.
3	Tidal chan with sm no fw			0.2	Limited opportunity for access.
3	Salt marsh no tide chan no fw			0	No access for stop-over.
2	Subestuary functional loss		1		Degraded subestuaries and tidal marshes provide less benefit to migrating smolts.
3	River mouth subestuary			1	Degraded river mouth estuaries would contribute most to loss of opportunities for migrant smolts.
3	Creek mouth subestuary			0.75	Degraded creek mouth estuaries would contribute less to loss of opportunities for migrant smolts.
3	Tidal chan with sm & fw			0.25	Limited opportunity for access.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
3	Tidal chan no sm with fw			0.15	Limited opportunity for access.
3	Salt marsh no tide chan with fw			0	No access for stop-over.
3	Tidal chan with sm no fw			0.25	Limited opportunity for access.
3	Salt marsh no tide chan no fw			0	No access for stop-over..

9.7 Chemicals Habitat Factor

Table 20. Environmental attribute weights for the chemicals habitat factor for smolts during the epibenthic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Metals in the water column	1			Pollutants which have toxic effects on juvenile salmonids.
1	Dioxins in the sediments	1			Pollutants which have toxic effects on juvenile salmonids.
1	Metals in the sediments	1			Pollutants which have toxic effects on juvenile salmonids.

Table 21. Environmental attribute weights for the chemicals habitat factor for smolts during the neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Metals in the water column	1			Pollutants which have toxic effects on juvenile salmonids.
1	Metals in the sediments	1			Pollutants which have toxic effects on juvenile salmonids.
1	Surface outflow average velocity	1			Surface outflow carries pollutants away from the shoreline and into deeper water.
1	Wave exposure	1			High wave energy resuspends pollutants found in the sediments into the water column.

9.8 Oxygen Habitat Factor

Table 22. Environmental attribute weights for the oxygen habitat factor for smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Dissolved oxygen	1			Adequate dissolved oxygen levels is critical for juvenile salmonids migrating through or rearing in estuaries.

9.9 Temperature Habitat Factor

Table 23. Environmental attribute weights for the temperature habitat factor for smolts during the epibenthic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Maximum temperature	1			In shallow water, small increases in temperature may affect the timing of salmon smolt migration through the estuary, and thus their residence time in the estuary, and large increases in temperature may be lethal to juvenile salmon.

Table 24. Environmental attribute weights for the temperature habitat factor for smolts during the neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Maximum temperature	0			Temperature changes are less dramatic in deeper water.

9.10 Sediment Load Habitat Factor

Table 25. Environmental attribute weights for the sediment load habitat factor for smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Turbidity (susp. sed.)	1			High levels of turbidity may help reduce predation on juvenile salmon.

9.11 Intraspecific Competition with Hatchery Fish Habitat Factor

Table 26. Environmental attribute weights for the intraspecific competition with hatchery fish survival habitat for chum smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Hatchery chum release	1			Competition for food between wild juvenile salmon and hatchery juvenile salmon of the same species can be substantial if large numbers of hatchery fish are released.

Table 27. Environmental attribute weights for the intraspecific competition with hatchery fish habitat factor for Chinook smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Hatchery Chinook release	1			Competition for food between wild juvenile salmon and hatchery juvenile salmon of the same species can be substantial if large numbers of hatchery fish are released.

Table 28. Environmental attribute weights for the intraspecific competition with hatchery fish habitat factor for pink smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Hatchery pink release	1			Competition for food between wild juvenile salmon and hatchery juvenile salmon of the same species can be substantial if large numbers of hatchery fish are released.

Table 29. Environmental attribute weights for the intraspecific competition with hatchery fish habitat factor for sockeye smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Hatchery sockeye release	1			Competition for food between wild juvenile salmon and hatchery juvenile salmon of the same species can be substantial if large numbers of hatchery fish are released.

Table 30. Environmental attribute weights for the intraspecific competition with hatchery fish habitat factor for Coho smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Hatchery Coho release	1			Competition for food between wild juvenile salmon and hatchery juvenile salmon of the same species can be substantial if large numbers of hatchery fish are released.

Table 31. Environmental attribute weights for the intraspecific competition with hatchery fish habitat factor for steelhead smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Hatchery steelhead release	0			No hatchery steelhead are currently being released in the Skeena River estuary region.

9.12 Interspecific Competition with Other Species Habitat Factor

Table 32. Environmental attribute weights for the interspecific competition with other species habitat factor for chum smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Total Chinook status (hatchery + wild)	1			Chinook smolts can prey on the same organisms eaten by chum; reducing prey density.
1	Total Coho status (hatchery + wild)	0			Coho smolts prey on different organisms than those eaten by chum.
1	Total pink status (hatchery + wild)	1			Presence of pink smolts, especially on strong pink years, can cause chum smolts to migrate more rapidly, presumably due to competition for food resources.
1	Total sockeye status (hatchery + wild)	0			Sockeye smolts prey on different organisms than those eaten by chum.
1	Total steelhead status (hatchery + wild)	0			Steelhead smolts prey on different organisms than those eaten by chum.
1	Total cutthroat status (hatchery + wild)	0			Cutthroat smolts and subadults prey on different organisms than those eaten by chum.

Table 33. Environmental attribute weights for the interspecific competition with other species habitat factor for Chinook smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Total chum status (hatchery + wild)	1			Chum smolts can prey on the same organisms eaten by Chinook; reducing prey density.
1	Total Coho status (hatchery + wild)	0			Coho smolts prey on different organisms than those eaten by Chinook.
1	Total pink status (hatchery + wild)	1			Presence of pink smolts, especially on strong pink years, can cause Chinook smolts to migrate more rapidly, presumably due to competition for food resources.
1	Total sockeye status (hatchery + wild)	0			Sockeye smolts prey on different organisms than those eaten by Chinook.
1	Total steelhead status (hatchery + wild)	0			Steelhead smolts prey on different organisms than those eaten by Chinook.
1	Total cutthroat status (hatchery + wild)	0			Cutthroat smolts and subadults prey on different organisms than those eaten by Chinook.

Table 34. Environmental attribute weights for the interspecific competition with other species habitat factor for pink smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Total Chinook status (hatchery + wild)	1			Chinook smolts can prey on the same organisms eaten by pink; reducing prey density.
1	Total Coho status (hatchery + wild)	0			Coho smolts prey on different organisms than those eaten by pink.
1	Total chum status (hatchery + wild)	1			Chum smolts can prey on the same organisms eaten by pink; reducing prey density.
1	Total sockeye status (hatchery + wild)	1			Sockeye smolts can prey on the same organisms eaten by pink; reducing prey density.
1	Total steelhead status (hatchery + wild)	0			Steelhead smolts prey on different organisms than those eaten by pink.
1	Total cutthroat status (hatchery + wild)	0			Cutthroat smolts and subadults prey on different organisms than those eaten by pink.

Table 35. Environmental attribute weights for the interspecific competition with other species habitat factor for sockeye smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Total Chinook status (hatchery + wild)	1			Chinook smolts can prey on the same organisms eaten by sockeye; reducing prey density.
1	Total Coho status (hatchery + wild)	0			Coho smolts prey on different organisms than those eaten by sockeye.
1	Total pink status (hatchery + wild)	1			Pink smolts can prey on the same organisms eaten by sockeye; reducing prey density.
1	Total chum status (hatchery + wild)	0			Chum smolts prey on different organisms than those eaten by sockeye.
1	Total steelhead status (hatchery + wild)	0			Steelhead smolts prey on different organisms than those eaten by sockeye.
1	Total cutthroat status (hatchery + wild)	0			Cutthroat smolts and subadults prey on different organisms than those eaten by sockeye.

Table 36. Environmental attribute weights for the interspecific competition with other species habitat factor for Coho smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Total Chinook status (hatchery + wild)	0			Chinook smolts prey on different organisms than those eaten by Coho.
1	Total chum status (hatchery + wild)	0			Chum smolts prey on different organisms than those eaten by Coho.
1	Total pink status (hatchery + wild)	0			Pink smolts prey on different organisms than those eaten by Coho.
1	Total sockeye status (hatchery + wild)	0			Sockeye smolts prey on different organisms than those eaten by Coho.
1	Total steelhead status (hatchery + wild)	1			Steelhead smolts can prey on the same organisms eaten by Coho; reducing prey density.
1	Total cutthroat status (hatchery + wild)	1			Cutthroat smolts can prey on the same organisms eaten by Coho; reducing prey density.

Table 37. Environmental attribute weights for the interspecific competition with other species habitat factor for steelhead smolts during both the epibenthic and neritic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Total Chinook status (hatchery + wild)	0			Chinook smolts prey on different organisms than those eaten by steelhead.
1	Total chum status (hatchery + wild)	0			Chum smolts prey on different organisms than those eaten by steelhead.
1	Total pink status (hatchery + wild)	0			Pink smolts prey on different organisms than those eaten by steelhead.
1	Total sockeye status (hatchery + wild)	0			Sockeye smolts prey on different organisms than those eaten by steelhead.
1	Total coho status (hatchery + wild)	1			Coho smolts can prey on the same organisms eaten by steelhead; reducing prey density.
1	Total cutthroat status (hatchery + wild)	1			Cutthroat smolts can prey on the same organisms eaten by steelhead; reducing prey density.

9.13 Predation Habitat Factor

Table 38. Environmental attribute weights for the predation habitat factor for smolts during the epibenthic phase.

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Other wild salmonids	1			Potential for predation effects on juvenile salmonids by wild cutthroat, steelhead, Coho, and Chinook can be high when these populations of other species are abundant.
2	Status of wild Chinook salmon		1		
2	Status of wild Coho salmon		1		
2	Status of wild steelhead		1		
2	Status of wild cutthroat		1		
1	Hatchery salmonids	1			Potential for predation effects on juvenile salmonids by hatchery Coho, and Chinook can be high when hatchery releases are high.
2	Hatchery Chinook releases		1		
2	Hatchery Coho releases		1		

Group level	Environmental attribute	Weight by group level			Rationale
		1	2	3	
1	Other predatory fish	0.75			Potential for predation marine fish is generally relatively low, though unusual concentrations of species of marine fish (e.g., spiny dogfish and river lamprey) can cause high predation.
1	Marine mammals	0.5			Potential for predation marine mammals is generally relatively low.
1	Marine birds	0.75			Potential for predation by seabirds is generally relatively low, though unusual concentrations of seabirds can cause high predation.

9.14 Species-specific Habitat Utilization Adjustment Factors

Table 39. Species-specific habitat utilization adjustment factor (Hiss & Boomer 1986).

Habitat factor	Chum	Chinook	Pink	Sockeye	Coho	Steelhead
Food						
Epibenthic phase	1.0	0.5	0.25	0.25	0.25	0.25
Neritic phase	0.25	0.5	1.0	1.0	1.0	1.0
Habitat diversity						
Epibenthic phase	1.0	1.0	1.0	0.25	0.25	0.25
Neritic phase	0.25	0.25	0.25	1.0	1.0	1.0
Chemicals						
Epibenthic phase	1.0	1.0	1.0	0.25	0.25	0.25
Neritic phase	0.25	0.25	0.25	1.0	1.0	1.0
Oxygen	1.0	1.0	1.0	1.0	1.0	1.0
Flow	1.0	1.0	1.0	1.0	1.0	1.0
Obstructions	1.0	1.0	1.0	0.25	0.25	0.25
Temperature						
Epibenthic phase	1.0	1.0	1.0	0.25	0.25	0.25
Neritic phase	0.25	0.25	0.25	1.0	1.0	1.0
Sediment load	1.0	1.0	1.0	1.0	1.0	1.0
Intraspecific competition (with hatchery fish)	1.0	1.0	1.0	1.0	1.0	1.0
Interspecific competition (with other species)	1.0	1.0	1.0	1.0	1.0	1.0
Predation	1.0	1.0	1.0	1.0	1.0	1.0

9.15 Environmental Attributes

Table 40. Environmental Attribute Index Definitions.

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
1 Basin/shoreline features								
Morphometry	SegLength	Unit length	Length of subestuary, segment or region; applies to all zones. Measured in meters.	Approximate length of the segment. This attribute is not given a rating - it is the actual estimated length in meters.				
Morphometry	ITZWidth	ITZ Width	Width of the intertidal zone for the segment. Measured in meters.	Average width of the intertidal zone for the segment. This attribute is not given a rating - it is the actual estimated average width in meters.				
Morphometry	ITZGrad	Slope of intertidal zone	Average slope of the intertidal zone within the segment.	≥ 0% and < 6%	≥ 6% and < 18%	≥ 18% and < 30%	≥ 30% and < 42%	≥ 42%
Flow and circulation	OutflwVel	Surface outflow average velocity	Average velocity of the surface outflow within the segment measured in cm/s.	≥ 0 cm/s and < 0.7 cm/s	≥ 0.7 cm/s and < 2 cm/s	≥ 2 cm/s and < 3.3 cm/s	≥ 3.3 cm/s and < 4.7 cm/s	≥ 4.7 cm/s
Flow and circulation	Exposure	Wave exposure	Average wave exposure of the intertidal zone within the segment (weighted by shorezone unit length).	Average shorezone rating of ≥ 1 and < 1.5	Average shorezone rating of ≥ 1.5 and < 2.5	Average shorezone rating of ≥ 2.5 and < 3.5	Average shorezone rating of ≥ 3.5 and < 5	Average shorezone rating of ≥ 5 and ≤ 6
Shoreline/channel structure	AccessSubest	Accessibility to subestuary habitats	The extent that all portions of a subestuary are accessible to juvenile salmonids during tidal stages that would normally facilitate access; e.g., tidal gates may block access.	All subestuary channels and associated wetland complexes are accessible to juvenile fish that seek entrance or passage.	< 10% (but > 0%) of the wetted area of wetland complexes and smaller sloughs and blind channels is blocked to access by juvenile fish by man-made structures.	>= 10% and < 30% of the wetted area of wetland complexes and smaller sloughs and blind channels is blocked to access by juvenile fish by man-made structures.	>= 30% and < 60% of the wetted area of wetland complexes and smaller sloughs and blind channels is blocked to access by juvenile fish by man-made structures.	>= 60% of the wetted area of wetland complexes and smaller sloughs and blind channels is blocked to access by juvenile fish by man-made structures.
Shoreline/channel structure	DensityRMEst	Density of river mouth estuaries	Density of river mouth estuaries within the shoreline segment. Density as number per km of shoreline.	≥ 0.17 sites per km of shoreline.	≥ 0.12 and < 0.17 sites per km of shoreline.	≥ 0.07 and < 0.12 sites per km of shoreline.	≥ 0.02 and < 0.07 sites per km of shoreline.	≥ 0 and < 0.02 sites per km of shoreline.

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
	DensityCMEst	Density of creek mouth estuaries	Density of creek mouth estuaries within the shoreline segment. Density as number per km of shoreline.	≥ 0.35 sites per km of shoreline.	≥ 0.25 and < 0.35 sites per km of shoreline.	≥ 0.15 and < 0.25 sites per km of shoreline.	≥ 0.05 and < 0.15 sites per km of shoreline.	≥ 0 and < 0.05 sites per km of shoreline.
	DensityTideChanMarshFW	Density of tidal channels with salt marsh and FW input	Density of tidal channels with salt marsh and FW input within the shoreline segment. Density as number per km of shoreline.	≥ 0.30 sites per km of shoreline.	≥ 0.22 and < 0.30 sites per km of shoreline.	≥ 0.13 and < 0.22 sites per km of shoreline.	≥ 0.04 and < 0.13 sites per km of shoreline.	≥ 0 and < 0.04 sites per km of shoreline.
	DensityTideChanFW	Density of tidal channels without salt marsh with FW input	Density of tidal channels without salt marsh with FW input within the shoreline segment. Density as number per km of shoreline.	≥ 0.30 sites per km of shoreline.	≥ 0.22 and < 0.30 sites per km of shoreline.	≥ 0.13 and < 0.22 sites per km of shoreline.	≥ 0.04 and < 0.13 sites per km of shoreline.	≥ 0 and < 0.04 sites per km of shoreline.
	DensityTideMarshFW	Density of salt marshes without tidal channel with FW input	Density of salt marshes without tidal channel with FW input within the shoreline segment. Density as number per km of shoreline.	≥ 0.22 sites per km of shoreline.	≥ 0.16 and < 0.22 sites per km of shoreline.	≥ 0.09 and < 0.16 sites per km of shoreline.	≥ 0.03 and < 0.09 sites per km of shoreline.	≥ 0 and < 0.03 sites per km of shoreline.
	DensityTideChanMarsh	Density of tidal channels with salt marsh and no FW input	Density of tidal channels with salt marsh and no FW input within the shoreline segment. Density as number per km of shoreline.	≥ 1.3 sites per km of shoreline.	≥ 0.9 and < 1.3 sites per km of shoreline.	≥ 0.6 and < 0.9 sites per km of shoreline.	≥ 0.2 and < 0.6 sites per km of shoreline.	≥ 0 and < 0.2 sites per km of shoreline.
	DensityTideMarsh	Density of salt marshes without tidal channel with no FW input	Density of salt marshes without tidal channel with no FW input within the shoreline segment. Density as number per km of shoreline.	≥ 1.3 sites per km of shoreline.	≥ 0.9 and < 1.3 sites per km of shoreline.	≥ 0.6 and < 0.9 sites per km of shoreline.	≥ 0.2 and < 0.6 sites per km of shoreline.	≥ 0 and < 0.2 sites per km of shoreline.
Shoreline/channel structure	SubestLossFunc	Loss in function of subestuary and tidal marsh types	Average percent loss of function of subestuary and tidal marsh types within the segment by the seven types. SEE BELOW.					
	FuncLossRMEst	Function loss of river mouth estuaries	Loss in function of river mouth estuaries within the shoreline segment.	≥ 0 and < 12% loss in function	≥ 12 and < 37% loss in function	≥ 37 and < 62% loss in function	≥ 62 and < 87% loss in function	≥ 87 and ≤100% loss in function

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
	FuncLossCMEst	Function loss of creek mouth estuaries	Loss in function of creek mouth estuaries within the shoreline segment.	≥ 0 and < 12% loss in function	≥ 12 and < 37% loss in function	≥ 37 and < 62% loss in function	≥ 62 and < 87% loss in function	≥ 87 and ≤ 100% loss in function
	FuncLossTide ChanMarshFW	Function loss of tidal channels with salt marsh and FW input	Loss in function of tidal channels with salt marsh and FW input within the shoreline segment.	≥ 0 and < 12% loss in function	≥ 12 and < 37% loss in function	≥ 37 and < 62% loss in function	≥ 62 and < 87% loss in function	≥ 87 and ≤ 100% loss in function
	FuncLossTideChanFW	Function loss of tidal channels without salt marsh with FW input	Loss in function of tidal channels without salt marsh with FW input within the shoreline segment.	≥ 0 and < 12% loss in function	≥ 12 and < 37% loss in function	≥ 37 -and < 62% loss in function	≥ 62 and < 87% loss in function	≥ 87 and ≤ 100% loss in function
	FuncLossTideMarshFW	Function loss of salt marshes without tidal channel with FW input	Loss in function of salt marshes without tidal channel with FW input within the shoreline segment.	≥ 0 and < 12% loss in function	≥ 12 and < 37% loss in function	≥ 37 and < 62% loss in function	≥ 62 and < 87% loss in function	≥ 87 and ≤ 100% loss in function
	FuncLossTideChanMarsh	Function loss of tidal channels with salt marsh and no FW input	Loss in function of tidal channels with salt marsh and no FW input within the shoreline segment.	≥ 0 and < 12% loss in function	≥ 12 and < 37% loss in function	≥ 37 and < 62% loss in function	≥ 62 and < 87% loss in function	≥ 87 and ≤ 100% loss in function
	FuncLossTideMarsh	Function loss of salt marshes without tidal channel with no FW input	Loss in function of salt marshes without tidal channel with no FW input within the shoreline segment.	≥ 0 and < 12% loss in function	≥ 12 and < 37% loss in function	≥ 37 and < 62% loss in function	≥ 62 and < 87% loss in function	≥ 87 and ≤ 100% loss in function
Shoreline/channel structure	WAreaITZRatio	Ratio of river/creek watersheds to ITZ in segment	Ratio of the total area of river and creek watersheds entering the segment to the intertidal zone area within the segment.	≥ 1.4 km^2 of watershed per hectare of ITZ in the nearshore segment.	≥ 1.0 and < 1.4 km^2 of watershed per hectare of ITZ in the nearshore segment.	≥ 0.6 and < 1.0 km^2 of watershed per hectare of ITZ in the nearshore segment.	≥ 0.2 and < 0.6 km^2 of watershed per hectare of ITZ in the nearshore segment.	≥ 0 and < 0.2 km^2 of watershed per hectare of ITZ in the nearshore segment.
Shoreline/channel structure	EmergITZRatio	Ratio of total emergent vegetation to ITZ in segment	Ratio of total area of emergent vegetation to the intertidal zone area within the segment	≥ 0.44 hectares of emergent marsh (subestuary and tidal marsh) per hectare of ITZ in the nearshore segment.	≥ 0.31 and < 0.44 hectares of emergent marsh (subestuary and tidal marsh) per hectare of ITZ in the nearshore segment.	≥ 0.19 and < 0.31 hectares of emergent marsh (subestuary and tidal marsh) per hectare of ITZ in the nearshore segment.	≥ 0.06 and < 0.19 hectares of emergent marsh (subestuary and tidal marsh) per hectare of ITZ in the nearshore segment.	≥ 0 and < 0.06 hectares of emergent marsh (subestuary and tidal marsh) per hectare of ITZ in the nearshore segment.

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Shoreline/channel structure	RipVegPercent	Riparian vegetation - segment	The total percent of the shoreline within the segment with vegetation that hangs over into the intertidal zone. Riparian estimated only for unconsolidated (gravel, pebble, sand, mud, etc) shorelines.	≥ 87.5% of segment's shoreline length contains overhanging riparian vegetation. A value of 0 is assigned when the shoreline contains 100% overhanging vegetation.	≥ 62.5% and < 87.5% of segment's shoreline length contains overhanging riparian vegetation.	≥ 37.5% and < 62.5% of segment's shoreline length contains overhanging riparian vegetation.	≥ 12.5% and < 37.5% of segment's shoreline length contains overhanging riparian vegetation.	≥ 0% and < 12.5% of segment's shoreline length contains overhanging riparian vegetation. A value of 4 is assigned when 0% of shoreline has overhanging vegetation.
Shoreline/channel structure	ShoreModPercent	Shoreline modifications segment percent	The total percent of the shoreline that has been modified by bulkhead, riprap, and other man-made structures.	≥ 0% and < 12.5% of segment's shoreline is modified by development. A value of 0 is assigned when 0% of shoreline is modified.	≥ 12.5% and < 37.5% of segment's shoreline is modified by development.	≥ 37.5% and < 62.5% of segment's shoreline is modified by development.	≥ 62.5% and < 87.5% of segment's shoreline length is modified by development.	≥ 87.5% of segment's shoreline length is modified by development. A value of 4 is assigned when the shoreline is 100% modified.
2 Biological community								
Competitors or predators	HatRel-sp	Hatchery salmonid releases	Relative magnitude of hatchery chinook, coho, chum, pink, sockeye, and steelhead that utilize the subestuary or estuarine segment.	Hatchery fish for the species designated have been rarely released over the past decade and any releases that have been made are very small in number compared to the number of wild fish for this species present.	Hatchery fish for the species designated are released at infrequently to at least every other year currently, are a small fraction of the abundance of wild conspecifics, and produce densities of total juveniles or adults for the species judged to be <20% of historic densities.	Hatchery fish for the species designated are released at least every other year currently, are 1/4 as abundant to more abundant than wild conspecifics, and produce densities of total juveniles or adults for the species judged to be 20-50% of historic densities.	Hatchery fish for the species designated are released in most years, are more abundant than wild conspecifics, and produce densities of total juveniles or adults for the species judged to be 50-75% of historic densities.	Hatchery fish for the species designated are released in most years, are more abundant than wild conspecifics, and produce densities of total juveniles or adults for the species that might approach densities expected historically.

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Competitors or predators	MarFshStatus	Status of marine fish populations	Status of marine fish populations in the segment.	Predatory marine fish species not present.	Populations of predatory marine fish species at very low densities, reflecting marginal sustainability.	Densities of marine fish species correspond to stable, though depressed levels compared to healthy average levels that might be expected in the absence of fishing pressures and environmental change.	Densities of marine fish species correspond to healthy populations for the species under average conditions that might have prevailed prior to fishing pressures and environmental changes.	Extremely high densities of marine fish species present due to unusually favorable conditions or proximity to reproductive areas.
Competitors or predators	MarMamStatus	Status of marine mammals	Status of marine mammals in the subestuary or estuarine segment.	Predatory marine mammal species not present.	Populations of predatory marine mammal species at very low densities, reflecting marginal sustainability.	Densities of marine mammal species correspond to stable, though depressed levels compared to healthy average levels that might have occurred in the absence of environmental changes and bans on capture or killing.	Densities of marine mammal species correspond to healthy populations for the species under average conditions that might have prevailed prior to environmental changes and bans on capture or killing.	Extremely high densities of marine mammal species present due to unusually favorable conditions or proximity to reproductive areas.
Competitors or predators	SeabirdStatus	Status of seabirds	Status of seabirds in the subestuary or estuarine segment.	Predatory seabird species not present.	Populations of predatory seabird species at very low densities, reflecting marginal sustainability.	Densities of seabird species correspond to stable, though depressed levels compared to healthy average levels that might be expected in the absence of environmental change.	Densities of seabird species correspond to healthy populations for the species under average conditions that might have prevailed prior to environmental changes.	Extremely high densities of seabird species present due to unusually favorable conditions or proximity to reproductive areas.
Competitors or predators	SalStatus-sp	Status of wild salmonids	Status of wild salmonids by species: Chinook, Coho, chum, pink, sockeye, steelhead, cutthroat	Wild salmonid species of concern not present.	Population of wild salmonid species of concern at very low density, reflecting a population of marginal sustainability.	Density of wild salmonid species corresponds to a stable, though depressed level compared to the healthy average level associated with pristine condition due to watershed development.	Density of wild salmonid species corresponds to a healthy population for the species under average conditions that might have prevailed prior to watershed development.	Extremely high densities of the wild salmonid species present due to unusually favorable conditions or proximity to reproductive areas.

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Food resources and/or refuge	EelgrAllPercent	Eelgrass - all percent	The total percent of the lineal shoreline within the segment containing patchy or continuous eelgrass; abundance classified as continuous, patchy, or not present.	≥ 87.5% of segment's shoreline length contains patchy or continuous eelgrass, where eelgrass abundance. A value of 0 is assigned when 100% of the shoreline is identified as having either patchy or continuous eelgrass.	≥ 62.5% and < 87.5% of segment's shoreline length contains patchy or continuous eelgrass.	≥ 37.5% and < 62.5% of segment's shoreline length contains patchy or continuous eelgrass.	≥ 12.5% and < 37.5% of segment's shoreline length contains patchy or continuous eelgrass.	≥ 0% and < 12.5% of segment's shoreline length contains patchy or continuous eelgrass. A value of 4 is assigned when 0% of shoreline contains eelgrass.
Food resources and/or refuge	EelgrContPercent	Eelgrass - continuous percent	The total percent of the lineal shoreline within the segment containing continuous eelgrass; abundance classified as continuous, patchy, or not present.	≥ 52.5% of segment's shoreline length contains continuous eelgrass. A value of 0 is assigned when 60% or more of the shoreline is identified as having continuous eelgrass.	≥ 37.5% and < 52.5% of segment's shoreline length contains continuous eelgrass.	≥ 22.5% and < 37.5% of segment's shoreline length contains continuous eelgrass.	≥ 7.5% and < 22.5% of segment's shoreline length contains continuous eelgrass.	≥ 0% and < 7.5% of segment's shoreline length contains continuous eelgrass. A value of 4 is assigned when 0% of shoreline contains continuous eelgrass.
Food resources and/or refuge	KelpAllPercent	Kelp - all percent	The total percent of the lineal shoreline within the segment containing patchy or continuous kelp (all species); abundance classified as continuous, patchy, or not present.	≥ 87.5% of segment's shoreline length contains patchy or continuous kelp. A value of 0 is assigned when 100% of the shoreline is identified as having either patchy or continuous kelp.	≥ 62.5% and < 87.5% of segment's shoreline length contains patchy or continuous kelp.	≥ 37.5% and < 62.5% of segment's shoreline length contains patchy or continuous kelp.	≥ 12.5% and < 37.5% of segment's shoreline length contains patchy or continuous kelp, where kelp abundance.	≥ 0% and < 12.5% of segment's shoreline length contains patchy or continuous kelp. A value of 4 is assigned when 0% of shoreline contains kelp.
Food resources and/or refuge	KelpContPercent	Kelp - continuous percent	The total percent of the lineal shoreline within the segment containing continuous kelp (all species); abundance classified as continuous, patchy, or not present.	≥ 52.5% of segment's shoreline length contains continuous kelp. A value of 0 is assigned when 60% or more of the shoreline is identified as having continuous kelp.	≥ 37.5% and < 52.5% of segment's shoreline length contains continuous kelp.	≥ 22.5% and < 37.5% of segment's shoreline length contains continuous kelp.	≥ 7.5% and < 22.5% of segment's shoreline length contains continuous kelp.	≥ 0% and < 7.5% of segment's shoreline length contains continuous kelp. A value of 4 is assigned when 0% of shoreline contains continuous kelp.

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Food resources and/or refuge	SalmCarcass	Salmon carcasses	Relative abundance of anadromous salmonid carcasses within the subestuary watershed.	Super abundant -- number of carcasses per km of main channel habitat within streams entering the segment (within an appropriately designated area) ≥ 497.	Very abundant -- number of carcasses per km of main channel habitat within streams entering the segment (within an appropriately designated area) ≥ 249 and < 497.	Moderately abundant -- number of carcasses per km of main channel habitat within streams entering the segment (within an appropriately designated area) ≥ 124 and < 249.	Not abundant -- number of carcasses per km of main channel habitat within streams entering the segment (within an appropriately designated area) ≥ 16 and < 124.	Very few or none -- number of carcasses per km of main channel habitat within streams entering the segment (within an appropriately designated area) < 16.
Food resources and/or refuge	NeriticZoo	Zooplankton within the upper water column	Index of average abundance of zooplankton within the segment during a month (in neritic waters).	Relative density of neritic zooplankton is ≥ 87.5% of the maximum observed density in the study area.	Relative density of neritic zooplankton is ≥ 62.5% and < 87.5% of the maximum observed density in the study area.	Relative density of neritic zooplankton is ≥ 37.5% and < 62.5% of the maximum observed density in the study area.	Relative density of neritic zooplankton is ≥ 12.5% and < 37.5% of the maximum observed density in the study area.	Relative density of neritic zooplankton is ≥ 0% and < 12.5% of the maximum observed density in the study area.
3 Water quality								
Chemistry	DisOxy	Dissolved oxygen	Average dissolved oxygen within the water column during the time from April to October.	≥ 8 mg/L (allows for all biological functions for salmonids without impairment at temperatures ranging from 0-25 °C)	≥ 6 mg/L and < 8 mg/L (causes initial stress symptoms for some salmonids at temperatures ranging from 0-25 °C)	≥ 4 and < 6 mg/L (stress increased, biological function impaired)	≥ 3 and < 4 mg/L (growth, food conversion efficiency, swimming performance adversely affected)	< 3 mg/L
Chemistry	MetWatCol	Metals in water column	The extent of dissolved heavy metals within the water column.	< 0.7 µg/L (no toxicity expected due to dissolved heavy metals to salmonids under prolonged exposure; Price 2013).	≥ 0.7 µg/L and < 2 µg/L (may exert some low level chronic toxicity to salmonids; Price 2013, Singleton 1987).	≥ 2 µg/L and < 3 µg/L (some persistent chronic toxicity expected to salmonids; Singleton 1987).	≥ 3 µg/L and < 8 µg/L (acute toxicity may be experienced in salmonids; Singleton 1987,).	≥ 8 (acute toxicity to salmonids likely; Environment Canada 2005).

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Chemistry	MetSeds	Metals in sediments	The extent of heavy metals within the shore segment.	$SedQ_{UNC} \leq 1.0$ (metals are at natural [background] levels with no or negligible effects on benthic dwelling organisms or riparian vegetation).	$SedQ_{UNC} > 1.0$ and $SedQ_{SCS} \leq 1.0$ (deposition of metals in low concentrations such that some stress symptoms may occur to benthic dwelling organisms or riparian vegetation root/shoot growth may be impaired; levels considered low enough for sensitive habitats).	$SedQ_{SCS} > 1.0$ and $SedQ_{TCS} \leq 1.0$ (stress symptoms increased or biological functions of benthic dwelling organisms moderately impaired to; may be a few areas within the riparian zone present where no vegetation exists; some areas occupied only by tolerant species; root growth may be affected; levels considered low enough for contaminated habitats).	$SedQ_{TCS} > 1.0$ and $SedQ_{CCME} \leq 1.0$ (growth, food conversion, reproduction, or mobility of benthic organisms severely affected; or large areas of the riparian zone devoid of vegetation; may be areas occupied only by metals tolerant species; few areas in the riparian zones which are unaffected; pose unacceptable risks to sediment dwelling organisms).	$SedQ_{CCME} > 1.0$ (metal concentrations in sediments/soils are lethal to large numbers of the benthic species and/or riparian zone is practically devoid of vegetation; levels in excess of the Canadian Environmental Quality Guidelines).
Chemistry	DioxinSeds	Dioxins in the sediments	The extent of dioxins within the shore segment.	< 0.85 ng/kg (no toxicity expected due to dioxins present; below the CCME Interim Sediment Guideline's ISQG level).	≥ 0.85 ng/kg and < 4 ng/kg (some low level chronic toxicity may occur, particularly if sediments are resuspended in the water column; above the CCME Interim Sediment Guideline's ISQG level but below the Washington State's Dredged Material Management Program level).	≥ 4 ng/kg and < 21.5 ng/kg (possible cumulative effects may occur; bioaccumulation testing recommended; above Washington State's Dredged Material Management Program level but below the CCME Interim Sediment Guideline's PEL level).	≥ 21.5 ng/kg and < 260 ng/kg (sediment considered too toxic for disposal at sea; toxic effects on organisms probable; above the CCME Interim Sediment Guideline's PEL level, but below BC's level for contaminated sites).	≥ 260 ng/kg (highly contaminated sediments).
Temperature	TmpMx	Temperature - maximum	Maximum water temperatures within the shore unit.	Warmest day < 10 °C	Warmest day ≥ 10 °C and < 16 °C	Warmest day ≥ 16 °C and < 22 °C	Warmest day ≥ 22 °C and < 25 °C	Warmest day ≥ 25 °C and < 27.5 °C

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Sediment	Turbidity	Turbidity	Average turbidity within the shore unit.	> 100 NTU or estuarine classification is slat wedge(water is highly turbid and juvenile salmonids successfully escape predation).	≤ 100 NTU and > 75 NTU or estuarine classification is riverine plume.	≤ 75 NTU and > 50 NTU or estuarine classification is estuarine plume.	≤ 50 NTU and > 25 NTU or estuarine classification is riverine influence.	≤ 25 NTU or estuarine classification is ocean (water is very clear and predators can easily find juvenile salmonids)

Table 41. Environmental Attribute Data Sources.

Category	Code	Data Sources
1 Basin/shoreline features		
Morphometry	SegLength	Segments within Prince Rupert Harbour were taken from the Prince Rupert Harbour Foreshore Habitat Classification (Archipelago Marine Research Ltd. 1999). These were extended to the full range of the 1997 Borstad CASI Survey (Borstad Associates Ltd. 1996; Forsyth *et al*. 1998) using shorezone segments from the North Coast 2000 Aerial Video Imaging Survey (CORI 2000). Five segments were discarded from the combined data set as no longer being representative of the current shoreline. 24 segments were classified as strictly intertidal (e.g., defining underwater reefs and sandbars), with the remainder being shoreline segments.
Morphometry	ITZWidth	The ITZ was defined using seven categories from the 1997 Borstad CASI Survey (Borstad Associates Ltd. 1996; Forsyth *et al*. 1998): "Bare Substrate", "Eelgrass", "Green Algae", "High Intertidal Fucus", "Intertidal Greens", "Low Density Intertidal Vegetation", and "Mixed Low Intertidal Fucus". Using this data in combination with the upper and lower ITZ limits shown on CHS marine charts, the upper and lower limits of the ITZ was estimated and hand digitized. For shore segments, the perpendicular distance between the upper and lower limits of the ITZ was determined at 50 m intervals along the shoreline. Each shore segment was then assigned the average value of all the width measurements that occurred within it. For intertidal segments adjacent to the shore, the segment was assigned the average value of all the width measurements for the shoreline adjacent to it. For intertidal segments separated from the shore by intervening reaches of deeper water (e.g., offshore reefs), the segment was assigned the average width of the bounding polygon defining the area of interest.
Morphometry	ITZGrad	The slope of the ITZ was calculated by dividing the maximum tidal range (7.6 m) for the Prince Rupert region with the average ITZ width for a segment. This value was multiplied by 100% to give gradient in percent.
Flow and circulation	OutflwVel	Outflow velocities were taken from the Oceanography of Chatham Sound (Trites 1956), the Federal-Provincial Joint Committee on Tsimpsean Peninsula Port Development report (NEAT 1975), the Review of Oceanographic Data Relating to Ocean Dumping in the Prince Rupert Area (McGreer *et al*. 1980), and the Circulation and Water Property Study of Prince Rupert Harbour (Stucchi and Orr 1993). Since data were sparse, congested regions with the Prince Rupert Harbour were assumed to have outflow velocities as measured by Stucchi and Orr (1993), whereas areas of the Prince Rupert Harbour opening onto Chatham Sound were assumed to have outflow velocities as determined by Trites (1956) and NEAT (1975).
Flow and circulation	Exposure	Exposure data were taken from the Prince Rupert Harbour Foreshore Habitat Classification (Archipelago Marine Research Ltd. 1999) and the North Coast 2000 Aerial Video Imaging Survey (CORI 2000). If the exposure data disagreed between the two sources, preference was given to the Prince Rupert Harbour Foreshore Habitat Classification, as it was the more detailed of the two surveys.
Shoreline/channel structure	AccessSubest	Data were taken from the Freshwater Atlas Obstructions (DataBC Geo 2008a) and the Freshwater Atlas Stream Network (DataBC Geo 2008b).
Shoreline/channel structure	DensityRMEst	No river mouth estuaries present in the study area.
	DensityCMEst	Data were taken from the Freshwater Atlas Stream Network (DataBC Geo 2008b).

Category	Code	Data Sources
	DensityTideChanMarshFW	Data were taken from the Prince Rupert Harbour Foreshore Habitat Classification (Archipelago Marine Research Ltd. 1999), the North Coast 2000 Aerial Video Imaging Survey (CORI 2000), and the Freshwater Atlas Stream Network (DataBC Geo 2008b).
	DensityTideChanFW	Data were taken from the Prince Rupert Harbour Foreshore Habitat Classification (Archipelago Marine Research Ltd. 1999), the North Coast 2000 Aerial Video Imaging Survey (CORI 2000), and the Freshwater Atlas Stream Network (DataBC Geo 2008b).
	DensityTideMarshFW	Data were taken from the Prince Rupert Harbour Foreshore Habitat Classification (Archipelago Marine Research Ltd. 1999), the North Coast 2000 Aerial Video Imaging Survey (CORI 2000), and the Freshwater Atlas Stream Network (DataBC Geo 2008b).
	DensityTideChanMarsh	Data were taken from the Prince Rupert Harbour Foreshore Habitat Classification (Archipelago Marine Research Ltd. 1999), the North Coast 2000 Aerial Video Imaging Survey (CORI 2000), and the Freshwater Atlas Stream Network (DataBC Geo 2008b).
	DensityTideMarsh	Data were taken from the Prince Rupert Harbour Foreshore Habitat Classification (Archipelago Marine Research Ltd. 1999), the North Coast 2000 Aerial Video Imaging Survey (CORI 2000), and the Freshwater Atlas Stream Network (DataBC Geo 2008b).
Shoreline/channel structure	SubestLossFunc	
	FuncLossRMEst	No river mouth estuaries present in the study area.
	FuncLossCMEst	Functional loss was estimated by comparing the present day shoreline with the shorelines shown in the Prince Rupert Harbour and southern approaches chart created from surveys carried out in 1906-9 (Library and Archives Canada 2014a) and the Browning Entrance to Prince Rupert Harbour chart created from surveys carried out in 1907-9 (Library and Archives Canada 2014b).
	FuncLossTide ChanMarshFW	Functional loss was estimated by comparing the present day shoreline with the shorelines shown in the Prince Rupert Harbour and southern approaches chart created from surveys carried out in 1906-9 (Library and Archives Canada 2014a) and the Browning Entrance to Prince Rupert Harbour chart created from surveys carried out in 1907-9 (Library and Archives Canada 2014b).
	FuncLossTideChanFW	Functional loss was estimated by comparing the present day shoreline with the shorelines shown in the Prince Rupert Harbour and southern approaches chart created from surveys carried out in 1906-9 (Library and Archives Canada 2014a) and the Browning Entrance to Prince Rupert Harbour chart created from surveys carried out in 1907-9 (Library and Archives Canada 2014b).
	FuncLossTideMarshFW	Functional loss was estimated by comparing the present day shoreline with the shorelines shown in the Prince Rupert Harbour and southern approaches chart created from surveys carried out in 1906-9 (Library and Archives Canada 2014a) and the Browning Entrance to Prince Rupert Harbour chart created from surveys carried out in 1907-9 (Library and Archives Canada 2014b).
	FuncLossTideChanMarsh	Functional loss was estimated by comparing the present day shoreline with the shorelines shown in the Prince Rupert Harbour and southern approaches chart created from surveys carried out in 1906-9 (Library and Archives Canada 2014a) and the Browning Entrance to Prince Rupert Harbour chart created from surveys carried out in 1907-9 (Library and Archives Canada 2014b).

Category	Code	Data Sources
	FuncLossTideMarsh	Functional loss was estimated by comparing the present day shoreline with the shorelines shown in the Prince Rupert Harbour and southern approaches chart created from surveys carried out in 1906-9 (Library and Archives Canada 2014a) and the Browning Entrance to Prince Rupert Harbour chart created from surveys carried out in 1907-9 (Library and Archives Canada 2014b).
Shoreline/channel structure	WAreaITZRatio	Data were taken from the Freshwater Atlas Stream Network (DataBC Geo 2008b), the Freshwater Atlas Watersheds (DataBC Geo 2008c), and the previously calculated ITZ width.
Shoreline/channel structure	EmergITZRatio	Data were taken from the Prince Rupert Harbour Foreshore Habitat Classification (Archipelago Marine Research Ltd. 1999) and the North Coast 2000 Aerial Video Imaging Survey (CORI 2000). The width of the upland zone was assumed to be (250/ITZGrad), and the width of the upper, middle, and lower intertidal zones were each assumed to be (ITZWidth/3). Area of emergent vegetation was determined by multiplying the length of the shoreline along which the vegetation occurred by the width of the zone in which the vegetation was found. For emergent vegetation given a "P" or "patchy" rating, the calculated width was multiplied by 0.5 to reflect the reduced amount of coverage. For the North Coast 2000 Aerial Video Imaging Survey data, the SAL bioband [*Salicornia* (goose grass), marsh grasses, dune grasses and other salt-tolerant herbaceous plants] was used as a measure of emergent vegetation. For the Prince Rupert Harbour Foreshore Habitat Classification data, the coding "marsh grass" was used as a measure of emergent vegetation. "Fringing" or "perched" marsh grass was assumed to be in the upland zone, and all other marsh grass, unless specifically coded otherwise, was assumed to be in the upper intertidal zone. Where there were data overlaps between the two data sets, the data from the North Coast 2000 Aerial Video Imaging Survey was used.
Shoreline/channel structure	RipVegPercen t	Presence/absence of riparian vegetation along the shoreline and channels was determined by examining satellite images from Bing maps (images taken in 2012 by DigitalGlobe's WorldView-2 satellite with a multispectral imagery resolution of 1.8 meters).
Shoreline/channel structure	ShoreModPercent	Length of modified shoreline was estimated by comparing the present day shoreline with the shorelines shown in the Prince Rupert Harbour and southern approaches chart created from surveys carried out in 1906-9 (Library and Archives Canada 2014a) and the Browning Entrance to Prince Rupert Harbour chart created from surveys carried out in 1907-9 (Library and Archives Canada 2014b)
2 Biological Community		
Competitors or predators	HatRel-sp	All salmon enhancement in the study area is carried out by the Oldfield Creek Fish Hatchery. Data for hatchery releases were taken from the DFO 2009 post season salmon review for North Coast areas (DFO 2010a) and the Oldfield Creek Hatchery Facebook site (Oldfield Creek Fish Hatchery 2014). Maximum release numbers were used for estimating competition. Historical escapements data was taken from the Pacific DFO escapement database (NuSEDS) for 1950 to 2013. The maximum escapement value over that time period was used to calculate historical juvenile salmon abundance for a given waterbody. Historical fry abundance was calculated by (fry abundance = ½ * maximum escapement * species specific fecundity * species specific egg-to-fry survival). Average values for fecundity and egg-to-fry survival values were obtained from Quinn (2005).

Category	Code	Data Sources
Competitors or predators	MarFshStatus	The main marine predators of juvenile salmonids in the study area are spiny dogfish and river lamprey. The North Pacific spiny dogfish population has been given a COSEWIC designation of "special concern" due to a decline in large individuals in the population. River lampreys do not appear to be abundant in the Skeena River area. Populations of river lampreys are probably relatively stable or slowly declining. An overall index value of 2 was assigned for the study area.
Competitors or predators	MarMamStatus	The primary marine mammal predators of juvenile salmonids in the study area are harbour seals. Seal populations grew exponentially at a rate of about 11.5% per year during the 1970s and 1980s, which probably represents the biological maximum rate of increase for this species. The rate of increase began to slow in the mid-1990s, and abundance now appears to have stabilized and attained pre-exploitation levels, indicating that the population has fully recovered (DFO 2010b). An overall index value of 3 was assigned for the study area, except for segments near seal haul outs (BCMCA 2014a), which were given an index value of 4.
Competitors or predators	SeabirdStatus	Within the study area, juvenile salmonids are preyed upon by double-crested (2) and pelagic (3) cormorants ,Caspian terns (2), sooty shearwaters (3), common murres (1), hooded (3), common (3), and red-breasted (3) mergansers, Bonaparte's (3), mew (3), herring (3), and glaucous-winged gulls (4), belted kingfishers (3), red-necked (3) and horned (2) grebes, Pacific (3) and common (3) loons, great blue herons (2), ospreys (3), and bald eagles (3). The index value, shown in brackets behind each bird species, was determined based on the conservation status of the species (provincial status, BC list, and COSEWIC) as taken from the E-Fauna BC website (E-Fauna BC 2014). The average index value for the study area is 3 (2.75 rounded up to 3). Data for seabird colonies were taken from the BCMCA Marine Atlas of Pacific Canada hosted by the Community Mapping Network (BCMCA 2014b). Segments located near seabird colonies were assigned and index value of 4.
Competitors or predators	SalStatus-sp	Status of the different salmonid species was determined based on (1) the Benchmark Analysis for Pacific Salmon Conservation Units in the Skeena Watershed (Korman & English 2013) which rates chum and pink in the study area based on the green, amber, and red conservation unit stock benchmarks as designated by the Wild Salmon Policy (DFO 2005); (2) the report on the Status of Salmon Spawning Stocks of the Skeena River System (Morrell 2000) which rates chinook, coho, and sockeye in the study area based on the categories "unthreatened", "of some concern", and "at risk of extinction"' (3) the status of steelhead trout in British Columbia (Ahrens 2005); (4) the results of the Kloiya River resistivity counter (Peard 2011); and (5) the E-Fauna BC website (E-Fauna BC 2014). Segments located at the mouths of spawning rivers [as determined by the BC Historical Fish Distribution (DataBC Geo 2006), Mapster v3.1 (DFO 2014), and the background environment report for the Prince Rupert Official Community Plan (City of Prince Rupert 1995)] were given an index value of 4.
Food resources and/or refuge	EelgrAllPercent	The percentage of total eelgrass coverage in each shoreline segment was determined on the basis of data from several sources: (1) North Coast Watershed Atlas (2014); (2) BC Eelgrass Inventory Application (2014); (3) Chatham Sound Eelgrass Study (Faggetter 2013); (4) Prince Rupert Harbour Foreshore Habitat Classification (Archipelago Marine Research Ltd. 1999); (5) North Coast 2000 Aerial Video Imaging Survey (CORI 2000), (6) Priority Eelgrass Habitat (BCMCA 2014c); and (7) Eelgrass Bioband (BCMCA 2014d).

Category	Code	Data Sources
Food resources and/or refuge	EelgrContPercent	The percentage of continuous eelgrass coverage in each shoreline segment was determined on the basis of data from several sources: (1) North Coast Watershed Atlas (2014); (2) BC Eelgrass Inventory Application (2014); (3) Chatham Sound Eelgrass Study (Faggetter 2013); (4) Prince Rupert Harbour Foreshore Habitat Classification (Archipelago Marine Research Ltd. 1999); (5) North Coast 2000 Aerial Video Imaging Survey (CORI 2000), (6) Priority Eelgrass Habitat (BCMCA 2014c); and (7) Eelgrass Bioband (BCMCA 2014d).
Food resources and/or refuge	KelpAllPercent	The percentage of total kelp coverage in each shoreline segment was determined on the basis of data from several the Prince Rupert Harbour Foreshore Habitat Classification (Archipelago Marine Research Ltd. 1999).
Food resources and/or refuge	KelpContPercent	The percentage of continuous kelp coverage in each shoreline segment was determined on the basis of data from several the Prince Rupert Harbour Foreshore Habitat Classification (Archipelago Marine Research Ltd. 1999).
Food resources and/or refuge	SalmCarcass	The number of salmon carcasses per km of main channel habitat was determined using historical escapements data taken from the Pacific DFO escapement database (NuSEDS) for 1950 to 2013. The most recent escapement value for a given water body was used as an estimate of spawners, and thus salmon carcasses. For those water bodies with only an AP (adults present) code, the number of salmon carcasses was arbitrarily chosen to be 2. Steelhead carcasses were estimated using the spawning numbers from the study on the natural rearing capacity of the Kloiya river system (Tredger 1981). The length of the main channel where spawning occurred was determined from information on the BC historical fish distribution (DataBC Geo 2006). Since multiple species spawned in each water body, all salmon species carcasses were normalized to a weight of 1.5 kg using data from DFO's Guidelines for the in-stream placement of hatchery carcasses (2000).
Food resources and/or refuge	NeriticZoo	Data for neritic zooplankton abundance were obtained from the Federal-Provincial Joint Committee on Tsimpsean Peninsula Port Development report (NEAT 1975; data collected during Oct. - Nov., 1974) and the biological assessment of fish utilization of the Skeena River estuary (Higgins & Schouwenburg 1973; data collected during Apr. - Aug., 1972). Total zooplankton for each tow was expressed as organisms/m^3. Where there were multiple tows per station, the values for the tows were averaged. The contouring program Surfer was used to create contours of zooplankton abundance from the averaged station data. Values for shoreline segments were the average values from the contour plot over the length of the shoreline segment. Values were normalized to the maximum zooplankton abundance from the contour plot (110 organisms/m^3).
3 Water Quality		
Chemistry	DisOxy	Data for dissolved oxygen were obtained from the surveys of the region carried out between April and October by the Pacific Biological Station (1962, 1964, 1967), the Provincial Interagency Study (1973), and the Environmental Protection Service (1974, 1978, 1979, 1981) as tabulated in the study on the biophysical suitability of the northern British Columbia coastal waterways for net pen rearing of salmonids (Ricker 1989). Values for shoreline segments were the average values of dissolved oxygen in the water over the length of the shoreline segment.

Category	Code	Data Sources
Chemistry	MetWatCol	Little data exists on the concentrations of dissolved heavy metals in the water column for the study area. However, the largest contributor towards dissolved metals in the estuary will be the Skeena River plume, which carries metals derived from terrestrial erosion, and inland mining and industrial activities. The Skeena River as Usk frequently exceeds CCME or BC Guidelines for Al, Cd, Cr, Cu, Pb, Ag, Zn, and As (Environment Canada 2005). Sub-lethal effects on salmonids from metals such as Cu, Ni, and Zn have been reported at concentrations below the CCME or BC Guidelines (Price 2013). Additionally, levels of dissolved copper in the freshwater-saltwater mixing zone of estuaries are expected to increase since greater ionic strength causes desorption from sediment particles (Spear and Pierce 1979). Although synergistic and antagonistic effects have been shown for some mixtures of heavy metals, an additive model is generally considered adequate to describe the joint effects of metals in a mixture (Singleton 1987). Therefore, the following equation was used to determine heavy metal concentrations in the study region: [(mean total Cu at Usk) + (0.43 x mean total Zn at Usk)]*[½ x 0.01 x ((average percent freshwater during freshet) + (average percent freshwater during normal))]. Values for shoreline segments were the average values of heavy metals in the water over the length of the shoreline segment.
Chemistry	MetSeds	Data for metals in the sediment were obtained from the review of oceanographic data relating to ocean dumping in the Prince Rupert are (McGree *et al.* 1980), the report on the assessment of the Skeena Cellulose pulp mill on the environment (Pomeroy 1983), and the sediment technical data report from the comprehensive study for the Canpotex Potash Export Terminal (2011). Mean sediment quality criteria-quotients were calculated based on the methodology described by the BC Ministry of Water, Land and Air Protection (BCMWLAP 2004; MacDonald *et al.* 2003) using sediment values for uncontaminated baseline, sensitive, and contaminated sites. Uncontaminated baseline data was taken from Surf Inlet (Harding and Goyette 1989). Values for shoreline segments were the average values of heavy metals in the water over the length of the shoreline segment.

Category	Code	Data Sources
Chemistry	DioxinSeds	Reference values for dioxins were obtained from the CCME reports (CCME 2001), the BC Ministry of Water, Land and Air Protection (BCMWLAP 2004), and the Washington Dredged Material Management Program (DMMP 2010). Data on the areal extent of the Skeena Cellulose effluent plume was obtained from the Skeena Cellulose Environmental Effects Monitoring Program (Hatfield Consultants Limited 1994). No published values for dioxin levels in the study area are available. References in the CEAA report for the Canpotex Potash Export Terminal suggest that sediment dioxin values within the Skeena Cellulose effluent plume range between the CCME ISQG and PEL values (Stantec 2012). This is supported by other unpublished sources, which indicate that the levels of dioxins are between the CCME ISQG and PEL values, and possibly exceeding the Washington DMMP value within Porpoise Harbour. Using this information, shoreline segments within the Skeena Cellulose effluent plume from Porpoise Harbour to approximately halfway through Porpoise Channel were assigned an index value of 2. The remainder of the shoreline segments within the Skeena Cellulose effluent plume were assigned an index value of 1. All other shoreline segments were given an index value of 0.
Temperature	TmpMx	Data for maximum temperatures were obtained from the surveys of the region carried out between June and August by the Pacific Biological Station, the Provincial Interagency Study, and the Environmental Protection Service as tabulated in the study on the biophysical suitability of the northern British Columbia coastal waterways for net pen rearing of salmonids (Ricker 1989). All maximum temperatures recorded for the region fell between 10.2 and 14.1 °C. Thus an index value of 1 was assigned to all the shoreline segments.
Sediment	Turbidity	Turbidity in the study area is directly related to shoreline position relative to the Skeena plume. The position of the plume and the estuarine classification during both normal and freshet conditions was based on data from Cameron (1948), Trites (1956), Harrison *et al.* (1991), and Stronach and Zaremba (2002). Data for turbidity outside of the plume region were obtained from the surveys of the region carried out between April and October by the Provincial Interagency Study (1973) as tabulated in the study on the biophysical suitability of the northern British Columbia coastal waterways for net pen rearing of salmonids (Ricker 1989). JTU turbidity units were converted to NTU turbidity units by multiplying by a factor of 19. Values for shoreline segments were the average values of turbidity (based on the plume position during both normal and freshet conditions for those shoreline segments within the influence of the plume) in the water over the length of the shoreline segment.

10 Disclaimer

The findings presented in this report are based on data available as of May, 2014. Ocean Ecology has exercised reasonable skill, care, and diligence to collect and interpret the data, but makes no guarantees or warranties as to the accuracy or completeness of this data.

This report has been prepared solely for the use of the Skeena Watershed Conservation Coalition and Skeena Wild Conservation Trust, pursuant to the agreement between Ocean Ecology and Skeena Watershed Conservation Coalition and Skeena Wild Conservation Trust. Any use which other parties make of this report, or any reliance on or decisions made based on it, are the responsibility of such parties. Ocean Ecology accepts no responsibility for damages, if any, suffered by other parties as a result of decisions made or actions based on this report.

Any questions concerning the information or its interpretation should be directed to the undersigned.

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